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16. Abstract This report is Volume 3 of the Final Report under Contract DTNH22-80-C-07502, "Development of Anthropometrically Based Design Specifications for an Advanced Adult Anthropomorphic Dummy Family." Volume 1 describes the collection of data on which the specifications are based as well as the fabrication of surface forms. The purpose of Volume 3 is to present the anthropometric specifications for small female and large male dummies. Data gathered during the project as well as data available in the literature were used in formulating these specifications. Most of the analytical techniques used in combining the various data resources have been described in Volume 2 which presents the specifications for the mid-sized male dummy. Where techniques and procedures differ, they are included in Volume 3. The report is supplemented by full-size blueprint nos. SF-201, SF-202, and SF-203 for the small female and nos. LM-301, LM-302, and LM-303 for the large male. These show side, front, and top views of the following: surface landmarks, joint centers, segment centers of gravity, origins of segment coordinate systems, surface profile of actual surface forms, information on anatomical and principal axes, and information on segmentation planes.			
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## 1.0 INTRODUCTION

The purpose of Volume 3 is to present the anthropometric specifications for small female and large male dummies. Data gathered during the project as well as data available in the literature were used in formulating these specifications. Most of the analytical techniques and procedures used in combining the various data resources have been described in Volume 2 which presents the specifications for the mid-sized male dummy. Where techniques and procedures differ, they are included in Volume 2. As in Volumes 1 and 2 the subscripts L, H, and A are used with coordinate axes to indicate the laboratory, the whole body or H-point, and the anatomical or body segment reference systems, respectively.

The report is supplemented by full-size blueprint nos. SF-201, SF-202, and SF-203 for the small female and Nos. LM-301, LM-302, and LM-303 for the large male. These show side, front, and top views of the following:

- Surface landmarks
- Joint centers
- Segment centers of gravity
- Origins of segment coordinate systems
- Surface profile of actual surface form
- Information on anatomical and principal axes
- Information on segmentation planes





## 2.0 SMALL FEMALE AND LARGE MALE SUBJECT DATA

### IN HIP POINT COORDINATES

#### 2.1 Development of Standard Seat Coordinate Systems

The same system of surface landmarks has been used to define the small female and large male surface forms as was used for the mid-sized male. These are described in detail in Volume 2.

To locate the hip joints (used to define an H-point which has been selected as the origin of coordinates for the surface form), the data of Reynolds et al. (1981) were again used. For the small female, Reynolds et al. obtained data from two body size cells. Both cells are for short females, but the weights range from light to heavy. The following compares the two cells of Reynolds et al. with the current data.

	<u>Cell 1</u>	<u>Cell 2</u>	<u>Current Study</u>
Weight, kg (lb)	74.8 (165)	46.9 (103)	46.4 (102)
Stature, cm (in)	151.5 (59.6)	153.9 (60.6)	151.1 (59.5)

As should be expected, the match is good with the short, light segment of the population. In that the short height of all subjects generally implies a small frame, the pelvic data were accepted even though they may be slightly too large. No alternative data are known to exist.

Likewise, two body size cells were used for the large male. The two cells are fixed on tall subjects with weight varying widely. The following is a comparison of the two cells with the large male subject group of the current study.

	<u>Cell 3</u>	<u>Cell 6</u>	<u>Current Study</u>
Weight, kg (lb)	91.5 (201.3)	76.1 (167.4)	102.6 (225.8)
Stature, cm (in)	182.8 (72.0)	184.8 (72.8)	186.4 (73.4)

Although somewhat heavy, the large male standing height matches fairly well with the Reynolds et al. sample. Again, it is assumed that the height variable is the more important predictor of skeletal dimensions for the pelvis. Although the Reynolds et al. pelvis data may be somewhat small for the large male, there are no known alternatives and it is believed any differences will be small (less than 1 cm).

The direction of the Reynolds et al. coordinate system was superimposed upon the UMTRI data for anterior-superior iliac spine (ilio-spinal summum) and pelvic crest (pubic symphysis). In order to accomplish this, tissue thickness estimates were made for the distances from the surface targets to the underlying bony landmarks in the vehicle-seated posture. The first estimates were made for the mid-sized male. A tissue depth of 5 mm over the anterior-superior iliac spines was estimated from palpation of this point on standing subjects. While the subjects were standing, the overlying tissue is fairly taut across the pelvic spines. However, when they were seated, the abdominal tissue tended to slacken and rest over the pelvic girdle. Therefore, the tissue thickness was much greater in the seated subjects. For photographic determination of the pelvic surface landmarks, the technique used was to palpate the point and place the end of a metal probe rod firmly on the location so that a projection to the landmark could be determined by photometric analysis of calibrated marks on the rod. Because the tissue was effectively pushed out of the way by the probe, the 5-mm tissue thickness estimate was used for pelvic location. Also, because the probe was held within  $10^\circ$  of vertical, the depth to the bone was applied to the  $Z_L$  coordinate.

A tissue depth of 15 mm over the pubic symphysis was estimated by palpation in placing the probe and by analysis of general anatomical factors such as muscle attachments in this region. The probe was held within  $10^\circ$  of vertical in the  $Y_L Z_L$  plane and  $30^\circ$  of vertical in the  $X_L Z_L$  plane. Therefore, with an estimated tissue thickness of 15 mm, the depth to the bone landmark was 13 mm in the  $Z_L$  coordinate and 7 mm in the  $X_L$  coordinate. These results were scaled for the case of the small

female and large male. The data used to locate points on the pelvis from surface landmark data are summarized as follows:

<u>Surface Landmark</u>	<u>Coordinate</u>	<u>Small Female</u>	<u>Mid-Sized Male</u>	<u>Large Male</u>
ASIS	X <sub>L</sub> coord (+ to front)	0	0	0
	Z <sub>L</sub> coord (+ up)	-3	-5	-7
Symphysis	X <sub>L</sub> coord (+ to front)	-5	-7	-10
	Z <sub>L</sub> coord (+ up)	-8	-13	-17

With respect to laboratory coordinates the two coordinate systems made angles of 55.53° (large male) and 48.37° (small female). These compare with the 54.07° for the mid-sized male. Using the resulting coordinate transformation it was possible to obtain the following points needed for construction of joint centers, segmentation planes, anatomical segment axis construction, etc.

- H-points
- Pubic symphysis
- Inferior symphyseal pole
- Superior pole, pubic symphysis
- Ilio-spinale summum
- Ilio-cristale summum
- Inferior tuberosity point
- Posterior point on 1st sacral vertebral body
- Promontorion
- Lateral point on 1st sacral vertebral body
- Pubotuberosity
- Lateral tuberosity point

The key points for development of standard seat coordinate systems for the surface forms were the H-points which, when referred to the original UMTRI laboratory coordinate system, are at:

<u>Form</u>		<u>X<sub>L</sub> (mm)</u>	<u>Y<sub>L</sub> (mm)</u>	<u>Z<sub>L</sub> (mm)</u>
Small Female:	Left	755	699	425
	Right	755	539	425
Large Male:	Left	618	705	409
	Right	618	533	409

The  $Y_L$ -shifts from the body centerline were  $\pm 80$  and  $86$  mm as reported by Reynolds et al. The centers of the lines connecting the two H-points are at  $Y_L = 619$  mm, yielding the origins of the standard seat coordinate systems for the two forms.

## 2.2 Subject Data Translated to Standard Seat Coordinate System

Tables 1 and 2 present all skeletal and surface landmarks used in the development of the anthropometric specifications for the small female and large male surface forms. The origin of coordinates is the center of a line connecting the H-points.

### 3.0 BODY SEGMENTATION

The segmentation scheme used for the mid-sized male (and documented in detail in Volume 2) has been adopted for use in developing segmentation plane formulae for the small female and large male specification packages. Using this scheme, it was necessary to quantify a variety of points in addition to those already available in the list of measured surface landmarks. These included:

- Nuchale
- Intersection point on back of surface form of a perpendicular from the center of a line connecting the 10th rib targets to a line connecting the T12 and L5 surface targets
- Intersection point on back of surface form of a perpendicular from the center of a line connecting the ilio-cristale targets to a line connecting the T12 and L5 surface targets
- Pubotuberosity surface (35 mm lateral from pubic symphysis surface point)
- Shifted ASIS (a point 10 mm lateral to ASIS surface)
- Shifted inferior tuberosity (a point 10 mm lateral to inferior tuberosity point which is projected vertically to the seat surface)

Other than nuchale, these points were obtained directly using geometric construction.

For the small female an estimation of the nuchale location was obtained using the data of Young et al. (1983). In their report, the location of nuchale was given in anatomical coordinates (millimeters) as  $X_A = -88$ ,  $Y_A = 0$ ,  $Z_A = -31$ . In other words, nuchale is behind and below the center of a line connecting the tragions which serves as the origin. In addition, the coordinates of the center of a line connecting the infraorbitales are given as  $X_A = 69.8$  mm. When this construction is superimposed on the same coordinate direction using the same origin, it is found that the Young et al. (1983) infraorbitale is 9 mm behind that obtained in the current study. Also, the nuchale was projected to be 18 mm behind the surface of the head profile line which was measured directly. If the mismatch between infraorbitales is eliminated by shifting tragion forward, then the nuchale still falls 9 mm behind the

surface of the head. It can be suggested that the nuchale target was measured too far behind tragion in the Young et al. study based on hair thickness and the use of a cap during their photography. Based on this assumption, the nuchale point was moved along the  $X_L$  coordinate axis to lie on the surface form. A similar shift was necessary in the case of the large male form. In that case the infraorbitale predicted from the McConville et al. (1980) report was found to be 17 mm behind that measured at UMTRI. Also, the nuchale was 16 mm behind the surface of the dummy form. It appears that there is a discrepancy in tragion locations as measured in the two sets of studies. This issue has also been discussed in Volume 2 on the mid-sized male.

With all the points available, each segmentation plane was computed directly using three points. Tables 3 and 4 show the formulae for the segmentation plans for the small female and large male surface forms.

#### 4.0 DEVELOPMENT OF ANATOMICALLY BASED SEGMENT COORDINATE SYSTEMS

This section of the report summarizes the development of anatomically based coordinate systems for each of the various segments of the body. The coordinate systems which have been constructed are the same as, or very similar to, those which have been reported by McConville et al. (1980) in developing anthropometric relationships of body and body segment moments of inertia. As such, they have been used directly in the presentation of center of mass and inertial data and provide the linkage between the coordinate system defining the principal axes of inertia and the standard coordinate system at the center of the H-points. In order to construct coordinate systems and relate them to the standard system, it was necessary to know three points in the segment. The following three were used:

- One at the origin
- One on an axis
- One in one of the orthogonal planes

The points used for each system are defined in Table 2 of Volume 2. Data used are given in Tables 1 and 2 of this volume. The locations of the origins of the various segment anatomical coordinate systems are given in Tables 5 and 6 for the small female and large male. Tables 7 and 8 give the cosine matrices expressed in degrees for all anatomical axis systems with respect to the hip point coordinate system, while Tables 9 and 10 present the cosine matrices directly.





## 5.0 VOLUME, MASS, AND INERTIAL PROPERTIES

The basic information for these computations is contained in the reports by McConville et al. (1980) and Young et al. (1983). Specific numbers are given for the distance from the origins of anatomically based segment coordinate systems to centers of volume. In addition, regression formulas have been provided to predict volume and inertial properties of the various segments of the body.

The basic anthropometric data for the small female and large male groups (see Section 3 of Volume 1) have been supplemented by the surface profile data given in Tables 11 and 12. These were measured directly on the clay form before molds and castings for the final surface forms were made. The data from these two resources was then used to select anthropometric variables for use in the regression equations. This task was made more complicated by the difference between the seated postures of the current study and the standing postures which were the basis of the regression equations. Variables selected were similar to those used in the mid-sized male computations (Volume 2).

The predicted volumes and the sum of volumes for the whole body are given in Tables 13 and 14 for the small female and large male surface forms. The values obtained for the left and right sides of the body have been averaged. These calculations are based on a density assumption of  $1.0 \text{ gm/cm}^3$ . Using this value for density, the resulting total body weights would be overestimated by

Small Female = 3.0 percent  
Large Male = 5.4 percent

If a density value of 0.92, as has been proposed by Dempster (1955), is used for the thorax, the predicted values for weight are much closer to subject means, especially for the small female. Because of the apparent overestimation, volume scaling factors were used to yield body segment weights which, when summed, yielded the correct total body weight. For

volume, the large male scale factor was 0.949 based on the 5.4 percent overestimation. For moment of inertia corrections this led to a scale factor of 0.966 using the analog

$$\text{Volume} = 0.949V \sim (.9827\ell)^3$$

The scale factor for the small female was selected as 1.0. This was based on the smaller overestimation of volume and the fact that using Dempster's data (1955), the overestimation can become an underestimation. Clearly, some additional work should be done to better specify segment densities.

