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ATB PROGRAM AND ITS APPLICATIONS TO BIODYNAMIC RESPONSE SIMULATION OF UNDERWATER EXPLOSION EVENTS

by

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March 1998

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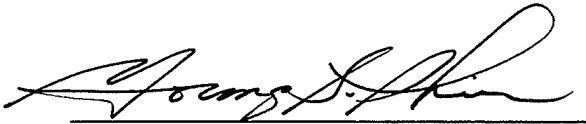Superintendent   Provost

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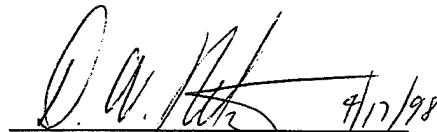
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ABSTRACT

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I. INTRODUCTION

The response of a ship's structure, and that of the equipment contained within it, to an underwater explosion is a subject that has been extensively studied. However, in evaluating a ship's ability to remain a viable warfighting asset, crew survivability must also be addressed. In order to evaluate crew survivability, it becomes necessary to assess or predict the biodynamic response of shipboard personnel to underwater explosion events, making an already complex task even more difficult. Fortunately, there exists a group of powerful computer simulation programs, the Articulated Total Body (ATB) Model, Generator of Body Data (GEBOD), VIEW, and IMAGE programs, which may be readily applied to the task of predicting and visualizing biodynamic response to underwater explosion events. This report is not meant to be a replacement for the ATB user's guide [Ref. 1], the GEBOD Manual [Ref. 2], or the VIEW user's guide [Ref. 3]. Rather, it seeks to supplement these guides for the new user by elaborating on the application of these programs for both validation of a model using recorded video footage and accelerometer data from actual testing, and for making the extension to predicting biodynamic responses based on the validated model. One example of this application is used throughout the report in order to illuminate the process further.

II. PROGRAM UNITS

A. ARTICULATED TOTAL BODY (ATB) VERSION IV

The ATB program is the heart of this group of simulation tools. It is in this program that a model of the shipboard environment is created, the input excitation applied, and the biodynamic response computed. The ATB program may also be used to produce output formatted for use with the VIEW or IMAGE programs for the purpose of two- or three-dimensional visualization, respectively.

1. Program Overview

Primarily designed to simulate the three dimensional response of a system of rigid bodies subjected to dynamic applied and interactive contact forces, the ATB program was originally developed to model the response of crash test dummies. However, it has been used in many varied applications including human body motion, transient response of a MX missile in a wind tunnel, and pilot ejection from aircraft. The program is very general and can be used to model most any system that can be approximated by connected or free rigid bodies [Ref. 1]. The ATB program is written in FORTRAN and may be run from a personal computer (in a DOS window).

Since the ATB program is quite versatile and has a tremendous number of options, this overview cannot hope to adequately cover each one; it serves as a brief introduction to some of the more important and widely used options. The reader is strongly encouraged to refer to Ref. [1] to learn about options and details not covered in this report.

a. Representation of bodies

In the ATB environment, the term "segment" refers to an individual rigid element which, when connected to other segments, makes up a body. More than one body may be modeled in a single system, but the total number of segments modeled is limited to 30 by the program [Ref. 1].

Segments are rigid, lumped mass elements with mass and inertial properties that may either defined by the user or may be automatically generated using the GEBOD program if the body being modeled is a human being or an anthropomorphic test device (ATD). The volume that a segment occupies is described by one or more ellipsoids (or hyperellipsoids) that typically match closely the physical dimensions of the actual object that the segment models. These (hyper) ellipsoids also serve as the contact surfaces that are used for calculating the dynamic forces produced through interaction with other segments or the contact surfaces of the environment [Ref. 1]. If the user specifies segments in addition to those generated by the GEBOD program, then the user must provide the weight, principal moments of inertia, any rotation of the principal axes with respect to the segment local reference system, and the lengths of the semi-axes of the ellipsoid for each additional segment.

A body is created from one or more segments connected to each other by joints of various configurations into an open chain or tree structure (although the program does not preclude the construction of a closed chain, computational problems may be encountered [Ref. 1]). Figure 1 summarizes the joint types that are provided for in the

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ATB program. If more than one body is specified, then the first segment of the second body would be connected to the last segment of the first body using a null joint. Ball and socket joints are used to represent hip or shoulder, while pin or Euler joints are used to represent knees and elbows. Null joints are used when more than one body is specified.

JOINT TYPES

Null

Ball & Socket or Free

Pin (Hinge)

Euler

Slip With Rotation About Z Axis

Slip With Rotation About Y Axis

Slip With Complete Angular Freedom
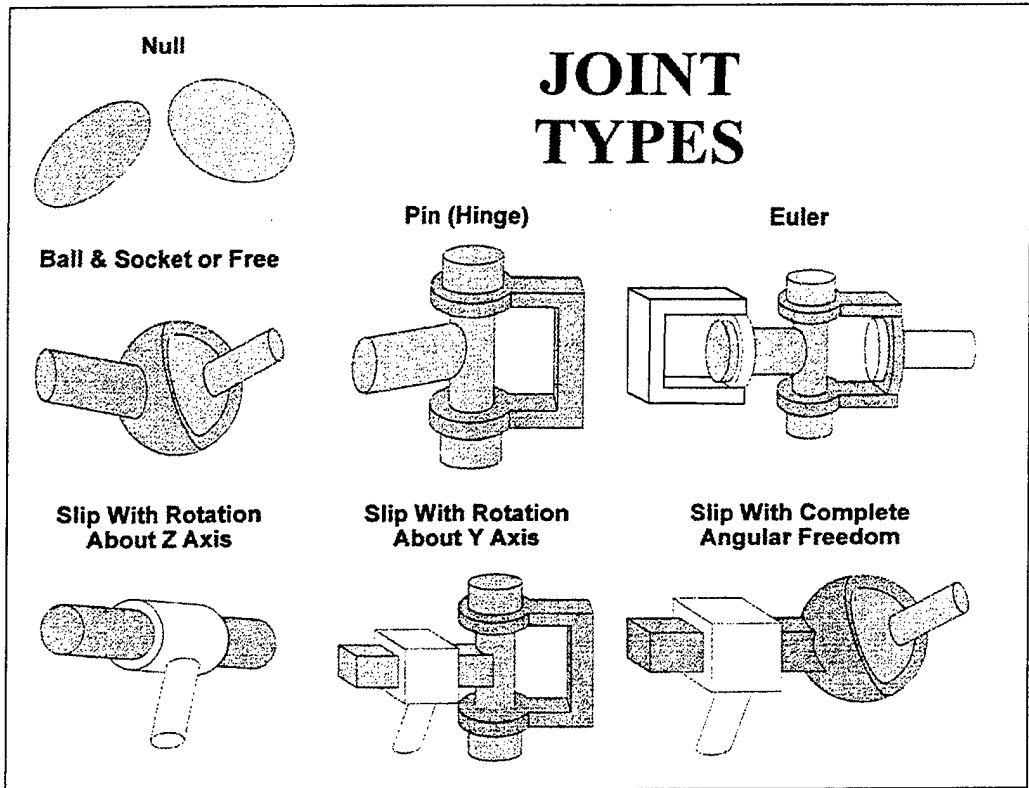
Figure 1. Joint Types Provided for in the ATB Program. From Ref. [4]

For each joint, the user must specify the flexural and torsional spring characteristics, as well as the viscous and coulomb friction characteristics. The torque characteristics, either flexural or torsional, are specified using five parameters: S1, the linear spring coefficient (in-lbs/deg); S2, the quadratic spring coefficient (in-lbs/deg^2); S3, the cubic spring coefficient (in-lbs/deg^3); S4, an energy dissipation coefficient between 0 (maximum loss) and 1 (no loss); and S5, the joint stop location (deg) with respect to the center of symmetry of the joint [Ref. 1]. Figure 2 graphically shows the manner in which the torques are computed from these five parameters. The coulomb torque is defined by specifying two parameters: V2, the coulomb friction coefficient (in-lb); and V3, the relative angular velocity (deg/sec) at the joint for which maximum coulomb friction is applied. The viscous torque is defined by simply specifying V1, the viscous coefficient (in-lb-sec/deg). Figure 3 illustrates both the coulomb and viscous torque functions.

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Joint Spring Torque

$S_1\theta + S_2(\theta - S_5)^2 + S_3(\theta - S_5)^3$

$S_1\theta$

$S_1\theta + S_4[S_2(\theta - S_5)^2 + S_3(\theta - S_5)^3]$

S_5

θ, Joint Angle (deg)
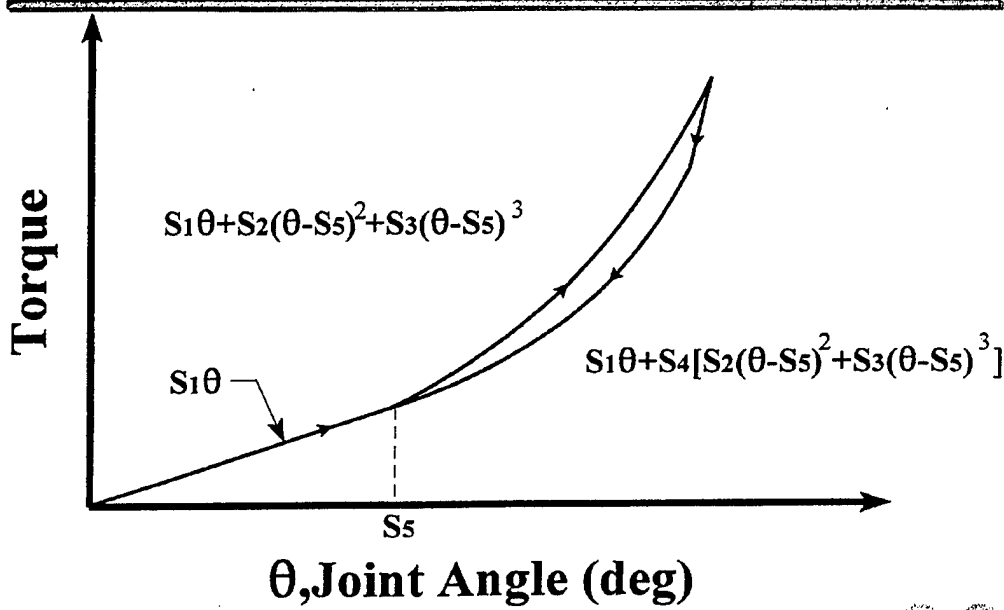
Figure 2. Joint Spring Torque Definition. From Ref. [4]

Joint Torques

Coulomb Torque

V_2

ramp

V_3

ω, Angular Velocity

Viscous Torque

$V_1 t$

ω, Angular Velocity
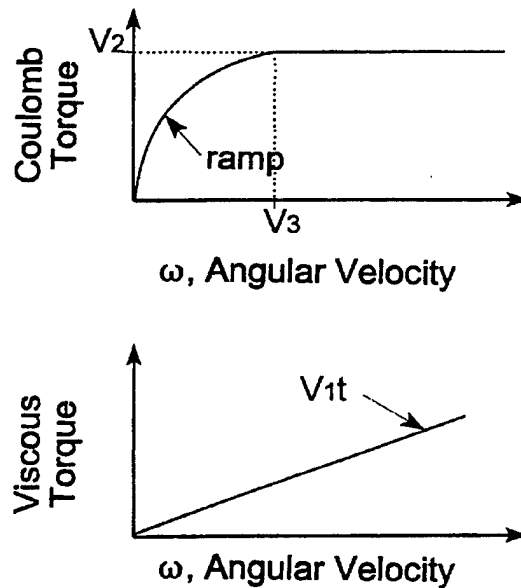
Figure 3. Joint Viscous and Coulomb Torque Definition. From Ref. [4]

b. Representation of the environment

In the ATB program, the environment within which the body or bodies exist and interact is composed of contact planes, ellipsoids, and hyperellipsoids. Up to 30 contact planes and up to 40 contact (hyper) ellipsoids may be defined by the user to create the environment. These contact surfaces may be attached to one of up to six allowed vehicles for which motion is specified as described in the section concerning input excitation. Note that each vehicle counts as a segment, so the total number of segments allowed (30) is reduced by one for each specified vehicle.

Contact planes are specified by defining three points, P1, P2, and P3, which form the sides of a parallelogram as shown in Figure 4. Contact with a plane must occur from the positive side, the outward normal to which is defined by the cross product of edges P1-P2 and P1-P3 as shown. The points P1, P2, and P3 are defined by (x,y,z) values referenced to a designated coordinate system in a manner discussed in more detail in the section on creating an input deck.
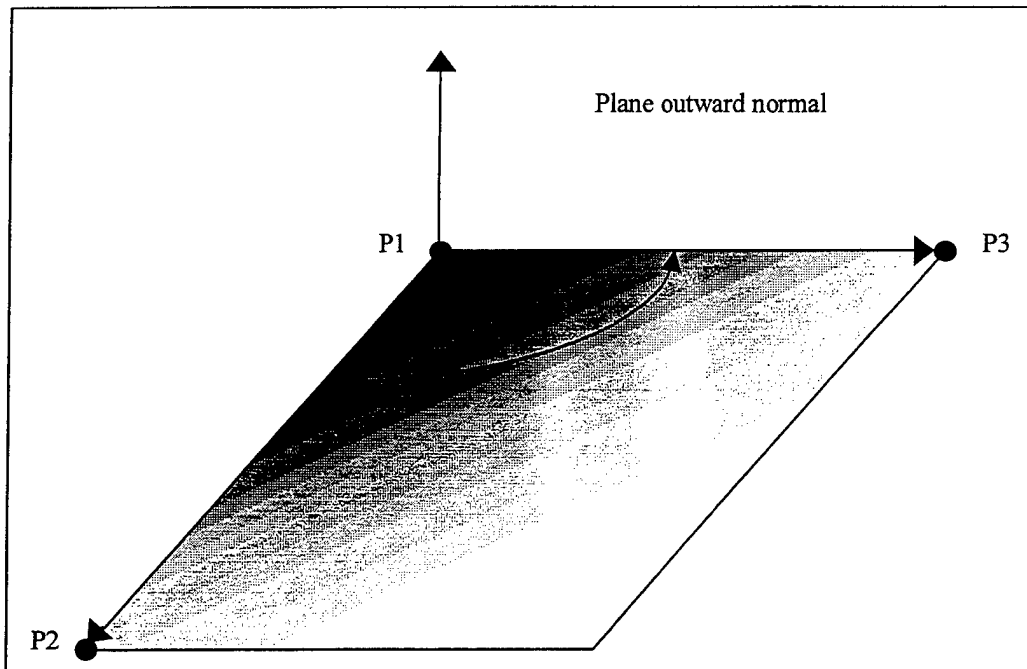
Figure 4. Plane Definition. After Ref. [4]

In a similar fashion, additional contact ellipsoids and hyperellipsoids may be defined by the user. Figure 5 shows an example ellipsoid and Figure 6 shows an example hyperellipsoid. These (hyper) ellipsoids are defined by specifying the center of the ellipsoid (in the reference frame of the segment with which they are associated), the lengths of the three semi-axes (a, b, and c), and, for hyperellipsoids, the powers (m, n, and p). For hyperellipsoids, the powers must all be even integers, and must all be the same.

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$$\left(\frac{x}{a}\right)^2 + \left(\frac{y}{b}\right)^2 + \left(\frac{z}{c}\right)^2 = 1$$
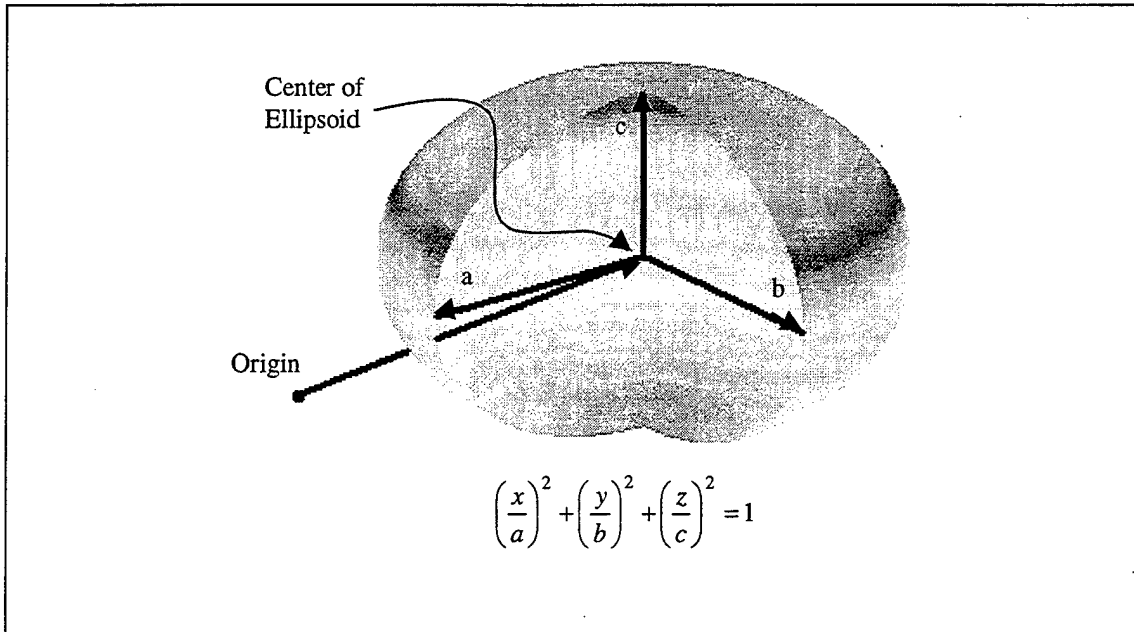
Figure 5. Ellipsoid Definition

$$\left(\frac{x}{a}\right)^m + \left(\frac{y}{b}\right)^n + \left(\frac{z}{c}\right)^p = 1$$
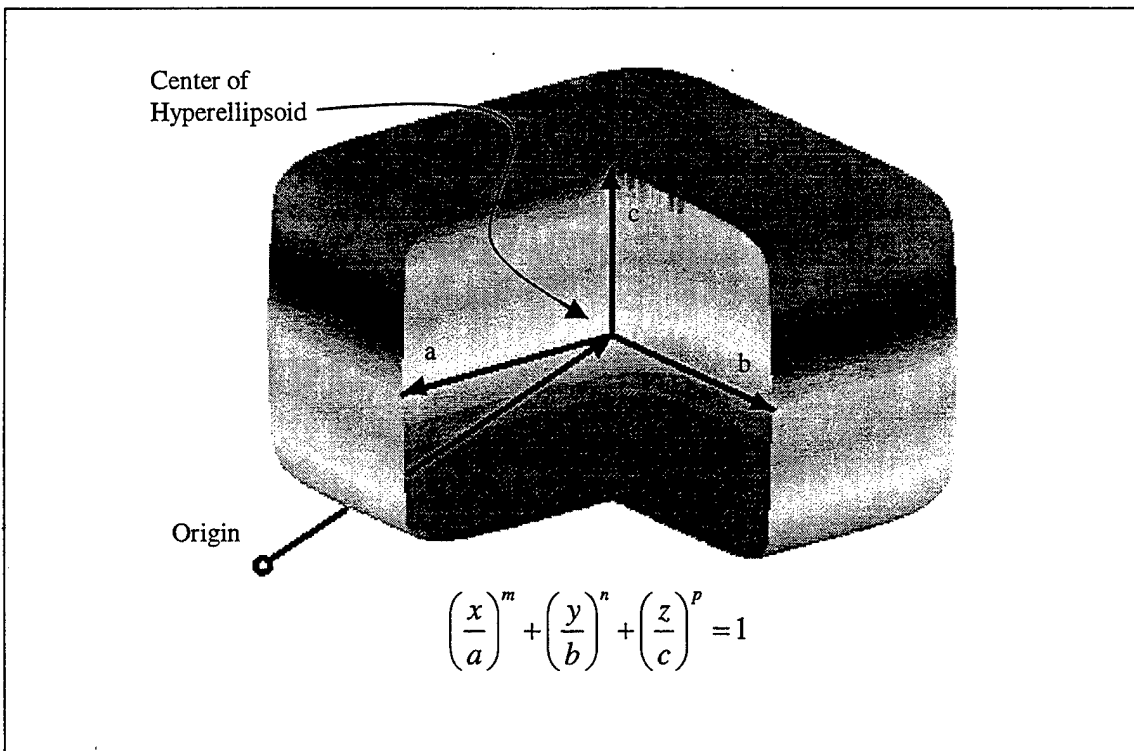
Figure 6. Hyperellipsoid Definition.

c. Input excitation

Excitation of the model is provided by prescribing the motion of the vehicle or vehicles to which the contact surfaces (planes, ellipsoids, or hyperellipsoids)

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are attached. This motion may be prescribed in one of four basic manners: (1) Half-sine wave deceleration pulse, (2) Tabular unidirectional deceleration, (3) Six degree-of-freedom deceleration, or (4) Spline fit position, velocity or deceleration data. Deceleration, vice acceleration, pulses are used since the ATB program was originally developed to model the response of crash dummies, which typically experience decelerations upon impact.

Option 1, the half-sine wave deceleration pulse, is the easiest of the four options. The user simply specifies the initial velocity of the vehicle, the duration of the. deceleration pulse, and the azimuth and elevation of the deceleration vector as shown in Figure 7.

Option 1

Half Sine Wave Deceleration Pulse

Note: The user inputs the initial speed (VIPS). The amplitude of the deceleration is calculated so that the speed after VTIME is zero. Alternatively, if the initial speed is specified as negative, the vehicle will accelerate from zero velocity to a final speed of -VIPS.
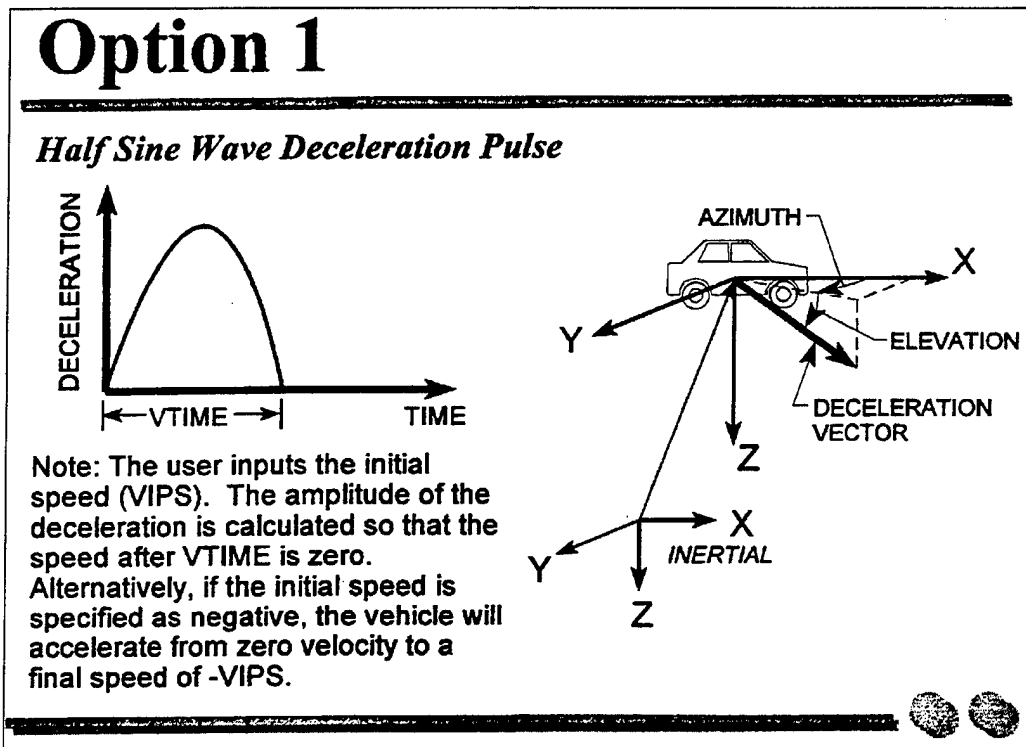
Figure 7. Half-sine Wave Deceleration Pulse Specification. From Ref. [4]

Option 2, the tabular unidirectional deceleration is also quite easy to specify. The user simply defines the initial velocity of the vehicle and the azimuth and elevation of the deceleration vector as for Option 1, but instead of specifying a duration, the user specifies a start time, time increment, and the tabulated values for deceleration at each time step as shown in Figure 8. Without modifications, the ATB program requires that there be an odd number of tabulated decelerations with a maximum of 99.

Option 3, the six degree-of-freedom deceleration, makes it simple to directly use recorded data from accelerometers as the input excitation to the ATB model. The user again specifies the initial velocity of the vehicle, but must also specify the initial roll, pitch, and yaw angles as shown in Figure 9. In addition, the user must specify the number of time points, the start time, and the time increment as for the tabulated unidirectional deceleration option. However, instead of specifying an azimuth and

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elevation for the deceleration vector, the user must specify all components of the vector – the three linear and three angular deceleration components – at each time step as shown in Figure 10. Without modification, the ATB program limits the number to time steps to a maximum of 501.
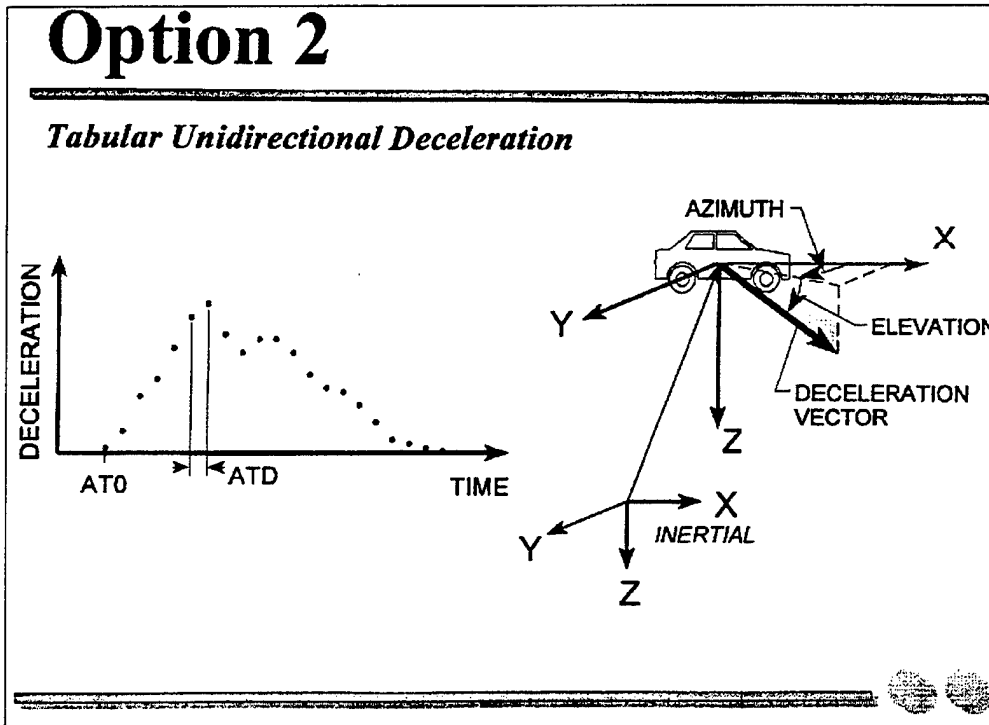
Figure 8. Tabular Unidirectional Deceleration Specification. From Ref. [4]

The final option, Option 4, the spline fit of position, velocity, or acceleration data, is the most general of the input methods. In this method, the user specifies the tabulated input data, in six degrees of freedom, as shown in Figure 11. The ATB program, without modifications, limits to 101 the maximum number of time points that may be specified. If velocity data is specified, then the initial position, as well as the initial roll, pitch and yaw, of the vehicle must be specified. If deceleration data is specified, then, in addition to the initial position information, the initial velocities, both linear and angular, must also be specified as shown in Figure 12.

From the preceding paragraphs, it is obvious that the ATB program imposes relatively strict limits on the quantity of tabulated data points that may be used as input. These limitations were imposed when the program was initially developed and reflected the limitations in available computing power. In order to simulate response to an underwater explosion event, it is generally necessary to have a relatively long time record sampled at a relatively high frequency to adequately capture the impulse-like peaks. This combination would typically yield far more data points than allowed by the ATB program. Fortunately, it is simple to modify the source code to increase the allowed number of data records.

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Option 3

INITIAL ROLL

INITIAL VELOCITY VECTOR

INITIAL YAW

INITIAL PITCH

X0

DECELERATION VECTOR

X

Y

INERTIAL

Z
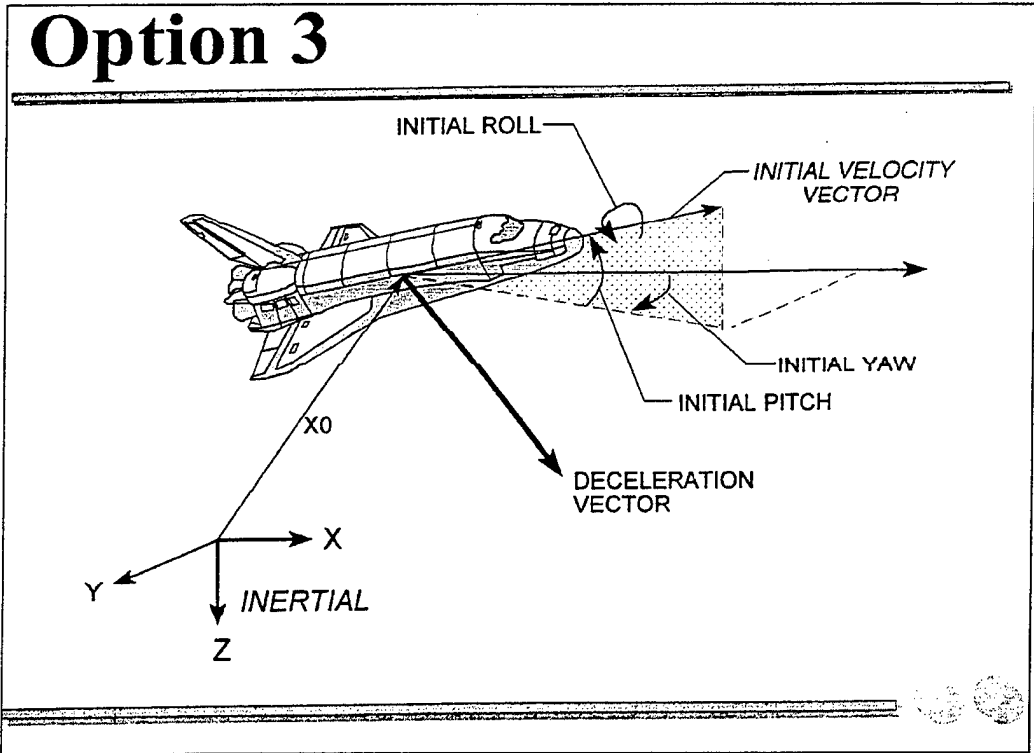
Figure 9. Six Degree-of-Freedom Deceleration Initial Conditions. From Ref. [4]

Option 3

Six Degree of Freedom Deceleration

a_x

t

α_x

t

a_y

t

α_y

t

a_z

t

α_z

t
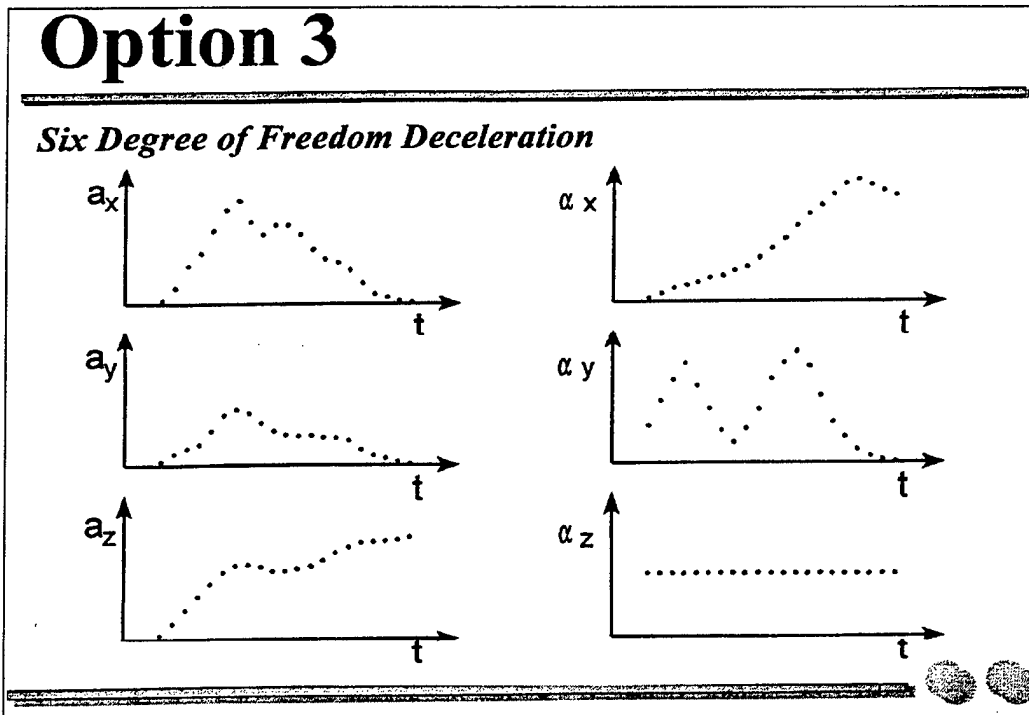
Figure 10. Six Degree-of-Freedom Deceleration Specification. From Ref. [4]

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Option 4

Spline Fit Position, Velocity, or Deceleration
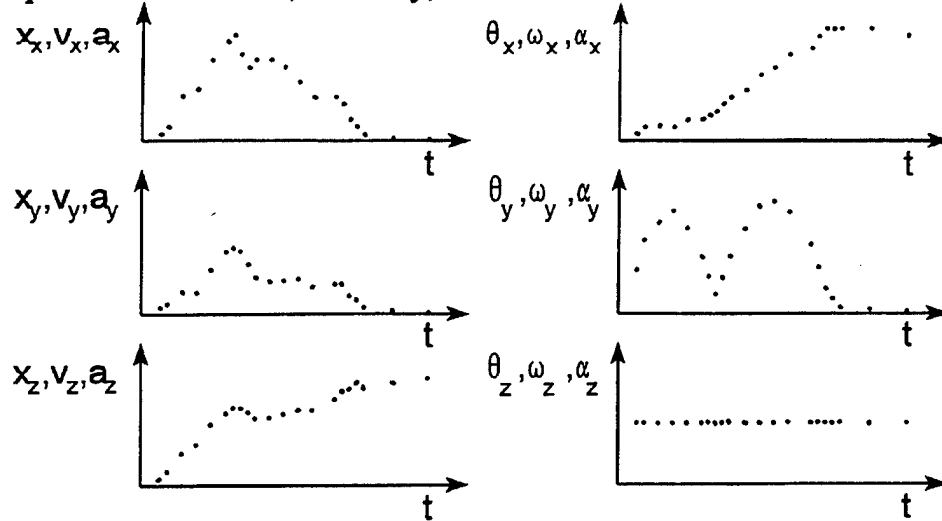
Figure 11. Spline Fit Specification. From Ref. [4]

Option 4
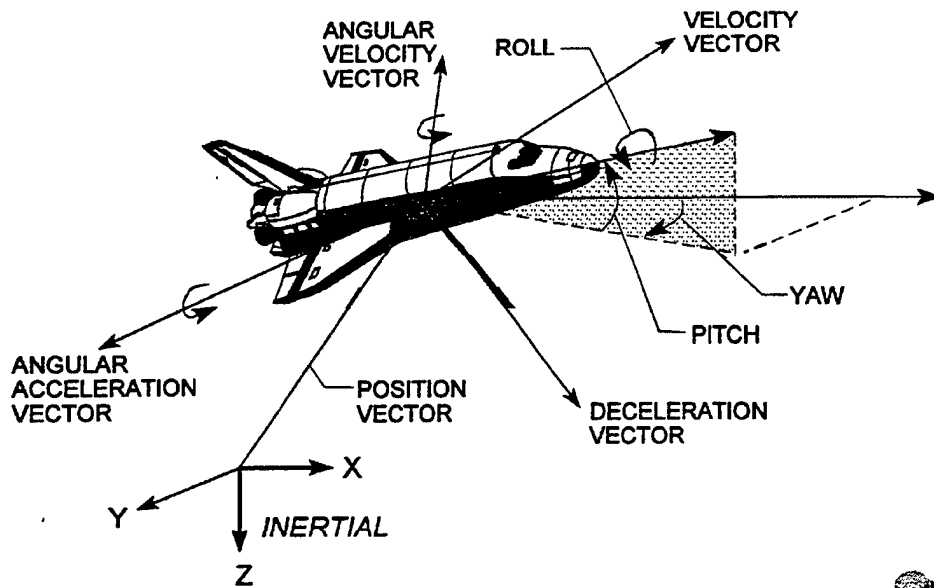
Figure 12. Spline Fit Initial Conditions. From Ref. [4]

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d. Interaction between bodies and the environment

Forces are applied to the body segments by means of evaluating the penetration of the body segment ellipsoids into the contact surfaces, either planes or (hyper) ellipsoids, representing the environment. The motion of the body elements is then determined by solving Newton's equations of motion, including the compatibility relationships based on Newton's Third Law. For further reading on the manner in which the interaction between body segments and the environment is computed, consult Ref. [5].

Figure 13 shows how a plane-segment contact is evaluated. The intersection of the ellipsoid with the plane forms an ellipse. The perpendicular distance from the plane to the point of maximum penetration of the ellipsoid is defined to be the penetration (or deflection). This value is used in the force-deflection formulas to compute the force resulting from the contact. The computed force is then applied, normal to the plane, to a point along the line between the center of the ellipse formed by the ellipsoid-plane intersection and the point of maximum penetration. The point at which the force is applied is set by the user through the specification of a parameter, D4, that ranges from 0 – force applied at point of maximum penetration, to 1 – force applied at center of the intersection area. If the segment is harder than the plane, e.g., head contact with seat cushion, then the force should be applied closer to the point of maximum penetration (D4 closer to 0). If the segment is softer than the plane, e.g., abdomen contact with a table surface, then the force should be applied closer to the center of the intersection area (D4 closer to 1) [Ref. 5].

Another parameter governs how plane-segment contacts are evaluated when the intersecting ellipse does not lie fully within the boundaries of the plane as shown in Figure 13. The plane can be assumed to be infinite, thus no check is made to see if the intersecting ellipse lies fully within the plane, or the plane can be assumed to be finite, thus an edge check is performed. If an edge check is specified, the user must then specify whether a force is applied when the center of the intersecting ellipse does not lie within the boundaries of the plane. If the user does desire a force to be applied in this case, then the deflection and corresponding force are computed based on the centroid of the area of the ellipse that lies within the boundaries of the plane [Ref. 1]. For either infinite or finite planes, the user may also specify whether a force is applied for complete penetration of the ellipsoid. The ATB program limits the number of plane-segment contacts to five per plane, with a maximum of 70 total plane-segment contacts. Duplicate planes may be added if more than five segments are expected to contact the surface in question.

Evaluation of segment to segment contacts is significantly simpler than evaluation of segment to plane contacts as can be seen in Figure 14. There are no edge effect or point of application decisions to be made, just the force-deflection characteristics, as described in the following paragraph. The ATB program limits the number of segment-segment contacts to five per segment, with a maximum of 40 total segment-segment contacts.

Force-deflection characteristics must be defined for each allowed contact, either between segments and planes or segments and other segments. In each case, the characteristics are defined by five parameters or functions (plus the edge effect parameter

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in the case of plane-segment contacts). These five functions are used to define force-deflection characteristics that are either rate dependent or have inertial spike, permanent deformation, and energy absorption properties.
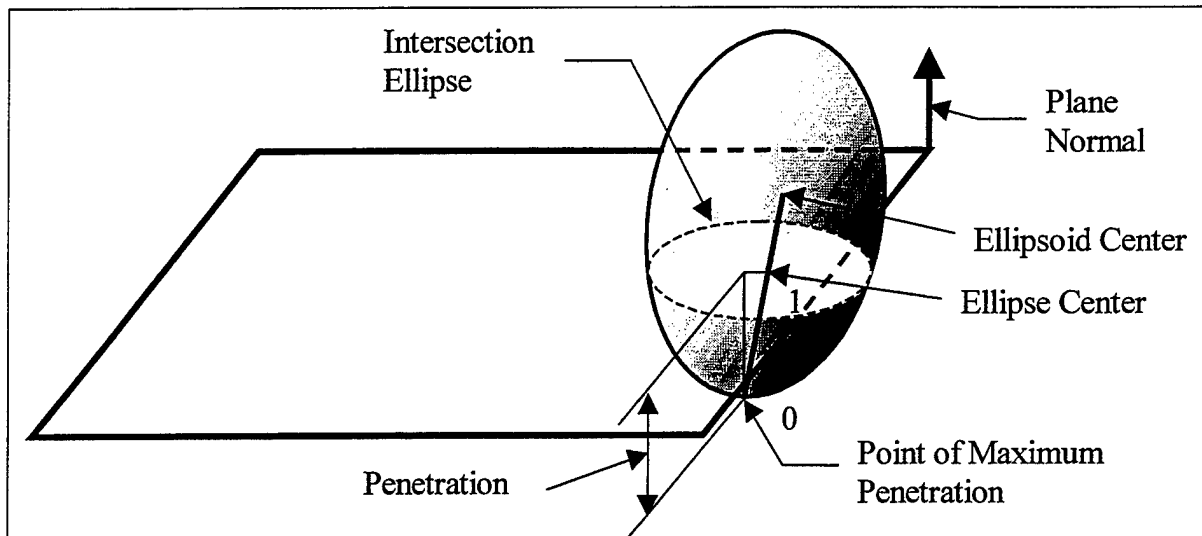
Figure 13. Plane-Segment Contact Definition. After Ref. [4]
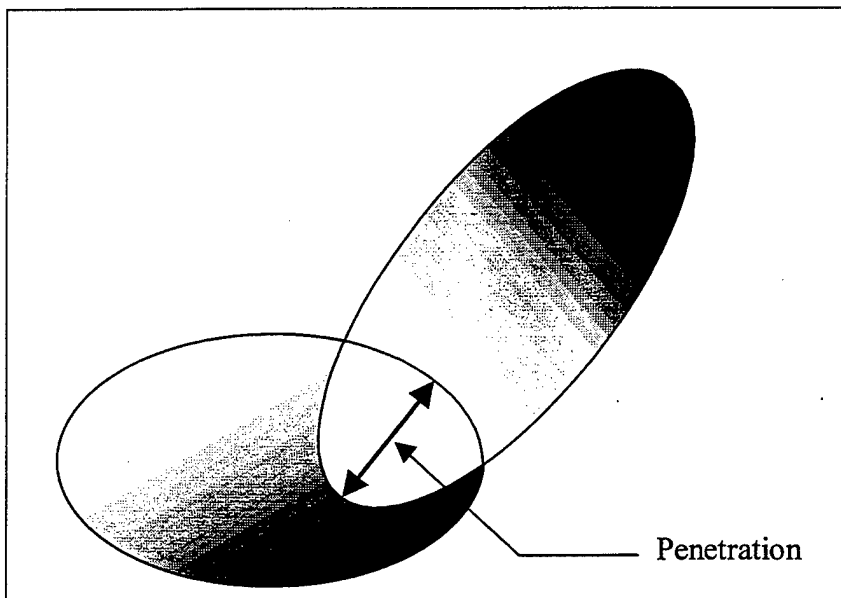
Figure 14. Segment-Segment Contact Definition. After Ref. [4]

If rate dependent force-deflection characteristics are desired, then four functions, f1 through f4 as shown in Figure 15, plus a friction coefficient, are defined. Each of the individual functions that make up the overall force-deflection characteristic is defined as shown in Figure 16. The lower and upper abscissa values for the each part of the function (D0, D1, and D2) are defined, then, the function components themselves (F1 and F2) are defined in either tabular or polynomial form, or, for F1, as a constant. The

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allowed combinations are summarized in Table 1. So, for each portion of the rate dependent force-deflection characteristic definition (f1 through f4 as shown in Figure 15), an entire function must be specified (created as shown in Figure 16 and Table 1). The ATB program limits the number of individual functions to 50.
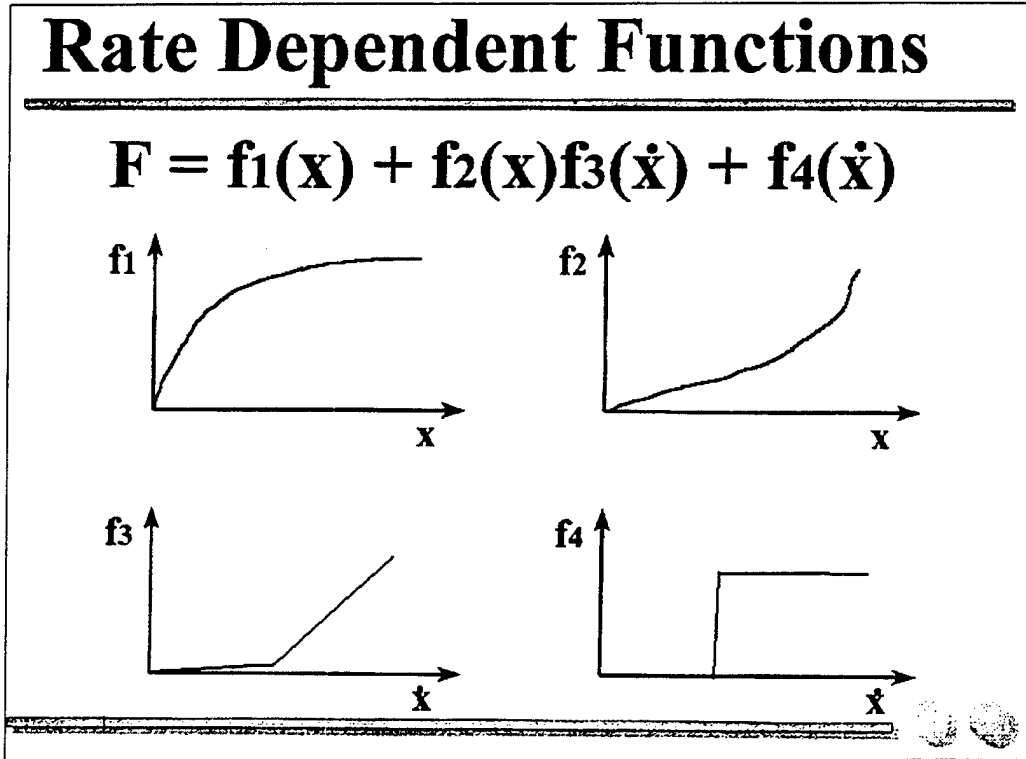
Figure 15. Rate Dependent Functions. From Ref. [4]

Table 1. Function Subdivision Definitions. After Ref. [1]

FUNCTION COMPONENT		ABSCISSA VALUE		
F1	F2	D0	D1	D2
Constant	--	0	0	D2 = F1
Tabular	--	D0	D1 < 0	0
Polynomial	--	D0	D1 > 0	0
Tabular	Polynomial	D0	D1 < 0	D2 > 0
Polynomial	Tabular	D0	D1 > 0	D2 < 0
Polynomial	Polynomial	D0	D1 > 0	D2 > 0

If rate dependent functions are not desired, but it is desired to specify inertial spike, permanent deformation and/or energy absorption properties based solely upon the deflection, then the force-deflection characteristics are defined as shown in Figure 17. The individual functions for the base, inertial spike, energy absorption factor, and permanent deflection factor components of the force-deflection characteristic are each defined as described in the above paragraph.

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Function Subdivisions
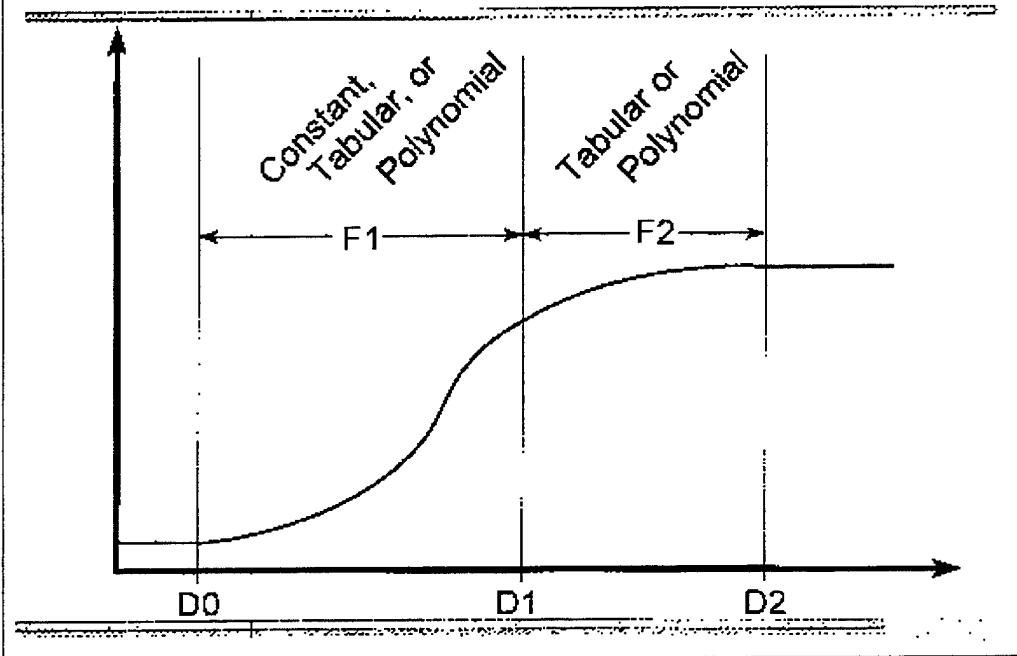
Figure 16. Function Subdivisions. From Ref. [4]

Functions
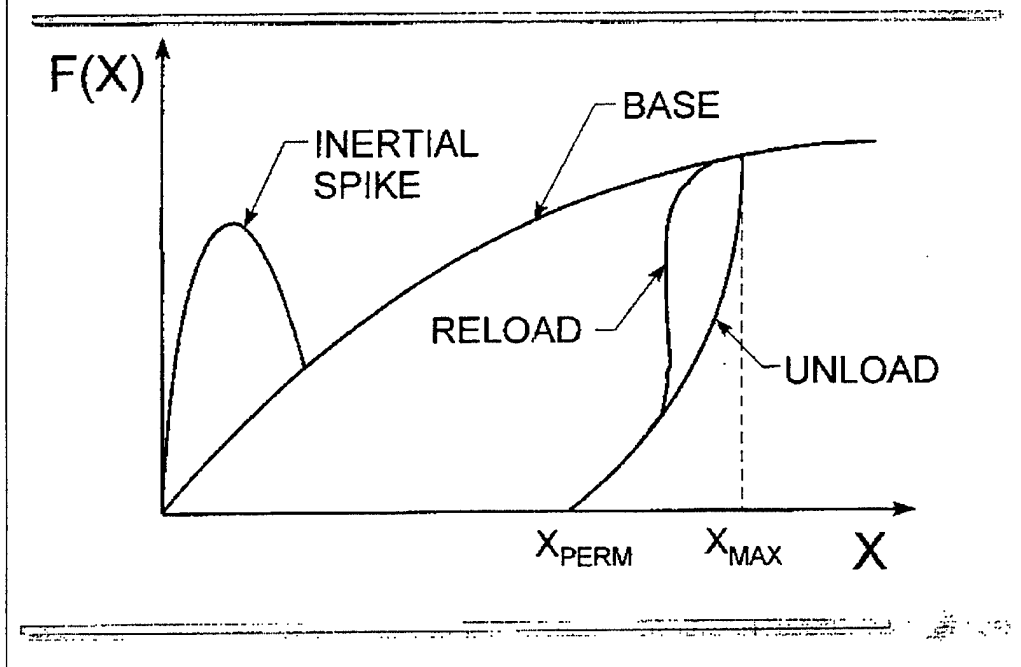
Figure 17. Alternate Function Definition. From Ref. [4]

e. Simple and harness belts

The ATB program allows for the incorporation of up to eight simple belts and/ or up to five harness belt systems into the model. These belts are commonly used to model seat belts in cars or ejection seat harnesses in aircraft.

Simple belts are defined by two anchor points and a single fixed contact point on a body segment as shown in Figure 18. It is required that the anchor points do not coincide (if they are physically the same point, they must be defined slightly separated) since the ATB program defines a plane using the two anchor points and the fixed segment contact point [Ref. 1]. Belt-segment contact forces (a maximum of one segment may contact each simple belt) are evaluated in a manner similar to plane-segment forces. The force-deflection characteristic functions are also defined in the same manner, although rate dependent functions are not permitted and the abscissa is in terms of strain (in/in) vice deflection. The friction force between the belt and a contacting segment is either full friction (forces computed separately for each half of the belt) or no friction (belt tension is the same throughout the belt). In addition to the force-deflection characteristics for the simple belts, an initial slack may be specified. The belt length is specified to be the sum of the distances between the anchor points and the fixed contact point on the plus the initial slack. Belt pre-tensioning is not allowed and the specification of a negative initial slack has the same result as specifying an initial slack of zero.
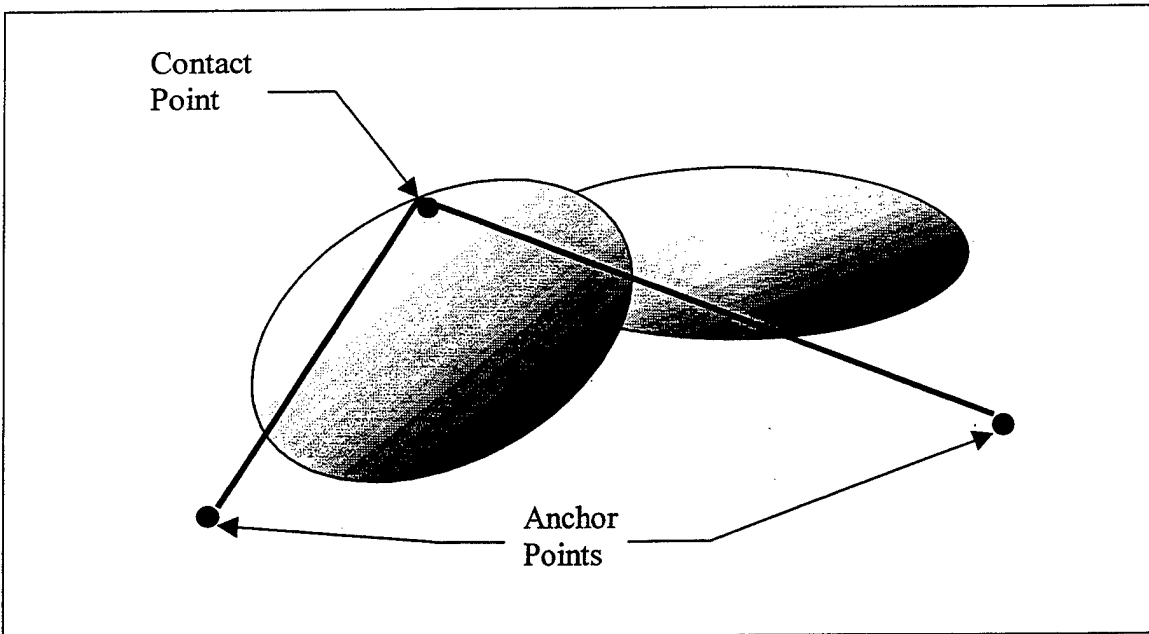
Figure 18. Simple Belt Illustration. After Ref. [4]

Harness belts are significantly different from simple belts and provide the user much more control over the construction of the belt system and the interaction between the belts and body segments. As stated earlier, a maximum of five harness belt systems may be defined. Each such system may have one or more belts, but the total number of belts in all harness belt systems must be no greater than 20. For each belt, force-deflection characteristics and initial slack are defined as for the simple belt, but the

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harness belt option allows for the use of rate dependent functions and pre-tensioning by specification of a negative initial slack. In addition, the characteristics are defined for the contact between the belt and the segment at each reference point described in the following paragraph.

For each belt in a harness belt system, the user must define anchor points and reference points, as shown in, for up to a maximum of 50 for any one harness belt system and 100 for all harness belt systems combined. The anchor points may be fixed or allowed to move with a force-deflection characteristic defined in the same manner as for each reference point. The reference points are the user specified contact points along the path of the belt and may be associated with one or more segments, as shown in Figure 19. For each reference point, in addition to the normal force-deflection characteristics (rate dependence is permitted), the user may specify a preferred direction for the reference point to move along the surface of the segment, or the user may allow the belt to slip along the nominal belt line. If the function f1 (base function as shown in Figure 17 or F1(x) as shown in Figure 15 for rate dependent characteristics) is given as zero, then the surface of the segment is treated as rigid and the belt is not allowed to move normal to the surface. If the forces computed are such that they would tend to pull the belt away from the surface of the segment, then the reference point is dropped as shown in Figure 19 unless it is specified to be an anchor or tie point. When the friction coefficient is defined for the belt-segment contact, a value must be specified for motion along the belt line tangent and a separate value specified for motion along the belt line normal. See Ref. [1] for further details on options regarding harness belts.
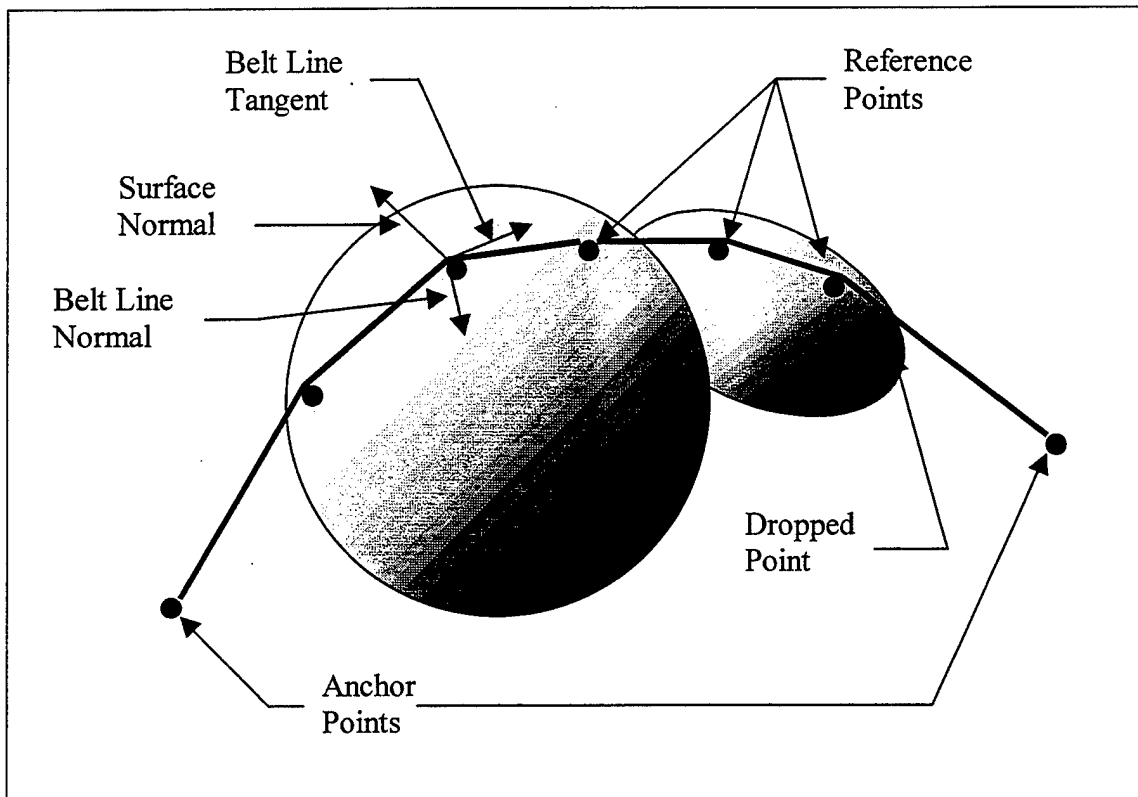
Figure 19. Harness Belt Illustration. After Ref. [4]

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f. Miscellaneous features

There are several additional features of the ATB program, including airbags, wind forces, spring-dampers and applied forces or torques.

A maximum of five airbags can be defined, but the total number of segments, vehicles, and airbags must be less than 30. A sample airbag setup is shown in Figure 20. Up to four reaction panels (ellipsoids defined by their center, semi-axis lengths, and angular orientation with respect to the vehicle) may be defined for each airbag in order to model the surfaces in the vehicle with which the airbag would interact. The first such panel to be defined is the primary reaction panel and the deployment point of the airbag is defined on this panel. The size and location of the fully deployed, but undeformed, airbag contact ellipsoid are specified by the location of the center of the ellipsoid and the three semi-axis lengths. In addition, the user must specify the appropriate gas dynamics properties (temperature, pressure, ratio of specific heats, gas constant, sonic throat area and discharge coefficient, etc.) for each specified airbag. See Ref. [1] for further details on airbags.
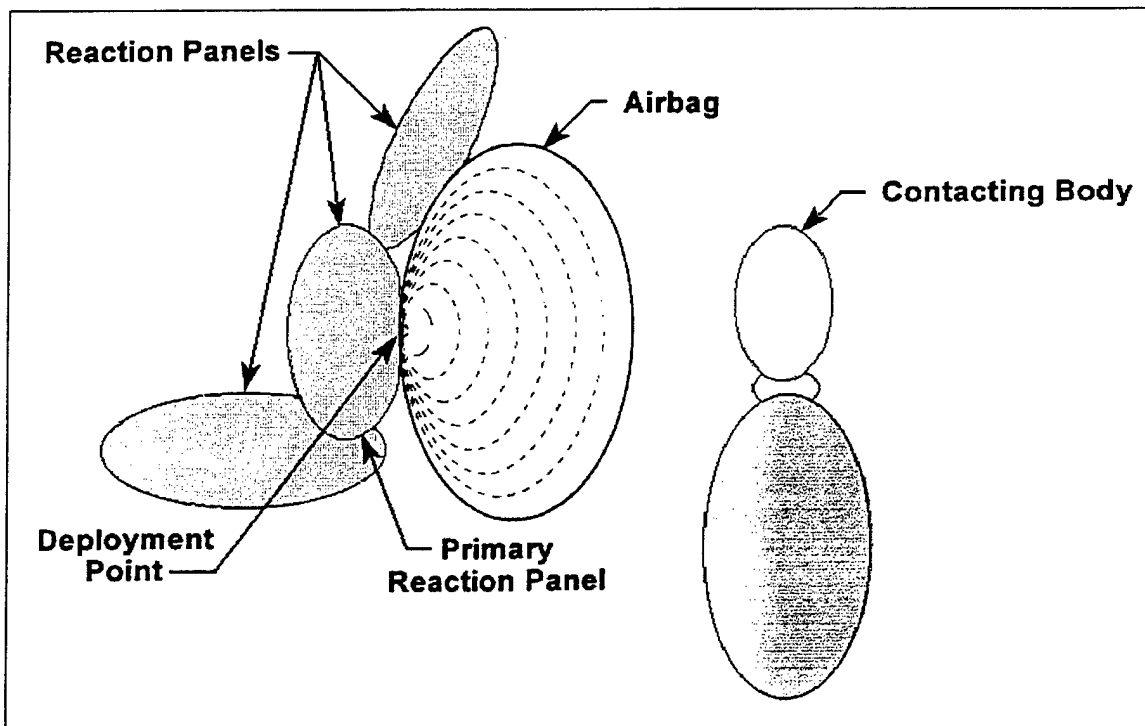
Figure 20. Airbag Setup. After Ref. [4]

Wind forces may be applied to segments as shown in Figure 21. A wind plane is specified such that aerodynamic forces are applied to a segment (which must be identified as a segment for which wind force calculations are to be performed) only if it passes through the plane. Wind pressure and drag forces may be specified and their functions are defined in a similar manner as the individual functions making up the force-deflection characteristics. For the wind pressure force, a time dependent force may be defined in exactly the same manner as an individual function for force-deflection

characteristics. Or, alternatively, a wind force function may be defined that computes the force based on the relative velocity of the segment in question using a subsonic, inviscid, compressible flow formulation with user specified fluid properties. In either case, the drag force is computed as from a user specified drag coefficient multiplied by the wind pressure force. See Ref. [1] for further details on wind forces.

Up to 20 spring-damper combinations may also be specified. Each spring-damper is defined, as shown in Figure 22, by the points of connection on two specified segments and by specifying the force-deflection/force-rate of deflection properties. The spring and damper are both represented by quadratic functions and specified by the initial length of the spring and two coefficients for each. Equation (1) shows the function used to compute the applied force for the spring. D is the distance between points APSDM and APSDN as shown in Figure 22, D_0 is the initial length, A1 is the linear spring constant (lb/in), and A2 is the quadratic spring constant (lb/in^2). If A1 is defined as negative, then the spring-damper will act as a tension element only and for (D- D_0) <0, no forces will be applied. Equation (2) shows the function used to compute the applied force for the damper. DV is the time derivative of the value D, B1 is the linear damping coefficient (lb sec/in), and B2 is the quadratic damping coefficient (lb sec^2/in^2). See Ref. [1] for further details on spring-dampers.

$$F_S = (D - D_0) * (|A1| + A2 * |D - D_0|) \qquad (1)$$

$$F_D = DV * (B1 + B2 * |DV|) \qquad (2)$$
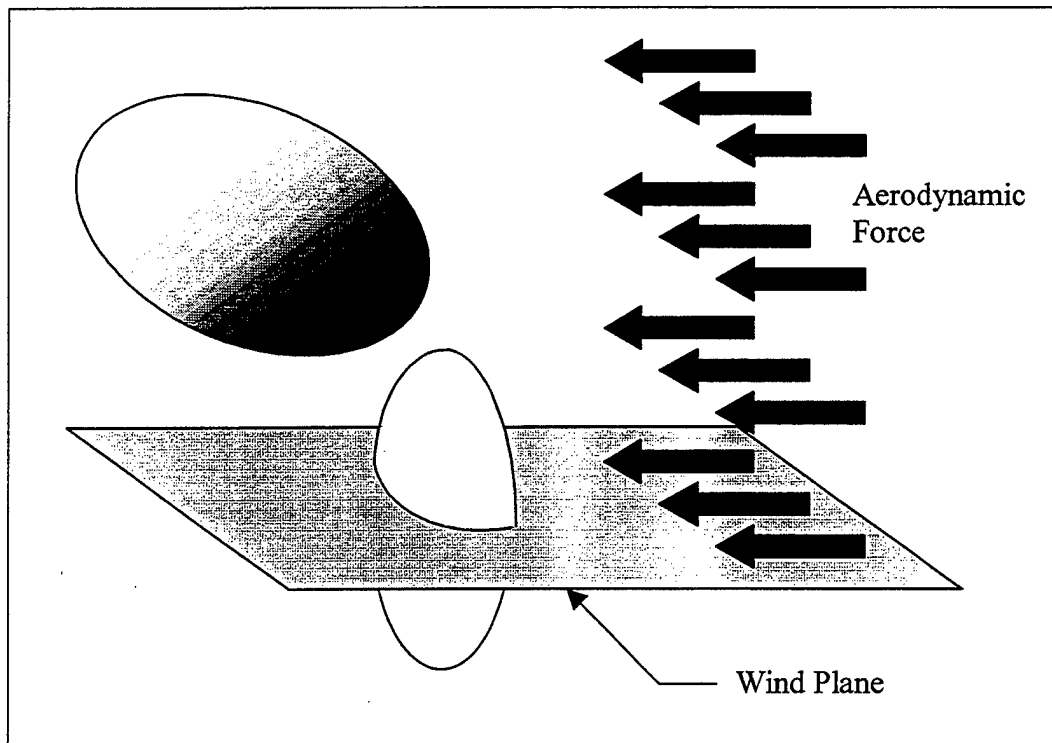
Figure 21. Wind Force Illustration. After Ref. [4]

Up to five time dependent forces or torques can be applied to user specified segments. Each force (torque) is defined by a function, the point of application is defined by (x,y,z) coordinates in the local reference system of the segment, and the direction vector is defined by yaw, pitch, and roll angles with respect to the segment's local axes. See Ref. [1] for further details on applied forces and torques.
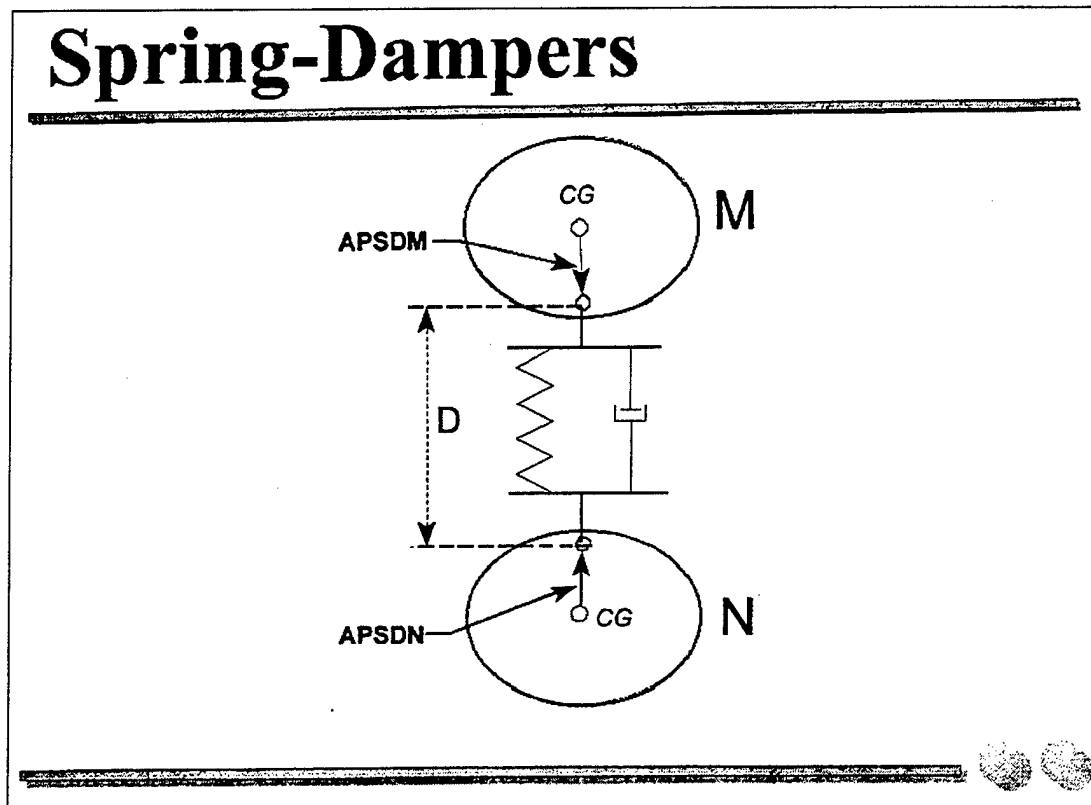
Figure 22. Spring-Damper Illustration. From Ref. [4]

2. File Structure.

The ATB program requires a single primary input file and can produce several output files. Each type of file is associated with the same filename, but with different extensions based on the kind of file in question. The ATB program file structure and interconnections are illustrated in Figure 23. The terminology used with the ATB program results from its development, using the FORTRAN programming language, in the early 1970's and the fact that punch cards were used for input. The input file (*.AIN) is frequently referred to as the input deck and the individual lines of this file are referred to as cards. The output files have extensions *.TP# or *.T##, abbreviations for tape.

a. Input deck

The input file, or deck, to the ATB program contains all the necessary information to build models of bodies and vehicles, to apply excitation to one or more of the vehicles, and to specify what data output is desired. This information is structured in 80 column lines of formatted alphanumeric data, each of which is referred to as a card.

