01 Apr 1991

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The Articulated Total Body Model (ATB) is used for predicting gross segmented body response in various dynamic environments. The ATB computer program, originally written by the Department of Transportation as a Crash Victim Simulation (CVS) program, was later modified by the Calspan Corporation and More recently by the Armstrong Aerospace Medical Research Laboratory (AAMRL) to allow for aerodynamic force applications, harness belt capabilities and hyper-ellipsoidal graphical display of the modeled segments. The ATB model has been successfully used to investigate gross human body responses to bodies placed in such complex dynamic environments as high-speed aircraft ejection. This ATB model is quite versatile due to the variety of inputs it can handle. Because of this versatility , a wide range of physical systems may be simulated.

In this work, the ATB computer program has been modified for use on the Apollo workstation and utilized to predict limb and joint limitations a modeled human arm for the purpose of creating more effective rehabilitation schedules. A patient's left shoulder, left-upper and left-lower arm have been modeled for a case study. The required information consists of segment physical dimensions, weight ,center of gravity and maximum forces and torques obtainable from various body muscles. From this information, forces a graphical display of desired segment positions, and numerical approximations of forces, torques, positions, velocities, and accelerations of any desired point of the modeled segment. A comparison of this numerical output found from the ATB will be made with actual patient response, further input will be created tracking the patient's rehabilitation progress. A mathematical model of this will be incorporated into the ATB for the purpose of predicting future patient responses and a predicted schedule for disabled patient rehabilitation.

An accurate numerical and visual prediction of patient responses and limitations would be very beneficial in the creation of rehabilitation schedules. For such a service to be obtainable in a hospital environment, the ATB must be executable on a personal computing level. The Apollo workstation was selected for this project due to its relative mobility and availability. Many similar computing systems could be used where the criteria of mobility, large memory capabilities and superior graphics are obtainable. These criteria must be met so that the ATB could eventually be used by physicians in a clinic or office environment.

INTRODUCTION

The Articulated Total Body Model (ATB) is a computer model of the human body used for predicting gross segmented body response in various dynamic environments. The ATB program evolved from the Crash Victim Simulation (CVS) Program which was created by the Department of Transportation in 1973. Aerodynamic force applications and a harness belt capability were added to the CVS by Calspan Corporation in 1975 for the Armstrong Aerospace Medical Research Laboratory (AAMRL). The resulting program became known as the Articulated Total Body Model. In 1980, Calspan made a number of modifications to the ATB model, combining it with the then current 3-D Crash Victim Simulation program to form the ATB-II model. A new version, ATB-III , was generated which included improvements made by J&J Technologies, Inc. AND used to model the body response to wind blast for AAMRL. The ATB-III is the program version used for implementation on an Apollo workstation.

In this paper, first a general description of the human body model is treated. This description consists of the actual FORTRAN code within the ATB and its capabilities found from numerous executions (successful and unsuccessful) of the ATB program. This paper does not attempt to explain the actual computer coding of the ATB or any of the non-biodynamic options available to the ATB Model. Then a brief case study of a modeled human limb is presented to demonstrate succcessful implementation on the Apollo workstation for possible utilization of the model in a clinical environment. It should be emphasized that this model and the corresponding output obtained are simplified cases of a full body model. Although much more complex models could be presented, this simplicity has been emphasized so that the huge amounts of input and output data would not distract from the main point which is to demonstrate the utility of a computer model in a clinical setting. The unique aspect of this work is the use of the ATB model on a personal computing level with graphical display capabilities for determining the dynamic characteristics of various limbs and joints of the human body while carrying out prescribed motion. The Apollo workstation was selected for this project due to its relative mobility and availability. Many similar computing systems could be used where the criteria of mobility, large memory capabilities and superior graphics are obtainable. These are essential if the ATB were to eventually be used by physicians in a clinical environment. In that environment, an accurate numerical and visual prediction of patient responses and limitations would be very beneficial in the assessment of reach and flexion of the injured patient under a rehabilitation program, for example.

GENERAL FORMULATION OF THE ATB MODEL

"The Articulated Total Body (ATB) Model is primarily designed to evaluate the three-dimensional dynamic response of a system of rigid bodies when subjected to a dynamic environment consisting of applied forces and interactive contact forces." (Calspan Co 3). The structure of the ATB program input is quite versatile making the ATB a very general model. "The ATB Model has been used to model such widely diverse physical phenomenal as human body dynamics, the motion of balls in a billiards game and transient response of an MX missile suspended from cables in a wind tunnel"(Calspan Co. 3).

To avoid confusion between the individual segments and the total body model, the term "segment" will be used to refer to the individual rigid bodies and the term "body" will refer to the overall modeled body. A model of a human body structure showing the labeling of each segment and corresponding joints is shown in Figure 1. The ATB model divides the human body into individual rigid segments. These segments are linked together into a "tree" of coupled segments. Segments are assigned center of gravity, mass, moment of inertia, physical dimensions and are joined at positions representing human joint locations such as shoulders and elbows. Segments branch out from a central segment to form open chains analogous to limbs branching out from a tree trunk. A maximum of 30 segments can be modeled without program changes. The ATB input format is quite flexible and allows wide variation in the number and make-up of the segments.

SEGMENTS

H	HEAD
N	NECK
UT	UPPER TORSO
CT	CENTER TORSO
LT	LOWER TORSO
RUL	RIGHT UPPER LEG
RLL	RIGHT LOWER LEG
RF	RIGHT FOOT
LUL	LEFT UPPER LEG
LLL	LEFT LOWER LEG
LF	LEFT FOOT
RUA	RIGHT UPPER ARM
RLA	RIGHT LOWER ARM
LUA	LEFT UPPER ARM
LLA	LEFT LOWER ARM

JOINTS

HP	HEAD PIVOT
NP	NECK PIVOT
W	WAIST
P	PELVIS
RH	RIGHT HIP
RK	RIGHT KNEE
RA	RIGHT ANKLE
LH	LEFT HIP
LK	LEFT KNEE
LA	LEFT ANKLE
RS	RIGHT SHOULDER
RE	RIGHT ELBOW
LS	LEFT SHOULDER
LE	LEFT ELBOW