Young et al. (1983) and McConville et al. (1980) give the locations of centers of volume in segment anatomical coordinate systems. The assumption has been made that center of volume and center of mass are coincident. These data are provided for average females and males. To take this into account, the data have been scaled down for the small female and scaled up for the large male. The scaling is based on comparisons of anthropometric data on length, depth, height, breadth, etc. for the various segments. As anatomically based coordinate systems are oriented primarily in the same directions as heights, depths, and breadths are measured, this scaling procedure appears reasonable. Tables 15 and 16 give the locations of estimated segment centers of gravity with respect to the whole-body coordinate systems for the small female and large male. Tables 17 and 18 give the locations with respect to the individual segment coordinate system, thus documenting the scaling which was carried out.

The anthropometric variables used in the moment of inertia regression equations are given in Tables 19 and 20 for the two surface forms. The resulting moments of inertia are given in Tables 21 and 22. Both predicted and scaled results are included in the tables.

The principal axes of inertial for each segment have been computed by both Young et al. (1983) and McConville et al. (1980) with respect to segment anatomical coordinate systems. In the present study, these transformations were modified slightly to reflect the body symmetry assumption. Tables 23 and 24 present the principal axes of

inertia with respect to anatomical axes as cosine matrices in degrees while Tables 25 and 26 present the cosine matrices directly. Tables 27 through 30 do the same for the principal axes with respect to the H-point coordinate system.



## 6.0 JOINT CENTERS

The development of joint centers for the small female and large male was based on the results already obtained for the mid-sized male and presented in Volume 2. Because of the similarity of body posture of the three surface forms, it was possible to scale up for the large male and scale down for the small female. The locations of the resulting joint centers are given in Tables 31 and 32 with respect to H-point coordinates. Tables 33 and 34 list the results in segment coordinates.

Head/Neck. For the head/neck junction, the location is chosen to be the occipital condyles. For the mid-sized male, this point is at  $(X_H, Z_H) = (-11, -26)$  in head segment coordinates. The scale factor on head length ( $X_H$ ) and head height ( $Z_H$ ) is 0.978 for the small female yielding a scaled joint which rounds off to  $(-11, -25)$ . The location of this point can be transformed to H-point coordinates using the appropriate cosine matrix and translated to the origin using data from the table listing segment origins. Scale factors for the large male are 1.025 on the  $X_H$  coordinate and 1.009 on the  $Z_H$  coordinate. This yields a scaled condyle point with segment coordinates  $(-11, -26)$ . Scaled locations for some joints show a greater difference from the mid-sized male.

C7/T1. In this case the C7 and glabella surface landmark data were used to establish the angle required for use in the regression equations given in the torso link study by Snyder et al. (1972). Cervical vector prediction equations were available to predict the distance of the C7 surface marker to the C7/T1 interspace as well as the angle made by the vector connecting C7 to the interspace. The predicted angle to the interspace was used directly. However, the distance to the interspace was scaled.

The following chart shows the scaling used in the torso from C7 to S1.

Quantity	Large Male	Mid-Sized Male	Small Female
Upper torso depth (cm)	13.788	11.912	8.976
Abdominal depth (cm)	31.608	26.948	20.956
C7-T12 vector distance (mm)	376	344	325
T12-L5 vector distance (mm)	158	151	109
Upper torso $Z_H$ scale factor	1.09	1	0.86
Upper torso $X_H$ scale factor	1.16	1	0.75
Abdomen $Z_H$ scale factor	1.05	1	0.72
Abdomen $X_H$ scale factor	1.17	1	0.78

So, the value of 2.99 inches, the distance from the C7 surface marker to the C7/T1 interspace for the mid-sized male, was broken into  $Z_H$  and  $X_H$  components and scaled to 2.26 inches (57.4 mm) for the small female and 3.45 inches (87.6 mm) for the large male.

T4/T5, T8/T9, T12/L1. Similarly, thorax vector prediction equations were used in estimating the location of these interspaces. These required the availability of T4 and T12 surface markers. The angle between a line connecting these two points and a vertical line served as the reference angle for use in the regression equations. After computation of this angle for the small female and large male forms, the equations were then used to predict the following:

- Distance from T4 to T4/T5 interspace
- Vector direction from T4 to T4/T5 interspace
- Distance from T8 to T8/T9 interspace
- Vector direction from T8 to T8/T9 interface
- Distance from T12 to T12/L1 interspace
- Vector direction from T12 to T12/L1 interspace

In each case the predicted distance was broken into components and scaled for large male or small female.

L5/S1. The same procedure was adopted for definition of the L5/S1 joint as has been used for the mid-sized male. This was to choose a point on the centerline of the body with  $X_H$  and  $Z_H$  coordinates the same as the lateral point on the first sacral vertebral body. These values were taken directly from the pelvis skeletal reconstruction discussed in Section 2 and presented in Tables 1 and 2.

L2/L3. As in the case of the mid-sized male, this joint was selected to be 60 percent of the distance along a line connecting L5/S1 with T12/L1.

Sternoclavicular. For the mid-sized male, this point was estimated to be one centimeter below and two centimeters lateral from the body centerline. Scaling for this point is based on the  $Y_H$  values for the acromion points or 0.84 for the small female and 1.02 for the large male.

Claviscapular. For the mid-sized male, this point was estimated from a definition by Dempster (1955) and measurements on bony material to be the following distances from the acromio-clavicular articulation landmark.

- $\Delta Y_H = 27.5/2$  mm toward the center of the body
- $\Delta X_H = 15$  mm toward the rear of the body
- $\Delta Z_H = 10$  mm down

The scale factor based on biacromial diameter developed for the sternoclavicular joint was also used for this joint.

Glenohumeral. The glenohumeral joint center for the mid-sized male was based on a reconstruction of skeletal material (the humerus) in three-dimensional space using tissue thickness estimates and three surface landmarks (greater tubercle of the humerus, lateral humeral epicondyle, and medial humeral epicondyle). This point is more or less fixed with respect to the scapula, and as such, with respect to the acromion. To estimate the glenohumeral joint center for the small female and large male, the mid-sized male vector from acromion to this joint was scaled by the factor used for the sternoclavicular and claviscapular joints.

Elbow. This point was computed directly for both the small female and large male as the midpoint of a line between the medial humeral epicondyle and a point 8 mm above the radiale. The "8 mm" point was estimated to be along a line connecting radiale with ulnar styloid for the seated occupants.

Wrist. The reconstruction of the wrist joint was based on the definitions used for the mid-sized male. The dimensions used were scaled based on radius length for the two forms (0.84 for the small female and 1.07 for the large male).

Hip. The hip joints are the H-points discussed earlier and given in Tables 1 and 2.

Knee. The knee joints were computed directly as the center of a line connecting the medial and lateral femoral epicondyle.

Ankle. The ankle joint has been defined for the mid-sized male as the midpoint of a line between the tip of the lateral malleolus of the fibula and a point 5 mm distal to the tibial malleolus. In order to obtain the "5 mm" point, the sphyrion was shifted down the leg a resultant of 5 mm for the seated subjects.



TABLE 1  
SURFACE LANDMARKS RELATIVE TO H-POINT (mm):  
SMALL FEMALE

Landmark	$X_H$	$Y_H$	$Z_H$
HEAD			
Glabella	- 90	0	578
Infraorbitale (L)	-103	32	550
Infraorbitale (R)	-103	- 32	550
Tragion (L)	-180	67	545
Tragion (R)	-180	- 67	545
Gonion (L)	-167	55	484
Gonion (R)	-167	- 55	484
Gnathion	- 91	0	465
Nuchale*	-247	0	517
TORSO			
Suprasternale	-144	0	391
Mesosternale	-110	0	353
Substernale	- 89	0	316
Nipple (L)	- 39	85	250
Nipple (R)	- 39	- 85	250
10th Rib, anterior, midline	- 10	0	150
Umbilicus	1	0	141
Maximum Abdominal Protrusion	22	0	129
10th Rib (L)	- 96	129	125
10th Rib (R)	- 96	-129	125
VERTEBRAL COLUMN			
C7	-238	0	445
T4	-259	0	364
T8	-247	0	242
T12	-200	0	122
L2	-180	0	79
L5	-154	0	23
Mid-Spine 10th Rib	-201	0	126
Intersection point on back of surface form of a perpendicular from center of line connecting 10th rib targets to line connecting T12 and L5 surface targets*	-183	0	85
Intersection point on back of surface form of a perpendicular from center of line connecting iliocristale targets to line connecting T12 and L5 surface targets*	-165	0	48

TABLE 1  
SURFACE LANDMARKS RELATIVE TO H-POINT (mm):  
SMALL FEMALE (Continued)

Landmark	$X_H$	$Y_H$	$Z_H$
PELVIS (SURFACE)			
Trochanterion (UMTRI photo) (L)	- 3	187	- 19
Trochanterion (UMTRI photo) (R)	- 3	-187	- 19
Iliocristale (L)	- 83	138	86
Iliocristale (R)	- 83	-138	86
Anterior-Superior Iliac Spine (L)	- 15	103	75
Anterior-Superior Iliac Spine (R)	- 15	-103	75
Pubic Symphysis	44	0	32
Thigh/Abdominal Junction (L)	22	117	60
Thigh/Abdominal Junction (R)	22	-117	60
Trochanterion (Skeletal Reconstruction)*	18	±190	- 18
Pubotuberosity	44	± 35	32
PELVIS (SKELETAL)			
Pubic Symphysis	42	0	22
H-Point	0	± 80	0
Inferior Symphyseal Pole	40	± 4	- 10
Left Superior Pole, Pubic Symphysis	46	± 5	26
Ilio-Spinale Summum	- 15	±109	72
Iliocristale Summum	- 81	±114	77
Inferior Tuberosity Point	24	± 48	- 56
Posterior Point, 1st Sacral Vertebral Body	- 92	0	41
Promontorion	- 66	0	42
Lateral Point, 1st Sacral Vertebral Body	- 80	± 19	46
SHOULDER			
Clavicale (L)	-146	17	397
Clavicale (R)	-146	- 17	397
Acromio-Clavicular Articulation (L)	-198	152	398
Acromio-Clavicular Articulation (R)	-198	-152	398
Greater Tubercle Humerus (L)	-152	178	380
Greater Tubercle Humerus (R)	-152	-178	380
Acromion (L)	-206	171	376
Acromion (R)	-206	-171	376
Anterior Scye (L)	-106	130	337
Anterior Scye (R)	-106	-130	337
Posterior Scye (L)	-191	164	286
Posterior Scye (R)	-191	-164	286
Superior Margin Scapula (L)	-262	66	379
Superior Margin Scapula (R)	-262	- 66	379
Inferior Margin Scapula (L)	-250	109	292
Inferior Margin Scapula (R)	-250	-109	292

TABLE 1  
SURFACE LANDMARKS RELATIVE TO H-POINT (mm):  
SMALL FEMALE (Continued)

Landmark	$X_H$	$Y_H$	$Z_H$
ARM			
Lateral Humeral Epicondyle (L)	12	211	206
Lateral Humeral Epicondyle (R)	12	-211	206
Radiale (L)	28	207	193
Radiale (R)	28	-207	193
Medial Humeral Epicondyle (L)	15	150	190
Medial Humeral Epicondyle (R)	15	-150	190
Olecranon (L)	34	183	177
Olecranon (R)	34	-183	177
Ulnar Styloid (L)	130	182	383
Ulnar Styloid (R)	130	-182	383
Stylian (L)	121	136	387
Stylian (R)	121	-136	387
LEG AND FOOT			
Lateral Femoral Epicondyle (L)	360	119	72
Lateral Femoral Epicondyle (R)	360	-119	72
Medial Femoral Epicondyle (L)	365	32	69
Medial Femoral Epicondyle (R)	365	- 32	69
Tibiale (L)	378	35	58
Tibiale (R)	378	- 35	58
Patella (L)	404	81	91
Patella (R)	404	- 81	91
Sphyrion (L)	599	57	-172
Sphyrion (R)	599	- 57	-172
Metatarsal-Phalangeal I (L)	698	76	-120
Metatarsal-Phalangeal I (R)	698	- 76	-120
Digit II (L)	729	126	- 74
Digit II (R)	729	-126	- 74
Metatarsal-Phalangeal V (L)	683	157	-147
Metatarsal-Phalangeal V (R)	683	-157	-147
Lateral Malleolus (L)	584	115	-194
Lateral Malleolus (R)	584	-115	-194
Posterior Calcaneus (heel point) (L)*	618	90	-254
Posterior Calcaneus (heel point) (R)*	618	- 90	-254

\*Landmark determined by construction.

