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INVESTIGATION OF INERTIAL PROPERTIES OF THE HUMAN BODY

AEROSPACE MEDICAL RESEARCH LABORATORY

PREPARED FOR

NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION

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16. Abstract

Knowledge of the anthropometric parameters of the human body is essential for understanding of human kinetics and particularly for the design and testing of impact protective systems. Considerable information is available on the size, weight and center of mass of the body and its segments. This report supplements existing information with data regarding mass distribution characteristics of the human body as described by the principal moments of inertia and their orientation to body and segment anthropometry. The weight, center of mass location and principal moments of inertia of six cadavers were measured, the cadavers were then segmented and the mass, center of mass, moments of inertia and volume were measured on the fourteen segments from each cadaver. Standard and three-dimensional anthropometry of the body and segments was also determined.

This report describes the mathematical rationale and the techniques of measurement in detail. Results of the investigation are given as individual data values as well as summary statistics.

17. Key Words
Anthropometry, Biomechanics, Human body models, Moments of inertia, Human mass distribution.

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FOREWORD

This study was accomplished as a joint research effort among Engineering Anthropology, Crew Station Integration Branch, Human Engineering Division, Aerospace Medical Research Laboratory (AMRL), U. S. Air Force; the Protection and Survival Branch, Civil Aeromedical Institute (CAMI), Federal Aviation Administration; and the Anthropology Research Project, Webb Associates. Financial support was provided under interagency agreement DOT HS-0172-315IA, by the National Highway Traffic Safety Administration, U. S. Department of Transportation, with Mr. Arnold K. Johnson acting as Contract Monitor.

The efforts and responsibilities of this research were shared among the authors, but the task could not have been accomplished without the cooperation and assistance of many individuals. We make special acknowledgment to Dr. James Woods, Secretary, Anatomical Board of the State of Oklahoma for providing the cadaver specimens; to Mr. Edwin Trout (CAMI) for assistance in developing experimental procedures and techniques, instrumentation and computer programs; to Dr. Earl Folk (CAMI) for the development of a matrix rotation computer program; to Dr. Arnold Higgins (CAMI) for use of the environmental chamber; and to Dr. Charles Brake (CAMI) for use of X-ray facilities. Mr. Francis Anderson, Mr. Don Rowland and Mr. Bill Reed (CAMI) provided invaluable assistance in the design and fabrication of the many items of special test equipment and were often called upon for

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assistance in laboratory procedures. Mr. Frank Henry, University of Dayton Research Institute (UDRI) served as a research assistant in the development of experimental procedures and techniques and Ms. Charlene Reed (UDRI) as a research assistant during the data collection and preliminary data analysis phases. Mr. Bill Nixon (CAMI) was of major assistance in the development of the photographic instrumentation technique and provided photographic support throughout the course of the research. Mr. Waldo Adsum (CAMI) was of invaluable assistance during the procedural development and data collection phases of the research.

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Ms. LaNelle Murcko (CAMI) edited the draft manuscript and Ms. Jane Reese (Webb Associates) typed and assembled the various drafts and final manuscript.

We gratefully acknowledge the skill and labor devoted to this effort by our many colleagues and co-workers.

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Section I. INTRODUCTION AND PHYSICAL BASIS FOR MEASUREMENT OF INERTIAL PROPERTIES

Mass distribution properties of the human body were first applied to the practical problems of an industrialized world during the 19th Century. The pioneering work of Braune and Fischer (1889) and Fischer (1906) was useful in evaluating the "military position" of an infantry soldier carrying full field equipment and rifle and in evaluating the effectiveness of the "new pack" for carrying equipment. Other studies, described elsewhere in this report, gradually added to our knowledge of human body mass distribution; however, it was not until the advent of high-speed, ejection seat equipped aircraft, manned space vehicles, and a recognition of the importance of dynamic crash protection that the need for more precise data to predict the body's response to these hazardous environments became apparent. This requirement initiated the development of analogues of the human body, or dummies, to serve in lieu of human test subjects.

Perhaps the earliest dynamic tests using an anthropometric dummy were accomplished by Stark and Roth (1944) of the Dornier-Werke while investigating the ejection seat of the Do 335 aircraft. Problems of dynamic evaluation of ejection systems and capsules are still of major concern, and the simple wooden form used by Stark and Roth has evolved, through many "generations" of dummies, to the highly sophisticated "Dynamic Dan" developed by Payne and associates (1970). This dummy attempts to duplicate spinal response to impact, visceral dynamics, and head-on-neck response and provides realistic and carefully adjustable joints. The first dummy used in dynamic tests of civil aircraft was developed by Swearingen (1951). This dummy was the first used in crash tests in the United States that attempted to simulate the human body with a flexible torso and elastic neck. Since that time, continual development has resulted in the trauma-indicating dummies reported by Cichowski (1968) and in the advanced dummies reported by LeFevre and Silver (1973), Warner (1974), and others.

Mathematical analyses have been developed recently to evaluate the reaction of man in a dynamic crash situation. The early work of McHenry (1965) evolved into the sophisticated three-dimensional, 15-segment body described by Bartz (1971). Several others have developed similar models, and this development has progressed to provide concurrent analysis of the seat system and injury prediction for the occupant as reported by Laananen (1974). These computer models hold great promise for effective analysis of humans in a dynamic environment. Unfortunately, they also pose major problems in validation.