Cards containing related information are collected into groups and are referred to as A Cards, B Cards, etc. Table 2 provides an outline correlating the card groups and the information contained within each. The format for each individual card is explicitly defined in Ref. [1].

Since there are so many different options available within the ATB program, not all cards are required for every situation. The information contained within one card may dictate that other cards must be included, and still others are not required. In the following chapter, the construction of an input file is discussed in detail.
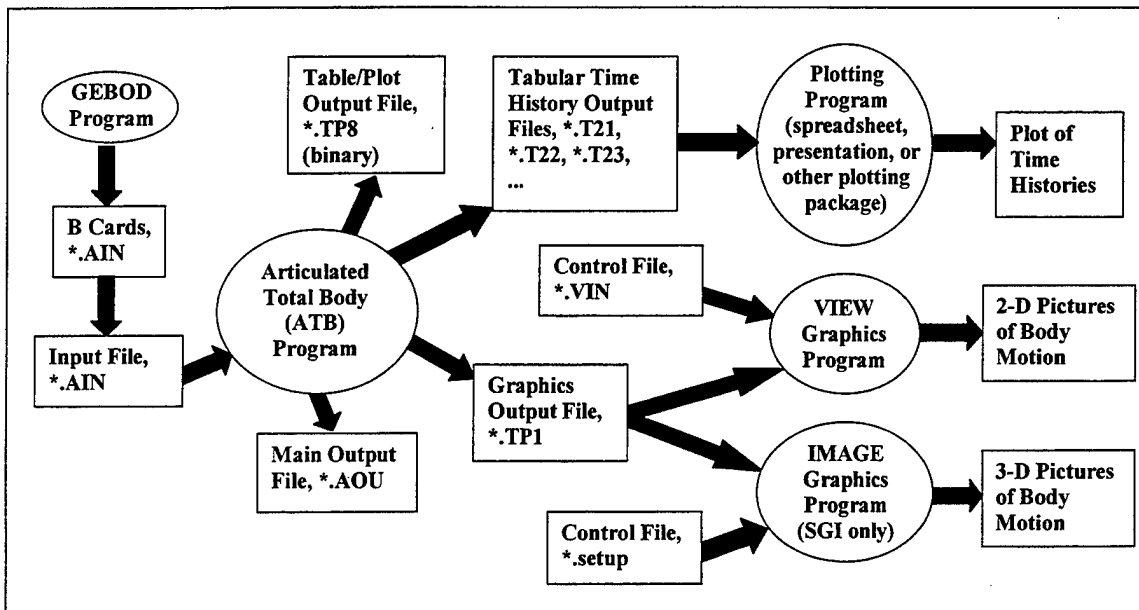
Figure 23. ATB Program File Structure. After Ref. [4]

b. Output options

The ATB program allows the user to specify nearly any combination of a variety of output options. The main output file from the ATB program (*.AOU) produces a completely annotated reproduction of all of the data in the input file, as well as some data concerning the amount of central processing unit (CPU) time used by the major subroutines in the program. Another output file (*.TP1) can be generated for use with the VIEW and/or IMAGE programs to provide 2- or 3-dimensional graphical representation of the model. A third output file (*.TP8) can be generated for use with postprocessors included within the ATB program for the computation of Head Injury Criteria (HIC), Head Severity Index (HSI), and Chest Severity Index (CSI), which are all measures of the severity of an injury and will be discussed in greater detail later.

Table 2. Outline of ATB Input Deck. After Ref. [1]

Card Group	Information Contained
A	Date and run description, units of input and output, control of restart, integrator and optional output.
B	Physical characteristics of the segments and joints.
C	Description of the vehicle motion.
D	Contact planes, belts, air bags, contact (hyper) ellipsoids, constraints, symmetry options, spring dampers, and prescribed forces and torques.
E	Functions defining force-deflections, inertial spike, energy absorption factor, and friction coefficients.
F	Allowed contacts among segments, planes, belts, airbags, contact (hyper) ellipsoids and harnesses.
G	Initial orientations and velocities of the segments
H	Control of output of time history of selected segment motions, joint parameters, wind forces, joint forces and torques, total body properties, and injury criteria.
I	Control information for plotter output.

The user may also specify, using a single parameter, to have time histories generated for nearly any combination (see Ref. [1] for allowed combinations) from the following list:

1. Plane-segment contact forces.
2. Belt-segment contact forces.
3. Harness belt forces.
4. Spring-damper forces.
5. Segment-segment contact forces.
6. Airbag contact forces.

Perhaps the most common selections would be plane-segment and segment-segment contact forces. For the plane-segment contact forces, the deflection, normal, friction and resultant forces, and the location of the contact in the coordinate system of the segment to which the plane is attached are tabulated at a frequency specified by the user. A separate file is generated for each two plane-segment contacts allowed. For the segment-segment contact forces, the deflection and normal, friction, and resultant forces are tabulated just as in the plane-segment contact case, but the location is now specified in the reference coordinates of each of the contacting segments, again at the frequency specified by the user. In contrast to the plane-segment contact option, a separate file is generated for every single allowed segment-segment contact. All tabulated time history output files are sequentially numbered beginning with *.T21.

In addition to the above options, which provide tabulated output for each allowed contact or force, the user may specify a total of up to 20 individual tabulated time histories from the following list:

1. Linear acceleration, velocity or displacement of a segment.
2. Angular acceleration, velocity or displacement of a segment.

3. Angles and torques for a joint.

For the linear and angular accelerations, velocities, and displacements, the tabulated output includes the x, y, and z components of the quantity, as well as the resultant, in the user specified coordinate system. In addition, the quantities can be computed at the center of gravity of the segment, or at any point offset from the center of gravity, allowing more flexibility for the user. For the joint parameters, the angles of flexion, azimuth, and torsion, as well as the spring, viscous, and total torques, are tabulated.

The user may also elect to have a tabulation of wind forces or to have printer plots generated. See Ref. [1] for further details on tabulated time history options.

For a typical run, many output files can be generated. If the user elects to specify the outputs to be tabulated at frequent intervals (e.g. to allow for easy comparison with recorded accelerometer data for a model validation), then these files can become quite large. For example, a plane-segment contact file generated at 1 msec intervals for a 2 second simulation (2000 lines) will require approximately 250 KB of disk space, which, if there are 40 similar size files, equates to roughly 10 MB of disk space. This figure does not include the individual files for use with the VIEW/IMAGE programs or with the ATB program's post-processing routines. Another point of concern is the total number of files open at one time. When the ATB program is started, it creates/opens all of the required output files and keeps them open, writing data to each file as it is computed, until the completion of the simulation. Use of a compiler such as Microsoft's FORTRAN Visual Workbench Version 1.00 limits the number of files which may be open at one time to 61. If more output files are required when working in such an environment, then multiple runs of the simulation may be required with different selections (e.g., run with plane-segment contacts only tabulated, then run a second time with segment-segment contacts only tabulated). Other environments may not impose this restriction, or may have different restrictions.

B. GENERATOR OF BODY DATA (GEBOD) PROGRAM

In order to use the ATB program to model the biodynamic response of anthropomorphic test devices (ATD's) or human beings, one must first determine an accurate representation of the ATD or human being as a series of individual rigid segments connected by various kinds of joints. It is for this reason that the GEBOD program was developed [Ref. 2].

1. Program Overview

The GEBOD program is used to provide the input data sets for use with the ATB program for modeling ATD's or human beings. Each input data set includes the geometric and mass properties of the body segments as well as the locations and mechanical properties of the joints connecting the body segments. The program is written in FORTRAN 77 and may be run on a personal computer either in DOS or from a DOS window in a Windows environment.

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a. Modeling options

The GEBOD program may be used to generate ATB input data for the following types of subjects [Ref. 2]:

1. Child (2-19 years of age)
2. Adult human female
3. Adult human male
4. User-supplied body dimensions
5. Seated Hybrid III Dummy (50th percentile)
6. Standing Hybrid III Dummy (50th percentile)
7. Hybrid II Dummy (50th percentile)

Upon starting the program, the user must input a description of the subject to be modeled and an output filename. Then, the user must choose one of the above options to specify the type of subject to be modeled and, depending upon the choice, may have to specify further information.

For the child, the user must decide if the data set is to be based upon the child's age, weight, height, or all three, and, depending upon the selection, the user must then provide the appropriate information. For the adult human male and female options, the user decide if the data set is to be based upon the subject's weight, height, or both, and, again, must specify the appropriate information. For the adult humans, the user may elect to specify the weight and/or height in terms of percentile rather than specific quantities. Additionally, the user may elect to have the hand and forearm modeled as a single segment, producing a 15-segment body, or as individual segments, producing a 17-segment body.

If the user elects to supply body dimensions, thus allowing the generation of a more specific body configuration than based solely upon weight and/or height, the dimensions shown in Table 3 must be defined. For a detailed description of each of the required dimensions, consult Ref. [2].

The GEBOD program allows the user to generate the body data sets for three ATD's – the Hybrid II Dummy (50th percentile male), and the Hybrid III Dummy (50th percentile male) with either the standing pelvis or the seated pelvis. The Hybrid II Dummy was developed in the early 1970's by the General Motors Corporation in order to asses the integrity of automobile lap/shoulder belt systems and has been widely used in motor vehicle and aviation safety standards tests [Ref. 6]. The Hybrid III Dummy was developed in the mid 1970's, also by the General Motors Corporation, has improved impact response biofidelity of the head, neck, chest and knees, and is used worldwide [Ref. 6]. Figure 24 shows a Hybrid III Dummy partially disassembled to reveal some of the internal structure.

Table 3. Body Dimensions. After Ref. [2]

#	Dimension	#	Dimension
0	Weight	16	Hip Breadth, Standing
1	Standing Height	17	Shoulder to Elbow Length
2	Shoulder Height	18	Forearm-Hand Length
3	Armpit Height	19	Biceps Circumference
4	Waist Height	20	Elbow Circumference
5	Seated Height	21	Forearm Circumference
6	Head Length	22	Waist Circumference
7	Head Breadth	23	Knee Height, Seated
8	Head to Chin Height	24	Thigh Circumference
9	Neck Circumference	25	Upper Leg Circumference
10	Shoulder Breadth	26	Knee Circumference
11	Chest Depth	27	Calf Circumference
12	Chest Breadth	28	Ankle Circumference
13	Waist Depth	29	Ankle Height, Outside
14	Waist Breadth	30	Foot Breadth
15	Buttock Depth	31	Foot Length
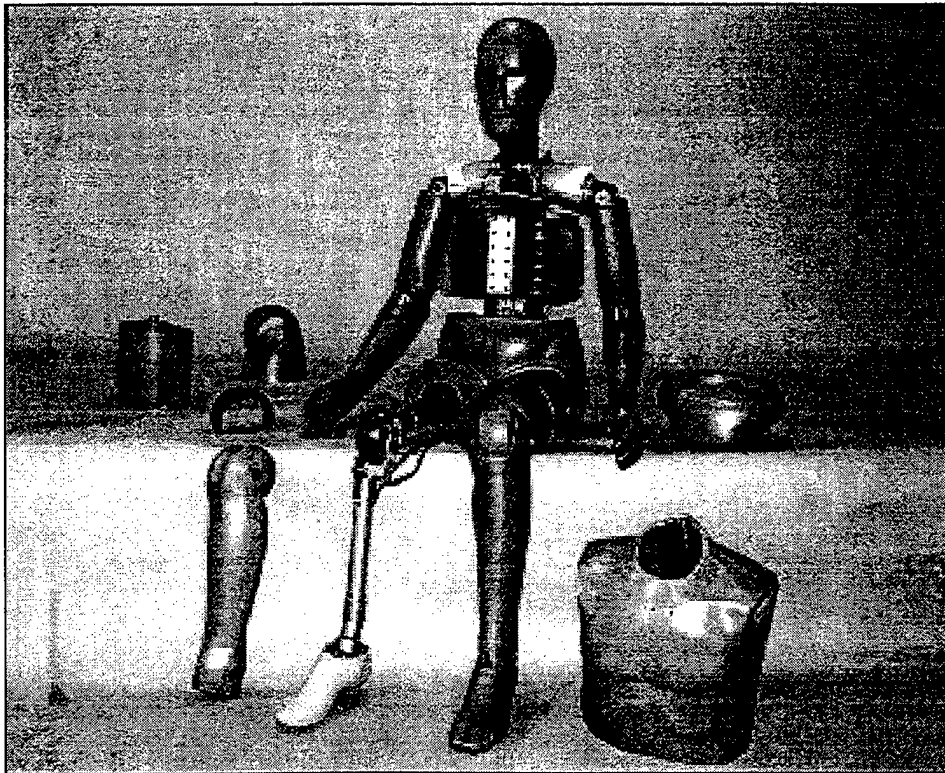
Figure 24. Hybrid III Dummy (50th Percentile Male). From Ref. [7]

b. Source of model data

The data used by the GEBOD program to generate the body segment and joint properties comes from a variety of sources. According to Ref. [2], the Hybrid II dummy data set was developed by Fleck, et. al., [see Ref. 8], and the Hybrid III dummy data sets were developed by Kaleps, et. al., [see Ref. 9]. For the humans, the body data sets are generated from four independent groups of regression equations: Body measurements, joint locations, segment volumes for mass calculations, and segment principal moments of inertia. These regression equations are first order linear equations with height and/or weight as independent variables (age is also an independent variable for the child body data sets) and were computed from body measurement survey data or stereophotometric data [Ref. 2]. For a far more detailed description of the process of converting survey data in to body data sets, see Ref. [2].

2. File Structure

The GEBOD program requires no input file, unless the user-supplied body dimensions option is selected. In that case, the user is prompted for the filename (including the extension) of the input file containing the body dimensions. This input file must be formatted as four rows of eight numbers with field lengths of ten and the dimensions must be specified in the order shown in Table 3. The GEBOD program will produce tabulated output file (*.TAB) and, if the user so desires, will produce another file (*.AIN) in the proper format for inclusion in the input file to the ATB program.

a. *.TAB output file

The *.TAB output file is always produced by the GEBOD program. It contains fully annotated listings and tabulations of the generated body data set. If the generated subject was a human, the dimensions of the body, as listed in Table 3 are included, along with segment and joint data. For each segment, the principal moments of inertia, the orientation of the principal axes, and the contact segment semi-axis lengths and location of its center are provided. For each joint, the location of the center and orientation of the axes (in the reference of each of the segments involved), the flexural and torsional spring characteristics, and the viscous characteristics are all provided.

If the generated subject was an ATD, the *.TAB file contains the same data as for the humans, excluding the dimensions of the body, as well as some more detailed information. Force-deflection characteristics for the head surface, back of shoulder, chest, anterior pelvis, posterior pelvis, upper arm, forearm, hand, upper leg, knee, front of lower leg, back of lower leg, and foot are provided. Joint restoring forces are also provided for the right and left shoulder and hip joints, the lumbar spine, and the head and neck pivots.

b. *.AIN output file

If the user desires, the GEBOD program will produce an output file (*.AIN) with the generated body data set already in the proper format for the ATB input file. This allows the user to simply insert the information directly into the input file without having to format or transcribe any data. If the generated subject was a human, the *.AIN file will contain the segment and joint information on the B cards. If the generated subject was an ATD, the *.AIN file will contain not only the B cards, but also

some D, E, and F cards containing the force-deflection and joint restoring force information described in the section above. The user must be careful when inserting this information into the input file for the ATB program as each group of cards (B, D, E, and F) are spread out throughout the input file.

C. VIEW PROGRAM

The ATB program can generate copious quantities of data concerning the predicted motions of body segments during a simulation, but it can be difficult to visualize and evaluate the gross body motion from this data. The VIEW program is used to convert this data into a series of two-dimensional line drawings of body segments and contact planes and provides a valuable aid to the simulation and modeling process. VIEW, also written in FORTRAN, must be run from DOS – it cannot be run from a DOS window in a Window's environment.

1. Program Overview

The VIEW program is capable of representing two basic types of elements – ellipsoids and polygons. The body segments are illustrated using line drawings of ellipsoids and the contact planes are illustrated using line drawings of polygons. There is no provision for plotting hyperellipsoids or simple belts, although harness belts can be rendered. Graphical output from the VIEW program may be directed either to a display terminal or to a variety of printers and plotters. An option exists to allow the graphical output be directed to a file for deferred plotting.

Figure 25 shows a sample graphics frame produce by the VIEW program. Note that there is, in addition to the time stamp, a title line displayed. This title line is optional, may be up to 40 characters in length, and, if specified, is displayed on every frame produced. In addition to the planes specified as contact surfaces in the ATB program model, the user may define a number of supplemental polygons to be plotted in each frame. There is no interaction between body segments and these supplemental polygons for VIEW is simply a graphics rendering utility, not a dynamic motion simulator as is ATB. The user may also identify certain ellipsoids and/or planes from the ATB model that are not to be rendered in the graphical output of the VIEW program. The user has control over the color in which each ellipsoid and plane is rendered, as well as the colors to be used in the title frame, title line and time stamp on each frame. The viewpoint or perspective from which the model is rendered must be specified by the user.

The user may also specify one or more title frames to appear at the beginning of the sequence of plotting frames. These title frames each contain 20 lines (not all must have text, some may be blank) of 30 characters per line. Figure 26 shows a sample title frame.

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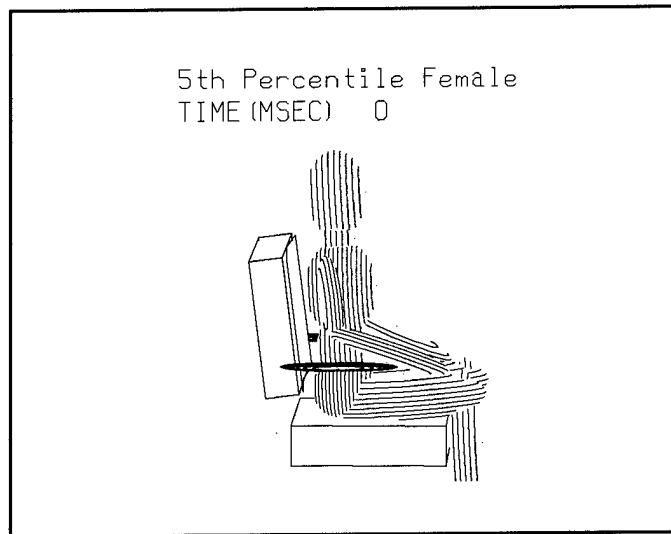
Figure 25. Sample VIEW Drawing.
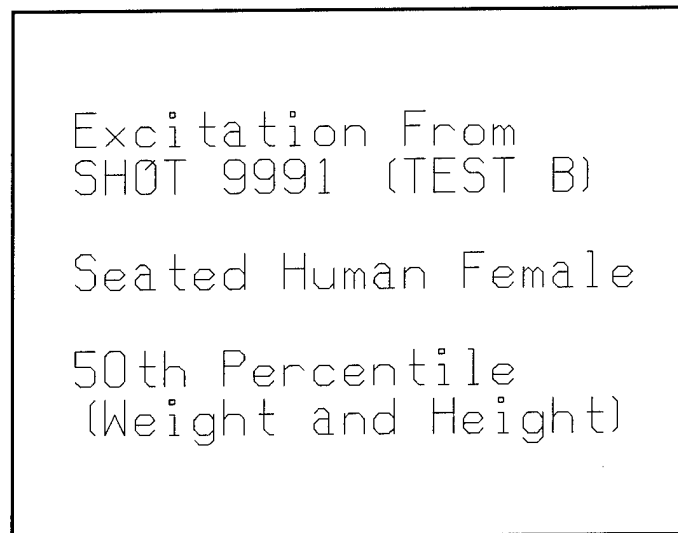
Figure 26. Sample VIEW Title Frame.

2. File Structure
The VIEW program uses two input files and produces one or two output files depending upon the desired device for graphical output.

a. Input files
The two input files required by the VIEW program are a control (*.VIN) file and a source data (*.TP1) file. The *.VIN file is a structured input file containing 80 character lines of formatted alphanumeric data much like the ATB input file. It is in the *.VIN file that the user defines title frames and title strips, defines supplemental polygons if desired, specifies the colors for ellipsoids, planes and titles, determines the start, stop, and increment times, and sets up the viewpoint. See Ref. [3] for detailed information concerning the content and formatting for the *.VIN file.

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The *.TP1 file is the output file produced by the ATB program that provides the data concerning the model construction and motion. Since the VIEW program is only a graphics rendering utility, it cannot interpolate between data points, thus each time step to be rendered as specified in the *.VIN file, there must exist data at the same time step in the *.TP1 file.

b. Output files and devices

One output file, the *.VOU file, is always produced by the VIEW program. This file contains a formatted listing of the input data provided in the *.VIN file, as well as debug information. The user has some control over what debug information is printed to the *.VOU file – see Ref. [3] for details.

The second output file may or may not be produced, depending upon the user's choices for output device and format. These choices are made by specifying two parameters – MODEL and IOPORT. MODEL specifies the type of monitor or printer to be used and IOPORT specifies the hardware interface (parallel port, serial port, or data file). If the user elects to send the graphical output to a file (for deferred plotting), this file has the extension *.VPL. Ref. [3] provides an extensive listing of the recommended combinations of MODEL and IOPORT for several printers, plotters, and displays.

D. IMAGE PROGRAM

The IMAGE program, much like the VIEW program, is a tool used to visualize the gross body dynamics as computed using the ATB program. However, the IMAGE program generates solid object rendering in a 3-D environment and is a much more powerful tool. Unlike the ATB, GEBOD, and VIEW programs, IMAGE is written in C and must be run on a Silicon Graphics (SGI) computer. There is no published user's manual for the IMAGE program, but rather it comes with the program files in the form of a text file. For the convenience of the reader, the user's manual is included as APPENDIX A.

1. Program Overview

The IMAGE program, like the VIEW program, is capable of rendering only ellipsoids and polygons. However, instead of line and contour drawings, the IMAGE program produces shaded solid objects and allows the user to change the viewing angle and zoom in/out while the program is running.

Like VIEW, IMAGE produces only a series of still images based upon information generated by the ATB program. However, IMAGE provides the user with a VCR-like interface to control the display of the still images. By clicking on the appropriate buttons, the user can play the images like a movie, in forward or reverse, pause, restart the movie, step forward or backward frame by frame, or change the speed at which the images are displayed. By using the three mouse buttons the user can also zoom in or out (left button), rotate the image (middle button), or translate the image on the screen (right button). These changes in orientation can be made while the image sequence is playing, or while it is stopped. Figure 27 shows a sample frame from the IMAGE program.

In addition to interactive controls, the user may add and delete planes, specify plane and ellipsoid colors, specify the direction from which incident light comes, and

specify a default viewing position through the use of a setup file described in the following section. Using the IMAGE program and a media-recording program, it is quite simple to create movie files and videotapes of the simulation.

2. File Structure

The IMAGE program requires two input files. The first file is the *.TP1 file containing the data generated by the ATB program. Just as in the VIEW program, the IMAGE program can only display images at times that information is stored in the *.TP1 file. Unlike the VIEW program, where the user can specify a start, stop, and increment time, the IMAGE program displays all of the times for which there is data in the *.TP1 file.

The second input file is a *.setup file. It is in this file that the user defines the colors for the planes, ellipsoids, background and time stamp, designates any planes or ellipsoids to be removed, adds any desired planes, specifies the camera position and viewpoint, and specifies the light direction. The *.setup file does not require the rigid structuring that the *.AIN and *.VIN files must maintain, but there are specific variable names that define the appropriate properties and a specific order in which the information must be included in the file. For more details concerning the *.setup file and use of the IMAGE program, see APPENDIX A.
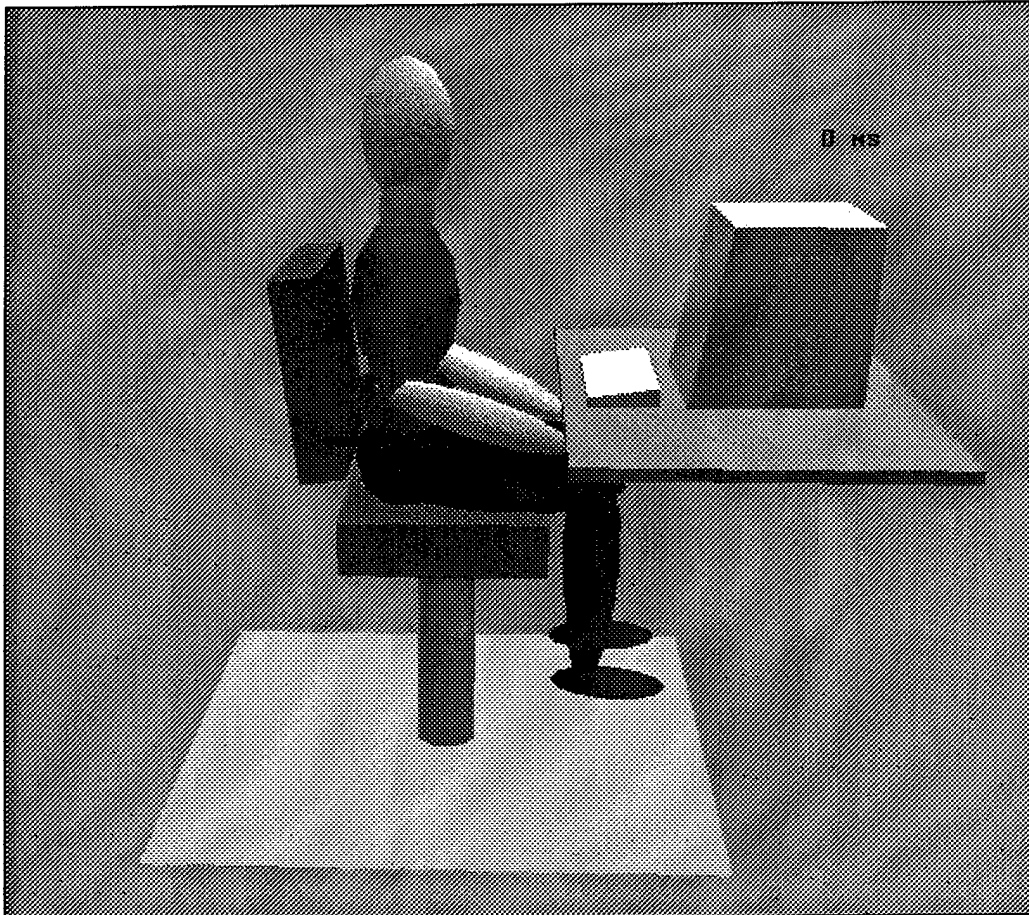
Figure 27. Sample IMAGE Frame.

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III. CREATING AN INPUT DECK

This chapter examines the process by which an input deck is created. One example is chosen and used throughout the remainder of the report for consistency. The chosen example involves the generation of a model of a Hybrid III Dummy seated in a standard operator's chair in a test vessel that is subjected to an underwater explosion. Measured accelerations of the deck to which the chair is attached, and of the head, chest, and pelvis of the dummy, along with video footage of the test, provide a basis for validation of the simulation. Following validation, the model is extended to simulate humans and to estimate injury potentials. From the videotape of the test, a still frame image, Figure 28, has been captured to aid in the construction of the environment and initial positioning of the test subject.

Each section covers a major category of the input deck data. In each section, the process by which the required data is obtained is discussed, and then the manner in which the data is formatted as required by the ATB program is illustrated. Note that this report does not replace Ref. [1], but rather illustrates the application to a single example problem. All formatting requirements are fully detailed in Ref. [1].

Finally, the completed input deck (*.AIN file), with a major portion of the tabulated excitation history removed for brevity, is included as APPENDIX B. In addition, the main output file (*.AOU) for this input deck, again with a major portion of the tabulated excitation history removed for brevity, is included as APPENDIX C to aid in the interpretation of the ATB formatted input data.
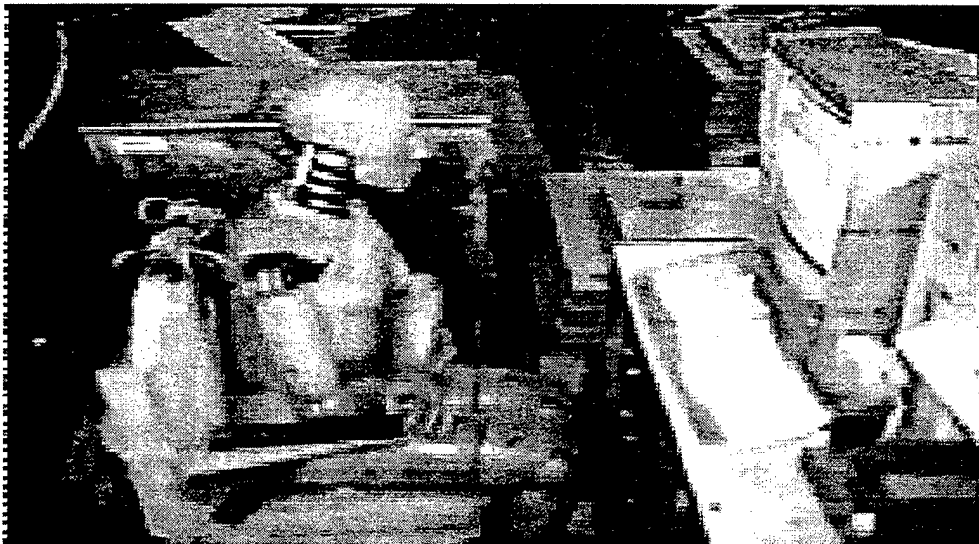
Figure 28. Example Test Setup.

When first using the ATB program, it is advisable to start with an example input (*.AIN) file, and the associated main output (*.AOU) file, and compare the two. The *.AOU file contains the information from the *.AIN file, but in an easy to read tabular form. Then, make small modifications to the existing *.AIN file, run ATB, and examine

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the results. This is much easier than trying to create an *.AIN file from scratch due to the extensive formatting requirements

A. USING GEBOD TO GENERATE BODY SET DATA

Perhaps the easiest step in creating the input deck is to generate the required data for the test subject, be it an ATD or a human. The GEBOD program, using simple input from the user, generates the appropriate information in the correct format for use in the *.AIN input file to the ATB program. In this case, the test subject is a 50th percentile male Hybrid III dummy, one of the ATD's for which GEBOD can generate the body data.

1. Running the GEBOD Program

In order to generate the body data, the GEBOD program is executed by typing "GEBODIV1" at a DOS prompt (GEBOD may be executed from a DOS window). Figure 29 shows the display from the run of GEBOD used to generate the body data set for the 50th percentile male Hybrid III dummy, using English units and creating an ATB formatted input file. The dark text is generated by the GEBOD program; the lighter text is user input from the keyboard.

The first required input is a description of the test subject. This description is printed in the each of output files and should sufficiently describe what the associated data represents. In this case, the description "Seated, 50th %-ile male Hybrid III" was used as can be seen from the first line of lighter text in Figure 29. GEBOD then redisplays the description and makes the next request for information – output file name. Again, it helps to make the output file name somewhat descriptive. A word of caution, though – if there is an existing *.AIN file with the same filename, it will be overwritten if that filename is used for output of ATB formatted data in GEBOD. In this case, the filename "SM50H3" was chosen and represents Seated Male 50th percentile Hybrid 3.

Next, the user is prompted to choose what kind of test subject is to be modeled, as shown in Figure 29. Since the subject used in the actual test was a 50th percentile male Hybrid III dummy, option 5 is chosen. Had the subject been a human (options 1-4), further information would have been required by the GEBOD program. This will be covered in detail in the section concerning extending the validated model to the simulation of human motion.

English or metric units must be specified. The selection is entirely up to the user, although the entire ATB input file must be in consistent units. The ATB user's manual [Ref. 1], as well as this example, utilize the units of inches, pounds, and seconds. In addition, Ref. [1] cautions that if other units are used, it may be necessary to modify the field widths of some of the output format statements.

Since in this case the purpose of running the GEBOD program was to generate body data for use in an ATB input file, ATB model formatted output is desired. In addition, since there is only one subject in this example, no further body description data sets are required.

```
PROGRAM GEBOD
GEBOD GENERATES BODY DESCRIPTION DATA
SUITABLE FOR INPUT TO THE ATB MODEL
PLEASE ENTER A DESCRIPTION OF THE SUBJECT (<60 CHARS.)


Seated, 50th %-ile male Hybrid III

ENTER FILENAME FOR ALL OUTPUT FILES,
EXTENSIONS WILL BE ASSIGNED:



          1)    CHILD (2 - 19 YEARS)

          2)    ADULT HUMAN FEMALE

          3)    ADULT HUMAN MALE

          4)    USER-SUPPLIED BODY DIMENSIONS

          5)    SITTING HYBRID III DUMMY (50%)

          6)    STANDING HYBRID III DUMMY (50%)

          7)    HYBRID II DUMMY (50%)

ENTER NUMBER CORRESPONDING TO DESIRED SUBJECT TYPE

-

SELECT UNITS FOR OUTPUT
          1)      ENGLSH
          2)      METRIC


IS ATB MODEL FORMATTED OUTPUT DESIRED (Y/N) ?

-

IS IT DESIRED TO PRODUCE ANOTHER BODY DESCRIPTION DATA SET (Y/N) ?

-
```

Figure 29. GEBOD Execution Example.

2. GEBOD Program Output Files

Running the GEBOD program as described in the above paragraphs results in the generation of two output files – a *.TAB and a *.AIN file. In this example, the files SM50H3.TAB and SM50H3.AIN have been created in the same directory in which the GEBOD program resides.

The *.TAB file generated from the above run of the GEBOD program is included as APPENDIX D. This information is the same as is contained within the ATB formatted (*.AIN) file, but in the *.TAB file, it is in tabular form and is much easier to read. In order to make sense of the *.AIN file, which is included as APPENDIX E, it helps to compare the information it contains with the corresponding portion of the *.TAB file. Note that in the *.AIN file, each line has an associated card number (Card B.1, Card B.2, etc.) located at the right margin. The *.TAB file groups the like cards together under headings, also located at the right margin. For example, the B.2 cards contain the mass and geometrical properties of the segments making up the body of the Hybrid III dummy. The information as presented in the *.TAB file is much easier to read, whereas reading the *.AIN file requires the user to consult the appropriate section in Ref. [1].

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Notice that the *.AIN file contains information on Cards B.1 through B.6, D.1, E.1 through E.4, E.7, and F.4 through F.5. When the complete input file is constructed, this information can easily be cut and pasted in the appropriate locations with no change in formatting required.

Figure 30 shows the segment and joint numbering scheme created by GEBOD for the 50th percentile male Hybrid III dummy. The segments and joints are numbered on the figure as they are shown in the B.2 and B.3 cards. The fourth column on the B.3 cards lists the JNT parameter, which defines how the segments are connected. As shown in Figure 30, the Pelvis (Joint J=1) connects the Middle Torso (Segment J+1=2) to the Lower Torso (Segment JNT=1).
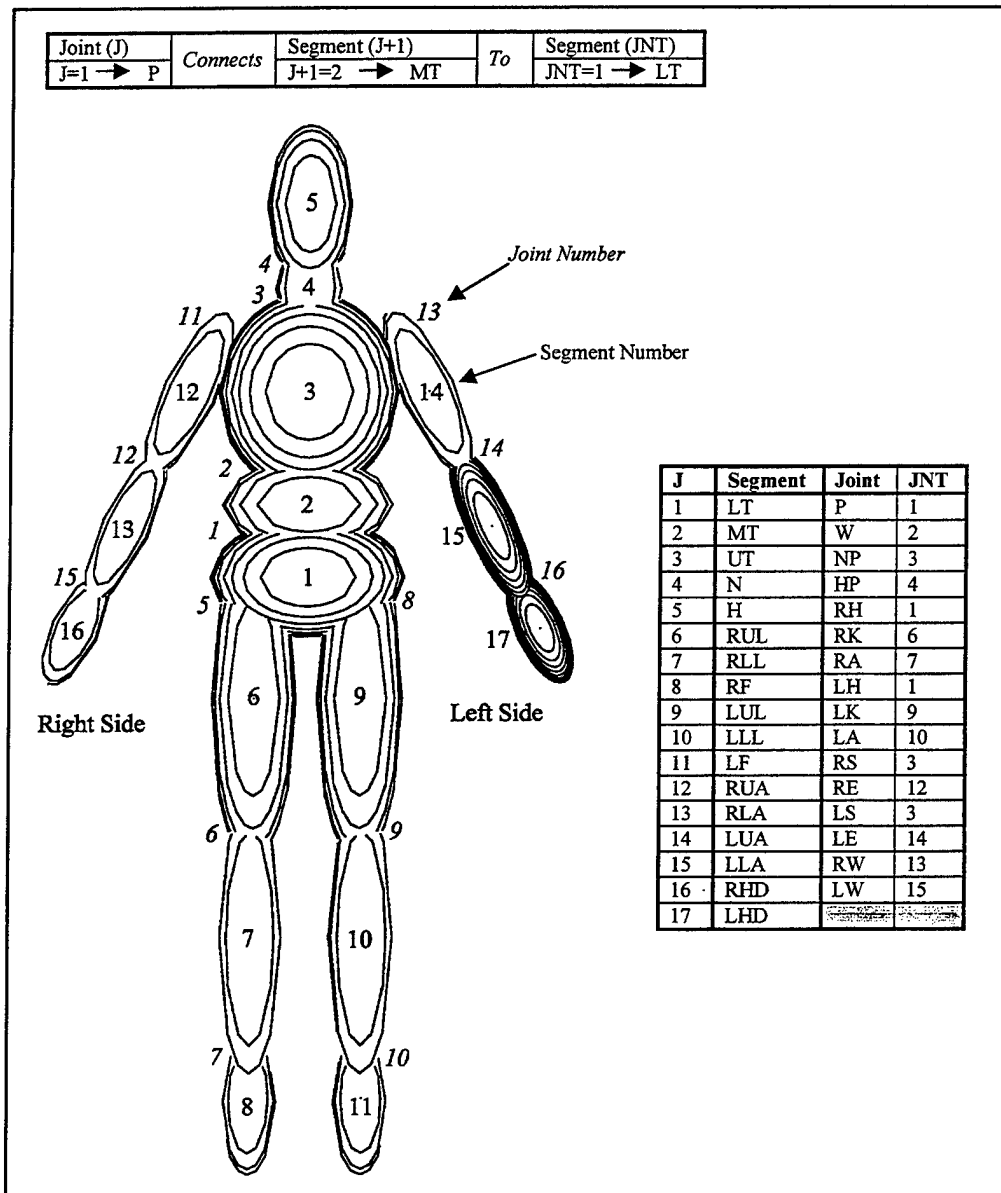
Figure 30. Standard 17 Segment Body. After Ref. [4]

B. BUILDING THE ENVIRONMENT

Constructing the model of the environment within which the test subject exists is quite possibly the most time consuming portion of creating the input deck. The more information that is available concerning the environment to be modeled, the easier the process will be. Overall, steps for constructing a model of the environment include:

1. Choosing a coordinate system
2. Determining what contact surfaces are to be modeled
3. Drawing a detailed diagram of the contact surfaces in the appropriate coordinate system
4. Creating any additional features such as harness belts, spring-dampers, or airbags.

1. Choosing a Coordinate System

There are several aspects to choosing coordinate systems. The coordinate system should be easy to work with in terms of defining the components of the model. It would be convenient to have the coordinate system be consistent with input excitation data or data to be used for validation, thus preventing or reducing the need to convert or transform either the measured data or the output from the ATB program. In addition, there are sign conventions related to the use of ATD's that should be considered when first setting up the model. A little time and forethought can greatly reduce the effort required in later steps.

a. Various coordinate systems in the ATB program

There are several coordinate systems utilized by the ATB program and they may be grouped in the following categories:

1. Inertial
2. Vehicle
3. Local body segment
4. Principal
5. Joint
6. Contact ellipsoid

The inertial coordinate system is assumed by the ATB program to have its origin at the point (0,0,0) and the user may equate this point to any convenient location within the model. It is within this frame of reference that the locations and orientations of the vehicle and local body segment coordinate systems are defined. The inertial coordinate system is partially specified by defining the gravity vector. Typically, this vector will be specified as (0,0,g) such that the positive Z-axis points down. Further convention would have the X-axis pointing forward and, by the right hand rule, the Y-axis pointing to the right as shown in Figure 31.

The vehicle coordinate system is typically the coordinate system in which most contact surfaces will be defined. It is defined by specifying the (x,y,z) coordinates of the origin with respect to the inertial coordinate system, then by specifying the yaw, pitch and roll angles to define the coordinate transformation matrix. The standard axis transformation, as shown in Figure 32, is to yaw about the Z axis, pitch about the new Y

(now Y') axis, the finally roll about the new X (now X") axis to yield the (X^*, Y^*, Z^*) system.
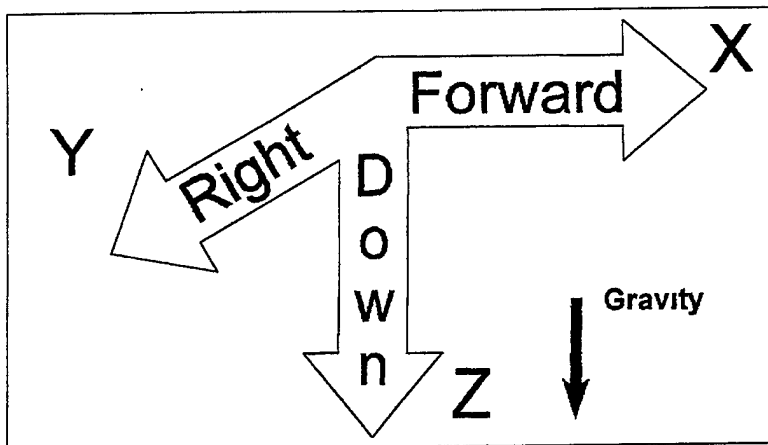
Figure 31. General Coordinate System Sign Convention. After Ref. [4]
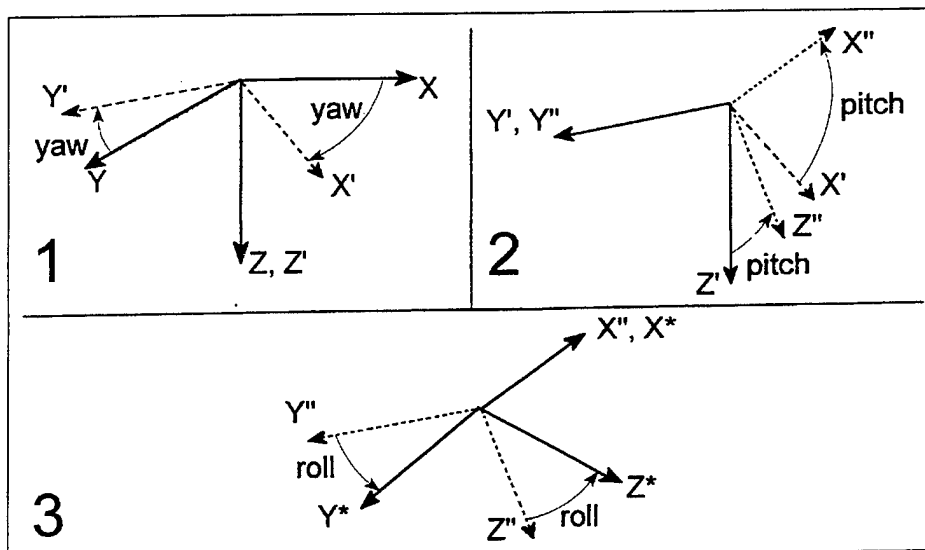
Figure 32. Standard Yaw, Pitch, Roll Sequence. After Ref. [4]

Body segments are defined by the locations of their centers of mass and the centers of their associated contact ellipsoids. Joints locations are defined by the coordinates of their centers. Figure 33 shows this arrangement in terms of the inertial coordinate system. The local body segment coordinate system has its origin located at the center of mass of the segment. When generated by GEBOD, the standard convention is that the body is standing upright, with arms hanging at the sides and feet dangling. In this position, all of the local body segment coordinate systems are aligned such that +Z is down (from head to feet), +X is forward (from back to front), and +Y is to the right (from left to right). All input or output concerning the segments is referenced to the local body segment coordinate systems.

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There is another coordinate system associated with each body segment, the principal coordinate system. This coordinate system has its origin coincident with the local body segment coordinate system at the center of mass of the segment. However, if the axes of the principal moments of inertia of the segment are not aligned with the local body segment coordinate system, then the yaw, pitch and roll angles that define the transformation must be specified. The orientation of the principal axes with respect to the local body segment axes is fixed. This coordinate system is illustrated in Figure 34. It is in the principal coordinate system that the ATB program performs the calculations for the dynamics of the motion of the body segment. The program transforms input data from the local body segment coordinate system into the principal coordinate system prior to performing calculations. Then, once the calculations have been performed, the data is transformed back into the local body segment coordinate system prior to output.
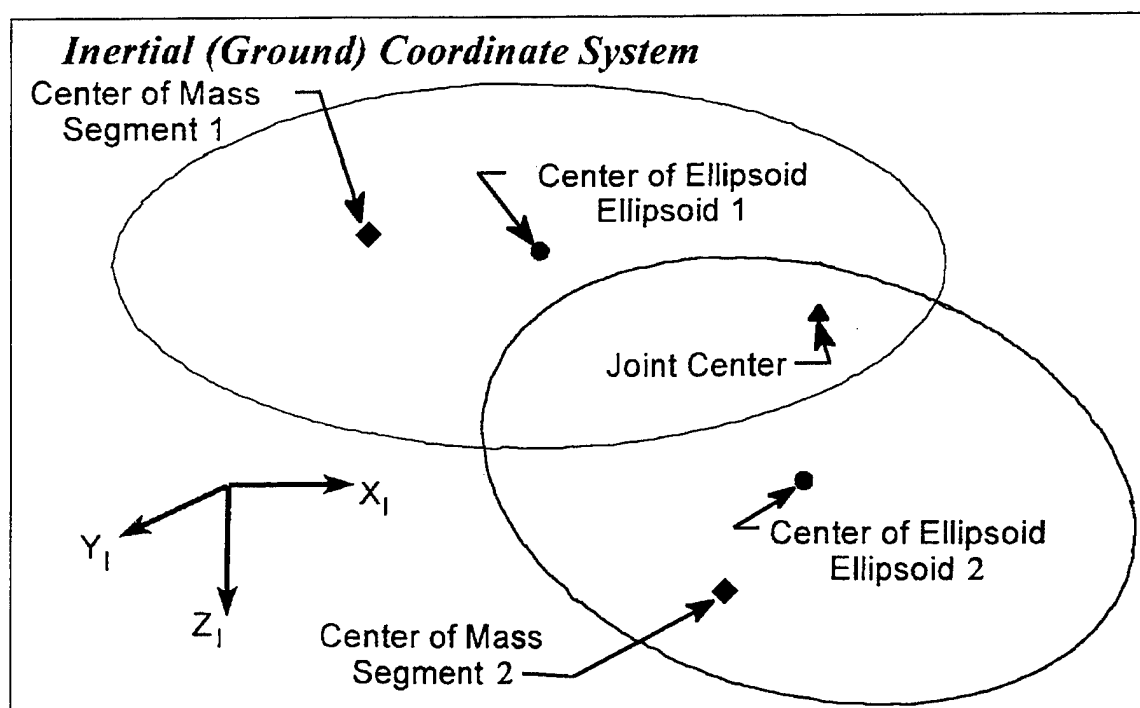
Figure 33. Inertial Coordinate System. After Ref. [4]

Associated with each joint are two coordinate systems. The location of the center of the joint is specified with respect to the local body segment coordinate system for each of the segments forming the joint. This location, and the associated orientation of the joint axis as defined by their yaw, pitch and roll angles, are fixed for each segment. Figure 35 shows a joint (J=1) with its two associated coordinate systems, one attached to segment J+1 (=2) and the other attached to segment JNT (=1). The joint forces and torques are computed based upon the relative orientation of the two joint coordinate systems.

Finally, for each contact (hyper) ellipsoid there is a coordinate system. The axes of this coordinate system are aligned with the x, y, and z semi-axes used to define the dimensions of the (hyper) ellipsoid. The location of the center of the

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coordinate system, and the orientation, are defined by the (x,y,z) coordinates and yaw, pitch, and roll angles with respect to the local segment coordinate system with which the (hyper) ellipsoid is associated.
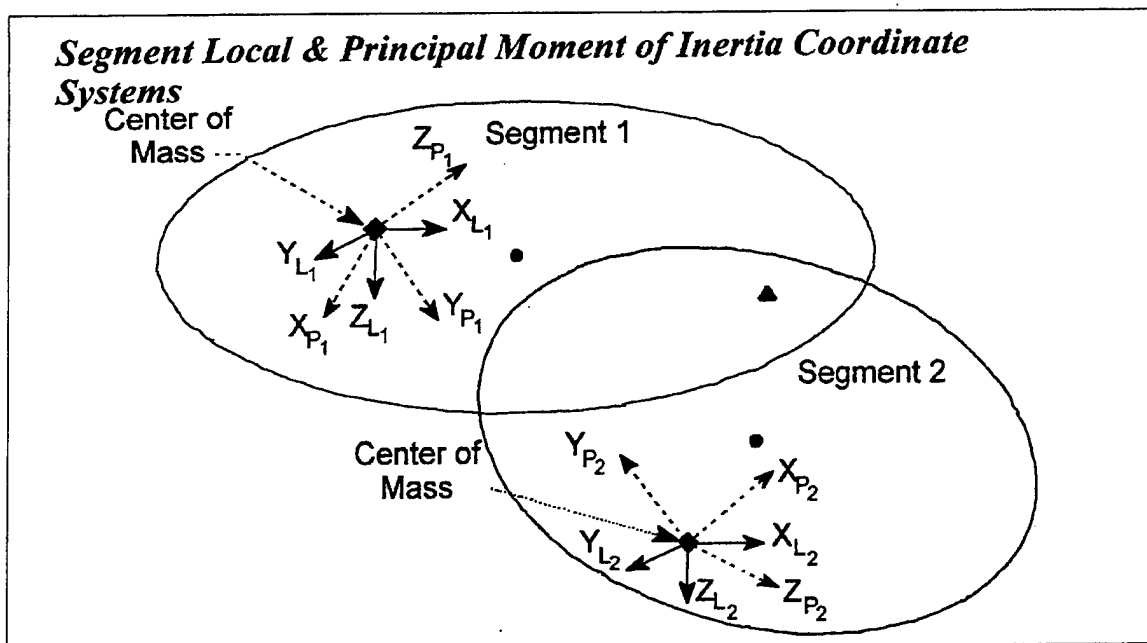
Figure 34. Local Body Segment Coordinate System. After Ref. [4]
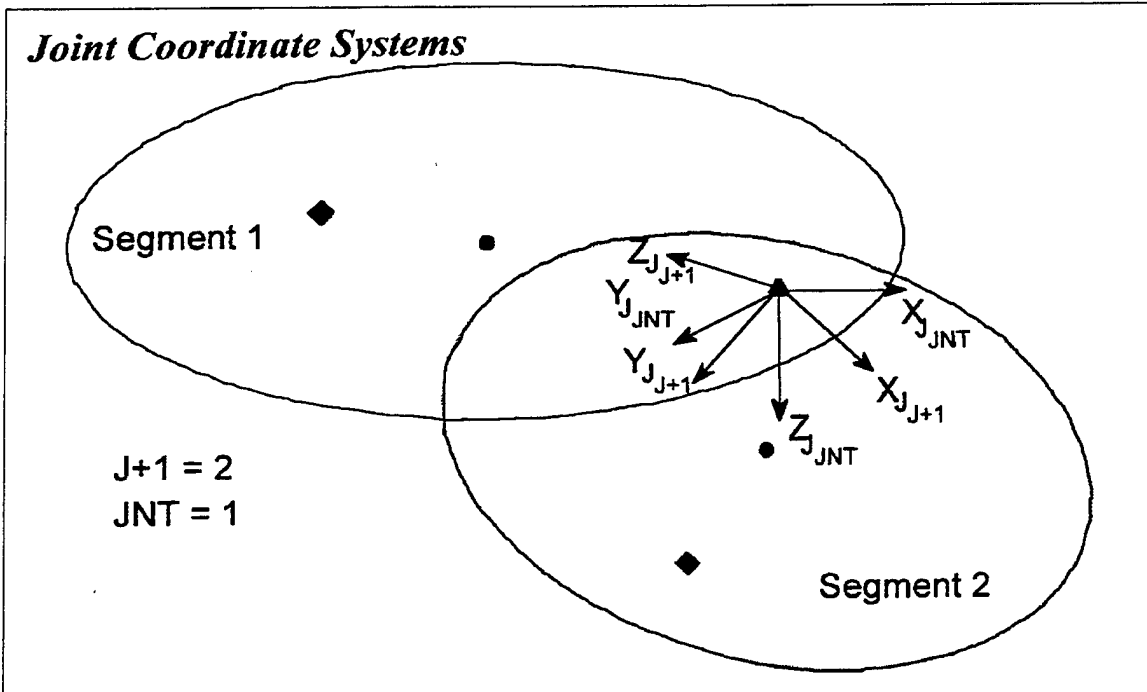
Figure 35. Joint Coordinate Systems. After Ref. [4]

b. Sign convention for crash testing

There is a standard sign convention, as specified in the Society of Automotive Engineers (SAE) Information Report J1733, associated with the used of ATD's [Ref. 6]. This convention, which applies to forces, moments, accelerations and displacements, is consistent with the definition of the body segment coordinate system described above. The convention, for both standing and seated postures, is illustrated in Figure 36.
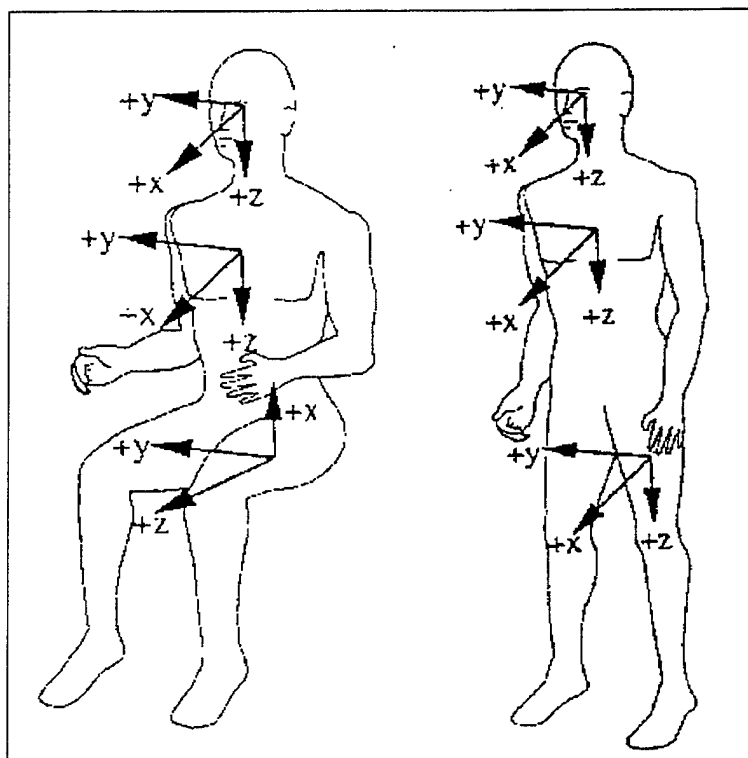
Figure 36. SAE Sign Convention. After Ref. [6]

c. Compatibility with input and/or output data

If modeling and test instrumentation sign conventions can be coordinated prior to conducting the test, assigning and keeping track of coordinate systems is greatly simplified. However, if no thought is given to modeling prior to conducting a test, as was the case in this example, more effort will be required for pre- and post-processing of data. It is relatively simple to make whatever transformations may be required to input and/or output data using either a spreadsheet or perhaps a simple conversion program written in MATLAB or FORTRAN.

In this example, the ATD was seated, facing starboard, in a standard operator's chair on the upper platform of a two-platform test vessel that was subjected to an underwater explosion. See Figure 37 for the arrangement of this platform. The locations of the accelerometers are labeled using a code beginning with the letter A (for accelerometer), followed by four numbers (identification numbers), and then followed by an A, an F, or a V. The A, F, and V refer to the orientation: A=athwartships, F=fore-and-

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aft, and V=vertical. Some codes have an I at the end to signify that the orientation of the accelerometer is inverted. The convention used in placing and aligning these accelerometers was that forward was positive for F-oriented accelerometers, up was positive for V-oriented accelerometers, and port was positive for A-oriented accelerometers.
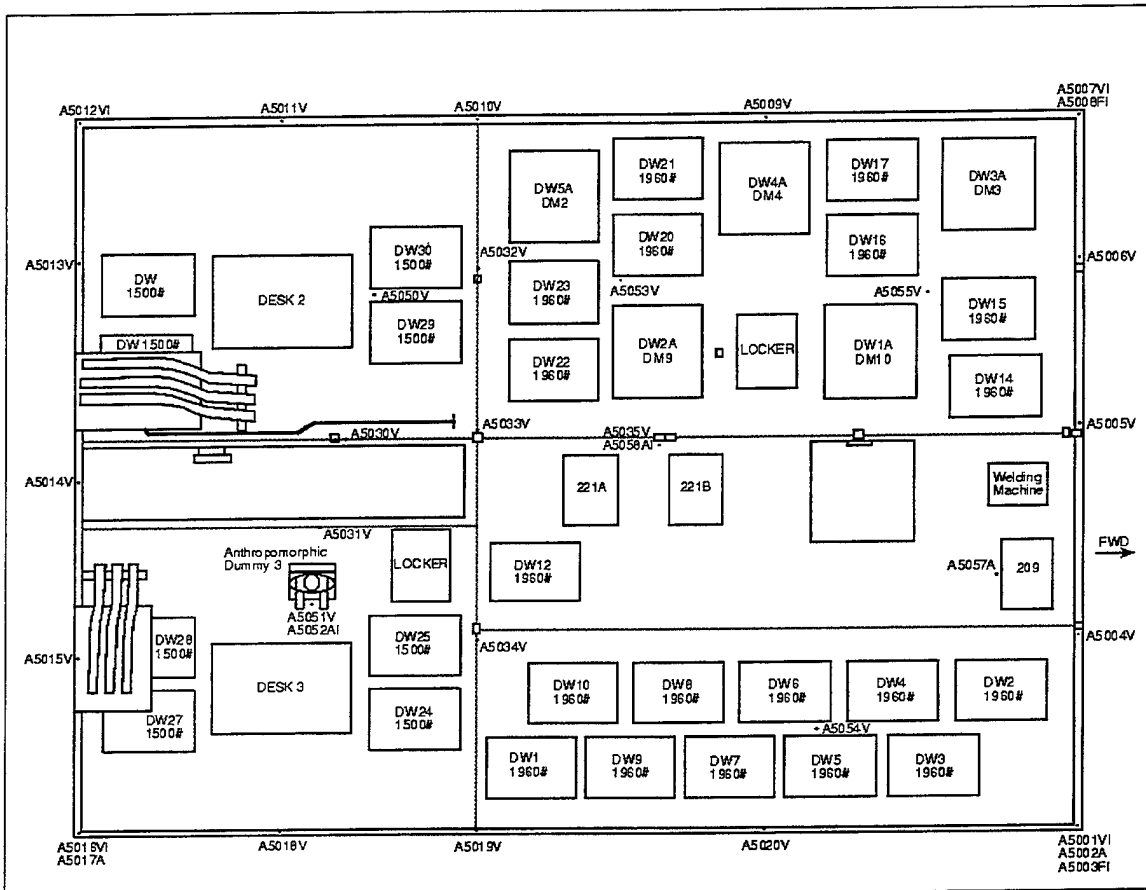
Figure 37. Accelerometer Locations (First Platform). From Ref. [10]

For the example, the choice was made to align the inertial coordinate system such that the X-axis pointed in the forward direction. In addition, it was desired to have the positive Z-axis pointing down; thus, the Y-axis was defined (via the right hand rule) to point to starboard. This orientation is shown in Figure 38. Since the ATD is seated facing starboard, it would have been a better choice to align the X-axis of the inertial coordinate system such that it pointed starboard to be consistent with the sign convention for ATD's. The location of the origin of the inertial coordinate system was selected to be on the deck at the center of the base of the chair in which the ATD was seated. This choice was made so that the origin coincided roughly with the location of the accelerometers at the base of the chair.

In order to relate the data as recorded to the inertial coordinate system, and to avoid confusion later, it is convenient to create a simple table. The conversion from the test vehicle (SSTV) to the model (ATB) is shown in Table 4. For example, to transfer

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the data from an athwartships mounted accelerometer into the inertial coordinates, all that is required is multiplying the data by negative one.

Table 4. Test Vessel to Model Conversion

SSTV Coordinates	Multiplier	Inertial Coordinates
F (fore and aft)	+1	X
FI (fore and aft – inverted)	-1	X
A (athwartships)	-1	Y
AI (athwartships – inverted)	+1	Y
V (vertical)	-1	Z
VI (vertical – inverted)	+1	Z
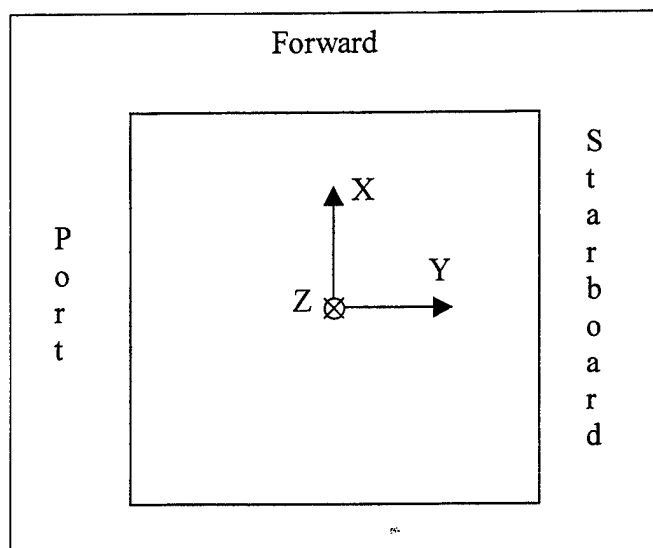
Figure 38. Inertial Coordinate System Definition.

2. Selecting Contact Surfaces

Once the basics of selecting and locating an inertial coordinate system have been completed, the next logical step is to decide how much of the environment must be modeled. The only items that need be modeled are those with which the test subject interacts. Other items may be modeled, if desired, to provide additional visual reference when using the VIEW program. It is important to keep in mind the limitations on the number of contact planes, contact (hyper) ellipsoids, plane-segment contacts, and segment-segment contacts allowed by the unmodified ATB program.

In this example, in addition to the deck, the only object to be modeled was the chair in which the ATD was seated. There was no apparent contact with the desk, so this object was not included in the modeling for validation. The important components of the chair included the seat bottom (cushion and right, left, and front sides), seat back (cushion and right, left, and top sides), left and right armrests, and lap belt. The pedestal supporting the chair and the footrest were not thought to interact with the ATD and thus were not considered.

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Once the objects to be modeled are identified, the next step is to determine how to model them. Contact surfaces can be modeled as either planes or (hyper) ellipsoids and belts can be modeled as either simple or harness belts. In this example, it was decided to model the surfaces of the seat (bottom cushion, right, left, and front sides; back cushion, right, left, and top sides), as well as the deck, as planes. An alternative would have been to model the seat bottom as one hyperellipsoid and the seat back as a second hyperellipsoid. A drawback to this method is that there are only 40 segment-segment contacts allowed. This number includes the expected interactions between the individual body segments (e.g., right lower arm and right upper leg) and it is quite easy to reach the limit if (hyper) ellipsoids are used as contact surfaces. The decision was made to model the armrests as ellipsoids, although the use of hyperellipsoids might have been a better choice in order to capture their physical dimensions more accurately. A simple, vice harness, belt was deemed adequate for the model. Table 5 summarizes the surfaces to be modeled and the corresponding model element selected.

Table 5. Correlation of Model Element to Physical Surface

Physical Surface	Selected Model Element
Seat Bottom Cushion	Plane
Seat Bottom Right Side	Plane
Seat Bottom Left Side	Plane
Seat Bottom Front Side	Plane
Seat Back Cushion	Plane
Seat Back Right Side	Plane
Seat Back Left Side	Plane
Seat Back Top	Plane
Right Arm Rest	Ellipsoid
Left Arm Rest	Ellipsoid
Lap Belt	Simple Belt
Deck	Plane

3. Drawing a Picture and Defining Contact Surfaces

After selecting the physical objects to be modeled, and determining the types of ATB elements to use for the modeling, the next step is to define the physical properties of the ATB elements. It is highly recommended that a few sketches be drawn and labeled to avoid confusion. One method would be to create a drawing similar to the one shown in Figure 39. This gives an overall view of the objects to be modeled, includes the origin and orientation of the inertial coordinate system (also selected as the coordinate system for the vehicle), and numbers all of the contact surfaces to be modeled. Note that the ellipsoids representing the arm rests are numbered 18 and 19. This is because the test subject is created from segments 1 through 17.