TABLE 2  
SURFACE LANDMARKS RELATIVE TO H-POINT (mm) :  
LARGE MALE

Landmark	$X_H$	$Y_H$	$Z_H$
HEAD			
Glabella	-111	0	684
Infraorbitale (L)	-128	37	650
Infraorbitale (R)	-128	- 37	650
Tragion (L)	-212	83	646
Tragion (R)	-212	- 83	646
Gonion (L)	-195	70	576
Gonion (R)	-195	- 70	576
Gnathion	-108	0	555
Nuchale*	-293	0	612
TORSO			
Suprasternale	-162	0	459
Mesosternale	-119	0	415
Substernale	- 89	0	364
Nipple (L)	- 59	132	320
Nipple (R)	- 59	-132	320
10th Rib, anterior, midline	33	0	218
Umbilicus	60	0	172
Maximum Abdominal Protrusion	75	0	153
10th Rib (L)	-126	194	143
10th Rib (R)	-126	-194	143
VERTEBRAL COLUMN			
C7	-300	0	531
T4	-333	0	421
T8	-327	0	284
T12	-283	0	155
L2	-246	0	95
L5	-202	0	19
Mid-Spine 10th Rib	-277	0	144
Intersection point on back of surface form of a perpendicular from center of line connecting R10 targets to line connecting T12 and L5 surface targets*	-237	0	77
Intersection point on back of surface form of a perpendicular from center of line connecting iliocristale targets to line connecting T12 and L5 surface targets*	-217	0	44

TABLE 2  
SURFACE LANDMARKS RELATIVE TO H-POINT (mm):  
LARGE MALE (Continued)

Landmark	$X_H$	$Y_H$	$Z_H$
PELVIS (SURFACE)			
Trochanterion (UMTRI photo) (L)	- 34	217	33
Trochanterion (UMTRI photo) (R)	- 34	-217	33
Iliocristale (L)	-114	197	105
Iliocristale (R)	-114	-197	105
Anterior-Posterior Iliac Spine (L)	- 27	121	86
Anterior-Posterior Iliac Spine (R)	- 27	-121	86
Pubic Symphysis	50	0	50
Thigh-Abdominal Junction (L)	19	155	94
Thigh-Abdominal Junction (R)	19	-155	94
Trochanterion (Skeletal reconstruction)*	22	±215	- 22
Inferior Tuberosity Point*	42	± 51	-115
Pubotuberosity*	50	± 35	50
PELVIS (SKELETAL)			
Pubic Symphysis	40	0	33
H-Point	0	± 86	0
Inferior Symphyseal Pole	43	± 4	- 6
Left Superior Pole, Pubic Symphysis	38	± 5	37
Ilio-Spinale Summum	- 27	±115	79
Iliocristale Summum	-107	±125	74
Inferior Tuberosity Point*	42	± 41	- 62
Posterior Point, 1st Sacral Vertebral Body	-105	0	34
Promontorion	- 73	0	41
Lateral Point, 1st Sacral Vertebral Body	- 93	± 28	42
SHOULDER			
Clavicale (L)	-171	25	473
Clavicale (R)	-171	-25	473
Acromio-Clavicular Articulation (L)	-247	192	480
Acromio-Clavicular Articulation (R)	-247	-192	480
Greater Tubercle Humerus (L)	-185	223	469
Greater Tubercle Humerus (R)	-185	-223	469
Acromion (L)	-256	217	454
Acromion (R)	-256	-217	454
Anterior Scye (L)	-115	167	421
Anterior Scye (R)	-115	-167	421
Posterior Scye (L)	-245	221	328
Posterior Scye (R)	-245	-221	328
Superior Margin Scapula (L)	-331	83	446
Superior Margin Scapula (R)	-331	- 83	446
Inferior Margin Scapula (L)	-301	147	271
Inferior Margin Scapula (R)	-301	-147	271

TABLE 2  
SURFACE LANDMARKS RELATIVE TO H-POINT (mm):  
LARGE MALE (Continued)

Landmark	$X_H$	$Y_H$	$Z_H$
ARM			
Lateral Humeral Epicondyle (L)	34	266	270
Lateral Humeral Epicondyle (R)	34	-266	270
Radiale (L)	52	261	252
Radiale (R)	52	-261	252
Medial Humeral Epicondyle (L)	27	189	236
Medial Humeral Epicondyle (R)	27	-189	236
Olecranon (L)	48	234	225
Olecranon (R)	48	-234	225
Ulnar Styloid (L)	262	197	398
Ulnar Styloid (R)	262	-197	398
Stylian (L)	245	138	414
Stylian (R)	245	-138	414
LEG AND FOOT			
Lateral Femoral Epicondyle (L)	411	207	157
Lateral Femoral Epicondyle (R)	411	-207	157
Medial Femoral Epicondyle (L)	414	98	175
Medial Femoral Epicondyle (R)	414	-98	175
Tibiale (L)	433	97	163
Tibiale (R)	433	-97	163
Patella (L)	460	168	202
Patella (R)	460	-168	202
Sphyrion (L)	721	63	-131
Sphyrion (R)	721	-63	-131
Metatarsal-Phalangeal I (L)	845	85	-70
Metatarsal-Phalangeal I (R)	845	-85	-70
Digit II (L)	889	150	-14
Digit II (R)	889	-150	-14
Metatarsal-Phalangeal V (L)	832	187	-105
Metatarsal-Phalangeal V (R)	832	-187	-105
Lateral Malleolus (L)	711	135	-169
Lateral Malleolus (R)	711	-135	-169
Posterior Calcaneus (heel point) (L)*	741	97	-238
Posterior Calcaneus (heel point) (R)*	741	-97	-238

\*Landmark determined by construction.

TABLE 3

## FORMULATION OF SEGMENTATION PLANES: SMALL FEMALE

Head:	$.38133X_H + .92444Z_H - 383.75 = 0$
Neck:	$.70711X_H + .70711Z_H - 177.48 = 0$ (for all $X_H \geq -194$ )
Thorax:	$.41773X_H - .90857Z_H + 153.67 = 0$
Abdomen:	$.42046X_H - .90731Z_H + 112.93 = 0$
Hip:	$-.79326X_H \pm .60868Y_H + .01568Z_H + 55.706 = 0$ (+ sign on $Y_H$ for right side of body)
Knee:	$-.95067X_H + .31022Z_H + 319.90 = 0$
Ankle:	$.74130X_H - .67118Z_H - 519.21 = 0$
Shoulder:	$.37621X_H \pm .92649Y_H - .00936Z_H - 77.411 = 0$ (+ sign on $Y_H$ for left side of body)
Elbow:	$-.71664X_H \pm .14376Y_H - .68246Z_H + 118.85 = 0$ (+ sign on $Y_H$ for left side of body)

TABLE 4  
FORMULATION OF SEGMENTATION PLANES: LARGE MALE

Head:	$.34482X_H + .93867Z_H - 473.43 = 0$
Neck:	$.70711X_H + .70711Z_H - 213.55 = 0$
Thorax:	$.51108X_H - .85954Z_H + 187.31 = 0$
Abdomen:	$.50957X_H - .86043Z_H + 148.44 = 0$
Hip:	$-.78392X_H \pm .62046Y_H - .02216Z_H + 62.020 = 0$ (+ sign on $Y_H$ for right side of body)
Knee:	$-.97780X_H + .20953Z_H + 368.98 = 0$
Ankle:	$.69191X_H - .72199Z_H - 593.44 = 0$
Shoulder:	$.34605X_H \pm .93630Y_H + .05993Z_H - 141.80 = 0$ (+ sign on $Y_H$ for left side of body)
Elbow:	$-.84192X_H \pm .28017Y_H - .46117Z_H + 78.614 = 0$ (+ sign on $Y_H$ for left side of body)



TABLE 5

LOCATION OF ORIGIN OF SEGMENT ANATOMICAL  
COORDINATE SYSTEMS: SMALL FEMALE

Segment	$X_H$ (mm)	$Y_H$ (mm)	$Z_H$ (mm)
Head	-180	0	545
Neck	-238	0	445
Thorax	-183	0	85
Abdomen	- 96	0	125
Pelvis	- 15	0	75
Upper Arms	-206	$\pm 171^*$	376
Lower Arms	28	$\pm 207$	193
Upper Legs	18	$\pm 190$	- 18
Lower Legs	378	$\pm 35$	58
Feet	695	$\pm 115$	-126

\*Positive sign on  $Y_H$  for left side of body.

TABLE 6

LOCATION OF ORIGIN OF SEGMENT ANATOMICAL  
COORDINATE SYSTEMS: LARGE MALE

Segment	$X_H$ (mm)	$Y_H$ (mm)	$Z_H$ (mm)
Head	-212	0	646
Neck	-300	0	531
Thorax	-237	0	77
Abdomen	-126	0	143
Pelvis	- 27	0	86
Upper Arms	-256	$\pm 217^*$	454
Lower Arms	52	$\pm 261$	252
Upper legs	22	$\pm 215$	- 22
Lower Legs	433	$\pm 97$	163
Feet	843	$\pm 134$	- 80

\*Positive sign on  $Y_H$  for left side of body.

TABLE 7

ANATOMICAL AXES WITH RESPECT TO HIP POINT AXIS SYSTEM: SMALL FEMALE  
(Cosine Matrix Expressed in Degrees)

Segment		$X_H$	$Y_H$	$Z_H$
Head	$X_A$	3.7	90.0	86.3
	$Y_A$	90.0	0.0	90.0
	$Z_A$	93.7	90.0	3.7
Neck	$X_A$	27.5	90.0	117.6
	$Y_A$	90.0	0.0	90.0
	$Z_A$	62.4	90.0	27.5
Thorax	$X_A$	8.7	90.0	81.3
	$Y_A$	90.0	0.0	90.0
	$Z_A$	98.7	90.0	8.7
Abdomen	$X_A$	24.7	90.0	65.3
	$Y_A$	90.0	0.0	90.0
	$Z_A$	114.7	90.0	24.7
Pelvis	$X_A$	53.9	90.0	36.1
	$Y_A$	90.0	0.0	90.0
	$Z_A$	143.9	90.0	53.9
Upper Arm (L)	$X_A$	51.3	99.7	40.4
	$Y_A$	90.4	12.8	77.2
	$Z_A$	141.3	98.2	52.5
Upper Arm (R)	$X_A$	51.3	80.3	40.4
	$Y_A$	89.6	12.8	102.8
	$Z_A$	141.3	81.8	52.5
Lower Arm with Hand (L)	$X_A$	148.2	78.0	61.1
	$Y_A$	76.2	13.8	90.0
	$Z_A$	118.0	83.4	151.1
Lower Arm with Hand (R)	$X_A$	148.2	102.0	61.1
	$Y_A$	103.8	13.8	90.0
	$Z_A$	118.0	96.6	151.1
Upper Leg (L)	$X_A$	105.3	92.8	15.5
	$Y_A$	79.8	11.7	84.4
	$Z_A$	161.5	78.6	104.4
Upper Leg (R)	$X_A$	105.3	87.2	15.5
	$Y_A$	100.2	11.7	95.6
	$Z_A$	161.5	101.4	104.4

TABLE 7  
 ANATOMICAL AXES WITH RESPECT TO HIP POINT AXIS SYSTEM:  
 SMALL FEMALE (Cosine Matrix Expressed in Degrees, Continued)

Segment		$X_H$	$Y_H$	$Z_H$
Lower Leg (L)	$X_A$	50.4	65.7	49.3
	$Y_A$	109.9	24.7	103.9
	$Z_A$	133.7	93.9	44.0
Lower Leg (R)	$X_A$	50.4	114.3	49.3
	$Y_A$	70.1	24.7	76.1
	$Z_A$	133.7	86.1	44.0
Foot (L)	$X_A$	59.5	80.3	32.3
	$Y_A$	94.4	9.6	98.7
	$Z_A$	149.1	89.3	59.1
Foot (R)	$X_A$	59.5	99.7	32.3
	$Y_A$	85.6	9.6	81.3
	$Z_A$	149.1	90.7	59.1

TABLE 8

ANATOMICAL AXES WITH RESPECT TO HIP POINT AXIS SYSTEM: LARGE MALE  
(Cosine Matrix Expressed in Degrees)

Segment		$X_H$	$Y_H$	$Z_H$
Head	$X_A$	2.7	90.0	87.3
	$Y_A$	90.0	0.0	90.0
	$Z_A$	92.7	90.0	2.7
Neck	$X_A$	24.2	90.0	114.2
	$Y_A$	90.0	0.0	90.0
	$Z_A$	65.8	90.0	24.2
Thorax	$X_A$	7.9	90.0	82.1
	$Y_A$	90.0	0.0	90.0
	$Z_A$	97.9	90.0	7.9
Abdomen	$X_A$	30.7	90.0	59.3
	$Y_A$	90.0	0.0	90.0
	$Z_A$	120.7	90.0	30.7
Pelvis	$X_A$	64.9	90.0	25.1
	$Y_A$	90.0	0.0	90.0
	$Z_A$	154.9	90.0	64.9
Upper Arm (L)	$X_A$	57.3	112.4	41.4
	$Y_A$	84.5	23.9	66.8
	$Z_A$	146.7	98.1	58.0
Upper Arm (R)	$X_A$	57.3	67.6	41.4
	$Y_A$	95.5	23.9	113.2
	$Z_A$	146.7	81.9	58.0
Lower Arm with Hand (L)	$X_A$	117.3	69.3	35.4
	$Y_A$	66.8	25.4	99.8
	$Z_A$	142.8	76.0	123.6
Lower Arm with Hand (R)	$X_A$	117.3	110.7	35.4
	$Y_A$	113.2	25.4	80.2
	$Z_A$	142.8	104.0	123.6
Upper Leg (L)	$X_A$	114.3	82.1	25.7
	$Y_A$	85.7	8.0	96.7
	$Z_A$	155.3	88.9	114.7
Upper Leg (R)	$X_A$	114.3	97.9	25.7
	$Y_A$	94.3	8.0	83.3
	$Z_A$	155.3	91.1	114.7