The development of these mechanical and mathematical models of man has proceeded by making maximum use of such data describing man as are available and making empirical assumptions for such data as are unknown. Among the missing data are measurements that completely describe the mass distribution (inertial) properties of the human body. A cursory look at the dynamics of an elementary body link will demonstrate the importance of these data.

Dynamics of a Simple Rigid Body

Basic analyses of the dynamics of simple rigid bodies can be found in many introductory textbooks of mechanics. The discussion presented here follows that given by Ham and Crane (1948).

Consider the rigid body with plane motion shown in Figure 1, where

G is the center of mass of the rigid body M,
P is an elemental particle of M,
dm is the mass of P,
A_G is the translational acceleration of G,
ω is the angular velocity of M,
α is the angular acceleration of M, and
r is the distance between G and P.

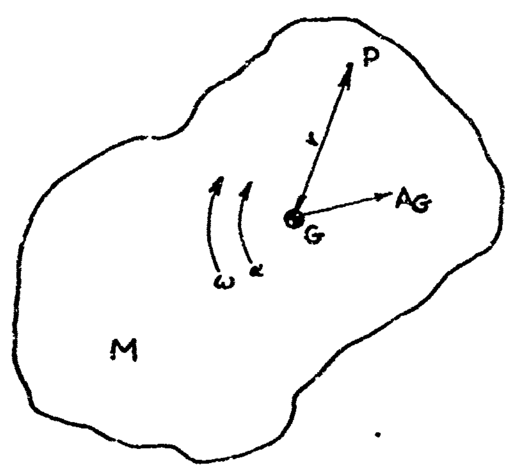


FIGURE 1. RIGID BODY WITH MOTION IN THE PLANE OF THE PAGE. AFTER HAM AND CRANE (1948).

The rigid body of mass M, composed of an infinite number of elements P, can be considered to be both translating and rotating in the plane of the page.

An inertial force, equal to the accelerating force but opposite in direction, acts on each element P. The acceleration of the element P is

$$A_P = A_G \nrightarrow A^n{}_{P/G} \nrightarrow A^t{}_{P/G} = A_G \nrightarrow r\omega^2 \nrightarrow r\alpha \qquad (1)$$

or, stated in words, the acceleration of the element P is equal to the vector sum of the acceleration of the center of gravity of mass M, the normal component of acceleration of P with respect to G, and the tangential component of acceleration of P with respect to G. The inertial force of element P with mass dm is then

$$dF = A_P\ dm = A_G dm \nrightarrow A^n{}_{P/G} dm \nrightarrow A^t{}_{P/G} dm. \qquad (2)$$

Since M is composed of elements P, the inertial force of the body as a whole is made up of:

1. The resultant of all forces like $A_G dm$, or

   $$F = \Sigma A_G dm = A_G \Sigma dm = MA_G. \qquad (3)$$

2. The resultant of all forces like $A^n{}_{P/G} dm$. These forces all pass through the center of mass, G, and thus cannot have a couple as a resultant. The magnitude of each elemental force is proportional to $r \cdot dm$, and since the center of mass is defined such that $\Sigma\ rdm = 0$, the vector sum of all the elemental forces must be zero. Thus $\Sigma A^n{}_{P/G} dm$ is zero.

3. The resultant of all forces like $A^t_{P/G}dm$.

Again, the magnitude of each elemental force is proportional to $r \cdot dm$; therefore, the vector sum must be zero. However, in this case, the elemental forces do <u>not</u> pass through a common point. These two conditions imply that the elemental forces resolve into a couple; i.e., two parallel forces of equal magnitude but opposite sign. If moments are taken about the point G, the moment (torque, T) of the resultant couple is

$$T = \Sigma r A^t_{P/G} dm\ r = \alpha \Sigma r^2 dm = I\alpha \qquad (4)$$

where

$$I = \Sigma r^2 dm \qquad (5)$$

is the "moment of inertia" of the body with respect to the center of mass, G.

From this analysis, it is seen that two equations are necessary to describe the motion of the mass, M. The first of these, $F = MA_G$, is the familiar restatement of Newton's second law applied to translating systems. The second equation, $T = I\alpha$, is a similar statement applied to rotating systems. It is important to note that it is necessary to know the mass distribution of the system, as represented by the moment of inertia, as well as the mass and the center of gravity. With these body parameters known, application of linear and angular accelerations to the body will permit computation of inertial forces or moments. Conversely, application of known forces or torques will permit computation of resulting accelerations, velocities, and displacements.

The basic principle, expanded to enable consideration of three-dimensional motion and multiple-segment body forms, is the basis for computer simulation of the human body in a crash environment. One diagrammatic representation of such a simulation model is shown in Figure 2. This model, like all others, requires data describing human segment moments of inertia. Similarly, anthropomorphic dummies cannot be more than a "best guess" mechanical simulator of the human until segment moments of inertia are also simulated. This lack of data is apparent upon review of recent specifications for dummy construction (Anthropomorphic Test Device for Use in Dynamic Testing of Motor Vehicles (1974); Anthropomorphic Test Dummy (1973)).