For each plane to be modeled, three corner points (P1, P2, and P3) must be specified to define not only the location and size, but also the orientation of the parallelogram representing the surface. Refer back to Figure 4 for an illustration of how a plane is defined in the ATB program. It is very important to ensure that the normal to

the plane, as defined by the vector formed by crossing P1P2 into P1P3, is correctly oriented. Thus, sketching the points P1, P2, and P3, and the outward normal, is a good idea. Figure 40 illustrates this process for the right side of the seat bottom, plane number three.
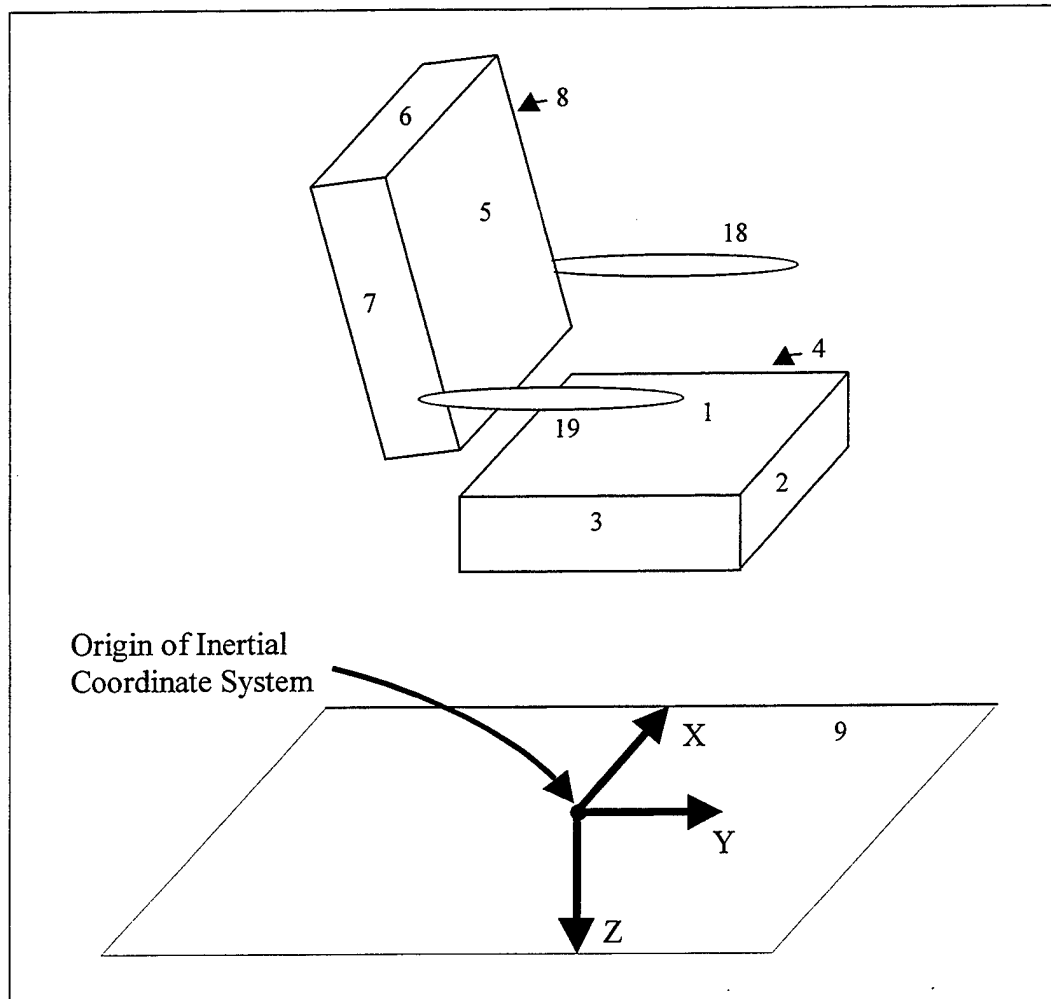
Figure 39. Sketch of Operator's Chair.

Once the three points defining each plane have been identified, and the correct orientation of the outward normals verified, the next step is to determine the coordinates of each of these points. Dimensions for the operator's chair in this example were determined by physical measurement and the resulting coordinates of the points defining each of the identified planes are shown in Table 6.

The planes defining the chair and deck are rigidly attached to the vehicle and there can be no relative motion between them. This does not exactly model reality in that there is some flexibility in the real chair. In addition, the seat back, which is adjustable for angle, is definitely not rigidly attached to the seat bottom. However, the motion between the seat back and the seat, and between the seat and the deck, is assumed to be relatively minor. If a more sophisticated model was required, then the seat back and seat

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bottom planes could each be attached to separate segments. These segments could then be connected to each other and to the deck using appropriate joint types and parameters.

From examination of the videotape of the actual test, significant motion of the armrests was observed. Thus, it was desired to have these armrests free to pivot about their hinges with appropriate joint and inertial parameters. The physical dimensions of the armrests were first defined. Since segments were used to model the armrests, it was necessary to specify the center of mass and inertial properties of the segment and the center, semi-axis lengths, and orientation of the associated contact ellipsoids. In addition, the location and orientation of the joint used to connect the armrest segments to the vehicle must also be specified.

Table 6. Coordinates of Points Defining a Contact Plane.

Plane #	Plane ID	Point	X	Y	Z
1	Seat Cushion. Bottom.	P1	-9.50	-9.25	-24.50
		P2	-9.50	9.25	-24.50
		P3	9.50	-9.25	-24.50
2	Seat Cushion. Front.	P1	9.50	9.25	-19.75
		P2	9.50	9.25	-24.50
		P3	-9.50	9.25	-19.75
3	Seat Cushion. Right Side.	P1	-9.50	9.25	-19.75
		P2	-9.50	9.25	-24.50
		P3	-9.50	-9.25	-19.75
4	Seat Cushion. Left Side.	P1	9.50	-9.25	-19.75
		P2	9.50	-9.25	-24.50
		P3	9.50	9.25	-19.75
5	Seat Back.	P1	-9.50	-8.30	-28.25
		P2	9.50	-8.30	-28.25
		P3	-9.50	-10.25	-44.55
6	Seat Back. Top.	P1	-9.50	-10.25	-44.55
		P2	9.50	-10.25	-44.55
		P3	-9.50	-14.22	-44.07
7	Seat Back. Right Side.	P1	-9.50	-12.27	-27.77
		P2	-9.50	-8.30	-28.25
		P3	-9.50	-14.22	-44.07
8	Seat Back. Left Side.	P1	9.50	-12.27	-27.77
		P2	9.50	-14.22	-28.25
		P3	9.50	-8.30	-44.07
9	Deck.	P1	-25.00	-25.00	0.00
		P2	-25.00	25.00	0.00
		P3	25.00	-25.00	0.00

The armrests were measured to be 14 inches long, 2 inches wide, and 1 inch high. The weight of each armrest was estimated to be 2 pounds. While the actual armrests were rectangular, ellipsoids, with semi-axis lengths equal to half of the actual length, width, and height, were chosen as the modeling elements. As previously mentioned, using a hyperellipsoid as the modeling element would allow the actual physical shape of the armrest to be more closely approximated. The armrests were assumed to be

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symmetric and homogeneous, thus their centers of mass and the centers of the associated contact ellipsoids were specified to be coincident. In addition, the local body segment coordinate system axes and principal axes were specified to be coincident. Figure 41 shows the details for one of the armrests.

The principal moments of inertial for the armrests were computed using Equations 3, 4, and 5. The physical dimensions and resulting moments of inertia are summarized in Table 7.
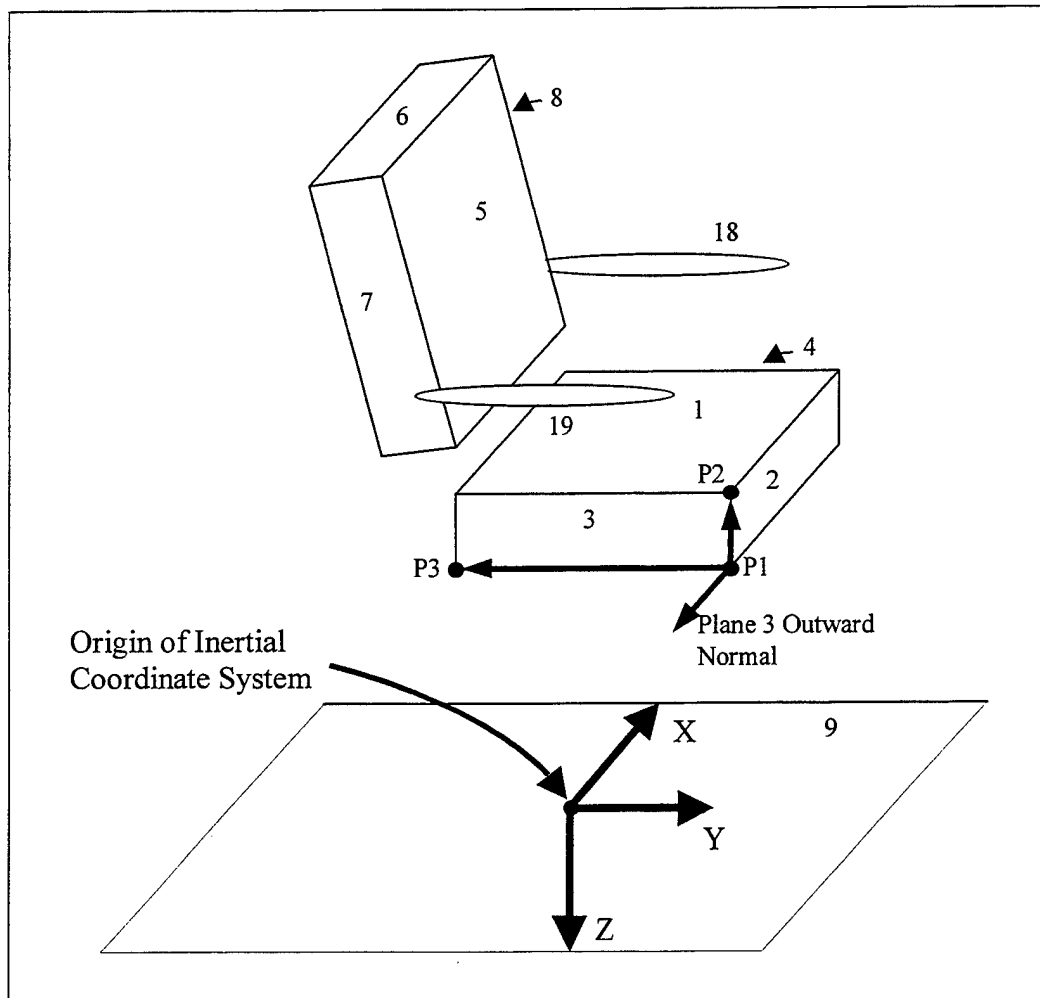
Figure 40. Identifying Plane Outward Normals.

$$I_X = \tfrac{1}{12} m \left(L^2 + H^2 \right) \tag{3}$$

$$I_Y = \tfrac{1}{12} m \left(H^2 + W^2 \right) \tag{4}$$

$$I_Z = \tfrac{1}{12} m \left(L^2 + W^2 \right) \tag{5}$$

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Table 7. Armrest Physical Data.

Armrest	Principle Moment of Inertia (lb sec^2 in)			Semi-axis Lengths (in)			Center of Ellipsoid Offset (in)		
	x	y	z	x	y	z	x	y	z
Left	0.0850	0.0022	0.0863	1.00	7.00	0.50	0.00	0.00	0.00
Right	0.0850	0.0022	0.0863	1.00	7.00	0.50	0.00	0.00	0.00
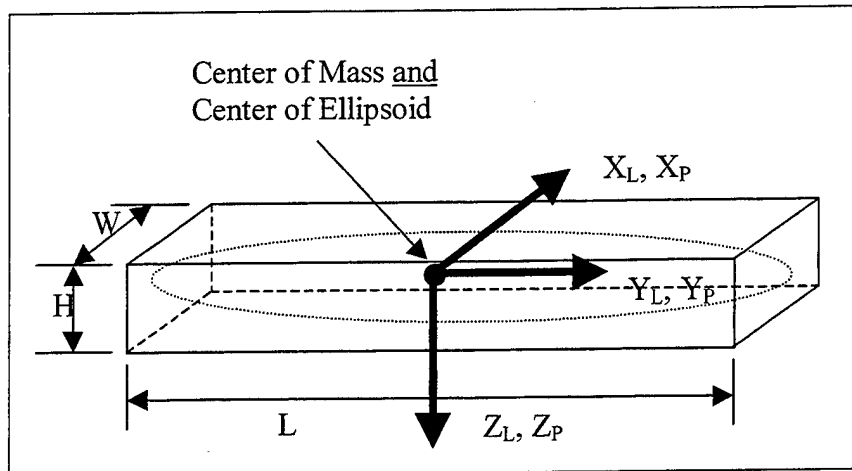
Figure 41. Armrest Detail.

In addition to specifying the physical dimensions and moments of inertia for the armrests, the parameters for the joints connecting the armrests to the vehicle must also be specified. The logical choice for the joint type (see Figure 1 for options) is a pin joint. The specification of a joint requires that not only the type of joint must be specified, but also that the location and orientation of the two sets of joint axes must be specified (see Figure 35 for joint coordinate system details). The location of the joint center (origin of the joint coordinate systems) is easily specified. The point was chosen to be one-half inch from the end and centered on the major axis of the ellipsoid and the coordinates are specified in both the vehicle and the armrest local coordinate systems (see Table 8 for values). Reference [1] requires that pin joints have the y-axis as their axis of rotation, thus requiring a coordinate transformation for both sets of joint axes. A yaw of 90 degrees is necessary to align the y-axes of both joint coordinate systems with the desired axis of rotation of the armrest (see Figure 42 for details).

The armrests on the actual chair were free to move from a horizontal position to a position roughly parallel to the seat back. This range of motion was estimated to be 97 degrees and, within this range, there was no resistance (other than friction). At the stops (horizontal and parallel with the seat back), however, there was considerable resistance to further motion. This behavior can be modeled using a joint stop angle of 48.5 degrees (half of 97 degrees), a linear spring coefficient of zero, and a large quadratic spring coefficient (refer to Figure 2, S1=0, S2=large number, S5=48.5 deg). As previously stated, the joint torques are computed based on the relative orientation of the two sets of joint axes. This angle (flexure, or rotation about the y-axis, for a pin joint) is referenced

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to the JNT segment set of axes as the center of symmetry. In other words, if the JNT and J+1 segment joint axes are coincident, the segment is oriented such that there is no flexure about the joint (θ=0 in Figure 2). So, for the armrest to be at one joint stop angle (-48.5 deg) when in the horizontal position and at the other joint stop angle (+48.5 deg) when aligned with the seat back, the center of symmetry (JNT segment joint axes) must be rotated 48.5 degrees counter-clockwise from the J+1 segment joint axes. This condition is illustrated in Figure 42 and the corresponding angles listed in Table 8. Note that is would have been equivalent, and probably less confusing, to have the J+1 segment joint axes aligned with the segment and to have the JNT segment joint axes rotated 48.5 degrees counterclockwise. This would have the X_{JNT} aligned with the physical center of symmetry of the armrest range of motion.
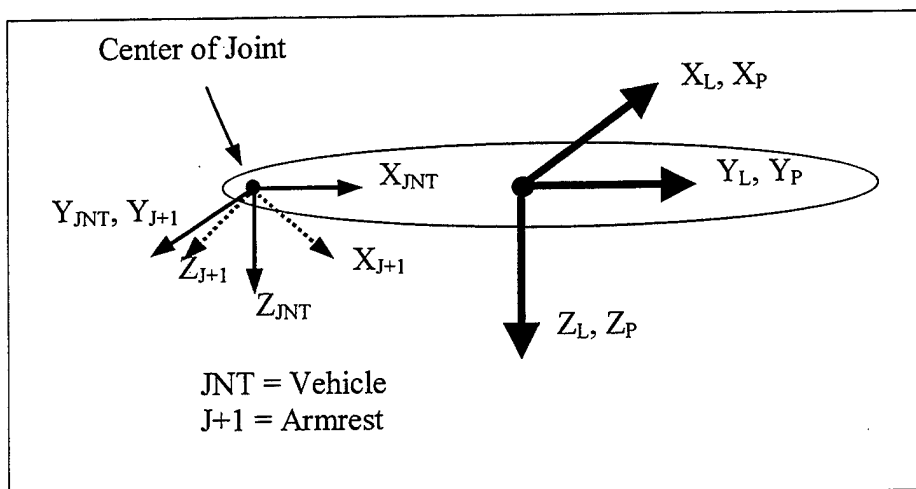
Figure 42. Armrest Joint Detail.

Table 8. Armrest Joint Parameters.

Armrest	Location (in)						Joint Axes Orientation (deg)					
	Vehicle Coordinates			Armrest Coordinates			WRT Vehicle Axes			WRT Segment Axes		
	x	y	z	x	y	z	yaw	pitch	roll	yaw	pitch	roll
Left	10.50	-10.00	-31.75	0.00	-6.50	0.00	90.00	0.00	0.00	90.00	-48.50	0.00
Right	-10.50	-10.00	-31.75	0.00	-6.50	0.00	90.00	0.00	0.00	90.00	-48.50	0.00

The only component of the model yet to be discussed is the lap belt. It was decided that use of a simple belt, vice a harness belt, would be adequate in this example problem. A simple belt, as previously described (see Figure 18), requires only that the two anchor points and a fixed contact point on a segment, plus an initial slack length, be specified. The anchor points in this example are simply the two points at which the lap belt is attached to the chair. The belt runs across the lap, so the lower torso is the segment that will be allowed to interact with the belt. The contact point on the lower torso was specified such that it was aligned with the center plane of the body and roughly 60 degrees above horizontal. Figure 43 shows the side view of the lap belt specification with the armrests and remainder of the body segments removed for clarity. The coordinates of these three points are specified in Table 9. The initial slack for the lap belt

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was set to zero (recall that simple belts cannot be pre-tensioned by specifying a negative initial slack).

Table 9. Lap Belt Anchor/Contact Point Locations.

Point	Coordinate System	X (in)	Y (in)	Z (in)
Left Anchor	Vehicle Local	**9.50**	-9.50	-24.50
Right Anchor	Vehicle Local	-9.50	-9.50	-24.50
Segment Contact	Lower Torso Local	2.72	0.00	-4.03
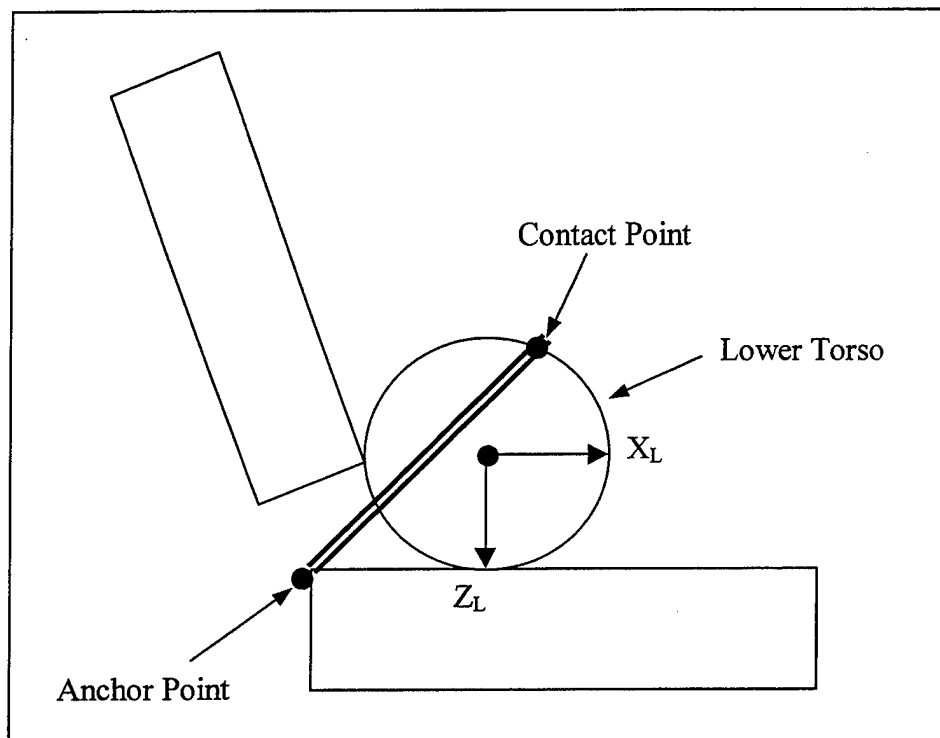
Figure 43. Lap Belt Detail.

4. Formatting the Data

Now that the necessary data concerning the definitions of the contact surfaces and the lap belt has been accumulated, the next step is to format the data in accordance with Ref. [1]. Formatting the contact surface (including the armrest joint parameters) and lap belt data will be discussed in the following paragraphs. Refer to APPENDIX B and APPENDIX C to see the placement of the formatted data in the input file and to see the data in a more easily interpreted form in the output file, respectively. Refer to Ref. [1] for the structure and variable names that are used in the ATB program.

a. Planar contact surfaces

The data defining each of the contact planes is placed on cards D.1 and D.2.a through D.2.d. Card D.1 lists the number of planes, simple belts, airbags, contact (hyper) ellipsoids, etc. Card D.2.a list the plane identification number and a 20-character

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description of the plane. Cards D.2.b, c, and d list the (x,y,z) coordinates of points P1, P2, and P3, respectively. These coordinates are referenced to the local coordinate system of whatever segment to which the planes are attached. In this example, all planes are attached to the vehicle and the vehicle local coordinate system is coincident with the inertial coordinate system. Figure 44 shows the D.1 card along with the D.2 cards for plane number one, the seat bottom (cushion).
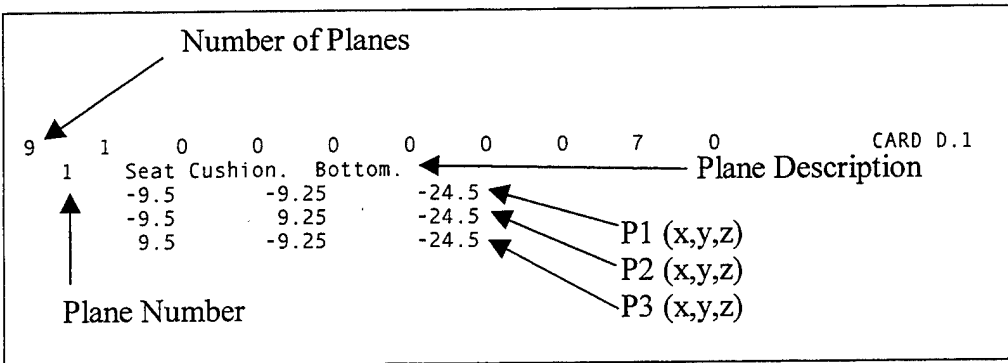
Figure 44. Planar Contact Surface Formatting.

b. Armrests

There is a difference between a segment and a contact (hyper) ellipsoid. When a segment is defined, a contact ellipsoid is associated with it. This data is defined in the B Cards as was seen in APPENDIX E for the body data set. Additional contact (hyper) ellipsoids may be defined in much the same way the planar contact surfaces are defined, with the data being entered on Cards D.5. In this example problem, the armrests are defined to be segments (thus possessing mass and inertial properties) and have contact ellipsoids associated with them. This means that the data for the armrests will be entered with the remainder of the body segments on the B Cards.

The number of segments and number of joints, along with a 20-character description of the crash victim, are entered on Card B.1. For each segment, Card B.2.a contains the four-character abbreviation, weight, principal moments of inertia, contact ellipsoid semi-axis lengths and offset values, and a flag alerting whether or not the principal axes are rotated. If the principal axes are rotated with respect to the local coordinate system, then the yaw, pitch, and roll angles are specified on Card B.2.b. For the armrests, segments 18 and 19, the B.2 cards are shown in Figure 45.

In addition to formatting the parameters for the armrest segments, it is necessary to format the data for the joints connecting the armrests to the vehicle. Each joint has its data specified on Cards B.3.a-b, B.4, and B.5. On Card B.3.a, the abbreviation, value for JNT (see Figure 30), joint type, and joint center location in both segment's coordinates are specified. On Card B.3.b, the orientation of the joint axes with respect to the segment local axes is specified. The torsional spring characteristics of the joint are specified on Card B.4 and the viscous and coulomb friction characteristics are specified on Card B.5. The formatted data for the joints connecting the armrests to the vehicle is shown in Figure 46. Although not shown, a Card B.6 is required for each joint.

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This card controls the convergence criteria and can generally be copied from the B.6 cards for the other joints.


```
      Abbreviation        Ellipsoid Semi-axis      0 – Principle axes
                          Lengths (x,y,z)          not rotated
          Weight

LAR 8 2.000 .0850 .0022 .0863 1.000 7.000 .5000  .000  .000  .000  0  CARD B.2
RAR 9 2.000 .0850 .0022 .0863 1.000 7.000 .5000  .000  .000  .000  0  CARD B.2

        Principle Moments                        Center of Ellipsoid
        Of Inertia (x,y,z)                        Offset (x,y,z)
```

Figure 45. Armrest Segment Data Formatting.


```
                        Joint Center Location
    Abbreviation        (x,y,z) in Vehicle Coord.    Joint Center Location
                                                     (x,y,z) in Armrest Coord.
        JNT (20 = Vehicle)

LR   20   1  0.50-10.00-31.75    .00 -6.50   .00  0  .00   .00        CARD B.3
             90.00   .00   .00 90.00-48.50   .00   .00   .00   .00 0 0 0 0 0 0
RR   20   1-10.50-10.00-31.75    .00 -6.50   .00  0  .00   .00        CARD B.3
             90.00   .00   .00 90.00-48.50   .00   .00   .00   .00 0 0 0 0 0 0

Joint Type    Joint Axes Rotation      Joint Axes Rotation
(1 = pin)     (yaw, pitch, roll) wrt   (yaw, pitch, roll) wrt
              Vehicle Coord.           Armrest Coord.


Energy Dissipation (1 = No Loss)

.00150.00   .00  1.00      48.50   .00   .00   .00 1.00      .00CARD B.4
.00150.00   .00  1.00      48.50   .00   .00   .00 1.00      .00CARD B.4

      Linear, Quadratic, Cubic            Joint Stop Angle
      Spring Coeff. (0.0, 150.0, 0.0)


                          Relative Velocity Above Which
    Viscous Coefficient   Full Coulomb Friction Applied

.0001   0.   30.    0.    0.              0.   0.          CARD B.5
.0001   0.   30.    0.    0.              0.   0.          CARD B.5

    Coulomb Friction Coefficient
```

Figure 46. Armrest Joint Data Formatting.

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c. Lap belt

The lap belt data is the final portion of the environmental specification to be formatted (force-deflection characteristics are covered in the next section). The number of simple belts is specified on Card D.1 (second column, see Figure 44), the 20 character description and the coordinates of the anchor points are specified on Cards D.3.a and D.3.b, respectively, and the coordinates of the segment contact point and the initial slack are specified on Card D.3.c. The formatted data for the lap belt is shown in Figure 47.
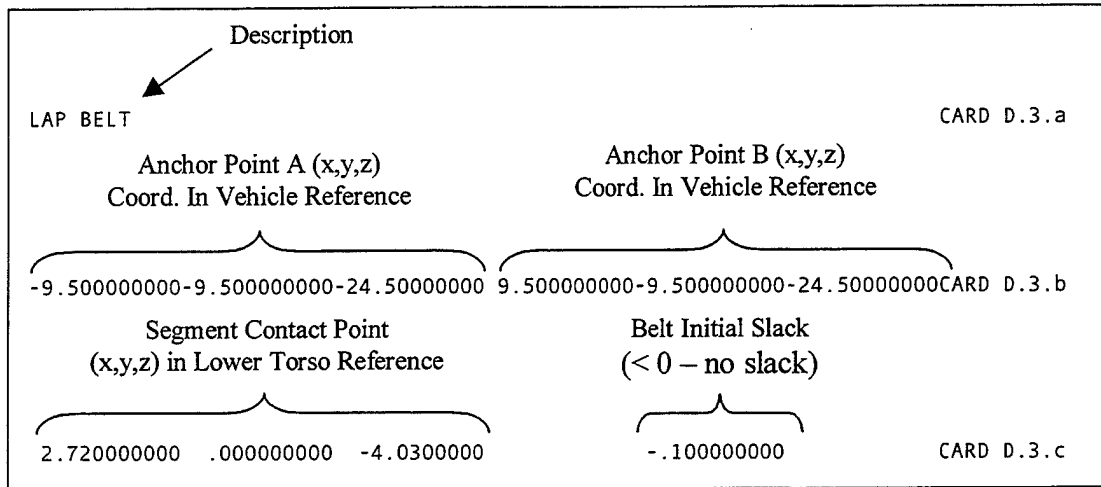
Figure 47. Lap Belt Data Formatting.

C. DEFINING FORCE-DEFLECTION CHARACTERISTICS

Once the contact surfaces have been identified and laid out as described in the previous section, the manner in which the body segments interact with these surfaces must be defined. A systematic approach will help to ensure that no important interactions are overlooked.

1. Allowed Plane-Segment Contacts

For each previously identified plane, determine what body segments are likely to interact with it. As previously stated, there can be a maximum of five segments contacting a single plane. If more than five segments are expected to interact with a given surface, a duplicate plane can be defined. In addition, the total number of plane-segment contacts must be less than 70. Use of a table to lay out the allowed plane-segment contacts makes it easy to verify that neither limit is exceeded.

By examining the videotape of the actual test, it was estimated that the only plane-segment contacts that would be required are those detailed in Table 10. Note that not all planes that were previously identified have contacts specified. This is completely acceptable and by defining the planes in the input deck, they will be rendered in the visualization. In order to verify that the assumptions were adequate and that no important interactions were excluded, the visualization (either using VIEW or IMAGE) can be examined once the simulation has been performed. If, during this examination, a segment is seen to pass through a plane, then that plane-segment contact should be

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allowed. This is most easily done using the IMAGE program, which allows for changing the viewing angles while the simulation is playing.

Table 10. Allowed Plane-Segment Contacts.

Plane #	Plane ID	# of Contacts	Segment #	Segment ID
1	Seat Cushion. Bottom.	3	1	Lower Torso
			6	Right Upper Leg
			9	Left Upper Leg
2	Seat Cushion. Front.	2	7	Right Lower Leg
			10	Left Lower Leg
5	Seat Back.	5	1	Lower Torso
			2	Middle Torso
			3	Upper Torso
			12	Right Upper Arm
			14	Left Upper Arm
6	Seat Back. Top.	2	4	Neck
			5	Head
7	Seat Back. Right Side.	2	12	Right Upper Arm
			13	Right Lower Arm
8	Seat Back. Left Side	2	15	Left Upper Arm
			14	Left Lower Arm
9	Deck.	2	8	Right Foot
			11	Left Foot
Total Number of Contacts		18		

2. Allowed Segment-Segment Contacts

As was the case for identifying plane-segment contacts, constructing a table helps to systematically identify what segment-segment contacts are to be allowed and to verify that no limits are exceeded. Again, there is a limit of five contacts per segment. The total number of segment-segment contacts is limited to 40 vice 70 as for plane-segment contacts.

Viewing the videotape of the actual test led to the list of allowed segment-segment contacts detailed in Table 11. Note that contacts can be specified in either order. For example, segment 16 (Right Hand) can be specified as a segment allowed to contact segment 1 (Lower Torso), or segment 1 can be specified as a segment allowed to contact segment 16. This flexibility helps avoid problems with having more than five contacts specified for any given segment.

As for the plane-segment contacts, the assumptions that were made can be verified by examining the visualization (easiest to do using IMAGE) for any segments that appear to pass through another segment.

Table 11. Allowed Segment-Segment Contacts.

Seg. #	Segment ID	# of Contacts	Seg. #	Segment ID
1	Lower Torso	4	13	Right Lower Arm
			15	Left Lower Arm
			16	Right Hand
			17	Left Hand
2	Middle Torso	4	6	Right Upper Leg
			9	Left Upper Leg
			16	Right Hand
			17	Left Hand
3	Upper Torso	4	6	Right Upper Leg
			9	Left Upper Leg
			13	Right Lower Arm
			15	Left Lower Arm
5	Head	4	13	Right Lower Arm
			15	Left Lower Arm
			16	Right Hand
			17	Left Hand
6	Right Upper Leg	5	9	Left Upper Leg
			12	Right Upper Arm
			13	Right Lower Arm
			16	Right Hand
			17	Left Hand
7	Right Lower Leg	2	10	Left Lower Leg
			11	Left Foot
9	Left Upper Leg	4	14	Left Upper Arm
			15	Left Lower Arm
			16	Right Hand
			17	Left Hand
10	Left Lower Leg	1	8	Right Foot
13	Right Lower Arm	3	2	Middle Torso
			15	Left Lower Arm
			17	Left Hand
15	Left Lower Arm	2	2	Middle Torso
			16	Right Hand
18	Left Armrest	3	3	Upper Torso
			14	Left Upper Arm
			15	Left Lower Arm
19	Right Armrest	3	3	Upper Torso
			12	Right Upper Arm
			13	Right Lower Arm
Total Number of Contacts		39		

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3. Sources of Force-Deflection Data

Determining these characteristics for each allowed plane-segment or segment-segment contact can be a difficult and time-consuming process. Obviously, direct measurement of the characteristics will lead to the most accurate results in the simulation. Unfortunately, this may not always be possible or even desired. Time, availability, or funding constraints may preclude direct measurements, thus requiring the force-deflection characteristics be obtained in another fashion. One method is to use characteristics that have previously been defined for similar contacts. For example, the force-deflection characteristics for the seating surfaces in this example model were derived from the characteristics used in a model of an aircraft ejection seat.

For the ATD's, GEBOD provides several force-deflection functions for various contact surfaces as previously discussed. These functions can be used directly, or combined with additional functions, to characterize the interactions between segments and planes or segments and other segments. Alternatively, a general segment-segment characteristic can be defined to simplify the modeling process.

4. Defining the Functions

There are two categories of force-deflection characteristics as described in Chapter II. Rate-dependent characteristics, as illustrated in Figure 15, may be used, or characteristics dependent upon the deflection alone, as illustrated in Figure 17, may be used. In either case, functions defining the various components of the force-deflection characteristics must be defined as illustrated in Figure 16. As previously described, the functions can be constant, tabular, or polynomial, subject to the constraints detailed in Table 1.

The force-deflection characteristics for the planes making up the seat bottom (cushion, right side, left side, and front) as well as the sides for the seat back (right side, left side, and top) are shown in Figure 48. The seat back cushion itself has force-deflection characteristics as defined by the functions shown in Figure 49 and the characteristics for the deck are illustrated in Figure 50. As far as segment-segment contacts are concerned, a generic force-deflection characteristic was defined and was used for all body segment to body segment interactions. These characteristics functions are shown in Figure 51. The only other segment-segment interactions are body segment to armrest contacts and the characteristic functions are shown in Figure 52. Finally, the force-deflection characteristics for the lap belt are illustrated in Figure 53. The tabulated values used to generate these function curves are summarized in Table 12. These same values will be used in the input deck. Function 20, as seen in Figure 48, is defined as a polynomial such that F=200*x, where F is the force in pounds and x is the deflection in inches.

As previously mentioned, the force-deflection characteristics for the contacts in this example were not measured directly due to availability and funding constraints, but rather were derived from other example simulations (aircraft ejection seat, etc.). Note that the majority of the force-deflection characteristics were defined using the rate dependent functions, and only the deck and lap belt characteristics were defined using the functions dependent on deflection alone. Also, note that the base function for the lap belt has strain, vice deflection, as the abscissa.

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In addition, for each allowed contact, there must be a friction function defined. In this example, all body segment to body segment contacts have a friction coefficient of 0.1 specified. All body segment to chair surface (planes and armrests) contacts have a friction coefficient of 0.9 specified. For the lap belt to lower torso contact, there are only two friction options (previously described) since a simple, vice harness, belt was chosen. In this example, full belt friction is specified so that the tension in each belt half is computed separately.

Table 12. Summary of Function Values

Function #	# of Point								
14	5	abscissa	0.000	1.000	2.000	3.000	4.000		
		ordinate	0.000	60.000	200.000	800.000	2000.000		
21	21	abscissa	-40.000	-30.000	-20.000	-10.000	0.000	5.000	10.000
		ordinate	0.000	0.000	0.000	0.000	0.000	1.000	1.000
		abscissa	20.000	30.000	40.000	50.000	60.000	70.000	80.000
		ordinate	0.990	0.965	0.930	0.860	0.690	0.475	0.340
		abscissa	90.000	100.000	110.000	120.000	130.000	140.000	150.000
		ordinate	0.260	0.200	0.180	0.090	0.060	0.025	0.000
24	6	abscissa	0.000	0.010	0.020	0.030	0.050	0.100	
		ordinate	0.000	165.000	330.000	495.000	935.000	3850.000	
25	8	abscissa	0.000	0.200	0.401	0.603	0.803	0.834	0.930
		ordinate	0.000	6.750	25.290	48.720	101.790	121.200	1212.000
		abscissa	1.354						
		ordinate	12120.000						
27	6	abscissa	0.000	0.100	0.200	1.000	2.000	3.000	
		ordinate	0.000	100.000	1000.000	5000.000	10000.000	15000.000	
28	6	abscissa	0.000	1.000	2.000	3.000	4.000	6.000	
		ordinate	0.000	60.000	150.000	500.000	2000.000	10000.000	
29	6	abscissa	0.000	1.000	2.000	3.000	4.000	6.000	
		ordinate	0.000	50.000	125.000	250.000	500.000	1000.000	
30	5	abscissa	-1000.000	-6.000	-5.000	0.000	1000.000		
		ordinate	0.500	0.500	1.000	1.000	1.000		
31	5	abscissa	-2000.000	-200.000	0.000	200.000	2000.000		
		ordinate	0.000	0.000	0.000	10.000	200.000		
34	6	abscissa	0.000	0.500	1.000	1.500	1.800	2.000	
		ordinate	0.000	30.000	60.000	90.000	900.000	9000.000	
35	5	abscissa	-1000.000	-6.000	-5.000	0.000	1000.000		
		ordinate	0.460	0.460	1.000	1.000	1.000		
36	5	abscissa	-2000.000	-200.000	0.000	200.000	2000.000		
		ordinate	0.000	0.000	0.000	50.000	1000.000		
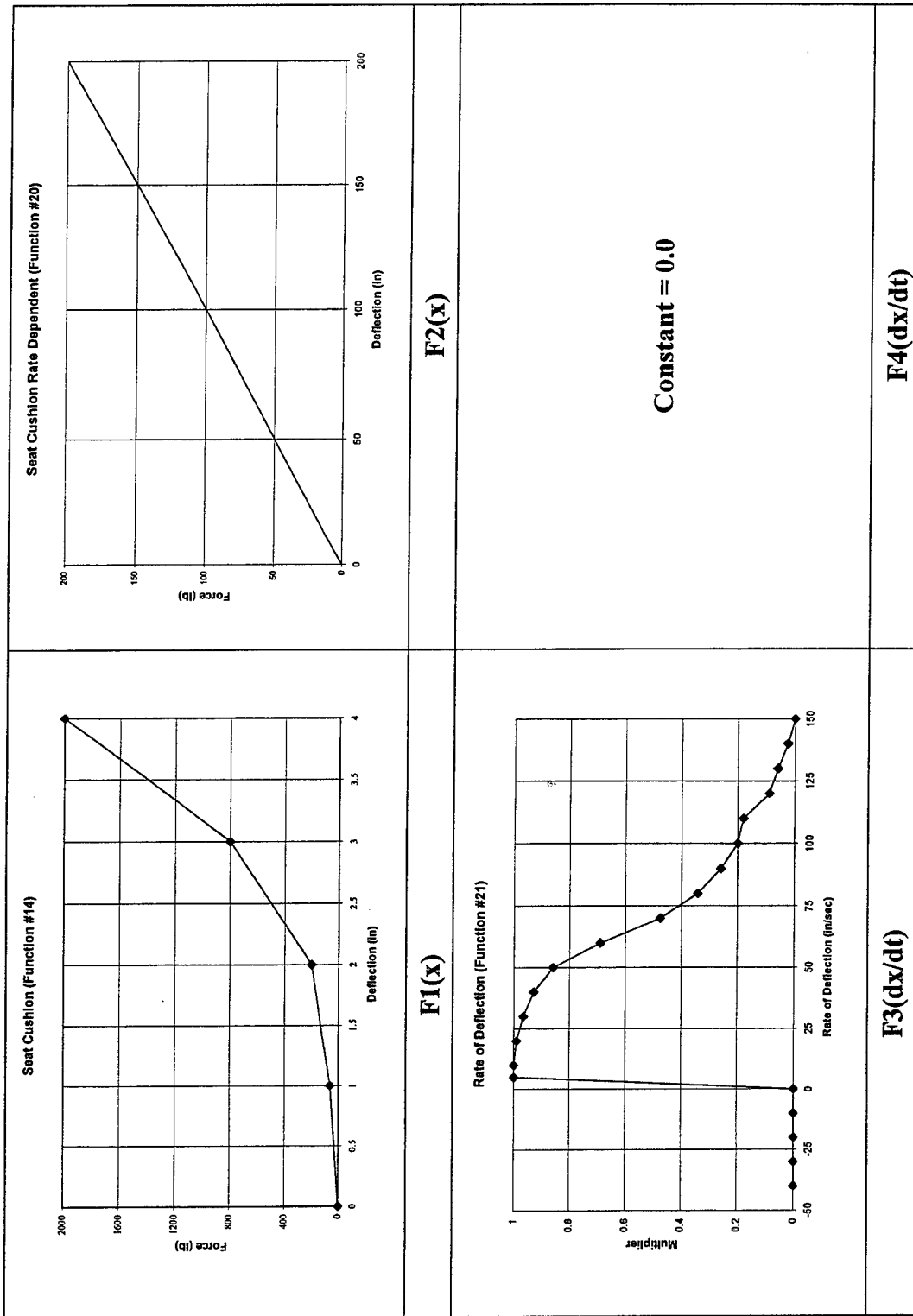
Figure 48. Seat Cushion Force-Deflection Characteristics.
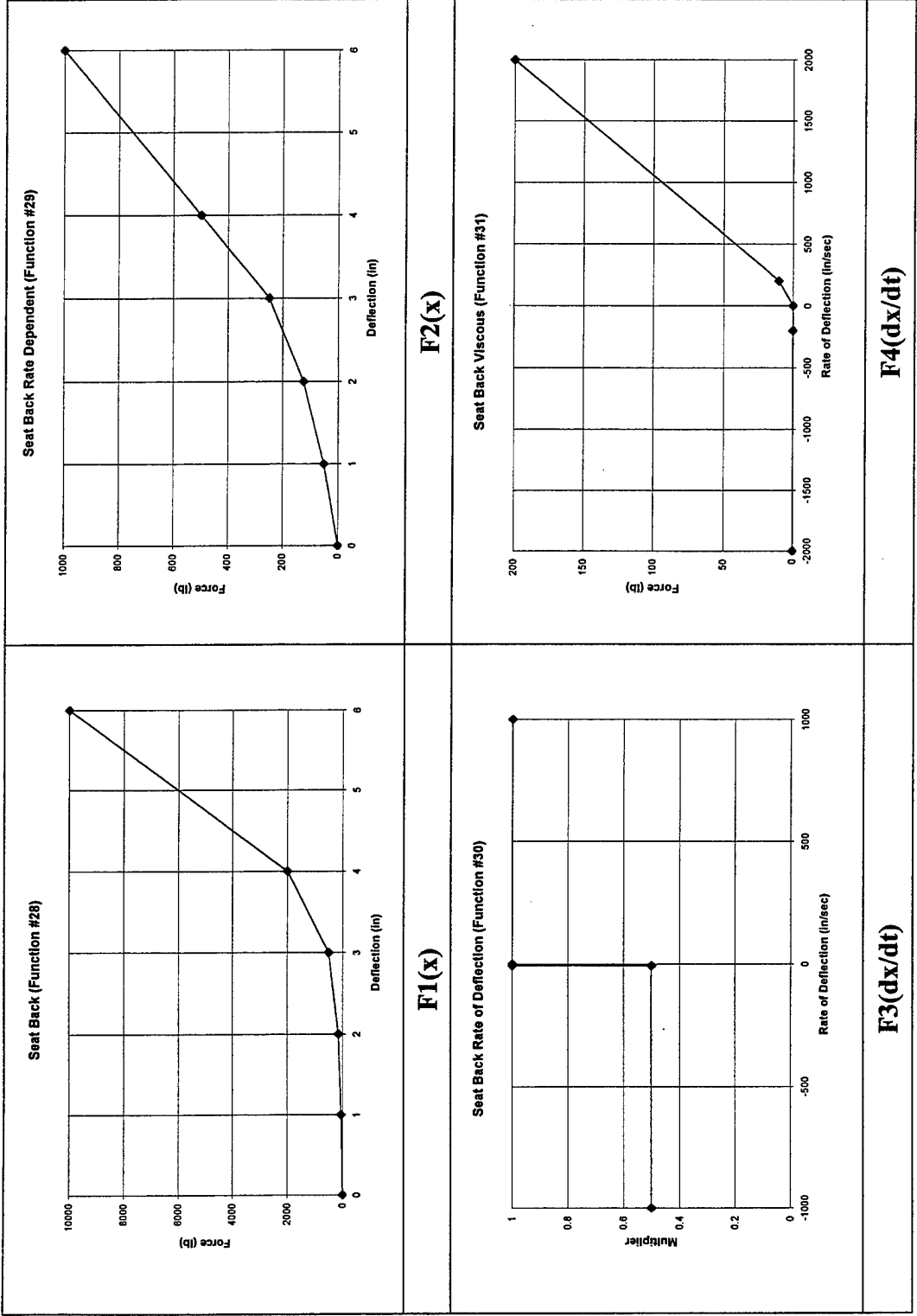
Figure 49. Seat Back Force Deflection Characteristics.

Figure 50. Deck Force-Deflection Characteristics.

Constant = 0.0

F1(x)

Dummy Stiffness (Function #34)

F2(x)

Dummy Viscous (Function #36)
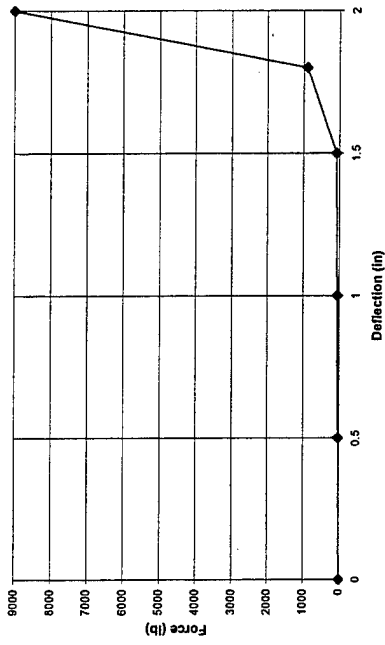
F3(dx/dt)

Dummy Rate of Deflection (Function #35)
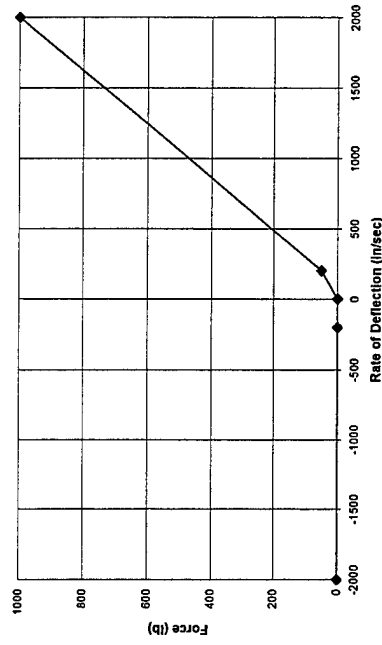
F4(dx/dt)

Figure 51. Dummy Force-Deflection Characteristics.
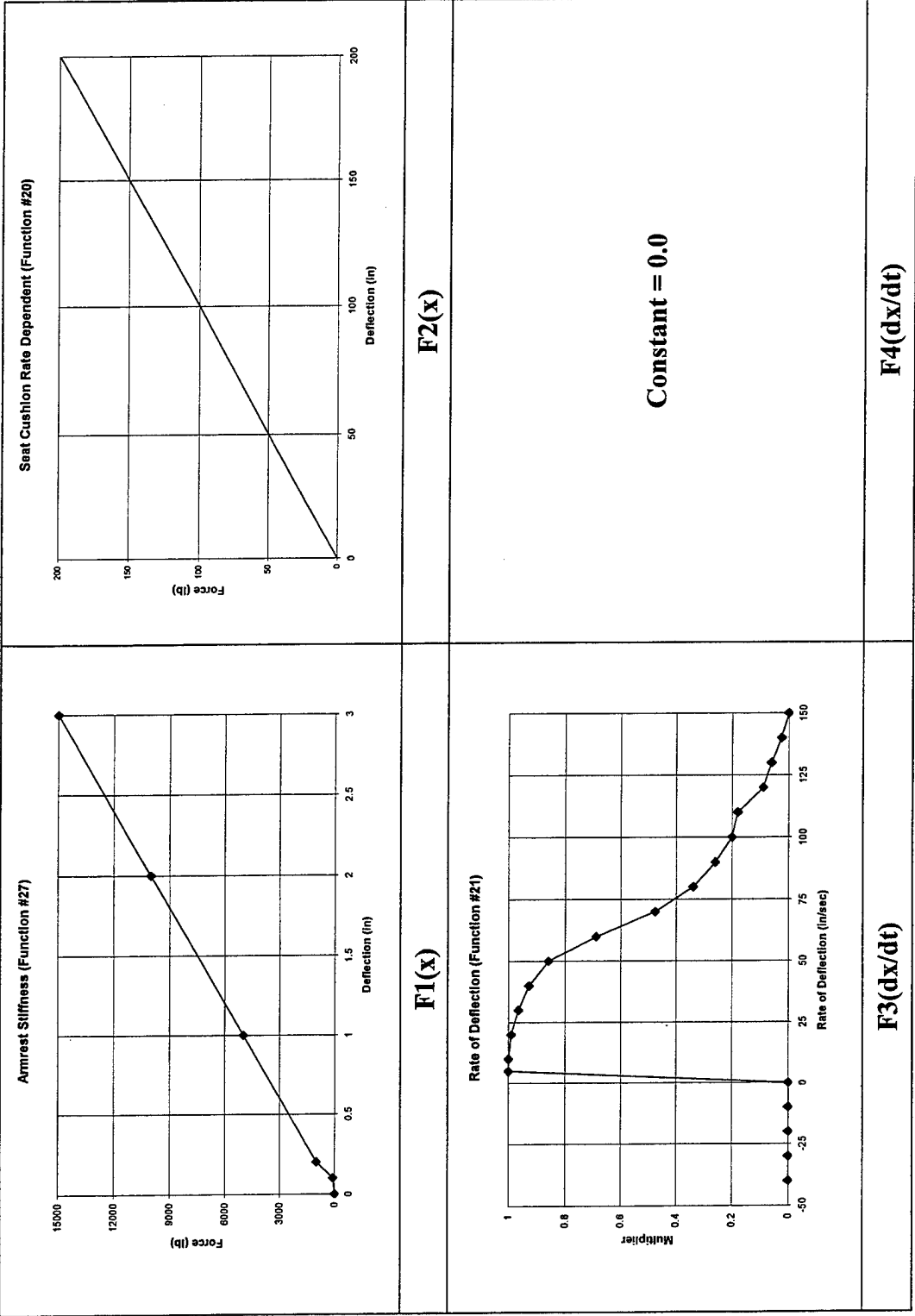
Figure 52. Armrest Force-Deflection Characteristics.

Energy Absorption Factor Function	Base Function	Inertial Spike Function
Restraint Belt (Function #24)	Constant = 1.0	Constant = 0.0
Permanent Deflection Factor Function		
Constant = 0.0		

Figure 53. Lap Belt Force-Deflection Characteristics.

5. Combining Functions

If the force-deflection characteristics for two elements, e.g., the deck plating and the foot of the Hybrid III dummy, are known, then these two functions can be combined to yield a single function that can then be used for contacts between those two elements. This is the method used to generate the deck-foot force-deflection function illustrated in Figure 50.

The procedure is much like that used to determine an effective spring constant for two springs in series. Each spring is subjected to the same force, thus deflects an amount determined by its own spring constant, and the total deflection for the given applied force is simply the sum of the deflections. Analogously, the foot and the deck both experience the same force, and the deflections of each element required to generate that force are based upon their respective force-deflection characteristics. To generate a composite force-deflection characteristic, the deflections of each element for a given force are simply added.

The GEBOD program provides a force-deflection characteristic for the feet of the 50th percentile male Hybrid III dummy as a composite polynomial and tabular function. The polynomial portion of the foot force-deflection function is given by Equation (6) and the tabular portion is detailed in Table 13. The deck surface was simply assumed to have a stiffness of 30,000 lb/in.

$$F(x) = -0.68 + 82.75x - 704.17x^2 + 3367.10x^3$$
$$- 5570.69x^4 + 3188.30x^5 \qquad (6)$$
$$for \ 0 \le x \le 0.83$$

Table 13. Tabular Portion of Foot Force-Deflection Characteristic.

Deflection (in)	Force (lb)
0.83	121.20
0.89	1212.00
0.95	12120.00
Valid for x > 0.83 inches	

To create a combined force-deflection function (in tabular form), the polynomial portion of the foot force-deflection function was first converted to a tabular form by evaluating the polynomial at several deflections. Then, the deflection of the deck was computed for each of the forces determined from the foot force-deflection characteristic at the specified deflections. These two deflections were then added at each force level to create the combined foot-deck contact force-deflection characteristics. These values are detailed in Table 14.

Table 14. Combined Foot-Deck Force-Deflection Function Values.

Force (lb)	Foot Deflection (in)	Associated Deck Deflection (in)	Sum of Deflections (in)
0.00	0.00	0.0000	0.000
6.75	0.20	0.0002	0.200
25.29	0.40	0.0008	0.401
48.72	0.60	0.0016	0.602
101.79	0.80	0.0030	0.803
121.20	0.83	0.0040	0.834
1212.00	0.89	0.0404	0.930
12120.00	0.95	0.4040	1.354

6. Formatting the Data

As was the case for the definitions of the environmental elements, the data for the allowed contacts, and the functions the are used to make up the force-deflection characteristics of those contacts, must be transformed into the proper ATB format in accordance with Ref. [1]. The following paragraphs describe the manner in which the data for the functions and the allowed plane-segment, segment-segment, and lap belt-segment contacts are formatted.

a. Allowed contacts

All data pertaining to the allowed contacts is specified on the F Cards. Card F.1.a lists the number of contacts that are allowed for each specified plane. Then, for each plane that has contacts allowed, one F.1.b card must be provided per contact. Each of these F.1.b cards contains the plane number, the segment number to which the plane is attached, the segment number for which contact is allowed, the number of the contact ellipsoid associated with that segment, the function numbers defining the force-deflection characteristics, the friction function number, and an edge effect control parameter. A portion of the formatted data for the plane-segment contacts is shown in Figure 54.

Segment-segment contact data is similarly specified, although there is no edge effect option control parameter for segment-segment contacts. The number of contacts allowed for each segment is specified on Card F.3.a. Then, for each segment that has contacts allowed, one F.3.b card must be provided per contact. Each of these F.3.b cards contains the segment number, the number of the associated contact ellipsoid, the segment number for which contact is allowed, the number of the contact ellipsoid associated with that segment, the function numbers defining the force-deflection characteristics, and the friction function number. A portion of the formatted segment-segment contact data is shown in Figure 55.

The contact information for simple belts is also formatted in a manner similar to the plane-segment and segment-segment contact information. Card F.2.a lists the number of segments each belt can interact with (note that this can be only zero or one). Then, for each belt that has an allowed contact, a Card F.2.b must be specified. This card contains the belt number, the segment number to which the belt is attached, the

number of the segment with which contact is allowed, the number of the contact ellipsoid associated with that segment, the force-deflection characteristic function numbers, and a belt friction control parameter. The formatted data for the lap belt (contact with lower torso) is shown in Figure 56.
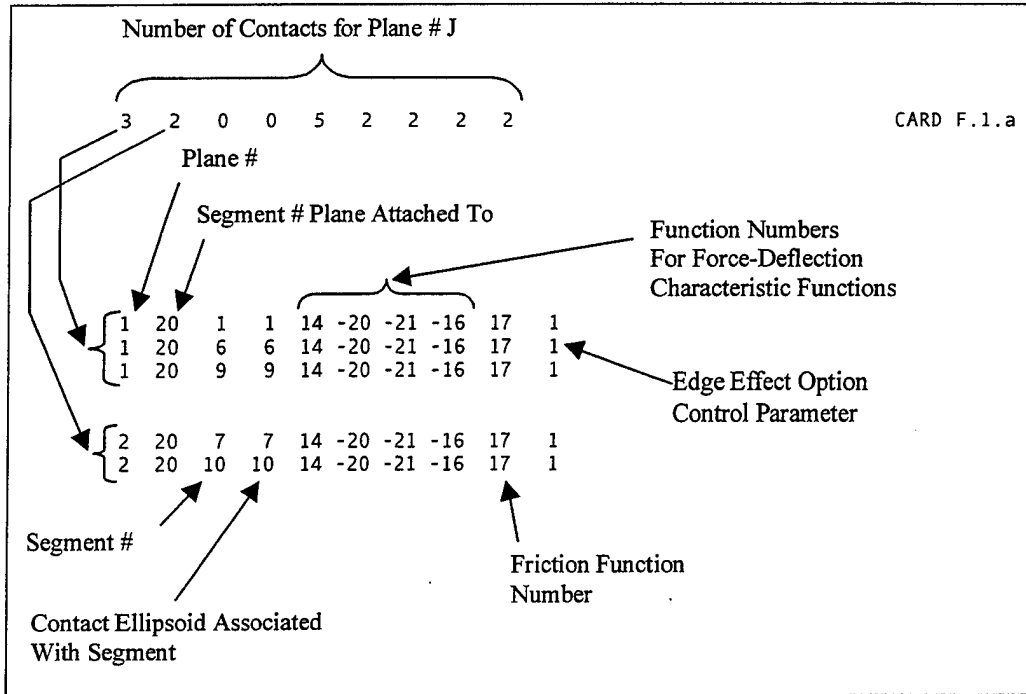
Figure 54. Plane-Segment Contact Data Formatting.
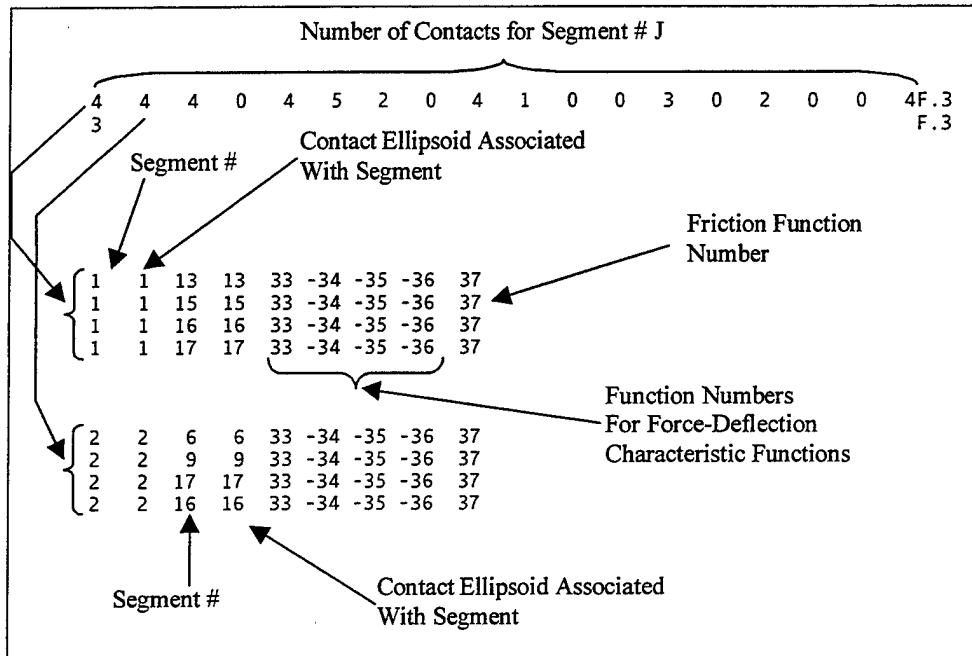
Figure 55. Segment-Segment Contact Data Formatting.

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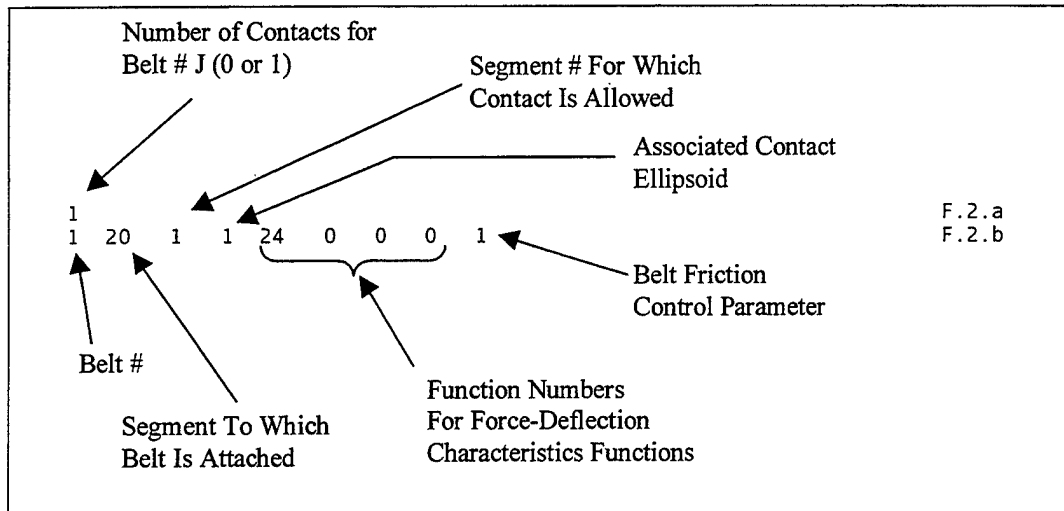
Figure 56. Lap Belt Contact Data Formatting.

b. Functions

Each of the functions that have been identified in the sections above must have their defining data properly formatted. The E Cards contain the data defining all of the force-deflection, inertial spike, energy absorption factor, and friction coefficient functions. Each function has an E.1 card that contains the function identifying number and a 20-character description. This is followed by an E.2 card containing significant points on the abscissa, including D0, D1, and D2 as shown in Figure 16 and Table 1. Then, if the function is a polynomial, the five coefficients are specified on Card E.3. If the function is tabular, then Card E.4.a list the number of pairs of data points that make up the table, and these pairs are specified on Cards E.4.b (three pairs per card). The formatted data for the force-deflection function, F1, for the foot-deck contact is shown in Figure 57. If a constant value is to be specified for a function, then only Cards E.1 and E.2 are required. Card E.1 is the same as described above, and for Card E.2, the values of D0 and D1 are specified to be zero while the value of the function (constant) is specified in field D2.
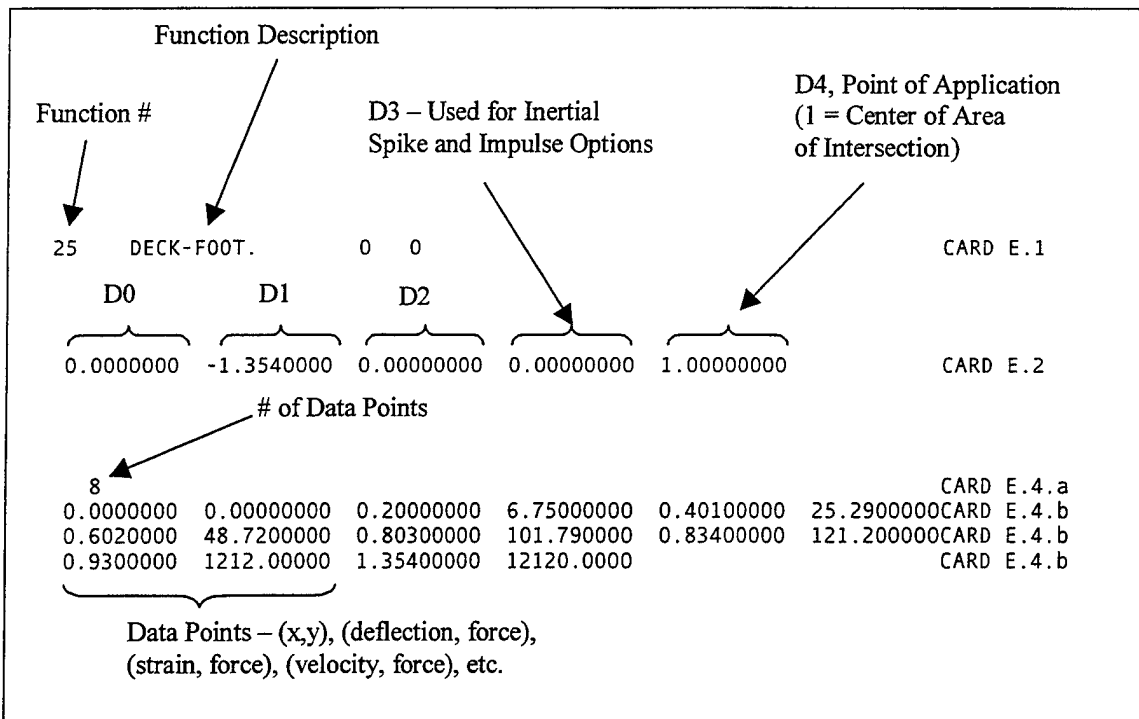
Figure 57. Function Data Formatting.

D. VEHICLE EXCITATION

The specification of vehicle excitation is another major component of the input deck. Of the four previously described methods by which the vehicle motion can be specified, the six-degree-of-freedom tabular deceleration was the most appropriate for this example problem since accelerometer data was available.

1. Pre-Processing Input Data

Only with careful forethought can the necessity to pre-process excitation data measured during an actual test be eliminated. In this example, the deck vertical and athwartships accelerations were measured at the base of the chair and the fore-and-aft accelerations were measured at the forward end of the test vessel. No angular acceleration measurements were made during the test. The locations (and associated orientations) for which accelerometer data was available are shown in Figure 37.

The vertical and athwartships accelerations (A5051V and A5052A, respectively) could be used with only minor transformations since they were measured at the base of the operator's chair. First, the athwartships and vertical orientations from the test vessel must be transformed into the vehicle local coordinate system as described in Table 4. Then, since the vehicle excitation is to be specified as a deceleration vice acceleration, as previously stated, an additional factor of negative one must be included. The final conversion of measured acceleration to input deceleration is summarized in Table 15.

Figure 58 shows the measured acceleration of the deck in the athwartships direction (same as deceleration in the vehicle Y-axis). Figure 59 shows the measured acceleration of the deck in the vertical direction (same as deceleration in the vehicle Z-axis). The excitation of the deck in the fore-and-aft direction was not measured at the

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base of the operator's chair, as were the vertical and athwartships components. Rather, there were accelerometers oriented in the fore-and-aft direction located at either side of the forward end of the deck (A5003F and A5008F in Figure 37). This component of the excitation was of significantly lower amplitude than either the vertical or the athwartships components. In addition, the fore-and-aft orientation is perpendicular to the plane in which motion of the test subject predominantly occurred, as determined through close examination of the videotape. Thus, the fore-and-aft component of the acceleration was not included in the vehicle excitation

Table 15. Measured Acceleration to Input Deceleration Conversion.

Measure Acceleration Direction	Multiplier	Input Deceleration Direction
Fore-and-Aft	-1	X
Athwartships	+1	Y
Vertical	+1	Z
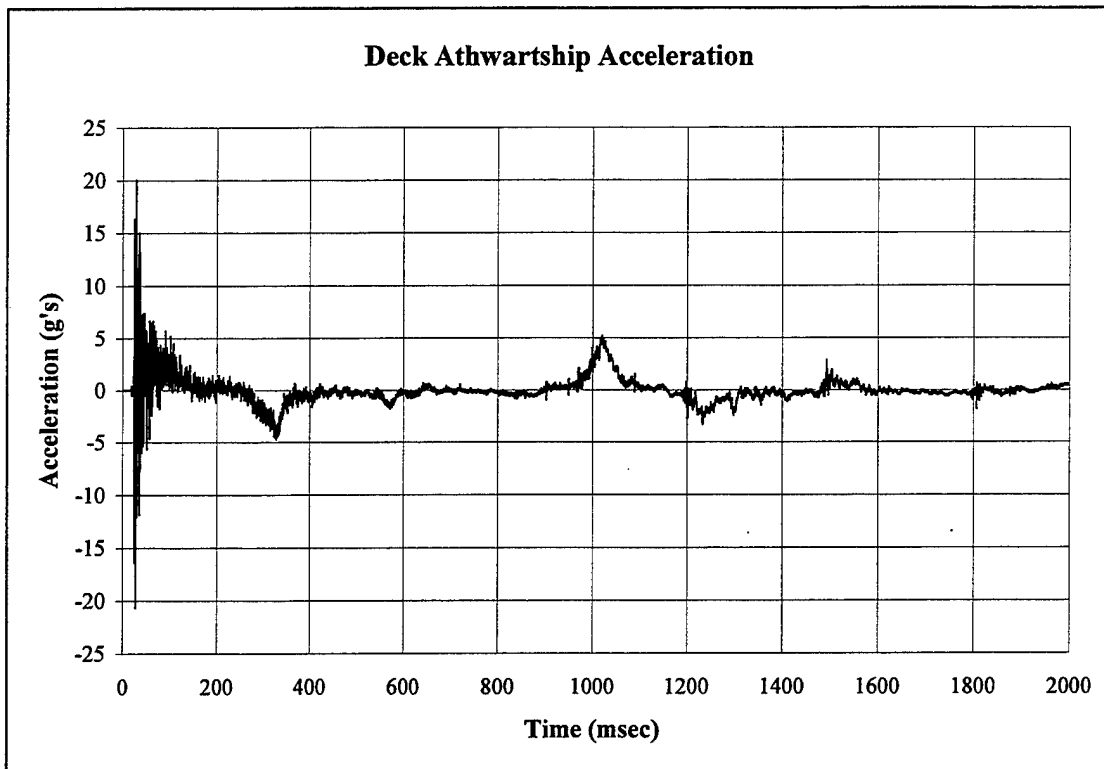
Figure 58. Deck Athwartships Acceleration.