TABLE 8  
 ANATOMICAL AXES WITH RESPECT TO HIP POINT AXIS SYSTEM:  
 LARGE MALE (Cosine Matrix Expressed in Degrees, Continued)

Segment		$X_H$	$Y_H$	$Z_H$
Lower Leg (L)	$X_A$	47.7	65.4	52.3
	$Y_A$	104.2	25.1	110.2
	$Z_A$	134.2	85.3	44.6
Lower Leg (R)	$X_A$	47.7	114.6	52.3
	$Y_A$	75.8	25.1	69.8
	$Z_A$	134.2	94.7	44.6
Foot (L)	$X_A$	57.8	79.0	34.4
	$Y_A$	92.3	11.8	101.5
	$Z_A$	147.7	85.8	58.1
Foot (R)	$X_A$	57.8	101.0	34.4
	$Y_A$	87.7	11.8	78.5
	$Z_A$	147.7	94.2	58.1

TABLE 9

ANATOMICAL AXES WITH RESPECT TO HIP POINT AXIS SYSTEM: SMALL FEMALE  
(Cosine Matrix)

Segment		$X_H$	$Y_H$	$Z_H$
Head	$X_A$	.998	0.000	.0649
	$Y_A$	.000	1.000	.000
	$Z_A$	-.0649	0.000	.998
Neck	$X_A$	.887	0.000	-.463
	$Y_A$	.000	1.000	.000
	$Z_A$	.463	0.000	.887
Thorax	$X_A$	.989	0.000	.151
	$Y_A$	.000	1.000	.000
	$Z_A$	-.151	0.000	.989
Abdomen	$X_A$	.909	0.000	.418
	$Y_A$	.000	1.000	.000
	$Z_A$	-.418	0.000	.909
Pelvis	$X_A$	.589	0.000	.808
	$Y_A$	.000	1.000	.000
	$Z_A$	-.808	0.000	.589
Upper Arm (L)	$X_A$	.625	-0.169	.762
	$Y_A$	-.006	0.975	.222
	$Z_A$	-.780	-0.143	.609
Upper Arm (R)	$X_A$	.625	0.169	.762
	$Y_A$	.0062	0.975	-.222
	$Z_A$	-.780	0.143	.609
Lower Arm with Hand (L)	$X_A$	-.850	0.208	.484
	$Y_A$	.238	0.971	-.000
	$Z_A$	-.470	0.115	-.875
Lower Arm with Hand (R)	$X_A$	-.850	-0.208	.484
	$Y_A$	-.238	0.971	.000
	$Z_A$	-.470	-0.115	-.875
Upper Leg (L)	$X_A$	-.264	-0.048	.963
	$Y_A$	.178	0.979	.098
	$Z_A$	-.948	0.197	-.250
Upper Leg (R)	$X_A$	-.264	0.048	.963
	$Y_A$	-.178	0.979	-.098
	$Z_A$	-.948	-0.197	-.250

TABLE 9  
 ANATOMICAL AXES WITH RESPECT TO HIP POINT AXIS SYSTEM:  
 SMALL FEMALE (Cosine Matrix, Continued)

Segment		$X_H$	$Y_H$	$Z_H$
Lower Leg (L)	$X_A$	.637	0.412	.652
	$Y_A$	-.341	0.909	-.241
	$Z_A$	-.691	-0.069	.719
Lower Leg (R)	$X_A$	.637	-0.412	.652
	$Y_A$	.341	0.909	.241
	$Z_A$	-.691	0.069	.719
Foot (L)	$X_A$	.508	0.169	.845
	$Y_A$	-.076	0.986	-.152
	$Z_A$	-.858	0.013	.514
Foot (R)	$X_A$	.508	-0.169	.845
	$Y_A$	.076	0.986	.152
	$Z_A$	-.858	-0.013	.514

TABLE 10

ANATOMICAL AXES WITH RESPECT TO HIP POINT AXIS SYSTEM: LARGE MALE  
(Cosine Matrix)

Segment		$X_H$	$Y_H$	$Z_H$
Head	$X_A$	.999	0.000	.0476
	$Y_A$	.000	1.000	.000
	$Z_A$	-.0476	0.000	.999
Neck	$X_A$	.912	0.000	-.410
	$Y_A$	.000	1.000	.000
	$Z_A$	.410	0.000	.912
Thorax	$X_A$	.991	0.000	.137
	$Y_A$	.000	1.000	.000
	$Z_A$	-.137	0.000	.991
Abdomen	$X_A$	.860	0.000	.511
	$Y_A$	.000	1.000	.000
	$Z_A$	-.511	0.000	.860
Pelvis	$X_A$	.424	0.000	.906
	$Y_A$	.000	1.000	.000
	$Z_A$	-.906	0.000	.424
Upper Arm (L)	$X_A$	.540	-0.380	.750
	$Y_A$	.096	0.914	.394
	$Z_A$	-.836	-0.141	.530
Upper Arm (R)	$X_A$	.540	0.380	.750
	$Y_A$	-.096	0.914	-.394
	$Z_A$	-.836	0.141	.530
Lower Arm with Hand (L)	$X_A$	-.459	0.353	.815
	$Y_A$	.394	0.903	-.170
	$Z_A$	-.797	0.243	-.554
Lower Arm with Hand (R)	$X_A$	-.459	-0.353	.815
	$Y_A$	-.394	0.903	.170
	$Z_A$	-.797	-0.242	-.554
Upper Leg (L)	$X_A$	-.412	0.137	.901
	$Y_A$	.074	0.990	-.117
	$Z_A$	-.908	0.019	-.418
Upper Leg (R)	$X_A$	-.412	-0.137	.901
	$Y_A$	-.074	0.990	.117
	$Z_A$	-.908	-0.019	-.418



TABLE 10  
 ANATOMICAL AXES WITH RESPECT TO HIP POINT AXIS SYSTEM:  
 LARGE MALE (Cosine Matrix, Continued)

Segment		$X_H$	$Y_H$	$Z_H$
Lower Leg (L)	$X_A$	.673	0.416	.611
	$Y_A$	-.246	0.906	-.346
	$Z_A$	-.697	0.082	.712
Lower Leg (R)	$X_A$	.673	-0.416	.611
	$Y_A$	.246	0.906	.346
	$Z_A$	-.697	-0.082	.712
Foot (L)	$X_A$	.532	0.190	.825
	$Y_A$	-.040	0.979	-.200
	$Z_A$	-.846	0.073	.529
Foot (R)	$X_A$	.532	-0.190	.825
	$Y_A$	.040	0.979	.200
	$Z_A$	-.846	-0.073	.529

TABLE 11

## COORDINATES OF SURFACE POINTS ON CLAY FORM: SMALL FEMALE

Line	Selected Point	X <sub>H</sub>	Y <sub>H</sub>	Z <sub>H</sub>	
BODY CENTERLINE	Crotch	69	0	25	
		67	0	47	
		63	0	63	
		59	0	76	
		53	0	89	
		45	0	102	
		38	0	113	
		28	0	125	
		16	0	134	
		Umbilicus	2	0	140
			- 15	0	157
			- 27	0	172
			- 37	0	188
			- 44	0	203
	- 52		0	219	
	- 59		0	236	
	- 66		0	253	
	- 73		0	274	
	- 79		0	293	
	- 86		0	312	
	- 96		0	332	
	-106		0	348	
	-116		0	360	
	-126		0	370	
	-136		0	383	
	-145	0	392		
	Suprasternale	-152	0	400	
		-152	0	416	
		-152	0	433	
	Back of Chin (neck)	-150	0	445	
	Under Chin, Front	-103	0	457	
	Front of Chin, Low	- 91	0	467	
	Lower Lip (mid)	- 87	0	496	
	Top Lip (mid)	- 85	0	506	
	Root of Nose	- 89	0	518	
	Tip of Nose	- 73	0	531	
	Nasion	- 89	0	578	
		- 90	0	593	
		- 93	0	610	
		-102	0	629	
-112		0	642		
-130		0	654		
-147		0	661		
-175		0	667		

TABLE 11  
COORDINATES OF SURFACE POINTS ON CLAY FORM:  
SMALL FEMALE (Continued)

Line	Selected Point	$X_H$	$Y_H$	$Z_H$
Centerline (Continued)	Top of Head	-185	0	667
		-200	0	666
		-225	0	658
		-249	0	643
		-266	0	618
		-273	0	595
		-272	0	575
		-268	0	553
		-255	0	527
		-240	0	507
		-235	0	488
		-235	0	467
		-236	0	449
		-243	0	432
		-247	0	412
	-253	0	392	
	-259	0	372	
	Edge of Seatback	-272	0	363
BACK OF SHOULDER TO BELOW BREAST	Rear of Shoulder	-264	75	373
		-254	80	392
		-241	84	405
		-233	85	417
	Top of Shoulder	-226	86	418
		-192	84	407
		-172	80	393
		-164	77	388
	Clavicle	-147	74	378
		-125	73	361
		-107	76	341
		- 87	79	318
		- 70	81	294
		- 55	82	274
	Tip of Breast	- 41	83	257
		- 39	85	250
		- 39	83	232
		- 42	81	217
		- 46	78	208
	Base of Breast	- 53	75	204

TABLE 11  
COORDINATES OF SURFACE POINTS ON CLAY FORM:  
SMALL FEMALE (Continued)

Line	Selected Point	$X_H$	$Y_H$	$Z_H$	
TOP OF SHOULDER TO HAND	Top of Shoulder	-188	150	400	
		-165	153	394	
		-145	157	384	
		-123	160	366	
		-103	164	345	
		- 88	168	325	
		- 67	173	309	
		- 45	176	289	
		- 24	178	272	
	Crook of Elbow	5	181	248	
		20	178	269	
		32	175	284	
		47	172	301	
		63	170	322	
		82	167	347	
		95	163	368	
		107	157	388	
	Wrist	114	153	403	
		172	148	423	
	At Hand	132	140	454	
TOP OF HEAD TO LATERAL SHOULDER	Top of Head	-185	0	667	
		-184	19	665	
		-182	41	656	
		-181	57	643	
		-180	68	622	
		-179	73	598	
		-174	70	579	
		Front of Ear	-169	66	556
			Bottom of Ear, Front	-165	63
	Jaw			-163	52
	Behind Ear, Down Neck		-194	54	508
		-199	46	479	
		-206	48	450	
		Back of Neck	-212	56	433
	-214		80	420	
	-215		105	413	
	-209		131	404	
	Lateral Shoulder	-202	156	396	
		-186	179	382	

TABLE 11  
COORDINATES OF SURFACE POINTS ON CLAY FORM:  
SMALL FEMALE (Continued)

Line	Selected Point	X <sub>H</sub>	Y <sub>H</sub>	Z <sub>H</sub>
SIDE OF ARM TO WRIST	Shoulder	-169	193	358
		-147	199	336
		-128	201	316
		-105	203	295
		- 83	204	272
		- 55	208	252
		- 28	212	232
		Lateral Humeral Epicondyle (bend of elbow)	5	212
	25		214	226
	44		212	245
	64		208	266
	83		202	291
	Ulnar Styloid	97	193	321
		110	187	348
		129	183	382
146		179	403	
	166	184	427	
UNDERSIDE OF ARM	Anterior Scye (close)	-165	162	272
		-147	165	255
		-124	168	239
		-102	168	224
		- 81	170	213
		- 64	172	202
		- 44	176	188
		4	181	174
	Low Point on Elbow	34	186	177
		56	183	199
		77	179	225
		91	176	253
		103	173	289
	Ulnar Styloid	111	170	311
		119	169	327
130		166	356	
139		165	370	
	162	159	402	
FLANK	Posterior Scye (close)	-191	164	285
		-186	149	260
		-171	141	225
		-189	135	191
		-145	130	164
		-128	130	132
		-112	135	100
		- 98	142	77
		- 81	150	55

TABLE 11  
COORDINATES OF SURFACE POINTS ON CLAY FORM:  
SMALL FEMALE (Continued)

Line	Selected Point	X <sub>H</sub>	Y <sub>H</sub>	Z <sub>H</sub>	
Flank (Continued)	Near Seat	- 61	162	32	
		- 40	177	7	
		5	188	- 15	
INSIDE ARM	Scye	-104	131	357	
		- 88	136	285	
		- 59	139	262	
		- 29	142	237	
	Humeral Condyle	3	150	213	
		27	145	225	
		52	146	255	
		73	146	295	
		91	144	333	
		111	140	374	
	Wrist	123	135	394	
		142	101	434	
	OUTSIDE OF LEG	Max. Circ. Pt. Upper Thigh	25	188	-11
			62	186	- 4
102			181	5	
113			180	5	
142			174	14	
175			165	24	
204			157	30	
238			149	39	
275			141	47	
301			134	52	
Lateral Femoral Epicondyle		337	128	57	
		368	121	61	
		382	125	40	
		397	132	19	
		416	138	- 11	
Max. Calf Circ. Pt.		437	138	- 37	
		456	137	- 61	
		477	132	- 87	
		500	125	-110	
		525	119	-136	
Min. Ankle Circ. Pt.		548	115	-160	
		573	116	-186	
		586	119	-197	
Lateral Malleolus		603	122	-210	
		626	128	-229	
		642	134	-212	
		654	139	-194	
	680	156	-156		
Metatarsal Phalangeal V	697	163	-131		