Measurement Technique

The major reason for the lack of data describing moment of inertia for the human body is the difficulty of measurement of that characteristic. Unlike weight, mass, center of mass, or anthropometric measures, there is no simple single measurement that can describe the moment of inertia of a body segment. Furthermore, the human body is not composed of rigid segments but is composed of tissue that distorts as the body changes position or is subjected to varying accelerations. A moment

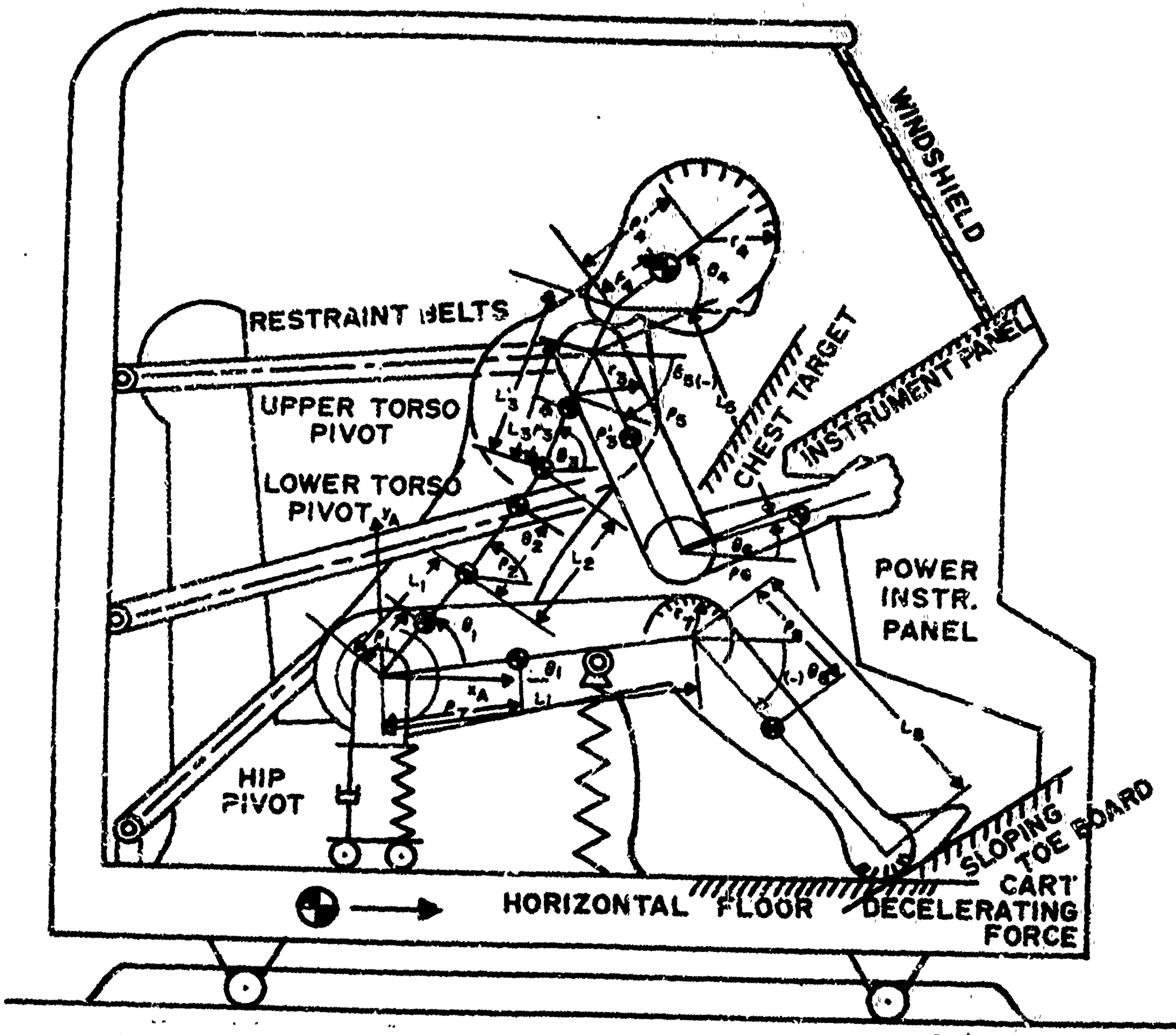


FIGURE 2. EARLY COMPUTER MODEL OF THE HUMAN BODY IN A CRASH ENVIRONMENT. AFTER McHENRY AND NAAB (1966).

of inertia of the torso, in particular, is difficult to measure because of the variability of the organs it contains and the flexibility of the spine. To make inertial measurements within the available state-of-the-art and within such resources as could be reasonably devoted to this program, it is necessary to assume that the segments of the body are rigid. This is a fundamental assumption and limitation of the data of this study. Reference to the preceding discussion of a simple rigid body will show that the moment of inertia of a rigid body was defined relative to an axis through the center of mass. In a three-dimensional body, an infinite number of axes can be passed through the center of mass, resulting in an infinite number of moments of inertia. Fortunately, these measurements are related in a regular manner, so that by specifying only six parameters the entire inertial system of a rigid body can be described.