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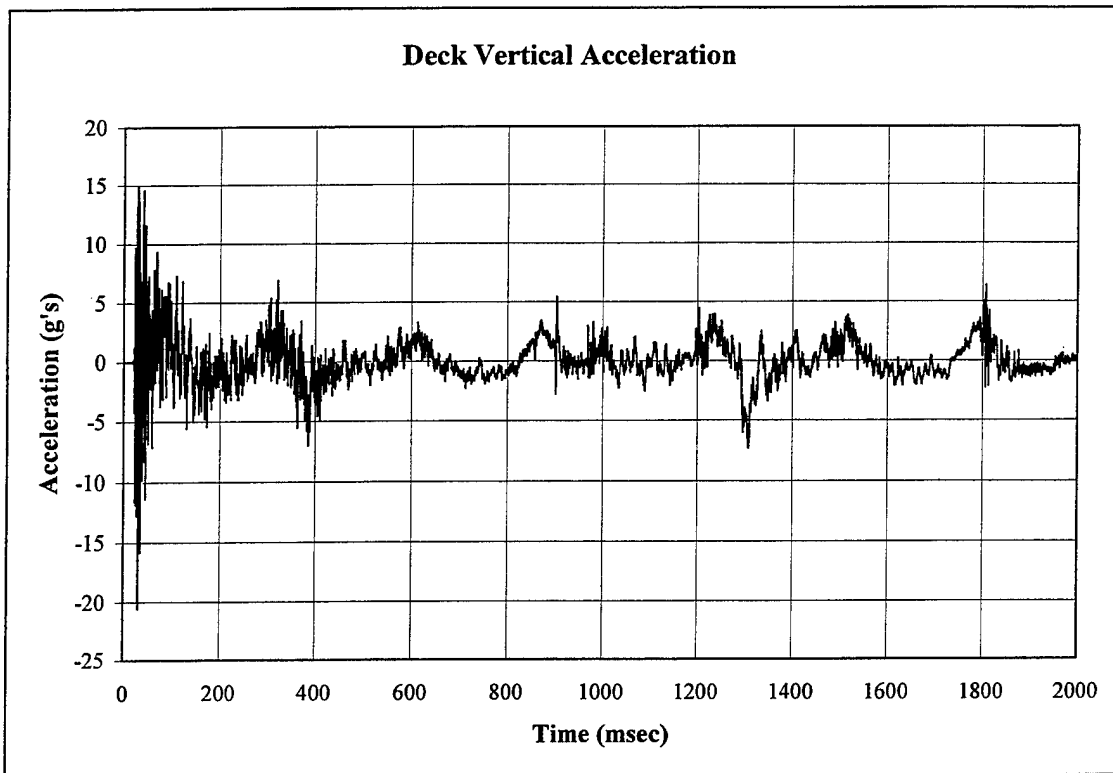
Figure 59. Deck Vertical Acceleration.

Since no deck angular acceleration measurements were made during the test, and these accelerations were expected to be significant, some method must be devised to estimate their values. As accelerometer data was available for all of the accelerometers shown in Figure 37, angular acceleration estimates were constructed from sets of two linear accelerometers oriented in the same direction, but separated by a distance. The roll angular acceleration was constructed from the data recorded using accelerometers A5018V (starboard side of test vessel near ATD) and A5011V (port side of test vessel near ATD). The acceleration values recorded with A5018V were subtracted from those recorded with A5011V, thus making A5018V (starboard side of test vessel) the reference. Then this value was divided by the linear distance separating the two accelerometers (roughly 30 feet). This value representing the angular acceleration about the longitudinal axis of the test vessel (the X-axis of the vehicle), but the units are g's per foot. Multiplication by 32.2 ft/(sec^2 g) and by 57.3 degree/radian yields the desired units (as required by the ATB program) of deg /sec^2. The deck pitch acceleration is computed in a similar manner using accelerometers A5051V (base of the operator's chair) and A5015V (aft end of test vessel near ATD) and a separation distance of ten feet. The roll and pitch angular accelerations derived using this method are shown in Figure 60 and Figure 61, respectively. The deck yaw angular acceleration, similarly derived, was of significantly lower magnitude and subsequently not included in the vehicle excitation.

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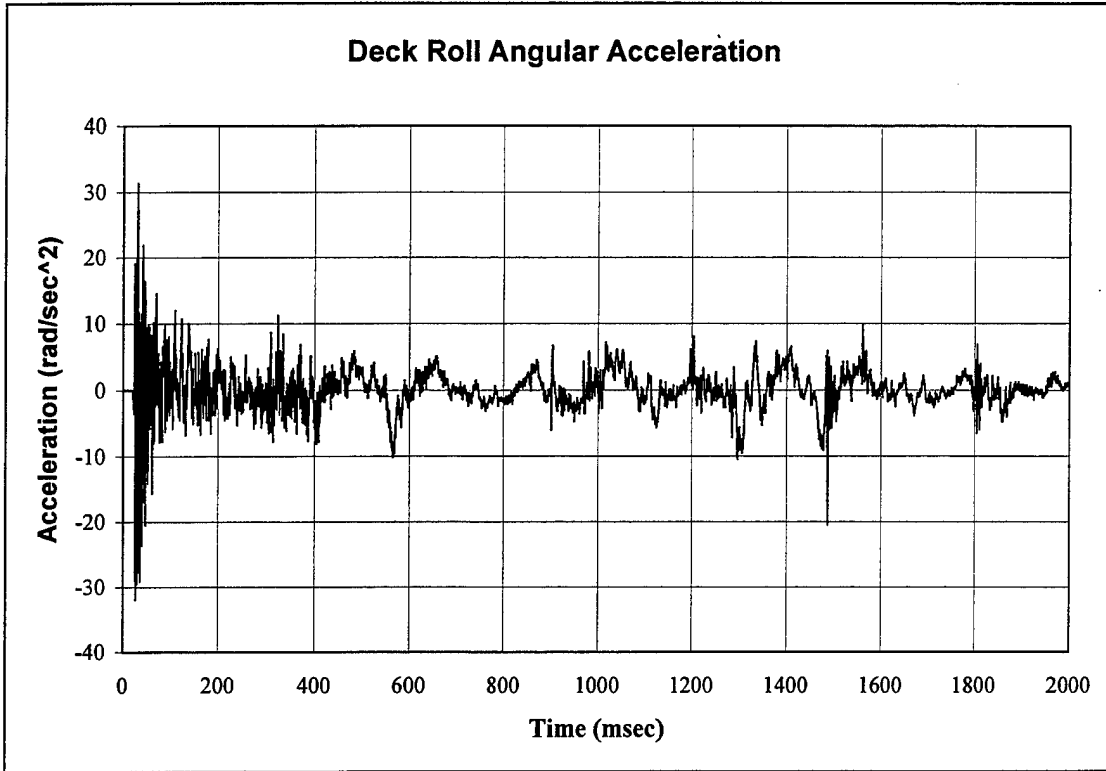
Figure 60. Deck Roll Angular Acceleration.
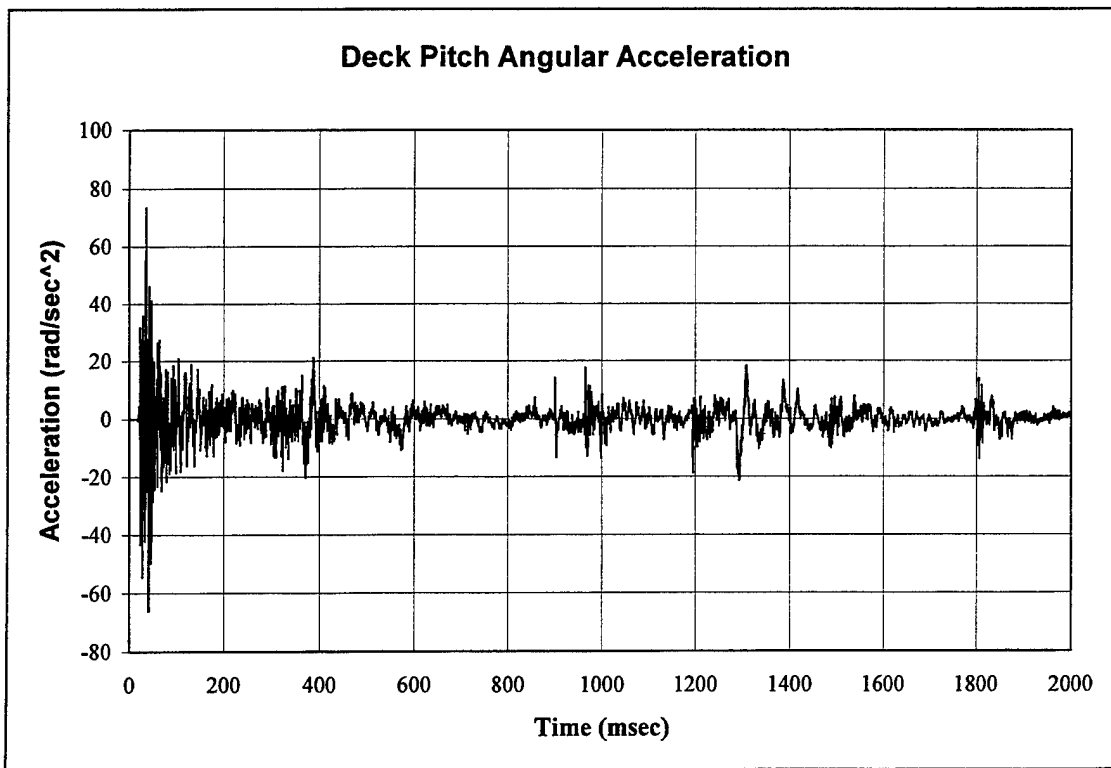
Figure 61. Deck Pitch Angular Acceleration.

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Finally, as was the case with the linear accelerations, the angular accelerations must be transformed into the vehicle coordinates and converted into decelerations. The coordinate systems were defined such that the vehicle's X-axis was aligned with the test vessel's longitudinal axis. Thus, positive angular accelerations about the test vessel's longitudinal axis need only be multiplied by a negative one to yield positive decelerations about the vehicle's X-axis. The pitch component was defined by referencing the accelerations at the base of the operator's chair to those at the aft end of the test vessel. Thus, positive pitch values defined in this manner correspond to negative values about the test vessel's transverse axis and to positive values about the vehicle's Y-axis. Finally, to convert the derived pitch angular accelerations into decelerations, the values need only be multiplied by a negative one.

2. Formatting the Data

Once the excitation data has been pre-processed so that all sign conventions have been observed, the accelerations have been converted to decelerations, and the correct units are in use, it is necessary to format the data for use in the ATB program. All vehicle excitation data is contained on the C Cards. Card C.1 consists of an 80-character description of the crash vehicle deceleration. Card C.2.a contains information concerning the orientation of the deceleration (or initial orientation of the vehicle), the initial velocity of the vehicle, the inertial coordinates of the vehicle coordinate system origin, the segment number associated with the vehicle, and time control data (start time, time step, number of points). If tabular six degree of freedom deceleration or spline fit deceleration options are chosen, then the type of data, degree of polynomial for the spline fit, number of points, and initial angular velocities are specified on Cards C.2.b. For the six degree-of-freedom option, chosen for this example, the six components of the deceleration vector at each time step are listed on individual C.4 cards. The first portion of the C Cards for the example problem is illustrated in Figure 62. Note that the ATB program has been modified to allow up to 10,001 data points instead of the original 501 points.

3. Use of a Formatting Code

For problems where the vehicle excitation has been measured using accelerometers, as is the case in this example, the task of formatting this data in the manner required by the ATB program could be quite formidable. This is particularly the case if the ATB program has been modified to allow a larger number of data points. In these instances, it might be beneficial to create a program that takes the raw data and generates a properly formatted set of C cards. Such a program was written, in MATLAB, to generate the C cards used in the input deck of this example. The program file is included as APPENDIX F.

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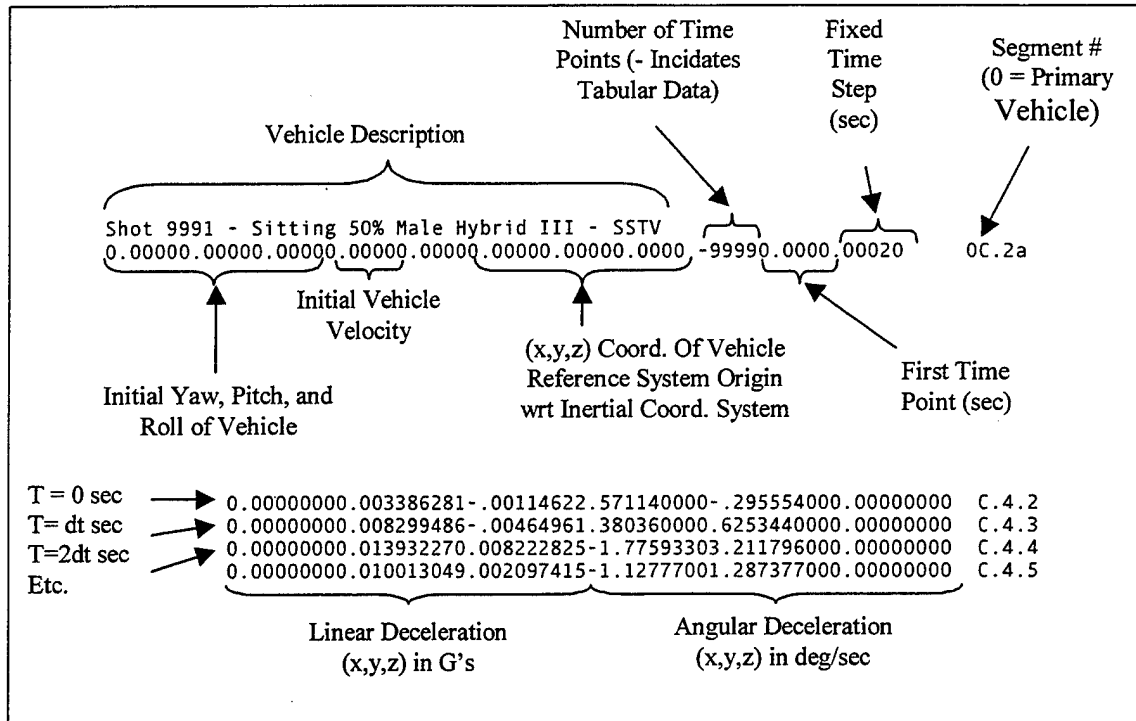
Figure 62. Vehicle Excitation Data Formatting.

E. SPECIFYING DESIRED OUTPUT

The ATB program is capable of generating a tremendous amount of output data. If desired, tabulated time histories of plane-segment contact forces, segment-segment contact forces, belt tensions, body segment linear or angular accelerations, displacements, or velocities, joint forces and torques, and more can be output by the ATB program. However, it is likely that only a few parameters will be of interest. This section explores how to control what data is output by the ATB program.

1. Data for Troubleshooting and Establishing Equilibrium

The test subject or subjects must have their initial positions specified. The actual manner in which this specification is done will be covered in the next chapter, but some concerns about the applicable output will be addressed here.

To establish the initial equilibrium of a test subject, the forces exerted by gravity must be offset by some means. For a seated subject, as is the case in the example, these offsetting forces arise from interaction of the body segments with the contact surfaces of the chair. Evaluating the equilibrium of the body is done by checking the velocities and/or accelerations of the components. Troubleshooting problems with the initial equilibrium is done by examining the forces generated between the body segments and the contact surfaces of the chair. In addition, if any initial contact between body segments is specified, e.g., hands resting on upper legs, then the forces generated between the segments in question must be examined. Corrections are made by changing the initial positions of the body segments with respect to the chair and/or each other.

Tabular time histories of plane-segment or segment-segment contact forces may be generated to provide much of the necessary information for initial positioning of the

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test subjects. To determine the accelerations and/or velocities of the body segments, there are two options. First, the tabular time histories of the accelerations, velocities, or displacements may be specified for any individual segment. Alternatively, the linear and angular positions, velocities and accelerations for all segments can be printed to the main output file (*.AOU) at user specified intervals. Since it is necessary to verify that no body segments are subjected to an unexpected acceleration, it is simpler to have the values for all segments printed to the main output file.

Control of the output data is specified in two places in the ATB input deck. Card A.5 contains 36 flags used for program control and output specification. Individual segment position, velocity, and acceleration, as well as individual joint torque time history output may be specified on the H Cards. Since there are so many potential combinations, Ref. [1] should be consulted for a detailed description of the available options. For this example, it is desired to output the tabular time histories of the plane-segment and segment-segment contact forces to individual (*.T##) output files and the position/velocity/acceleration data for all segments to the main output file. This is done by specifying the appropriate values on the third, fourth and eighteenth flags on Card A.5. The third flag controls the frequency at which the data is written to the main output file. The integer value refers to the number of main program time intervals (discussed in section F below). In this example, the time interval will be specified to be one msec, and the data is to be written to the main output file every 10 msec. The fourth flag determines whether the tabular time histories (plane-segment and segment-segment contacts in this example) are to be printed to individual output files or to a single output file. In this example, individual output files are desired, so the value zero is specified. The eighteenth flag determines what tabular time histories are output. In this case, it is desired to have both plane-segment and segment-segment contacts. Unfortunately, the FORTRAN compiler used to generate the modified (to allow for an increased number of data points in the vehicle excitation) version of the ATB program used for this example does not allow a sufficient number of files to be open simultaneously. Thus, it is necessary to first specify that all plane-segment contact force tabular time histories are desired. Then, in a subsequent run of the ATB program, to specify that all segment-segment contact force tabular time histories are desired. This is done by first specifying a value of five for the eighteenth flag and then by specifying a value of fourteen. See Ref. [1] for a detailed description of what values provide what output files. Figure 63 shows the formatting of Card A.5 for the example.

2. Data for Validation Purposes

Validation of a model is an important step prior to using that model to predict injury levels or gross body motion. In this example, the data available from the experiment includes video footage and triaxial linear accelerometer data for the head, thorax, and pelvis. Thus, the basis of validation of the model of the chair, ATD, and input excitation is the comparison of the predicted and recorded gross body motion and aforementioned accelerations. Output parameter control associated with comparisons to the video footage is discussed in Subsection 3 below. The accelerometers used during the test were located at the centers of gravity of the head, thorax, and pelvis, as shown in Figure 64. For validation purposed, it is desired to compare the three components of acceleration at each of the sensor locations for which recorded data is available. This

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type of output is specified on the H Cards in the input deck. Cards H.1, 2, and 3 are used to specify time histories of point linear accelerations, velocities, and displacements, respectively. Cards H.4, 5, and 6 are used to specify time histories of point angular accelerations, velocities, and displacements, respectively. Card H.7 is used to specify time histories of joint parameters.

Figure 63. Output File Control Formatting.

As can be seen in Figure 65, tabular time histories of linear accelerations, velocities and displacements for the head, upper torso (thorax), and lower torso (pelvis) are specified. The zero in the second column indicates that the accelerations, velocities, and displacements are all to be output in the local coordinate system. For the three accelerations, the segment numbers (5 = Head, 3 = Upper Torso, 1 = Lower Torso) are given as negative because it is desired that the accelerations be output as if they were recorded by accelerometers located at the specified points. This makes comparison with the recorded acceleration values quite simple. In each case, the coordinates of the point were (0,0,0), thus the values are output for the center of gravity of the segments.

Figure 65 also shows that the angular accelerations, velocities, and displacements for the head are to be output to time history files. While these are not used for comparison with the recorded data, they will be used later for injury estimation. Similarly, the joint parameters for joints 17 and 18, the hinges for the left and right armrests, respectively, are not used for comparison with recorded data, but are used to verify that the joint characteristics were properly defined in the input deck.

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Figure 64. Hybrid III Sensor Locations. After Ref. [6]

Of Points For Which Time
Histories Are Desired:
  Linear Acceleration
  Linear Velocity
  Linear Displacement

Segment # For Which Time
Histories Are Desired.
(negative – values as if an accelerometer
located at the point)

```
3  0 -5   .00000000   .00000000   .00000000          H.1
   0 -3   .00000000   .00000000   .00000000
   0 -1   .00000000   .00000000   .00000000
```

Reference System For
Time History Values
(0 = Local)

```
3  0  5   .00000000   .00000000   .00000000          H.2
   0  3   .00000000   .00000000   .00000000
   0  1   .00000000   .00000000   .00000000
```

(x,y,z) Location Of Point
In Segment Coord. System

```
3  0  5   .00000000   .00000000   .00000000          H.3
   0  3   .00000000   .00000000   .00000000
   0  1   .00000000   .00000000   .00000000
```

Same As Above

```
1  0  5                                              H.4
1  0  5                                              H.5
1  3  5                                              H.6
```

Of Points for Which Time
Histories Are Desired:
  Angular Acceleration
  Angular Velocity
  Angular Displacement

```
2   17   18                                          H.7
```

Joint #'s

Of Joints for Which Time
Histories Are Desired

Figure 65. Point Time History Data Formatting.

3. Data for the VIEW and IMAGE Programs

The previous section discussed how to instruct the ATB program to provide the necessary tabular time histories to validate the model against the recorded data. If the data generated during the simulation does not match the recorded data, then something must be changed in the model to represent more accurately the actual test. The problem

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is determining what must be changed. Visualization of the gross body motion as predicted by the simulation, and comparison of this motion against the video footage of the actual test, can provide excellent clues as to what problems exist in the model.

As previously mentioned, the VIEW and IMAGE programs can only display images at the times for which data has been generated by the ATB program. They are not capable of interpolating between time steps. In addition, film or video of a test results in a sequence of discrete images rather than a continuous flow. Thus, to make accurate comparisons, the times for which data is provided to the VIEW and/or IMAGE programs must correspond to the times for which recorded images exist. In this example, the motion of the ATD was recorded using a standard video camera. Standard video cameras record images at a rate of 30 frames per second; thus, still images are recorded approximately every 33 milliseconds. Subsequently, it is desired to have the ATB program provide data at 33 msec intervals to the *.TP1 file for later use in the VIEW and/or IMAGE programs. Referring back to Figure 63, the first flag is seen to be specified as 33, meaning data will be written to the *.TP1 file every 33 main program time intervals, or every 33 msec.

F. PROCESSING PARAMETERS

The major portions of the input deck have been described in the above sections. In this section, the parameters that specify the unit system, control the length of the simulation, and control the operation of the integration routine are discussed

1. Primary Control of Time

The main program portion of the ATB program maintains the primary control of time. A main program time interval is defined by the user, as is the number of steps. Thus, the length of the simulation will be the number of steps multiplied by the main program time interval. At each step, the main program calls the integrator, which processes the simulation for a length of time equal to the main program time interval. At this point, control is passed back to the main program and the appropriate data, as specified in the previous sections, is written to the output files. The values for the number of steps and the main program time interval are specified on Card A.4. The second field is the number to steps and the third field is the time interval. For this example, there are two seconds worth of recorded data. This data is recorded at 0.2 msec intervals, for a total of 10,000 points. To limit the size of the tabular time history files, it was decided that data output every msec would be adequate. Thus, the main program time interval was specified to be one msec and the number of steps to be 2,000 for a simulation length of two seconds. This can be seen in Figure 66.

2. Secondary Control of Time

The integrator routine of the ATB program maintains secondary control of time. The integrator advances time using an integrator time interval that lies between user specified minimum and maximum values. If the integrator cannot achieve convergence using the current integrator time step, then that time step is halved, but is not allowed to be less than the specified minimum. The simulation will terminate if convergence cannot be obtained using the minimum allowed time step. Similarly, the time step is doubled if convergence is satisfied for several consecutive integration steps, but is not allowed to be

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more than the specified maximum. Ref. [1] recommends that the main program time interval be an integer multiple of the maximum integrator time interval, and that the maximum integrator time interval be a power of two multiple of both the initial and minimum integrator time intervals.
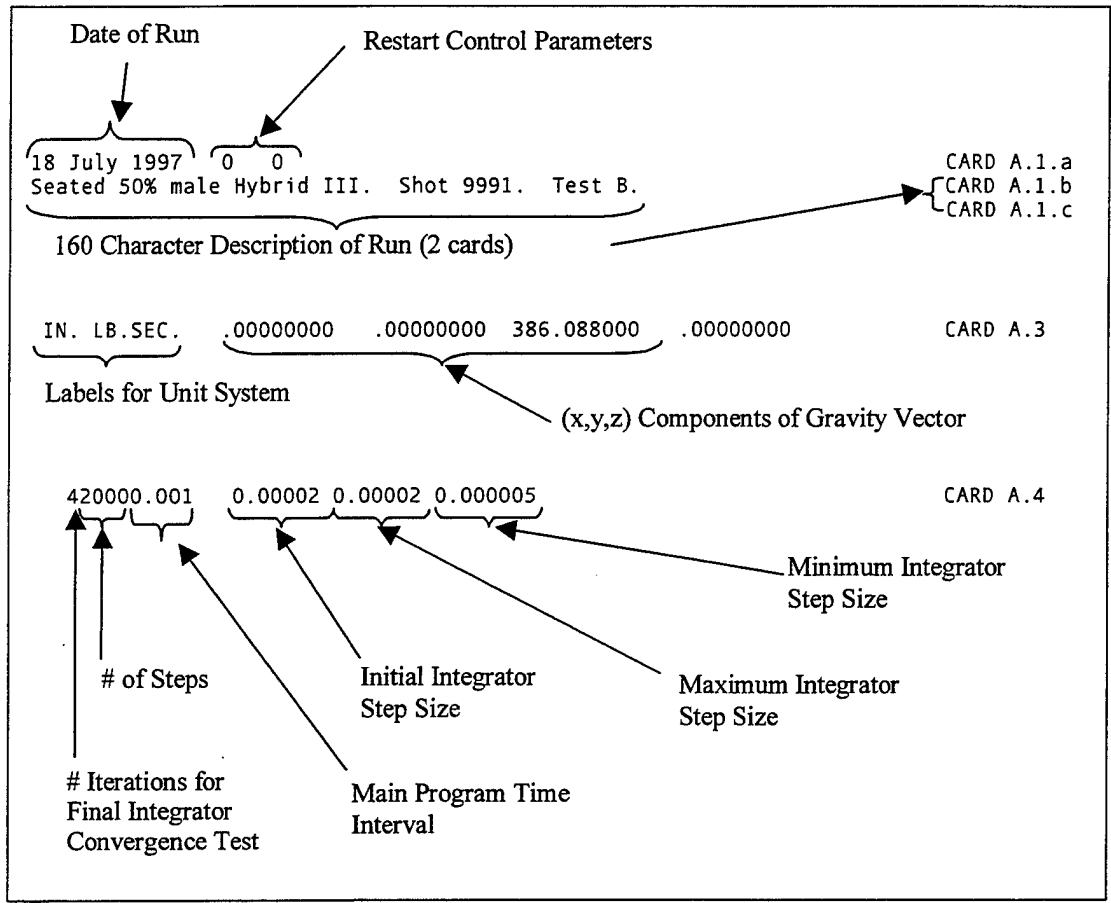
Figure 66. ATB Time Control Data Formatting.

Ref. [1] notes that for most simulations of occupants and pedestrians, suitable main program time intervals are on the order of 10 msec, maximum integrator time intervals are on the order of one to five msec, and minimum integrator time intervals are on the order of one-eighth to one-quarter msec. Obviously, if the input excitation is discretized at 0.2 msec intervals, the above time control values are too large to yield adequate results. As previously mentioned, it was determined that the main program time interval was to be one msec. In this case, the maximum integrator time step was specified to be one-tenth the time interval between input excitation values, or 0.02 msec (0.00002 seconds). The minimum integrator time step was specified to be one-quarter of the maximum, or 0.005 msec (0.000005 seconds). The initial integrator time step was set equal to the maximum integrator time step. The formatting of these values can be seen in Figure 66.

3. Miscellaneous Parameters

The date and a description of the simulation are input on Cards A.1.a, b, and c. Card A.3 contains the labels for the unit system to be used – inches, pounds, and seconds in this example. Card A.3 also contains the specification of the gravity vector. As previously discussed, the definition of the gravity vector partially defines the inertial coordinate system and the convention is to specify this vector as (0,0,g). Thus, the inertial Z-axis points down. The formatting of these parameters can be seen clearly in Figure 66.

G. FINAL ASSEMBLY OF THE INPUT DECK

In the previous sections, the construction of the major components of the ATB program input deck has been discussed. The numbering scheme for the cards makes assembling them relatively simple. However, this report cannot replace the ATB Users Guide [Ref. 1]. When all of the previously generated sections of the input deck have been assembled in the correct order, the user should go line by line through the input deck and verify against Ref. [1] that all required cards and fields have been included and are properly formatted. The complete input deck for this example is included as APPENDIX B.

IV. RUNNING THE ATB PROGRAM

Once the input deck has been assembled and verified line-by-line against Ref. [1], the ATB program may be executed. This may be performed either in a DOS window or in DOS itself. For initial positioning of the test subject, if it is desired to use the VIEW program for 2-D visualization, then it will be faster to execute the ATB program in DOS rather than in a DOS window. This is because the VIEW program cannot be run from a DOS window, but must be executed from DOS itself.

Execution of the ATB program is performed by typing ATBIV4 at the DOS prompt. The user is then prompted for the name of the input (*.AIN) file. This filename is entered without the extension. The user is then prompted for the common name for all output files. Each output file will have the same name, but a different extension (*.TP1, *.T##, etc.) as previously described. A sample execution of the ATB program is shown in Figure 67. As before, the lighter colored text represents input by the user. Although not shown in the figure, this example was run on a modified version of the ATB program that allows for an increased number of vehicle excitation time points as previously described. This modified version was named Mod1.exe, thus to execute the modified version, type MOD1 at the DOS prompt.

```
D:\Biodyn\ATB Files>atbiv4

ENTER INPUT FILENAME, EXTENSION .ain IS ASSUMED:
s9991

ENTER FILENAME FOR ALL OUTPUT FILES,
EXTENSIONS WILL BE ASSIGNED:
s9991
```

Figure 67. Example ATB Program Execution.

A. INITIAL TROUBLESHOOTING

A few short runs of the ATB program are typically required in order to locate and correct problems in the input deck and to initially position the test subject. Until these initial problems have been worked out, it is recommended that the length of the run be kept short. It is acceptable to specify the length of the run to be zero time steps.

1. Run-time Errors and Numbered Stops

There are two basic categories of errors associated with execution of the ATB program. The first category of errors is run-time errors, which are those errors that are associated with the FORTRAN language itself. An example of this would be an Invalid Integer Error. This would occur if the ATB program executed a formatted read statement to read in an integer value from the input file, but the corresponding location in the input file contained a real number. The second category of errors is the numbered stops within the ATB program. During the initial reading of the input deck, the ATB program performs some checking of the input data for consistency. If there are inconsistencies, the ATB program terminates execution and returns a numbered stop to the user. The meaning of each of these numbered stops is detailed in Ref. [1]. An example of a

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numbered stop is Stop Number 65 which means that the specified number of contact planes exceeds the maximum allowed (30).

Resolution of both the run-time errors and the numbered stops is greatly facilitated by use of the main output (*.AOU) file. Since the ATB program writes the input information to this file as the input deck is read, the last items written to the output file can be used to indicate the location in the input file that is incorrect. By executing the ATB program, consulting the *.AOU file and Ref. [1] to correct any errors, and then re-executing the ATB program, any formatting or setup errors can be easily resolved.

2. Establishing Equilibrium

For a simulation to accurately match an actual event, the initial conditions must be the same in the simulation as they were in real life. Typically, this means that the test subject is in static equilibrium. While true static equilibrium is essentially impossible to obtain in the ATB program, a close approximation is possible. Since vehicle excitations are typically applied shortly after the start of the simulation, all that is necessary for equilibrium is for the subject to have no initial velocity and to experience comparably low accelerations.

a. Initial positioning of body segments

The initial positions of the body segments are specified on the G Cards in the ATB input deck. The initial position and linear velocity components are specified, in inertial coordinates, for each reference segment. For a standard body, the reference segment is segment number one, the lower torso. Then, for each subsequent body segment, the user specifies yaw, pitch, and roll angles to define that segments initial position. The user also specifies what coordinate system these angles are with respect to and the order in which the rotations are to occur.

The process of initial positioning can be confusing since various coordinate systems are used and it can be difficult to visualize the effects of a yaw, pitch, and roll sequence of rotations. Figure 68 shows the formatting of the initial position data for the subject in the example problem. The center of the lower torso is first located by its x, y, and z coordinates in the inertial reference frame as specified on card G.2 as shown in Figure 68. Then the orientation of the lower torso is established by specifying its yaw, pitch, and roll angles with respect to segment number zero (inertial frame). The order in which these rotations occur is given by the 1, 2, 3 sequence near the end of the data card. This sequence – 1,2,3 – indicates that the standard yaw, pitch, roll sequence has been reversed so that the segment is first rolled, then pitched, and finally yawed. Recall that the inertial coordinate system was established such that the X-axis was aligned with the longitudinal axis of the test vehicle, the Y-axis pointed towards starboard, and the Z-axis pointed downward. Thus, with yaw, pitch, and roll angles all set to zero, the test subject would be facing forward in an upright position. Since the proper position for the test subject is seated facing starboard, the lower torso and other segments must be repositioned. As shown on the first G.3.a card in Figure 68, the lower torso is first rolled by three degrees about the inertial X-axis. This corresponds to a three degree lean to starboard. The lower torso is then pitched by 2.5 degrees about the new Y-axis. This corresponds to a 2.5 degree lean backward. Finally, the lower torso is yawed by 90 degrees about the new Z-axis. This corresponds to a 90 degree turn to the right.

Thus, the test subject is now positioned facing starboard with a slight lean backward and to the right.

Each subsequent segment must be positioned in a similar manner. Since the ATB program allows the user to specify in what coordinate system the rotations are to be made, the initial positioning is greatly facilitated. For example, the second G.3.a card specifies zero yaw, pitch, and roll angles for the middle torso with respect to the lower torso. Similarly, each line of the G.3.a cards refers to the positioning of the corresponding body segment.

```
   0.0         0.0         0.0    0   0   0   0   0                          G.1

   Initial Position of Lower          Initial Linear Velocity of
   Torso in Inertial Coordinates      Lower Torso in Inertial Coordinates



   1.5000000-2.8500000-28.060000  .00000000  .00000000  .00000000          G.2.A

   Initial Rotations (deg) about the
   X,Y,Z Axes of Segment #

                                      Initial Angular Velocities
                                      About Local X,Y,Z Axes



   90.000000  2.5000000  3.0000000  .00000000 .00000000 .00000000  1  2  3  0G.3.A
   .00000000  .00000000  .00000000  .00000000 .00000000 .00000000  3  2  1  1
   .00000000  .00000000  .00000000  .00000000 .00000000 .00000000  3  2  1  2
   .00000000  .00000000  .00000000  .00000000 .00000000 .00000000  3  2  1  3
   .00000000  .00000000  .00000000  .00000000 .00000000 .00000000  3  2  1  4
   5.0000000  97.800000 -3.000000   .00000000 .00000000 .00000000  3  2 -3  1
   .00000000-100.00000   .00000000  .00000000 .00000000 .00000000  3  2  1  6
   .00000000  .00000000  .00000000  .00000000 .00000000 .00000000  3  2  1  7
   -5.000000  97.800000 -3.000000   .00000000 .00000000 .00000000  3  2 -3  1
   .00000000-100.00000   .00000000  .00000000 .00000000 .00000000  3  2  1  9
   .00000000  .00000000  .00000000  .00000000 .00000000 .00000000  3  2  1 10
   -67.000000 23.100000 -7.600000   .00000000 .00000000 .00000000  1  2  3  3
   -30.000000 74.000000  .00000000  .00000000 .00000000 .00000000  1  2  3 12
```

Left Upper Arm is rolled -10 deg, then pitched 47.15 deg, then yawed 101 deg with respect to the Upper Torso axes. Initial angular velocities are all zero.

```
   101.000000 47.150000-10.000000  .00000000 .00000000 .00000000  1  2  3  3
   90.000000  80.000000  .00000000  .00000000 .00000000 .00000000  1  2  3 14
   .00000000  20.000000-2.7000000   .00000000 .00000000 .00000000  3  2  1 13
   .00000000 -12.00000   .00000000  .00000000 .00000000 .00000000  3  2  1 15
   .00000000  .00000000  .00000000  .00000000 .00000000 .00000000  3  2  1  0
   .00000000  .00000000  .00000000  .00000000 .00000000 .00000000  3  2  1  0
```

Order in which Rotations
Are Performed – 3,2,1 = yaw,
pitch, roll

Figure 68. Body Segment Initial Position Data Formatting.

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In order to verify that the body segments have been properly positioned, the ATB program can be run and then the resulting positions displayed using either the VIEW or IMAGE programs. In this manner, the test subjects body segments can be positioned such that they match as closely as possible the positions of the test subject in the actual test. Figure 69 shows the initial position of the test subject, as viewed using the IMAGE program, as well as the initial position of the ATD as seen in the videotape of the actual test. By properly orienting the viewing points in the IMAGE program (described in Chapter V), comparisons can easily be made between the initial positioning of the body segments in the simulation and those of the actual subject as seen in the videotape. Recall that the desk was not modeled in this example.
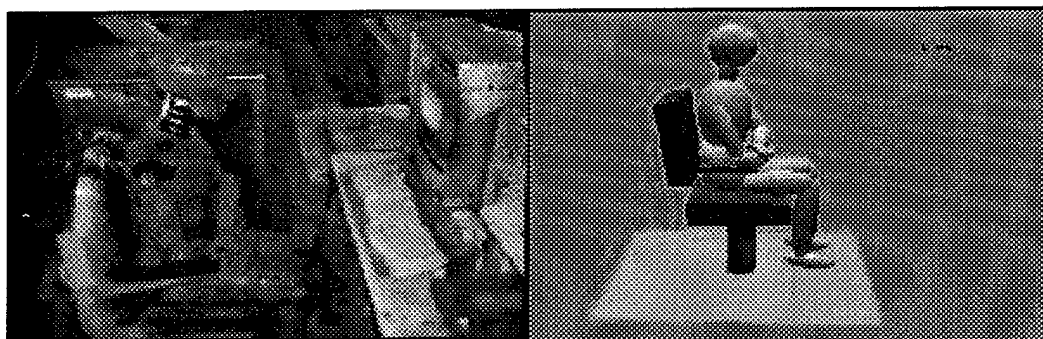
Figure 69. Initial Positioning of Test Subject.

b. Verifying equilibrium conditions

Ensuring that the positions of the body segments closely match those seen in the videotape is only part of the initial positioning process. It is also necessary to ensure that all of the body segments are in equilibrium (as described previously).

Reference [4] provides a suggested procedure for positioning a seated body. This procedure is summarized as follows:

1. Start with torso segments parallel to the seat back and the legs rotated clear of the floor surfaces.
2. Adjust the position of the lower torso to balance more than half of the total body weight.
3. Rotate the upper legs down in order to balance most of the remaining weight of the body.
4. Check horizontal forces.
5. Rotate lower legs to fully balance remaining body weight.

This procedure was used to position the test subject in the example problem. First, the lower torso was positioned such that its contact with the seat bottom balanced most of the weight of the body. That positioning was checked by viewing the file containing the tabular time history of the lower torso to seat bottom contact force after performing a short run of the ATB program. For the example problem, that was file S9991.t28. This file, for a ten msec run, is included as Figure 70. Note that just over 90 pounds is supported by the lower torso. The total weight of the 50th percentile male Hybrid III dummy is 168 pounds. Also included in the S9991.t28 file is the right upper leg-seat bottom contact force. This contact supports nearly 37 pounds. Although not shown, the

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left upper leg-seat bottom contact also supports nearly 37 pounds. Thus, between the three contacts, the entire weight of the test subject is support. Since the feet of the ATD did not reach the deck in the original test, none of the body weight is support through this contact. Similarly, since there was no contact between the torso of the ATD and the seat back in the original test, none is specified in the initial positioning of the ATB model test subject. Note that after 10 msec, there is no significant change in the distribution of the test subjects weight.

```
1                    DATE:   18 July 1997
           RUN DESCRIPTION:   Seated 50% male Hybrid III.   Shot 9991.   Test B.                    CARD A.1
                                                                                                    CARD A.1.c
    PAGE: 28.00
    VEHICLE DECELERATION:   Shot 9991 - Sitting 50% Male Hybrid III - SSTV
             CRASH VICTIM:   SITTING HYBRID III
                             CONTACT FORCES - SEGMENT PANELS VS. SEGMENTS

              PANEL   1 (Seat  Cushion.  Botto) VS  SEG  1 ( LT )  ELLIP  1   PANEL   1 (Seat  Cushion.  Botto) VS  SEG  6 ( RUL)  ELLIP  6
              DEFL-   NORMAL   FRICTION  RESULTANT  CONTACT LOCATION ( IN.)   DEFL-   NORMAL   FRICTION  RESULTANT  CONTACT LOCATION ( IN.)
     TIME     ECTION  FORCE    FORCE     FORCE      (VEH  REFERENCE)          ECTION  FORCE    FORCE     FORCE      (VEH  REFERENCE)
    (MSEC)    ( IN.)  ( LB.)   ( LB.)    ( LB.)     X      Y        Z         ( IN.)  ( LB.)   ( LB.)    ( LB.)     X      Y        Z

     .000     1.245   94.33     .00      94.33     1.308  -2.856  -24.500     .614    36.85     .00      36.85     -2.462  5.402  -24.500
    1.000     1.245   94.30    21.21     96.66     1.308  -2.856  -24.500     .614    36.84    3.36      36.99     -2.462  5.402  -24.500
    2.000     1.244   94.22    28.70     98.50     1.309  -2.857  -24.500     .614    36.82    7.13      37.50     -2.462  5.403  -24.500
    3.000     1.244   94.11    31.91     99.37     1.310  -2.858  -24.500     .613    36.79   10.31      38.21     -2.462  5.404  -24.500
    4.000     1.243   93.96    33.43     99.73     1.311  -2.859  -24.500     .613    36.76   12.82      38.93     -2.462  5.405  -24.500
    5.000     1.241   93.80    34.25     99.85     1.312  -2.860  -24.500     .612    36.71   14.72      39.55     -2.462  5.406  -24.500
    6.000     1.240   93.61    34.74     99.85     1.314  -2.861  -24.500     .611    36.66   16.16      40.07     -2.462  5.407  -24.500
    7.000     1.239   93.42    34.75     99.67     1.315  -2.862  -24.500     .610    36.61   17.28      40.48     -2.462  5.409  -24.500
    8.000     1.237   93.21    34.63     99.43     1.317  -2.864  -24.500     .609    36.55   18.05      40.76     -2.462  5.410  -24.500
    9.000     1.236   92.99    34.41     99.15     1.319  -2.865  -24.500     .608    36.48   18.58      40.94     -2.462  5.412  -24.500
   10.000     1.234   92.77    34.28     98.90     1.320  -2.867  -24.500     .607    36.41   18.90      41.03     -2.462  5.413  -24.500
```

Figure 70. Lower Torso to Seat Bottom Contact Forces.

Although the weight of the test subject is properly distributed and the initial positions of the body segments match closely those of the ATD as seen in the videotape of the actual test, the process of establishing initial equilibrium is not yet complete. It is necessary to verify that the positioning of the body segments will not yield significant initial accelerations. These accelerations could be due to contacts between body segments or from torques generated at one or more joints.

In order to verify that no unexpected accelerations are imposed upon any of the body segments, the *.AOU file may be examined following a short run of the ATB program. Figure 71 shows an excerpt from the S9991.AOU file (included as APPENDIX C). This shows the initial external accelerations of the body segments and the forces and torques on each of the joints. The 386.1 in/sec^2 in the Z direction is the acceleration imposed on all of the body segments by gravity. The additional accelerations imposed on the lower torso and right and left upper legs are due to their contacts with the seat bottom. It can be seen that there are externally applied accelerations present for the right lower arm, right hand, and middle torso. By consulting the appropriate tabular time history files for the segment-segment contacts, it can be established that the right lower arm touches the middle torso and that the right hand contacts the left upper leg. This is in agreement with the initial position of the ATD as seen in the videotape of the original test. Note that there are no unusually large joint forces or torques.

The entire initial positioning and establishing of equilibrium process is highly iterative in nature and can be quite time consuming. A systematic approach, as described above, can make the process significantly easier. Once the user is confident that there are no unexpected contact forces, and that the accelerations experienced by the body segments do not become large (compared to the accelerations to be applied by the vehicle) prior to the application of the vehicle excitation, then the test subject can be

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considered to be in initial equilibrium. The process of obtaining a match between the simulation and the actual test may now be started.

```
                       (INERTIAL)                        (LOCAL)
            U1 ARRAY ( IN./SEC.**2)          U2 ARRAY (RAD/SEC.**2)              KINETIC ENERGY
            EXTERNAL LINEAR ACCELERATIONS    EXTERNAL ANGULAR ACCELERATIONS         ( LB.- IN.)
  SEGMENT     X         Y         Z            X          Y          Z        LINEAR      ANGULAR      TOTAL
 1 LT      -.2025D-15  .3038D-13 -.1276D+04  -.10694D+03  .98991D+02  .39954D+02   .00000D+00  .00000D+00  .00000D+00
 2 MT       .8829D+03 -.1463D+04  .1408D+04  -.42639D+03  .61269D+03  .15204D+04   .00000D+00  .00000D+00  .00000D+00
 3 UT       .0000D+00  .0000D+00  .3861D+03   .00000D+00  .00000D+00  .00000D+00   .00000D+00  .00000D+00  .00000D+00
 4 N        .0000D+00  .0000D+00  .3861D+03   .00000D+00  .00000D+00  .00000D+00   .00000D+00  .00000D+00  .00000D+00
 5 H        .0000D+00  .0000D+00  .3861D+03   .00000D+00  .00000D+00  .00000D+00   .00000D+00  .00000D+00  .00000D+00
 6 RUL     -.1613D-13 -.2937D-13 -.3258D+03  -.80957D+01  .18905D+02 -.80978D+02   .00000D+00  .00000D+00  .00000D+00
 7 RLL      .0000D+00  .0000D+00  .3861D+03  -.43751D-16 -.94597D-34 -.14019D-14   .00000D+00  .00000D+00  .00000D+00
 8 RF       .0000D+00  .0000D+00  .3861D+03  -.11783D-14 -.44045D-16 -.13236D-14   .00000D+00  .00000D+00  .00000D+00
 9 LUL      .2079D+02  .2050D+02  .1814D+03   .32385D+02  .17786D+02  .29110D+03   .00000D+00  .00000D+00  .00000D+00
10 LLL      .0000D+00  .0000D+00  .3861D+03   .10848D-14 -.82537D-33 -.34760D-13   .00000D+00  .00000D+00  .00000D+00
11 LF       .0000D+00  .0000D+00  .3861D+03   .29214D-13 -.10921D-14 -.32818D-13   .00000D+00  .00000D+00  .00000D+00
12 RUA      .0000D+00  .0000D+00  .3861D+03   .00000D+00  .00000D+00  .00000D+00   .00000D+00  .00000D+00  .00000D+00
13 RLA     -.6182D+03  .1025D+04  .5579D+03  -.34128D+02  .61398D+02  .12577D+02   .00000D+00  .00000D+00  .00000D+00
14 LUA      .0000D+00  .0000D+00  .3861D+03   .00000D+00  .00000D+00  .00000D+00   .00000D+00  .00000D+00  .00000D+00
15 LLA      .0000D+00  .0000D+00  .3861D+03   .00000D+00  .00000D+00  .00000D+00   .00000D+00  .00000D+00  .00000D+00
16 RHD     -.3220D+03 -.3176D+03 -.1220D+04  -.16843D+03  .63509D+03  .65836D+03   .00000D+00  .00000D+00  .00000D+00
17 LHD      .0000D+00  .0000D+00  .3861D+03   .00000D+00  .00000D+00  .00000D+00   .00000D+00  .00000D+00  .00000D+00
18 LAR      .0000D+00  .0000D+00  .3861D+03   .00000D+00  .00000D+00  .00000D+00   .00000D+00  .00000D+00  .00000D+00
19 RAR      .0000D+00  .0000D+00  .3861D+03   .00000D+00  .00000D+00  .00000D+00   .00000D+00  .00000D+00  .00000D+00
                                                                             TOTAL BODY KINETIC ENERGY
                                                                          .00000D+00  .00000D+00  .00000D+00


                     (INERTIAL)                      (INERTIAL)
               JOINT FORCES ( LB.)            JOINT TORQUES ( IN. LB.)       RELATIVE ANGULAR
 JOINT IPIN      X         Y         Z          X          Y          Z      VELOCITY (RAD/SEC.)
 1 P    0      -.457D+01  .877D+01 -.335D+02   .0000D+00  .0000D+00  .0000D+00    .000
 2 W    0       .355D+01  .106D+01 -.337D+02   .0000D+00  .0000D+00  .0000D+00    .000
 3 NP   0      -.389D+00  .609D+00 -.586D+01   .0000D+00  .0000D+00  .0000D+00    .000
 4 HP   0      -.160D+00  .193D+00 -.460D+01   .0000D+00  .0000D+00  .0000D+00    .000
 5 RH   0      -.170D+01  .371D+01 -.710D+01   .2899D+02 -.1241D+02 -.1227D+00    .000
 6 RK   1      -.152D+00  .104D+01 -.583D+01   .5831D+00 -.6068D+01 -.9662D+00    .000
 7 RA   3      -.159D+00 -.194D+01 -.122D+01   .2263D+00 -.2377D+00 -.2261D-01    .000
 8 LH   0      -.942D+00  .827D+01 -.526D+01   .3243D+02  .5722D+02 -.6581D+01    .000
 9 LK   1       .308D+01  .125D+01 -.648D+01   .4012D+00  .5003D+02  .4389D+01    .000
10 LA   3       .138D+01 -.302D+00 -.203D+00   .1499D+00  .1869D+01  .1634D+00    .000
11 RS   0      -.181D+00 -.155D+01 -.561D+01   .0000D+00  .0000D+00  .0000D+00    .000
12 RE   7       .437D+00 -.410D+01 -.388D+01  -.6331D+01  .1467D+02 -.6184D+01    .000
13 LS   0       .115D+01 -.165D+01 -.329D+01   .0000D+00  .0000D+00  .0000D+00    .000
14 LE   7       .792D+00 -.139D+01 -.104D+01   .1094D+01 -.5737D+01  .6078D+01    .000
15 RW   3      -.126D+01  .976D+00 -.266D+00  -.1107D+01  .1343D+01  .1777D+01    .000
16 LW   3       .196D+00 -.241D+00 -.277D+00   .7119D-01 -.5272D+00  .5251D+00    .000
17 LR   1       .848D-03 -.513D-02  .559D+00   .0000D+00 -.1135D-04 -.5515D-02    .000
18 RR   1       .848D-03 -.513D-02  .559D+00   .0000D+00 -.1135D-04 -.5515D-02    .000
```

Figure 71. Initial Accelerations and Joint Forces.

B. OBTAINING A MATCH

Now that the initial positioning of the test subject within its environment has been accomplished, and the body is in equilibrium, the process of matching the simulation to the test is begun. Matching can be broken down into two categories – visual and numerical. For the example problem, the videotape of the test serves as the visual standard for comparison. Similarly, the measured data from the triaxial linear accelerometers located at the center's of gravity of the head, thorax, and pelvis serve as the numerical standards for comparison.

1. Visual Comparison

As previously discussed, the actual test used for this example was videotaped using standard video, resulting in a still frame image of the motion of the test subject being recorded approximately every 33 msec (30 frames per second). These images were captured as individual graphics files using a personal computer equipped with a video capture card. These graphics files were then printed as contact sheets, with nine images per sheet, for use as a visual reference. The first of these sheets is shown (reduced) as Figure 72. Each image represents a 33 msec incremental change in the position of the test subject. Thus, the fourth frame (F004.jpg) corresponds to the position of the test subject at 99 msec ([4-1]*33=99).

The ATB program is now executed and the resulting predicted motion is compared against the visual reference. Since running the ATB program for the full two second simulation can take significant time (nearly three hours on a 100MHz Pentium PC

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for this example), it may be efficient to make shorter runs until the match between simulation and test is close, then perform the full run.
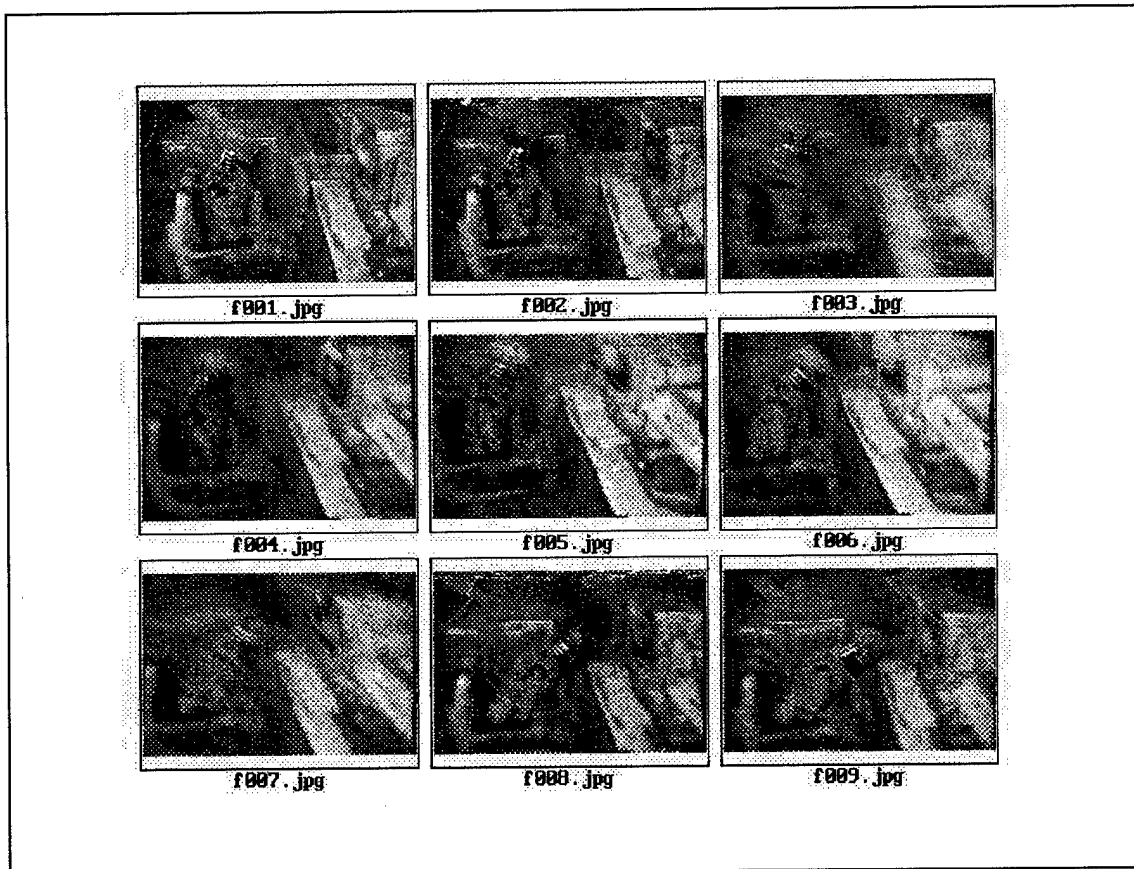
Figure 72. Example Contact Sheet of Video Capture Images.

After performing the simulation, visual comparison against the printed contact sheets can be made using the images produced by VIEW or, alternatively, those produced by IMAGE. There are advantages and disadvantages to each. Using VIEW produces 2-D line drawings whereas using IMAGE produces 3-D shaded renderings that are easier to compare against the video images. However, VIEW can be run from the same PC that the ATB program is run from, but to use IMAGE, the *.TP1 file must be transferred to a Silicon Graphics workstation and the program run there. In either case, the gross bodily motion as predicted by the simulation can be compared to the images captured from the videotape. From this comparison, conclusions can be drawn concerning the accuracy of the simulation. If the match between the simulation and the videotape is poor, then the differences in the motion can often serve as indicators for the problem areas in the simulation. Figure 73 shows several frames of the comparison for the example problem using the IMAGE program. Note that the motion of the torso agrees quite well, but that the motion of the arms is less pronounced in the simulation. This was considered to be of only minor concern. The actual execution of the VIEW and IMAGE programs is discussed in detail in Chapter V.

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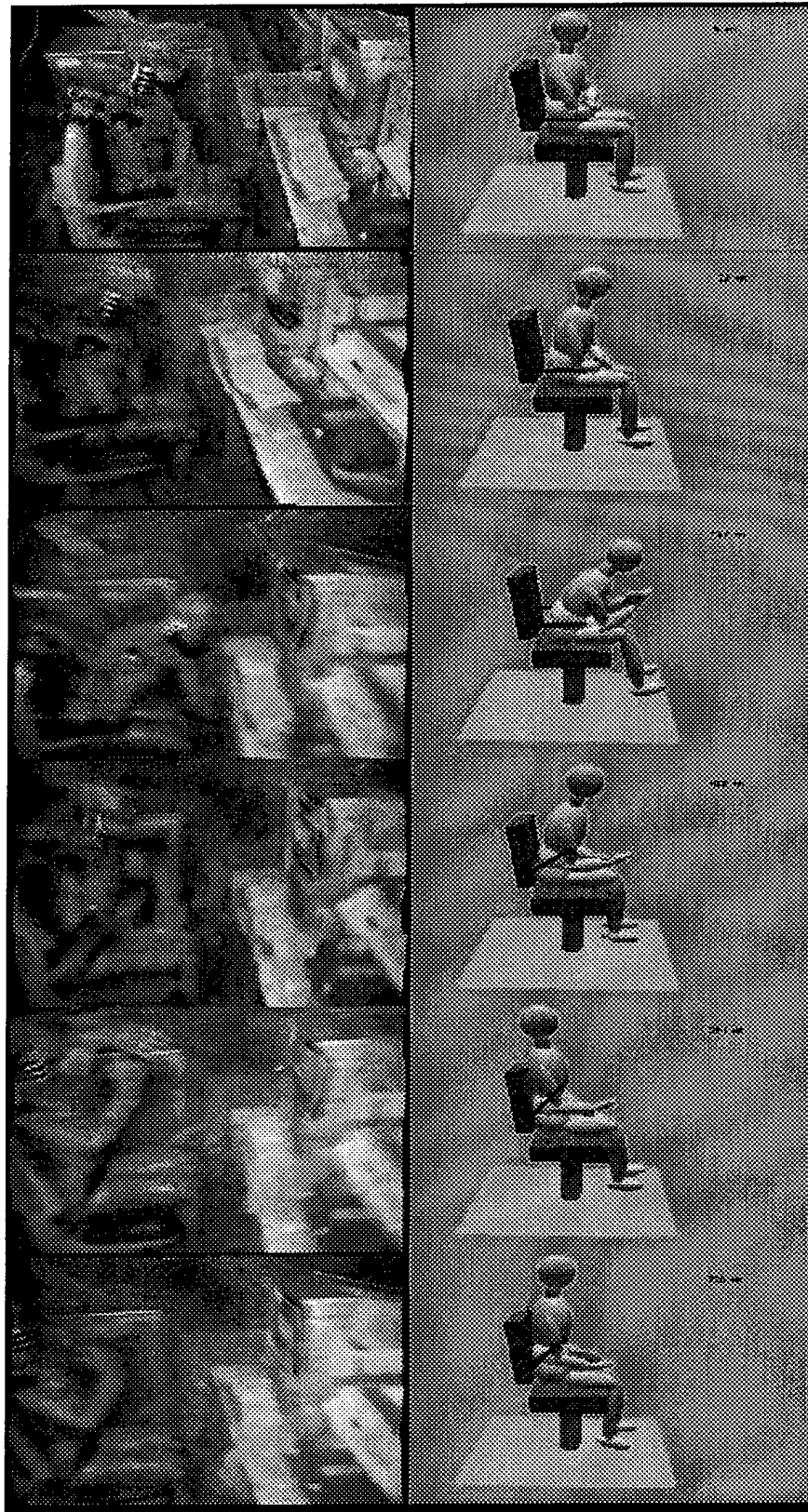
Figure 73. Sample Comparison Frames.

2. Numerical Comparison

Another significant portion of the validation process is the comparison of predicted to measured accelerations. By specifying the acceleration time histories to be printed out for the head, thorax, and pelvis, as previously described, this comparison process is greatly simplified. The data from the time history files can easily be plotted along with the corresponding measured accelerations using a spreadsheet or data plotting program.

The comparisons between the measured and predicted accelerations for the head X and Z directions are shown in Figure 74 and Figure 75, respectively. The comparisons for the thorax X and Z directions are shown in Figure 76 and Figure 77, respectively, and the comparisons for the pelvis X and Z directions are shown in Figure 78 and Figure 79, respectively. Note that no comparisons were made for accelerations in the Y direction. Recall that the Y direction (for the head, thorax, and pelvis) corresponds to the longitudinal axis of the test vessel. No excitation was specified in this direction, as previously described, and the predominant motion of the test subject occurred in the X-Z (transverse) plane. In addition, the measured accelerations for the pelvis in the Y direction were lost due to a data recorder channel failure. The six figures shown below were all created using Microsoft Excel, but any spreadsheet or plotting program of choice may be used.

As was the case for the visual comparisons, differences between the measured and predicted numerical results can serve as indicators of problems with the simulation. Using visual and numerical comparisons together, inaccuracies in the simulation may be identified and corrected to yield a better match to the actual test. Some possible problems could include poor initial positioning, poor estimation of plane-segment force-deflection characteristics, and failure to include an important plane-segment or segment-segment contact.

The agreement between the accelerations as predicted by the simulation and those measured during the test, as seen in the following figures, was considered adequate, particularly when viewed in conjunction with the agreement in the visual comparison discussed above. Obtaining an agreement of this quality is a highly iterative process. As described previously, short runs (one second of vehicle excitation) were performed until the first portion of the simulation was in relatively close agreement with the measured data and videotape. Between each of these runs, the visual and numerical comparisons were performed and minor adjustments were made to the input deck. The ATB program was then executed again and the comparison process repeated. Once adequate agreement for the first portion of the simulation was obtained, the runs were extended to full length (two seconds of vehicle excitation) and the process continued.

It was found to be beneficial to maintain a record of the major points of disagreement in the visual and numerical comparisons, and of the changes made to the input deck to resolve these disagreements. This helps to identify trends in the quality of the agreement and to determine which modifications should be retained, and which should be discarded. It was also found to be prudent to not change too many parameters at once, for doing so can make it difficult to determine the effects on the output of each individual change to the input deck.
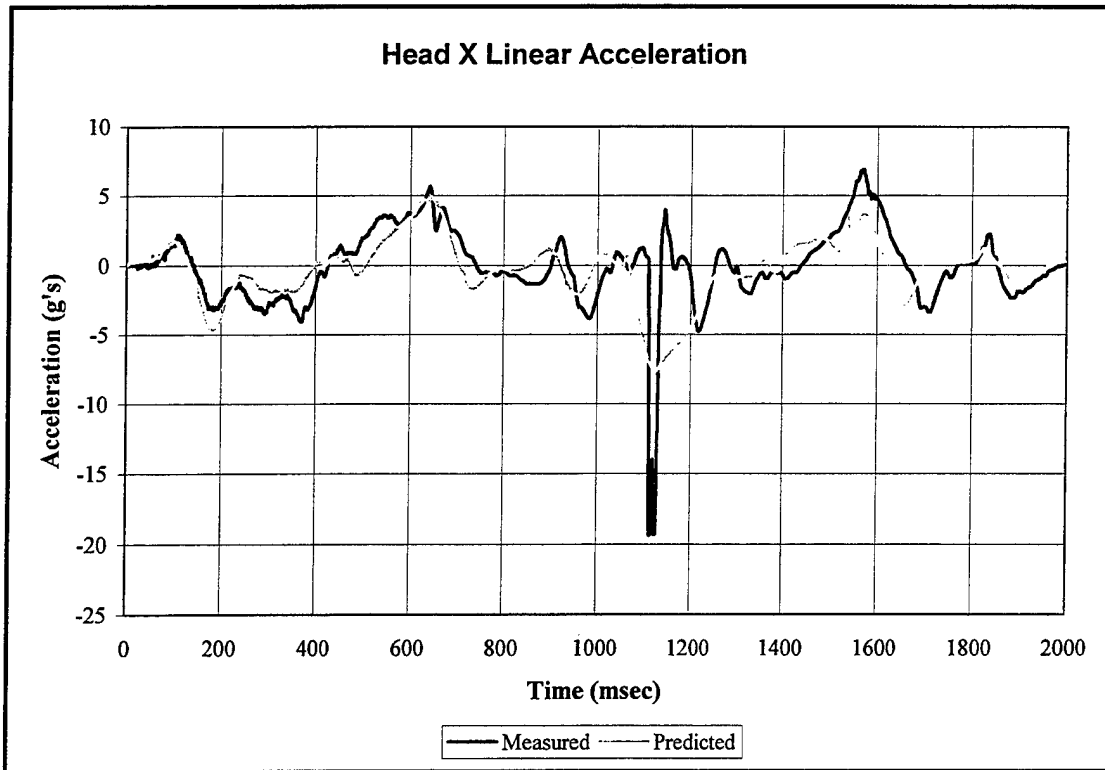
Figure 74. Comparison of Measured and Predicted Head X Accelerations.
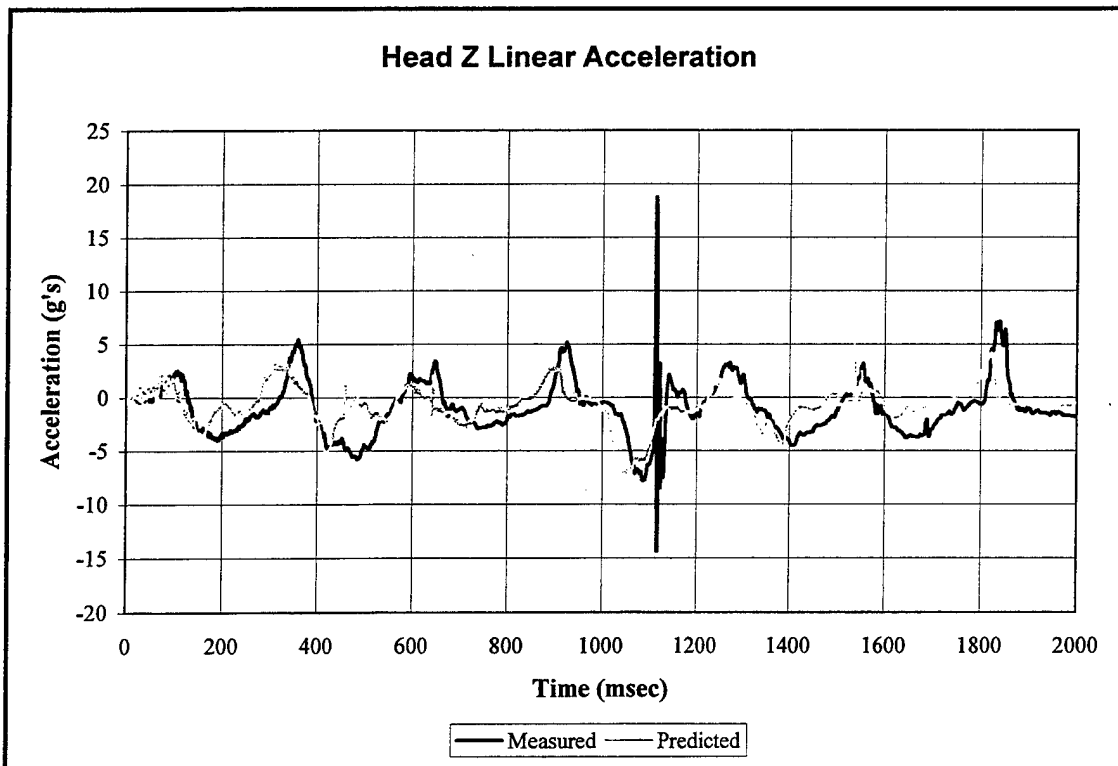
Figure 75. Comparison of Measured and Predicted Head Z Accelerations.