TABLE 11  
COORDINATES OF SURFACE POINTS ON CLAY FORM:  
SMALL FEMALE (Continued)

Line	Selected Point	X <sub>H</sub>	Y <sub>H</sub>	Z <sub>H</sub>	
UNDERSIDE OF LEG	Seat-Thigh Juncture	--	--	--	
		305	73	- 11	
	Knee Pit	328	71	1	
		344	76	8	
		368	75	- 15	
		381	78	- 40	
		398	79	- 64	
		422	80	- 92	
		445	82	-114	
		469	81	-128	
		502	82	-153	
		537	85	-180	
		567	86	-205	
		576	87	-215	
TOP OF LEG	Thigh Abdominal Point	32	109	61	
		61	106	65	
		96	102	72	
		127	92	80	
		213	87	98	
		245	84	105	
		277	83	112	
		299	83	116	
		328	81	120	
		Top of Knee	367	79	172
			387	80	113
			Patella	408	81
	430			83	53
	Toe I Toe II Toe III Toe IV Toe V	455	87	22	
		480	89	- 8	
		518	92	- 56	
		550	91	- 98	
		585	91	-134	
		606	91	-143	
		632	96	-138	
		658	99	-123	
		685	104	-103	
		715	105	- 77	
		733	107	- 66	
		728	128	- 74	
		722	145	- 86	
717		156	- 99		
708	163	-155			

TABLE 11  
 COORDINATES OF SURFACE POINTS ON CLAY FORM:  
 SMALL FEMALE (Continued)

Line	Selected Point	$X_H$	$Y_H$	$Z_H$	
INSIDE LEG	Crotch	76	12	- 3	
		107	14	4	
		147	12	13	
		182	19	23	
		207	27	32	
		242	35	49	
		285	35	60	
		321	31	69	
		Medial Femoral Epicondyle Tibiale	350	33	74
			373	38	56
	388		42	35	
	Max. Calf Circ. Pt.	422	45	- 10	
		446	48	- 33	
		483	52	- 70	
	Ankle	508	61	- 96	
		535	64	-124	
		575	66	-156	
	Sphyrion Arch	592	61	-178	
		626	71	-213	
	Metatarsal Phalangeal I	635	72	-165	
682		78	-138		



TABLE 12

## COORDINATES OF SURFACE POINTS ON CLAY FORM: LARGE MALE

Line	Selected Point	X <sub>H</sub>	Y <sub>H</sub>	Z <sub>H</sub>	
BODY CENTERLINE	Crotch	77	0	77	
		82	0	122	
		79	0	144	
		74	0	158	
		67	0	167	
		58	0	172	
		56	0	187	
		40	0	211	
		11	0	244	
		- 29	0	281	
		- 57	0	303	
		- 74	0	341	
		- 96	0	376	
		-116	0	412	
		-142	0	437	
		-163	0	459	
		-175	0	469	
	-176	0	497		
	-173	0	515		
	Throat	-162	0	532	
		-134	0	539	
	Under Chin	-115	0	547	
		Front of Chin	-108	0	554
	-108		0	564	
	-113		0	573	
	Lip, Bottom	-108	0	586	
		Mid Lip	-110	0	592
		Top Lip	-106	0	597
	Back of Nose	-110	0	599	
		Tip of Nose	-110	0	614
		- 93	0	624	
	Nasion/Glabella	- 99	0	647	
		-111	0	670	
		-110	0	681	
	Top of Forehead	-110	0	701	
		-119	0	725	
		-129	0	744	
		-142	0	758	
		-178	0	774	
		-206	0	778	
		-238	0	775	
		-278	0	757	
		-299	0	731	
-301		0	731		
-310	0	701			

TABLE 12  
COORDINATES OF SURFACE POINT ON CLAY FORM:  
LARGE MALE (Continued)

Line	Selected Point	X <sub>H</sub>	Y <sub>H</sub>	Z <sub>H</sub>
Body Centerline (Continued)	Neck	-307	0	654
		-291	0	608
		-291	0	565
		-304	0	520
		-319	0	479
		-332	0	429
	Top of Seat	-336	0	385
		-341	0	374
SHOULDER TO HAND	Shoulder	-335	125	386
		-325	150	431
		-297	166	462
		-265	178	479
		-225	186	489
		-187	195	482
		-143	205	454
		-113	213	426
		- 94	217	405
		- 58	217	378
		- 60	217	379
		- 18	216	348
		8	223	321
		21	226	314
	42	231	327	
	79	218	340	
	Wrist	137	205	362
		185	190	385
		236	173	415
		269	153	456
		298	133	499
Hand	306	128	504	
TOP OF HEAD TO LATERAL SHOULDER	Top of Head	-207	0	778
		-202	43	767
		-201	63	749
	Front of Ear	-199	79	667
		-198	78	618
	End Line on Jaw	-197	73	580
	Start of Line on Neck	-222	66	576
		-237	63	542
	Neck and Shoulder Junction	-250	75	517
		-252	117	501
		-235	160	493
		-226	187	485
		-202	230	465

TABLE 12  
COORDINATES OF SURFACE POINT ON CLAY FORM:  
LARGE MALE (Continued)

Line	Selected Point	X <sub>H</sub>	Y <sub>H</sub>	Z <sub>H</sub>
Top of Head to Lateral Shoulder (Continued)		-189	244	445
		-188	252	415
		-185	252	382
SIDE OF ARM TO WRIST		-185	253	382
		-128	255	345
		- 66	258	311
		- 22	261	291
	Lateral Humeral Condyle	25	266	267
	Radiale	43	267	271
		72	268	285
		122	252	315
		186	225	351
		217	211	371
	Closest to Ulnar Styloid	245	200	386
UNDERSIDE OF ARM	Scye	-241	224	328
		-186	215	308
		-147	216	291
		-107	208	264
		- 53	216	246
	Low Pt. Elbow	- 8	216	229
		29	206	221
		89	214	237
		147	196	270
		226	181	342
	Wrist Crease	257	177	370
		272	168	393
		308	166	401
		331	169	427
		348	169	448
SIDE FROM POSTERIOR SCYE TO SEAT	Posterior Scye	-240	218	326
		-196	203	267
		-174	192	237
	"Flat-Tire" Crease	-154	183	214
		-128	183	187
		-110	191	166
		- 93	198	133
	Thigh-Abdominal Junction	- 81	187	67
		- 53	209	39
		- 29	223	6
		- 10	219	- 19
		(Last Point Measured)	+ 2	218

TABLE 12  
COORDINATES OF SURFACE POINT ON CLAY FORM:  
LARGE MALE (Continued)

Line	Selected Point	$X_H$	$Y_H$	$Z_H$
OUTSIDE OF LEG		- 72	215	- 9
		+ 9	226	21
		53	226	38
		120	229	63
		217	226	96
		283	221	119
		343	215	139
		398	210	158
	Approx. 0.5 cm in front of Lateral Femoral Epicondyle	417	206	160
		442	200	133
		477	201	89
		513	203	44
	Max. Calf Circ. Point	532	201	18
		589	172	- 50
		663	137	-129
		693	131	-161
	Approx. 0.5 cm behind and below Malleolus	705	134	-175
		718	129	-189
	Lowest Points on Leg and Foot	734	128	-222
		744	129	-220
		751	135	-214
		773	141	-190
		800	163	-159
Metatarsal Phalangeal V	832	181	-105	
	852	185	- 76	
UNDERSIDE OF LEG	Base of Heel	695	88	-239
		692	89	-213
		682	95	-199
		643	102	-154
		568	120	-102
		503	133	- 60
		454	140	- 5
	Knee Pit	411	148	+ 81
		360	140	48
	(Closest Pt. to Seat)	307	132	8

TABLE 12  
COORDINATES OF SURFACE POINT ON CLAY FORM:  
LARGE MALE (Continued)

Line	Selected Point	$X_H$	$Y_H$	$Z_H$	
TOEBOARD POINTS		929	227	18	
		928	-227	19	
		765	-226	-238	
		766	227	-239	
TOP OF LEG		907	131	- 15	
		857	123	- 36	
		823	117	- 65	
		780	111	- 95	
		750	110	-107	
		739	108	-107	
		705	113	- 95	
		676	121	- 72	
		645	128	- 43	
		599	141	7	
		573	151	52	
		522	161	118	
		482	164	169	
		Patella Top of Knee	459	168	202
		429	160	225	
		404	157	226	
		356	156	219	
	249	149	188		
	174	148	164		
	120	144	143		
	97	138	125		
	Nearest to Thigh-Abdom. Jct.	54	136	108	
TOE TIPS	Toe I	897	131	- 8	
	Toe II	887	149	- 15	
	Toe III	888	162	- 25	
	Toe IV	882	173	- 37	
	Toe V	874	184	- 52	

TABLE 12  
 COORDINATES OF SURFACE POINT ON CLAY FORM:  
 LARGE MALE (Continued)

Line	Selected Point	$X_H$	$Y_H$	$Z_H$
INSIDE OF LEG	Crotch	146	9	8
		182	16	26
		226	37	47
		254	55	61
		270	64	73
		348	89	131
		404	96	168
	Closest to Med. Fem. Epicon.	452	99	135
		484	91	83
	Closest to Tibiale	511	85	45
		593	86	- 34
		624	83	- 65
		667	79	-101
	Closest to Sphyrion	703	69	-129
		722	64	-137
		753	69	-141
	Near Arch	798	77	-128
Closest to Metatarsal Phal. I	854	90	- 68	
INSIDE ARM	Anterior Scye	-115	167	421
		- 83	159	362
		- 63	157	327
		- 27	167	301
		9	183	258
	Closest to Med. Hum. Epicon.	34	191	238
		70	181	262
		100	174	287
		149	166	323
	Closest to Stylion	201	154	369
		242	141	412
	Closest to Wrist Crease	251	138	419
		262	128	431
		283	103	446

TABLE 13  
ESTIMATED SEGMENT MASS AND VOLUME:  
SMALL FEMALE

Segment	Predicted Volume (cm <sup>3</sup> )	Predicted Mass (gm)
Head	3,697	3,697
Neck	601	601
Thorax	12,983	12,983 (11,944) *
Abdomen	1,610	1,610
Pelvis	6,976	6,976
Right Upper Arm	1,124	1,124
Left Upper Arm	1,124	1,124
Right Lower Arm with Hand	1,138	1,138
Left Lower Arm with Hand	1,138	1,138
Right Upper Leg	5,914	5,914
Left Upper Leg	5,914	5,914
Right Lower Leg	2,360	2,360
Left Lower Leg	2,360	2,360
Right Foot	638	638
Left Foot	638	638
TOTAL	48,215	48,215 (47,176) *

\*The number in parenthesis is based on a density=0.92. This yields a total body weight less than 1 percent different from the actual value obtained by the subject population.

TABLE 14  
ESTIMATED SEGMENT MASS AND VOLUME:  
LARGE MALE

Segment	Predicted Volume (cm <sup>3</sup> )	Scaled Volume (cm <sup>3</sup> )	Estimated Mass (gm)
Head	4,753	4,511	4,511
Neck	1,231	1,168	1,168
Thorax	34,160	32,418	32,418
Abdomen	3,108	2,949	2,949
Pelvis	16,900	16,038	16,038
Right Upper Arm	2,431	2,307	2,307
Left Upper Arm	2,431	2,307	2,307
Right Lower Arm with Hand	2,556	2,426	2,426
Left Lower Arm with Hand	2,556	2,426	2,426
Right Upper Leg	11,950	11,341	11,341
Left Upper Leg	11,950	11,341	11,341
Right Lower Leg	5,331	5,059	5,059
Left Lower Leg	5,331	5,059	5,059
Right Foot	1,638	1,554	1,554
Left Foot	1,638	1,554	1,554
<b>TOTAL</b>	<b>107,964</b>	<b>102,458</b>	<b>102,458*</b>

\*This mass corresponds to a weight of 225.8 lb.



TABLE 15

LOCATION OF ESTIMATED SEGMENT CENTERS OF GRAVITY  
WITH RESPECT TO WHOLE-BODY COORDINATE SYSTEM:  
SMALL FEMALE

Segment	$X_H$ (mm)	$Y_H$ (mm)	$Z_H$ (mm)
Head	-184	0	578
Neck	-172	0	460
Thorax	-147	0	238
Abdomen	- 82	0	107
Pelvis	- 76	0	25
Upper Arms	- 91	$\pm 163^*$	280
Lower Arms with Hands	97	$\pm 176$	306
Upper Legs	147	$\pm 104$	- 4
Lower Legs	444	$\pm 82$	- 56
Feet	653	$\pm 101$	-178

\*Positive sign on  $Y_H$  refers to left side of the body.

TABLE 16

LOCATION OF ESTIMATED SEGMENT CENTERS OF GRAVITY  
WITH RESPECT TO WHOLE-BODY COORDINATE SYSTEM:  
LARGE MALE

Segment	$X_H$ (mm)	$Y_H$ (mm)	$Z_H$ (mm)
Head	-205	0	678
Neck	-217	0	557
Thorax	-198	0	292
Abdomen	-118	0	120
Pelvis	- 73	0	13
Upper Arms	- 94	$\pm 205^*$	356
Lower Arms with Hands	183	$\pm 182$	347
Upper Legs	203	$\pm 140$	80
Lower Legs	514	$\pm 136$	26
Feet	805	$\pm 119$	-151

\*Positive sign on  $Y_H$  refers to left side of body.