The description of inertial measurements for a three-dimensional rigid body is more complex than the previous two-dimensional example. The discussion that follows is based on the description presented by Synge and Griffith (1942).

Consider the illustration shown in Figure 3. Again let P represent an elemental particle of a mass, M, now in three dimensions. If we locate a rectangular axis system with its origin, O, coincident with the center of mass, the moment of inertia of the mass with respect to any axis, L, through the origin is

$$I_{LL} = p^2 dm \tag{6}$$

where p is the perpendicular distance of the particle P from the axis line L. The line L can be located by measuring the angles α, β, and γ that the line makes with the X-, Y-, and Z-axes respectively. If a unit vector λ (i.e., a vector of unit magnitude) is drawn along line L from the origin, it will have components of magnitude cos α, cos β, and cos γ along the X-, Y-, and Z-axes. These components are called the "direction cosines" of the line.

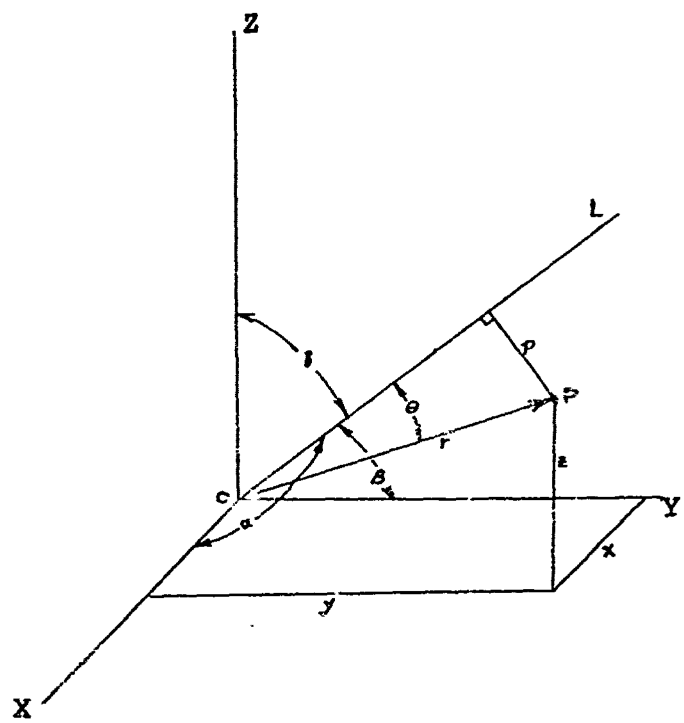


FIGURE 3. MASS PARTICLE IN THREE-DIMENSIONAL SPACE. AFTER SYNGE AND GRIFFITH (1942).

The distance p can be calculated as

$$p = OP \sin \theta \tag{7}$$

where θ is the angle between OP and L. However, the magnitude of the vector product $\lambda \chi r$ is defined as

$$|\lambda \chi r| = |\lambda| |r| \sin \theta . \tag{8}$$

Since λ has a unit magnitude, and $r = OP$,

$$p = |\lambda \chi r| . \tag{9}$$

This expression can be written in the form

$$p = \lambda \chi r = i \begin{vmatrix} \cos \beta & \cos \gamma \\ y & z \end{vmatrix} + j \begin{vmatrix} \cos \gamma & \cos \alpha \\ z & x \end{vmatrix} + k \begin{vmatrix} \cos \alpha & \cos \beta \\ x & y \end{vmatrix} \tag{10}$$

or

$$p = i(z \cos \beta - y \cos \gamma) + j\,(x \cos \gamma - z \cos \alpha) + k\,(y \cos \alpha - x \cos \beta) \tag{11}$$

where i, j, and k are unit vectors along the X-, Y-, and Z-axes and x, y, z are the coordinates of p. Thus the components of p are

$(z \cos \beta - y \cos \gamma)$ in the X-direction (12)

$(x \cos \gamma - z \cos \alpha)$ in the Y-direction (13)

$(y \cos \alpha - x \cos \beta)$ in the Z-direction. (14)

Applying the Pythagorean theorem,

$$p^2 = (z \cos \beta - y \cos \gamma)^2 + (x \cos \gamma - z \cos \alpha)^2 + (y \cos \alpha - x \cos \beta)^2 \tag{15}$$

$$= z^2 \cos^2\beta - 2\,yz \cos \beta \, \cos \gamma + y^2 \cos^2\gamma + x^2 \cos^2\gamma - 2\,x\,z \cos \alpha \, \cos \gamma + z^2 \cos^2\alpha + y^2 \cos^2\alpha - 2\,xy \cos \alpha \, \cos \beta + x^2 \cos^2\beta \tag{16}$$

$$= (y^2 + z^2) \cos^2\alpha + (x^2 + z^2) \cos^2\beta + (x^2 + y^2) \cos^2\gamma - 2yz \cos \beta \, \cos \gamma - 2\,zx \cos \alpha \, \cos \gamma - 2\,xy \cos \alpha \, \cos \beta . \tag{17}$$