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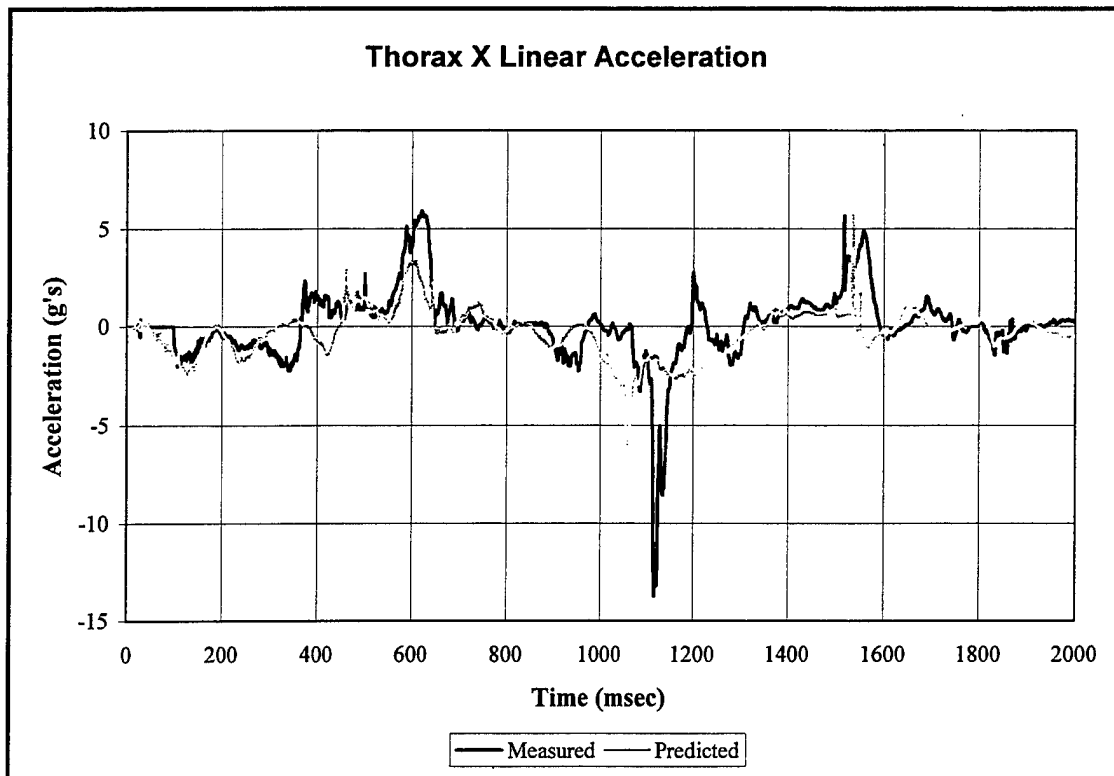
Figure 76. Comparison of Measured and Predicted Thorax X Accelerations.
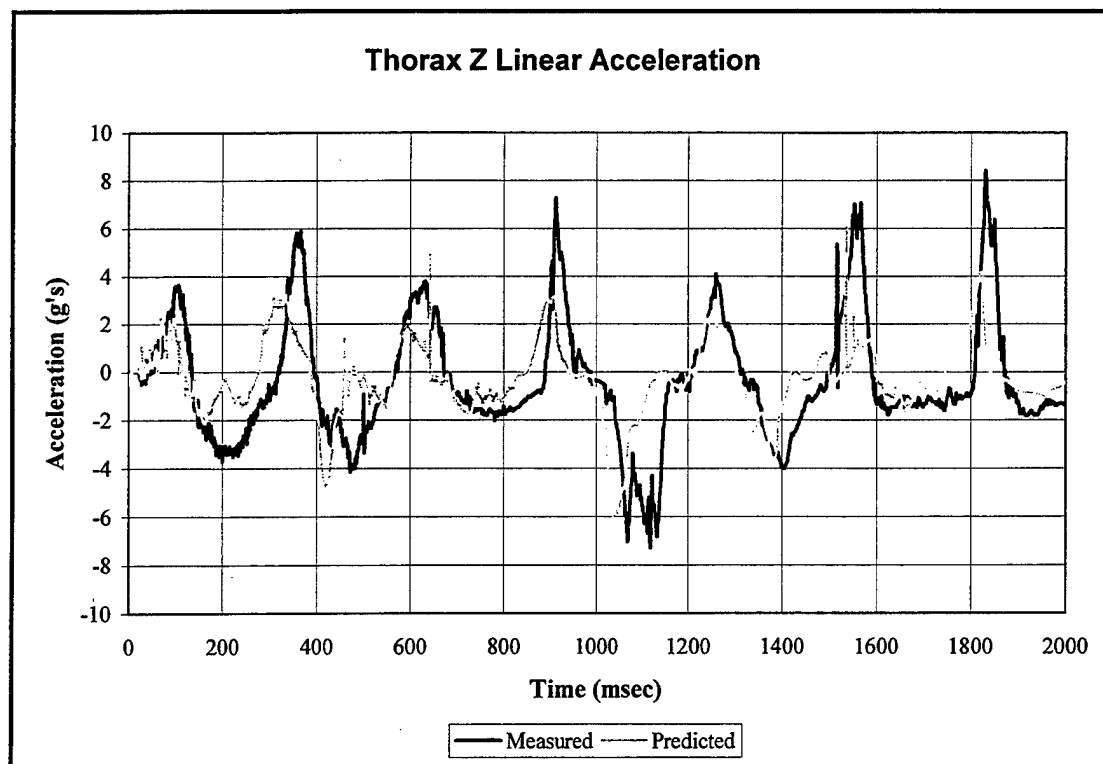
Figure 77. Comparison of Measured and Predicted Thorax Z Accelerations.

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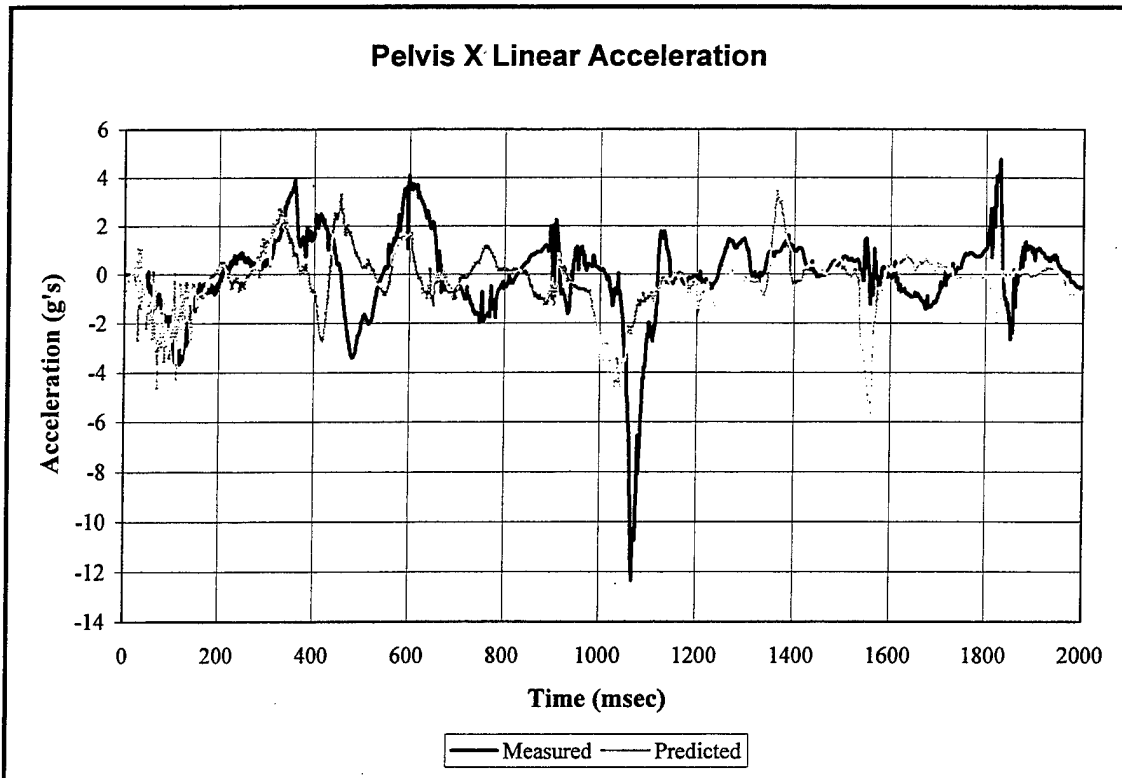
Figure 78. Comparison of Measured and Predicted Pelvis X Accelerations.
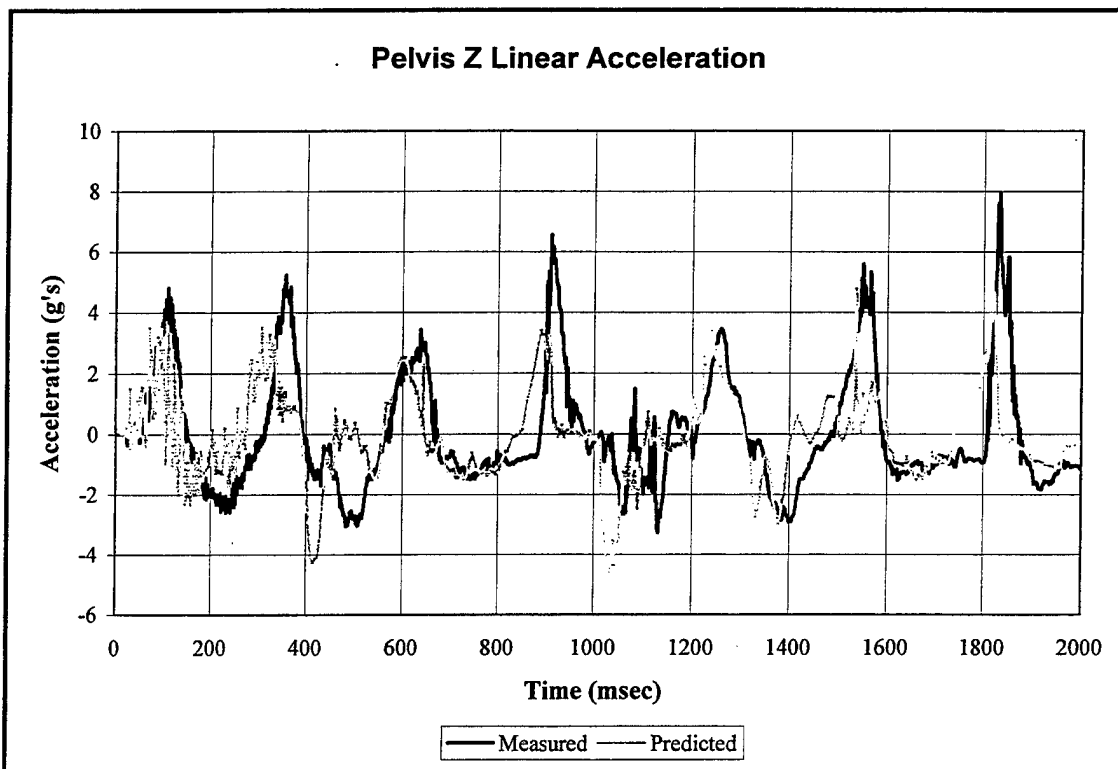
Figure 79. Comparison of Measured and Predicted Pelvis Z Accelerations.

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C. EXTENSION OF THE MODEL

Once the validity of the model has been ascertained to an acceptable level, the model may be extended as desired. The model of the ATD can be removed and a model of a human being may be substituted. The simulation can then be run and then injury estimates may be may by comparing predicted accelerations, forces, torques, etc., against corresponding injury tolerances.

1. Substitution of Bodies

In the previous section, the validity of the model of the chair and the vehicle excitation has been verified to the desired level. Now it is desired to remove the model of the Hybrid III dummy and substitute in models of various humans. In this example, it was desired to substitute in both a 50th percentile male and a 5th percentile female subject. The GEBOD program was used to generate ATB formatted body data sets for these two human subjects. For each subject, the percentiles (50th for the male, 5th for the female) were used for both the weight and the height.

The substitution of human subjects for the Hybrid III dummy in the input deck is relatively simple. The portions of the deck relating to the ATD are removed and the appropriate portions from the *.AIN file generated by GEBOD for the human subjects are inserted in their place. There are some differences in the body data sets for the ATD's and the humans that must be considered when making the substitutions. For the human subjects, GEBOD does not generate the detailed force-deflection functions that were provided in the ATD body data sets. These functions should be removed from the input deck to ensure that they are not inadvertently used for the human subjects. In addition, the dimensions of the body segments for the humans and the ATD will be different, so the appropriate changes must be made in the input deck. For example, the location of the lap belt contact point on the lower torso will be different for the human subjects than it was for the Hybrid III dummy and this change must be made on card D.3.c.

Another major adjustment that must be made to the input deck when changing the test subject is the establishment of equilibrium. Since the dimensions and, in the case of the female, the weight of the test subject have changed, it will be necessary to readjust the initial locations of the segments to reestablish equilibrium. The same process that was used for the ATD may be used for the human subjects.

2. Variation of Initial Positions

Another change that can be made as an extension of the model is in the initial position of the test subject. The positioning of the test subject's arms as seen in videotape (see Figure 69) was not considered very realistic. Instead, it was desired to place the arms and hands in a more natural position. Once the model of the 50th percentile human male was incorporated into the input deck, the initial positioning of the arms was changed as shown in Figure 80. Again, when any changes are made to the initial positions of the body segments, equilibrium must be reestablished.

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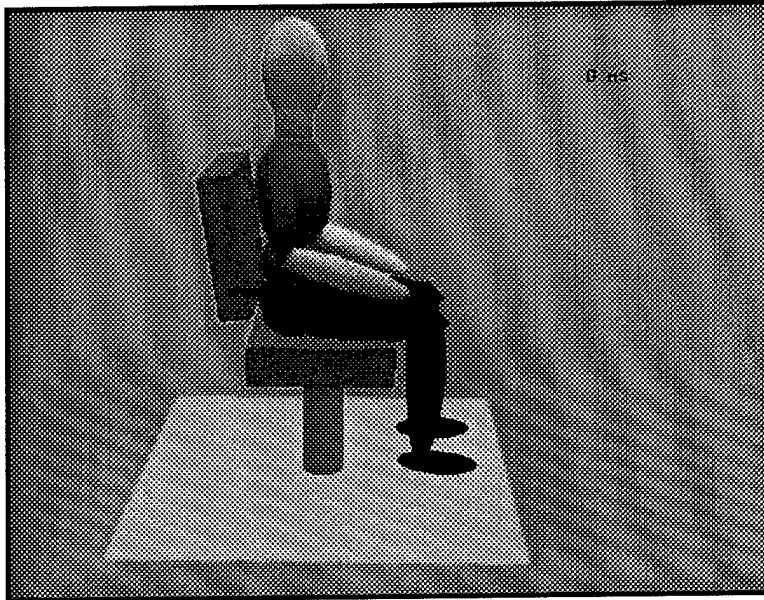
Figure 80. 50th Percentile Human Male Initial Position.

3. Additional Changes

Further changes that were made as extensions of the basic model were removal of the lap belt with the addition of a desk, and addition of a computer terminal and keyboard resting on the desk.

Removal of the lap is very simple. The number of simple belts as specified on card D.1 is changed to zero, and the cards defining the positioning of the lap belt (D.3.a, b, and c), as well as those defining the characteristics of the interaction between the lap belt and the lower torso (cards F.2.a and b), were deleted.

To prevent the test subject from being ejected from the operator's chair entirely and to construct a more realistic environment, a simple desk was added in front of the subject. The desk as seen in the videotape of the original test (see Figure 69) was considered to be too far from the test subject. Thus, the desk added to the model was placed closer to the chair and subject.

A desk can be constructed in essentially two ways. First, a series of contact planes can be defined to represent the top, bottom, and edges of the desk. Second, a single hyperellipsoid can be defined to represent the entire desk. In the development of the model of the desk, the first method was initially attempted and several problems were discovered in the process. For some segments, such as the lower arms, it was considered necessary to allow contacts with the planes representing the top, bottom, and front edge. Since these are finite planes and edge contacts are definitely expected, the edge effect option was specified. Unfortunately, this has an undesired effect for contacts as shown in Figure 81. For a contact between the lower arm segment and the bottom front edge of the desk, one would expect to have components of reaction force normal to both the front edge and the desk bottom. However, since it was necessary to allow contacts between the lower arms and the desk top, a component of force normal to the desk top also arises from this contact. This is a physically unrealistic result and therefore a poor method by which to model the desk.

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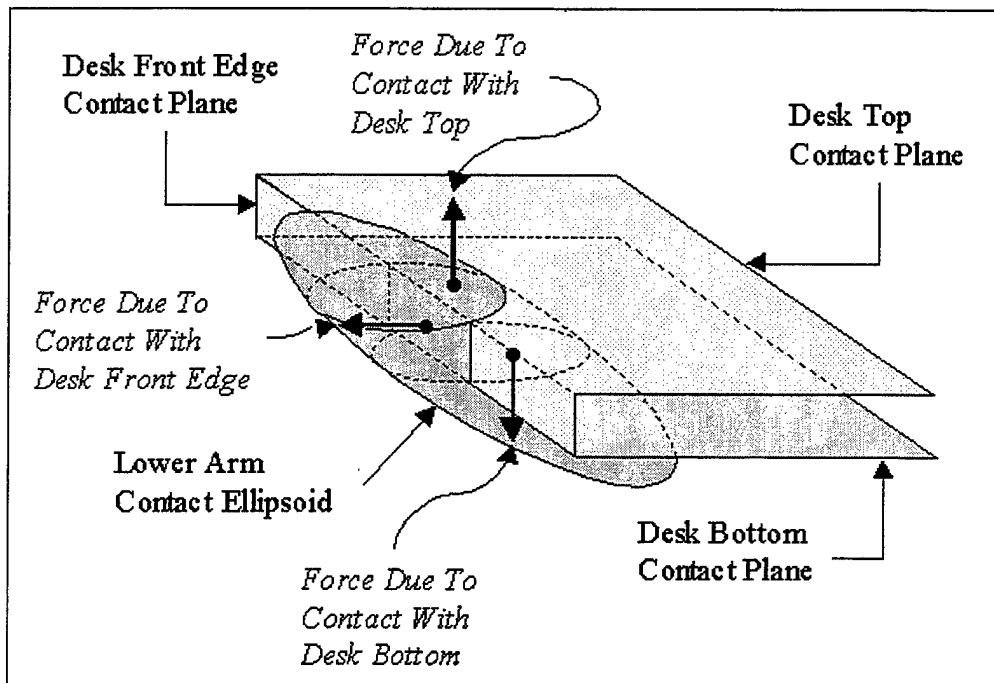
Figure 81. Lower Arm to Desk Edge Contact Illustration.

The second method of modeling the desk, using a hyperellipsoid, was then implemented. The semi-axis lengths of the hyperellipsoid were chosen to be equal to half of the length, width, and thickness of the desk that was constructed from planes. The powers for each semi-axis were specified to be equal and set at a value of 20. Thus, contacts between body segments and the hyperellipsoid representing the desk result in a single force based on the penetration as previously described (see Figure 14). This selection yielded much improved results over the planar contact surface method. A drawback of using a hyperellipsoid is the limitation on the number of segment-segment contacts that may be specified. Recall that this limit is set at 40 by the ATB program and can be easily reached since several body segments must be allowed to contact the desk surface.

4. Changing the Specified Output

Typically, the purpose of extending a model will include the estimation of injury potentials. In order to make these estimates, the appropriate data must be output by the ATB program. In most instances, this data will be different, or in addition to, the data that was generated in order to validate the model. Thus, the input deck must be altered in order to specify the desired output. The choice of which injury potentials to estimate, and the associated tolerances, will be problem dependant and is beyond the scope of this report.

For the example problem, it was desired to examine, in addition to the linear accelerations of the head, the angular accelerations and velocities of the head. In addition, the relative angular position of the head with respect to the upper torso was desired, as was the torque present at the head-neck pivot point. Finally, the contact forces between the head and the surfaces of the desk and computer were desired. With the

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exception of the head-desk and head-computer contact forces, the desired output parameters are all specified using the H cards in the input deck. Most of the output parameter formatting was previously discussed and will not be repeated. Referring back to Figure 65, Card H.6 specifies that the angular position of the head (segment five) is to be output with respect to the coordinate system of the upper torso (segment three). To obtain the head-neck pivot (joint four) torque time history, Card H.7 must contain the number four. For further information concerning the formatting of the input deck for desired output, consult Ref. [1].

V. USE OF THE IMAGE AND VIEW PROGRAMS

The IMAGE and VIEW programs can serve as invaluable tools for obtaining a match between a simulation and an actual test as well as for visualizing the gross bodily motion of one or more test subjects in an extension of a previously validated model. This chapter covers the setup and execution of each of these programs.

A. VIEW PROGRAM

As previously described, the VIEW program is run from DOS and produces two dimensional line drawings of the test subject and environment using data provided by the ATB program in the *.TP1 file. The details concerning the element colors, times, title frames and lines, and viewpoint are specified in the control (*.VIN) file.

1. Control File

The *.VIN control file for the VIEW program is constructed in much the way the *.AIN input deck is constructed for the ATB program, but is significantly smaller. A sample *.VIN file, as used for the example problem, is included as APPENDIX G. Ref. [3] gives detailed instructions concerning the use of the VIEW program and proper formatting of the *.VIN file.

The first line of the control file (each line is referred to as a record, vice card as in the ATB input deck) specifies the output device and format. For use on a PC, the first parameter is set to seven. For output directed to a 16 color VGA (640 x 480) monitor, the next two parameters are set to 091 as shown in Figure 82. Ref. [3] gives an extensive listing of output devices and their associated parameters.
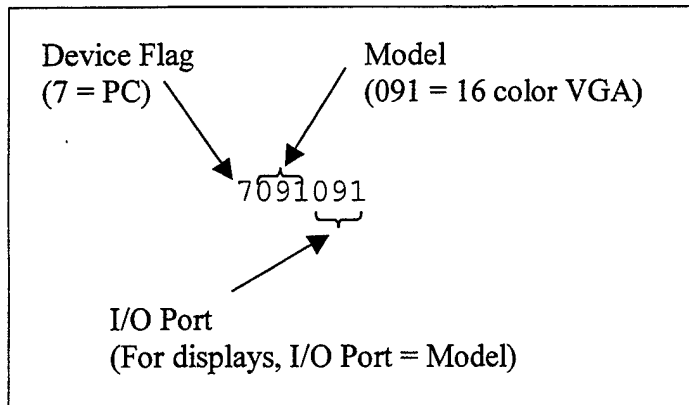
Figure 82. Output Device Data Formatting.

The second line of the control file specifies the number of title frames to be generated. Each title frame consists of 20 lines of text, with up to 30 characters per line. If no title frames are desired, the second line contains a zero and there are no following lines of text. The numbers along the right hand side of the title frame text lines define the color in which the corresponding line of text will be displayed or plotted. The correlation between number and color depends upon the specific device being used for display or

plotting. For each specified title frame, there must be 20 lines of text (blank lines allowed) following. This formatting is illustrated for one title frame, as used in the example problem, in Figure 83.
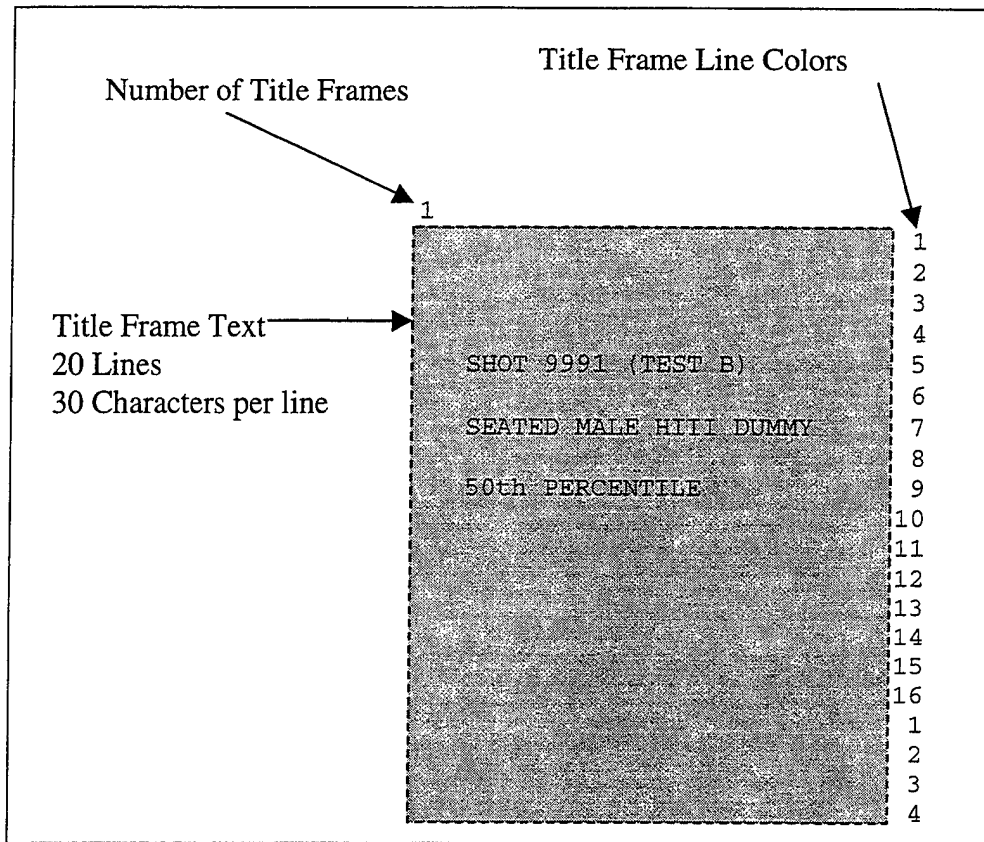
Figure 83. Title Frame Formatting.

The third record contains the optional one line title that is printed on each frame of the display above the time stamp. If no title is desired, a blank line is inserted into the control file. For the example, the title is as shown in Figure 84.
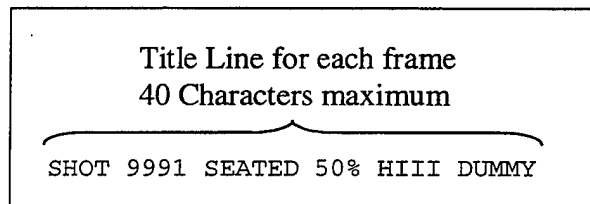
Figure 84. Title Line Formatting.

Records 4.0 and 5.0 contain the time control and debug control parameters, respectively. On record four, the user specifies the start time, end time, and time increment for data plotting. As previously stated, the VIEW program can only plot time frames for which data exists in the *.TP1 file. Thus, the time increment should be an

integer multiple of the time increment used in the ATB program to record data to the *.TP1 file. For the example problem, in order to match the times for which still images captured from the videotape exist, the time increment was set at 33 msec, the start time at 0 msec, and the end time at 1980 msec as shown in Figure 85. On record 5.0, the user specifies what debug information is desired. For the example problem, no debug information was required, so the four fields were set to zero as shown in Figure 85. For more information concerning what debug options are available, consult Ref. [3].
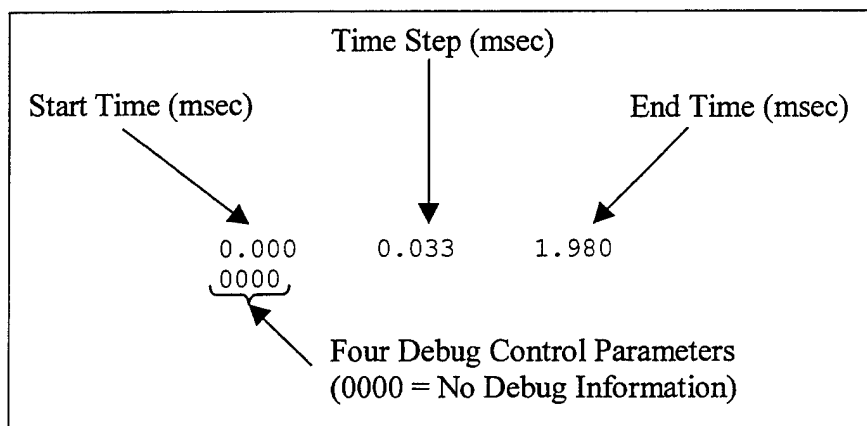
Figure 85. Time and Debug Control Data Formatting.

Record 6.0 contains three parameters that control what elements from the *.TP1 file are plotted. The first parameter specifies how many segments from the ATB program are not to be plotted. Ref. [3] states that plotting extremely small ellipsoids from a great distance should be avoided using the VIEW program and this parameter can be used to eliminate these ellipsoids if they are the last ones defined in the ATB input deck. The second parameter specifies how many polygons (planes) from the ATB simulation are not to be plotted. The specific plane numbers are to be specified on a following line, record 6.1. The third parameter specifies the coordinate system to be used for any unattached planes or planes for which there were no contacts specified on the F cards in the ATB input deck. For the example problem, there were no ellipsoids or polygons to be removed from the plots, and all planes were attached to the vehicle, segment 20. This can be seen in Figure 86.

Record 7.0, 7.1, and 7.2 contain information pertaining to additional polygons that are to be plotted. If no additional polygons are desired, as is the case in the example problem, then record 7.0 contains a zero and records 7.1 and 7.2 are not required. For details on proper data formatting for additional polygons, consult Ref. [3].

Records 8.0, 9.0, 10.0, and 10.1 contain the color information for the ellipsoids, polygons, title line printed on each frame, and harness belts, respectively. As before, the correlation between number and color is device specific. For the example, all body segment ellipsoids were plotted in light green (color #2), all chair components were plotted in blue (color #9), and the title lines on each frame were plotted in green (color #10). There were no harness belts used in the example, so the colors specified on record 10.1 are ignored. This formatting is shown in Figure 87.

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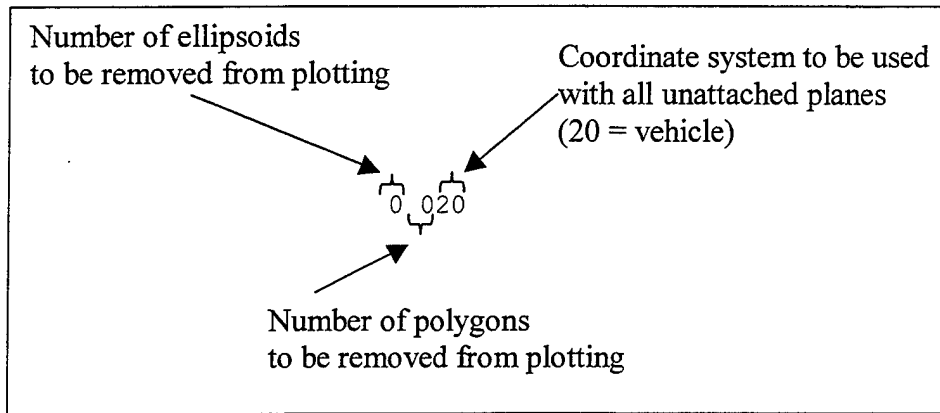
Figure 86. Record 6.0 Data Formatting.
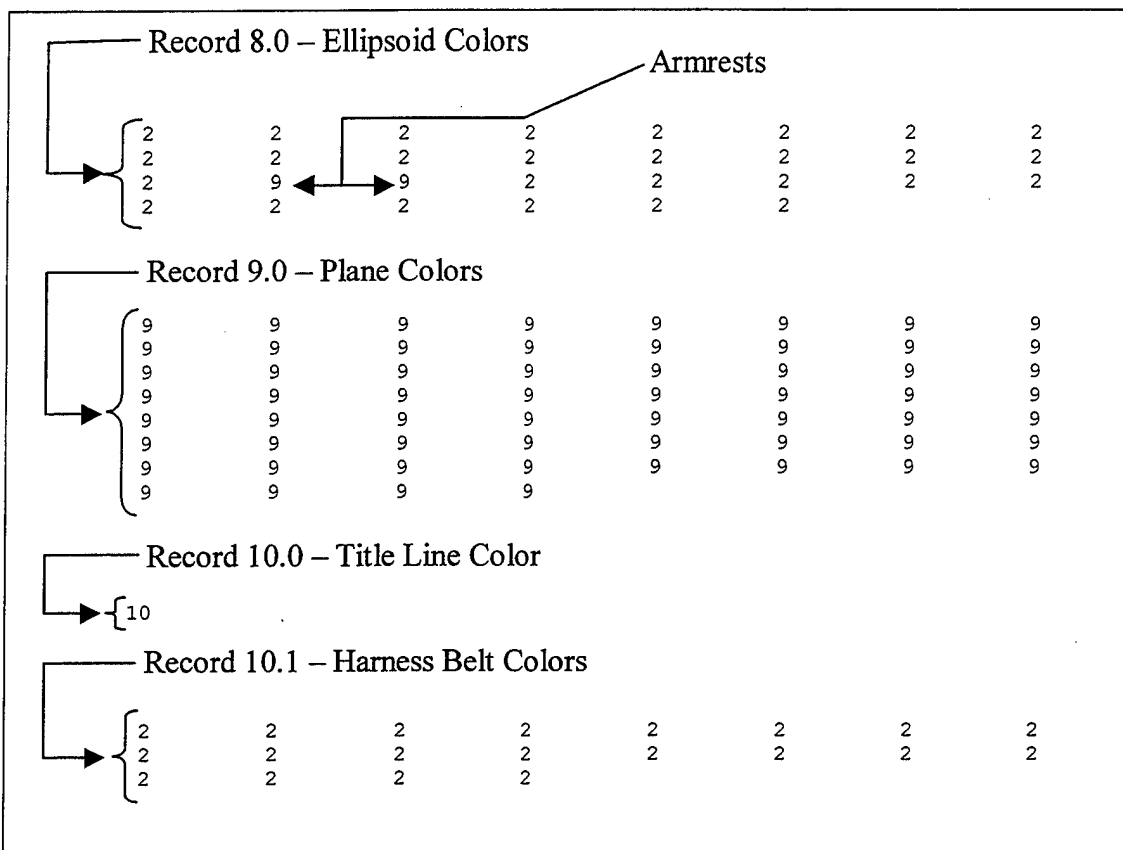
Figure 87. Color Specification Data Formatting.

Records 11.0 and 12.0 contain parameters specifying the manner in which ellipsoids and polygons are plotted. On record 11.0, the user specifies the number of steps used for plotting the contour lines for each of the ellipsoids. On record 12.0, the user specifies the number pieces into which each side of a polygon is divided. If more than 30 polygons are specified, then an optional record 12.1 is included. Record 12.2

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contains parameters related to harness belts, consult Ref. [3] for further details. Figure 88 shows the data used in the example problem for records 11.0, 12.0, and 12.2.
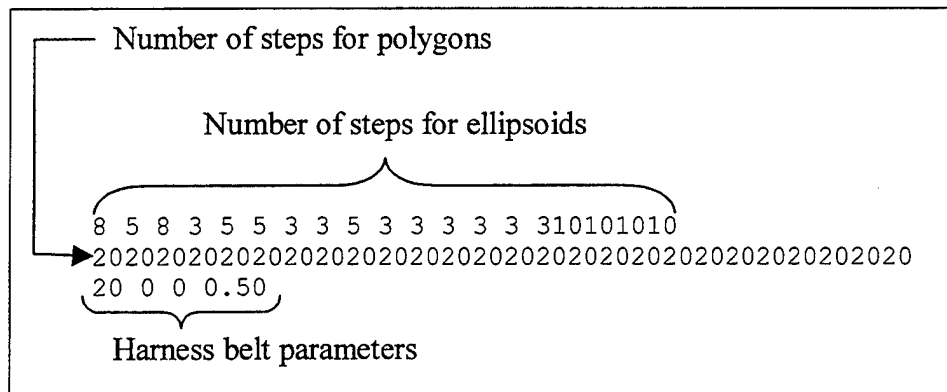
Figure 88. Plotting Control Parameters.

Records 13.0, 14.0, 15.0, and 16.0 control the location and size of the plotted image with respect to the screen or paper. Within the VIEW program, there are three methods for defining the viewing point and the manner in which the object is plotted or displayed. These three methods are described in detail in Ref. [3], but the method used in the example problem is summarized here.

A viewpoint (the point at which the camera exists) and a focal point (the point at which the camera is looking) are defined. In addition, the height and width of the viewing plane (corresponding to paper or display size) are specified. Finally, a scale factor is defined that controls how large the image appears on the plot. Figure 89 illustrates the terms and setup of a viewpoint system. The height of the object, measured in the ATB program units, is H. The distance from the viewpoint to the focal point, again in ATB program units, is D. The height of the viewing plane, in inches, is PPD, and the width of the viewing plane, also in inches, is Xmax-Xmin. The scale factor, which is the distance from the viewpoint to the origin of the viewing plane, is defined using similar triangles as shown in Equation (7).

$$Scale\,Factor = \left(\frac{PPD}{H}\right) * D \qquad (7)$$

The height of the object, H, in the example problem was estimated as 60 inches. The distance from the viewpoint to the focal point, D, is calculated from the (x,y,z) coordinates of the two points in the ATB coordinate system associated with whichever segment is specified by the user. In this case, the vehicle was specified to be the reference system for the viewpoint. The location of the viewpoint itself is arbitrary and should be chosen to provide the desired perspective of the test subject. Reference [3] suggests that the distance D be approximately 1000 inches. For the example problem, the focal point was chosen to be the origin of the vehicle coordinate system and the viewpoint was chosen such that the perspective was similar to the perspective of the test setup as seen in the videotape. The coordinates of the viewpoint were (-850.0, 40.0, -

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175.0) inches. The distance D is simply calculated as the length of the vector between the two points and its value in the example problem was 868.75 inches. The height of the viewing plane, PPD, was chosen to be the height of the display being used, or 8 inches. Thus, the scale factor can be calculated as (8.0/60.0)*868.75 and the resulting value is 115.8 inches. The width of the viewing plane was also set to the dimensions of the display being used, 11.0 inches. The formatting of the above results on records 13.0 through 16.0 can be seen in Figure 90.
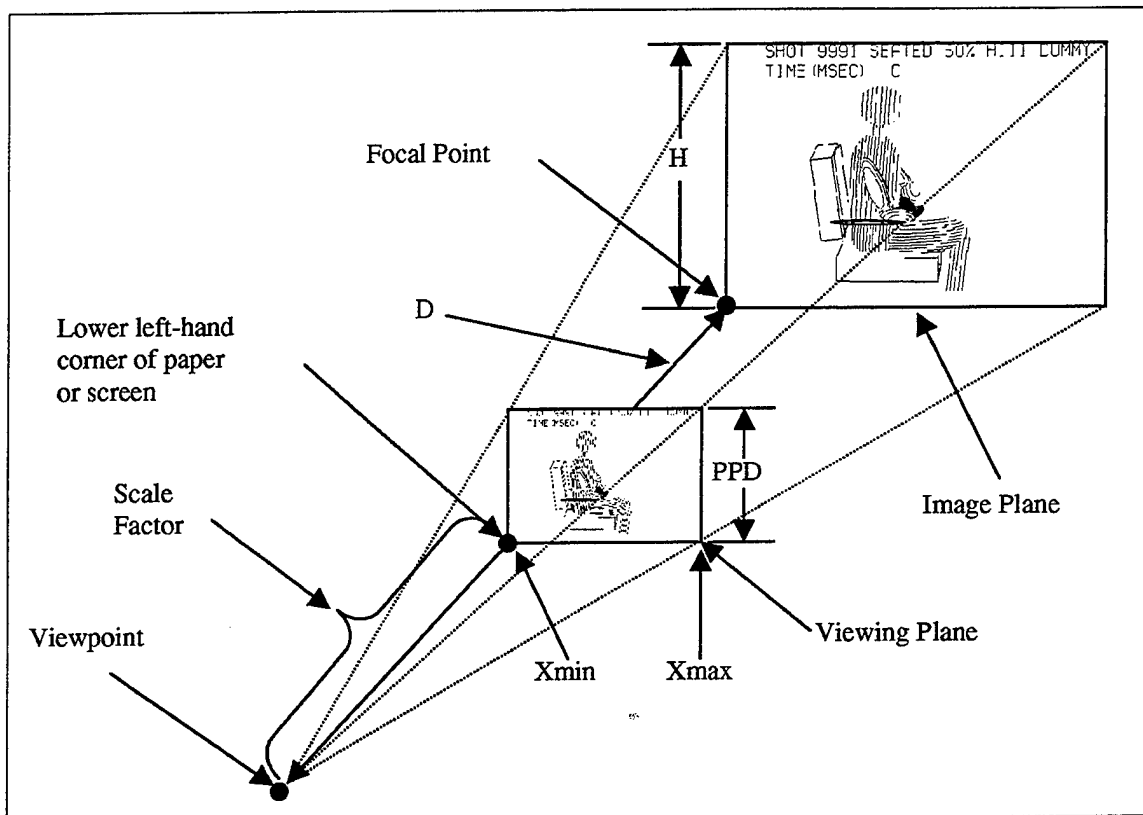
Figure 89. Viewpoint Illustration. After Ref. [3]

2. Printing VIEW Images

The printing of the images generated by VIEW is highly device dependent. As previously stated, Ref. [3] contains a listing of devices and ports which may be used in conjunction with the VIEW program. Only two of these options will be mentioned here. First, if it is desired to print only a single image, that image can be saved as an encapsulated postscript file for later printing on a postscript capable printer. This option can be exercised by specifying the model to be 111 and the port to be 011 for deferred plotting. Second, an entire series of frames can be saved to a file in the Hewlett Packard Graphics Language (HPGL) for latter viewing or printing using a program capable of reading HPGL files. This may be performed by specifying the model to be 030 and the port to be 010 for deferred plotting.
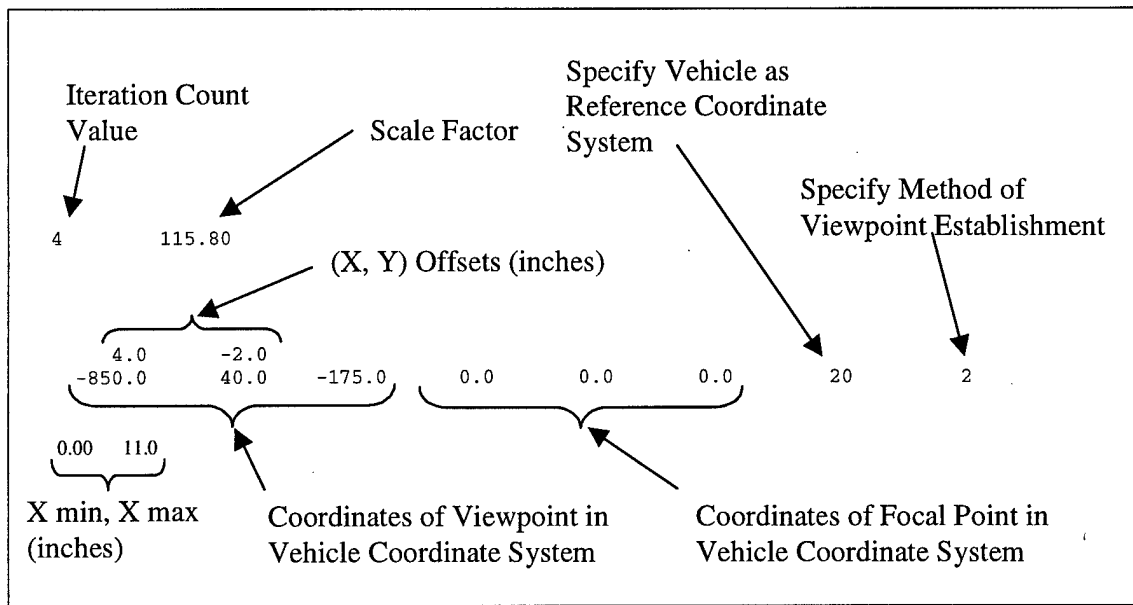
Figure 90. Viewpoint System Data Formatting.

B. IMAGE PROGRAM

As previously described, the IMAGE program is run from a Silicon Graphics (SGI) workstation and produces three dimensional shaded renderings of the test subject and environment using data provided by the ATB program in the *.TP1 file. The details concerning the element colors, additional planes, and viewing orientation are specified in the setup (*.SETUP) file.

1. Execution of IMAGE

The image program is executed from UNIX by typing "image filename", where filename corresponds to the name of the *.TP1 file, but does not include the extension. The program then searches for a file with the same root name, but with a .setup extension. For more information concerning the execution of the IMAGE program, consult the user's manual included as APPENDIX A.

2. Setup File

The *.setup file required by the IMAGE program is similar in nature to the *.VIN file required by the VIEW program. In the *.setup file, the colors for the ellipsoids and planes are specified, additional planes may be defined, and a viewpoint system similar to the one used in the VIEW program is defined. However, the IMAGE program does not render harness belts, does not provide for title frames or title lines (although a time stamp is displayed), and does not allow the user to specify which frames from the *.TP1 file are to be displayed

The general construction of the *.setup file is less rigorous than that of the *.VIN file. IMAGE is C based, whereas VIEW is FORTRAN based. Specifications in the *.setup file are performed using keywords and pairs of keywords. These keywords can have mixed cases, but must be spelled exactly as defined in the user's manual, including

the underscore and equal sign followed by a space. In addition, single line comments may be included in the *.setup file by preceding the comment text by "/*" and following the text by "*/". In addition, the order in which the parameters are specified is generally not significant. The user's manual (APPENDIX A) gives further details concerning the ordering in keyword pairs.

As for the VIEW program, each individual plane or ellipsoid must have a specified color. With the IMAGE program, these colors are defined using red-green-blue (rgb) triplets. The value of each color component is an integer between 0 and 255. The triplet (0,0,0) corresponds to black, and (255,255,255) corresponds to white. A convenient way to determine what triplet values corresponds to what colors is to execute the command "cedit" which brings up a window with three slider bars, one for each component, and a color window that displays the resulting color. Figure 91 shows the CEDIT window and an example color definition.
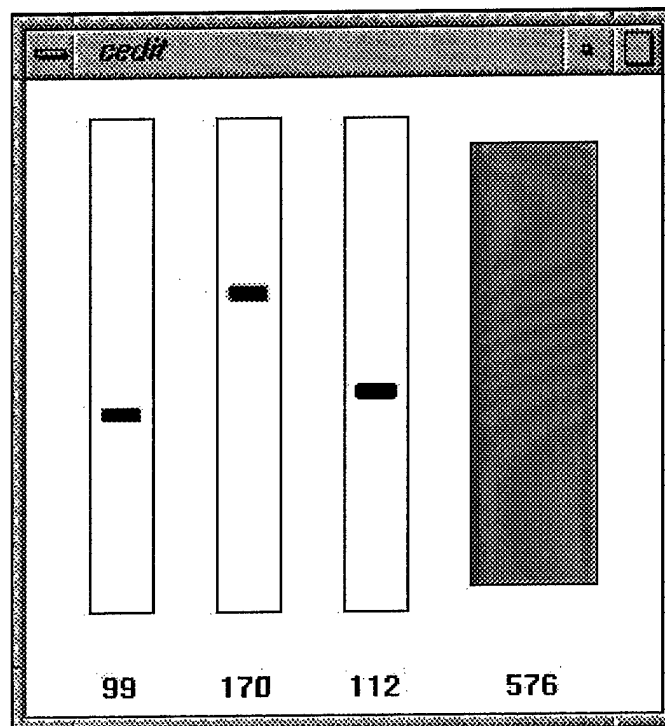
Figure 91. CEDIT Window.

Once a color has been determined using the CEDIT utility, the specification is performed in the *.setup file. This is done through use of pairs of keywords for both planes and ellipsoids as shown in Figure 92. The two keywords (ID Number and Color) may appear in any order, but the usage must be consistent.

Additional planes may be defined in the IMAGE program much like additional polygons could be defined in the VIEW program. This is done using the Add_Plane keyword and the specification of the (x,y,z) coordinates of the four corners of the plane. In the example problem, several planes were added to represent the physical surfaces of the chair that were not modeled in the ATB program. Additionally, If there were any

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planes defined in the ATB program that did not have any allowed contacts, they will not be rendered by the IMAGE program. Thus, to have these planes rendered, they must be added in the *.setup file. Figure 93 shows the format for the addition of the back of the seat bottom. This plane was not originally defined in the ATB program, but rendering is desired for aesthetic purposes. A comment line is included to identify what the plane represents, followed by a line containing the (x,y,z) coordinates of the four corners defining the plane. These values are referenced to the coordinate system of the segment to which the plane is attached. This attachment occurs in the following pair of keywords in which the plane ID is assigned and the plane is attached to segment number 20, the vehicle in the example problem. Finally, the color specification pair of keywords follows.
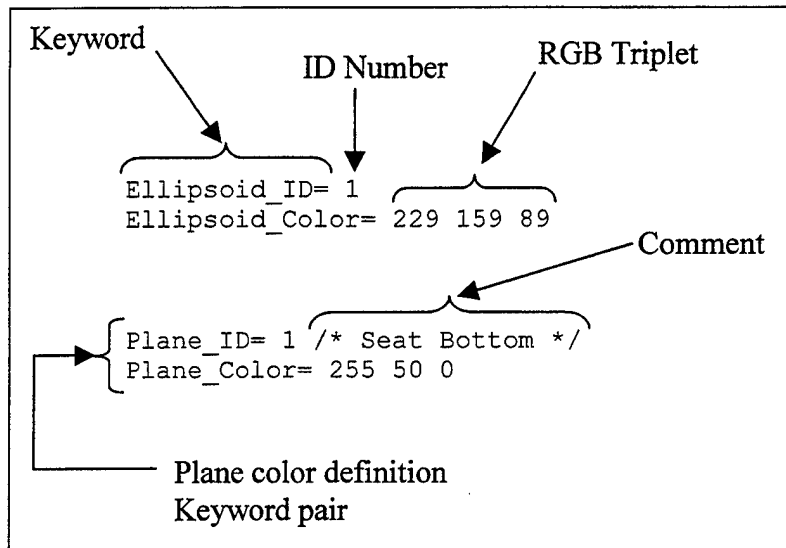
Figure 92. Color Specification Data Formatting.

Although it was not necessary for the example problem, planes and/or ellipsoids can be removed from the plotting just as was the case with the VIEW program. This removal is simply done for planes by using the keyword "Remove_Plane_ID= ", followed by the plane ID number as specified in the ATB program. Similarly, ellipsoids may be removed by using the keyword "Remove_Ellipsoid_ID= ", followed by the ellipsoid ID number as specified in the ATB program.

The IMAGE program does not allow for the generation of title frames or title lines, but does provide a time stamp on the rendering. The user has control over both the color of the background and the color of the time stamp. This is accomplished using RGB triplets, as described above, and the keywords "Background_Color= " and "Time_Color= ".

A viewpoint system similar to the one used in the VIEW program is defined by the user in the *.setup file. A camera position (corresponding to the viewpoint) and a looking at position (corresponding to the focal point) are defined in the coordinates of the segment to which the camera is attached (also a user specified quantity). An initial scale, similar to the scale factor in the VIEW program, is defined to control the size of the

image in the window. The user also has the option to specify initial yaw and roll angles. In the example problem, the camera was attached to the vehicle, segment number 20, and the camera position, looking at position, and initial scale were specified as shown in Figure 94.

Comment line used to identify additional plane

(x,y,z) coordinates of the four corners of the plane in vehicle coordinate system

```
/* Seat Bottom - Back */

Add_Plane= 9.5 -9.25 -19.75 -9.5 -9.25 -19.75 -9.5 -9.25 -24.5 9.5 -9.25 -24.5


Attach_Plane_ID= 74      Plane ID assignment and attachment
To_Segment= 20           to vehicle (segment #20)


Plane_ID= 74             Plane color assignment
Plane_Color= 255 50 0    Keyword pair
```
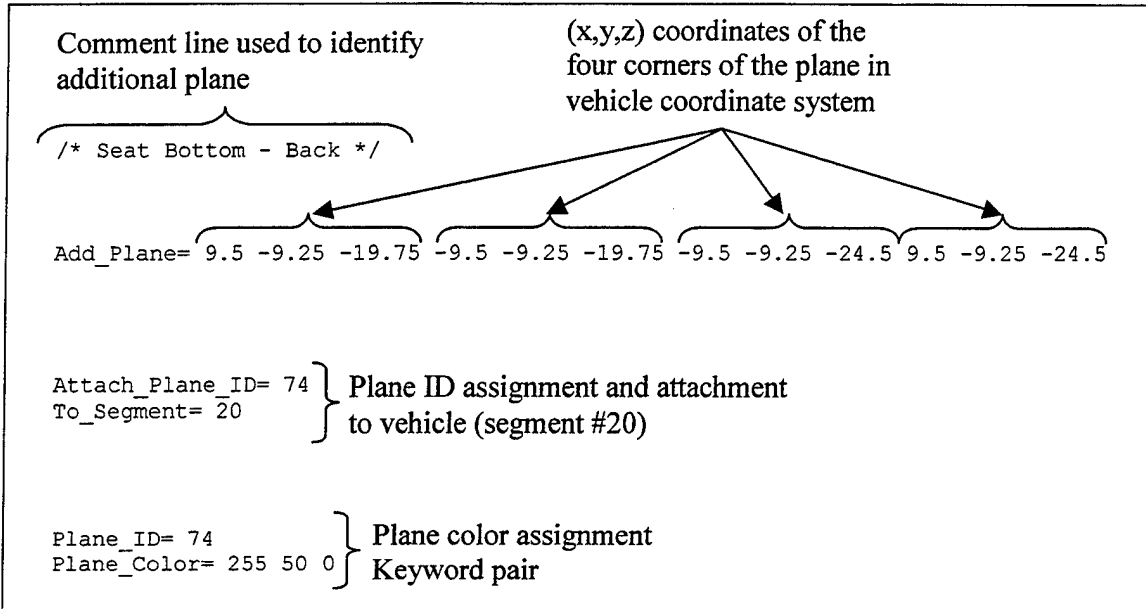
Figure 93. Additional Plane Data Formatting.

(x,y,z) coordinates of the focal point in the vehicle coordinate system

```
Camera_Position= -91.0 4.0 -46.0
```

(x,y,z) coordinates of the camera in the vehicle coordinate system

```
Looking_At_Position= -6.0 0.0 -2.0

Camera_Segment= 20      Attaching the camera
                        to the vehicle
Initial_Scale= .720
```

Initial scaling factor
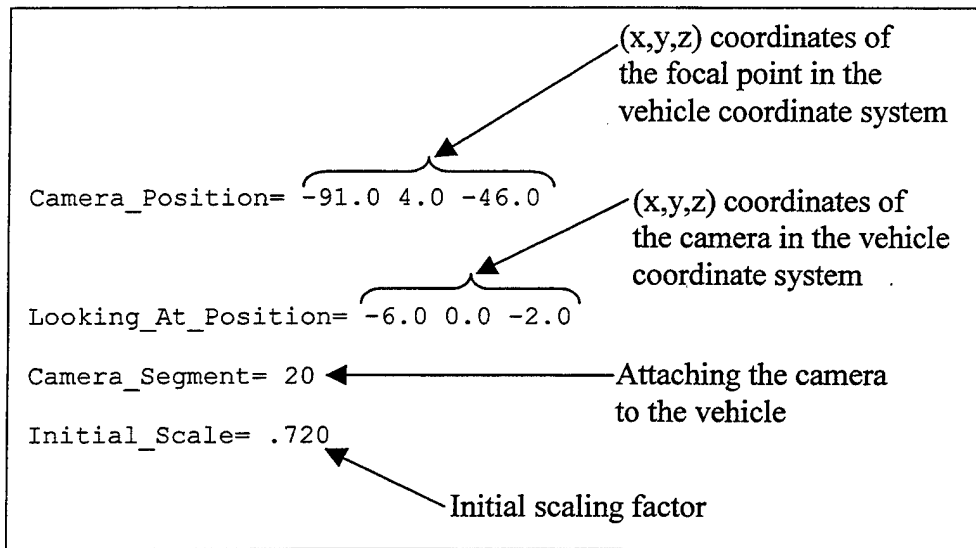
Figure 94. Viewpoint Data Formatting for IMAGE.

3. Interactive Functions

The IMAGE program provides a simple, easy to use, interactive interface. When the program is executed, the IMAGE window appears as shown in Figure 95. In the right upper corner are several buttons that control the play of the simulation. Below these

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buttons is a region containing information regarding the simulation. By pressing any of
the control buttons (left-click with the mouse), the simulation may be easily controlled.
During play of the simulation, the perspective can be changed by using the mouse
positioned anywhere in the viewing window. Holding down the left button and moving
the mouse results in zooming (increasing or decreasing the scale factor of) the image.
Holding down the middle button and moving the mouse results in rotation of the image.
Finally, holding down the right button and moving the mouse results in translation of the
image. Since the values for the camera position, looking at position, scale factor, yaw
and roll angles are all displayed along the right side of the window, the mouse may be
used to position the image in a desired perspective, then the appropriate values recorded.
These values can then be used in the *.setup file to reproduce the same perspective upon
initial execution of the IMAGE program.
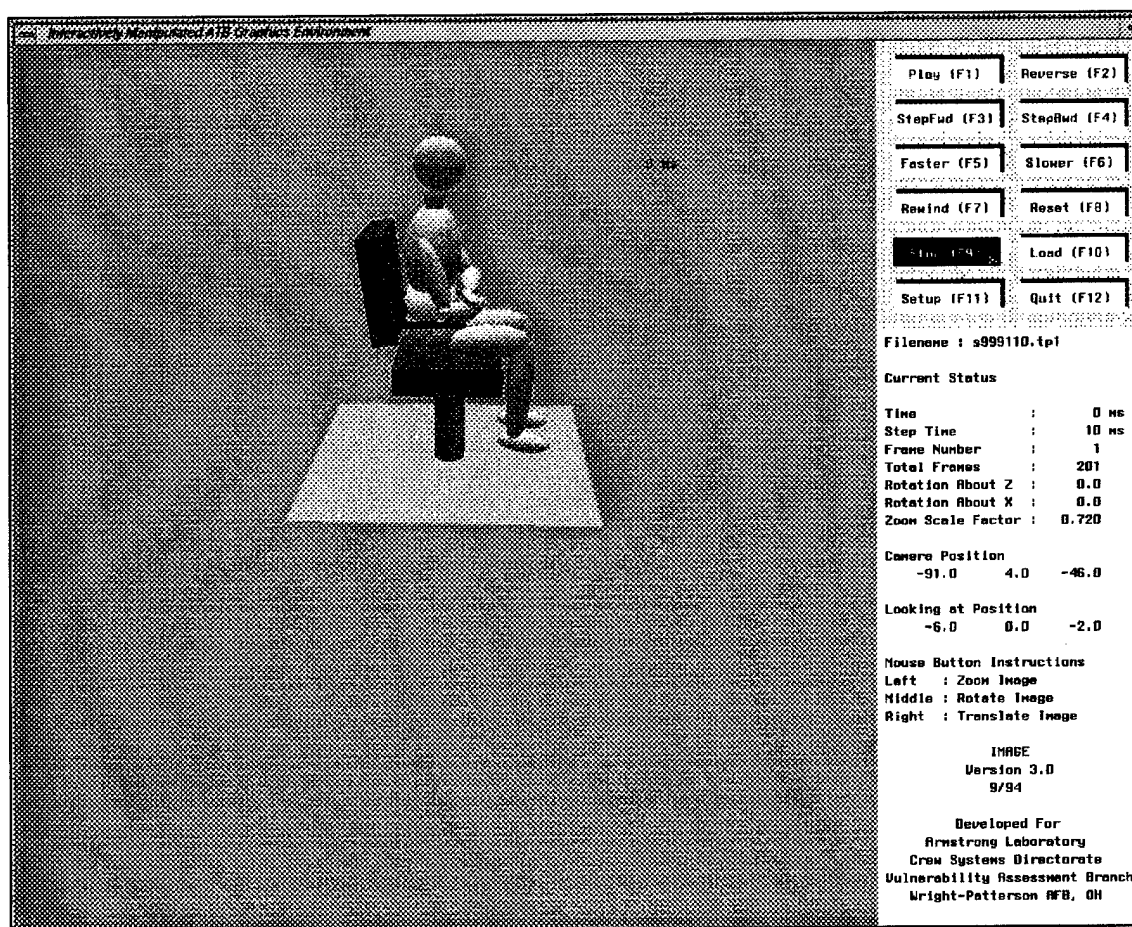
Figure 95. IMAGE Interactive Window.

4. Video and Still Images

The three-dimensional renderings produced by the IMAGE program are ideally
suited for producing still frame or video images. The manner in which these images may
be recorded is dependent upon the specific hardware and software installation being used,
but one method will be discussed here. The Media Recorder program can be used either

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to capture still frame images or to create a movie file. If still frame images are created, they may later be combined to produce a movie file. These images or movie files can then be compared against videotape of an original test for the purpose of validation, or can be used for easy visualization of gross bodily motion.

VI. SUMMARY

The ATB program, and the associated GEBOD, VIEW, and IMAGE programs, provide a powerful simulation and modeling group capable of examining the biodynamic response of humans or anthropomorphic test devices subjected to vehicle excitations caused by underwater explosions. Models can be validated against measured quantities, such as accelerometer data and videotape from actual test events. These validated models can then be extended in order to develop estimated injury potentials or to visualize gross body motion. Graphical representation of the body motion as predicted by the ATB program can be accomplished using either the VIEW program, for two-dimensional line drawings, or the IMAGE program, for three-dimensional shaded renderings. These graphical representations can then be displayed on a screen, printed to paper, or recorded to image or movie files for later use. For further details concerning the use of these programs, consult References [1], [2], [3], and APPENDIX A.

APPENDIX A. IMAGE VERSION 3.0 USERS MANUAL

IMAGE v. 3.0

□

USERS MANUAL

□

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□

□

□
COMMAND LINE:
□

To start the program just type:

image [Data File Root Name [Resolution]]
where brackets indicate options. Resolution is in degrees.

If the program is started without a data file name, the
user is prompted for a data file name. Whether the name is typed
on the command line or at the prompt, the file must be an ATB
'.tpl' file. Enter only the root name; the extension '.tpl' is
added by the program.

The program will also look for a setup file with the same root
name and the extension '.setup'. If the program is unable to
open that file, it will try to open a setup file named
"default.setup". If the program is unable to open either of
these files, then the current values or internal default
values will be used. For a list of setup values that can
be set, see the section on the SETUP FILE. If suitable data and
setup files are provided, then the program will display the first
frame of that file in the modeling screen.

RESOLUTION:

If a resolution is provided as an integer on the command line,
then that value will be used to specify the polygon size in the
ellipsoid generation. Smaller resolutions give better looking
images, but cause the program to run slower. Unpredictable
results will occur if the resolution provided does not divide
evenly into 180 degrees. It is also recommended that the
resolution not be greater than 60 degrees. Default resolution is
30 degrees; 15 degrees produces nicely smoothed ellipsoids suitable
for permanent recording.

Note that the resolution can only be set in the command line,
after the file root name. It cannot be entered when the filename
is entered after prompting, or when the interactive "Load" button
is used.

SETUP FILE:

The program allows the user to have some control over the graphical
environment by accessing a setup file. The program determines the
parameters to be set by the use of keywords. The keywords can be
in mixed case, but each must be spelled exactly as given,
including underscores (_) and equal sign. Be sure to leave a space
after the equal sign; the keyword and equal sign are read
by the program as a data constant. Note also that the setup file
follows 'c' language conventions so that comments may be added if
preceded by '/*' and closed by '*/' (must be on a single line).

The list of currently supported keywords and their meanings follow.
Note for RGB colors, to see what color the RGB triplet corresponds to,
use the GL library command 'cedit'.

Background_Color= 0 125 255
     Sets the background color for the modeling screen. The
     color is specified as an integer red, green, and blue
     triplet, where the values range from 0 to 255. The default
     color is black (0 0 0).

Time_Color= 0 0 0
     Sets the color for the time stamp text. The color is
     specified as a red, green, and blue color triplet, values 0
     to 255. Default is yellow (255 255 0).

Ellipsoid_Color= 25 200 100
     Will set the color of the ellipsoid specified by
     Ellipsoid_ID to the red, green, blue color triplet
     specified, where the values range from 0 to 255. May be set
     before or after setting the Ellipsoid_ID, providing you are
     consistent. The Ellipsoid_ID and its color are taken as
     pairs in the order they are read in. The color applies only
     to the matching Ellipsoid_ID read in. After a pair is read
     in, the color is set and internal flags are reset. The
     default is blue (150 150 255).

Ellipsoid_ID= 3
     Identifies the ellipsoid to be colored with Ellipsoid_Color.
     May be set before or after setting the Ellipsoid_Color,
     providing you are consistent. The Ellipsoid_ID and its
     color are taken as pairs in the order they are read in. The
     Ellipsoid_ID applies only to the matching Ellipsoid_Color
     read in. After a pair is read in, the color is set and
     internal flags are reset.

Plane_Color= 200 200 200
     Will set the color of the ellipsoid specified by Plane_ID to
     the red, green, blue color triplet specified, where the
     values range from 0 to 255. May be set before or after
     setting the Plane_ID, providing you are consistent. The
     Plane_ID and its color are taken as pairs in the order they
     are read in. The color applies only to the matching
     Plane_ID read in. After a pair is read in, the color is set

and internal flags are reset. The default is light grey
(200 200 200).

Plane_ID= 3
       Identifies the plane to be colored with Plane_Color.
       May be set before or after setting the Plane_Color,
       providing you are consistent. The Plane_ID and its color
       are taken as pairs in the order they are read in. The
       Plane_ID applies only to the matching Plane_Color read in.
       After a pair is read in, the color is set and internal flags
       are reset.

Remove_Ellipsoid_ID= 10
       Removes the specified ellipsoid from the modeling object list.

☐
Remove_Plane_ID= 10
☐
       Removes the specified plane from the modeling object list.

☐

☐
Add_Plane= 0.0 0.0 0.0 10.0 0.0 0.0 8.0 9.0 0.0 1.0 7.0 0.0
       Adds a plane with the vertices specified. Each group of
       three values is assumed to be the x,y, and z coordinates
       of a vertex. The points are read in and used in the order
       specified. The points are assumed to be planar, this means
       the points are not tested to determine if they are planar.
       The normal to the plane is calculated using the cross product
       of the two vectors Point 2 - Point 1 and Point 3 - Point 1. The
       plane identification number starts with 71.

Attach_Plane_ID= 71
       Identifies the plane to be attached to segment To_Segment.
       May be set before or after setting the To_Segment, providing
       you are consistent. The Attach_Plane_ID and its To_Segment
       are taken as pairs in the order they are read in. The
       Attach_Plane_ID applies only to the matching To_Segment read in.
       After a pair is read in, the attachment is made and internal flags
       are reset.

To_Segment= 1
       Identifies the segment to attach Attach_Plane_ID to.
       May be set before or after setting the Attach_Plane_ID, providing
       you are consistent. The Attach_Plane_ID and its To_Segment
       are taken as pairs in the order they are read in. The
       Attach_Plane_ID applies only to the matching To_Segment read in.
       After a pair is read in, the attachment is made and internal flags
       are reset.

Camera_Position= 25.0 85.0 -20.0
       The position, in ATB data file units, of the camera. The
       default is (25.0, 85.0, -25.0). Use 'Initial_Scale'
       to change size.

Looking_At_Position= 25.0 0.0 -20.0
    The position, in ATB data file units, for the camera to look at.
    The default is (25.0, 0.0, -25.0). Use 'Initial_Scale' to
    change size.

Initial_Yaw= 600
    Sets the initial yaw about the -z axis. Units in tenths of
    degrees. The default is zero (0). Positive angle gives CCW
    rotation.

Initial_Roll= 100
    Sets the initial roll about the x axis. Units in tenths of
    degrees. The default is zero (0). Positive angle gives CCW
    rotation.

Initial_Scale= 0.75
    Sets the initial scaling factor of the image. The default
    is one (1).

Camera_Segment= 16
    Sets the segment to which the camera is attached. The
    camera then moves with that segment. The default is zero
    (0).

Default_Segment= 16
    Sets the default segment to which any unattached planes are
    attached. The default is zero (0).

Light_Direction= 0.0 1.0 -1.0
    Sets the direction to the light. Assumed to be at infinity.
    The default is out the -z axis (0.0 0.0 -1.0).