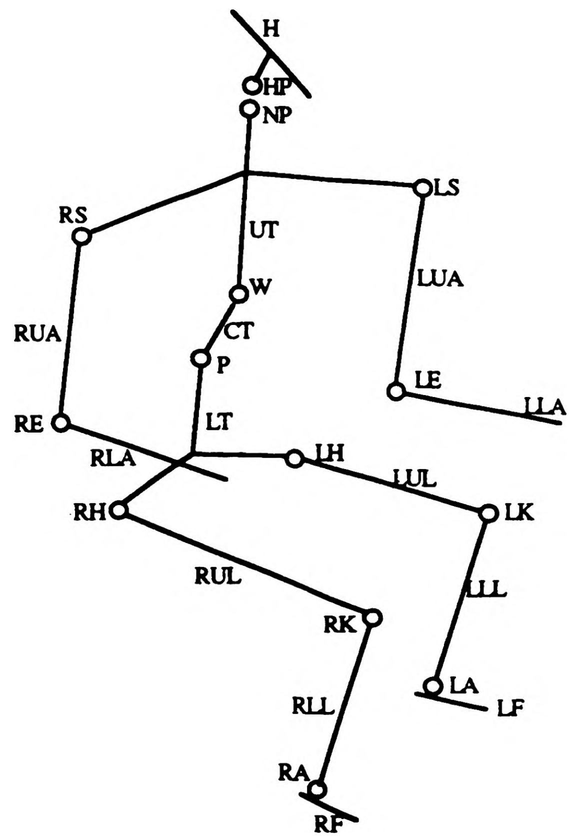


FIGURE 1- Body Dynamics Model

A chain structure is used to identify and relate the segments and their corresponding joints. The body models are composed of a Number of body SEGments, NSEG, and a Number of JoiNTs, NJNT. An example of a 15-segment, 14-joint human body model, and a 3-segment, 2-joint left arm model along with the methods of numbering these segments and joints are presented in Figures 2 and 3 respectively.

The ATB model utilizes many reference coordinate systems with respect to which position in space and segment orientations are calculated. The primary coordinate systems used in the model are the inertial, vehicle, local body segment, principal, joint and contact ellipsoid. The specification of each reference coordinate system requires an origin and a direction cosine matrix defined by three rotation angles yaw, pitch and roll- which relate one reference coordinate system to another. All the above mentioned coordinate systems are orthonormal. The inertial coordinate system represents the ground and can be positioned at the user's convenience. The inertial frame of reference is specified by defining a gravity vector as seen in Figure 2. Any values can be used for the vector components, however a convenient method is to assign the frame values of (zero, zero, g), defining the Z axis as pointing downward. In terms of a standing patient, the positive force of gravity would be pointing from head to foot. By assigning the positive X axis from the patients back to front, the right hand rule defines the positive Y axis as pointing in the lateral direction from the patients left to right side (see Figure 2). Segment coordinate systems are then defined with respect to the inertial system. These local segment coordinate systems are used to define the joint, force, vehicle, contact ellipsoid, and external planar coordinate systems.

FULL BODY MODEL

I	SEGMENT	J	JOINT	JNT(J)	CONNECTS
1	LT	1	P	1	LT-CT
2	CT	2	W	2	CT-UT
3	UT	3	NP	3	UT-H
4	N	4	HP	4	N-H
5	H	5	RH	1	LT-RUL
6	RUL	6	RK	6	RUL-RLL
7	RLL	7	RA	7	RLL-RF
8	RF	8	LH	1	LT-LUL
9	LUL	9	LK	9	LUL-LLL
10	LLL	10	LA	10	LLL-LF
11	LF	11	RS	3	UT-RUA
12	RUA	12	RE	12	RUA-RLA
13	RLA	13	LS	3	UT-LUA
14	LUA	14	LE	14	LUA-LLA
15	LLA				

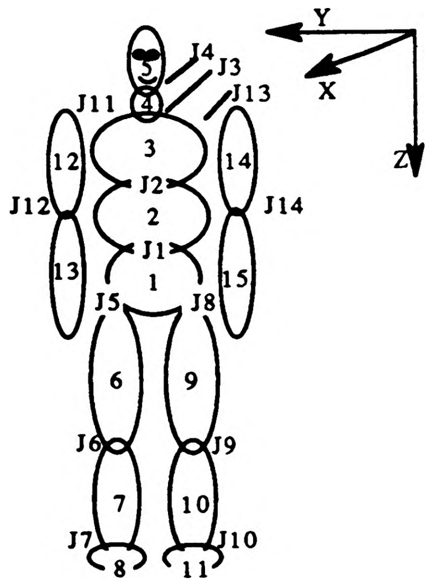


FIGURE 2- Example of segment, joint, and connectivity assignments (Full Body Model)

LEFT ARM MODEL

I	SEGMENT	J	JOINT	JNT(J)	CONNECTS
1	B-Body	1	LS	1	B-LUA
2	LUA	2	LE	2	LUA-LLA
3	LLA				
4	*-Vehical				

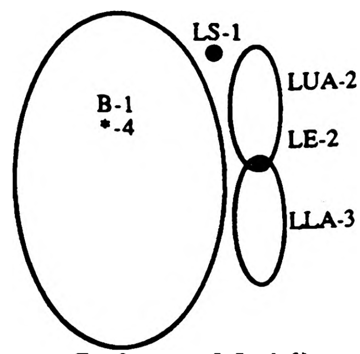


FIGURE 3- Example of segment, joint, and connectivity assignments (Left Arm Model)

LEFT ARM UNDER A CONSTANT ELEMENT TORQUE

To relate segments and joints to each other, the identification numbers i=1 to NSEG and j=1 to NJNT are used along with the array, JNT(j) which defines the connectivity of the segments. Referring to the left upper and lower arm model in Figure 3, the torso or body (BODY) is assigned the segment number, NSEG=1, defining the torso as the reference segment. Although any segment can be defined as the reference segment, a segment with maximum joint connections and minimal acceleration is desirable for the reference segment in order to avoid errors with the program integrator. After selection of the reference segment, the first joint j, must be defined. For the arm model, the left shoulder (LS) is defined as joint number 1. The requirement for sequential numbering of segments results in the upper arm (LUA) being designated as segment number 2, with the lower arm (LLA) being assigned segment number 3. The elbow (E) joint connects segment 2 and 3 and is assigned joint number 2.

To accurately model the human arm structure, the arm needed to be joined to a relatively stable structure via a joint. Originally an ellipsoid-planar contact was defined at the shoulder joint position. The planar surfaces are actually defined as finite rectangles which contact the segment ellipsoids at a finite number of points. For this type of contact, the contact force is determined by a force deflection routine which allows for energy losses (hysteresis), permanent offset, and impulsive forces. The force deflection is associated with each paired contact. Mutual force deflection characteristics which allow for the specific paired contacts must be accurately specified. For this particular ellipsoid-planar contact, unrealistic contact forces were continuously encountered.