Thus

$$I_{LL} = \Sigma p^2 dm = \tag{18}$$

$$\cos^2\alpha\ \Sigma dm(y^2 + z^2) + \cos^2\beta\ \Sigma dm(x^2 + z^2) + \cos^2\gamma\ \Sigma dm(x^2 + y^2) -$$

$$2 \cos\beta \cos\gamma\ \Sigma dmyz - 2 \cos\alpha \cos\gamma\ \Sigma dmxz - 2 \cos\beta\ \Sigma dmxy. \tag{19}$$

For simplicity of notation in the following discussion, let

$\Sigma m\ (y^2+z^2) = I_{xx}$ (the moment of inertia about the X-axis) (20)

$\Sigma m\ (x^2+z^2) = I_{yy}$ (the moment of inertia about the Y-axis) (21)

$\Sigma m\ (x^2+y^2) = I_{zz}$ (the moment of inertia about the Z-axis) (22)

$\Sigma m\ yz = I_{yz}$ (the product of inertia with respect to the xy- and xz-planes) (23)

$\Sigma m\ xz = I_{xz}$ (the product of inertia with respect to the xy- and yz-planes) (24)

$\Sigma mxy = I_{xy}$ (the product of inertia with respect to the xz- and yz- planes). (25)

Then

$$I_{LL} = I_{xx}\cos^2\alpha + I_{yy}\cos^2\beta + I_{zz}\cos^2\gamma - 2(I_{yz}\cos\beta\cos\gamma + I_{xz}\cos\alpha\cos\gamma + I_{xy}\cos\alpha\cos\beta). \tag{26}$$

If a vector is directed from the origin along line L, let its length be $\overline{OQ}$. The x, y, and z components of $\overline{OQ}$ will be

$$x = \overline{OQ} \cos\alpha \tag{27}$$

$$y = \overline{OQ} \cos\beta \tag{28}$$

$$z = \overline{OQ} \cos\gamma. \tag{29}$$

If these values are substituted into the general equation for a three-dimensional quadratic centered at the origin,

$$Ax^2 + By^2 + Cz^2 - 2Fyz - 2Gzx - 2Hxy = 1, \tag{30}$$

the resulting equation is

$$A\ \overline{OQ}^2\cos^2\alpha + B\ \overline{OQ}^2\cos^2\beta + C\ \overline{OQ}^2\cos^2\gamma - 2\ F\ \overline{OQ}^2\cos\beta\ \cos\gamma - 2\ G\ \overline{OQ}^2\cos\alpha\ \cos\gamma - 2\ H\ \overline{OQ}^2\cos\alpha\ \cos\beta = 1. \tag{31}$$

This equation can be made identical to the equation for the moment of inertia about line L by letting

$$\frac{1}{\sqrt{I_{LL}}} = \overline{OQ} \tag{32}$$

$$A = I_{xx} \tag{33}$$

$$B = I_{yy} \tag{34}$$

$$C = I_{zz} \tag{35}$$

$$F = I_{yz} \tag{36}$$

$$G = I_{zx} \tag{37}$$

$$H = I_{xy} \tag{38}$$

so that

$$I_{xx}x^2 + I_{yy}y^2 + I_{zz}z^2 - 2I_{yz}yz - 2I_{zx}zx - 2I_{xy}xy = 1. \tag{39}$$

Thus the moment of inertia of a body about any line through its center of mass can be described by a vector $\overline{OQ}$, where $\overline{OQ}=I_{LL}^{-1/2}$. The locus of Q can be shown to be an ellipsoid. This ellipsoid is called an "ellipsoid of inertia" of the "momental ellipsoid." The properties of an ellipsoid can also be represented in a mathematical array called a "tensor" so that the ellipsoid of inertia is often called an "inertia tensor." The fact that the inertial properties of a body can be described by an ellipsoid is particularly convenient, for it means that a geometric treatment of an ellipsoid will also treat the inertial properties of a general rigid body.

Every ellipsoid possesses three orthogonal principal axes. The principal axes for the ellipsoid of inertia are called the principal axes of inertia, and the moments of inertia about those axes are called the principal moments of inertia. If the coordinate axes system were made coincident with the principal axes, the equation of the ellipsoid of inertia would reduce to

$$I_{xx}x^2 + I_{yy}y^2 + I_{zz}z^2 = 1. \tag{40}$$

The absence of the product terms in the equation indicates that the principal axes are coincident with the coordinate axes. Conversely, the presence of product terms indicates that the principal axes are rotated relative to the coordinate axes.

The ellipsoid of inertia can be specified for any body segment by either of two manners: the moments and products of inertia for a given axis system or the principal moments of inertia and the orientation of the principal axes system relative to the segment axes.