Sensitivity= 3.0
    Sets the sensitivity of the mouse movement. The default is
    two (2.0). The higher the number, the less mouse movement
    required.

INTERACTIVE COMMANDS:

    The VCR-like commands may be chosen either by using
the keyboard or the VCR front panel with the LEFT mouse button.
The following is a list of the available functions, with the
associated key shown in parentheses. Except for play, reverse,
and quit, the program will reset to stop mode.

Play (F1)
    Displays every frame in the data file in sequence, looping
    back to the beginning after the last frame. The speed of
    frame update is dependent on the speed of the machine and by
    the delay factor set with slower/faster buttons.

Reverse (F2)
    Displays every frame in the data file in reverse sequence,

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looping back to the end after the first frame. The speed of
frame update is dependent on the speed of the machine and by
the delay factor set with the slower/faster buttons.

StepFwd (F3)
    Displays the next frame in the sequence. Loops back to the
    beginning after the last frame.

StepBwd (F4)
    Displays the last frame in the sequence. Loops back to the
    end after the first frame.

Faster (F5)
    Decrements the delay factor one step toward zero. Will
    never decrease past zero. Note that when the program is
    initialized the delay factor is set to zero, so it initially
    runs in its fastest mode.

Slower (F6)
    Increments the delay factor by one step. Each increment
    slows down the frame rate by about 1/3 second, up to five
    increments.

Rewind (F7)
    Sets the frame sequence back to the beginning. Also sets
    the delay factor back to zero.

Reset (F8)
    Resets the rotations, translations, scaling factor, and the
    delay factor back to their initial values.

Stop (F9)
    Stops the frame sequencing for both play and reverse.

Load (F10)
    Asks for and loads a new data file and setup file.

Setup (F11)
    Loads an easy-to-use file editor to modify the setup file
    without leaving the program. After quitting, the current
    setup file is read and the time is set to zero.

Quit (F12)
    Quits the program, asks if OK.

MOUSE FUNCTIONALITY:

    The mouse buttons have the following definitions:

LEFT
    If the cursor is in the modeling screen , pressing and holding the
    left mouse button and moving the mouse toward the screen will
    zoom the image, while moving the mouse away from the screen

will shrink the image.

If the cursor is in a button on the VCR front panel, then
that option will be chosen.

MIDDLE
Pressing and holding the middle mouse button will rotate the
image about its local -Z axis if the mouse is moved to the
left or right. It will rotate the image about its local X
axis if the mouse is moved up or down.

RIGHT
Pressing and holding the right mouse button and moving the mouse
up will move the image along the Z axis in the negative direction,
while moving the mouse down will move the image along the Z axis
in
the positive direction. Moving the mouse to the right will move
the image image along the X axis in the positive direction, while
moving the mouse left will move the image along the X axis in
the negative direction.

APPENDIX B. EXAMPLE INPUT DECK (S9991.AIN)

```
18 July 1997   0   0                                        CARD A.1.a
Seated 50% male Hybrid III.  Shot 9991.  Test B.            CARD A.1.b
                                                            CARD A.1.c
 IN. LB.SEC.   .00000000   .00000000 386.088000   .00000000 CARD A.3
   420000.001   0.00002 0.00002 0.000005                    CARD A.4
33 110 0 0 0 0 0 0 0 0 0 0 0 0 0 0 5 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1CARD A.5
     19    18         SITTING HYBRID III                    CARD B.1
LT  521.912 .8019 .6182 .4678 4.725 7.185 4.800  .000  .000  .000  1  CARD B.2
              .00-43.00 180.0
MT   4 2.661 .0196 .0196 .0083 4.775 6.500 4.000 1.000  .000-1.000  1  CARD B.2
              .00   .00 180.0
UT  339.2162.62032.05171.7336 4.825 6.500 7.785  .000  .000  .000  1  CARD B.2
              .00  4.99 180.0
N    2 2.668 .0254 .0257 .0084 1.675 1.675 3.000  .000  .000  .000  1  CARD B.2
              .00   .00 180.0
H    1 9.921 .1408 .2128 .1956 4.250 2.875 4.000  .000  .000  .000  1  CARD B.2
              .00-26.58 180.0
RUL 619.9841.44941.4968 .1989 2.950 3.050 7.285  .000  .000 2.300  1  CARD B.2
            11.82  5.69-172.7
RLL 7 7.237 .6708 .6745 .0397 2.165 2.050 9.750  .000  .000 2.000  1  CARD B.2
              .00 -1.90 180.0
RF   8 2.756 .0067 .0524 .0491 4.900 1.675 1.675  .000  .000  .000  1  CARD B.2
              .96 -9.57 158.2
LUL 919.9841.44941.4968 .1989 2.950 3.050 7.285  .000  .000 2.300  1  CARD B.2
           -11.82  5.69 172.7
LLL 0 7.237 .6708 .6745 .0397 2.165 2.050 9.750  .000  .000 2.000  1  CARD B.2
              .00 -1.90 180.0
LF   1 2.756 .0067 .0524 .0491 4.900 1.675 1.675  .000  .000  .000  1  CARD B.2
             -.96 -9.57-158.2
RUA 2 4.597 .1024 .0997 .0109 1.900 1.800 6.000  .000  .000-1.000  1  CARD B.2
              .00 -1.31 180.0
RLA 3 3.800 .1191 .1128 .0069 1.775 1.775 5.800  .000  .000  .000  1  CARD B.2
              .00 -1.31 180.0
LUA 4 4.597 .1024 .0997 .0109 1.900 1.800 6.000  .000  .000-1.000  1  CARD B.2
              .00 -1.31 180.0
LLA 5 3.800 .1191 .1128 .0069 1.775 1.775 5.800  .000  .000  .000  1  CARD B.2
              .00 -1.31 180.0
RHD 6 1.290 .0114 .0093 .0036 1.000 1.870 3.650  .000  .000  .000  1  CARD B.2
            -5.35 30.75 173.5
LHD 7 1.290 .0114 .0093 .0036 1.000 1.870 3.650  .000  .000  .000  1  CARD B.2
             5.35 30.75-173.5
LAR 8 2.000 .0850 .0022 .0863 1.000 7.000 .5000  .000  .000  .000  0  CARD B.2
RAR 9 2.000 .0850 .0022 .0863 1.000 7.000 .5000  .000  .000  .000  0  CARD B.2
 P  M   1  0 -2.50   .00 -1.08  -.89   .00  2.56  0   .00   .00        CARD B.3
              .00   .00   .00   .00   .00   .00   .00   .00   .00 0 0 0 0 0 0
 W  N   2  0   .00   .00 -2.56  -.89   .00  5.85  0   .00   .00        CARD B.3
              .00   .00   .00   .00   .00   .00   .00   .00   .00 0 0 0 0 0 0
 NP O   3  0   .00   .00 -5.96   .00   .00  2.76  0   .00   .00        CARD B.3
              .00   .00   .00   .00   .00   .00   .00   .00   .00 0 0 0 0 0 0
 HP P   4  0   .00   .00 -2.84  -.55   .00  2.00  0   .00   .00        CARD B.3
              .00   .00   .00   .00   .00   .00   .00   .00   .00 0 0 0 0 0 0
 RH Q   1  0   .00  3.28  2.04  -.24   .00 -7.23  0   .00   .00        CARD B.3
              .00   .00   .00   .00   .00   .00   .00   .00   .00 0 0 0 0 0 0
 RK R   6  1  -.24   .00  8.90  -.20   .00 -6.74  0   .00   .00        CARD B.3
              .00   .00   .00   .00 55.00   .00   .00   .00   .00 0 0 0 0 0 0
 RA S   7 -8  -.20   .00  9.65 -2.12   .00 -1.54  0   .00   .00        CARD B.3
            90.00   .00   .00 90.00   .00   .00   .00-10.00   .00 0 0 0 0 0 0
 LH T   1  0   .00 -3.28  2.04  -.24   .00 -7.23  0   .00   .00        CARD B.3
              .00   .00   .00   .00   .00   .00   .00   .00   .00 0 0 0 0 0 0
 LK U   9  1  -.24   .00  8.90  -.20   .00 -6.74  0   .00   .00        CARD B.3
              .00   .00   .00   .00 55.00   .00   .00   .00   .00 0 0 0 0 0 0
 LA V  10 -8  -.20   .00  9.65 -2.12   .00 -1.54  0   .00   .00        CARD B.3
            90.00   .00   .00 90.00   .00   .00   .00-10.00   .00 0 0 0 0 0 0
 RS W   3  0  -.88  7.38 -2.66   .00   .00 -5.43  0   .00   .00        CARD B.3
              .00 90.00   .00   .00   .00   .00   .00   .00   .00 0 0 0 0 0 0
 RE X  12 -4   .00   .00  4.94   .00   .00 -3.67  0   .00   .00        CARD B.3
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115

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          90.00    .00    .00 90.00    .00    .00    .00 62.50    .00 0 0 0 0 0 0
LS Y  3   0 -.88 -7.38 -2.66    .00    .00 -5.43 0    .00    .00      CARD B.3
          .00 90.00    .00    .00    .00    .00    .00    .00    .00 0 0 0 0 0 0
LE Z 14  -4  .00    .00  4.94    .00    .00 -3.67 0    .00    .00      CARD B.3
          90.00    .00    .00 90.00    .00    .00    .00 62.50    .00 0 0 0 0 0 0
RW   13  -8  .00    .00  6.07  -.30    .00 -2.13 0    .00    .00      CARD B.3
          90.00    .00    .00 90.00    .00    .00    .00 15.00    .00 0 0 0 0 0 0
LW   15  -8  .00    .00  6.07  -.30    .00 -2.13 0    .00    .00      CARD B.3
          90.00    .00    .00 90.00    .00    .00    .00 15.00    .00 0 0 0 0 0 0
LR   20   1 10.50-10.00-31.75    .00 -6.50    .00 0    .00    .00      CARD B.3
          90.00    .00    .00 90.00-48.50    .00    .00    .00    .00 0 0 0 0 0 0
RR   20   1-10.50-10.00-31.75    .00 -6.50    .00 0    .00    .00      CARD B.3
          90.00    .00    .00 90.00-48.50    .00    .00    .00    .00 0 0 0 0 0 0
  .00    .00    .00 1.00          .00 34.38    .00    .00 1.00         .00CARD B.4
  .00    .00    .00 1.00          .00 34.38    .00    .00 1.00         .00CARD B.4
  .00    .00    .00 1.00          .00 15.00    .00    .00 1.00         .00CARD B.4
  .00    .00    .00 1.00          .00 15.00    .00    .00 1.00         .00CARD B.4
  .00    .00    .00 1.00          .00  7.50 75.00 75.00 1.00       55.00CARD B.4
  .00   2.32    .00 1.00        48.90    .00    .00    .00  1.00        .00CARD B.4
 1.00 10.00 10.00 1.00        27.00    .00  6.69    .00 1.00       30.00CARD B.4
  .00    .00    .00 1.00          .00    .00    .00    .00
  .00    .00    .00 1.00          .00  7.50 75.00 75.00 1.00       55.00CARD B.4
  .00   2.32    .00 1.00        48.90    .00    .00    .00 1.00        .00CARD B.4
 1.00 10.00 10.00 1.00        27.00    .00  6.69    .00 1.00       30.00CARD B.4
  .00    .00    .00 1.00          .00    .00    .00    .00
  .00    .00    .00 1.00          .00    .00100.00100.00 1.00      125.00CARD B.4
  .00 20.00 20.00 1.00        52.00    .00  4.65    .00 1.00       65.30CARD B.4
  .00    .00    .00 1.00          .00    .00 90.00    .00
  .00    .00    .00 1.00          .00    .00100.00100.00 1.00      125.00CARD B.4
  .00 20.00 20.00 1.00        52.00    .00  4.65    .00 1.00       65.30CARD B.4
  .00    .00    .00 1.00          .00    .00 90.00    .00
  .00    .00    .00 1.00          .00    .00  4.32  .14 1.00       55.50CARD B.4
  .00    .00    .00 1.00          .00    .00    .00    .00
  .00    .00    .00 1.00          .00    .00  4.32  .14 1.00       55.50CARD B.4
  .00    .00    .00 1.00          .00    .00    .00    .00
  .00150.00    .00 1.00        48.50    .00    .00    .00 1.00        .00CARD B.4
  .00150.00    .00 1.00        48.50    .00    .00    .00 1.00        .00CARD B.4
1.200  0.  30.   0.   0.                         0.   0.      CARD B.5
1.200  0.  30.   0.   0.                         0.   0.      CARD B.5
 .350  0.  30.   0.   0.                         0.   0.      CARD B.5
 .192  0.  30.   0.   0.                         0.   0.      CARD B.5
1.000  0.  30.   0.   0.                         0.   0.      CARD B.5
1.000  0.  30.   0.   0.                         0.   0.      CARD B.5
 .500  0.  30.   0.   0.                         0.   0.      CARD B.5
 .500  0.  30.   0.   0.                         0.   0.      CARD B.5
 .000  0.  30.   0.   0.                         0.   0.      CARD B.5
1.000  0.  30.   0.   0.                         0.   0.      CARD B.5
1.000  0.  30.   0.   0.                         0.   0.      CARD B.5
 .500  0.  30.   0.   0.                         0.   0.      CARD B.5
 .500  0.  30.   0.   0.                         0.   0.      CARD B.5
 .000  0.  30.   0.   0.                         0.   0.      CARD B.5
 .100  0.  30.   0.   0.                         0.   0.      CARD B.5
 .100  0.  30.   0.1  0.                         0.   0.      CARD B.5
 .100  0.  30.  38.0  0.                         0.   0.      CARD B.5
 .000  0.  30.   0.   0.                         0.   0.      CARD B.5
 .100  0.  30.   0.   0.                         0.   0.      CARD B.5
 .100  0.  30.   0.1  0.                         0.   0.      CARD B.5
 .100  0.  30.  58.0  0.                         0.   0.      CARD B.5
 .000  0.  30.   0.   0.                         0.   0.      CARD B.5
 .500  0.  30.   0.   0.                         0.   0.      CARD B.5
 .500  0.  30.   0.   0.                         0.   0.      CARD B.5
 .000  0.  30.   0.   0.                         0.   0.      CARD B.5
 .500  0.  30.   0.   0.                         0.   0.      CARD B.5
 .500  0.  30.   0.   0.                         0.   0.      CARD B.5
 .000  0.  30.   0.   0.                         0.   0.      CARD B.5
.0001  0.  30.   0.   0.                         0.   0.      CARD B.5
.0001  0.  30.   0.   0.                         0.   0.      CARD B.5
 .01  .01  .01  .01  .01  .01  .10  .10  .10  .10  .10 .01CARD B.6
 .01  .01  .01  .00  .00  .00  .10  .10  .10  .00  .00 .00CARD B.6
 .01  .01  .01  .00  .00  .00  .10  .10  .10  .00  .00 .00CARD B.6
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 .01   .01   .01   .00   .00   .00   .10   .10   .10   .00   .00   .00CARD B.6
 .01   .01   .01   .00   .00   .00   .10   .10   .10   .00   .00   .00CARD B.6
 .01   .01   .01   .00   .00   .00   .10   .10   .10   .00   .00   .00CARD B.6
 .01   .01   .01   .00   .00   .00   .10   .10   .10   .00   .00   .00CARD B.6
 .01   .01   .01   .00   .00   .00   .10   .10   .10   .00   .00   .00CARD B.6
 .01   .01   .01   .00   .00   .00   .10   .10   .10   .00   .00   .00CARD B.6
 .01   .01   .01   .00   .00   .00   .10   .10   .10   .00   .00   .00CARD B.6
 .01   .01   .01   .00   .00   .00   .10   .10   .10   .00   .00   .00CARD B.6
 .01   .01   .01   .00   .00   .00   .10   .10   .10   .00   .00   .00CARD B.6
 .01   .01   .01   .00   .00   .00   .10   .10   .10   .00   .00   .00CARD B.6
 .01   .01   .01   .00   .00   .00   .10   .10   .10   .00   .00   .00CARD B.6
 .01   .01   .01   .00   .00   .00   .10   .10   .10   .00   .00   .00CARD B.6
 .01   .01   .01   .00   .00   .00   .10   .10   .10   .00   .00   .00CARD B.6
 .01   .01   .01   .00   .00   .00   .10   .10   .10   .00   .00   .00CARD B.6
Shot 9991 - Sitting 50% Male Hybrid III - SSTV
0.00000.00000.00000.00000.00000.00000.00000.0000 -99990.0000.00020      0C.2a

       0.00000000.003386281-.00114622.571140000-.295554000.00000000  C.4.2
       0.00000000.008299486-.00464961.380360000.6253440000.00000000  C.4.3
       0.00000000.013932270.008222825-1.77593303.211796000.00000000  C.4.4
```

Majority of C Cards omitted for brevity.

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       0.00000000.431750000.015949778-60.558468-60.7502440.00000000  C.4.9998
       0.00000000.522669850.034962922-61.659485-61.3530650.00000000  C.4.9999
       0.00000000.567563530.043777686-62.550011-68.1936340.00000000  C.4.10000
     9     1     0     0     0     0     0     0     7     0       CARD D.1
  1    Seat Cushion.  Bottom.
       -9.5        -9.25        -24.5
       -9.5         9.25        -24.5
        9.5        -9.25        -24.5
  2    Seat Cushion.  Front.
        9.5         9.25        -19.75
        9.5         9.25        -24.5
       -9.5         9.25        -19.75
  3    Seat Cushion.  Right Side.
       -9.5         9.25        -19.75
       -9.5         9.25        -24.5
       -9.5        -9.25        -19.75
  4    Seat Cushion.  Left Side.
        9.5        -9.25        -19.75
        9.5        -9.25        -24.5
        9.5         9.25        -19.75
  5    Seat Back.
       -9.5        -8.3         -28.25
        9.5        -8.3         -28.25
       -9.5       -10.25        -44.55
  6    Seat Back.  Top.
       -9.5       -10.25        -44.55
        9.5       -10.25        -44.55
       -9.5       -14.22        -44.07
  7    Seat Back.  Right Side.
       -9.5       -12.27        -27.77
       -9.5        -8.3         -28.25
       -9.5       -14.22        -44.07
  8    Seat Back.  Left Side.
        9.5       -12.27        -27.77
        9.5       -14.22        -44.07
        9.5        -8.3         -28.25
  9    Deck.
      -25.0       -25.0          0.00
      -25.0        25.0          0.00
       25.0       -25.0          0.00
LAP BELT                                                    CARD D.3.a
-9.500000000-9.500000000-24.50000000 9.500000000-9.500000000-24.50000000CARD D.3.b
 2.720000000  .000000000  -4.0300000              -.100000000       CARD D.3.c
    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0  0CARD D.7
    0    0                                                   CARD D.7
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 1    HEAD  SURFACE                                                        CARD E.1
          .00           .71          -.80            .00            .00    CARD E.2
         2.57       -175.98       4495.67        -8953.11        6029.59   .00CARD E.3
    3                                                                      CARD E.4
          .71        358.00          .75         3580.00            .80  35800.00CARD E.4
 2    BACK OF SHOULDER                                                     CARD E.1
          .00          1.62         -1.70            .00            .00    CARD E.2
          .01        -26.59        380.91         -678.22         456.53   .00CARD E.3
    3                                                                      CARD E.4
         1.62         48.30         1.65          483.00           1.70   4830.00CARD E.4
 3    CHEST                                                                CARD E.1
          .00          1.31         -1.40            .00            .00    CARD E.2
          .55          5.46         73.49          -15.01            .00   .00CARD E.3
    3                                                                      CARD E.4
         1.31        158.60         1.35         1586.00           1.40  15860.00CARD E.4
 4    ANTERIOR PELVIS                                                      CARD E.1
          .00          2.02         -2.10            .00            .00    CARD E.2
         -.14          1.58         24.39          -29.33          13.76   .00CARD E.3
    3                                                                      CARD E.4
         2.02         89.70         2.05          897.00           2.10   8970.00CARD E.4
 5    POSTERIOR PELVIS                                                     CARD E.1
          .00          1.96         -2.10            .00            .00    CARD E.2
         -.76         35.10         40.04          -12.49            .00   .00CARD E.3
    3                                                                      CARD E.4
         1.96        127.80         2.03         1278.00           2.10  12780.00CARD E.4
 6    UPPER ARM                                                            CARD E.1
          .00           .89         -1.00            .00            .00    CARD E.2
         1.54        -30.63        627.09        -1197.70         917.23   .00CARD E.3
    3                                                                      CARD E.4
          .89        203.10          .95         2031.00           1.00  20310.00CARD E.4
 7    FOREARM                                                              CARD E.1
          .00          1.31         -1.40            .00            .00    CARD E.2
        -2.40        107.37       -313.36          504.61        -196.37   .00CARD E.3
    3                                                                      CARD E.4
         1.31        156.20         1.35         1562.00           1.40  15620.00CARD E.4
 8    HAND                                                                 CARD E.1
          .00           .38         -.45            .00            .00     CARD E.2
         -.04        -31.04       2384.47       -10193.90       19172.50   .00CARD E.3
    3                                                                      CARD E.4
          .38        139.40          .41         1394.00            .45  13940.00CARD E.4
 9    UPPER LEG                                                            CARD E.1
          .00          1.31         -1.40            .00            .00    CARD E.2
         -.28         14.19         81.94         -122.62          98.73  -29.09CARD E.3
    3                                                                      CARD E.4
         1.31         61.60         1.35          616.00           1.40   6160.00CARD E.4
10    KNEE                                                                 CARD E.1
          .00           .54         -.58            .00            .00     CARD E.2
         -.04          2.22        867.34         -401.61            .00   .00CARD E.3
    3                                                                      CARD E.4
          .54        187.80          .56         1878.00            .58  18780.00CARD E.4
11    FRONT OF LOWER LEG                                                   CARD E.1
          .00          1.78         -1.90            .00            .00    CARD E.2
         -.74         26.79         3.92           29.05            .00    .00CARD E.3
    3                                                                      CARD E.4
         1.78        223.60         1.84         2236.00           1.90  22360.00CARD E.4
12    BACK OF LOWER LEG                                                    CARD E.1
          .00          1.66         -1.75            .00            .00    CARD E.2
         -.08         29.42         -2.08            .00            .00    .00CARD E.3
    3                                                                      CARD E.4
         1.66         43.20         1.70          432.00           1.75   4320.00CARD E.4
13    FOOT                                                                 CARD E.1
          .00           .83         -.95            .00            .00     CARD E.2
         -.68         82.75       -704.17         3367.10       -5570.69  3188.30CARD E.3
    3                                                                      CARD E.4
          .83        121.20          .89         1212.00            .95  12120.00CARD E.4
14    SEAT CUSHION                       0    0                            CARD E.1
 0.0000000     -4.000000      .00000000      .00000000      1.00000000    CARD E.2
    5                                                                      CARD E.4.a
 0.0000000      0.000000     1.0000000       60.000000      2.00000000  200.000000CARD E.4.b
 3.0000000      800.0000     4.0000000     2000.0000                      CARD E.4.b
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16     CONSTANT = 0.0                                                      CARD E.1
  0.0000000    0.0000000   0.0000000    .00000000   0.00000000            CARD E.2
17     CONSTANT, F=0.9            0    0                                   CARD E.1
  0.0000000    0.0000000   0.9000000   0.0000000    0.00000000            CARD E.2
20     DAMPING COEFF. C=200     0    0                                    CARD E.1
  0.0000000    2.0000000   0.0000000    .00000000   1.00000000            CARD E.2
  0.0000000  200.00000     0.0000000   0.0000000    0.00000000  0.00000000CARD E.3
21     RATE OF DEFLEC. .         0    0                                   CARD E.1
-40.0000000 -150.000000    .00000000    .00000000   1.00000000            CARD E.2
    21                                                                     CARD E.4.a
-40.0000000    .00000000 -30.0000000    .00000000 -20.0000000    .00000000CARD E.4.b
-10.0000000    .00000000   .00000000    .00000000   5.00000000  1.00000000CARD E.4.b
 10.0000000   1.00000000  20.0000000    .989999900  30.0000000   .965000000CARD E.4.b
 40.0000000    .927999800 50.0000000    .860000100  60.0000000   .690000000CARD E.4.b
 70.0000000    .475000000 80.0000000    .340000000  90.0000000   .260000000CARD E.4.b
100.000000     .200000000 110.000000    .180000000 120.000000    .090000000CARD E.4.b
130.000000     .059999990 140.000000    .025000000 150.000000    .00000000CARD E.4.b
24     RESTRAINT BELT            0    0                                    CARD E.1
  0.0000000   -0.1000000   0.00000000   0.00000000  0.00000000            CARD E.2
    6                                                                      CARD E.4.a
  0.0000000    0.00000000  0.01000000 165.000000    0.02000000  330.000000CARD E.4.b
  0.0300000  495.000000    0.05000000 935.000000    0.10000000  3850.00000CARD E.4.b
25     DECK-FOOT.                0    0                                    CARD E.1
  0.0000000   -1.3540000   0.00000000   0.00000000  1.00000000            CARD E.2
    8                                                                      CARD E.4.a
  0.0000000    0.00000000  0.20000000   6.75000000  0.40100000  25.2900000CARD E.4.b
  0.6020000   48.7200000   0.80300000 101.790000    0.83400000 121.200000CARD E.4.b
  0.9300000 1212.00000     1.35400000 12120.0000                          CARD E.4.b
27     ARM RESTS.                0    0                                    CARD E.1
  0.0000000   -3.0000000   0.00000000   0.00000000  0.00000000            CARD E.2
    6                                                                      CARD E.4.a
  0.0000000    0.0000000   0.10000000 100.000000    0.20000000 1000.00000CARD E.4.b
  1.0000000 5000.0000      2.00000000 10000.0000    3.00000000 15000.0000CARD E.4.b
28     CUSHION (REV2)                                                      CARD E.1
  0.000000    -6.0000000   0.00000000   0.00000000  1.00000000            CARD E.2
    6                                                                      CARD E.4.a
  0.000000     0.0000000   1.00000000  60.0000000   2.00000000 150.000000CARD E.4.b
  3.000000   500.000000    4.00000000 2000.00000     6.00000000 10000.0000CARD E.4.b
29     CUSHION                   .                                         CARD E.1
  0.000000    -6.0000000   0.00000000   0.00000000  1.00000000            CARD E.2
    6                                                                      CARD E.4.a
  0.000000     0.00000000  1.00000000  50.0000000   2.00000000 125.000000CARD E.4.b
  3.000000   250.000000    4.00000000 500.000000     6.00000000 1000.00000CARD E.4.b
30     CUSHION ABSORPTION                                                  CARD E.1
-1000.00    -1000.00000    0.00000000   0.00000000  1.00000000            CARD E.2
    5                                                                      CARD E.4.a
-1000.00       0.500000000 -6.0000000   0.50000000 -5.0000000  1.00000000CARD E.4.b
  0.000000     1.000000000 1000.00000   1.00000000                        CARD E.4.b
31     CUSHION VISCOUS                                                     CARD E.1
-2000.00    -2000.00000    0.00000000   0.00000000  1.00000000            CARD E.2
    5                                                                      CARD E.4.a
-2000.00       0.000000000 -200.00000   0.00000000  0.00000000  0.00000000CARD E.4.b
200.0000      10.00000000  2000.00000 200.000000                          CARD E.4.b
33     CONSTANT = 0.0                                                      CARD E.1
  0.000000     0.000000000 0.00000000   0.00000000  0.00000000            CARD E.2
34     DUMMY STIFFNESS                                                     CARD E.1
  0.000000    -4.0000000   0.00000000   0.00000000  0.00000000            CARD E.2
    6                                                                      CARD E.4.a
  0.000000     0.00000000  0.50000000  30.0000000   1.00000000  60.0000000CARD E.4.b
  1.500000    90.0000000   1.80000000 900.000000    2.00000000 9000.00000CARD E.4.b
35     DUMMY ABSORPTION                                                    CARD E.1
-1000.00    -1000.0000     0.00000000   0.00000000  1.00000000            CARD E.2
    5                                                                      CARD E.4.a
-1000.00       0.46000000 -6.0000000   0.46000000 -5.0000000  1.00000000CARD E.4.b
  0.000000     1.00000000  1000.00000   1.00000000                        CARD E.4.b
36     ABDOMINAL VISCOUS                                                   CARD E.1
-2000.00    -2000.0000     0.00000000   0.00000000  1.00000000            CARD E.2
    5                                                                      CARD E.4.a
-2000.00       0.00000000 -200.00000   0.00000000  0.00000000  0.00000000CARD E.4.b
200.0000      50.0000000   2000.00000 1000.00000                          CARD E.4.b
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 37    CONSTANT F = 0.1                                              CARD E.1
  0.000000    0.00000000   0.10000000   0.00000000   0.00000000      CARD E.2
9999                                                                 CARD E.1
 41    RIGHT SHOULDER JOINT                                          CARD E.7

  -4    8                                                            CARD E.7
   151.000         .000    87900.000         .000
    75.000         .000    13700.000         .000
      .000         .000     -312.000    11800.000
    66.000         .000     7780.000  3010000.000
    68.000         .000    22200.000   376000.000
    89.000         .000    22000.000         .000
   111.000         .000     2470.000    17600.000
   153.000         .000    13000.000         .000
 42    LEFT SHOULDER JOINT                                           CARD E.7

  -4    8                                                            CARD E.7
   151.000         .000    87900.000         .000
   153.000         .000    13000.000         .000
   111.000         .000     2470.000    17600.000
    89.000         .000    22000.000         .000
    68.000         .000    22200.000   376000.000
    66.000         .000     7780.000  3010000.000
      .000         .000     -312.000    11800.000
    75.000         .000    13700.000         .000
 43    STANDING RIGHT HIP                                            CARD E.7

  19    4                                                            CARD E.7
      .000       2.000       7.000      21.000      49.000     105.000CARD E.7
   217.000     441.000     889.000    1790.000    3580.000    7160.000CARD E.7
 14300.000   28700.000   57300.000  115000.000  229000.000  459000.000CARD E.7
917000.000
      .000       5.000      11.000      22.000      39.000      73.000CARD E.7
   141.000     277.000     549.000    1090.000    2180.000    4360.000CARD E.7
  8710.000   17400.000   34800.000   69600.000  139000.000  279000.000CARD E.7
557000.000
      .000       1.000       2.000       3.000       5.000       7.000CARD E.7
    10.000      13.000      17.000      22.000      27.000      32.000CARD E.7
    38.000      46.000      62.000      94.000     158.000     286.000CARD E.7
   542.000
      .000       1.000       3.000       4.000       6.000       8.000CARD E.7
     9.000      10.000      18.000      34.000      66.000     130.000CARD E.7
   258.000     514.000    1030.000    2050.000    4100.000    8190.000CARD E.7
 16400.000
 44    STANDING LEFT HIP                                             CARD E.7

  19    4                                                            CARD E.7
      .000       2.000       7.000      21.000      49.000     105.000CARD E.7
   217.000     441.000     889.000    1790.000    3580.000    7160.000CARD E.7
 14300.000   28700.000   57300.000  115000.000  229000.000  459000.000CARD E.7
917000.000
      .000       1.000       3.000       4.000       6.000       8.000CARD E.7
     9.000      10.000      18.000      34.000      66.000     130.000CARD E.7
   258.000     514.000    1030.000    2050.000    4100.000    8190.000CARD E.7
 16400.000
      .000       1.000       2.000       3.000       5.000       7.000CARD E.7
    10.000      13.000      17.000      22.000      27.000      32.000CARD E.7
    38.000      46.000      62.000      94.000     158.000     286.000CARD E.7
   542.000
      .000       5.000      11.000      22.000      39.000      73.000CARD E.7
   141.000     277.000     549.000    1090.000    2180.000    4360.000CARD E.7
  8710.000   17400.000   34800.000   69600.000  139000.000  279000.000CARD E.7
557000.000
 45    STANDING LUMBAR SPIN                                          CARD E.7

  19    4                                                            CARD E.7
      .000    1200.000    2400.000    3600.000    4800.000    6000.000CARD E.7
  7200.000    8400.000    9600.000   10800.000   13200.000   18000.000CARD E.7
 27600.000   46800.000   85200.000  162000.000  314600.000  622800.000CARD E.7
1237200.000
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        .000     1200.000     2400.000     3600.000     4800.000     6000.000CARD E.7
    7200.000     8400.000     9600.000    10800.000    13200.000    18000.000CARD E.7
   27600.000    46800.000    85200.000   162000.000   314600.000   622800.000CARD E.7
 1237200.000
        .000      960.000     1920.000     2880.000     3840.000     4800.000CARD E.7
    5760.000     6720.000     7680.000     8640.000    10560.000    14400.000CARD E.7
   22080.000    37440.000    68160.000   129600.000   252480.000   498240.000CARD E.7
  989760.000
        .000     1200.000     2400.000     3600.000     4800.000     6000.000CARD E.7
    7200.000     8400.000     9600.000    10800.000    13200.000    18000.000CARD E.7
   27600.000    46800.000    85200.000   162000.000   314600.000   622800.000CARD E.7
 7010800.000
 46    NECK PIVOT                                                    CARD E.7

   19     4                                                          CARD E.7
        .000      700.000     1400.000     2100.000     2800.000     3500.000CARD E.7
    4200.000     4900.000     5600.000     6300.000     7000.000     7700.000CARD E.7
    8400.000     9800.000    12600.000    18200.000    29400.000    51800.000CARD E.7
   96600.000
        .000      600.000     1200.000     1800.000     2400.000     3000.000CARD E.7
    3600.000     4200.000     4800.000     5400.000     6000.000     6600.000CARD E.7
    7200.000     8400.000    10800.000    15600.000    25200.000    44400.000CARD E.7
   82800.000
        .000      300.000      600.000      900.000     1200.000     1500.000CARD E.7
    1800.000     2100.000     2400.000     2700.000     3000.000     3300.000CARD E.7
    3600.000     4200.000     5400.000     7800.000    12600.000    22200.000CARD E.7
   41400.000
        .000      600.000     1200.000     1800.000     2400.000     3000.000CARD E.7
    3600.000     4200.000     4800.000     5400.000     6000.000     6600.000CARD E.7
    7200.000     8400.000    10800.000    15600.000    25200.000    44400.000CARD E.7
   82800.000
 47    HEAD PIVOT                  .                                 CARD E.7

   19     4                                                          CARD E.7
        .000      490.000      980.000     1680.000     2380.000     3080.000CARD E.7
    3780.000     4480.000     5180.000     5880.000     6580.000     7280.000CARD E.7
    7980.000     9380.000    12180.000    17780.000    28980.000    51380.000CARD E.7
   96180.000
        .000      600.000     1200.000     1800.000     2400.000     3000.000CARD E.7
    3600.000     4200.000     4800.000     5400.000     6000.000     6600.000CARD E.7
    7200.000     8400.000    10800.000    15600.000    25200.000    44400.000CARD E.7
   82800.000
        .000      250.000      500.000      800.000     1100.000     1400.000CARD E.7
    1700.000     2000.000     2300.000     2600.000     2900.000     3200.000CARD E.7
    3500.000     4100.000     5300.000     7700.000    12500.000    22100.000CARD E.7
   41300.000
        .000      600.000     1200.000     1800.000     2400.000     3000.000CARD E.7
    3600.000     4200.000     4800.000     5400.000     6000.000     6600.000CARD E.7
    7200.000     8400.000    10800.000    15600.000    25200.000    44400.000CARD E.7
   82800.000
 3    2    0    0    5    2    2    2    2                CARD F.1.a
 1   20    1    1   14  -20  -21  -16   17    1
 1   20    6    6   14  -20  -21  -16   17    1
 1   20    9    9   14  -20  -21  -16   17    1
 2   20    7    7   14  -20  -21  -16   17    1
 2   20   10   10   14  -20  -21  -16   17    1
 5   20    1    1   28  -29  -30  -31   17    1
 5   20    2    2   28  -29  -30  -31   17    1
 5   20    3    3   28  -29  -30  -31   17    1
 5   20   12   12   28  -29  -30  -31   17    1
 5   20   14   14   28  -29  -30  -31   17    1
 6   20    4    4   14  -20  -21  -16   17    1
 6   20    5    5   14  -20  -21  -16   17    1
 7   20   12   12   14  -20  -21  -16   17    1
 7   20   13   13   14  -20  -21  -16   17    1
 8   20   15   15   14  -20  -21  -16   17    1
 8   20   14   14   14  -20  -21  -16   17    1
 9   20    8    8   25    0    0    0   17   -1
 9   20   11   11   25    0    0    0   17   -1
 1                                                       F.2.a
```

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    1   20    1    1   24    0    0    0    1                              F.2.b
    4    4    4    0    4    5    2    0    4    1    0    0    3    0    2    0    0   4F.3
    3                                                                      F.3
    1    1   13   13   33  -34  -35  -36   37
    1    1   15   15   33  -34  -35  -36   37
    1    1   16   16   33  -34  -35  -36   37
    1    1   17   17   33  -34  -35  -36   37
    2    2    6    6   33  -34 .-35  -36   37
    2    2    9    9   33  -34  -35  -36   37
    2    2   17   17   33  -34  -35  -36   37
    2    2   16   16   33  -34  -35  -36   37
    3    3   13   13   33  -34  -35  -36   37
    3    3   15   15   33  -34  -35  -36   37
    3    3    6    6   33  -34  -35  -36   37
    3    3    9    9   33  -34  -35  -36   37
    5    5   13   13   33  -34  -35  -36   37
    5    5   15   15   33  -34  -35  -36   37
    5    5   16   16   33  -34  -35  -36   37
    5    5   17   17   33  -34  -35  -36   37
    6    6   12   12   33  -34  -35  -36   37
    6    6   13   13   33  -34  -35  -36   37
    6    6   16   16   33  -34  -35  -36   37
    6    6    9    9   33  -34  -35  -36   37
    6    6   17   17   33  -34  -35  -36   37
    7    7   10   10   33  -34  -35  -36   37
    7    7   11   11   33  -34  -35  -36   37
    9    9   15   15   33  -34  -35  -36   37
    9    9   14   14   33  -34  -35  -36   37
    9    9   16   16   33  -34  -35  -36   37
    9    9   17   17   33  -34  -35  -36   37
   10   10    8    8   33  -34  -35  -36   37
   13   13   15   15   33  -34  -35  -36   37
   13   13   17   17   33  -34  -35  -36   37
   13   13    2    2   33  -34  -35  -36   37
   15   15   16   16   33  -34  -35  -36   37
   15   15    2    2   33  -34  -35  -36   37
   18   18    3    3   27  -20  -21  -16   17
   18   18   14   14   27  -20  -21  -16   17
   18   18   15   15   27  -20  -21  -16   17
   18   18   17   17   27  -20  -21  -16   17
   19   19    3    3   27  -20  -21  -16   17
   19   19   12   12   27  -20  -21  -16   17
   19   19   13   13   27  -20  -21  -16   17
    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0   OCARD F.4
   45   45   46   47   43    0    0   44    0    0   41    0   42    0    0    0    0   OCARD F.5
         0.0         0.0              0.0    0    0    0    0    0                    G.1
 1.5000000-2.8500000-28.060000  .00000000  .00000000  .00000000                     G.2.A
 90.000000 2.5000000 3.0000000  .00000000  .00000000  .00000000    1    2    3   0G.3.A
  .00000000  .00000000  .00000000  .00000000  .00000000  .00000000    3    2    1    1
  .00000000  .00000000  .00000000  .00000000  .00000000  .00000000    3    2    1    2
  .00000000  .00000000  .00000000  .00000000  .00000000  .00000000    3    2    1    3
  .00000000  .00000000  .00000000  .00000000  .00000000  .00000000    3    2    1    4
 5.0000000 97.800000 -3.000000  .00000000  .00000000  .00000000    3    2   -3    1
  .00000000-100.00000  .00000000  .00000000  .00000000  .00000000    3    2    1    6
  .00000000  .00000000  .00000000  .00000000  .00000000  .00000000    3    2    1    7
 -5.000000 97.800000 -3.000000  .00000000  .00000000  .00000000    3    2   -3    1
  .00000000-100.00000  .00000000  .00000000  .00000000  .00000000    3    2    1    9
  .00000000  .00000000  .00000000  .00000000  .00000000  .00000000    3    2    1   10
-67.000000 23.100000 -7.600000  .00000000  .00000000  .00000000    1    2    3    3
-30.000000 74.000000  .00000000  .00000000  .00000000  .00000000    1    2    3   12
101.000000 47.150000-10.000000  .00000000  .00000000  .00000000    1    2    3    3
 90.000000 80.000000  .00000000  .00000000  .00000000  .00000000    1    2    3   14
  .00000000 20.000000-2.7000000  .00000000  .00000000  .00000000    3    2    1   13
  .00000000 -12.00000  .00000000  .00000000  .00000000  .00000000    3    2    1   15
  .00000000  .00000000  .00000000  .00000000  .00000000  .00000000    3    2    1    0
  .00000000  .00000000  .00000000  .00000000  .00000000  .00000000    3    2    1    0
    3    0   -5  .00000000      .00000000      .00000000                  H.1
         0   -3  .00000000      .00000000      .00000000
         0   -1  .00000000      .00000000      .00000000
    3    0    5  .00000000      .00000000      .00000000                  H.2
```

```
        0  3    .00000000    .00000000    .00000000
        0  1    .00000000    .00000000    .00000000
  3     0  5    .00000000    .00000000    .00000000            H.3
        0  3    .00000000    .00000000    .00000000
        0  1    .00000000    .00000000    .00000000
  1     0  5                                                    H.4
  1     0  5                                                    H.5
  1     3  5                                                    H.6
  2       17     18                                             H.7
  0                                                             H.8
                                                               H.9
   0                                                           H.10
0     0                                                        H.11
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APPENDIX C. EXAMPLE OUTPUT FILE (S9991.AOU)

AAMRL ARTICULATED TOTAL BODY (ATB) MODEL

DEVELOPED BY CALSPAN CORP., P.O. BOX 400, BUFFALO NY 14225
AND BY J&J TECHNOLOGIES INC., ORCHARD PARK, NY 14127

FOR THE ARMSTRONG AEROSPACE MEDICAL RESEARCH LABORATORY
WRIGHT PATTERSON AIR FORCE BASE
UNDER CONTRACTS F33615-75C-5002,-78C-0516 AND -80C-05117

AND FOR THE NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION,
U.S. DEPARTMENT OF TRANSPORTATION, UNDER CONTRACTS
FH-11-7592, HS-053-2-485, HS-6-01300 AND HS-6-01410.

PROGRAM DOCUMENTATION: NHTSA REPORT NOS. DOT-HS-801-507
THROUGH 510 (FORMERLY CALSPAN REPORT NO. ZQ-5180-L-1),
AVAILABLE FROM NTIS (ACCESSION NOS. PB-241692,3,4 AND 5),
APPENDIXES A-J TO THE ABOVE (AVAILABLE FROM CALSPAN),
AND REPORT NOS. AMRL-TR-75-14 (NTIS NO. AD-A014 816),
AFAMRL-TR-80-14 (NTIS NO. AD-A088 029), AND
AFAMRL-TR-83-073 (NTIS NO. AD-B079 184).

THE MOST RECENT DOCUMENTATION IS IN REPORT NOS.
AAMRL-TR-88-007 (NTIS NO. AD-A197 940),
AAMRL-TR-88-009 (NTIS NO. AD-A198 726),
AAMRL-TR-88-043 (NTIS NO. AD-A203 566).

PROGRAM ATBIV.4, (LATEST REVISION 04/14/94),
EXECUTED ON A ABC COMPUTER
AT XYZ COMPANY, CITY, STATE.

18 July 1997 IRSIN= 0 IRSOUT= 0 RSTIME = .0000   CARDS A

Seated 50% male Hybrid III. Shot 9991. Test B.   CARD A.1

UNITL = IN.   UNITM = LB.   UNITT = SEC.   GRAVITY VECTOR = (.0000,   .0000, 386.0880)   G = 386.0880

NDINT = 4   NSTEPS = 10   DT = .001000   HO = .000020   HMAX = .000020   HMIN = .000005
0 NPRT ARRAY   CARD A.1.c

```
   1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36
  10  1 10  0  0  0  0  0  0  0  0  0  0  0  0  0  0  5  5  1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  1
1 CRASH VICTIM     SITTING HYBRID III      19 SEGMENTS      18 JOINTS                          CARD  B.1
2                                                                                              CARDS B.2
```

PAGE

SEGMENT I		SYM	PLOT	WEIGHT (LB.)	PRINCIPAL MOMENTS OF INERTIA (LB.-SEC.**2-IN.)			SEGMENT CONTACT ELLIPSOID SEMIAXES (IN.)			CENTER (IN.)			PRINCIPAL AXES (DEG)		
					X	Y	Z	X	Y	Z	X	Y	Z	YAW	PITCH	ROLL
1	LT	5		21.912	.8019	.6182	.4678	4.725	7.185	4.800	.000	.000	.000	.00	-43.00	180.00
2	MT	4		2.661	.0196	.0196	.0083	4.775	6.500	4.000	1.000	.000	-1.000	.00	.00	180.00
3	UT	3		39.216	2.6203	2.0517	1.7336	4.825	6.500	7.785	.000	.000	.000	.00	4.99	180.00
4	N	2		2.668	.0254	.0257	.0084	1.675	1.675	3.000	.000	.000	.000	.00	.00	180.00
5	H	1		9.921	.1408	.2128	.1956	4.250	2.875	4.000	.000	.000	.000	.00	-26.58	180.00
6	RUL	6		19.984	1.4494	1.4968	.1989	2.950	3.050	7.285	.000	.000	2.300	11.82	5.69	-172.70
7	RLL	7		7.237	.6708	.6745	.0397	2.165	1.675	9.750	.000	.000	2.000	.00	-1.90	180.00
8	RF	8		2.756	.0067	.0524	.0491	4.900	1.675	1.675	.000	.000	.000	.96	-9.57	158.20
9	LUL	9		19.984	1.4494	1.4968	.1989	2.950	3.050	7.285	.000	.000	2.300	-11.82	5.69	172.70
10	LLL	0		7.237	.6708	.6745	.0397	2.165	1.675	9.750	.000	.000	2.000	.00	-1.90	180.00
11	LF	1		2.756	.0067	.0524	.0491	4.900	1.675	1.675	.000	.000	.000	-.96	-9.57	-158.20
12	RUA	2		4.597	.1024	.0997	.0109	1.900	1.800	6.000	.000	.000	-1.000	.00	-1.31	180.00
13	RLA	3		3.800	.1191	.1128	.0069	1.775	1.775	5.800	.000	.000	.000	.00	-1.31	180.00
14	LUA	4		4.597	.1024	.0997	.0109	1.900	1.800	6.000	.000	.000	-1.000	.00	-1.31	180.00
15	LLA	5		3.800	.1191	.1128	.0069	1.775	1.775	5.800	.000	.000	-1.000	.00	-1.31	180.00
16	RHD	6		1.290	.0114	.0093	.0036	1.000	1.870	3.650	.000	.000	.000	-5.35	30.75	173.50
17	LHD	7		1.290	.0114	.0093	.0036	1.000	1.870	3.650	.000	.000	.000	5.35	30.75	-173.50
18	LAR	8		2.000	.0850	.0022	.0863	1.000	7.000	.500	.000	.000	.000	.00	.00	.00
19	RAR	9		2.000	.0850	.0022	.0863	1.000	7.000	.500	.000	.000	.000	.00	.00	.00

CARDS B.3

JOINT SEG(J+1)		J	SYM	PLOT	JNT	PIN	LOCATION(IN.) - SEG(JNT)			LOCATION(IN.) - SEG(J+1)			JOINT AXIS(DEG) - SEG(JNT)			JOINT AXIS(DEG) -		
							X	Y	Z	X	Y	Z	YAW	PITCH	ROLL	YAW	PITCH	ROLL
1	P		M		1	0	-2.500	.000	-1.080	-.890	.000	2.560	.00	.00	.00	.00	.00	.00
2	W		N		2	0	.000	.000	-2.560	-.890	.000	5.850	.00	.00	.00	.00	.00	.00
3	NP		O		3	0	.000	.000	-5.960	.000	.000	2.760	.00	.00	.00	.00	.00	.00
4	HP		P		4	0	.000	.000	-2.840	-.550	.000	2.000	.00	.00	.00	.00	.00	.00
5	RH		Q		1	0	-.240	3.280	-2.040	-.240	.000	-7.230	.00	.00	.00	.00	.00	.00
6	RK		R		6	1	-.200	.000	8.900	-.200	.000	-6.740	.00	.00	.00	.00	55.00	.00
7	RA		S		7	-8	-.240	.000	9.650	-2.120	.000	-1.540	90.00	.00	.00	.00	.00	.00
8	LH		T		1	0	.000	-3.280	2.040	-.240	.000	-7.230	.00	.00	.00	.00	55.00	.00
9	LK		U		9	1	-.240	.000	8.900	-.200	.000	-6.740	90.00	.00	.00	.00	.00	.00
10	LA		V		10	-8	-.200	.000	9.650	-2.120	.000	-1.540	90.00	.00	.00	90.00	.00	.00
11	RS		W		3	0	-.880	7.380	-2.660	.000	.000	-5.430	.00	90.00	.00	90.00	.00	.00
12	RE		X		12	-4	.000	.000	4.940	.000	.000	-3.670	.00	90.00	.00	90.00	.00	.00

JOINT TORQUE CHARACTERISTICS

		Y Z											
13	LS	3 0	-.880	-7.380	-2.660	.000	.00	90.00	.00	.00	.00	.00	.00
14	LE	14 -4	.000	.000	4.940	.000	90.00	.00	90.00	.00	.00	.00	.00
15	RW	13 -8	.000	.000	6.070	-.300	90.00	.00	90.00	.00	.00	.00	.00
16	LW	15 -8	.000	.000	6.070	-.300	90.00	.00	90.00	.00	.00	.00	.00
17	LR	20 1	10.500	-10.000	-31.750	.000	90.00	.00	90.00	-6.500	-48.50	-48.50	.00
18	RR	20 1	-10.500	-10.000	-31.750	.000	90.00	.00	90.00	-6.500	-48.50	-48.50	.00

1 JOINT TORQUE CHARACTERISTICS
3

CARDS B.4

FLEXURAL SPRING CHARACTERISTICS

JOINT		SPRING COEF. LINEAR (J=1)	QUADRATIC (J=2)	(IN. LB./DEG**J) CUBIC (J=3)	ENERGY DISSIPATION COEF.	JOINT STOP (DEG)
1	P	.000	.000	.000	1.000	.000
2	W	.000	.000	.000	1.000	.000
3	NP	.000	.000	.000	1.000	.000
4	HP	.000	.000	.000	1.000	.000
5	RH	.000	.000	.000	1.000	.000
6	RK	.000	2.320	.000	1.000	48.900
7	RA	1.000	10.000	10.000	1.000	27.000
8	LH	.000	.000	.000	1.000	.000
9	LK	.000	2.320	.000	1.000	48.900
10	LA	1.000	10.000	10.000	1.000	27.000
11	RS	.000	.000	.000	1.000	.000
12	RE	.000	20.000	20.000	1.000	52.000
13	LS	.000	.000	.000	1.000	.000
14	LE	.000	20.000	20.000	1.000	52.000
15	RW	.000	.000	.000	1.000	.000
16	LW	.000	.000	.000	1.000	.000
17	LR	.000	150.000	.000	1.000	48.500
18	RR	.000	150.000	.000	1.000	48.500

TORSIONAL SPRING CHARACTERISTICS

JOINT		SPRING COEF. LINEAR (J=1)	QUADRATIC (J=2)	(IN. LB./DEG**J) CUBIC (J=3)	ENERGY DISSIPATION COEF.	JOINT STOP (DEG)
1	P	34.380	.000	.000	1.000	.000
2	W	34.380	.000	.000	1.000	.000
3	NP	15.000	.000	.000	1.000	.000
4	HP	15.000	.000	.000	1.000	.000
5	RH	7.500	75.000	75.000	1.000	55.000
6	RK	.000	.000	.000	1.000	.000
7	RA	.000	6.690	.000	1.000	30.000
8	LH	7.500	75.000	75.000	1.000	55.000
9	LK	.000	.000	.000	1.000	.000
10	LA	.000	6.690	.000	1.000	30.000
11	RS	.000	100.000	100.000	1.000	125.000
12	RE	.000	4.650	.000	1.000	65.300
13	LS	.000	100.000	100.000	1.000	125.000
14	LE	.000	4.650	.000	1.000	65.300
15	RW	.000	4.320	.140	1.000	55.500
16	LW	.000	4.320	.140	1.000	55.500
17	LR	.000	.000	.000	1.000	.000
18	RR	.000	.000	.000	1.000	.000

CARDS B.5

JOINT VISCOUS CHARACTERISTICS AND LOCK-UNLOCK CONDITIONS

JOINT	VISCOUS COEFFICIENT (IN. LB.SEC./DEG)	COULOMB FRICTION COEF. (IN. LB.)	FULL FRICTION ANGULAR VELOCITY (DEG/SEC.)	MAX TORQUE FOR A LOCKED JOINT (IN. LB.)	MIN TORQUE FOR UNLOCKED JOINT (IN. LB.)	MIN. ANG. VELOCITY FOR UNLOCKED JOINT (RAD/SEC.)	IMPULSE RESTITUTION COEFFICIENT

	SYM					
1	P	1.200	.00	.00	.00	.000
2	W	1.200	.00	.00	.00	.000
3	NP	.350	.00	.00	.00	.000
4	HP	.192	.00	.00	.00	.000
5	RH	1.000	.00	.00	.00	.000
6	RK	1.000	.00	.00	.00	.000
7	RA	.500	.00	.00	.00	.000
		.500	.00	.00	.00	.000
8	LH	.000	.00	.00	.00	.000
9	LK	1.000	.00	.00	.00	.000
10	LA	1.000	.00	.00	.00	.000
		.500	.00	.00	.00	.000
		.500	.00	.00	.00	.000
11	RS	.000	.00	.00	.00	.000
12	RE	.100	.00	.00	.10	.000
		.100	.00	.00	.00	.000
13	LS	.100	.00	.00	.00	.000
14	LE	.000	.00	.00	.00	.000
		.100	.00	.00	.00	.000
		.100	.00	.00	.00	.000
15	RW	.000	.00	.00	38.00	.000
		.500	.00	.00	.00	.000
16	LW	.500	.00	.00	.10	.000
		.000	.00	.00	58.00	.000
		.500	.00	.00	.00	.000
17	LR	.500	.00	.00	.00	.000
18	RR	.000	.00	.00	.00	.000
		.000	.00	.00	.00	.000
		.000	.00	.00	.00	.000

PAGE

CARDS B.6

SEGMENT INTEGRATION CONVERGENCE TEST INPUT

SEGMENT NO.	SYM	ANGULAR VELOCITIES (RAD/SEC.)			LINEAR VELOCITIES (IN./SEC.)			ANGULAR ACCELERATIONS (RAD/SEC.**2)			LINEAR ACCELERATIONS (IN./SEC.**2)		
		MAG. TEST	ABS. ERROR	REL. ERROR	MAG. TEST	ABS. ERROR	REL. ERROR	MAG. TEST	ABS. ERROR	REL. ERROR	MAG. TEST	ABS. ERROR	REL. ERROR
1	LT	.010	.010	.0100	.010	.010	.0100	.100	.100	.1000	.100	.100	.0100
2	MT	.010	.010	.0100	.000	.000	.0000	.100	.100	.1000	.000	.000	.0000
3	UT	.010	.010	.0100	.000	.000	.0000	.100	.100	.1000	.000	.000	.0000
4	N	.010	.010	.0100	.000	.000	.0000	.100	.100	.1000	.000	.000	.0000
5	H	.010	.010	.0100	.000	.000	.0000	.100	.100	.1000	.000	.000	.0000
6	RUL	.010	.010	.0100	.000	.000	.0000	.100	.100	.1000	.000	.000	.0000
7	RLL	.010	.010	.0100	.000	.000	.0000	.100	.100	.1000	.000	.000	.0000
8	RF	.010	.010	.0100	.000	.000	.0000	.100	.100	.1000	.000	.000	.0000

129

VEHICLE DECELERATION INPUTS

		YAW	PITCH	ROLL	VIPS	VTIME	XO(X)	XO(Y)	XO(Z)	NATAB	ATO	ADT
9	LUL	.010	.010	.0100	.000	.000	.0000	.100	.100	.1000	.000	.000	.0000
10	LLL	.010	.010	.0100	.000	.000	.0000	.100	.100	.1000	.000	.000	.0000
11	LF	.010	.010	.0100	.000	.000	.0000	.100	.100	.1000	.000	.000	.0000
12	RUA	.010	.010	.0100	.000	.000	.0000	.100	.100	.1000	.000	.000	.0000
13	RLA	.010	.010	.0100	.000	.000	.0000	.100	.100	.1000	.000	.000	.0000
14	LUA	.010	.010	.0100	.000	.000	.0000	.100	.100	.1000	.000	.000	.0000
15	LLA	.010	.010	.0100	.000	.000	.0000	.100	.100	.1000	.000	.000	.0000
16	RHD	.010	.010	.0100	.000	.000	.0000	.100	.100	.1000	.000	.000	.0000
17	LHD	.010	.010	.0100	.000	.000	.0000	.100	.100	.1000	.000	.000	.0000
18	LAR	.010	.010	.0100	.000	.000	.0000	.100	.100	.1000	.000	.000	.0000
19	RAR	.010	.010	.0100	.000	.000	.0000	.100	.100	.1000	.000	.000	.0000

1 VEHICLE DECELERATION INPUTS
5

Shot 9991 - Sitting 50% Male Hybrid III - SSTV   CARDS C

MSEG	YAW	PITCH	ROLL	VIPS	VTIME	XO(X)	XO(Y)	XO(Z)	NATAB	ATO	ADT	I1	I3
.000	.000	.000	.000	.000	.000	.000	.000	.000-9999	.00000	.00020	0	0	0

0 VEHICLE LINEAR TIME HISTORY   Shot 9991 - Sitting 50% Male Hybrid III - SSTV   MSEG = 0

TIME (MSEC)	LINEAR DECELERATIONS (G'S)			LINEAR VELOCITIES (IN./SEC.)			LINEAR DISPLACEMENTS (IN.)		
	X	Y	Z	X	Y	Z	X	Y	Z
.000	.000	.003	-.001	.000	.000	.000	.000	.000	.000
.200	.000	.008	-.005	.000	.000	.000	.000	.000	.000
.400	.000	.014	.008	.000	-.001	.000	.000	.000	.000
.600	.000	.010	.002	.000	-.002	.000	.000	.000	.000
.800	.000	.006	.002	.000	-.003	.000	.000	.000	.000
1.000	.000	.007	.002	.000	-.003	-.001	.000	.000	.000

Majority of vehicle excitation omitted for brevity.

TIME (MSEC)	X	Y	Z	X	Y	Z	X	Y	Z
1999.000	.000	.466	.055	.000	33.227	.000	.000	7.537	-2.003
1999.200	.000	.432	.016	.000	33.192	.000	.000	7.544	-2.002
1999.400	.000	.523	.035	.000	33.155	.000	.000	7.551	-2.002
1999.600	.000	.568	.044	.000	33.113	.000	.000	7.557	-2.001

1 VEHICLE ANGULAR TIME HISTORY   Shot 9991 - Sitting 50% Male Hybrid III - SSTV   PAGE
228   MSEG = 0

TIME (MSEC)	ANGULAR ACCELERATIONS (DEG/SEC.**2)			ANGULAR VELOCITIES (DEG/SEC.)			ANGULAR DISPLACEMENTS (DEG)		
	X	Y	Z	X	Y	Z	YAW	PITCH	ROLL
.000	.571	-.296	.000	.000	.000	.000	.000	.000	.000
.200	.380	.625	.000	.000	.000	.000	.000	.000	.000

```
     .400    -1.776    3.212    .000    .000    .000    .000    .000
     .600    -1.128    1.287    .000    .001    .000    .000    .000
     .800     -.808     .451   -.001    .001    .000    .000    .000
```

Majority of vehicle excitation omitted for brevity.

```
1999.000   -63.241   -51.779    .000   -5.798   3.425    .000   -.230   4.014   -5.557
1999.200   -60.558   -60.750    .000   -5.810   3.414    .000   -.230   4.015   -5.558
1999.400   -61.659   -61.353    .000   -5.822   3.402    .000   -.230   4.016   -5.559
1999.600   -62.550   -68.194    .000   -5.835   3.389    .000   -.230   4.016   -5.560
1 VEHICLE PATHS TO GROUND                                                         PAGE
451

THE GROUND (INERTIAL) SEGMENT IS REPRESENTED HERE BY A 0.
THE COORD CATEGORY REFERS TO THE COORDINATE SYSTEM IN WHICH THE VEHICLE DATA ARE SPECIFIED.
A NEGATIVE VALUE FOR COORD INDICATES THAT THE DATA REPRESENT ACCELEROMETER DATA.