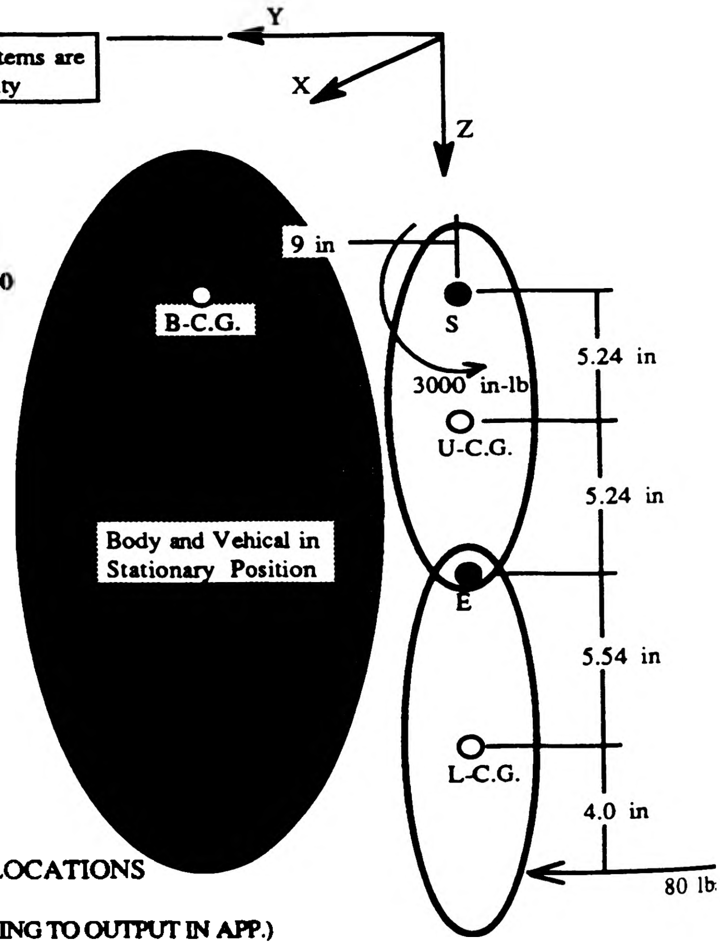
Instead of the planar contact, the BODY segment was introduced along with a fourth segment defined as a vehicle segment. By defining the vehicle with respect to BODY and mounting BODY upon the vehicle, the numerical descriptions of both segments were used to create a stationary segment to which the shoulder joint could be connected. To obtain this stationary position, the BODY segment was defined to have extremely large x, y, and z components of moment of inertia: 5000 (lbs-sec^2-in). The velocity and acceleration of the vehicle were then set to the constant value of zero.

As mentioned above, the BODY segment was created to act as an anchor for the modeling of the 2-segment left arm. The BODY segment was given a weight of 210 lbs and a contact ellipsoidal semi-axis of 6.0, 8.7, and 36.0 inches (x, y, z) which somewhat corresponds with the physical dimensions of the arm. The upper arm was given a weight of 5.542 lbs with a contact ellipsoidal semi-axis of 2.212, 2.212, and 7.497 inches (x, y, z) where the left lower arm weight was set at 5.901 lbs with ellipsoidal axes of 1.871, 1.871 and 10.269 inches (x, y, z respectively). These values were obtained from recorded human dimensions, with this example representing a 95th percentile male. Referring to Figure 4 and the corresponding table, both the linear positioning and the prescribed physical dimensions of each segment can be seen. The shoulder joint is located at (0.0, 9.0, 0.0) inches in the BODY coordinate system. The shoulder joint is located at (0.0, 0.0, -5.42) with in the upper arm coordinate system, which is located at the center of gravity of segment 2. The elbow and the shoulder joints are defined to be 8.2 and 19.04 inches respectively in the negative Z direction of the left lower arm coordinate system.

Individual Segment Coordinate Systems are Located at Segment Center of Gravity

SEGMENT	WEIGHT (lbs)	MI- (X	Y	Z) (lbs-sec^2-in)
BODY-B	210	5000	5000	5000
UPPER-U	5.5	.17	.17	.03
LOWER-L	5.9	.33	.33	.02
VEHICAL-* --stationary				

JOINT	TYPE	FRICTION FORCE
SHOULDER-S	BALL	30 lbs--at 30 rad/sec
ELBOW-E	SLIP	10 lbs



SEGMENT AND JOINT DESCRIPTIONS AND LOCATIONS
FORCE AND TORQUE LOCATIONS
(MODEL USED FOR ATB CASE STUDY CORRISPONDING TO OUTPUT IN APP.)

FIGURE 4- Left Arm Model Physical Description

The ATB has the ability to accurately model standard ball and pin, hinge, Euler, slip, and universal joints. These joints can be linear or angular locking joints with maximum and minimum locking and unlocking joint forces. For simplicity, a totally free ball joint was specified for the shoulder joint of the modeled arm. The elbow was specified as a slip joint with a coulomb frictional force applied when joint angular velocities exceed 30 rad/sec. This slip joint allows small linear motion between the joint's segment coordinate systems. Although this particular joint is unlocked, joints can easily be locked to limit rotation, and angular velocity. Joint torques can be both applied and calculated for each joint by relating joint parameters and yaw, pitch, and roll with all related local segments.

The ATB model has the capability to apply time-dependent forces and torques to body segments. A force or torque coordinate system is defined such that a positive force is applied in the positive X direction of the force or torque coordinate system and a positive torque is applied about the positive X axis of the coordinate system using the right hand rule. The origin and orientation (rotation) of the force or torque coordinate systems are specified with respect to the local reference coordinate system of the segment to which the force or torque is being applied. Each time dependent force can be subdivided over the time domain that it acts on. The force over each of these smaller domains can be defined either as a constant force, a polynomial, or the force can be defined over an even smaller domain by using tabular data to describe the force. For the arm model, a constant torque was placed on the left upper arm at (0, 0, -4) with respect to the left upper arm center of gravity.

MODEL RESPONSE

The ATB outputs requested time histories of selected total and angular accelerations, velocities, displacements, joint parameters, joint forces and torques, and total body properties. For the 2-segment arm model, only relative positioning and joint parameters were requested. For this run, end point positioning of the upper and lower arm segments (segments 2 and 3) were calculated with respect to segment 1 (BODY). The positioning of segment 3 with respect to segment 2 was also calculated and this tabular output can be seen in Appendix B. The shoulder joint forces and torques on the upper arm were also tabulated and can be seen in Appendix C. These tables of displacements represent the displacements of each of the specified points over the specified time frame of 40 msec. This 40 msec is divided into specified one time units which for this case was 1 msec.