The prior discussion was limited to the ellipsoid of inertia about an axis through the body center of mass. More generally, the body will rotate about an axis displaced from the center of mass. The inertia about the displaced axis is related to the inertia of the body about an axis through the center of mass and parallel to the displaced axis. Consider the axis system shown in Figure 4. This axis system represents a

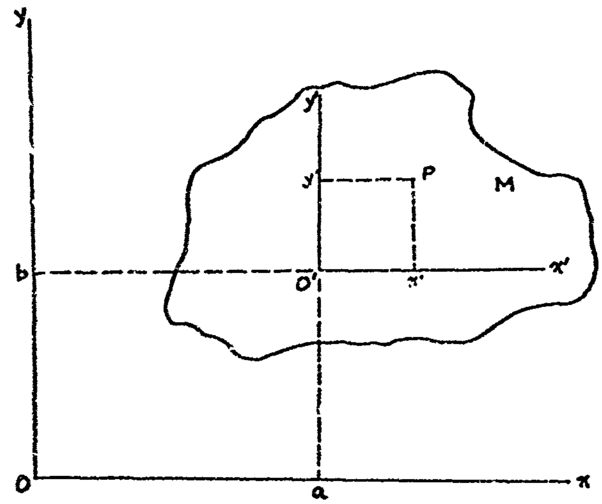


FIGURE 4. AXIS SYSTEM FOR PARALLEL AXIS TRANSFORMATION.

plane perpendicular to the axis of rotation, O, and a parallel axis through the mass center, O'. For any such parallel axis system, a point P with coordinates (x',y') relative to the x'y'-axis will have coordinates

$$x = x' + a \tag{41}$$

$$y = y' + b \tag{42}$$

relative to the xy-axis system. As previously stated, the moment of inertia about O is

$$I_O = \Sigma m(x^2 + y^2) \tag{43}$$

$$= \Sigma m[(x' + a)^2 + (y' + b)^2] \tag{44}$$

$$= \Sigma m[x'^2 + 2x'a + a^2 + y'^2 + 2y'b + b^2] \tag{45}$$

$$= \Sigma m[(x'^2 + y'^2) + (a^2 + b^2) + 2x'a + 2y'b] \tag{46}$$

$$= M\ (a^2+b^2) + I_{O'} + 2a\Sigma mx' + 2b\Sigma my' \tag{47}$$

but $\Sigma mx' = \Sigma my' = 0$ from the definition of mass center. Therefore

$$I_O = I_{O'} + M(a^2 + b^2) \tag{48}$$

This equation is a statement of the parallel axis theorem.

With the above background, a procedure can be established for measuring the ellipsoid of inertia of a rigid specimen. Winstandley et al. (1968), Becker (1972), Schaeffer and Ovenshire (1972) present different interpretations of a similar methodology. Basically, it is required to determine the moment of inertia of the specimen about six axes passing through a given point relative to the specimen. Because of its relative simplicity, the approach of Winstandley et al. will be followed here.

Consider the simple pendulum shown in Figure 5.

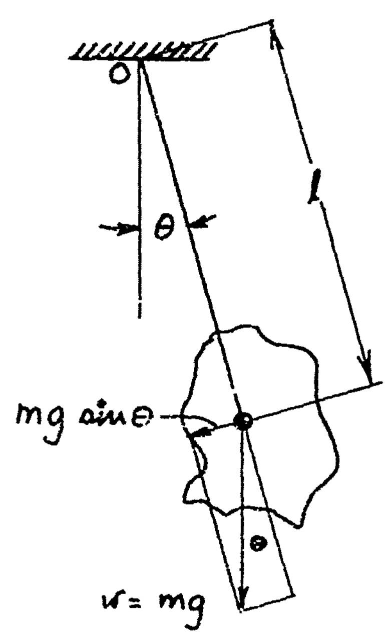


FIGURE 5. PENDULUM SYSTEM FOR DETERMINATION OF MOMENTS OF INERTIA. AFTER WINSTANDLEY ET AL. (1968).

The equation of the motion is

$$I_{oo} \frac{d^2\Theta}{dt^2} = mgl \sin \Theta \tag{49}$$

where I_{oo} = mass moment of inertia of the pendulum about O-axis, m = mass of the pendulum, Θ = angle of motion (in radians), $\frac{d^2\Theta}{dt^2}$ = angular acceleration = $\ddot{\Theta}$, and l = distance from axis of rotation to the mass center of the pendulum. Since w = mg, the equation can be rewritten as

$$\ddot{\Theta} + \frac{wl}{I_{oo}} \sin \Theta = 0. \tag{50}$$

Since

$$\sin \Theta = \Theta - \frac{\Theta^3}{3!} + \frac{\Theta^5}{5!} - \cdots + (-1)^{n+1} \frac{\Theta^{(2n-1)}}{(2n-1)!} + \cdots \tag{51}$$

for small oscillations the higher order terms become insignificant, so that the equation can again be rewritten

$$\ddot{\Theta} + \frac{wl}{I_{oo}} \Theta = 0. \tag{52}$$

This is the common expression for free oscillation of a simple harmonic system where the natural frequency of the system is

$$\omega = \sqrt{\frac{wl}{I}} \tag{53}$$

or

$$I = \frac{wl}{\omega^2}. \tag{54}$$

Since

$$\omega = \frac{2\pi}{T} \tag{55}$$

$$\omega^2 = \frac{4\pi^2}{T^2} \tag{56}$$

where T = period of oscillation in seconds, the moment of inertia of the simple pendulum about its axis of rotation is

$$I_{oo} = \frac{wlT^2}{4\pi^2} \tag{57}$$

and can be determined by measuring w and l and observing T.