VEH  COORD     VEHICLE PATH TO GROUND
VEH  GRND      GRND
 20    0         0

 NPL   NBLT   NBAG   NELP   NQ   NSD   NHRNSS   NWINDF   NJNTF   NFORCE
  9     1      0      0     0    0      0        0        7        0

0 PLANE INPUTS
0 PLANE NO.  1    Seat Cushion. Botto
              X         Y          Z
POINT 1    -9.5000   -9.2500   -24.5000
POINT 2    -9.5000    9.2500   -24.5000
POINT 3     9.5000   -9.2500   -24.5000
0 PLANE NO.  2    Seat Cushion. Front
              X         Y          Z
POINT 1     9.5000    9.2500   -19.7500
POINT 2     9.5000    9.2500   -24.5000
POINT 3    -9.5000    9.2500   -19.7500
0 PLANE NO.  3    Seat Cushion. Right
              X         Y          Z
POINT 1    -9.5000    9.2500   -19.7500
POINT 2    -9.5000    9.2500   -24.5000
POINT 3    -9.5000   -9.2500   -19.7500
0 PLANE NO.  4    Seat Cushion. Left
              X         Y          Z
POINT 1     9.5000   -9.2500   -19.7500

1
452

                                            CARD D.1
                                            CARDS D.2
```

POINT 2   9.5000   -9.2500   -24.5000
POINT 3   9.5000   9.2500   -19.7500
0 PLANE NO.   5   Seat Back.

                    X   Y   Z
POINT 1   -9.5000   -8.3000   -28.2500
POINT 2   9.5000   -8.3000   -28.2500
POINT 3   -9.5000   -10.2500   -44.5500
0 PLANE NO.   6   Seat Back. Top.

                    X   Y   Z
POINT 1   -9.5000   -10.2500   -44.5500
POINT 2   9.5000   -10.2500   -44.5500
POINT 3   -9.5000   -14.2200   -44.0700
0 PLANE NO.   7   Seat Back. Right Si

                    X   Y   Z
POINT 1   -9.5000   -12.2700   -27.7700
POINT 2   -9.5000   -8.3000   -28.2500
POINT 3   -9.5000   -14.2200   -44.0700
1 PLANE INPUTS
453

0 PLANE NO.   8   Seat Back. Left Sid

                    X   Y   Z
POINT 1   9.5000   -12.2700   -27.7700
POINT 2   9.5000   -14.2200   -44.0700
POINT 3   9.5000   -8.3000   -28.2500
0 PLANE NO.   9   Deck.

                    X   Y   Z
POINT 1   -25.0000   -25.0000   .0000
POINT 2   -25.0000   25.0000   .0000
POINT 3   25.0000   -25.0000   .0000
1 BELT INPUTS
454

0 BELT NO.   1   LAP BELT

                    ANCHOR POINT A   ANCHOR POINT B
           X   Y   Z   X   Y   Z
        -9.500   -9.500   -24.500   9.500   -9.500   -24.500   C

              FIXED POINT ON SEGMENT
           X   Y   Z   BLANK   SLACK(+)
        2.720   .000   -4.030   .000   LENGTH(-)   -.100

0 BODY SEGMENT SYMMETRY INPUT

132

```
SEG NO.     1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19
NSYM(J)     0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
1
455
FUNCTION NO.   1    HEAD SURFACE                      NTI( 1) =   1

   D0         D1         D2         D3         D4
   .0000      .7100      -.8000     .0000      .0000

FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL

   A0          A1           A2           A3           A4          A5
2.570000   -175.980000   4495.670000  -8953.110000  6029.590000  .000000

SECOND PART OF FUNCTION -   3 TABULAR POINTS

   D          F(D)
.710000     358.0000
.750000    3580.0000
.800000   35800.0000
```

```
FUNCTION NO.   2    BACK OF SHOULDER                  NTI( 2) =  19

   D0         D1         D2         D3         D4
   .0000     1.6200     -1.7000     .0000      .0000

FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL

   A0          A1           A2           A3          A4          A5
.010000    -26.590000   380.910000   -678.220000  456.530000   .000000

SECOND PART OF FUNCTION -   3 TABULAR POINTS

    D          F(D)
1.620000     48.3000
1.650000    483.0000
1.700000   4830.0000
```

133

1
456
FUNCTION NO. 3   CHEST   NTI(3) = 37

DO	D1	D2	D3	D4
.0000	1.3100	-1.4000	.0000	.0000

FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL

A0	A1	A2	A3	A4	A5
.550000	5.460000	73.490000	-15.010000	.000000	.000000

SECOND PART OF FUNCTION -   3 TABULAR POINTS

D	F(D)
1.310000	158.6000
1.350000	1586.0000
1.400000	15860.0000

FUNCTION NO. 4   ANTERIOR PELVIS   NTI(4) = 55

DO	D1	D2	D3	D4
.0000	2.0200	-2.1000	.0000	.0000

FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL

A0	A1	A2	A3	A4	A5
-.140000	1.580000	24.390000	-29.330000	13.760000	.000000

SECOND PART OF FUNCTION -   3 TABULAR POINTS

D	F(D)
2.020000	89.7000
2.050000	897.0000
2.100000	8970.0000

1
457
FUNCTION NO. 5   POSTERIOR PELVIS   NTI(5) = 73

134

D0	D1	D2	D3	D4
.0000	1.9600	-2.1000	.0000	.0000

FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL

A0	A1	A2	A3	A4	A5
-.760000	35.100000	40.040000	-12.490000	.000000	.000000

SECOND PART OF FUNCTION - 3 TABULAR POINTS

D	F(D)
1.960000	127.8000
2.030000	1278.0000
2.100000	12780.0000

FUNCTION NO. 6   UPPER ARM   NTI(6) = 91

D0	D1	D2	D3	D4
.0000	.8900	-1.0000	.0000	.0000

FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL

A0	A1	A2	A3	A4	A5
1.540000	-30.630000	627.090000	-1197.700000	917.230000	.000000

SECOND PART OF FUNCTION - 3 TABULAR POINTS

D	F(D)
.890000	203.1000
.950000	2031.0000
1.000000	20310.0000

1
458
FUNCTION NO. 7   FOREARM   NTI(7) = 109

D0	D1	D2	D3	D4
.0000	1.3100	-1.4000	.0000	.0000

FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL

A0	A1	A2	A3	A4	A5
-2.400000	107.370000	-313.360000	504.610000	-196.370000	.000000

SECOND PART OF FUNCTION - 3 TABULAR POINTS

D	F(D)
1.310000	156.2000
1.350000	1562.0000
1.400000	15620.0000

FUNCTION NO. 8 HAND   NTI(8) = 127

D0	D1	D2	D3	D4
.0000	.3800	-.4500	.0000	.0000

FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL

A0	A1	A2	A3	A4	A5
-.040000	-31.040000	2384.470000	-10193.900000	19172.500000	.000000

SECOND PART OF FUNCTION - 3 TABULAR POINTS

D	F(D)
.380000	139.4000
.410000	1394.0000
.450000	13940.0000

1
459
FUNCTION NO. 9 UPPER LEG   NTI(9) = 145

D0	D1	D2	D3	D4
.0000	1.3100	-1.4000	.0000	.0000

FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL

A0	A1	A2	A3	A4	A5
-.280000	14.190000	81.940000	-122.620000	98.730000	-29.090000

CARDS E

PAGE
CARDS E

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SECOND PART OF FUNCTION -   3 TABULAR POINTS

D	F(D)
1.310000	61.6000
1.350000	616.0000
1.400000	6160.0000

FUNCTION NO. 10   KNEE   NTI(10) = 163

D0	D1	D2	D3	D4
.0000	.5400	-.5800	.0000	.0000

FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL

A0	A1	A2	A3	A4	A5
-.040000	2.220000	867.340000	-401.610000	.000000	.000000

SECOND PART OF FUNCTION -   3 TABULAR POINTS

D	F(D)
.540000	187.8000
.560000	1878.0000
.580000	18780.0000

1
460
FUNCTION NO. 11   FRONT OF LOWER LEG   NTI(11) = 181   PAGE

D0	D1	D2	D3	D4
.0000	1.7800	-1.9000	.0000	.0000

FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL

A0	A1	A2	A3	A4	A5
-.740000	26.790000	3.920000	29.050000	.000000	.000000

SECOND PART OF FUNCTION -   3 TABULAR POINTS

```
           D              F(D)
        1.780000       223.6000
        1.840000      2236.0000
        1.900000     22360.0000
```

FUNCTION NO. 12   BACK OF LOWER LEG   NTI(12) = 199

D0	D1	D2	D3	D4
.0000	1.6600	-1.7500	.0000	.0000

FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL

A0	A1	A2	A3	A4	A5
-.080000	29.420000	-2.080000	.000000	.000000	.000000

SECOND PART OF FUNCTION -   3 TABULAR POINTS

```
           D              F(D)
        1.660000        43.2000
        1.700000       432.0000
        1.750000      4320.0000
```

1
461
FUNCTION NO. 13   FOOT   NTI(13) = 217

D0	D1	D2	D3	D4
.0000	.8300	-.9500	.0000	.0000

FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL

A0	A1	A2	A3	A4	A5
-.680000	82.750000	-704.170000	3367.100000	-5570.690000	3188.300000

SECOND PART OF FUNCTION -   3 TABULAR POINTS

```
           D              F(D)
        .830000        121.2000
        .890000       1212.0000
        .950000      12120.0000
```

138

FUNCTION NO. 14   SEAT CUSHION   NTI(14) = 235

DO	D1	D2	D3	D4
.0000	-4.0000	.0000	.0000	1.0000

FIRST PART OF FUNCTION -   5 TABULAR POINTS

D	F(D)
.000000	.0000
1.000000	60.0000
2.000000	200.0000
3.000000	800.0000
4.000000	2000.0000

1
462
FUNCTION NO.   16   CONSTANT = 0.0   NTI(16) =   251
CARDS E

DO	D1	D2	D3	D4
.0000	.0000	.0000	.0000	.0000

FUNCTION IS CONSTANT   .000000

FUNCTION NO.   17   CONSTANT, F=0.9   NTI(17) =   256
CARDS E

DO	D1	D2	D3	D4
.0000	.0000	.9000	.0000	.0000

FUNCTION IS CONSTANT   .900000

1
463
FUNCTION NO.   20   DAMPING COEFF. C=200   NTI(20) =   261
CARDS E

DO	D1	D2	D3	D4

.0000   2.0000   .0000   .0000   1.0000

FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL

A0	A1	A2	A3	A4	A5
.000000	200.000000	.000000	.000000	.000000	.000000

FUNCTION NO. 21   RATE OF DEFLEC.   NTI(21) = 272

D0	D1	D2	D3	D4
-40.0000	-150.0000	.0000	.0000	1.0000

FIRST PART OF FUNCTION -   21 TABULAR POINTS

D	F(D)
-40.000000	.0000
-30.000000	.0000
-20.000000	.0000
-10.000000	.0000
.000000	.0000
5.000000	1.0000
10.000000	1.0000
20.000000	.9900
30.000000	.9650
40.000000	.9280
50.000000	.8600
60.000000	.6900
70.000000	.4750
80.000000	.3400
90.000000	.2600
100.000000	.2000
110.000000	.1800
120.000000	.0900
130.000000	.0600
140.000000	.0250
150.000000	.0000

1
464
FUNCTION NO. 24   RESTRAINT BELT   NTI(24) = 320

140

D0	D1	D2	D3	D4
.0000	-.1000	.0000	.0000	.0000

FIRST PART OF FUNCTION - 6 TABULAR POINTS

D	F(D)
.000000	.0000
.010000	165.0000
.020000	330.0000
.030000	495.0000
.050000	935.0000
.100000	3850.0000

FUNCTION NO. 25   DECK-FOOT.

NTI(25) = 338

D0	D1	D2	D3	D4
.0000	-1.3540	0	.0000	1.0000

FIRST PART OF FUNCTION - 8 TABULAR POINTS

D	F(D)
.000000	.0000
.200000	6.7500
.401000	25.2900
.602000	48.7200
.803000	101.7900
.834000	121.2000
.930000	1212.0000
1.354000	12120.0000

1
465

FUNCTION NO. 27   ARM RESTS.

NTI(27) = 360

D0	D1	D2	D3	D4
.0000	-3.0000	.0000	.0000	.0000

FIRST PART OF FUNCTION - 6 TABULAR POINTS

D	F(D)

141

```
 .000000      .0000
 .100000    100.0000
 .200000   1000.0000
1.000000   5000.0000
2.000000  10000.0000
3.000000  15000.0000
```

FUNCTION NO. 28   CUSHION (REV2)   NTI(28) =   378
CARDS E

D0	D1	D2	D3	D4
.0000	-6.0000	.0000	.0000	1.0000

FIRST PART OF FUNCTION -   6 TABULAR POINTS

D	F(D)
.000000	.0000
1.000000	60.0000
2.000000	150.0000
3.000000	500.0000
4.000000	2000.0000
6.000000	10000.0000

1
466
FUNCTION NO. 29   CUSHION   CAR
396

CARDS E

D0	D1	D2	D3	D4
.0000	-6.0000	.0000	.0000	1.0000

FIRST PART OF FUNCTION -   6 TABULAR POINTS

D	F(D)
.000000	.0000
1.000000	50.0000
2.000000	125.0000
3.000000	250.0000
4.000000	500.0000
6.000000	1000.0000

FUNCTION NO. 30   CUSHION ABSORPTION   NTI(30) =   414
CARDS E

D0	D1	D2	D3	D4
-1000.0000	-1000.0000	.0000	.0000	1.0000

FIRST PART OF FUNCTION -   5 TABULAR POINTS

D	F(D)
-1000.000000	.5000
-6.000000	.5000
-5.000000	1.0000
.000000	1.0000
1000.000000	1.0000

1
467

FUNCTION NO.   31   CUSHION VISCOUS   NTI(31) =   430
CARDS E

D0	D1	D2	D3	D4
-2000.0000	-2000.0000	.0000	.0000	1.0000

FIRST PART OF FUNCTION -   5 TABULAR POINTS

D	F(D)
-2000.000000	.0000
-200.000000	.0000
.000000	.0000
200.000000	10.0000
2000.000000	200.0000

FUNCTION NO.   33   CONSTANT = 0.0   NTI(33) =   446
CARDS E

D0	D1	D2	D3	D4
.0000	.0000	.0000	.0000	.0000

143

FUNCTION IS CONSTANT   .000000

1
468
FUNCTION NO.   34   DUMMY STIFFNESS
CARDS E

D0	D1	D2	D3	D4
.0000	-4.0000	.0000	.0000	.0000

NTI(34) = 451

FIRST PART OF FUNCTION -   6 TABULAR POINTS

D	F(D)
.000000	.0000
.500000	30.0000
1.000000	60.0000
1.500000	90.0000
1.800000	900.0000
2.000000	9000.0000

FUNCTION NO.   35   DUMMY ABSORPTION
CARDS E

D0	D1	D2	D3	D4
-1000.0000	-1000.0000	.0000	.0000	1.0000

NTI(35) = 469

FIRST PART OF FUNCTION -   5 TABULAR POINTS

D	F(D)
-1000.000000	.4600
-6.000000	.4600
-5.000000	1.0000
.000000	1.0000
1000.000000	1.0000

1
469
FUNCTION NO.   36   ABDOMINAL VISCOUS
CARDS E

D0	D1	D2	D3	D4
-2000.0000	-2000.0000	.0000	.0000	1.0000

NTI(36) = 485

144

FIRST PART OF FUNCTION -   5 TABULAR POINTS

D	F(D)
-2000.000000	.0000
-200.000000	.0000
.000000	.0000
200.000000	50.0000
2000.000000	1000.0000

FUNCTION NO. 37   CONSTANT F = 0.1   NTI(37) = 501
CARDS E

DO	D1	D2	D3	D4
.0000	.0000	.1000	.0000	.0000

FUNCTION IS CONSTANT   .100000
1 JOINT FORCE FUNCTION NO. 41   RIGHT SHOULDER JOINT   NTI(41) = 506
470

DO	D1	D2	D3	REF. SEGMENT
.0000	.0000	.0000	.0000	.0000

0 FUNCTION IS COEFFICIENTS OF 3 ORDER POLYNOMIALS IN (THETA-THETAO)**N FOR 8 VALUES OF PHI.

COEFFICIENTS OF 3 ORDER POLYNOMIALS IN (THETA-THETAO)**N

PHI	THETAO	N = 1	N = 2	N = 3
-180.00	151.000	.0000000	87900.00	.0000000
-135.00	75.000	.0000000	13700.00	.0000000
-90.00	.000	.0000000	-312.0000	11800.00
-45.00	66.000	.0000000	7780.000	3010000.
.00	68.000	.0000000	22200.00	376000.0
45.00	89.000	.0000000	22000.00	.0000000
90.00	111.000	.0000000	2470.000	17600.00
135.00	153.000	.0000000	13000.00	.0000000

1 JOINT FORCE FUNCTION NO. 42   LEFT SHOULDER JOINT   NTI(42) = 545
471

DO	D1	D2	D3	REF. SEGMENT
.0000	.0000	.0000	.0000	.0000

FUNCTION IS COEFFICIENTS OF 3 ORDER POLYNOMIALS IN (THETA-THETA0)**N FOR 8 VALUES OF PHI.

COEFFICIENTS OF (THETA-THETA0)**N

PHI	THETA0	N = 1	N = 2	N = 3
-180.00	151.000	.0000000	87900.00	.0000000
-135.00	153.000	.0000000	13000.00	.0000000
-90.00	111.000	.0000000	2470.000	17600.00
-45.00	89.000	.0000000	22000.00	.0000000
.00	68.000	.0000000	22200.00	.0000000
45.00	66.000	.0000000	7780.000	376000.0
90.00		.0000000	-312.0000	3010000.
135.00	75.000	.0000000	13700.00	11800.00
				.0000000

JOINT FORCE FUNCTION NO. 43   STANDING RIGHT HIP   NTI(43) = 584

472

DO	D1	D2	D3	REF. SEGMENT
.0000	.0000	.0000	.0000	.0000

FUNCTION IS TABULAR FOR 19 X 4 VALUES OF THETA AND PHI

THETA

PHI	THETA0				
		10.000	20.000	30.000	40.000	50.000
		60.000	70.000	80.000	90.000	100.000
		110.000	120.000	130.000	140.000	150.000
		160.000	170.000	180.000		
-180.00	.000	2.000000	7.000000	21.00000	49.00000	105.0000
		217.0000	441.0000	889.0000	1790.000	3580.000
		7160.000	14300.00	28700.00	57300.00	115000.0
		229000.0	459000.0	917000.0		
-90.00	.000	5.000000	11.00000	22.00000	39.00000	73.00000
		141.0000	277.0000	549.0000	1090.000	2180.000
		4360.000	8710.000	17400.00	34800.00	69600.00
		139000.0	279000.0	557000.0		
.00	.000	1.000000	2.000000	3.000000	5.000000	7.000000
		10.00000	13.00000	17.00000	22.00000	27.00000
		32.00000	38.00000	46.00000	62.00000	94.00000
		158.0000	286.0000	542.0000		
90.00	.000	1.000000	3.000000	4.000000	6.000000	8.000000
		9.000000	10.00000	18.00000	34.00000	66.00000

146

1 JOINT FORCE FUNCTION NO. 44   STANDING LEFT HIP
473

| 130.0000 | 258.0000 | 514.0000 | 1030.000 | 2050.000 |
| 4100.000 | 8190.000 | 16400.00 | | |

NTI(44) = 667

DO	D1	D2	D3
.0000	.0000	.0000	.0000

REF. SEGMENT
.0000

0 FUNCTION IS TABULAR FOR 19 X 4 VALUES OF THETA AND PHI

THETA

10.000	20.000	30.000	40.000	50.000
60.000	70.000	80.000	90.000	100.000
110.000	120.000	130.000	140.000	150.000
160.000	170.000	180.000		

PHI	THETAO				
-180.00	.000				
	2.000000	7.000000	21.00000	49.00000	105.0000
	217.0000	441.0000	889.0000	1790.000	3580.000
	7160.000	14300.00	28700.00	57300.00	115000.0
	229000.0	459000.0	917000.0		
-90.00	.000				
	1.000000	3.000000	4.000000	6.000000	8.000000
	9.000000	10.00000	18.00000	34.00000	66.00000
	130.0000	258.0000	514.0000	1030.000	2050.000
	4100.000	8190.000	16400.00		
.00	.000				
	1.000000	2.000000	3.000000	5.000000	7.000000
	10.00000	13.00000	17.00000	22.00000	27.00000
	32.00000	38.00000	46.00000	62.00000	94.00000
	158.0000	286.0000	542.0000		
90.00	.000				
	5.000000	11.00000	22.00000	39.00000	73.00000
	141.0000	277.0000	549.0000	1090.000	2180.000
	4360.000	8710.000	17400.00	34800.00	69600.00
	139000.0	279000.0	557000.0		

1 JOINT FORCE FUNCTION NO. 45   STANDING LUMBAR SPIN
474

NTI(45) = 750

DO	D1	D2	D3
.0000	.0000	.0000	.0000

REF. SEGMENT
.0000

0 FUNCTION IS TABULAR FOR 19 X 4 VALUES OF THETA AND PHI

THETA

10.000	20.000	30.000	40.000	50.000
60.000	70.000	80.000	90.000	100.000
110.000	120.000	130.000	140.000	150.000

PHI	THETAO

147

Force function table (THETA columns 160, 170, 180 and continuation):

PHI	160.000	170.000	180.000		
-180.00	1200.000	2400.000	3600.000	4800.000	6000.000
	7200.000	8400.000	9600.000	10800.00	13200.00
	18000.00	27600.00	46800.00	85200.00	162000.0
	314600.0	622800.0	1237200.		
-90.00	1200.000	2400.000	3600.000	4800.000	6000.000
	7200.000	8400.000	9600.000	10800.00	13200.00
	18000.00	27600.00	46800.00	85200.00	162000.0
	314600.0	622800.0	1237200.		
.00	960.0000	1920.000	2880.000	3840.000	4800.000
	5760.000	6720.000	7680.000	8640.000	10560.00
	14400.00	22080.00	37440.00	68160.00	129600.0
	252480.0	498240.0	989760.0		
90.00	1200.000	2400.000	3600.000	4800.000	6000.000
	7200.000	8400.000	9600.000	10800.00	13200.00
	18000.00	27600.00	46800.00	85200.00	162000.0
	314600.0	622800.0	7010800.0		

NTI(46) = 833

475
1 JOINT FORCE FUNCTION NO. 46   NECK PIVOT

DO	D1	D2	D3	REF. SEGMENT
.0000	.0000	.0000	.0000	.0000

0 FUNCTION IS TABULAR FOR 19 X 4 VALUES OF THETA AND PHI

THETA: 10.000 20.000 30.000 40.000 50.000 / 60.000 70.000 80.000 90.000 100.000 / 110.000 120.000 130.000 140.000 150.000 / 160.000 170.000 180.000

PHI	THETA0					
-180.00	.000	700.0000	1400.000	2100.000	2800.000	3500.000
		4200.000	4900.000	5600.000	6300.000	7000.000
		7700.000	8400.000	9800.000	12600.00	18200.00
		29400.00	51800.00	96600.00		
-90.00	.000	600.0000	1200.000	1800.000	2400.000	3000.000
		3600.000	4200.000	4800.000	5400.000	6000.000
		6600.000	7200.000	8400.000	10800.00	15600.00
		25200.00	44400.00	82800.00		
.00	.000	300.0000	600.0000	900.0000	1200.000	1500.000
		1800.000	2100.000	2400.000	2700.000	3000.000
		3300.000	3600.000	4200.000	5400.000	7800.000
		12600.00	22200.00	41400.00		
90.00	.000	600.0000	1200.000	1800.000	2400.000	3000.000
		3600.000	4200.000	4800.000	5400.000	6000.000

148

1 JOINT FORCE FUNCTION NO. 47   HEAD PIVOT
476

6600.000	7200.000	8400.000	10800.00	15600.00
25200.00	44400.00	82800.00		

NTI(47) = 916

DO	D1	D2	D3	REF. SEGMENT
.0000	.0000	.0000	.0000	.0000

0 FUNCTION IS TABULAR FOR 19 X 4 VALUES OF THETA AND PHI

PHI	THETAO	10.000	20.000	30.000	40.000	50.000	60.000	70.000	80.000	90.000	100.000	110.000	120.000	130.000	140.000	150.000	160.000	170.000	180.000
-180.00	.000	490.0000	980.0000	1680.000	2380.000	3080.000	3780.000	4480.000	5180.000	5880.000	6580.000	7280.000	7980.000	9380.000	12180.00	17780.00	28980.00	51380.00	96180.00
-90.00	.000	600.0000	1200.000	1800.000	2400.000	3000.000	3600.000	4200.000	4800.000	5400.000	6000.000	6600.000	7200.000	8400.000	10800.00	15600.00	25200.00	44400.00	82800.00
.00	.000	250.0000	500.0000	800.0000	1100.000	1400.000	1700.000	2000.000	2300.000	2600.000	2900.000	3200.000	3500.000	4100.000	5300.000	7700.000	12500.00	22100.00	41300.00
90.00	.000	600.0000	1200.000	1800.000	2400.000	3000.000	3600.000	4200.000	4800.000	5400.000	6000.000	6600.000	7200.000	8400.000	10800.00	15600.00	25200.00	44400.00	82800.00

1 ALLOWED CONTACTS AND ASSOCIATED FUNCTIONS
477
0
OPT

PLANE	SEGMENT	FORCE DEFLECTION	INERTIAL SPIKE	R FACTOR	G FACTOR	FRICTION COEF.	
0 1- 20	1- 1 14	Botto LT SEAT CUSHION	-20 DAMPING COEFF. C=200 RATE OF DEFLEC.	-21	-16 CONSTANT = 0.0	17	1
		Seat Cushion. CONSTANT, F=0.9					
0 1- 20	6- 6 14	Botto RUL SEAT CUSHION	-20 DAMPING COEFF. C=200 RATE OF DEFLEC.	-21	-16 CONSTANT = 0.0	17	1
		Seat Cushion. CONSTANT, F=0.9					
0 1- 20	9- 9 14	Botto LUL SEAT CUSHION	-20 DAMPING COEFF. C=200 RATE OF DEFLEC.	-21	-16 CONSTANT = 0.0	17	1
		Seat Cushion. CONSTANT, F=0.9					

```
0   2- 20
Seat Cushion.  Front  7- 7  14  RLL SEAT CUSHION
   CONSTANT, F=0.9        -20 DAMPING COEFF. C=200 RATE OF DEFLEC. -21   -16 CONSTANT = 0.0   17   1
0   2- 20
Seat Cushion.  Front  10- 10  14  LLL SEAT CUSHION
   CONSTANT, F=0.9        -20 DAMPING COEFF. C=200 RATE OF DEFLEC. -21   -16 CONSTANT = 0.0   17   1
0   5- 20
Seat Back.     LT  1- 1  28  CUSHION (REV2)       -29 CAR CUSHION ABSORPTION -30 CUSHION VISCOUS  -31   17   1
F=0.9                                                                                          CONSTANT,
0   5- 20
Seat Back.     MT  2- 2  28  CUSHION (REV2)       -29 CAR CUSHION ABSORPTION -30 CUSHION VISCOUS  -31   17   1
F=0.9                                                                                          CONSTANT,
0   5- 20
Seat Back.     UT  3- 3  28  CUSHION (REV2)       -29 CAR CUSHION ABSORPTION -30 CUSHION VISCOUS  -31   17   1
F=0.9                                                                                          CONSTANT,
0   5- 20
Seat Back.     RUA  12- 12  28  CUSHION (REV2)    -29 CAR CUSHION ABSORPTION -30 CUSHION VISCOUS  -31   17   1
F=0.9                                                                                          CONSTANT,
0   5- 20
Seat Back.     LUA  14- 14  28  CUSHION (REV2)    -29 CAR CUSHION ABSORPTION -30 CUSHION VISCOUS  -31   17   1
F=0.9                                                                                          CONSTANT,
0   6- 20
Seat Back.  Top.  N  4- 4  14  SEAT CUSHION       -20 DAMPING COEFF. C=200 RATE OF DEFLEC. -21   -16 CONSTANT = 0.0   17   1
   CONSTANT, F=0.9
0   6- 20
Seat Back.  Top.  H  5- 5  14  SEAT CUSHION       -20 DAMPING COEFF. C=200 RATE OF DEFLEC. -21   -16 CONSTANT = 0.0   17   1
   CONSTANT, F=0.9
0   7- 20
Seat Back.  Right Si  12- 12  14  RUA SEAT CUSHION -20 DAMPING COEFF. C=200 RATE OF DEFLEC. -21  -16 CONSTANT = 0.0   17   1
   CONSTANT, F=0.9
0   7- 20
Seat Back.  Right Si  13- 13  14  RLA SEAT CUSHION -20 DAMPING COEFF. C=200 RATE OF DEFLEC. -21  -16 CONSTANT = 0.0   17   1
   CONSTANT, F=0.9
0   8- 20
Seat Back.  Left Sid  15- 15  14  LLA SEAT CUSHION -20 DAMPING COEFF. C=200 RATE OF DEFLEC. -21  -16 CONSTANT = 0.0   17   1
   CONSTANT, F=0.9
0   8- 20
Seat Back.  Left Sid  14- 14  14  LUA SEAT CUSHION -20 DAMPING COEFF. C=200 RATE OF DEFLEC. -21  -16 CONSTANT = 0.0   17   1
   CONSTANT, F=0.9
0   9- 20
Deck.       RF  8- 8  25  DECK-FOOT.   0   0   0   17   -1  CONSTANT, F=0.9
0   9- 20
Deck.       LF  11- 11  25  DECK-FOOT.   0   0   0   17   -1  CONSTANT, F=0.9
```

OPT	BELT	SEGMENT	FORCE DEFLECTION	INERTIAL SPIKE	R FACTOR	G FACTOR	CARDS F.2 FRICTION COEF.
0							
0	1- 20	1- 1	24	0	0	0	1
0	LAP BELT					C LT RESTRAINT BELT	
	HEAD SURFACE						

OPT	SEGMENT	SEGMENT	FORCE DEFLECTION		INERTIAL SPIKE	R FACTOR	G FACTOR		CARDS F.3 FRICTION COEF.
0	1- 1 LT DUMMY ABSORPTION	13- 13	33 RLA CONSTANT = 0.0		-34 ABDOMINAL VISCOUS	-35	-36	DUMMY STIFFNESS CONSTANT F = 0.1	37
0	1- 1 LT DUMMY ABSORPTION	15- 15	33 LLA CONSTANT = 0.0		-34 ABDOMINAL VISCOUS	-35	-36	DUMMY STIFFNESS CONSTANT F = 0.1	37
0	1- 1 LT DUMMY ABSORPTION	16- 16	33 RHD CONSTANT = 0.0		-34 ABDOMINAL VISCOUS	-35	-36	DUMMY STIFFNESS CONSTANT F = 0.1	37
0	1- 1 LT DUMMY ABSORPTION	17- 17	33 LHD CONSTANT = 0.0		-34 ABDOMINAL VISCOUS	-35	-36	DUMMY STIFFNESS CONSTANT F = 0.1	37
0	2- 2 MT DUMMY ABSORPTION	6- 6	33 RUL CONSTANT = 0.0		-34 ABDOMINAL VISCOUS	-35	-36	DUMMY STIFFNESS CONSTANT F = 0.1	37
0	2- 2 MT DUMMY ABSORPTION	9- 9	33 LUL CONSTANT = 0.0		-34 ABDOMINAL VISCOUS	-35	-36	DUMMY STIFFNESS CONSTANT F = 0.1	37
0	2- 2 MT DUMMY ABSORPTION	17- 17	33 LHD CONSTANT = 0.0		-34 ABDOMINAL VISCOUS	-35	-36	DUMMY STIFFNESS CONSTANT F = 0.1	37
0	2- 2 MT DUMMY ABSORPTION	16- 16	33 RHD CONSTANT = 0.0		-34 ABDOMINAL VISCOUS	-35	-36	DUMMY STIFFNESS CONSTANT F = 0.1	37
0	3- 3 UT DUMMY ABSORPTION	13- 13	33 RLA CONSTANT = 0.0		-34 ABDOMINAL VISCOUS	-35	-36	DUMMY STIFFNESS CONSTANT F = 0.1	37
0	3- 3	15- 15	33		-34	-35	-36		37

```
UT        LLA CONSTANT = 0.0                 ABDOMINAL VISCOUS      DUMMY STIFFNESS                    0
          DUMMY ABSORPTION              -34                    -35  CONSTANT F = 0.1             37
                                                                          -36

3- 3   6- 6    33                           ABDOMINAL VISCOUS      DUMMY STIFFNESS                    0
  UT     RUL CONSTANT = 0.0            -34                    -35  CONSTANT F = 0.1             37
          DUMMY ABSORPTION                                                -36
0

3- 3   9- 9    33                           ABDOMINAL VISCOUS      DUMMY STIFFNESS                    0
  UT     LUL CONSTANT = 0.0            -34                    -35  CONSTANT F = 0.1             37
          DUMMY ABSORPTION                                                -36
0

5- 5   13- 13   33                          ABDOMINAL VISCOUS      DUMMY STIFFNESS                    0
  H      RLA CONSTANT = 0.0            -34                    -35  CONSTANT F = 0.1             37
          DUMMY ABSORPTION                                                -36
0

5- 5   15- 15   33                          ABDOMINAL VISCOUS      DUMMY STIFFNESS                    0
  H      LLA CONSTANT = 0.0            -34                    -35  CONSTANT F = 0.1             37
          DUMMY ABSORPTION                                                -36
0

5- 5   16- 16   33                          ABDOMINAL VISCOUS      DUMMY STIFFNESS                    0
  H      RHD CONSTANT = 0.0            -34                    -35  CONSTANT F = 0.1             37
          DUMMY ABSORPTION                                                -36
0

5- 5   17- 17   33                          ABDOMINAL VISCOUS      DUMMY STIFFNESS                    0
  H      LHD CONSTANT = 0.0            -34                    -35  CONSTANT F = 0.1             37
          DUMMY ABSORPTION                                                -36
0

6- 6   12- 12   33                          ABDOMINAL VISCOUS      DUMMY STIFFNESS                    0
  RUL    RUA CONSTANT = 0.0            -34                    -35  CONSTANT F = 0.1             37
          DUMMY ABSORPTION                                                -36
0

6- 6   13- 13   33                          ABDOMINAL VISCOUS      DUMMY STIFFNESS                    0
  RUL    RLA CONSTANT = 0.0            -34                    -35  CONSTANT F = 0.1             37
          DUMMY ABSORPTION                                                -36
0

6- 6   16- 16   33                          ABDOMINAL VISCOUS      DUMMY STIFFNESS                    0
  RUL    RHD CONSTANT = 0.0            -34                    -35  CONSTANT F = 0.1             37
          DUMMY ABSORPTION                                                -36
0

6- 6   9- 9    33                           ABDOMINAL VISCOUS      DUMMY STIFFNESS                    0
  RUL    LUL CONSTANT = 0.0            -34                    -35  CONSTANT F = 0.1             37
          DUMMY ABSORPTION                                                -36
0

6- 6   17- 17   33                          ABDOMINAL VISCOUS      DUMMY STIFFNESS                    0
  RUL    LHD CONSTANT = 0.0            -34                    -35  CONSTANT F = 0.1             37
          DUMMY ABSORPTION                                                -36
0

7- 7   10- 10   33                     -34  ABDOMINAL VISCOUS -35        -36                     37   0
0
```

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```
                    RLL         LLL CONSTANT = 0.0
          DUMMY ABSORPTION          ABDOMINAL VISCOUS      DUMMY STIFFNESS
                                                           CONSTANT F = 0.1

 0   7- 7    11- 11    33             -34    -35            -36      37     0
     RLL     LF  CONSTANT = 0.0   ABDOMINAL VISCOUS    DUMMY STIFFNESS
     DUMMY ABSORPTION                                  CONSTANT F = 0.1

 0   9- 9    15- 15    33             -34    -35            -36      37     0
     LUL     LLA CONSTANT = 0.0   ABDOMINAL VISCOUS    DUMMY STIFFNESS
     DUMMY ABSORPTION                                  CONSTANT F = 0.1

 0   9- 9    14- 14    33             -34    -35            -36      37     0
     LUL     LUA CONSTANT = 0.0   ABDOMINAL VISCOUS    DUMMY STIFFNESS
     DUMMY ABSORPTION                                  CONSTANT F = 0.1

 0   9- 9    16- 16    33             -34    -35            -36      37     0
     LUL     RHD CONSTANT = 0.0   ABDOMINAL VISCOUS    DUMMY STIFFNESS
     DUMMY ABSORPTION                                  CONSTANT F = 0.1

 0   9- 9    17- 17    33             -34    -35            -36      37     0
     LUL     LHD CONSTANT = 0.0   ABDOMINAL VISCOUS    DUMMY STIFFNESS
     DUMMY ABSORPTION                                  CONSTANT F = 0.1

 0   10- 10  8- 8      33             -34    -35            -36      37     0
     LLL     RF  CONSTANT = 0.0   ABDOMINAL VISCOUS    DUMMY STIFFNESS
     DUMMY ABSORPTION                                  CONSTANT F = 0.1

 0   13- 13  15- 15    33             -34    -35            -36      37     0
     RLA     LLA CONSTANT = 0.0   ABDOMINAL VISCOUS    DUMMY STIFFNESS
     DUMMY ABSORPTION                                  CONSTANT F = 0.1

 0   13- 13  17- 17    33             -34    -35            -36      37     0
     RLA     LHD CONSTANT = 0.0   ABDOMINAL VISCOUS    DUMMY STIFFNESS
     DUMMY ABSORPTION                                  CONSTANT F = 0.1

 0   13- 13  2- 2      33             -34    -35            -36      37     0
     RLA     MT  CONSTANT = 0.0   ABDOMINAL VISCOUS    DUMMY STIFFNESS
     DUMMY ABSORPTION                                  CONSTANT F = 0.1

 0   15- 15  16- 16    33             -34    -35            -36      37     0
     LLA     RHD CONSTANT = 0.0.  ABDOMINAL VISCOUS    DUMMY STIFFNESS
     DUMMY ABSORPTION                                  CONSTANT F = 0.1

 0   15- 15  2- 2      33             -34    -35            -36      37     0
     LLA     MT  CONSTANT = 0.0   ABDOMINAL VISCOUS    DUMMY STIFFNESS
     DUMMY ABSORPTION                                  CONSTANT F = 0.1

 0   18- 18  3- 3      27             -20    -21            -16      17     0
```

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```
                 LAR              UT ARM RESTS.     DAMPING COEFF. C=200 RATE OF DEFLEC.          CONSTANT = 0.0
 0   18- 18  LAR    CONSTANT, F=0.9   14- 14  27            -21                  -20          -16    17    0
                 LUA ARM RESTS.                    DAMPING COEFF. C=200 RATE OF DEFLEC.          CONSTANT = 0.0
 0   18- 18  LAR    CONSTANT, F=0.9   15- 15  27            -21                  -20          -16    17    0
                 LLA ARM RESTS.                    DAMPING COEFF. C=200 RATE OF DEFLEC.          CONSTANT = 0.0
 0   18- 18  LAR    CONSTANT, F=0.9   17- 17  27            -21                  -20          -16    17    0
                 LHD ARM RESTS.                    DAMPING COEFF. C=200 RATE OF DEFLEC.          CONSTANT = 0.0
 0   19- 19  RAR    CONSTANT, F=0.9    3-  3  27            -21                  -20          -16    17    0
                 UT  ARM RESTS.                    DAMPING COEFF. C=200 RATE OF DEFLEC.          CONSTANT = 0.0
 0   19- 19  RAR    CONSTANT, F=0.9   12- 12  27            -21                  -20          -16    17    0
                 RUA ARM RESTS.                    DAMPING COEFF. C=200 RATE OF DEFLEC.          CONSTANT = 0.0
 0   19- 19  RAR    CONSTANT, F=0.9   13- 13  27            -21                  -20          -16    17    0
                 RLA ARM RESTS.                    DAMPING COEFF. C=200 RATE OF DEFLEC.          CONSTANT = 0.0
 1
478                                                                                              PAGE
```

THE FOLLOWING JOINT RESTORING FORCE FUNCTIONS AS DEFINED ON CARDS E.7 WILL BE USED.   CARD F.5

```
  JOINT      FUNCTION

  1- P       45-STANDING LUMBAR SPIN
  2- W       45-STANDING LUMBAR SPIN
  3- NP      46-NECK PIVOT
  4- HP      47-HEAD PIVOT
  5- RH      43-STANDING RIGHT HIP
  8- LH      44-STANDING LEFT HIP
 11- RS      41-RIGHT SHOULDER JOINT
 13- LS      42-LEFT SHOULDER JOINT
 1 SUBROUTINE INITIAL INPUT
479                                                                                              PAGE
```

```
 ZPLT(X)  ZPLT(Y)  ZPLT(Z)  ZPLT(2)   I1   J1   I2   J2   I3   SPLT(1)  SPLT(2)  SPLT(3)          CARD G.1
   0.       0.       0.       0.        0    0    0    0    0   10.00    6.00     1.00
0 INITIAL POSITIONS
```

```
 SEGMENT       LINEAR POSITION ( IN.)          LINEAR VELOCITY ( IN./SEC.)                        CARDS
   G.2
               (IREF4 REFERENCE)                      (INERTIAL)
 NO. SEG     X         Y         Z           X         Y         Z        IREF2  IREF4
  1  LT    1.50000  -2.85000  -28.06000    .00000    .00000    .00000       0      0
```

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NO.	SEG						
2	MT	1.34123	-4.26747	-31.77581	.00000	0	0
3	UT	.97439	-2.93897	-40.11971	.00000	0	0
4	N	.59403	-2.48303	-48.81948	.00000	0	0
5	H	.38291	-1.68072	-53.61946	.00000	0	0
6	RUL	-2.34943	4.19298	-26.69936	.00000	0	0
7	RLL	-3.22346	12.60220	-20.44380	.00000	0	0
8	RF	-3.45401	13.44036	-9.12360	.00000	0	0
9	LUL	5.44608	4.20861	-27.03937	.00000	0	0
10	LLL	6.10280	12.68430	-20.84724	.00000	0	0
11	LF	6.13119	13.62648	-9.53292	.00000	0	0
12	RUA	-6.95861	-1.82842	-37.41859	.00000	0	0
13	RLA	-4.16265	1.49730	-32.03443	.00000	0	0
14	LUA	7.74932	.12203	-39.27649	.00000	0	0
15	LLA	3.67075	3.53817	-35.29350	.00000	0	0
16	RHD	3.24257	4.45418	-31.07660	.00000	0	0
17	LHD	-4.49226	3.58474	-34.35268	.00000	0	0
18	LAR	10.50000	-3.50000	-31.75000	.00000	0	0
19	RAR	-10.50000	-3.50000	-31.75000	.00000	0	0

0 INITIAL ANGULAR ROTATION AND VELOCITY

SEGMENT		ANGULAR ROTATION (DEG) (IYPR4 REFERENCE)			ANGULAR VELOCITY (DEG/SEC.) (LOCAL)			IYPR		
NO.	SEG	YAW	PITCH	ROLL	X	Y	Z			
1	LT	90.00000	2.50000	3.00000	.00000	.00000	.00000	1	2	3	21
2	MT	.00000	.00000	.00000	.00000	.00000	.00000	3	2	1	1
3	UT	.00000	.00000	.00000	.00000	.00000	.00000	3	2	1	2
4	N	.00000	.00000	.00000	.00000	.00000	.00000	3	2	1	3
5	H	.00000	.00000	.00000	.00000	.00000	.00000	3	2	1	4
6	RUL	5.00000	97.80000	-3.00000	.00000	.00000	.00000	3	2	-3	6
7	RLL	.00000	-100.00000	.00000	.00000	.00000	.00000	3	2	1	7
8	RF	.00000	.00000	.00000	.00000	.00000	.00000	3	2	1	9
9	LUL	-5.00000	97.80000	-3.00000	.00000	.00000	.00000	3	2	-3	9
10	LLL	.00000	-100.00000	.00000	.00000	.00000	.00000	3	2	1	10
11	LF	.00000	.00000	.00000	.00000	.00000	.00000	3	2	1	3
12	RUA	-67.00000	23.10000	-7.60000	.00000	.00000	.00000	1	2	3	12
13	RLA	-30.00000	74.00000	.00000	.00000	.00000	.00000	1	2	3	3
14	LUA	101.00000	47.15000	-10.00000	.00000	.00000	.00000	1	2	3	14
15	LLA	90.00000	80.00000	.00000	.00000	.00000	.00000	1	2	3	13
16	RHD	.00000	20.00000	-2.70000	.00000	.00000	.00000	3	2	1	15
17	LHD	.00000	-12.00000	.00000	.00000	.00000	.00000	3	2	1	21
18	LAR	.00000	.00000	.00000	.00000	.00000	.00000	3	2	1	21
19	RAR	.00000	.00000	.00000	.00000	.00000	.00000	3	2	1	

0 LINEAR AND ANGULAR VELOCITIES HAVE BEEN SET EQUAL TO THE INITIAL VELOCITIES OF THE PRIMARY VEHICLE
FOR ALL NONVEHICLE BODY SEGMENTS WITH IREF2 = 0. FOR NONVEHICLE SEGMENTS WITH IREF2 # 0, THE LINEAR
AND ANGULAR VELOCITIES WERE DETERMINED BY THE VALUES OF IREF2.

0 INITIAL LENGTHS OF BELT NO. 1 AND ITS SEGMENTS ARE   34.1691   17.2227   16.9463   IN.
0 INITIAL TANGENT POINTS IN LOCAL REFERENCE OF SEGMENT 1 ARE:

.229 6.411 -2.155 -.430 -6.997 -1.000

TABULAR TIME HISTORY CONTROL PARAMETERS
```
TYPE  KSG     SELECTED SEGMENTS OR JOINTS
H.1    3     -5 -3 -1
       REF    0  0  0
```
NOTE: BEGINNING WITH ATB VERSION IV.3, THE 0 G ACCELEROMETER OPTION IS NOT AVAILABLE.
ALL ACCELEROMETER OUTPUT USES THE CORRECTED 1 G OPTION.
```
H.2    3      5  3  1
       REF    0  0  0
H.3    3      5  3  1
       REF    0  0  0
H.4    1      5
       REF    0
H.5    1      5
       REF    0
H.6    1      5
       REF    3
H.7    2     17 18
       REF    0  0
H.8    0
       REF
H.9    0
       REF
```

1
480 MAIN3D FUNCTIONS FOR TIME= .000 MSEC   PAGE

SEGMENT		(INERTIAL) ANGULAR ROTATION (DEG)			(LOCAL) ANGULAR VELOCITY (RAD/SEC.)			(LOCAL) ANGULAR ACCELERATION (RAD/SEC.**2)		
		YAW	PITCH	ROLL	X	Y	Z	X	Y	Z
1	LT	90.0000	-3.0000	2.5000	.00000	.00000	.00000	-93.213121	211.556025	24.202026
2	MT	90.0000	-3.0000	2.5000	.00000	.00000	.00000	-174.521936	-110.659244	1189.095735
3	UT	90.0000	-3.0000	2.5000	.00000	.00000	.00000	17.673238	-16.692019	3.411827
4	N	90.0000	-3.0000	2.5000	.00000	.00000	.00000	-9.764013	27.170509	.000000
5	H	90.0000	-3.0000	2.5000	.00000	.00000	.00000	.562067	-12.358069	.187688
6	RUL	-75.1875	85.3487	-170.5247	.00000	.00000	.00000	7.625228	-55.145721	-3.231657
7	RLL	95.4403	-5.4114	-.7683	.00000	.00000	.00000	-4.506668	-2.170170	-6.948212
8	RF	95.4403	-5.4114	-.7683	.00000	.00000	.00000	-4.506668	-40.220477	-10.147773
9	LUL	88.1224	95.0260	2.7382	.00000	.00000	.00000	-.442195	-30.810055	22.741552
10	LLL	85.4156	-4.9797	-.2407	.00000	.00000	.00000	22.472844	-11.528305	-3.513552
11	LF	85.4156	-4.9797	-.2407	.00000	.00000	.00000	22.472844	-3.445405	64.840058
12	RUA	21.2913	2.9783	-20.4917	.00000	.00000	.00000	-44.181892	-21.734874	28.784412
13	RLA	-53.4712	38.0501	-74.6917	.00000	.00000	.00000	-23.641539	-38.746720	-34.536302
14	LUA	-172.5222	-.2153	44.6255	.00000	.00000	.00000	-35.826416	-3.107157	-14.255682
15	LLA	-82.3097	-44.6251	79.6974	.00000	.00000	.00000	-3.107157	-7.817914	-37.757605
16	RHD	-79.2079	40.5632	-93.8645	.00000	.00000	.00000	-271.295828	729.177426	394.297534
17	LHD	80.7133	-134.4731	-88.2378	.00000	.00000	.00000	-5.888130	5.547303	-12.756876

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		(INERTIAL)			(INERTIAL)			(INERTIAL)		
18	LAR	.0000	.0000	.0000	.00000	.00000	.00000	42.738582	-.005158	.000000
19	RAR	.0000	.0000	.0000	.00000	.00000	.00000	42.750585	-.005158	.000000
20	VEH	.0000	.0000	.0000	.00000	.00000	.00000	.009968	-.005158	.000000

		(INERTIAL) LINEAR POSITION (IN.)			(INERTIAL) LINEAR VELOCITY (IN./SEC.)			(INERTIAL) LINEAR ACCELERATIONS (G'S)		
SEGMENT		X	Y	Z	X	Y	Z	X	Y	Z
1	LT	1.5000	-2.8500	-28.0600	.00000	.00000	.00000	.329369	.946405	-1.214528
2	MT	1.3412	-4.2675	-31.7758	.00000	.00000	.00000	-.765069	-.892270	.464897
3	UT	.9744	-2.9390	-40.1197	.00000	.00000	.00000	-.117308	.093034	.516524
4	N	.5940	-2.4830	-48.8195	.00000	.00000	.00000	-.085519	.155925	.528688
5	H	.3829	-1.6807	-53.6195	.00000	.00000	.00000	-.016173	.019502	.536152
6	RUL	-2.3494	4.1930	-26.6994	.00000	.00000	.00000	-.077636	-.133357	-.906919
7	RLL	-3.2235	12.6022	-20.4438	.00000	.00000	.00000	.000991	.170570	.361705
8	RF	-3.4540	13.4404	-9.1236	.00000	.00000	.00000	-.057860	.070429	.559139
9	LUL	5.4461	4.2086	-27.0394	.00000	.00000	.00000	-.147287	.404008	.239210
10	LLL	6.1028	12.6843	-20.8472	.00000	.00000	.00000	.233908	.214853	.938527
11	LF	6.1312	13.6265	-9.5329	.00000	.00000	.00000	.502253	-.109609	.926448
12	RUA	-6.9586	-1.8284	-37.4186	.00000	.00000	.00000	-.489810	.554201	.621822
13	RLA	-4.1627	1.4973	-32.0344	.00000	.00000	.00000	-1.154917	1.318745	.494961
14	LUA	7.7493	.1220	-39.2765	.00000	.00000	.00000	.078353	-.057302	.509712
15	LLA	3.6708	3.5382	-35.2935	.00000	.00000	.00000	-.156854	-.302094	.800051
16	RHD	3.2426	4.4542	-31.0766	.00000	.00000	.00000	-1.809961	-.065665	-3.365507
17	LHD	-4.4923	3.5847	-34.3527	.00000	.00000	.00000	.152008	-.186535	.785654
18	LAR	10.5000	-3.5000	-31.7500	.00000	.00000	.00000	.000424	-.002567	.720555
19	RAR	-10.5000	-3.5000	-31.7500	.00000	.00000	.00000	.000424	-.002567	.720477
20	VEH	.0000	.0000	.0000	.00000	.00000	.00000	.000000	-.003386	.001146

PAGE

		U1 ARRAY (INERTIAL) EXTERNAL LINEAR ACCELERATIONS (IN./SEC.**2)			U2 ARRAY (LOCAL) EXTERNAL ANGULAR ACCELERATIONS (RAD/SEC.**2)			KINETIC ENERGY (LB.- IN.)		
SEGMENT		X	Y	Z	X	Y	Z	LINEAR	ANGULAR	TOTAL
1	LT	-.2025D-15	.3038D-13	-.1276D+04	-.10694D+03	.98991D+02	.39954D+02	.00000D+00	.00000D+00	.00000D+00
2	MT	.8829D+03	-.1463D-04	-.1408D+03	-.42639D+03	.61269D+03	.15204D+04	.00000D+00	.00000D+00	.00000D+00
3	UT	.0000D+00	.0000D+00	.3861D+03	.00000D+00	.00000D+00	.00000D+00	.00000D+00	.00000D+00	.00000D+00
4	N	.0000D+00	.0000D+00	.3861D+03	.00000D+00	.00000D+00	.00000D+00	.00000D+00	.00000D+00	.00000D+00
5	H	.0000D+00	.0000D+00	.3861D+03	-.80957D+01	.18905D+02	-.80978D+02	.00000D+00	.00000D+00	.00000D+00
6	RUL	-.1613D-13	-.2937D-13	-.3258D+03	-.43751D-16	-.94597D-34	.14019D-14	.00000D+00	.00000D+00	.00000D+00
7	RLL	.0000D+00	.0000D+00	.3861D+03	-.11783D-14	-.44045D-16	-.13236D-14	.00000D+00	.00000D+00	.00000D+00
8	RF	.0000D+00	.0000D+00	.3861D+03	.32385D+02	.17786D+02	.29110D+03	.00000D+00	.00000D+00	.00000D+00
9	LUL	.2079D+02	.2050D+02	.1814D+03	.10848D-14	.82537D-33	-.34760D-13	.00000D+00	.00000D+00	.00000D+00
10	LLL	.0000D+00	.0000D+00	.3861D+03				.00000D+00	.00000D+00	.00000D+00

11	LF	.0000D+00	.29214D-13	.32818D-13	.3861D+03	.00000D+00	.00000D+00	.00000D+00
12	RUA	.0000D+00	.00000D+00	.00000D+00	.3861D+03	.00000D+00	.00000D+00	.00000D+00
13	RLA	-.6182D+03	-.34128D+02	-.12577D+02	.5579D+03	.00000D+00	.00000D+00	.00000D+00
14	LUA	.0000D+00	.00000D+00	.00000D+00	.3861D+03	.00000D+00	.00000D+00	.00000D+00
15	LLA	.0000D+00	.00000D+00	.00000D+00	.3861D+03	.00000D+00	.00000D+00	.00000D+00
16	RHD	-.3220D+03	.63509D+03	.65836D+03	-.1220D+04	.00000D+00	.00000D+00	.00000D+00
17	LHD	.0000D+00	.00000D+00	.00000D+00	.3861D+03	.00000D+00	.00000D+00	.00000D+00
18	LAR	.0000D+00	.00000D+00	.00000D+00	.3861D+03	.00000D+00	.00000D+00	.00000D+00
19	RAR	.0000D+00	.00000D+00	.00000D+00	.3861D+03	.00000D+00	.00000D+00	.00000D+00

TOTAL BODY KINETIC ENERGY   .00000D+00   .00000D+00   .00000D+00

JOINT	IPIN	(INERTIAL) JOINT FORCES (LB.)			(INERTIAL) JOINT TORQUES (IN. LB.)			RELATIVE ANGULAR VELOCITY (RAD/SEC.)
		X	Y	Z	X	Y	Z	
1	P	0	-.457D+01	.877D+01	-.335D+02	.0000D+00	.0000D+00	.0000D+00	.000
2	W	0	.355D+01	.106D+01	-.337D+02	.0000D+00	.0000D+00	.0000D+00	.000
3	NP	0	-.389D+00	.609D+00	-.586D+01	.0000D+00	.0000D+00	.0000D+00	.000
4	HP	0	-.160D+00	.193D+00	-.460D+01	.0000D+00	.0000D+00	.0000D+00	.000
5	RH	0	-.170D+01	.371D+01	-.710D+01	.2899D+02	-.1241D+02	.1227D+00	.000
6	RK	1	-.152D+00	.104D+01	-.583D+01	.5831D+00	-.6068D+01	.9662D+00	.000
7	RA	3	-.159D+00	.194D+00	-.122D+01	-.2263D-01	-.2377D+00	-.2261D-01	.000
8	LH	0	-.942D+00	.827D+01	-.526D+01	.3243D+02	.5722D+02	.6581D+01	.000
9	LK	1	.308D+01	-.125D+01	-.648D+00	.4012D+01	.5003D+02	-.4389D+01	.000
10	LA	3	.138D+01	-.302D+00	-.203D+00	.1499D+00	.1869D+01	.1634D+00	.000
11	RS	0	-.181D+01	-.155D+01	-.561D+01	.0000D+00	.0000D+00	.0000D+00	.000
12	RE	7	.437D+00	-.410D+01	-.388D+01	-.6331D+01	.1467D+02	-.6184D+01	.000
13	LS	0	.115D+01	-.165D+01	-.329D+01	.0000D+00	.0000D+00	.0000D+00	.000
14	LE	7	.792D+00	-.139D+01	-.104D+01	.1094D+01	-.5737D+01	.6078D+01	.000
15	RW	3	-.126D+01	.976D+00	-.266D+00	-.1107D+01	.1343D+01	.1777D+01	.000
16	LW	3	.196D+00	-.241D+00	-.277D+00	.7119D-01	-.5272D+00	.5251D+00	.000
17	LR	1	.848D-03	-.513D-02	-.559D+00	.0000D+00	-.1135D-04	-.5515D-02	.000
18	RR	1	.848D-03	-.513D-02	-.559D+00	.0000D+00	-.1135D-04	-.5515D-02	.000

1 ELAPSED CPU TIME =   1.53 SECONDS
482

SUB   CALLS   TIME   %

0 AT TIME =   .000 MSEC, IEULER(12) HAS BEEN CHANGED FROM 7 TO 4
0 AT TIME =   .000 MSEC, IEULER(14) HAS BEEN CHANGED FROM 7 TO 4
1 ELAPSED CPU TIME =   291.62 SECONDS
482
1   MAIN3D FUNCTIONS FOR TIME=   10.000 MSEC
482

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(INERTIAL) ANGULAR ROTATION, (LOCAL) ANGULAR VELOCITY & ACCELERATION

SEGMENT		ANGULAR ROTATION (DEG) (INERTIAL)			ANGULAR VELOCITY (LOCAL) (RAD/SEC.)			ANGULAR ACCELERATION (LOCAL) (RAD/SEC.**2)	
		YAW	PITCH	ROLL	X	Y	Z	X	Y	Z
1	LT	90.0245	-2.7572	2.4018	-.24341	.58987	.02802	-4.476438	7.077988	.860740
2	MT	90.0507	-3.0746	2.5070	.01097	-.09646	.08797	-2.134510	13.075598	1.438002
3	UT	90.0256	-3.0922	2.5486	.14961	.29424	.09574	6.472080	-16.485284	6.004483
4	N	90.0201	-2.9375	2.4768	-.03917	.12804	.05707	5.596939	-14.514762	3.706163
5	H	89.9987	-3.0060	2.4808	-.08748	.04779	-.00218	-9.691450	20.158266	1.074258
6	RUL	-74.8620	85.4042	-170.2016	-.00571	-.13441	-.06240	.160397	1.096245	-7.039095
7	RLL	95.4443	-5.4016	-.7848	-.06048	.02456	.01639	-6.963888	-.205619	1.046384
8	RF	95.4211	-5.4794	-.7826	-.06055	.17341	-.04702	-6.974102	-4.441306	.433218
9	LUL	87.6327	94.9589	2.2271	-.07703	.18612	.14241	-5.356637	-9.073388	10.585248
10	LLL	85.4307	-4.9804	-.1932	.15356	-.08277	.05130	11.341328	-2.170373	3.478066
11	LF	85.4708	-5.0035	-.1967	.15361	-.08871	.11956	11.350319	-8.896814	1.059818
12	RUA	21.3459	2.9756	-20.5883	-.25928	-.05375	.14856	2.244796	-.618909	12.332573
13	RLA	-53.4267	37.9568	-74.7223	-.18209	-.16718	-.20055	-16.698077	-10.347058	7.963744
14	LUA	-172.5365	-.2248	44.4822	-.48989	-.06278	-.00834	-41.809327	-6.995660	-1.829740
15	LLA	-82.3764	-44.4820	79.7274	-.06315	-.06611	-.50906	-7.098349	-3.906672	-43.128469
16	RHD	-79.5145	40.5473	-94.1646	-.22376	.29336	-.08824	-14.857714	-25.099808	-3.328472
17	LHD	80.6938	-134.6134	-88.2708	-.16687	-.06348	-.48147	-15.958614	-4.423336	-40.954376
18	LAR	.0000	.0000	.1211	.41325	-.00003	.00000	35.792192	.004245	-.000020
19	RAR	.0000	.0000	.1211	.41320	.00003	.00000	35.786579	.004245	-.000020
20	VEH	.0000	.0000	.0000	.00000	.00003	.00000	-.018540	.004246	.000000

(INERTIAL) LINEAR POSITION, VELOCITY & ACCELERATIONS

SEGMENT		LINEAR POSITION (IN.) (INERTIAL)			LINEAR VELOCITY (IN./SEC.) (INERTIAL)			LINEAR ACCELERATIONS (G'S) (INERTIAL)	
		X	Y	Z	X	Y	Z	X	Y	Z
1	LT	1.5052	-2.8611	-28.0708	.82459	-1.64020	-1.56907	.061102	-.071389	-.096296
2	MT	1.3481	-4.2806	-31.7750	1.11659	-2.10491	-.03844	.089811	-.176082	-.086068
3	UT	.9754	-2.9396	-40.1166	.13973	-.15648	.37275	-.006492	-.016094	-.033250
4	N	.5909	-2.4773	-48.8158	-.64371	1.23943	.48417	-.146727	.340951	-.006230
5	H	.3815	-1.6779	-53.6159	-.35761	.78288	.42188	-.140446	.344811	-.035030
6	RUL	-2.3482	4.1908	-26.7077	.24502	-.38820	-1.32580	.043914	-.042649	-.154172
7	RLL	-3.2246	12.6014	-20.4430	-.26722	-.20775	-.12662	-.077678	-.059432	-.181389
8	RF	-3.4576	13.4389	-9.1203	-.83755	-.32706	.23318	-.278520	-.103648	-.162417
9	LUL	5.4450	4.2079	-27.0359	-.21941	-.17818	.64555	-.066712	.000719	.111327
10	LLL	6.1040	12.6839	-20.8836	-.15365	-.12790	2.29987	.010159	-.031662	.318192
11	LF	6.1399	13.6246	-9.5184	1.60935	-.42429	2.47738	.326393	-.150655	.358424
12	RUA	-6.9646	-1.8215	-37.4135	-.91125	.98519	.75462	-.030400	-.053863	.064796
13	RLA	-4.1757	1.5157	-32.0328	-1.99956	2.80882	.18766	-.096962	.080386	.013707
14	LUA	7.7510	.1204	-39.2711	.35679	-.43346	.96989	.108413	-.183966	.230074
15	LLA	3.6750	3.5297	-35.2797	.89196	-1.76891	2.65706	.250798	-.478790	.624109
16	RHD	3.2251	4.4759	-31.0842	-2.71757	3.94569	-.77138	-.227187	.506402	-.057924
17	LHD	-4.4881	3.5803	-34.3389	-.90116	-.96856	2.69642	-.258987	-.299361	.682461
18	LAR	10.5000	-3.5001	-31.7363	-.00086	-.01504	2.68533	-.000348	-.002297	.596589

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 19 RAR    -10.5000    -3.5001   -31.7363    -.00086    -.01504    2.68556    -.000348    -.002296    .596725
 20 VEH       .0000      -.0001      .0000     .00000    -.00943    -.00047     .000000     .003376   -.006350
  1                                                                                                       PAGE
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		(INERTIAL) EXTERNAL LINEAR ACCELERATIONS (IN./SEC.**2) U1 ARRAY			(LOCAL) EXTERNAL ANGULAR ACCELERATIONS U2 ARRAY (RAD/SEC.**2)			KINETIC ENERGY (LB.- IN.)		
SEGMENT		X	Y	Z	X	Y	Z	LINEAR	ANGULAR	TOTAL
1	LT	.6842D+02	-.6001D+03	-.1248D+04	.18365D+02	-.37583D+03	.34384D+02	.16550D+00	.12581D+00	.29131D+00
2	MT	.3515D+03	-.5172D+03	.2634D+03	-.10198D+04	.38077D+04	-.30466D+03	.19570D-01	.12449D-03	.19695D-01
3	UT	.0000D+00	.0000D+00	.3861D+03	-.86469D+01	.15702D+02	-.97520D+00	.92916D-02	.12494D+00	.13423D+00
4	N	.0000D+00	.0000D+00	.3861D+03	-.24252D+03	-.72718D+03	.37062D+01	.75494D-02	.24383D-03	.77933D-02
5	H	.0000D+00	.0000D+00	.3861D+03	.33306D+01	.20210D+02	.54226D+01	.11804D-01	.81997D-03	.12624D-01
6	RUL	-.6399D+02	.3595D+02	-.3174D+03	-.21869D+02	.91165D+02	-.18174D+03	.50944D-01	.14930D-01	.65874D-01
7	RLL	.0000D+00	.0000D+00	.3861D+03	.14440D+01	-.21911D+02	-.46370D+02	.12240D-02	.14137D-02	.26377D-02
8	RF	.0000D+00	.0000D+00	.3861D+03	.50939D+02	-.11088D+03	.48307D+02	.30795D-02	.81305D-03	.38926D-02
9	LUL	-.2248D+01	.2676D+03	-.1902D+02	.22221D+02	.72530D+02	.18270D+03	.12853D-01	.37379D-01	.50231D-01
10	LLL	.0000D+00	.0000D+00	.3861D+03	.15660D+01	.19227D+02	.50256D+02	.49948D-01	.81216D-02	.58070D-01
11	LF	.0000D+00	.0000D+00	.3861D+03	-.47389D+02	.49035D+02	-.49398D+02	.31792D-01	.49388D-03	.32286D-01
12	RUA	-.2462D+03	.3622D+03	.4720D+03	.32586D+01	.23825D+01	.65366D+01	.14112D-01	.36248D-02	.17737D-01
13	RLA	.0000D+00	.0000D+00	.3861D+03	-.36968D+02	.96359D+02	.68107D+03	.58675D-01	.37834D-02	.62458D-01
14	LUA	.0000D+00	.0000D+00	.3861D+03	.10081D+02	.29936D+01	-.11742D+02	.74765D-02	.12487D-01	.19964D-01
15	LLA	.0000D+00	.0000D+00	.3861D+03	-.79214D+00	.89448D+01	.38155D+02	.54057D-01	.14679D-02	.55525D-01
16	RHD	-.2227D+03	-.3819D+03	-.9030D+03	-.38769D+02	-.83139D+02	-.21449D+03	.39341D-01	.61547D-03	.39956D-01
17	LHD	.0000D+00	.0000D+00	.3861D+03	-.10291D+02	-.71227D+01	-.22771D+02	.15070D-01	.54324D-03	.15614D-01
18	LAR	.0000D+00	.0000D+00	.3861D+03	-.25905D+02	-.13919D-07	.10694D-04	.18678D-01	.72579D-02	.25936D-01
19	RAR	.0000D+00	.0000D+00	.3861D+03	-.25890D+02	-.13914D-07	.10692D-04	.18681D-01	.72560D-02	.25937D-01

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                                                    TOTAL BODY KINETIC ENERGY
                                          .58965D+00      .35212D+00      .94177D+00
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		(INERTIAL) JOINT FORCES (LB.)			(INERTIAL) JOINT TORQUES (IN. LB.)			RELATIVE ANGULAR VELOCITY (RAD/SEC.)
JOINT	IPIN	X	Y	Z	X	Y	Z	
1	P	0	-.722D-01	.217D+01	-.668D+02	-.8526D+02	-.3016D+02	-.3361D+01	.734
2	W	0	.211D+01	-.930D+00	-.648D+02	-.15581D+02	-.1440D+02	.2344D+02	.242
3	NP	0	-.178D+01	.433D+01	-.130D+02	.1441D+02	.6526D+01	.6721D+00	.464
4	HP	0	-.139D+01	.342D+01	.103D+02	-.4257D+01	.3279D+00	.1132D+01	.111
5	RH	0	.286D+01	-.202D+02	.160D+01	-.1285D+02	-.2416D+02	.1820D+01	.754
6	RK	1	-.133D+01	-.716D+00	.118D+02	-.1137D+02	-.2360D+02	-.3073D+00	.159
7	RA	3	-.768D+00	-.286D+00	-.320D+01	-.5528D+01	-.2035D+01	.1631D+01	.208
8	LH	0	-.244D+00	-.145D+02	-.349D+01	-.1291D+02	.3408D+02	-.7700D+01	.872
9	LK	1	.973D+00	-.644D+00	-.670D+01	.1246D+02	.2395D+02	.5616D+00	.183
10	LA	3	.900D+00	-.415D+00	-.177D+01	-.2313D+01	.1857D+01	-.1868D+01	.110

11	RS	0	.237D+01	-.158D+01	-.595D+01	.3050D+01	.1344D+01	-.4624D+00	.587
12	RE	4	.251D+01	-.133D+01	-.165D+01	.2618D+01	-.1897D+02	.6852D+01	.028
13	LS	0	.179D+01	-.305D+01	-.538D+01	-.1045D+01	.2455D+00	.8158D+00	.235
14	LE	4	.129D+01	-.221D+01	-.184D+01	.1779D+01	-.8805D+01	.1013D+02	.145
15	RW	3	.451D+00	.193D+01	.294D+01	-.1077D+01	.1267D+02	.6495D+01	.495
16	LW	3	.334D+00	-.386D+00	-.410D+00	.2015D+00	-.8795D+00	.7541D+00	.004
17	LR	1	-.697D-03	-.459D-02	-.807D+00	-.2202D+01	-.2248D-06	-.4526D-02	.413
18	RR	1	-.697D-03	-.459D-02	-.807D+00	-.2201D+01	-.2220D-06	-.4526D-02	.413

.1 ELAPSED CPU TIME = 2902.07 SECONDS

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APPENDIX D. GEBOD PROGRAM *.TAB OUTPUT FILE (SM50H3.TAB)

1Seated, 50th %-ile male Hybrid III
OSITTING HYBRID III DUMMY (50%)
1 CRASH VICTIM   SITTING HYBRID III   17 SEGMENTS   16 JOINTS

SEGMENT			PRINCIPAL MOMENTS OF INERTIA (LB-SEC**2-IN)			SEGMENT CONTACT ELLIPSIOD SEMIAXES (IN.)			CENTER (IN.)			PRINCIPAL AXES (DEG)		
I	SYM	PLOT	WEIGHT (LB.)	X	Y	Z	X	Y	Z	X	Y	Z	YAW	PITCH	ROLL
1	LT	5	44.460	2.4575	1.2969	1.2080	5.000	7.185	4.800	-1.000	.000	.000	.00	-37.32	180.00
2	MT	4	4.890	.0612	.0593	.0205	4.775	6.500	4.000	1.000	.000	-1.000	.00	4.16	180.00
3	UT	3	39.216	2.6203	2.0517	1.7336	4.825	6.500	7.785	.000	.000	.000	.00	4.99	180.00
4	N	2	2.668	.0254	.0257	.0084	1.675	1.675	3.000	.000	.000	.000	.00	.00	180.00
5	H	1	9.921	.1408	.2128	.1956	4.250	2.875	4.000	.000	.000	.000	.00	-26.58	180.00
6	RUL	6	13.713	.6092	.5934	.1068	2.950	3.050	7.285	.000	.000	.000	.00	4.13	180.00
7	RLL	7	7.237	.6708	.6745	.0397	2.165	2.050	9.750	.000	.000	.000	.00	-1.90	180.00
8	RF	8	2.756	.0067	.0524	.0491	4.900	2.050	1.675	.000	.000	2.000	.96	-9.57	158.20
9	LUL	9	13.713	.6092	.5934	.1068	2.950	3.050	7.285	.000	.000	.000	.00	4.13	180.00
10	LLL	0	7.237	.6708	.6745	.0397	2.165	2.050	9.750	.000	.000	.000	.00	-1.90	180.00
11	LF	1	2.756	.0067	.0524	.0491	4.900	1.675	1.675	.000	.000	2.000	-.96	-9.57	-158.20
12	RUA	2	4.597	.1024	.0997	.0109	1.900	1.800	6.000	.000	.000	-1.000	.00	-1.31	180.00
13	RLA	3	3.800	.1191	.1128	.0069	1.775	1.775	5.800	.000	.000	.000	.00	-1.31	180.00
14	LUA	4	4.597	.1024	.0997	.0109	1.900	1.800	6.000	.000	.000	-1.000	.00	-1.31	180.00
15	LLA	5	3.800	.1191	.1128	.0069	1.775	1.775	5.800	.000	.000	.000	.00	-1.31	180.00
16	RHD	6	1.290	.0114	.0093	.0036	1.000	1.870	3.650	.000	.000	.000	-5.35	30.75	173.50
17	LHD	7	1.290	.0114	.0093	.0036	1.000	1.870	3.650	.000	.000	.000	5.35	30.75	-173.50

JOINT				LOCATION(IN.) - SEG(JNT)			LOCATION(IN.) - SEG(J+1)			JOINT AXIS(DEG) - SEG(JNT)			JOINT AXIS(DEG) - SEG(J+1)		
SEG(J+1)	SYM	PLOT	PIN	X	Y	Z	X	Y	Z	YAW	PITCH	ROLL	YAW	PITCH	ROLL
1 P	M	1	0	-2.150	.000	-1.660	-.350	.000	2.560	.00	.00	.00	.00	.00	.00
2 W	N	2	0	-.350	.000	-2.560	-.890	.000	5.850	.00	.00	.00	.00	.00	.00
3 NP	O	3	0	.000	.000	-5.960	.000	.000	2.760	.00	.00	.00	.00	.00	.00
4 HP	P	4	0	-.110	3.150	-2.840	-.550	.000	2.000	.00	.00	.00	.00	.00	.00
5 RH	Q	1	0	.000	.000	1.240	.000	.000	-9.960	.00	.00	.00	.00	90.00	.00
6 RK	R	6	1	-.200	.000	6.560	-.200	.000	-6.740	.00	.00	.00	.00	55.00	.00
7 RA	S	7	-8	-.110	-3.150	9.650	-2.120	.000	-1.540	90.00	.00	.00	90.00	.00	.00
8 LH	T	1	0	.000	.000	1.240	.000	.000	-9.960	.00	.00	.00	.00	90.00	.00
9 LK	U	9	1	-.200	.000	6.560	-.200	.000	-6.740	.00	.00	.00	.00	55.00	.00
10 LA	V	10	-8	-.880	7.380	9.650	-2.120	.000	-1.540	90.00	90.00	.00	90.00	90.00	.00
11 RS	W	3	0	.000	.000	-2.660	.000	.000	-5.430	.00	.00	.00	.00	.00	.00
12 RE	X	12	-8	-.880	-7.380	4.940	.000	.000	-3.670	90.00	90.00	.00	90.00	.00	.00
13 LS	Y	3	0	.000	.000	-2.660	.000	.000	-5.430	.00	.00	.00	.00	.00	.00
14 LE	Z	14	-8	.000	.000	4.940	.000	.000	-3.670	90.00	90.00	.00	90.00	.00	.00
15 RW		13	-8	.000	.000	6.070	-.300	.000	-2.130	90.00	.00	.00	90.00	.00	.00
16 LW		15	-8	.000	.000	6.070	-.300	.000	-2.130	90.00	.00	.00	90.00	.00	.00

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1 JOINT TORQUE CHARACTERISTICS

FLEXURAL SPRING CHARACTERISTICS

JOINT		SPRING COEF. (IN.LB. /DEG**J) LINEAR (J=1)	QUADRATIC (J=2)	CUBIC (J=3)	ENERGY DISSIPATION COEF.	JOINT STOP (DEG)
1	P	.000	.000	.000	1.000	.000
2	W	.000	.000	.000	1.000	.000
3	NP	.000	.000	.000	1.000	.000
4	HP	.000	.000	.000	1.000	.000
5	RH	.000	.000	.000	1.000	.000
6	RK	.000	2.320	.000	1.000	48.900
7	RA	1.000	10.000	10.000	1.000	27.000
8	LH	.000	.000	.000	1.000	.000
9	LK	.000	2.320	.000	1.000	48.900
10	LA	1.000	10.000	10.000	1.000	27.000
11	RS	.000	.000	.000	1.000	.000
12	RE	.000	20.000	20.000	1.000	52.000
13	LS	.000	.000	.000	1.000	.000
14	LE	.000	20.000	20.000	1.000	52.000
15	RW	.000	.000	.000	1.000	.000
16	LW	.000	.000	.000	1.000	.000

TORSIONAL SPRING CHARACTERISTICS

JOINT		SPRING COEF. (IN.LB. /DEG**J) LINEAR (J=1)	QUADRATIC (J=2)	CUBIC (J=3)	ENERGY DISSIPATION COEF.	JOINT STOP (DEG)
1	P	34.380	.000	.000	1.000	.000
2	W	34.380	.000	.000	1.000	.000
3	NP	15.000	.000	.000	1.000	.000
4	HP	15.000	.000	.000	1.000	.000
5	RH	7.500	75.000	75.000	1.000	55.000
6	RK	.000	.000	.000	1.000	.000
7	RA	.000	6.690	.000	1.000	30.000
8	LH	7.500	75.000	75.000	1.000	55.000
9	LK	.000	.000	.000	1.000	.000
10	LA	.000	6.690	.000	1.000	30.000
11	RS	.000	100.000	100.000	1.000	125.000
12	RE	.000	4.650	.000	1.000	65.300
13	LS	.000	100.000	100.000	1.000	125.000
14	LE	.000	4.650	.000	1.000	65.300
15	RW	.000	4.320	.143	1.000	55.500
16	LW	.000	4.320	.143	1.000	55.500

JOINT VISCOUS CHARACTERISTICS AND LOCK-UNLOCK CONDITIONS

JOINT		VISCOUS COEFFICIENT (IN.LB. SEC/DEG)	COULOMB FRICTION COEF. (IN.LB.)	FULL FRICTION ANGULAR VELOCITY (DEG/ SEC)	MAX TORQUE FOR A LOCKED JOINT (IN.LB.)	MIN TORQUE FOR UNLOCKED JOINT (IN.LB.)	MIN. ANG. VELOCITY (RAD/ SEC)	IMPULSE RESTITUTION COEFFICIENT
1	P	1.200	.00	30.00	.00	.00	.00	.00
2	W	1.200	.00	30.00	.00	.00	.00	.00
3	NP	.350	.00	30.00	.00	.00	.00	.00
4	HP	.192	.00	30.00	.00	.00	.00	.00
5	RH	1.000	.00	30.00	.00	.00	.00	.00
6	RK	1.000	.00	30.00	.00	.00	.00	.00
7	RA	.500	.00	30.00	.00	.00	.00	.00
		.500	.00	30.00	.00	.00	.00	.00
		.000						
8	LH	1.000	.00	30.00	.00	.00	.00	.00
9	LK	1.000	.00	30.00	.00	.00	.00	.00

165

10 LA
11 RS
12 RE
13 LS
14 LE
15 RW
16 LW

10 LA	.500	.00	.00	.00	.00
	.500	.00	.00	.00	.00
	.000	.00	.00	.00	.00
11 RS	.100	.00	.00	.00	.00
12 RE	.100	.00	.00	.00	.00
	.100	.00	.00	.00	.00
	.000	.00	.00	.00	.00
13 LS	.100	.00	.00	.00	.00
14 LE	.100	.00	.00	.00	.00
	.100	.00	.00	.00	.00
	.000	.00	.00	.00	.00
15 RW	.500	.00	.00	.00	.00
	.500	.00	.00	.00	.00
	.000	.00	.00	.00	.00
16 LW	.500	.00	.00	.00	.00
	.500	.00	.00	.00	.00
	.000	.00	.00	.00	.00

SEGMENT INTEGRATION CONVERGENCE TEST INPUT

SEGMENT NO.	SYM	ANGULAR VELOCITIES (RAD/SEC.) MAG. TEST	ABS. ERROR	REL. ERROR	LINEAR VELOCITIES (IN./SEC.) MAG. TEST	ABS. ERROR	REL. ERROR	ANGULAR ACCELERATIONS (RAD/SEC.**2) MAG. TEST	ABS. ERROR	REL. ERROR	LINEAR ACCELERATIONS (IN./SEC.**2) MAG. TEST	ABS. ERROR	REL. ERROR
1	LT	.010	.010	.0100	.010	.010	.0100	.100	.100	.1000	.100	.100	.0100
2	CT	.010	.010	.0100	.000	.000	.0000	.100	.100	.1000	.000	.000	.0000
3	UT	.010	.010	.0100	.000	.000	.0000	.100	.100	.1000	.000	.000	.0000
4	N	.010	.010	.0100	.000	.000	.0000	.100	.100	.1000	.000	.000	.0000
5	H	.010	.010	.0100	.000	.000	.0000	.100	.100	.1000	.000	.000	.0000
6	RUL	.010	.010	.0100	.000	.000	.0000	.100	.100	.1000	.000	.000	.0000
7	RLL	.010	.010	.0100	.000	.000	.0000	.100	.100	.1000	.000	.000	.0000
8	RF	.010	.010	.0100	.000	.000	.0000	.100	.100	.1000	.000	.000	.0000
9	LUL	.010	.010	.0100	.000	.000	.0000	.100	.100	.1000	.000	.000	.0000
10	LLL	.010	.010	.0100	.000	.000	.0000	.100	.100	.1000	.000	.000	.0000
11	LF	.010	.010	.0100	.000	.000	.0000	.100	.100	.1000	.000	.000	.0000
12	RUA	.010	.010	.0100	.000	.000	.0000	.100	.100	.1000	.000	.000	.0000
13	RLA	.010	.010	.0100	.000	.000	.0000	.100	.100	.1000	.000	.000	.0000
14	LUA	.010	.010	.0100	.000	.000	.0000	.100	.100	.1000	.000	.000	.0000
15	LLA	.010	.010	.0100	.000	.000	.0000	.100	.100	.1000	.000	.000	.0000
16	□□□	.010	.010	.0100	.000	.000	.0000	.100	.100	.1000	.000	.000	.0000
17	.ai	.010	.010	.0100	.000	.000	.0000	.100	.100	.1000	.000	.000	.0000

NPL		NBLT	NBAG	NELP	NQ	NSD	NHRNSS	NWINDF	NJNTF	NFORCE
XXXX		XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	7	XXXX

1

FUNCTION NO. 1   HEAD SURFACE

D0	D1	D2	D3	D4
.0000	.7100	-.8000	.0000	.0000

FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL

A0	A1	A2	A3	A4	A5
.2570000E+01	-.1759800E+03	.4495670E+04	-.8953110E+04	.6029590E+04	.0000000E+00

SECOND PART OF FUNCTION - 3 TABULAR POINTS

0	F(0)
.710000	358.0000
.750000	3580.0000
.800000	35800.0000

FUNCTION NO. 2   BACK OF SHOULDER

D0	D1	D2	D3	D4
.0000	1.6200	-1.7000	.0000	.0000

FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL

A0	A1	A2	A3	A4	A5
.1000000E-01	-.2659000E+02	.3809100E+03	-.6782200E+03	.4565300E+03	.0000000E+00

SECOND PART OF FUNCTION - 3 TABULAR POINTS

0	F(0)
1.620000	48.3000
1.650000	483.0000
1.700000	4830.0000

1

FUNCTION NO. 3   CHEST

D0	D1	D2	D3	D4
.0000	1.3100	-1.4000	.0000	.0000

FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL

A0	A1	A2	A3	A4	A5
.5500000E+00	.5460000E+01	.7349000E+02	-.1501000E+02	.0000000E+00	.0000000E+00

SECOND PART OF FUNCTION - 3 TABULAR POINTS

0	F(0)
1.310000	158.6000
1.350000	1586.0000
1.400000	15860.0000

FUNCTION NO.   4   ANTERIOR PELVIS

D0	D1	D2	D3	D4
.0000	2.0200	-2.1000	.0000	.0000

FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL

A0	A1	A2	A3	A4	A5
-.1400000E+00	.1580000E+01	.2439000E+02	-.2933000E+02	.1376000E+02	.0000000E+00

SECOND PART OF FUNCTION - 3 TABULAR POINTS

0	F(0)
2.020000	89.7000
2.050000	897.0000
2.100000	8970.0000

FUNCTION NO.   5   POSTERIOR PELVIS

D0	D1	D2	D3	D4
.0000	1.9600	-2.1000	.0000	.0000

FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL

A0	A1	A2	A3	A4	A5
-.7600000E+00	.3510000E+02	.4004000E+02	-.1249000E+02	.0000000E+00	.0000000E+00

SECOND PART OF FUNCTION - 3 TABULAR POINTS

0	F(0)
1.960000	127.8000
2.030000	1278.0000
2.100000	12780.0000

FUNCTION NO.   6   UPPER ARM

D0	D1	D2	D3	D4
.0000	.8900	-1.0000	.0000	.0000

FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL

A0	A1	A2	A3	A4	A5
.1540000E+01	-.3063000E+02	.6270900E+03	-.1197700E+04	.9172300E+03	.0000000E+00

SECOND PART OF FUNCTION - 3 TABULAR POINTS

O	F(O)
.890000	203.1000
.950000	2031.0000
1.000000	20310.0000

FUNCTION NO. 7   FOREARM

D0	D1	D2	D3	D4
.0000	1.3100	-1.4000	.0000	.0000

FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL

A0	A1	A2	A3	A4	A5
-.2400000E+01	.1073700E+03	-.3133600E+03	.5046100E+03	-.1963700E+03	.0000000E+00

SECOND PART OF FUNCTION - 3 TABULAR POINTS

O	F(O)
1.310000	156.2000
1.350000	1562.0000
1.400000	15620.0000

FUNCTION NO. 8   HAND

D0	D1	D2	D3	D4
.0000	.3800	-.4500	.0000	.0000

FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL

A0	A1	A2	A3	A4	A5
-.4000000E-01	-.3104000E+02	.2384470E+04	-.1019390E+05	.1917250E+05	.0000000E+00

SECOND PART OF FUNCTION - 3 TABULAR POINTS

O	F(O)
.380000	139.4000
.410000	1394.0000
.450000	13940.0000

FUNCTION NO. 9   UPPER LEG

D0	D1	D2	D3	D4
.0000	1.3100	-1.4000	.0000	.0000

FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL

AO	A1	A2	A3	A4	A5
-.2800000E+00	.1419000E+02	.8194000E+02	-.1226200E+03	.9873000E+02	-.2909000E+02

    SECOND PART OF FUNCTION -   3 TABULAR POINTS

0	F(0)
1.310000	61.6000
1.350000	616.0000
1.400000	6160.0000

FUNCTION NO. 10   KNEE

DO	D1	D2	D3	D4
.0000	.5400	-.5800	.0000	.0000

    FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL

AO	A1	A2	A3	A4	A5
-.4000000E-01	.2220000E+01	.8673400E+03	-.4016100E+03	.0000000E+00	.0000000E+00

    SECOND PART OF FUNCTION -   3 TABULAR POINTS

0	F(0)
.540000	187.8000
.560000	1878.0000
.580000	18780.0000

FUNCTION NO. 11   FRONT OF LOWER LEG

DO	D1	D2	D3	D4
.0000	1.7800	-1.9000	.0000	.0000

    FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL

AO	A1	A2	A3	A4	A5
-.7400000E+00	.2679000E+02	.3920000E+01	.2905000E+02	.0000000E+00	.0000000E+00

    SECOND PART OF FUNCTION -   3 TABULAR POINTS

0	F(0)
1.780000	223.6000
1.840000	2236.0000
1.900000	22360.0000

CARDS E.1

PAGE 11
CARDS E.1

PAGE 12
CARD E.7

PAGE 13
CARD E.7

FUNCTION NO. 12   BACK OF LOWER LEG

D0	D1	D2	D3	D4
.0000	1.6600	-1.7500	.0000	.0000

FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL

A0	A1	A2	A3	A4	A5
-.8000000E-01	.2942000E+02	-.2080000E+01	.0000000E+00	.0000000E+00	.0000000E+00

SECOND PART OF FUNCTION - 3 TABULAR POINTS

0	F(0)
1.660000	43.2000
1.700000	432.0000
1.750000	4320.0000

FUNCTION NO. 13   FOOT

D0	D1	D2	D3	D4
.0000	.8300	-.9500	.0000	.0000

FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL

A0	A1	A2	A3	A4	A5
-.6800000E+00	.8275000E+02	-.7041700E+03	.3367100E+04	-.5570690E+04	.3188300E+04

SECOND PART OF FUNCTION - 3 TABULAR POINTS

0	F(0)
.830000	121.2000
.890000	1212.0000
.950000	12120.0000

JOINT FORCE FUNCTION NO.   41   RIGHT SHOULDER JOINT

FUNCTION IS COEFFICIENTS OF 3 ORDER POLYNOMIALS IN (THETA-THETAO) FOR 8 VALUES OF PHI
COEFFIECIENTS OF (THETA-THETAO)**N

PHI	THETAO	N = 1	N = 2	N = 3
-180.00	151.000	.0000000	87900.00	.0000000
-135.00	75.000	.0000000	13700.00	.0000000
-90.00	.000	.0000000	-312.0000	11800.00
-45.00	66.000	.0000000	7780.000	3010000.
.00	68.000	.0000000	22200.00	376000.0
45.00	89.000	.0000000	22000.00	.0000000
90.00	111.000	.0000000	2470.000	17600.00
135.00	153.000	.0000000	13000.00	.0000000

JOINT FORCE FUNCTION NO.   42   LEFT SHOULDER JOINT

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FUNCTION IS COEFFICIENTS OF 3 ORDER POLYNOMIALS IN (THETA-THETAO) FOR 8 VALUES OF PHI

COEFFIECIENTS OF (THETA-THETAO)**N

PHI	THETAO	N = 1	N = 2	N = 3
-180.00	151.000	.0000000	87900.00	.0000000
-135.00	153.000	.0000000	13000.00	.0000000
-90.00	111.000	.0000000	2470.000	17600.00
-45.00	89.000	.0000000	22000.00	.0000000
.00	68.000	.0000000	22200.00	376000.0
45.00	66.000	.0000000	7780.000	3010000.
90.00	.000	.0000000	-312.0000	11800.00
135.00	75.000	.0000000	13700.00	.0000000

JOINT FORCE FUNCTION NO. 43   SEATED RIGHT HIP

FUNCTION IS TABULAR FOR 19 X 4 VALUES OF THETA AND PHI

PHI	THETAO	THETA				
		10.000	20.000	30.000	40.000	50.000
		60.000	70.000	80.000	90.000	100.000
		110.000	120.000	130.000	140.000	150.000
		160.000	170.000	180.000		
-180.00	.000	7.000000	22.00000	52.00000	112.0000	232.0000
		472.0000	952.0000	1910.000	3830.000	7670.000
		15400.00	30700.00	61400.00	123000.00	246000.0
		492000.0	983000.0	1970000.		
-90.00	.000	17.00000	51.00000	119.0000	255.0000	527.0000
		1070.000	2160.000	4340.000	8690.000	17400.00
		34900.00	69700.00	139000.0	279000.0	557000.0
		1110000.	2230000.	4460000.		
.00	.000	8.000000	17.00000	28.00000	50.00000	94.00000
		182.0000	358.0000	710.0000	1410.000	2820.000
		5640.000	11300.00	22500.00	45100.00	90100.00
		180000.0	360000.0	721000.0		
90.00	.000	7.000000	13.00000	18.00000	23.00000	33.00000
		53.00000	93.00000	173.0000	333.0000	653.0000
		1290.000	2570.000	5130.000	10300.00	20500.00
		41000.00	81900.00	164000.0		

JOINT FORCE FUNCTION NO. 44   SEATED LEFT HIP

FUNCTION IS TABULAR FOR 19 X 4 VALUES OF THETA AND PHI

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JOINT FORCE FUNCTION NO. 45   SEATED LUMBAR SPINE

FUNCTION IS TABULAR FOR 19 X 4 VALUES OF THETA AND PHI

THETA column groups (each block of rows reads):
10.000 20.000 30.000 40.000 50.000 / 60.000 70.000 80.000 90.000 100.000 / 110.000 120.000 130.000 140.000 150.000 / 160.000 170.000 180.000

PHI	THETA0					
-180.00	.000	7.000000	22.00000	52.00000	112.0000	232.0000
		472.0000	952.0000	1910.000	3830.000	7670.000
		15400.00	30700.00	61400.00	123000.00	246000.0
		492000.0	983000.0	1970000.		
-90.00	.000	7.000000	13.00000	18.00000	23.00000	33.00000
		53.00000	93.00000	173.0000	333.0000	653.0000
		1290.000	2570.000	5130.000	10300.00	20500.00
		41000.00	81900.00	164000.0		
.00	.000	8.000000	17.00000	28.00000	50.00000	94.00000
		182.0000	358.000	710.000	1410.000	2820.000
		5640.000	11300.00	22500.00	45100.00	90100.00
		180000.0	360000.0	721000.0		
90.00	.000	17.00000	51.00000	119.0000	255.0000	527.0000
		1070.000	2160.000	4340.000	8690.000	17400.00
		34900.00	69700.00	139000.0	279000.0	557000.0
		1110000.	2230000.	4460000.		

PHI	THETA0					
-180.00	.000	4600.000	9200.000	13800.00	18400.00	23000.00
		27600.00	32200.00	36800.00	41400.00	50600.00
		69000.00	105800.0	179400.0	326600.0	621000.0
		1209800.	2387400.	4742600.		
-90.00	.000	6800.000	13600.00	20400.00	27200.00	34000.00
		40800.00	47400.00	54400.00	61200.00	74800.00
		102000.0	156400.0	265200.0	482800.0	918000.0
		1788400.	3529200.	7010800.		
.00	.000	3000.000	6000.000	9000.000	12000.00	15000.00
		18000.00	21000.00	24000.00	27000.00	33000.00
		45000.00	69000.00	117000.0	213000.0	405000.0
		789000.0	1557000.	3093000.		
90.00	.000	6800.000	13600.00	20400.00	27200.00	34000.00
		40800.00	47600.00	54400.00	61200.00	74800.00

1

102000.0   156400.0   265200.0   482800.0   918000.0
1788400.   3529200.   7010800.

JOINT FORCE FUNCTION NO.   46   NECK PIVOT

- FUNCTION IS TABULAR FOR 19 X 4 VALUES OF THETA AND PHI

PHI	THETAO	THETA 10.000	20.000	30.000	40.000	50.000
		60.000	70.000	80.000	90.000	100.000
		110.000	120.000	130.000	140.000	150.000
		160.000	170.000	180.000		
-180.00	.000	700.0000	1400.000	2100.000	2800.000	3500.000
		4200.000	4900.000	5600.000	6300.000	7000.000
		7700.000	8400.000	9800.000	12600.00	18200.00
		29400.00	51800.00	96600.00		
-90.00	.000	600.0000	1200.000	1800.000	2400.000	3000.000
		3600.000	4200.000	4800.000	5400.000	6000.000
		6600.000	7200.000	8400.000	10800.00	15600.00
		25200.00	44400.00	82800.00		
.00	.000	300.000	600.000	900.0000	1200.000	1500.000
		1800.000	2100.000	2400.000	2700.000	3000.000
		3300.000	3600.000	4200.000	5400.000	7800.000
		12600.00	22200.00	41400.00		
90.00	.000	600.0000	1200.000	1800.000	2400.000	3000.000
		3600.000	4200.000	4800.000	5400.000	6000.000
		6600.000	7200.000	8400.000	10800.00	15600.00
		25200.00	44400.00	82800.00		

1

JOINT FORCE FUNCTION NO.   47   HEAD PIVOT

- FUNCTION IS TABULAR FOR 19 X 4 VALUES OF THETA AND PHI

PHI	THETAO	THETA 10.000	20.000	30.000	40.000	50.000
		60.000	70.000	80.000	90.000	100.000
		110.000	120.000	130.000	140.000	150.000
		160.000	170.000	180.000		
-180.00	.000	490.0000	980.0000	1680.000	2380.000	3080.000
		3780.000	4480.000	5180.000	5880.000	6580.000
		7280.000	7980.000	9380.000	12180.00	17780.00
		28980.00	51380.00	96180.00		
-90.00	.000	600.0000	1200.000	1800.000	2400.000	3000.000
		3600.000	4200.000	4800.000	5400.000	6000.000

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		6600.000	7200.000	8400.000	10800.00	15600.00
		25200.00	44400.00	82800.00		
.00	.000	250.0000	500.0000	800.0000	1100.000	1400.000
		1700.000	2000.000	2300.000	2600.000	2900.000
		3200.000	3500.000	4100.000	5300.000	7700.000
		12500.00	22100.00	41300.00		
		600.0000	1200.000	1800.000	2400.000	3000.000
90.00	.000	3600.000	4200.000	4800.000	5400.000	6000.000
		6600.000	7200.000	8400.000	10800.00	15600.00
		25200.00	44400.00	82800.00		

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THE FOLLOWING JOINT RESTORING FORCE FUNCTIONS AS DEFINED ON CARDS E.7 WILL BE USED.

JOINT		FUNCTION
1-	P	45-SEATED LUMBAR SPINE
2-	W	45-SEATED LUMBAR SPINE
3-	NP	46-NECK PIVOT
4-	HP	47-HEAD PIVOT
5-	RH	43-SEATED RIGHT HIP
8-	LH	44-SEATED LEFT HIP
11-	RS	41-RIGHT SHOULDER JOINT
13-	LS	42-LEFT SHOULDER JOINT

APPENDIX E. GEBOD PROGRAM *.AIN OUTPUT FILE (SM50H3.AIN)