The tabulated position data is depicted as Y-Z, X-Z, and X-Y plane views of the body segments in Appendix D. These printer plots, also called "stickman plots" give the location in the primary vehicle reference coordinate system. This is an optional feature to the ATB, and any or all of the three plots can be suppressed. These printed output pages consist of 60 lines of 120 characters each. The top line represents the Z axis and the first column or left side edge, running top to bottom, represents the plot X or Y axis. Rotating the pages 90 degrees in a counter-clockwise direction, the printed page becomes more familiarly orientated. In this position the negative Z is up and the positive X or Y is to the right from lower left corner. The X-Y axis has tick marks located every one length unit from input data. Table 1 gives the joint or segment center of gravity identifying symbols used in this plotting option.

Table 1
Identifying Symbols for Printer Plots App. B1

Segment C.G. or Joint	Number	Symbol
Body	S-1.	B
Upper Arm	S-2.	U
Lower Arm	S-3.	L
Vehicle	S-4.	*
Shoulder	J-1.	S
Elbow	S-2.	E

From these plots, the motion of the modeled segments can clearly be seen. It should be noted that the shoulder and body segment have very little motion forcing the two arm segments to respond to the torque placed on the upper arm. The response to the specified torque is extremely similar to the actual motion of a human raising a upper arm through a contraction of a series of shoulder muscles.

CONCLUSION

The Articulated Total Body Model (ATB) is a computer model of the human body used for predicting gross segmented body responses in various dynamic environments. In this paper a general description of the human body model and a case study of the human limb behavior are given. A brief case study of a modeled human limb using the ATB was also given. The purpose of this case study was to show the possibilities of adapting the ATB model for clinical applications. It should be emphasized that this model and the output are simplified cases of a full body model.

The ATB model is a useful tool. Although the flexibility of the input does initially cause the program to seem highly complex, once the system is mastered, the ATB has numerous possibilities for modeling most any rigid bodied structure in a dynamic environment. The ATB uses both Newtonian and Lagrange methods to formulate the equations of motions for these rigid bodies. The boundary conditions of these bodies are extremely well defined and a finite element analysis routine for evaluation of these rigid body structures could be implemented.

Before the ATB could be used in a hospital or clinical environment to predict human dynamic responses, very specific input would have to be prescribed. A program used in such a situation could also access generalized input data with only a limited amount of required patient data to be entered for individual computer runs. Whichever the method used, the next step is to understand what output would be needed in a rehabilitation environment and to specify what patient data would be required to obtain the desired output. For example, a mathematical model of rehabilitation prograess could be incorporated into the model and a clinical evaluation could be made. The modeling of such systems does seem inevitable due to the success and accuracy obtainable from computerized models as simply demonstrated by the ATB's ability to raise its own hand.

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APPENDIX

APPENDIX A1

```
MM_3-23-91:  LEFT ARM-DYNMC JNT TEST
SLIP JOINT / 3000 IN-LBS TENSION ELE TORQUE
 IN. LB.SEC.     0.0          0.0       386.088                          CARD A3
  4  20   0.002  0.0005   0.001 .0000625                                 CARD A4
 1 010 2 1 1 1 0 0 0 0 0 0 0 0 016 0 0 0 0 0 0 0 1 0 0 0 1 0 0 0 0 0 1CARD A5
   3     2        95TH PERCENTILE MALE                                   CARD B1
BODY B 210.0 5000. 5000. 5000. 6.000 10.50 36.00 0.000 0.000 26.00       CARD B2a
UARM U 5.542 .1743 .1743 .0259 2.122 2.122 7.497 1.000 1.000 1.000       CARD B2b
LARM L 5.901 .3331 .3331 .0214 1.871 1.87110.269 1.000 1.000 1.000       CARD B2c
SLDR S   1    0  0.00   9.00  0.00  0.00  0.00 -5.42   1  0.00  0.00     CARD B3a
                 0.00   0.00  0.00  0.00  0.00  0.00
ELBW E   2    5  0.00   0.00  5.42  0.00  0.00 -8.20   1  0.00  0.00     CARD B3b
                 0.00   0.00  0.00  0.00-67.19  0.00
  .00   .00   .00   .00        .00   .00   .00   .00   .00          .00CARD B4A
  .00   .00   .00   .00        .00   .00   .00   .00   .00          .00CARD B4B
  0.0   0.0   10    0.0   0.0                     0.0   0.0              CARD B5A
  0.0   0.0   30.   0.0   0.0                     0.0   0.0              CARD B5B
  .00   .00   .00   .00   .00   .00   .01   .01  .001  .001  .001   .001CARD B6A
  .00   .00   .00   .00   .00   .00   .01   .01  .001   .00   .00    .00CARD B6B
  .00   .00   .00   .00   .00   .00   .01   .01  .001   .00   .00    .00CARD B6C
EQUILIBRIUM-0 INTL MOTION-STATIONARY TORSO
  0.0   0.0   0.0   0.0  0.00  0.00  0.00  9.00    -3   0.0  2.30     0CARD C2A
    2     1     3                                                        CARD C2B
    0.000     0.000     0.000     0.000     0.000     0.000     0.000  CARD C5A
    0.000     0.000     0.000     0.000     0.000     0.000     0.000  CARD C5B
    2.300     0.000     0.000     0.000     0.000     0.000     0.000  CARD C5C
    4.600     0.000     0.000     0.000     0.000     0.000     0.000  CARD C5D
    0    0    0    0    0    0    0    0    0    2                       CARD D1
  0   0   0   0   0   0   0   0   0   0   0   0   0   0   0              CARD D7
   -2    1      0.0        0.0       -4.0       0.0        0.0       0.0  CARD D9a
    3    2      0.0        0.0        8.0      90.0        0.0       0.0  CARD D9b
  1     SHOULDER TORQUE                                                  CARD E1
      0.0        0.0    -3000.0          0.0          0.0                CARD E2
  2     +X FORCE ON HAND                                                 CARD E1
      0.0        0.0      -80.0          0.0          0.0                CARD E2
999
  0   0                                                                  CARD F3A
  0                                                                      CARD F4A
     20.0      20.0      60.0   0   0   0   0   1                        CARD G1A
  0.00000   0.00000   0.00000      0.0       0.0       0.0               CARD G2A
     0.00     -2.00      0.00     0.00      0.00      0.00  3  2  1      CARD G3A
     0.00     -2.00      0.00     0.00      0.00      0.00  3  2  1      CARD G3B
     0.00     -2.00      0.00     0.00      0.00      0.00  3  2  1      CARD G3B
    3  2  3        0.0         0.0        21.82                          CARD H1A
       1  2        0.0         9.0        10.84                          CARD H1B
       1  3        0.0         9.0        27.24                          CARD H1c
    3  2  3        0.0         0.0        21.82                          CARD H2A
       1  2        0.0         9.0        10.84                          CARD H2B
       1  3        0.0         9.0        27.24                          CARD H2c
    3  2  3        0.0         0.0        21.82                          CARD H3A
       1  2        0.0         9.0        10.84                          CARD H3C
       1  3        0.0         9.0        27.24                          CARD H3C
    0                                                                    CARD H4
    0                                                                    CARD H5
    0                                                                    CARD H6
    1     1                                                              CARD H7
    0                                                                    CARD H8
    1   1   1                                                            CARD H9
                                                                         CARD H10
```