Measurement of the moment of inertia of a complex specimen (body segment) will require the use of a specimen holder to position the segment and provide an axis of rotation. Thus the equation above represents a measurement of the moment of inertia of the composite system of specimen and specimen holder. We shall denote the composite system by subscript "c," the specimen by subscript "s," and the specimen holder by subscript "h." From the previous discussion of moment of inertia, it is obvious that

$$I_{ooc} = I_{oos} + I_{ooh} \text{ or } I_{oos} = I_{ooc} - I_{ooh}. \tag{58}$$

Also

$$w_c = w_s + w_h. \tag{59}$$

Referring to Figure 6, it is seen that

$$l_c^2 = x_c^2 + z_c^2 \tag{60}$$

and

$$l_c = \frac{\left[(w_s x_s + w_h x_h)^2 + (w_s z_s + w_h z_h)^2\right]^{1/2}}{w_c}. \tag{61}$$

To find the moment of inertia of the specimen about its center of mass, the parallel axis theorem is used. Thus

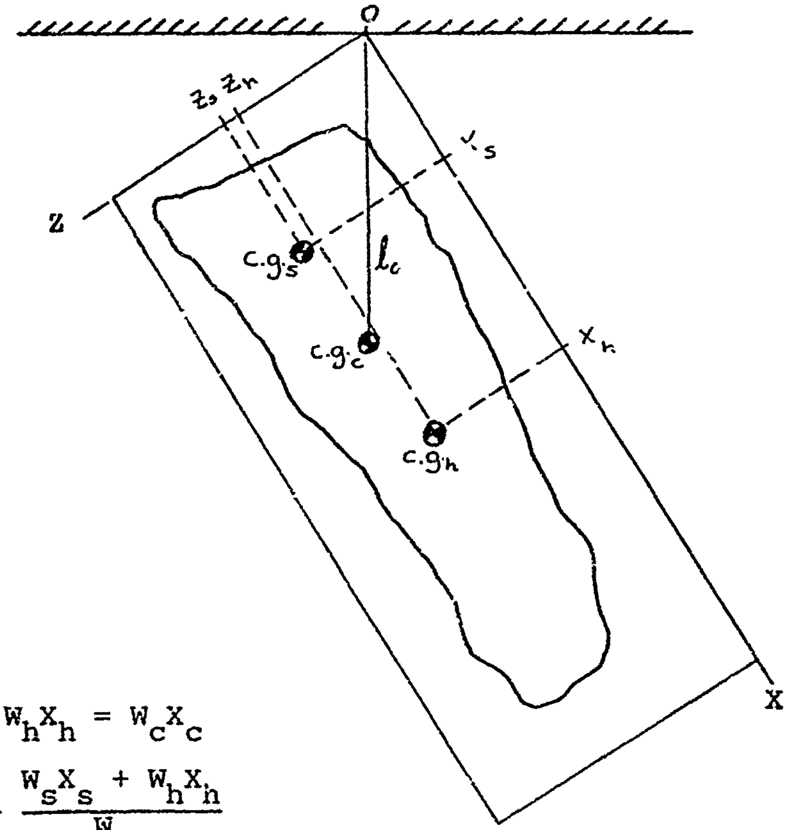
$$I_{oos} = I_{c.g.s} + m_s l_s^2 \tag{62}$$

or

$$I_{c.g.s} = I_{oos} - m_s l_s^2 \tag{63}$$

$$= I_{ooc} - m_s l_x^2 \tag{64}$$

$$= \frac{w_c l_c T_c^2}{4\pi^2} - \frac{w_h l_h T_h^2}{4\pi^2} - m_s l_s^2. \tag{65}$$



$$W_s X_s + W_h X_h = W_c X_c$$

$$\therefore X_c = \frac{W_s X_s + W_h X_h}{W_c}$$

$$W_s Z_s + W_h Z_h = W_c Z_c$$

$$\therefore Z_c = \frac{W_s Z_c + W_h Z_h}{W_c}$$

FIGURE 6. COMPOSITE PENDULUM CONSISTING OF SPECIMEN AND SPECIMEN HOLDER.

Thus it is possible to use the composite pendulum to determine the moment of inertia about an axis through the center of mass of the specimen. By swinging the composite pendulum about three orthogonal axes, the three moments of inertia required by the equation can be calculated. To specify completely the ellipsoid of inertia, the products of inertia with respect to planes through the axes must also be determined.