```
     17    16          SITTING HYBRID III                              CARD B.1
LT   544.4602.45751.29691.2080 5.000 7.185 4.800-1.000  .000  .000  1  CARD B.2
                 .00-37.32 180.0
MT   4 4.890 .0612 .0593 .0205 4.775 6.500 4.000 1.000  .000-1.000  1  CARD B.2
                 .00  4.16 180.0
UT   339.2162.62032.05171.7336 4.825 6.500 7.785  .000  .000  .000  1  CARD B.2
                 .00  4.99 180.0
N    2 2.668 .0254 .0257 .0084 1.675 1.675 3.000  .000  .000  .000  1  CARD B.2
                 .00   .00 180.0
H    1 9.921 .1408 .2128 .1956 4.250 2.875 4.000  .000  .000  .000  1  CARD B.2
                 .00-26.58 180.0
RUL  613.713 .6092 .5934 .1068 2.950 3.050 7.285  .000  .000  .000  1  CARD B.2
                 .00  4.13 180.0
RLL  7 7.237 .6708 .6745 .0397 2.165 2.050 9.750  .000  .000 2.000  1  CARD B.2
                 .00 -1.90 180.0
RF   8 2.756 .0067 .0524 .0491 4.900 1.675 1.675  .000  .000  .000  1  CARD B.2
                 .96 -9.57 158.2
LUL  913.713 .6092 .5934 .1068 2.950 3.050 7.285  .000  .000  .000  1  CARD B.2
                 .00  4.13 180.0
LLL  0 7.237 .6708 .6745 .0397 2.165 2.050 9.750  .000  .000 2.000  1  CARD B.2
                 .00 -1.90 180.0
LF   1 2.756 .0067 .0524 .0491 4.900 1.675 1.675  .000  .000  .000  1  CARD B.2
                -.96 -9.57-158.2
RUA  2 4.597 .1024 .0997 .0109 1.900 1.800 6.000  .000  .000-1.000  1  CARD B.2
                 .00 -1.31 180.0
RLA  3 3.800 .1191 .1128 .0069 1.775 1.775 5.800  .000  .000  .000  1  CARD B.2
                 .00 -1.31 180.0
LUA  4 4.597 .1024 .0997 .0109 1.900 1.800 6.000  .000  .000-1.000  1  CARD B.2
                 .00 -1.31 180.0
LLA  5 3.800 .1191 .1128 .0069 1.775 1.775 5.800  .000  .000  .000  1  CARD B.2
                 .00 -1.31 180.0
RHD  6 1.290 .0114 .0093 .0036 1.000 1.870 3.650  .000  .000  .000  1  CARD B.2
                -5.35 30.75 173.5
LHD  7 1.290 .0114 .0093 .0036 1.000 1.870 3.650  .000  .000  .000  1  CARD B.2
                 5.35 30.75-173.5
P  M   1   0 -2.15   .00 -1.66  -.35   .00  2.56   0   .00   .00        CARD B.3
                 .00   .00   .00   .00   .00   .00   .00   .00   .00 0 0 0 0 0 0
W  N   2   0  -.35   .00 -2.56  -.89   .00  5.85   0   .00   .00        CARD B.3
                 .00   .00   .00   .00   .00   .00   .00   .00   .00 0 0 0 0 0 0
NP O   3   0   .00   .00 -5.96   .00   .00  2.76   0   .00   .00        CARD B.3
                 .00   .00   .00   .00   .00   .00   .00   .00   .00 0 0 0 0 0 0
HP P   4   0   .00   .00 -2.84  -.55   .00  2.00   0   .00   .00        CARD B.3
                 .00   .00   .00   .00   .00   .00   .00   :00   .00 0 0 0 0 0 0
RH Q   1   0  -.11  3.15  1.24   .00   .00 -9.96   0   .00   .00        CARD B.3
                 .00 90.00   .00   .00   .00   .00   .00   .00   .00 0 0 0 0 0 0
RK R   6   1   .00   .00  6.56  -.20   .00 -6.74   0   .00   .00        CARD B.3
                 .00   .00   .00   .00 55.00   .00   .00   .00   .00 0 0 0 0 0 0
RA S   7  -8  -.20   .00  9.65 -2.12   .00 -1.54   0   .00   .00        CARD B.3
               90.00   .00   .00 90.00   .00   .00   .00-10.00   .00 0 0 0 0 0 0
LH T   1   0  -.11 -3.15  1.24   .00   .00 -9.96   0   .00   .00        CARD B.3
                 .00 90.00   .00   .00   .00   .00   .00   .00   .00 0 0 0 0 0 0
LK U   9   1   .00   .00  6.56  -.20   .00 -6.74   0   .00   .00        CARD B.3
                 .00   .00   .00   .00 55.00   .00   .00   .00   .00 0 0 0 0 0 0
LA V  10  -8  -.20   .00  9.65 -2.12   .00 -1.54   0   .00   .00        CARD B.3
               90.00   .00   .00 90.00   .00   .00   .00-10.00   .00 0 0 0 0 0 0
RS W   3   0  -.88  7.38 -2.66   .00   .00 -5.43   0   .00   .00        CARD B.3
                 .00 90.00   .00   .00   .00   .00   .00   .00   .00 0 0 0 0 0 0
RE X  12  -8   .00   .00  4.94   .00   .00 -3.67   0   .00   .00        CARD B.3
               90.00   .00   .00 90.00   .00   .00   .00 62.50   .00 0 0 0 0 0 0
LS Y   3   0  -.88 -7.38 -2.66   .00   .00 -5.43   0   .00   .00        CARD B.3
                 .00 90.00   .00   .00   .00   .00   .00   .00   .00 0 0 0 0 0 0
LE Z  14  -8   .00   .00  4.94   .00   .00 -3.67   0   .00   .00        CARD B.3
               90.00   .00   .00 90.00   .00   .00   .00 62.50   .00 0 0 0 0 0 0
RW    13  -8   .00   .00  6.07  -.30   .00 -2.13   0   .00   .00        CARD B.3
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                 90.00    .00    .00 90.00    .00    .00    .00 15.00    .00 0 0 0 0 0 0
    LW    15  -8   .00    .00 6.07  -.30    .00 -2.13   0    .00    .00    CARD B.3
                 90.00    .00    .00 90.00    .00    .00    .00 15.00    .00 0 0 0 0 0 0
 .00   .00   .00  1.00         .00 34.38   .00   .00  1.00       .00CARD B.4
 .00   .00   .00  1.00         .00 34.38   .00   .00  1.00       .00CARD B.4
 .00   .00   .00  1.00         .00 15.00   .00   .00  1.00       .00CARD B.4
 .00   .00   .00  1.00         .00 15.00   .00   .00  1.00       .00CARD B.4
 .00   .00   .00  1.00         .00  7.50 75.00 75.00  1.00     55.00CARD B.4
 .00  2.32   .00  1.00       48.90   .00   .00   .00  1.00       .00CARD B.4
1.00 10.00 10.00  1.00       27.00   .00  6.69   .00  1.00     30.00CARD B.4
 .00   .00   .00  1.00         .00   .00   .00   .00
 .00   .00   .00  1.00         .00  7.50 75.00 75.00  1.00     55.00CARD B.4
 .00  2.32   .00  1.00       48.90   .00   .00   .00  1.00       .00CARD B.4
1.00 10.00 10.00  1.00       27.00   .00  6.69   .00  1.00     30.00CARD B.4
 .00   .00   .00  1.00         .00   .00   .00   .00
 .00   .00   .00  1.00         .00   .00100.00100.00  1.00    125.00CARD B.4
 .00 20.00 20.00  1.00       52.00   .00  4.65   .00  1.00     65.30CARD B.4
 .00   .00   .00  1.00         .00   .00 90.00   .00
 .00   .00   .00  1.00         .00   .00100.00100.00  1.00    125.00CARD B.4
 .00 20.00 20.00  1.00       52.00   .00  4.65   .00  1.00     65.30CARD B.4
 .00   .00   .00  1.00         .00   .00 90.00   .00
 .00   .00   .00  1.00         .00   .00  4.32   .14  1.00     55.50CARD B.4
 .00   .00   .00  1.00         .00   .00   .00   .00
 .00   .00   .00  1.00         .00   .00  4.32   .14  1.00     55.50CARD B.4
 .00   .00   .00  1.00         .00   .00   .00   .00
1.200   0.  30.   0.   0.                          0.   0.       CARD B.5
1.200   0.  30.   0.   0.                          0.   0.       CARD B.5
 .350   0.  30.   0.   0.                          0.   0.       CARD B.5
 .192   0.  30.   0.   0.                          0.   0.       CARD B.5
1.000   0.  30.   0.   0.                          0.   0.       CARD B.5
1.000   0.  30.   0.   0.                          0.   0.       CARD B.5
 .500   0.  30.   0.   0.                          0.   0.       CARD B.5
 .500   0.  30.   0.   0.                          0.   0.       CARD B.5
 .000   0.  30.   0.   0.                          0.   0.       CARD B.5
1.000   0.  30.   0.   0.                          0.   0.       CARD B.5
1.000   0.  30.   0.   0.                          0.   0.       CARD B.5
 .500   0.  30.   0.   0.                          0.   0.       CARD B.5
 .500   0.  30.   0.   0.                          0.   0.       CARD B.5
 .000   0.  30.   0.   0.                          0.   0.       CARD B.5
 .100   0.  30.   0.   0.                          0.   0.       CARD B.5
 .100   0.  30.   0.   0.                          0.   0.       CARD B.5
 .100   0.  30.   0.   0.                          0.   0.       CARD B.5
 .000   0.  30.   0.   0.                          0.   0.       CARD B.5
 .100   0.  30.   0.   0.                          0.   0.       CARD B.5
 .100   0.  30.   0.   0.                          0.   0.       CARD B.5
 .100   0.  30.   0.   0.                          0.   0.       CARD B.5
 .000   0.  30.   0.   0.                          0.   0.       CARD B.5
 .500   0.  30.   0.   0.                          0.   0.       CARD B.5
 .500   0.  30.   0.   0.                          0.   0.       CARD B.5
 .000   0.  30.   0.   0.                          0.   0.       CARD B.5
 .500   0.  30.   0.   0.                          0.   0.       CARD B.5
 .500   0.  30.   0.   0.                          0.   0.       CARD B.5
 .000   0.  30.   0.   0.                          0.   0.       CARD B.5
 .01   .01   .01   .01   .01   .01   .10   .10   .10   .10   .10   .01CARD B.6
 .01   .01   .01   .00   .00   .00   .10   .10   .10   .00   .00   .00CARD B.6
 .01   .01   .01   .00   .00   .00   .10   .10   .10   .00   .00   .00CARD B.6
 .01   .01   .01   .00   .00   .00   .10   .10   .10   .00   .00   .00CARD B.6
 .01   .01   .01   .00   .00   .00   .10   .10   .10   .00   .00   .00CARD B.6
 .01   .01   .01   .00   .00   .00   .10   .10   .10   .00   .00   .00CARD B.6
 .01   .01   .01   .00   .00   .00   .10   .10   .10   .00   .00   .00CARD B.6
 .01   .01   .01   .00   .00   .00   .10   .10   .10   .00   .00   .00CARD B.6
 .01   .01   .01   .00   .00   .00   .10   .10   .10   .00   .00   .00CARD B.6
 .01   .01   .01   .00   .00   .00   .10   .10   .10   .00   .00   .00CARD B.6
 .01   .01   .01   .00   .00   .00   .10   .10   .10   .00   .00   .00CARD B.6
 .01   .01   .01   .00   .00   .00   .10   .10   .10   .00   .00   .00CARD B.6
 .01   .01   .01   .00   .00   .00   .10   .10   .10   .00   .00   .00CARD B.6
 .01   .01   .01   .00   .00   .00   .10   .10   .10   .00   .00   .00CARD B.6
 .01   .01   .01   .00   .00   .00   .10   .10   .10   .00   .00   .00CARD B.6
 .01   .01   .01   .00   .00   .00   .10   .10   .10   .00   .00   .00CARD B.6
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XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX      7XXXXXX                    CARD D.1
   1     HEAD SURFACE                                                            CARD E.1
          .00          .71         -.80          .00          .00               CARD E.2
         2.57      -175.98      4495.67     -8953.11      6029.59            .00CARD E.3
      3                                                                          CARD E.4
          .71       358.00          .75      3580.00          .80      35800.00CARD E.4
   2     BACK OF SHOULDER                                                        CARD E.1
          .00         1.62        -1.70          .00          .00               CARD E.2
          .01       -26.59       380.91      -678.22       456.53            .00CARD E.3
      3                                                                          CARD E.4
         1.62        48.30         1.65       483.00         1.70       4830.00CARD E.4
   3     CHEST                                                                   CARD E.1
          .00         1.31        -1.40          .00          .00               CARD E.2
          .55         5.46        73.49       -15.01          .00            .00CARD E.3
      3                                                                          CARD E.4
         1.31       158.60         1.35      1586.00         1.40      15860.00CARD E.4
   4     ANTERIOR PELVIS                                                         CARD E.1
          .00         2.02        -2.10          .00          .00               CARD E.2
         -.14         1.58        24.39       -29.33        13.76            .00CARD E.3
      3                                                                          CARD E.4
         2.02        89.70         2.05       897.00         2.10       8970.00CARD E.4
   5     POSTERIOR PELVIS                                                        CARD E.1
          .00         1.96        -2.10          .00          .00               CARD E.2
         -.76        35.10        40.04       -12.49          .00            .00CARD E.3
      3                                                                          CARD E.4
         1.96       127.80         2.03      1278.00         2.10      12780.00CARD E.4
   6     UPPER ARM                                                               CARD E.1
          .00          .89        -1.00          .00          .00               CARD E.2
         1.54       -30.63       627.09     -1197.70       917.23            .00CARD E.3
      3                                                                          CARD E.4
          .89       203.10          .95      2031.00         1.00      20310.00CARD E.4
   7     FOREARM                                                                 CARD E.1
          .00         1.31        -1.40          .00          .00               CARD E.2
        -2.40       107.37      -313.36       504.61      -196.37            .00CARD E.3
      3                                                                          CARD E.4
         1.31       156.20         1.35      1562.00         1.40      15620.00CARD E.4
   8     HAND                                                                    CARD E.1
          .00          .38         -.45          .00          .00               CARD E.2
         -.04       -31.04      2384.47    -10193.90     19172.50            .00CARD E.3
      3                                                                          CARD E.4
          .38       139.40          .41      1394.00          .45      13940.00CARD E.4
   9     UPPER LEG                                                               CARD E.1
          .00         1.31        -1.40          .00          .00               CARD E.2
         -.28        14.19        81.94      -122.62        98.73       -29.09CARD E.3
      3                                                                          CARD E.4
         1.31        61.60         1.35       616.00         1.40       6160.00CARD E.4
  10     KNEE                                                                    CARD E.1
          .00          .54         -.58          .00          .00               CARD E.2
         -.04         2.22       867.34      -401.61          .00            .00CARD E.3
      3                                                                          CARD E.4
          .54       187.80          .56      1878.00          .58      18780.00CARD E.4
  11     FRONT OF LOWER LEG                                                      CARD E.1
          .00         1.78        -1.90          .00          .00               CARD E.2
         -.74        26.79         3.92        29.05          .00            .00CARD E.3
      3                                                                          CARD E.4
         1.78       223.60         1.84      2236.00         1.90      22360.00CARD E.4
  12     BACK OF LOWER LEG                                                       CARD E.1
          .00         1.66        -1.75          .00          .00               CARD E.2
         -.08        29.42        -2.08          .00          .00            .00CARD E.3
      3                                                                          CARD E.4
         1.66        43.20         1.70       432.00         1.75       4320.00CARD E.4
  13     FOOT                                                                    CARD E.1
          .00          .83         -.95          .00          .00               CARD E.2
         -.68        82.75      -704.17      3367.10     -5570.69       3188.30CARD E.3
      3                                                                          CARD E.4
          .83       121.20          .89      1212.00          .95      12120.00CARD E.4
9999                                                                            CARD E.1
  41     RIGHT SHOULDER JOINT                                                    CARD E.7

     -4      8                                                                   CARD E.7
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   151.000          .000     87900.000            .000
    75.000          .000     13700.000            .000
      .000          .000      -312.000       11800.000
    66.000          .000      7780.000     3010000.000
    68.000          .000     22200.000      376000.000
    89.000          .000     22000.000            .000
   111.000          .000      2470.000       17600.000
   153.000          .000     13000.000            .000
 42    LEFT SHOULDER JOINT                                                      CARD E.7

   -4     8                                                                     CARD E.7
   151.000          .000     87900.000            .000
   153.000          .000     13000.000            .000
   111.000          .000      2470.000       17600.000
    89.000          .000     22000.000            .000
    68.000          .000     22200.000      376000.000
    66.000          .000      7780.000     3010000.000
      .000          .000      -312.000       11800.000
    75.000          .000     13700.000            .000
 43    SEATED RIGHT HIP                                                         CARD E.7

   19     4                                                                     CARD E.7
      .000        7.000        22.000         52.000        112.000       232.000CARD E.7
   472.000      952.000      1910.000       3830.000       7670.000     15400.000CARD E.7
 30700.000    61400.000    123000.000     246000.000     492000.000    983000.000CARD E.7
1970000.000
      .000       17.000        51.000        119.000        255.000       527.000CARD E.7
  1070.000     2160.000      4340.000       8690.000      17400.000     34900.000CARD E.7
 69700.000   139000.000    279000.000     557000.000    1110000.000   2230000.000CARD E.7
4460000.000
      .000        8.000        17.000         28.000         50.000        94.000CARD E.7
   182.000      358.000       710.000       1410.000       2820.000      5640.000CARD E.7
 11300.000    22500.000     45100.000      90100.000     180000.000    360000.000CARD E.7
721000.000
      .000        7.000        13.000         18.000         23.000        33.000CARD E.7
    53.000       93.000       173.000        333.000        653.000      1290.000CARD E.7
  2570.000     5130.000     10300.000      20500.000      41000.000     81900.000CARD E.7
164000.000
 44    SEATED LEFT HIP                                                          CARD E.7

   19     4                                                                     CARD E.7
      .000        7.000        22.000         52.000        112.000       232.000CARD E.7
   472.000      952.000      1910.000       3830.000       7670.000     15400.000CARD E.7
 30700.000    61400.000    123000.000     246000.000     492000.000    983000.000CARD E.7
1970000.000
      .000        7.000        13.000         18.000         23.000        33.000CARD E.7
    53.000       93.000       173.000        333.000        653.000      1290.000CARD E.7
  2570.000     5130.000     10300.000      20500.000      41000.000     81900.000CARD E.7
164000.000
      .000        8.000        17.000         28.000         50.000        94.000CARD E.7
   182.000      358.000       710.000       1410.000       2820.000      5640.000CARD E.7
 11300.000    22500.000     45100.000      90100.000     180000.000    360000.000CARD E.7
721000.000
      .000       17.000        51.000        119.000        255.000       527.000CARD E.7
  1070.000     2160.000      4340.000       8690.000      17400.000     34900.000CARD E.7
 69700.000   139000.000    279000.000     557000.000    1110000.000   2230000.000CARD E.7
4460000.000
 45    SEATED LUMBAR SPINE                                                      CARD E.7

   19     4                                                                     CARD E.7
      .000     4600.000      9200.000      13800.000      18400.000     23000.000CARD E.7
 27600.000    32200.000     36800.000      41400.000      50600.000     69000.000CARD E.7
105800.000   179400.000    326600.000     621000.000    1209800.000   2387400.000CARD E.7
4742600.000
      .000     6800.000     13600.000      20400.000      27200.000     34000.000CARD E.7
 40800.000    47600.000     54400.000      61200.000      74800.000    102000.000CARD E.7
156400.000   265200.000    482800.000     918000.000    1788400.000   3529200.000CARD E.7
7010800.000
      .000     3000.000      6000.000       9000.000      12000.000     15000.000CARD E.7
 18000.000    21000.000     24000.000      27000.000      33000.000     45000.000CARD E.7
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    69000.000    117000.000    213000.000    405000.000    789000.000  1557000.000CARD E.7
  3093000.000
         .000      6800.000     13600.000     20400.000     27200.000     34000.000CARD E.7
     40800.000     47600.000     54400.000     61200.000     74800.000    102000.000CARD E.7
    156400.000    265200.000    482800.000    918000.000   1788400.000  3529200.000CARD E.7
  7010800.000
  46    NECK PIVOT                                                              CARD E.7

    19     4                                                                    CARD E.7
         .000       700.000      1400.000      2100.000      2800.000      3500.000CARD E.7
      4200.000      4900.000      5600.000      6300.000      7000.000      7700.000CARD E.7
      8400.000      9800.000     12600.000     18200.000     29400.000     51800.000CARD E.7
     96600.000
         .000       600.000      1200.000      1800.000      2400.000      3000.000CARD E.7
      3600.000      4200.000      4800.000      5400.000      6000.000      6600.000CARD E.7
      7200.000      8400.000     10800.000     15600.000     25200.000     44400.000CARD E.7
     82800.000
         .000       300.000       600.000       900.000      1200.000      1500.000CARD E.7
      1800.000      2100.000      2400.000      2700.000      3000.000      3300.000CARD E.7
      3600.000      4200.000      5400.000      7800.000     12600.000     22200.000CARD E.7
     41400.000
         .000       600.000      1200.000      1800.000      2400.000      3000.000CARD E.7
      3600.000      4200.000      4800.000      5400.000      6000.000      6600.000CARD E.7
      7200.000      8400.000     10800.000     15600.000     25200.000     44400.000CARD E.7
     82800.000
  47    HEAD PIVOT                                                              CARD E.7

    19     4                                                                    CARD E.7
         .000       490.000       980.000      1680.000      2380.000      3080.000CARD E.7
      3780.000      4480.000      5180.000      5880.000      6580.000      7280.000CARD E.7
      7980.000      9380.000     12180.000     17780.000     28980.000     51380.000CARD E.7
     96180.000
         .000       600.000      1200.000      1800.000      2400.000      3000.000CARD E.7
      3600.000      4200.000      4800.000      5400.000      6000.000      6600.000CARD E.7
      7200.000      8400.000     10800.000     15600.000     25200.000     44400.000CARD E.7
     82800.000
         .000       250.000       500.000       800.000      1100.000      1400.000CARD E.7
      1700.000      2000.000      2300.000      2600.000      2900.000      3200.000CARD E.7
      3500.000      4100.000  .   5300.000      7700.000     12500.000     22100.000CARD E.7
     41300.000
         .000       600.000      1200.000      1800.000      2400.000      3000.000CARD E.7
      3600.000      4200.000      4800.000      5400.000      6000.000      6600.000CARD E.7
      7200.000      8400.000     10800.000     15600.000     25200.000     44400.000CARD E.7
     82800.000
   0   0   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0  OCARD F.4
  45  45  46   47   43    0    0   44    0    0   41    0   42    0    0    0    0  OCARD F.5
```

APPENDIX F. MATLAB PROGRAM CCARD.M

```
% Program CCARD.M
%
% LT Douglas B. Oglesby
% 08 August 1997
%
%     This program is a utility designed to facilitate the
% generation of formatted C.Cards for use in the Articulated
% Total Body (ATB) Program.
%
%     The program allows any of the options specified in the
% ATB Program to be used.  Input to the program is a combination
% of keyboard and text file.  Output is the formatted set of C
% Cards which may be directly inserted into the ATB Program.
% Only one vehicle may be defined at a time, requiring further
% combination of multiple output files if the ATB simulation is
% to have more than one vehicle.
%
%     The variable names used in this program are predominantly
% the same as those used in the ATB program.  Exceptions are
% sequence control variables, flags and temporary variables.



% BEGINNING OF PROGRAM

clc
clear all

% determine the format of the data

option = menu('OPTION','Half sine wave deceleration',...
                       'Tabular unidirectional deceleration',...
                       'Six DOF deceleration',...
                       'Spline fit position, velocity, or accel');

% card C.1 - description

disp('Enter description of crash vehicle deceleration (80 char max)')
VPSTTL = input('','s');
if length(VPSTTL) > 80
  VPSTTL = VPSTTL(1:80);
end

% card C.2

if option == 1

  ANGLE(1) = input('Azimuth of decel vector (inertial coords) in deg ');
  ANGLE(2) = input('Elevation of decel vector (intertial coords) in deg ');
  ANGLE(3) = 0;
  VIPS = input('Initial velocity (in/sec) of prescribed segment (neg - accel)
');
  VTIME = input('Time duration (sec) of decel impule ');
  if (VTIME == 0) | (VTIME == [])
    error('VTIME must not be zero of blank for option 1')
  end
  X0(1) = input('X coord (in) of vehicle reference origin (inertial) ');
  X0(2) = input('Y coord (in) of vehicle reference origin (inertial) ');
```

```
      XO(3) = input('Z coord (in) of vehicle reference origin (inertial) ');
      NATAB = 0;
      ATO = 0;
      ATD = 0;
      MSEG = input('Segment # for prescribed motion (0 = primary vehicle) ');

elseif option == 2

      ANGLE(1) = input('Azimuth of decel vector (inertial coords) in deg ');
      ANGLE(2) = input('Elevation of decel vector (intertial coords) in deg ');
      ANGLE(3) = 0;
      VIPS = input('Initial velocity (in/sec) of prescribed segment (neg - accel)
');
      VTIME = 0;
      XO(1) = input('X coord (in) of vehicle reference origin (inertial) ');
      XO(2) = input('Y coord (in) of vehicle reference origin (inertial) ');
      XO(3) = input('Z coord (in) of vehicle reference origin (inertial) ');
      NATAB = input('# of tabulated values (must be odd # <=99) ');
      ATO = input('First time point (sec) ');
      ATD = input('Fixed time interval (sec) ');
      MSEG = input('Segment # for prescribed motion (0 = primary vehicle) ');

elseif option == 3

      ANGLE(1) = input('Initial yaw angle of prescribed segment (deg) ');
      ANGLE(2) = input('Initial pitch angle of prescribed segment (deg) ');
      ANGLE(3) = input('Initial roll angle of prescribed segment (deg) ');
      VIPS = input('Initial velocity (in/sec) of prescribed segment (neg - accel)
');
      VTIME = 0;
      XO(1) = input('X coord (in) of vehicle reference origin (inertial) ');
      XO(2) = input('Y coord (in) of vehicle reference origin (inertial) ');
      XO(3) = input('Z coord (in) of vehicle reference origin (inertial) ');
      NATAB = input('# of time points supplied (must be negative, <=10001) ');
      ATO = input('First time point (sec) ');
      ATD = input('Fixed time interval (sec) ');
      MSEG = input('Segment # for prescribed motion (0 = primary vehicle) ');
      LTYPE = 0;
      LFIT = 0;
      NPTS = 0;
      VMEG(1) = input('Initial angular velocity (deg/sec) about vehicle X axis ');
      VMEG(2) = input('Initial angular velocity (deg/sec) about vehicle Y axis ');
      VMEG(3) = input('Initial angular velocity (deg/sec) about vehicle Z axis ');

elseif option == 4

      ANGLE(1) = 0;
      ANGLE(2) = 0;
      ANGLE(3) = 0;
      VIPS = 0;
      VTIME = 0;
      XO(1) = 0;
      XO(2) = 0;
      XO(3) = 0;
      NATAB = input('# of time points to be computed (must be negative, <=501) ');
      ATO = input('First time point (sec) ');
      ATD = input('Fixed time interval (sec) ');
      MSEG = input('Segment # for prescribed motion (0 = primary vehicle) ');
      LTYPE = menu('Data Type','Position','Velocity','Acceleration');
      LFIT = input('Degree of polynmial to be used (0, 1, 2, or 3) ');
      NPTS = input('# of time point data supplied (must be <=101) ');
      VMEG(1) = 0;
      VMEG(2) = 0;
```

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```
    VMEG(3) = 0;

end % of card C.2

% card C.3

if option == 2

  infile = input('Name of input file (.txt will be added) ','s');
  if infile == []
    for I=1:NATAB
      DEC(I) = input('Deceleration (g''s) ');
    end
  else
    eval(['load ',infile,'.txt']);
    tabdat = eval(infile);
    for I=1:NATAB
      index = find(tabdat(:,1) == (AT0 + (I-1)*ATD));
      DEC(I) = tabdat(index,2);
    end
  end

end % of card C.3

% card C.4

if option == 3

  MATAB = -NATAB;
  infile = input('Name of input file (.txt will be added) ','s');
  if infile == []
    for I=1:MATAB
      ATAB(1,I) = input('X decel (g''s) ');
      ATAB(2,I) = input('Y decel (g''s) ');
      ATAB(3,I) = input('Z decel (g''s) ');
      ATAB(4,I) = input('alpha X (deg/sec/sec) ');
      ATAB(5,I) = input('alpha Y (deg/sec/sec) ');
      ATAB(6,I) = input('alpha Z (deg/sec/sec) ');
    end
  else
    eval(['load ',infile,'.txt']);
    tabdat = eval(infile);
%    for I=1:MATAB
%       index = find(abs(tabdat(:,1)-(AT0 + (I-1)*ATD)) < 1e-6);
%       ATAB(1:6,I) = tabdat(index,2:7)';
%    end
     ATAB(1:6,1:MATAB) = tabdat(1:MATAB,2:7)';
  end

end % of card C.4

% card C.5

if option == 4

  infile = input('Name of input file (.txt will be added) ','s');
  if LTYPE == 1
    K=0;
  end
  if (LTYPE == 2) | (LTYPE == 3)
    T(1) = 0;
    XYZ(1,1) = input('Initial X position (in) of vehicle origin ');
    XYZ(2,1) = input('Initial Y position (in) of vehicle origin ');
```

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```
      XYZ(3,1) = input('Initial Z position (in) of vehicle origin ');
      XYZ(4,1) = input('Initial yaw (deg) of vehicle coord system ');
      XYZ(5,1) = input('Initial pitch (deg) of vehicle coord system ');
      XYZ(6,1) = input('Initial roll (deg) of vehicle coord system ');
      K = 1;
    end
    if LTYPE == 3
      T(2) = 0;
      XYZ(1,1) = input('Initial X velocity (in/sec) of vehicle origin ');
      XYZ(2,1) = input('Initial Y velocity (in/sec) of vehicle origin ');
      XYZ(3,1) = input('Initial Z velocity (in/sec) of vehicle origin ');
      XYZ(4,1) = input('Initial omega X (deg/sec) of vehicle coord system ');
      XYZ(5,1) = input('Initial omega Y (deg/sec) of vehicle coord system ');
      XYZ(6,1) = input('Initial omega Z (deg/sec) of vehicle coord system ');
      K = 2;
    end

    if infile == []
      for I=1:NPTS
        T(I+K) = input('Time (sec) ');
        if LTYPE == 1
          XYZ(1,I+K) = input('X position (in) of vehicle origin ');
          XYZ(2,I+K) = input('Y position (in) of vehicle origin ');
          XYZ(3,I+K) = input('Z position (in) of vehicle origin ');
          XYZ(4,I+K) = input('yaw (deg) of vehicle coord system ');
          XYZ(5,I+K) = input('pitch (deg) of vehicle coord system ');
          XYZ(6,I+K) = input('roll (deg) of vehicle coord system ');
        elseif LTYPE == 2
          XYZ(1,I+K) = input('X velocity (in/sec) of vehicle origin ');
          XYZ(2,I+K) = input('Y velocity (in/sec) of vehicle origin ');
          XYZ(3,I+K) = input('Z velocity (in/sec) of vehicle origin ');
          XYZ(4,I+K) = input('omega X (deg/sec) of vehicle coord system ');
          XYZ(5,I+K) = input('omega Y (deg/sec) of vehicle coord system ');
          XYZ(6,I+K) = input('omega Z (deg/sec) of vehicle coord system ');
        elseif LTYPE == 3
          XYZ(1,I+K) = input('X accel (in/sec/sec) of vehicle origin ');
          XYZ(2,I+K) = input('Y accel (in/sec/sec) of vehicle origin ');
          XYZ(3,I+K) = input('Z accel (in/sec/sec) of vehicle origin ');
          XYZ(4,I+K) = input('alpha X (deg/sec/sec) of vehicle coord system ');
          XYZ(5,I+K) = input('alpha Y (deg/sec/sec) of vehicle coord system ');
          XYZ(6,I+K) = input('alpha Z (deg/sec/sec) of vehicle coord system ');
        end
      end
    else
      eval(['load ',infile,'.txt']);
      tabdat = eval(infile);
      for I=1:NPTS
        T(I+K) = tabdat(I,1);
        XYZ(1:6,I+K) = tabdat(I,2:7)';
      end
    end

end % of card C.5

% create the C card file

outfile = input('Output file name (.txt will be added) ','s');
outfile = [outfile, '.txt'];
fid = fopen(outfile,'wt');

% C.1 card

fprintf(fid,'%s\n',VPSTTL);
```

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```matlab
% C.2 card

chp = [1:6;1:6;1:6];
for i = 1:3
  while ANGLE(i) >= 360
    ANGLE(i) = ANGLE(i) - 360;
  end
  while ANGLE(i) <= (-360)
    ANGLE(i) = ANGLE(i) + 360;
  end
  if (ANGLE(i) < 1.0) & (ANGLE(i) > 0.0)
    chp(i,:) = [2:7];
  elseif (ANGLE(i) < 0.0) & (ANGLE(i) > (-1.0))
    chp(i,:) = [1,3:7];
  end
end
a1 = sprintf('%0.6f',ANGLE(1));
a1 = a1(chp(1,:));
a2 = sprintf('%0.6f',ANGLE(2));
a2 = a2(chp(2,:));
a3 = sprintf('%0.6f',ANGLE(3));
a3 = a3(chp(3,:));

a4 = sprintf('%0.6f',VIPS);
if (VIPS < 1.0) & (VIPS > 0.0)
  a4 = a4(2:7);
elseif (VIPS < 0.0) & (VIPS > (-1.0))
  a4 = a4(1,3:7);
else
  a4 = a4(1:6);
end

a5 = sprintf('%0.6f',VTIME);
if (VTIME < 1.0) & (VTIME > 0.0)
  a5 = a5(2:7);
else
  a5 = a5(1:6);
end

chp = [1:6;1:6;1:6];
for i = 1:3
  if X0(i) > 999999
    error('Initial position out of range')
  elseif (X0(i) < 1.0) & (X0(i) > 0.0)
    chp(i,:) = [2:7];
  elseif (X0(i) < 0.0) & (X0(i) > (-1.0))
    chp(i,:) = [1,3:7];
  end
end
a6 = sprintf('%0.6f',X0(1));
a6 = a6(chp(1,:));
a7 = sprintf('%0.6f',X0(2));
a7 = a7(chp(2,:));
a8 = sprintf('%0.6f',X0(3));
a8 = a8(chp(3,:));

a9 = int2str(NATAB);
if NATAB > 999999
  error('NATAB out of range')
end
spc = [];
if length(a9) < 6
```

```
    for i = 1:(6-length(a9))
      spc = [spc, setstr(32)];
    end
end
a9 = [spc,a9];

a10 = sprintf('%0.6f',AT0);
if (AT0 < 1.0) & (AT0 > 0.0)
  a10 = a10(2:7);
else
  a10 = a10(1:6);
end

a11 = sprintf('%0.6f',ATD);
if (ATD < 1.0) & (ATD > 0.0)
  a11 = a11(2:7);
else
  a11 = a11(1:6);
end

a12 = int2str(MSEG);
if MSEG > 29
  error('MSEG out of range')
end
spc = [];
for i = 1:(6-length(a12))
  spc = [spc, setstr(32)];
end
a12 = [spc,a12];

a13 = ['              C.2a'];

c2a = [a1,a2,a3,a4,a5,a6,a7,a8,a9,a10,a11,a12,a13];

fprintf(fid,'%s\n',c2a);

% C.2b card

if (option == 3) | (option == 4)

  b1 = int2str(LTYPE);
  spc = [];
  for i = 1:(6-length(LTYPE))
    spc = [spc,setstr(32)];
  end
  b1 = [spc,b1];

  b2 = int2str(LFIT);
  spc = [];
  for i = 1:(6-length(LFIT))
    spc = [spc,setstr(32)];
  end
  b2 = [spc,b2];

  b3 = int2str(NPTS);
  spc = [];
  if NPTS > 101
    error('NPTS out of range')
  end
  for i = 1:(6-length(NPTS))
    spc = [spc,setstr(32)];
  end
  b3 = [spc,b3];
```

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```
    spc = [];
    for i = 1:22
      spc = [spc,setstr(32)];
    end
    b4 = spc;

    chp=[1:10;1:10;1:10];
    for i = 1:3
      if (VMEG(i) < 1.0) & (VMEG(i) > 0.0)
        chp(i,:) = [2:11];
      elseif (VMEG(i) < 0.0) & (VMEG(i) > (-1.0))
        chp(i,:) = [1,3:11];
      end
    end
    b5 = sprintf('%0.10f',VMEG(1));
    b5 = b5(chp(1,:));
    b6 = sprintf('%0.10f',VMEG(2));
    b6 = b6(chp(2,:));
    b7 = sprintf('%0.10f',VMEG(3));
    b7 = b7(chp(3,:));

    b8 = ['                C.2b'];

    c2b = [b1,b2,b3,b4,b5,b6,b7,b8];

    fprintf(fid,'%2\n',c2b);

end % of C.2b card

% C.3 cards

if option == 2

  for i = 1:NATAB
    b = sprintf('%0.6f',DEC(i));
    if DEC(i) > 999999
      error('DEC(i) out of range')
    elseif (DEC(i) < 1.0) & (DEC(i) > 0.0)
      chp = [2:7];
    elseif (DEC(i) < 0.0) & (DEC(i) > (-1.0))
      chp = [1,3:7];
    else
      chp = [1:6];
    end
    a(i,:) = b(chp);
  end

  numcards = round(NATAB/12) + 1;
  for k = 1:numcards
    if k ~= numcards
      c = [];
      for i = 1:12
        c = [c,a(i+(k-1)*12,:)];
      end
      c = [c,'   C.3.',int2str(k)];
    elseif k == numcards
      c = [];
      for i = 1:(NATAB-(k-1)*12)
        c = [c,a(i+(k-1)*12,:)];
      end
    end
    fprintf(fid,'%s\n',c);
```

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```
      end

end % of C.3 cards

% C.4 cards

if option == 3

   for i = 1:MATAB
     for j = 1:6
       b = sprintf('%0.10f',ATAB(j,i));
       if (ATAB(j,i) < 1.0) & (ATAB(j,i) > 0.0)
         chp = [2:11];
       elseif (ATAB(j,i) < 0.0) & (ATAB(j,i) > (-1.0))
         chp = [1,3:11];
       else
         chp = [1:10];
       end
       a(j,:) = b(chp);
     end
     c = [];
     for j = 1:10
       c = [c,setstr(32)];
     end
     for j = 1:6
       c = [c,a(j,:)];
     end
     c = [c,'              C.4.',int2str(i)];

     fprintf(fid,'%s\n',c);

   end

end % of C.4 cards

% C.5 cards

if option == 4

   for i = 1:(NPTS+LTYPE-1)
     a = sprintf('%0.10f',T(i));
     a = a(1:10);
     for j = 1:6
       b = sprintf('%0.10f',XYZ(j,i));
       if (XYZ(j,i) < 1.0) & (XYZ(j,i) > 0.0)
         chp = [2:11];
       elseif (XYZ(j,i) < 0.0) & (XYZ(j,i) > (-1.0))
         chp = [1,3:11];
       else
         chp = [1:10];
       end
       b = b(chp);
       a = [a,b];
     end
     a = [a,'            C.5,',int2str(i)];

     fprintf(fid,'%s\n',a);
   end

end % of C.5 cards

status = fclose(fid);
```

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% END OF PROGRAM

APPENDIX G. EXAMPLE VIEW CONTROL FILE (S9991.VIN)

```
7091091
 1
                                 1
                                 2
                                 3
                                 4
    SHOT 9991 (TEST B)           5
                                 6
    SEATED MALE HIII DUMMY       7
                                 8
    50th PERCENTILE              9
                                10
                                11
                                12
                                13
                                14
                                15
                                16
                                 1
                                 2
                                 3
                                 4
SHOT 9991 SEATED 50% HIII DUMMY
0.000      0.033      1.980
0000
 0 020

 0
        2          2          2          2          2          2          2          2
        2          2          2          2          2          2          2          2
        2          9          9          2          2          2          2          2
        2          2          2          2          2          2
        9          9          9          9          9          9          9          9
        9          9          9          9          9          9          9          9
        9          9          9          9          9          9          9          9
        9          9          9          9          9          9          9          9
        9          9          9          9          9          9          9          9
        9          9          9          9          9          9          9          9
        9          9          9          9          9          9          9          9
        9          9          9          9
       10
        2          2          2          2          2          2          2          2
        2          2          2          2          2          2          2          2
        2          2          2          2
 8 5 8 3 5 5 3 3 5 3 3 3 3 3 310101010
2020202020202020202020202020202020202020202020
20 0 0 0.50
    4        115.80
        4.0        -2.0
     -850.0        40.0    -175.0       0.0       0.0       0.0       20         2
        0.00        11.0
```

```
Ellipsoid_ID= 1
Ellipsoid_Color= 229 159 89
Ellipsoid_ID= 2
Ellipsoid_Color= 229 159 89
Ellipsoid_ID= 3
Ellipsoid_Color= 229 159 89
Ellipsoid_ID= 4
Ellipsoid_Color= 229 159 89
Ellipsoid_ID= 5
Ellipsoid_Color= 229 159 89
Ellipsoid_ID= 6
Ellipsoid_Color= 229 159 89
Ellipsoid_ID= 7
Ellipsoid_Color= 229 159 89
Ellipsoid_ID= 8
Ellipsoid_Color= 229 159 89
Ellipsoid_ID= 9
Ellipsoid_Color= 229 159 89
Ellipsoid_ID= 10
Ellipsoid_Color= 229 159 89
Ellipsoid_ID= 11
Ellipsoid_Color= 229 159 89
Ellipsoid_ID= 12
Ellipsoid_Color= 229 159 89
Ellipsoid_ID= 13
Ellipsoid_Color= 229 159 89
Ellipsoid_ID= 14
Ellipsoid_Color= 229 159 89
Ellipsoid_ID= 15
Ellipsoid_Color= 229 159 89
Ellipsoid_ID= 16
Ellipsoid_Color= 229 159 89
Ellipsoid_ID= 17
Ellipsoid_Color= 229 159 89
Ellipsoid_ID= 18
Ellipsoid_Color= 0 0 0
Ellipsoid_ID= 19
Ellipsoid_Color= 0 0 0

Plane_ID= 1 /* Seat Bottom */
Plane_Color= 255 50 0
Plane_ID= 2 /* Seat Bottom - Front */
Plane_Color= 255 50 0
Plane_ID= 3 /* Seat Bottom - Right Side */
Plane_Color= 255 50 0
Plane_ID= 4 /* Seat Bottom - Left Side */
Plane_Color= 255 50 0
Plane_ID= 5 /* Seat Back */
Plane_Color= 255 50 0
Plane_ID= 6 /* Seat Back - Top */
Plane_Color= 255 50 0
Plane_ID= 7 /* Seat Back - Right Side */
Plane_Color= 255 50 0
Plane_ID= 8 /* Seat Back - Left Side */
Plane_Color= 255 50 0
Plane_ID= 9
Plane_Color= 125 125 125

/* Seat Bottom - Right Side */
Add_Plane= -9.5 9.25 -19.75 -9.5 9.25 -24.5 -9.5 -9.25 -24.5 -9.5 -9.25 -19.75
Attach_Plane_ID= 72
To_Segment= 20
```

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```
Plane_ID= 72
Plane_Color= 255 50 0

/* Seat Bottom - Left Side */
Add_Plane= 9.5 9.25 -19.75 9.5 -9.25 -19.75 9.5 -9.25 -24.5 9.5 9.25 -24.5
Attach_Plane_ID= 73
To_Segment= 20
Plane_ID= 73
Plane_Color= 255 50 0

/* Seat Bottom - Back */
Add_Plane= 9.5 -9.25 -19.75 -9.5 -9.25 -19.75 -9.5 -9.25 -24.5 9.5 -9.25 -24.5
Attach_Plane_ID= 74
To_Segment= 20
Plane_ID= 74
Plane_Color= 255 50 0

/* Seat Bottom - Bottom */
Add_Plane= 9.5 -9.25 -19.75 9.5 9.25 -19.75 -9.5 9.25 -19.75 -9.5 -9.25 -19.75
Attach_Plane_ID= 75
To_Segment= 20
Plane_ID= 75
Plane_Color= 125 125 125

/* Seat Back - Back */
Add_Plane= 9.5 -12.27 -27.77 -9.5 -12.24 -27.77 -9.5 -14.22 -44.07 9.5 -14.22 -44.07
Attach_Plane_ID= 76
To_Segment= 20
Plane_ID= 76
Plane_Color= 125 125 125

/* Seat Back - Bottom */
Add_Plane= 9.5 -8.3 -28.25 -9.5 -8.3 -28.25 -9.5 -12.27 -27.77 9.5 -12.27 -27.77
Attach_Plane_ID= 77
To_Segment= 20
Plane_ID= 77
Plane_Color= 255 50 0

/* Pedestal */
Add_Plane= -2.72 -1.148 -5.0 -2.72 1.148 -5.0 -2.72 1.148 -19.75 -2.72 -1.148 -19.75
Attach_Plane_ID= 78
To_Segment= 20
Plane_ID= 78
Plane_Color= 125 125 125

Add_Plane= -2.72 1.148 -5.0 -1.148 2.72 -5.0 -1.148 2.72 -19.75 -2.72 1.148 -19.75
Attach_Plane_ID= 79
To_Segment= 20
Plane_ID= 79
Plane_Color= 125 125 125

Add_Plane= -1.148 2.72 -5.0 1.148 2.72 -5.0 1.148 2.72 -19.75 -1.148 2.72 -19.75
Attach_Plane_ID= 80
To_Segment= 20
Plane_ID= 80
Plane_Color= 125 125 125

Add_Plane= 1.148 2.72 -5.0 2.72 1.148 -5.0 2.72 1.148 -19.75 1.148 2.72 -19.75
Attach_Plane_ID= 81
To_Segment= 20
Plane_ID= 81
Plane_Color= 125 125 125

Add_Plane= 2.72 1.148 -5.0 2.72 -1.148 -5.0 2.72 -1.148 -19.75 2.72 1.148 -19.75
Attach_Plane_ID= 82
To_Segment= 20
Plane_ID= 82
Plane_Color= 125 125 125
```

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```
Add_Plane= 2.72 -1.148 -5.0 1.148 -2.72 -5.0 1.148 -2.72 -19.75 2.72 -1.148 -19.75
Attach_Plane_ID= 83
To_Segment= 20
Plane_ID= 83
Plane_Color= 125 125 125

Add_Plane= 1.148 -2.72 -5.0 -1.148 -2.72 -5.0 -1.148 -2.72 -19.75 1.148 -2.72 -19.75
Attach_Plane_ID= 84
To_Segment= 20
Plane_ID= 84
Plane_Color= 125 125 125

Add_Plane= -1.148 -2.72 -5.0 -2.72 -1.148 -5.0 -2.72 -1.148 -19.75 -1.148 -2.72 -19.75
Attach_Plane_ID= 85
To_Segment= 20
Plane_ID= 85
Plane_Color= 125 125 125

Background_Color= 108 165 255
Camera_Position= -91.0 4.0 -46.0
Looking_At_Position= -6.0 0.0 -2.0
Camera_Segment= 20
Initial_Scale= .720
Time_Color= 0 0 0
```

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