POINT REL. LINEAR DISPLACEMENT (IN.)

TIME	POINT (0.00, 0.00, 21.82) ON SEGMENT NO. 3 - LARM IN UARM REFERENCE				POINT (0.00, 9.00, 10.84) ON SEGMENT NO. 2 - UARM IN BODY REFERENCE				POINT (0.00, 9.00, 27.24) ON SEGMENT NO. 3 - LARM IN BODY REFERENCE			
(MSEC)	X	Y	Z	RES	X	Y	Z	RES	X	Y	Z	RES
0.000	0.000	0.000	35.440	35.440	0.000	18.000	16.260	24.257	0.000	18.000	46.280	49.657
0.500	0.000	-0.029	35.440	35.440	0.000	18.007	16.256	24.259	0.000	17.986	46.285	49.656
1.000	0.000	-0.115	35.440	35.440	0.000	18.027	16.245	24.267	0.000	17.943	46.299	49.654
1.500	0.000	-0.258	35.439	35.440	0.000	18.062	16.226	24.280	0.000	17.871	46.323	49.651
2.000	0.000	-0.459	35.437	35.440	0.000	18.110	16.199	24.297	0.000	17.770	46.356	49.645
3.000	0.000	-1.034	35.425	35.440	0.000	18.246	16.121	24.348	0.000	17.482	46.448	49.629
4.000	0.000	-1.837	35.392	35.440	0.000	18.436	16.011	24.418	0.000	17.077	46.571	49.603
5.000	0.000	-2.867	35.323	35.439	0.000	18.679	15.865	24.507	0.000	16.554	46.720	49.566
6.000	0.000	-4.122	35.197	35.438	0.000	18.971	15.683	24.614	0.000	15.908	46.889	49.514
7.000	0.000	-5.596	34.991	35.436	0.000	19.310	15.462	24.738	0.000	15.139	47.068	49.443
8.000	0.000	-7.278	34.676	35.432	0.000	19.693	15.200	24.877	0.000	14.241	47.247	49.347
9.000	0.000	-9.156	34.222	35.425	0.000	20.115	14.894	25.029	0.000	13.210	47.415	49.220
10.000	0.000	-11.208	33.593	35.414	0.000	20.570	14.544	25.192	0.000	12.040	47.555	49.056
11.000	0.000	-13.405	32.757	35.394	0.000	21.049	14.149	25.363	0.000	10.724	47.652	48.844
12.000	0.000	-15.708	31.679	35.359	0.000	21.545	13.712	25.538	0.000	9.257	47.683	48.573
13.000	0.000	-18.065	30.331	35.303	0.000	22.046	13.236	25.714	0.000	7.633	47.622	48.230
14.000	0.000	-20.414	28.692	35.213	0.000	22.539	12.731	25.886	0.000	5.848	47.440	47.799
15.000	0.000	-22.677	26.756	35.073	0.000	23.012	12.209	26.050	0.000	3.905	47.098	47.260
16.000	0.000	-24.768	24.537	34.864	0.000	23.451	11.685	26.201	0.000	1.818	46.557	46.593
17.000	0.000	-26.596	22.071	34.561	0.000	23.844	11.182	26.336	0.000	-0.388	45.775	45.776
18.000	0.000	-28.081	19.420	34.142	0.000	24.181	10.721	26.451	0.000	-2.668	44.713	44.793
19.000	0.000	-29.162	16.663	33.587	0.000	24.456	10.320	26.544	0.000	-4.962	43.347	43.630
20.000	0.000	-29.808	13.883	32.883	0.000	24.669	9.994	26.616	0.000	-7.202	41.666	42.284
21.000	0.000	-30.020	11.156	32.026	0.000	24.823	9.749	26.668	0.000	-9.319	39.679	40.759
22.000	0.000	-29.822	8.539	31.020	0.000	24.923	9.584	26.702	0.000	-11.250	37.410	39.064
23.000	0.000	-29.253	6.070	29.876	0.000	24.977	9.494	26.720	0.000	-12.945	34.891	37.215
24.000	0.000	-28.359	3.771	28.609	0.000	24.991	9.469	26.725	0.000	-14.367	32.164	35.227
25.000	0.000	-27.185	1.651	27.235	0.000	24.972	9.501	26.719	0.000	-15.492	29.269	33.116
26.000	0.000	-25.770	-0.290	25.772	0.000	24.925	9.580	26.703	0.000	-16.304	26.249	30.900
27.000	0.000	-24.153	-2.054	24.240	0.000	24.855	9.696	26.679	0.000	-16.795	23.143	28.595
28.000	0.000	-22.364	-3.647	22.660	0.000	24.765	9.842	26.649	0.000	-16.965	19.990	26.218
29.000	0.000	-20.431	-5.077	21.053	0.000	24.658	10.010	26.613	0.000	-16.817	16.825	23.789
30.000	0.000	-18.379	-6.350	19.445	0.000	24.539	10.195	26.572	0.000	-16.358	13.683	21.327
31.000	0.000	-16.227	-7.472	17.864	0.000	24.408	10.392	26.528	0.000	-15.601	10.593	18.858
32.000	0.000	-13.994	-8.449	16.346	0.000	24.268	10.596	26.480	0.000	-14.559	7.584	16.416
33.000	0.000	-11.696	-9.286	14.934	0.000	24.122	10.803	26.431	0.000	-13.248	4.680	14.050
34.000	0.000	-9.347	-9.986	13.678	0.000	23.972	11.010	26.380	0.000	-11.684	1.905	11.839
35.000	0.000	-6.961	-10.554	12.643	0.000	23.819	11.215	26.327	0.000	-9.888	-0.723	9.914
36.000	0.000	-4.550	-10.991	11.895	0.000	23.666	11.414	26.275	0.000	-7.878	-3.187	8.498
37.000	0.000	-2.123	-11.298	11.496	0.000	23.515	11.606	26.223	0.000	-5.674	-5.471	7.882
38.000	0.000	0.308	-11.477	11.481	0.000	23.368	11.788	26.173	0.000	-3.298	-7.563	8.250
39.000	0.000	2.734	-11.527	11.847	0.000	23.226	11.959	26.124	0.000	-0.768	-9.453	9.484
40.000	0.000	5.147	-11.446	12.550	0.000	23.092	12.116	26.078	0.000	1.895	-11.133	11.293