TABLE 17

LOCATION OF ESTIMATED SEGMENT CENTERS OF GRAVITY  
WITH RESPECT TO SEGMENT COORDINATE SYSTEMS:  
SMALL FEMALE

Segment	$X_A$ (mm)	$Y_A$ (mm)	$Z_A$ (mm)
Head	- 2	0	33
Neck	52	0	44
Thorax	59	0	146
Abdomen	5	0	- 22
Pelvis	-76	0	20
Upper Arm (R)	115	30	-147
Upper Arm (L)	115	-30	-147
Lower Arm with Hand (R)	11	-14	-135
Lower Arm with Hand (L)	11	14	-135
Upper Leg (R)	-16	60	-143
Upper Leg (L)	-16	-60	-143
Lower Leg (R)	-13	-48	-131
Lower Leg (L)	-13	48	-131
Foot (R)	-68	3	9
Foot (L)	-68	- 3	9

TABLE 18

LOCATION OF ESTIMATED SEGMENT CENTERS OF GRAVITY  
WITH RESPECT TO SEGMENT COORDINATE SYSTEMS:  
LARGE MALE

Segment	$X_A$ (mm)	$Y_A$ (mm)	$Z_A$ (mm)
Head	8.6	0.0	31.3
Neck	65.3	0.0	57.4
Thorax	68.3	0.0	207.5
Abdomen	- 4.7	0.0	- 24.2
Pelvis	-85.6	0.0	10.9
Upper Arm (R)	19.1	34.2	-185.6
Upper Arm (L)	19.1	-34.2	-185.6
Lower Arm with Hand (R)	-10.7	36.3	-176.5
Lower Arm with Hand (L)	-10.7	-36.3	-176.5
Upper Leg (R)	7.3	72.8	-208.6
Upper Leg (L)	7.3	-72.8	-208.6
Lower Leg (R)	-12.9	-62.7	-150.6
Lower Leg (L)	-12.9	62.7	-150.6
Foot (R)	-82.1	- 0.6	- 6.2
Foot (L)	-82.1	0.6	- 6.2

TABLE 19

ANTHROPOMETRIC VARIABLES USED IN MOMENT OF INERTIA  
REGRESSION EQUATIONS: SMALL FEMALE

Segment	Moment	Anthropometric Variables
Head	$I_X$ $I_Y$ $I_Z$	Stature, weight Head circumference Head circumference, head breadth, stature
Neck	$I_X$ $I_Y$ $I_Z$	Stature, neck circumference, neck breadth Stature, neck circumference, neck length Neck circumference, stature, neck length
Thorax	$I_X$ $I_Y$ $I_Z$	Weight, thorax length, bust circumference Weight, thorax length, bust circumference Bust circum., 10th rib breadth, thorax length
Abdomen	$I_X$ $I_Y$ $I_Z$	Stature, weight Stature, weight Stature, weight
Pelvis	$I_X$ $I_Y$ $I_Z$	Weight, bispinous breadth Stature, weight Weight, stature, suprailiac skinfold
Upper Arms	$I_X$ $I_Y$ $I_Z$	Weight, acromion-radiale length, biceps circumference (relaxed) Weight, acromion-radiale length, biceps circumference (relaxed) Stature, weight
Lower Arms (with hands)	$I_X$ $I_Y$ $I_Z$	Elbow circumference, forearm-hand length, wrist circumference, hand breadth Elbow circumference, forearm-hand length, wrist circumference, hand breadth Forearm circumference, elbow circumference, wrist circumference, forearm breadth
Upper Legs	$I_X$ $I_Y$ $I_Z$	Weight, thigh length, buttock circumference mid-thigh circumference Weight, thigh length, mid-thigh circumference Buttock circum., mid-thigh circum., stature
Lower Legs	$I_X$ $I_Y$ $I_Z$	Calf depth, calf length, knee circumference Calf depth, calf length, knee circumference Calf circum., knee circum., knee breadth
Feet	$I_X$ $I_Y$ $I_Z$	Stature, weight Foot length, sphyrion height, weight, ankle circum. Foot length, weight, sphyrion height, stature

TABLE 20

ANTHROPOMETRIC VARIABLES USED IN MOMENT OF INERTIA  
REGRESSION EQUATIONS: LARGE MALE

Segment	Moment	Anthropometric Variables
Head	I <sub>X</sub>	Head circumference, head breadth
	I <sub>Y</sub>	Head circumference
	I <sub>Z</sub>	Head circumference, head length
Neck	I <sub>X</sub>	Neck breadth, weight, neck length
	I <sub>Y</sub>	Neck circumference, weight, neck breadth
	I <sub>Z</sub>	Neck circumference, neck breadth, weight
Thorax	I <sub>X</sub>	Stature, weight
	I <sub>Y</sub>	Stature, weight
	I <sub>Z</sub>	Weight, chest circumference (seated)
Abdomen	I <sub>X</sub>	Waist circum., abdomen length, suprailiac skinfold
	I <sub>Y</sub>	Circum. at R10, abdomen length, suprailiac skinfold
	I <sub>X</sub>	Waist circum., abdomen length, suprailiac skinfold
Pelvis	I <sub>X</sub>	Buttock circumference, suprailiac skinfold
	I <sub>Y</sub>	Stature, weight
	I <sub>Z</sub>	Stature, weight
Upper Arms	I <sub>X</sub>	Weight, biceps circum., acromion-radiale length
	I <sub>Y</sub>	Weight, triceps skinfold, axilla arm depth, biceps circum., acromion-radiale length
	I <sub>Z</sub>	Biceps circumference, axilla arm circumference, acromion-radiale length
Forearms Plus Hands	I <sub>X</sub>	Forearm-hand length, wrist circum., hand breadth
	I <sub>Y</sub>	Forearm-hand length, wrist circum., hand breadth
	I <sub>Z</sub>	Elbow circumference, mid-forearm circumference, weight, hand breadth
Upper Legs	I <sub>X</sub>	Weight, stature, mid-thigh circum., thigh length
	I <sub>Y</sub>	Weight, mid-thigh circum., stature, thigh length
	I <sub>Z</sub>	Weight, mid-thigh circum., upper thigh circum.
Lower Legs	I <sub>X</sub>	Stature, calf depth, ankle circum., calf length
	I <sub>Y</sub>	Stature, calf depth, ankle circum., calf length
	I <sub>Z</sub>	Calf circum., weight, calf length, calf depth
Feet	I <sub>X</sub>	Stature, weight
	I <sub>Y</sub>	Foot length, sphyrion height, ankle circum., weight
	I <sub>Z</sub>	Foot length, ankle circum., sphyrion height, weight

TABLE 21  
ESTIMATED SEGMENT INERTIAL PROPERTIES:  
SMALL FEMALE

Segment	$I_x$ (gm cm <sup>2</sup> )	$I_y$ (gm cm <sup>2</sup> )	$I_z$ (gm cm <sup>2</sup> )
Head	146,150	172,919	131,715
Neck	6,084	9,510	10,295
Thorax	1,542,806	1,161,238	1,208,626
Abdomen	143,484	101,463	205,715
Pelvis	326,244	282,872	574,158
Upper Arms (each)	49,980	51,135	8,168
Lower Arms with Hands (each)	141,515	129,402	8,342
Upper Legs (each)	731,416	700,953	153,857
Lower Legs (each)	261,414	261,922	23,135
Feet (each)	3,441	18,428	16,614

TABLE 22  
ESTIMATED SEGMENT INERTIAL PROPERTIES:  
LARGE MALE

Segment	Predicted (gm cm <sup>2</sup> )			Scaled (gm cm <sup>2</sup> )		
	$I_x$	$I_y$	$I_z$	$I_x$	$I_y$	$I_z$
Head	229,900	267,700	171,700	225,900	263,100	168,700
Neck	22,200	24,860	32,460	21,800	24,400	31,900
Thorax	7,480,000	5,570,000	4,990,000	7,351,000	5,474,000	4,904,000
Abdomen	267,000	168,000	489,000	262,000	165,000	481,000
Pelvis	1,750,000	1,580,000	1,990,000	1,720,000	1,553,000	1,956,000
Up. Arm (L)	182,000	190,000	52,400	179,000	187,000	51,500
Up. Arm (R)	182,000	190,000	52,400	179,000	187,000	51,500
Low. Arm & Hand (L)	421,000	407,000	28,500	414,000	400,000	28,000
Low. Arm & Hand (R)	421,000	407,000	28,500	414,000	400,000	28,000
Up. Leg (L)	1,960,000	2,035,000	603,000	1,926,000	2,000,000	593,000
Up. Leg (R)	1,960,000	2,035,000	603,000	1,926,000	2,000,000	593,000
Low. Leg (L)	846,000	848,500	95,450	831,000	834,000	93,800
Low. Leg (R)	846,000	848,500	95,450	831,000	834,000	93,800
Foot (L)	10,600	76,400	79,000	10,400	75,100	77,600
Foot (R)	10,600	76,400	79,000	10,400	75,100	77,600

TABLE 23

PRINCIPAL AXES OF INERTIA WITH RESPECT TO ANATOMICAL AXES: SMALL FEMALE  
(Cosine Matrix Expressed in Degrees)

Segment		$X_A$	$Y_A$	$Z_A$
Head	$X_P$	42	90	48
	$Y_P$	90.0	0.0	90.0
	$Z_P$	132	90.0	42
Neck	$X_P$	8.6	90.0	81.4
	$Y_P$	90.0	0.0	90.0
	$Z_P$	98.6	90.0	8.6
Thorax	$X_P$	19.1	90.0	70.9
	$Y_P$	90.0	0.0	90.0
	$Z_P$	109.1	90.0	19.1
Abdomen	$X_P$	0.0	90.0	90.0
	$Y_P$	90.0	0.0	90.0
	$Z_P$	90.0	90.0	0.0
Pelvis	$X_P$	2.7	90.0	92.7
	$Y_P$	90.0	0.0	90.0
	$Z_P$	87.3	90.0	2.7
Upper Arm (L)	$X_P$	27	116.6	84.1
	$Y_P$	63.4	27.7	97.3
	$Z_P$	92.5	82.9	8.6
Upper Arm (R)	$X_P$	27	63.4	84.1
	$Y_P$	116.6	27.7	82.9
	$Z_P$	92.5	97.3	8.6
Lower Arm with Hand (L)	$X_P$	17	74.4	95.4
	$Y_P$	105.6	17.3	82.8
	$Z_P$	82.6	97.2	9.7
Lower Arm with Hand (R)	$X_P$	17	105.6	95.4
	$Y_P$	74.4	17.3	97.2
	$Z_P$	82.6	82.8	9.7
Upper Leg (L)	$X_P$	15.2	77.3	81.7
	$Y_P$	102.7	12.8	88.8
	$Z_P$	98.3	91.2	8.4
Upper Leg (R)	$X_P$	15.2	102.7	81.7
	$Y_P$	77.3	12.8	91.2
	$Z_P$	98.3	88.8	8.4

TABLE 23  
 PRINCIPAL AXES OF INERTIA WITH RESPECT TO ANATOMICAL AXES:  
 SMALL FEMALE (Cosine Matrix Expressed in Degrees, Continued)

Segment		$X_A$	$Y_A$	$Z_A$
Lower Leg (L)	$X_P$	0.0	90.0	90.0
	$Y_P$	90.0	0.0	90.0
	$Z_P$	90.0	90.0	0.0
Lower Leg (R)	$X_P$	0.0	90.0	90.0
	$Y_P$	90.0	0.0	90.0
	$Z_P$	90.0	90.0	0.0
Foot (L)	$X_P$	6.3	90.3	96.3
	$Y_P$	91.5	16.5	106.4
	$Z_P$	83.7	73.5	17.6
Foot (R)	$X_P$	6.3	89.7	96.3
	$Y_P$	88.4	16.5	73.6
	$Z_P$	83.7	106.5	17.6

TABLE 24

PRINCIPAL AXES OF INERTIA WITH RESPECT TO ANATOMICAL AXES: LARGE MALE  
(Cosine Matrix Expressed in Degrees)

Segment		$X_A$	$Y_A$	$Z_A$
Head	$X_P$	36	90	54
	$Y_P$	90.0	0.0	90.0
	$Z_P$	126	90.0	36
Neck	$X_P$	11	90.0	79
	$Y_P$	90.0	0.0	90.0
	$Z_P$	101	90.0	11
Thorax	$X_P$	14.5	90.0	75.5
	$Y_P$	90.0	0.0	90.0
	$Z_P$	104.5	90.0	14.5
Abdomen	$X_P$	2.6	90.0	92.2
	$Y_P$	90.0	0.0	90.0
	$Z_P$	87.8	90.0	2.6
Pelvis	$X_P$	8.4	90.0	81.6
	$Y_P$	90.0	0.0	90.0
	$Z_P$	98.4	90.0	8.4
Upper Arm (L)	$X_P$	33.9	56.1	90.0
	$Y_P$	123.9	33.9	90.0
	$Z_P$	90.0	90.0	0.0
Upper Arm (R)	$X_P$	33.9	123.9	90.0
	$Y_P$	56.1	33.9	90.0
	$Z_P$	90.0	90.0	0.0
Lower Arm with Hand (L)	$X_P$	19.5	70.5	90.0
	$Y_P$	109.5	19.5	90.0
	$Z_P$	90.0	90.0	1
Lower Arm with Hand (R)	$X_P$	19.5	109.5	90.0
	$Y_P$	70.5	19.5	90.0
	$Z_P$	90.0	90.0	1
Upper Leg (L)	$X_P$	9.8	80.2	90.0
	$Y_P$	99.8	9.8	90.0
	$Z_P$	90.0	90.0	0.0
Upper Leg (R)	$X_P$	9.8	99.8	90.0
	$Y_P$	80.2	9.8	90.0
	$Z_P$	90.0	90.0	0.0