APPENDIX B2

POINT REL. VELOCITY (IN./SEC.)

TIME	POINT (0.00, 0.00, 21.82) ON SEGMENT NO. 3 - LARM IN UARM REFERENCE				POINT (0.00, 9.00, 10.84) ON SEGMENT NO. 2 - UARM IN BODY REFERENCE				POINT (0.00, 9.00, 27.24) ON SEGMENT NO. 3 - LARM IN BODY REFERENCE			
(MSEC)	X	Y	Z	RES	X	Y	Z	RES	X	Y	Z	RES
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.500	0.000	-54.926	-0.045	54.926	0.000	27.492	-15.232	31.429	0.000	-57.342	19.183	60.466
1.000	0.000	-109.852	-0.362	109.853	0.000	54.944	-30.533	62.858	0.000	-114.746	38.174	120.929
1.500	0.000	-164.775	-1.221	164.780	0.000	82.318	-45.973	94.286	0.000	-172.274	56.780	181.390
2.000	0.000	-219.690	-2.895	219.709	0.000	109.570	-61.619	125.708	0.000	-229.988	74.810	241.849
3.000	0.000	-329.442	-9.770	329.587	0.000	163.518	-93.787	188.505	0.000	-346.238	108.377	362.804
4.000	0.000	-438.923	-23.165	439.534	0.000	216.354	-127.516	251.136	0.000	-464.040	137.347	483.939
5.000	0.000	-547.770	-45.265	549.637	0.000	267.531	-163.204	313.382	0.000	-583.988	160.184	605.558
6.000	0.000	-655.384	-78.282	660.043	0.000	316.362	-201.125	374.882	0.000	-706.747	175.312	728.166
7.000	0.000	-760.846	-124.472	770.961	0.000	361.995	-241.373	435.087	0.000	-833.063	181.063	852.512
8.000	0.000	-862.817	-186.155	882.670	0.000	403.398	-283.790	493.220	0.000	-963.760	175.583	979.624
9.000	0.000	-959.396	-265.733	995.517	0.000	439.356	-327.875	548.211	0.000	-1099.702	156.711	1110.811
10.000	0.000	-1047.924	-365.663	1109.889	0.000	468.477	-372.668	598.625	0.000	-1241.683	121.821	1247.644
11.000	0.000	-1124.714	-488.365	1226.165	0.000	489.226	-416.615	642.580	0.000	-1390.204	67.637	1391.849
12.000	0.000	-1184.713	-635.959	1344.615	0.000	499.984	-457.426	677.659	0.000	-1545.057	-9.926	1545.088
13.000	0.000	-1221.160	-809.732	1465.230	0.000	499.180	-491.971	700.868	0.000	-1704.628	-115.801	1708.557
14.000	0.000	-1225.418	-1009.176	1587.478	0.000	485.505	-516.299	708.717	0.000	-1864.894	-255.487	1882.313
15.000	0.000	-1187.345	-1230.577	1710.003	0.000	458.261	-525.940	697.579	0.000	-2018.211	-434.168	2064.383
16.000	0.000	-1096.772	-1465.437	1830.414	0.000	417.822	-516.691	664.488	0.000	-2152.452	-654.968	2249.896
17.000	0.000	-946.407	-1699.679	1945.403	0.000	366.078	-485.929	608.391	0.000	-2251.522	-916.512	2430.915
18.000	0.000	-735.544	-1915.021	2051.421	0.000	306.540	-434.046	531.379	0.000	-2298.265	-1210.871	2597.735
19.000	0.000	-472.453	-2093.114	2145.772	0.000	243.804	-365.120	439.036	0.000	-2279.367	-1523.614	2741.699
20.000	0.000	-173.197	-2220.713	2227.457	0.000	182.433	-286.006	339.236	0.000	-2189.689	-1836.783	2858.061
21.000	0.000	142.893	-2292.741	2297.190	0.000	125.859	-204.250	239.914	0.000	-2033.203	-2133.305	2947.016
22.000	0.000	458.258	-2311.684	2356.668	0.000	75.905	-126.085	147.170	0.000	-1820.344	-2400.257	3012.455
23.000	0.000	760.000	-2284.635	2407.729	0.000	32.998	-55.505	64.573	0.000	-1564.114	-2629.755	3059.749
24.000	0.000	1040.250	-2220.246	2451.859	0.000	-3.303	5.605	6.506	0.000	-1277.131	-2818.122	3094.006
25.000	0.000	1295.118	-2126.760	2490.068	0.000	-33.811	56.866	66.159	0.000	-970.251	-2964.515	3119.252
26.000	0.000	1523.335	-2011.181	2522.974	0.000	-59.398	98.769	115.254	0.000	-652.290	-3069.778	3138.315
27.000	0.000	1725.149	-1879.119	2550.926	0.000	-80.836	132.212	154.966	0.000	-330.264	-3135.677	3153.021
28.000	0.000	1901.592	-1734.959	2574.128	0.000	-98.752	158.215	186.505	0.000	-9.757	-3164.466	3164.480
29.000	0.000	2054.043	-1582.102	2592.709	0.000	-113.627	177.774	210.986	0.000	304.758	-3158.659	3173.327
30.000	0.000	2183.987	-1423.191	2606.774	0.000	-125.819	191.793	229.379	0.000	609.671	-3120.907	3179.899
31.000	0.000	2292.894	-1260.297	2616.431	0.000	-135.583	201.056	242.500	0.000	902.062	-3053.932	3184.371
32.000	0.000	2382.165	-1095.055	2621.803	0.000	-143.099	206.236	251.019	0.000	1179.586	-2960.482	3186.829
33.000	0.000	2453.104	-928.764	2623.036	0.000	-148.489	207.891	255.475	0.000	1440.389	-2843.296	3187.327
34.000	0.000	2506.916	-762.453	2620.298	0.000	-151.825	206.488	256.297	0.000	1683.052	-2705.073	3185.919
35.000	0.000	2544.707	-596.936	2613.784	0.000	-153.146	202.403	253.813	0.000	1906.544	-2548.438	3182.679
36.000	0.000	2567.479	-432.841	2603.709	0.000	-152.461	195.939	248.267	0.000	2110.184	-2375.916	3177.712
37.000	0.000	2576.139	-270.634	2590.315	0.000	-149.751	187.328	239.827	0.000	2293.605	-2189.898	3171.163
38.000	0.000	2571.484	-110.635	2573.863	0.000	-144.972	176.738	228.590	0.000	2456.722	-1992.614	3163.225
39.000	0.000	2554.205	46.969	2554.637	0.000	-138.056	164.274	214.582	0.000	2599.694	-1786.101	3154.135
40.000	0.000	2524.868	202.125	2532.945	0.000	-128.904	149.977	197.760	0.000	2722.895	-1572.181	3144.187