TABLE 24  
 PRINCIPAL AXES OF INERTIA WITH RESPECT TO ANATOMICAL AXES:  
 LARGE MALE (Cosine Matrix Expressed in Degrees, Continued)

Segment		$X_A$	$Y_A$	$Z_A$
Calf (L)	$X_P$	24	114	90
	$Y_P$	66	24	92
	$Z_P$	90	88	1
Calf (R)	$X_P$	24	66	90
	$Y_P$	114	24	88
	$Z_P$	90	92	1
Foot (L)	$X_P$	10	94	81
	$Y_P$	86	7	95
	$Z_P$	99	85	10
Foot (R)	$X_P$	10	86	81
	$Y_P$	94	7	85
	$Z_P$	99	95	10

TABLE 25

PRINCIPAL AXES OF INERTIA WITH RESPECT TO ANATOMICAL AXES: SMALL FEMALE  
(Cosine Matrix)

Segment		$X_A$	$Y_A$	$Z_A$
Head	$X_P$	0.743	0.000	0.669
	$Y_P$	0.000	1.000	0.000
	$Z_P$	-0.669	0.000	0.743
Neck	$X_P$	0.989	0.000	0.150
	$Y_P$	0.000	1.000	0.000
	$Z_P$	-0.150	0.000	0.989
Thorax	$X_P$	0.945	0.000	0.327
	$Y_P$	0.000	1.000	0.000
	$Z_P$	-0.327	0.000	0.945
Abdomen	$X_P$	1.000	0.000	0.000
	$Y_P$	0.000	1.000	0.000
	$Z_P$	0.000	0.000	1.000
Pelvis	$X_P$	0.999	0.000	-0.047
	$Y_P$	0.000	1.000	0.000
	$Z_P$	0.047	0.000	0.999
Upper Arm (L)	$X_P$	0.891	-0.448	0.103
	$Y_P$	0.448	0.885	-0.127
	$Z_P$	-0.044	0.124	0.989
Upper Arm (R)	$X_P$	0.891	0.448	0.103
	$Y_P$	-0.448	0.885	0.124
	$Z_P$	-0.044	-0.127	0.989
Lower Arm with Hand (L)	$X_P$	0.956	0.269	-0.094
	$Y_P$	-0.269	0.955	0.125
	$Z_P$	0.129	-0.125	0.986
Lower Arm with Hand (R)	$X_P$	0.956	-0.269	-0.094
	$Y_P$	0.269	0.955	-0.125
	$Z_P$	0.129	0.125	0.986
Upper Leg (L)	$X_P$	0.965	0.220	0.144
	$Y_P$	-0.220	0.975	0.021
	$Z_P$	-0.144	-0.021	0.989
Upper Leg (R)	$X_P$	0.965	-0.220	0.144
	$Y_P$	0.220	0.975	-0.021
	$Z_P$	-0.144	0.021	0.989

TABLE 25  
 PRINCIPAL AXES OF INERTIA WITH RESPECT TO ANATOMICAL AXES:  
 SMALL FEMALE (Cosine Matrix, Continued)

Segment		$X_A$	$Y_A$	$Z_A$
Lower Leg (L)	$X_P$	1.000	0.000	0.000
	$Y_P$	0.000	1.000	0.000
	$Z_P$	0.000	0.000	1.000
Lower Leg (R)	$X_P$	1.000	0.000	0.000
	$Y_P$	0.000	1.000	0.000
	$Z_P$	0.000	0.000	1.000
Foot (L)	$X_P$	0.994	-0.005	-0.110
	$Y_P$	-0.027	0.959	-0.282
	$Z_P$	0.110	0.284	0.953
Foot (R)	$X_P$	0.994	0.005	-0.110
	$Y_P$	0.027	0.959	0.282
	$Z_P$	0.110	-0.284	0.953

TABLE 26

PRINCIPAL AXES OF INERTIA WITH RESPECT TO ANATOMICAL AXES: LARGE MALE  
(Cosine Matrix)

Segment		$X_A$	$Y_A$	$Z_A$
Head	$X_P$	.809	0.000	0.588
	$Y_P$	.000	1.000	0.000
	$Z_P$	-.588	0.000	0.809
Neck	$X_P$	.981	0.000	0.192
	$Y_P$	.000	1.000	0.000
	$Z_P$	-.192	0.000	0.981
Thorax	$X_P$	.968	0.000	0.250
	$Y_P$	.000	1.000	0.000
	$Z_P$	-.250	0.000	0.968
Abdomen	$X_P$	.999	0.000	-0.038
	$Y_P$	.000	1.000	0.000
	$Z_P$	.038	0.000	0.999
Pelvis	$X_P$	.989	0.000	0.146
	$Y_P$	.000	1.000	0.000
	$Z_P$	-.146	0.000	0.989
Upper Arm (L)	$X_P$	.830	0.558	0.000
	$Y_P$	-.558	0.830	0.000
	$Z_P$	.000	0.000	1.000
Upper Arm (R)	$X_P$	.830	-0.558	0.000
	$Y_P$	-.558	0.830	0.000
	$Z_P$	.000	0.000	1.000
Lower Arm with Hand (L)	$X_P$	.943	0.334	0.000
	$Y_P$	-.334	0.943	0.000
	$Z_P$	.000	0.000	1.000
Lower Arm with Hand (R)	$X_P$	.943	-0.334	0.000
	$Y_P$	.334	0.943	0.000
	$Z_P$	.000	0.000	1.000
Upper Leg (L)	$X_P$	.985	0.170	0.000
	$Y_P$	-.170	0.985	0.000
	$Z_P$	.000	0.000	1.000
Upper Leg (R)	$X_P$	.985	-0.170	0.000
	$Y_P$	.170	0.985	0.000
	$Z_P$	.000	0.000	1.000

TABLE 26  
 PRINCIPAL AXES OF INERTIA WITH RESPECT TO ANATOMICAL AXES:  
 LARGE MALE (Cosine Matrix, Continued)

Segment		$X_A$	$Y_A$	$Z_A$
Calf (L)	$X_P$	.913	-0.407	0.000
	$Y_P$	.407	0.913	-0.0349
	$Z_P$	.000	0.0349	1.000
Calf (R)	$X_P$	.913	0.407	0.000
	$Y_P$	-.407	0.913	0.0349
	$Z_P$	.000	-0.0349	1.000
Foot (L)	$X_P$	.985	-0.0698	0.156
	$Y_P$	.0698	0.992	-0.0872
	$Z_P$	-.156	0.0872	0.985
Foot (R)	$X_P$	.985	0.0698	0.156
	$Y_P$	-.0698	0.992	0.0872
	$Z_P$	-.156	-0.0872	0.985

TABLE 27

PRINCIPAL AXES OF INERTIA WITH RESPECT TO HIP  
POINT AXIS SYSTEM: SMALL FEMALE  
(Cosine Matrix Expressed in Degrees)

Segment		$X_H$	$Y_H$	$Z_H$
Head	$X_P$	45.7	90.0	44.3
	$Y_P$	90.0	0.0	90.0
	$Z_P$	135.7	90.0	45.7
Neck	$X_P$	18.7	90.0	109.0
	$Y_P$	90.0	0.0	90.0
	$Z_P$	71.0	90.0	18.7
Thorax	$X_P$	28	90.0	62
	$Y_P$	90.0	0.0	90.0
	$Z_P$	118	90.0	28
Abdomen	$X_P$	24.7	90.0	65.3
	$Y_P$	90.0	0.0	90.0
	$Z_P$	114.7	90.0	24.7
Pelvis	$X_P$	51.2	90.0	38.7
	$Y_P$	90.0	0.0	90.0
	$Z_P$	141.3	90.0	51.2
Upper Arm (L)	$X_P$	61	127	50
	$Y_P$	68	36	63
	$Z_P$	143	91	53
Upper Arm (R)	$X_P$	61	53	50
	$Y_P$	112	36	117
	$Z_P$	143	89	53
Lower Arm with Hand (L)	$X_P$	134.7	63.3	57
	$Y_P$	66.6	27.6	103.9
	$Z_P$	127.1	88.9	143.1
Lower Arm with Hand (R)	$X_P$	134.7	116.7	57
	$Y_P$	113.3	27.6	76.1
	$Z_P$	127.1	91.1	143.1
Upper Leg (L)	$X_P$	110.6	78.6	23.8
	$Y_P$	77.8	14.3	97.0
	$Z_P$	154.6	79.6	112.8
Upper Leg (R)	$X_P$	110.6	101.4	23.8
	$Y_P$	102.2	14.3	83.0
	$Z_P$	154.6	100.4	112.8

TABLE 27  
 PRINCIPAL AXES OF INERTIA WITH RESPECT TO HIP POINT AXIS SYSTEM:  
 SMALL FEMALE (Cosine Matrix Expressed in Degrees, Continued)

Segment		$X_H$	$Y_H$	$Z_H$
Lower Leg (L)	$X_P$	50.4	65.7	49.3
	$Y_P$	109.9	24.7	103.9
	$Z_P$	133.7	93.9	44
Lower Leg (R)	$X_P$	50.4	114.3	49.3
	$Y_P$	70.1	24.7	76.1
	$Z_P$	133.7	86.1	44
Foot (L)	$X_P$	53.6	66.4	45.4
	$Y_P$	96.8	25.4	114.5
	$Z_P$	142.8	80.6	54.5
Foot (R)	$X_P$	53.6	113.6	45.4
	$Y_P$	83.2	25.4	65.5
	$Z_P$	142.8	99.4	54.5

TABLE 28

PRINCIPAL AXES OF INERTIA WITH RESPECT TO  
HIP POINT AXIS SYSTEM: LARGE MALE  
(Cosine Matrix Expressed in Degrees)

Segment		$X_H$	$Y_H$	$Z_H$
Head	$X_P$	38.7	90.0	51.3
	$Y_P$	90.0	0.0	90.0
	$Z_P$	128.7	90.0	38.7
Neck	$X_P$	13.2	90.0	103.1
	$Y_P$	90.0	0.0	90.0
	$Z_P$	76.9	90.0	13.2
Thorax	$X_P$	22.3	90.0	67.6
	$Y_P$	90.0	0.0	90.0
	$Z_P$	112.4	90.0	22.3
Abdomen	$X_P$	28.5	90.0	61.5
	$Y_P$	90.0	0.0	90.0
	$Z_P$	118.5	90.0	28.5
Pelvis	$X_P$	73.3	90.0	16.7
	$Y_P$	90.0	0.0	90.0
	$Z_P$	163.3	90.0	73.3
Upper Arm (L)	$X_P$	59.9	78.8	32.6
	$Y_P$	102.8	13.9	95.2
	$Z_P$	146.7	98.1	58.0
Upper Arm (R)	$X_P$	59.9	101.2	32.6
	$Y_P$	77.2	13.9	84.8
	$Z_P$	146.7	81.9	58.0
Lower Arm with Hand (L)	$X_P$	107.5	50.6	44.6
	$Y_P$	58.3	42.8	115.6
	$Z_P$	142.8	75.9	123.6
Lower Arm with Hand (R)	$X_P$	107.5	129.4	44.6
	$Y_P$	121.7	42.8	64.4
	$Z_P$	142.8	104.1	123.6
Upper Leg (L)	$X_P$	113.2	72.3	29.8
	$Y_P$	81.8	17.9	105.6
	$Z_P$	155.2	88.9	114.7
Upper Leg (R)	$X_P$	113.2	107.7	29.8
	$Y_P$	98.2	17.9	74.4
	$Z_P$	155.2	91.1	114.7



TABLE 28  
 PRINCIPAL AXES OF INERTIA WITH RESPECT TO HIP POINT AXIS SYSTEM:  
 LARGE MALE (Cosine Matrix Expressed in Degrees, Continued)

Segment		$X_H$	$Y_H$	$Z_H$
Lower Leg (L)	$X_P$	44.4	89.4	45.7
	$Y_P$	85.8	6.5	95.3
	$Z_P$	134.9	83.5	45.6
Lower Leg (R)	$X_P$	44.4	90.6	45.7
	$Y_P$	94.2	6.5	84.7
	$Z_P$	134.9	96.5	45.6
Foot (L)	$X_P$	66.7	82.5	24.6
	$Y_P$	85.9	12.0	100.8
	$Z_P$	156.9	82.7	68.0
Foot (R)	$X_P$	66.7	97.5	24.6
	$Y_P$	94.1	12.0	79.2
	$Z_P$	156.9	97.3	68.0

TABLE 29

PRINCIPAL AXES OF INERTIA WITH RESPECT TO HIP  
POINT AXIS SYSTEM: SMALL FEMALE  
(Cosine Matrix)

Segment		$X_H$	$Y_H$	$Z_H$
Head	$X_P$	.968	0.000	.716
	$Y_P$	.000	1.000	.000
	$Z_P$	-.716	0.000	.698
Neck	$X_P$	.947	0.000	-.325
	$Y_P$	.000	1.000	.000
	$Z_P$	.325	0.000	.947
Thorax	$X_P$	.885	0.000	.466
	$Y_P$	.000	1.000	.000
	$Z_P$	-.466	0.000	.885
Abdomen	$X_P$	.909	0.000	.418
	$Y_P$	.000	1.000	.000
	$Z_P$	-.418	0.000	.909
Pelvis	$X_P$	.626	0.000	.780
	$Y_P$	.000	1.000	.000
	$Z_P$	-.780	0.000	.626
Upper Arm (L)	$X_P$	.48	-0.60	.64
	$Y_P$	.37	0.81	.46
	$Z_P$	-.80	-0.01	.60
Upper Arm (R)	$X_P$	.48	0.60	.64
	$Y_P$	-.37	0.81	-.46
	$Z_P$	-.80	0.01	.60
Lower Arm with Hand (L)	$X_P$	-.704	0.449	.545
	$Y_P$	.397	0.886	-.240
	$Z_P$	-.603	0.019	-.800
Lower Arm with Hand (R)	$X_P$	-.704	-0.449	.545
	$Y_P$	-.397	0.886	.240
	$Z_P$	-.603	-0.019	-.800
Upper Leg (L)	$X_P$	-.352	0.197	.915
	$Y_P$	.212	0.969	-.122
	$Z_P$	-.903	0.181	-.388
Upper Leg (R)	$X_P$	-.352	-0.197	.915
	$Y_P$	-.212	0.969	.122
	$Z_P$	-.903	-0.181	-.388

TABLE 29  
 PRINCIPAL AXES OF INERTIA WITH RESPECT TO HIP POINT AXIS SYSTEM:  
 SMALL FEMALE (Cosine Matrix, Continued)

Segment		$X_H$	$Y_H$	$Z_H$
Lower Leg (L)	$X_P$	.637	0.412	.652
	$Y_P$	-.341	0.909	-.241
	$Z_P$	-.691	-0.069	.719
Lower Leg (R)	$X_P$	.637	-0.412	.652
	$Y_P$	.341	0.909	.241
	$Z_P$	-.691	0.069	.719
Foot (L)	$X_P$	.593	0.400	.702
	$Y_P$	-.119	0.903	-.415
	$Z_P$	-.797	0.163	.581
Foot (R)	$X_P$	.593	-0.400	.702
	$Y_P$	.119	0.903	.415
	$Z_P$	-.797	-0.163	.581

TABLE 30

PRINCIPAL AXES OF INERTIA WITH RESPECT TO  
HIP POINT AXIS SYSTEM: LARGE MALE  
(Cosine Matrix)

Segment		$X_H$	$Y_H$	$Z_H$
Head	$X_P$	.780	0.000	.626
	$Y_P$	.000	1.000	.000
	$Z_P$	-.626	0.000	.780
Neck	$X_P$	.973	0.000	-.227
	$Y_P$	.000	1.000	.000
	$Z_P$	.227	0.000	.973
Thorax	$X_P$	.925	0.000	.380
	$Y_P$	.000	1.000	.000
	$Z_P$	-.380	0.000	.925
Abdomen	$X_P$	.879	0.000	.478
	$Y_P$	.000	1.000	.000
	$Z_P$	-.478	0.000	.879
Pelvis	$X_P$	.287	0.000	.958
	$Y_P$	.000	1.000	.000
	$Z_P$	-.958	0.000	.287
Upper Arm (L)	$X_P$	.502	0.195	.842
	$Y_P$	-.222	0.971	-.091
	$Z_P$	-.836	-0.141	.530
Upper Arm (R)	$X_P$	.502	-0.195	.842
	$Y_P$	.222	0.971	.091
	$Z_P$	-.836	0.141	.530
Lower Arm with Hand (L)	$X_P$	-.301	0.634	.712
	$Y_P$	.525	0.734	-.433
	$Z_P$	-.797	0.243	-.554
Lower Arm with Hand (R)	$X_P$	-.301	-0.634	.712
	$Y_P$	-.525	0.734	.433
	$Z_P$	-.797	-0.243	-.554
Upper Leg (L)	$X_P$	-.393	0.303	.868
	$Y_P$	.143	0.952	-.268
	$Z_P$	-.908	0.019	-.418
Upper Leg (R)	$X_P$	-.393	-0.303	.868
	$Y_P$	-.143	0.952	.268
	$Z_P$	-.908	-0.019	-.418

TABLE 30  
 PRINCIPAL AXES OF INERTIA WITH RESPECT TO HIP POINT AXIS SYSTEM:  
 LARGE MALE (Cosine Matrix, Continued)

Segment		$X_H$	$Y_H$	$Z_H$
Lower Leg (L)	$X_P$	.715	0.011	.699
	$Y_P$	.074	0.994	-.092
	$Z_P$	-.706	0.114	.700
Lower Leg (R)	$X_P$	.715	-0.011	.699
	$Y_P$	-.074	0.994	.092
	$Z_P$	-.706	-0.114	.700
Foot (L)	$X_P$	.395	0.130	.909
	$Y_P$	.071	0.978	-.187
	$Z_P$	-.920	0.128	.375
Foot (R)	$X_P$	.395	-0.130	.909
	$Y_P$	-.071	0.978	.187
	$Z_P$	-.920	-0.128	.375

TABLE 31

## LOCATION OF JOINT CENTERS: SMALL FEMALE

Joint	$X_H$ (mm)	$Y_H$ (mm)	$Z_H$ (mm)
Head/Neck	-189	0	519
C7/T1	-183	0	429
T4/T5	-205	0	381
T8/T9	-196	0	273
T12/L1	-149	0	140
L2/L3	-121	0	102
L5/S1	- 80	0	46
Sternoclavicular	-146	$\pm 17$	389
Claviscapular	-211	$\pm 140$	390
Glenohumeral	-174	$\pm 146$	354
Elbow	20	$\pm 179$	188
Wrist	134	$\pm 155$	385
Hip	0	$\pm 80$	0
Knee	363	$\pm 75$	71
Ankle	593	$\pm 86$	-182

TABLE 32

## LOCATION OF JOINT CENTERS: LARGE MALE

Joint	$X_H$ (mm)	$Y_H$ (mm)	$Z_H$ (mm)
Head/Neck	-222	0	619
C7/T1	-216	0	506
T4/T5	-248	0	439
T8/T9	-246	0	320
T12/L1	-203	0	175
L2/L3	-159	0	122
L5/S1	- 93	0	42
Sternoclavicular	-171	$\pm 25$	462
Claviscapular	-261	$\pm 177$	470
Glenohumeral	-217	$\pm 186$	427
Elbow	36	$\pm 225$	242
Wrist	264	$\pm 162$	406
Hip	0	$\pm 86$	0
Knee	413	$\pm 153$	166
Ankle	718	$\pm 99$	-152

TABLE 33

LOCATION OF JOINT CENTERS IN SEGMENT COORDINATES:  
SMALL FEMALE

Joint	Segment	Coordinates (mm)		
		X <sub>A</sub>	Y <sub>A</sub>	Z <sub>A</sub>
Head/Neck	Head	- 11	0	- 25
Head/Neck	Neck	9	0	88
C7/T1	Neck	56	0	11
C7/T1	Thorax	52	0	340
T4/T5	Thorax	23	0	296
T8/T9	Thorax	16	0	188
T12/L1	Thorax	42	0	49
L2/L3	Thorax	64	0	7
L2/L3	Abdomen	- 32	0	- 10
L5/S1	Abdomen	- 18	0	- 78
L5/S1	Pelvis	- 62	0	35
Sternoclavicular (L)	Thorax	82	17	295
Sternoclavicular (R)	Thorax	82	- 17	295
Claviscapular (L)	Thorax	18	140	306
Claviscapular (R)	Thorax	18	-140	306
Glenohumeral (L)	Thorax	50	146	265
Glenohumeral (R)	Thorax	50	-146	265
Glenohumeral (L)	Upper Arm (L)	7	- 29	- 35
Glenohumeral (R)	Upper Arm (R)	7	29	- 35
Elbow (L)	Upper Arm (L)	- 3	- 35	-292
Elbow (R)	Upper Arm (R)	- 3	35	-292
Elbow (L)	Lower Arm (L)	- 1	- 29	5
Elbow (R)	Lower Arm (R)	- 1	29	5
Wrist (L)	Lower Arm (L)	- 8	- 25	-224
Wrist (R)	Lower Arm (R)	- 8	25	-224
Hip (L)	Pelvis	- 52	80	- 56
Hip (R)	Pelvis	- 52	- 80	- 56
Hip (L)	Upper Leg (L)	27	-109	- 9
Hip (R)	Upper Leg (R)	27	109	- 9
Knee (L)	Upper Leg (L)	0	- 42	-372
Knee (R)	Upper Leg (R)	0	42	-372
Knee (L)	Lower Leg (L)	15	38	17
Knee (R)	Lower Leg (R)	15	- 38	17
Ankle (L)	Lower Leg (L)	1	31	-325
Ankle (R)	Lower Leg (R)	1	- 31	-325
Ankle (L)	Foot (L)	-104	- 12	58
Ankle (R)	Foot (R)	-104	12	58

TABLE 34

LOCATION OF JOINT CENTERS IN SEGMENT COORDINATES:  
LARGE MALE

Joint	Segment	Coordinates (mm)		
		X <sub>A</sub>	Y <sub>A</sub>	Z <sub>A</sub>
Head/Neck	Head	- 11	0	- 26
Head/Neck	Neck	35	0	112
C7/T1	Neck	87	0	12
C7/T1	Thorax	80	0	422
T4/T5	Thorax	39	0	360
T8/T9	Thorax	24	0	242
T12/L1	Thorax	47	0	92
L2/L3	Thorax	83	0	34
L2/L3	Abdomen	- 39	0	- 1
L5/S1	Abdomen	- 23	0	-104
L5/S1	Pelvis	- 68	0	41
Sternoclavicular (L)	Thorax	118	25	372
Sternoclavicular (R)	Thorax	118	- 25	372
Claviscapular (L)	Thorax	78	177	386
Claviscapular (R)	Thorax	78	-177	386
Glenohumeral (L)	Thorax	68	186	348
Glenohumeral (R)	Thorax	68	-186	348
Glenohumeral (L)	Upper Arm (L)	13	- 35	- 43
Glenohumeral (R)	Upper Arm (R)	13	35	- 43
Elbow (L)	Upper Arm (L)	- 4	- 48	-358
Elbow (R)	Upper Arm (R)	- 4	48	-358
Elbow (L)	Lower Arm (L)	- 14	- 37	10
Elbow (R)	Lower Arm (R)	- 14	37	10
Wrist (L)	Lower Arm (L)	- 7	- 32	-278
Wrist (R)	Lower Arm (R)	- 7	32	-278
Hip (L)	Pelvis	- 66	86	- 61
Hip (R)	Pelvis	- 66	- 86	- 61
Hip (L)	Upper Leg (L)	11	-132	8
Hip (R)	Upper Leg (R)	11	132	8
Knee (L)	Upper Leg (L)	0	- 54	-435
Knee (R)	Upper Leg (R)	0	54	-435
Knee (L)	Lower Leg (L)	12	55	21
Knee (R)	Lower Leg (R)	12	- 55	21
Ankle (L)	Lower Leg (L)	0	41	-423
Ankle (R)	Lower Leg (R)	0	- 41	-423
Ankle (L)	Foot (L)	-133	- 15	65
Ankle (R)	Foot (R)	-133	15	65



## 7.0 REFERENCES

- Dempster, W.T. (1955) Space requirements of the seated operator. Wright-Patterson AFB, Wright Air Development Center, WADC-TR-55-159.
- McConville, J.T.; Churchill, T.D.; Kaleps, I.; Clauser, C.E.; and Cuzzi, J. (1980) Anthropometric relationships of body and body segment moments of inertia. Wright-Patterson AFB, Aerospace Medical Research Laboratory, AMRL-TR-80-119.
- Reynolds, H.M.; Snow, C.C.; and Young, J.W. (1981) Spatial geometry of the human pelvis. Federal Aviation Administration, Memorandum Report No. AAC-119-81-5.
- Snyder, R.G.; Chaffin, D.B.; and Schutz, R.K. (1972) Link system of the human torso. Wright-Patterson AFB, Aerospace Medical Research Laboratory, AMRL-TR-71-88.
- Young, J.W.; Chandler, R.F.; Snow, C.C.; Robinette, K.M.; Zehner, G.F.; and Lofberg, M.S. (1983) Anthropometric and mass distribution characteristics of adult female body segments (Draft Report). Federal Aviation Administration, Civil Aeromedical Institute.