DATE: MAR 23, 1991

PAGE 18

RUN DESCRIPTION: RUN_3-23-91: LEFT ARM-DYNMC JNT TEST

SLIP JOINT / 3000 IN-LBS TENSION ELB TORQUE

PAGE: 23.01

VEHICLE DECELERATION: EQUILIBRIUM-0 INTL MOTION-STATIONARY TORSO

APPENDIX B3

POINT TOTAL ACCELERATION (G'S)

	POINT (0.00, 0.00, 21.82) ON				POINT (0.00, 9.00, 10.84) ON				POINT (0.00, 9.00, 27.24) ON			
	SEGMENT NO. 3 - LARM				SEGMENT NO. 2 - UARM				SEGMENT NO. 3 - LARM			
TIME	IN UARM REFERENCE				IN BODY REFERENCE				IN BODY REFERENCE			
(MSEC)	X	Y	Z	RES	X	Y	Z	RES	X	Y	Z	RES
0.000	0.035	-238.710	0.999	238.712	0.035	140.781	-77.844	160.870	0.035	-298.653	100.536	315.120
0.500	0.035	-238.710	0.498	238.711	0.035	140.681	-78.023	160.868	0.035	-298.812	100.039	315.114
1.000	0.035	-238.709	-1.006	238.712	0.035	140.377	-78.558	160.863	0.035	-299.292	98.551	315.100
1.500	0.035	-238.704	-3.513	238.730	0.035	139.859	-79.442	160.847	0.035	-300.095	96.071	315.098
2.000	0.035	-238.686	-7.024	238.789	0.035	139.113	-80.668	160.809	0.035	-301.229	92.603	315.141
3.000	0.035	-238.570	-17.063	239.179	0.035	136.838	-84.084	160.607	0.035	-304.524	82.709	315.556
4.000	0.035	-238.244	-31.154	240.272	0.035	133.307	-88.639	160.086	0.035	-309.284	68.870	316.859
5.000	0.035	-237.531	-49.382	242.609	0.035	128.193	-94.070	159.005	0.035	-315.663	51.033	319.762
6.000	0.035	-236.172	-71.914	246.878	0.035	121.101	-99.992	157.047	0.035	-323.860	29.037	325.160
7.000	0.035	-233.778	-99.044	253.893	0.035	111.582	-105.856	153.805	0.035	-334.090	2.535	334.100
8.000	0.035	-229.738	-131.213	264.569	0.035	99.165	-110.902	148.772	0.035	-346.523	-29.094	347.742
9.000	0.035	-223.082	-169.009	279.874	0.035	83.379	-114.104	141.322	0.035	-361.154	-66.841	367.288
10.000	0.035	-212.267	-213.078	300.765	0.035	63.801	-114.112	130.737	0.035	-377.576	-112.153	393.881
11.000	0.035	-194.913	-263.889	328.068	0.035	40.123	-109.207	116.345	0.035	-394.585	-166.950	428.451
12.000	0.035	-167.515	-321.229	362.283	0.035	12.271	-97.330	98.101	0.035	-409.577	-233.471	471.447
13.000	0.035	-125.319	-383.301	403.267	0.035	-19.399	-76.256	78.685	0.035	-417.739	-313.754	522.444
14.000	0.035	-62.728	-445.411	449.806	0.035	-53.815	-44.100	69.576	0.035	-411.271	-408.468	579.647
15.000	0.035	25.159	-498.635	499.269	0.035	-88.835	-0.307	88.836	0.035	-379.353	-514.943	639.590
16.000	0.035	139.447	-529.715	547.763	0.035	-121.055	52.924	132.119	0.035	-310.186	-624.852	697.606
17.000	0.035	273.607	-524.091	591.212	0.035	-146.207	109.540	182.689	0.035	-196.134	-723.352	749.470
18.000	0.035	412.011	-472.558	626.948	0.035	-160.498	160.320	226.853	0.035	-40.354	-792.250	793.277
19.000	0.035	534.238	-377.783	654.316	0.035	-162.439	196.216	254.730	0.035	140.573	-817.372	829.372
20.000	0.035	623.776	-254.380	673.651	0.035	-153.721	212.493	262.266	0.035	322.429	-795.217	858.097
21.000	0.035	674.331	-121.637	685.214	0.035	-138.224	210.311	251.668	0.035	483.899	-733.248	878.528
22.000	0.035	689.319	4.726	689.336	0.035	-120.057	194.800	228.825	0.035	613.373	-644.381	889.637
23.000	0.035	677.041	116.030	686.912	0.035	-102.179	171.923	199.995	0.035	708.719	-541.072	891.651
24.000	0.035	646.222	209.576	679.356	0.035	-86.115	146.438	169.882	0.035	773.356	-432.467	886.063
25.000	0.035	603.856	286.089	668.198	0.035	-72.331	121.352	141.273	0.035	812.555	-324.267	874.868
26.000	0.035	554.849	347.646	654.763	0.035	-60.711	98.226	115.473	0.035	831.404	-219.689	859.939
27.000	0.035	502.412	396.547	640.052	0.035	-50.906	77.669	92.865	0.035	834.097	-120.454	842.750
28.000	0.035	448.587	434.853	624.762	0.035	-42.525	59.763	73.348	0.035	823.897	-27.468	824.355
29.000	0.035	394.672	464.265	609.350	0.035	-35.213	44.326	56.611	0.035	803.320	58.786	805.468
30.000	0.035	341.504	486.153	594.113	0.035	-28.681	31.075	42.288	0.035	774.351	138.054	786.561
31.000	0.035	289.637	501.623	579.237	0.035	-22.702	19.703	30.060	0.035	738.607	210.216	767.939
32.000	0.035	239.447	511.579	564.844	0.035	-17.103	9.914	19.769	0.035	697.456	275.254	749.806
33.000	0.035	191.194	516.782	551.016	0.035	-11.749	1.444	11.837	0.035	652.090	333.231	732.301
34.000	0.035	145.056	517.884	537.815	0.035	-6.537	-5.944	8.835	0.035	603.570	384.296	715.528
35.000	0.035	101.150	515.466	525.297	0.035	-1.382	-12.459	12.535	0.035	552.849	428.673	699.573
36.000	0.035	59.543	510.051	513.514	0.035	3.787	-18.287	18.675	0.035	500.785	466.670	684.519
37.000	0.035	20.254	502.122	502.531	0.035	9.036	-23.600	25.271	0.035	448.150	498.668	670.453
38.000	0.035	-16.740	492.135	492.420	0.035	14.429	-28.562	32.000	0.035	395.624	525.125	657.476
39.000	0.035	-51.507	480.522	483.274	0.035	20.036	-33.334	38.892	0.035	343.802	546.571	645.709
40.000	0.035	-84.165	467.698	475.210	0.035	25.934	-38.086	46.078	0.035	293.182	563.607	635.302

DATE: MAR 23, 1991

PAGE

RUN DESCRIPTION: RUN_3-23-91: LEFT ARM-DYNMC JNT TEST

SLIP JOINT / 3000 IN-LBS TENSION ELB TORQUE

PAGE: 22.01

VEHICLE DECELERATION: EQUILIBRIUM-0 INTL MOTION-STATIONARY TORSO

CRASH VICTIM: 95TH PERCENTILE MALE

APPENDIX C1

SLDR JOINT FORCES & TORQUES ON UARM IN BODY REFERENCE

TIME	JOINT FORCE (LB. 10**2)			JOINT TORQUE (IN.- LB. 10**2)		
(MSEC)	X	Y	Z	X	Y	Z
0.000	0.000	3.493	0.000	0.000E+00	0.000E+00	0.000E+00
0.500	0.000	3.493	-0.004	0.000E+00	0.000E+00	0.000E+00
1.000	0.000	3.493	-0.015	0.000E+00	0.000E+00	0.000E+00
1.500	0.000	3.493	-0.033	0.000E+00	0.000E+00	0.000E+00
2.000	0.000	3.493	-0.058	0.000E+00	0.000E+00	0.000E+00
3.000	0.000	3.490	-0.131	0.000E+00	0.000E+00	0.000E+00
4.000	0.000	3.483	-0.233	0.000E+00	0.000E+00	0.000E+00
5.000	0.000	3.468	-0.362	0.000E+00	0.000E+00	0.000E+00
6.000	0.000	3.441	-0.518	0.000E+00	0.000E+00	0.000E+00
7.000	0.000	3.397	-0.698	0.000E+00	0.000E+00	0.000E+00
8.000	0.000	3.329	-0.896	0.000E+00	0.000E+00	0.000E+00
9.000	0.000	3.230	-1.106	0.000E+00	0.000E+00	0.000E+00
10.000	0.000	3.092	-1.317	0.000E+00	0.000E+00	0.000E+00
11.000	0.000	2.906	-1.513	0.000E+00	0.000E+00	0.000E+00
12.000	0.000	2.662	-1.675	0.000E+00	0.000E+00	0.000E+00
13.000	0.000	2.353	-1.777	0.000E+00	0.000E+00	0.000E+00
14.000	0.000	1.974	-1.791	0.000E+00	0.000E+00	0.000E+00
15.000	0.000	1.530	-1.692	0.000E+00	0.000E+00	0.000E+00
16.000	0.000	1.043	-1.468	0.000E+00	0.000E+00	0.000E+00
17.000	0.000	0.556	-1.137	0.000E+00	0.000E+00	0.000E+00
18.000	0.000	0.129	-0.750	0.000E+00	0.000E+00	0.000E+00
19.000	0.000	-0.181	-0.383	0.000E+00	0.000E+00	0.000E+00
20.000	0.000	-0.346	-0.100	0.000E+00	0.000E+00	0.000E+00
21.000	0.000	-0.378	0.068	0.000E+00	0.000E+00	0.000E+00
22.000	0.000	-0.313	0.126	0.000E+00	0.000E+00	0.000E+00
23.000	0.000	-0.192	0.102	0.000E+00	0.000E+00	0.000E+00
24.000	0.000	-0.048	0.028	0.000E+00	0.000E+00	0.000E+00
25.000	0.000	0.100	-0.069	0.000E+00	0.000E+00	0.000E+00
26.000	0.000	0.242	-0.173	0.000E+00	0.000E+00	0.000E+00
27.000	0.000	0.373	-0.273	0.000E+00	0.000E+00	0.000E+00
28.000	0.000	0.495	-0.362	0.000E+00	0.000E+00	0.000E+00
29.000	0.000	0.606	-0.440	0.000E+00	0.000E+00	0.000E+00
30.000	0.000	0.710	-0.504	0.000E+00	0.000E+00	0.000E+00
31.000	0.000	0.808	-0.557	0.000E+00	0.000E+00	0.000E+00
32.000	0.000	0.900	-0.599	0.000E+00	0.000E+00	0.000E+00
33.000	0.000	0.990	-0.630	0.000E+00	0.000E+00	0.000E+00
34.000	0.000	1.077	-0.654	0.000E+00	0.000E+00	0.000E+00
35.000	0.000	1.163	-0.670	0.000E+00	0.000E+00	0.000E+00
36.000	0.000	1.249	-0.681	0.000E+00	0.000E+00	0.000E+00
37.000	0.000	1.336	-0.687	0.000E+00	0.000E+00	0.000E+00
38.000	0.000	1.425	-0.689	0.000E+00	0.000E+00	0.000E+00
39.000	0.000	1.518	-0.690	0.000E+00	0.000E+00	0.000E+00
40.000	0.000	1.615	-0.690	0.000E+00	0.000E+00	0.000E+00

APPENDIX D1

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1 T= 0.000 Y0= 0.00000 Z0= 0.00000 Y-Z PLANE