Consider the equation of the ellipsoid

$$I_{xx}x^2 + I_{yy}y^2 + I_{zz}z^2 - 2I_{yz}yz - 2I_{zx}zx - 2I_{xy}xy = 1. \tag{66}$$

The quantities I_{xx}, I_{yy}, I_{zz} are measured as described above. Consider the measurement of moment of inertia, I_{OO}, about an axis in the y = 0 plane, as shown in Figure 7. Substituting y = 0 into the equation of ellipsoid yields

$$I_{xx}x^2 + I_{zz}z^2 - 2I_{zx}zx = 1 \tag{67}$$

but

$$z = x \tan \Theta; \tag{68}$$

therefore,

$$I_{xx}x^2 + I_{zz}x^2\tan^2\Theta - 2I_{zx}x^2\tan \Theta = 1 \tag{69}$$

or

$$I_{xx} + I_{zz}\tan^2\Theta - 2I_{zx}\tan \Theta = \frac{1}{x^2}\ ; \tag{70}$$

but, in the y = 0 plane

$$x^2 + z^2 = \frac{1}{I_{\Theta\Theta}} \tag{71}$$

or

$$x^2 + x^2\tan^2\Theta = \frac{1}{I_{\Theta\Theta}} \tag{72}$$

or

$$x^2(1+\tan^2\Theta)I_{\Theta\Theta} = 1 \tag{73}$$

or

$$(1+\tan^2\Theta)I_{\Theta\Theta} = \frac{1}{x^2}\ ; \tag{74}$$

therefore,

$$I_{xx} + I_{zz}\tan^2\Theta - 2I_{zx}\tan\Theta = (1+\tan^2\Theta)I_{\Theta\Theta} \tag{75}$$

or

$$I_{xx} + I_{zz}\tan^2\Theta - (1+\tan^2\Theta)I_{\Theta\Theta} = 2\tan\Theta\, I_{zx} \tag{76}$$

or

$$I_{zx} = \frac{I_{xx} + I_{zz}\tan^2\Theta - (1+\tan^2\Theta)\, I_{\Theta\Theta}}{2\tan\Theta}\ . \tag{77}$$

Thus, the products of inertia can be determined by the measurement of three coplanar moments of inertia about nonparallel axes. By duplicating these measurements, the equation describing the ellipsoid of inertia of any complex rigid body can be fully defined.

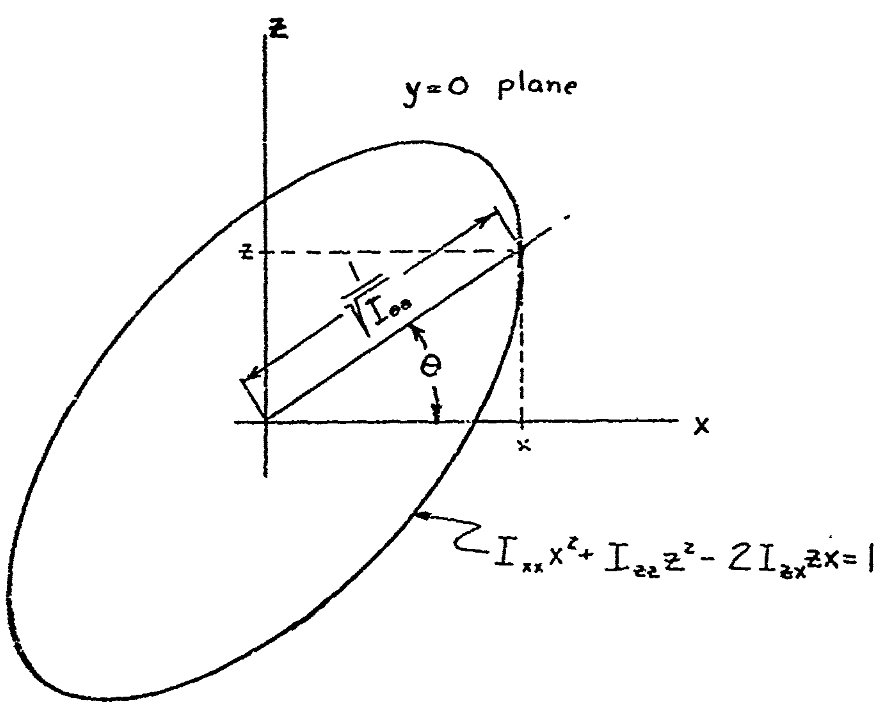


FIGURE 7. DETERMINATION OF PRODUCT OF INERTIA BY MEASUREMENT OF MOMENT OF INERTIA ABOUT THREE COPLANAR AXES.

Section II. HISTORICAL RESUME: MEASUREMENT OF INERTIAL PROPERTIES OF MAN

The principal moments and principal axes of the momental ellipsoid of inertia have rarely been measured for biological specimens. Early work in biomechanics from the 17th to 19th century, beginning with Borellus (1679), was devoted entirely to measurement of the center of mass. Late in the 19th century, Braune and Fischer (1892) measured moments of inertia about the longitudinal axis and about an axis perpendicular to the longitudinal axis of segments from two cadavers. These two axes have been used in modeling as if they were principal axes. This assumption would be empirically valid if the human body were homogeneous in composition and each primary segment fit its respective geometric model perfectly. Since, however, the human body is nonhomogeneous, its inertial properties can only be measured in the framework of the momental ellipsoid of inertia that defines the principal axes and the moments of inertia about those axes.

Weinbach (1938) was the first to use photogrammetry to estimate a moment of inertia of the human body. He derived his estimate of the moment of inertia "...about the soles of the feet as [sic] pivotal axis..." (p. 363) by mathematically constructing curves based on body surface-area measurements on the photographs and assuming an homogeneous body density equal to unity. Further work in estimating the inertial properties of biological specimens by using photogrammetry techniques, stereophotogrammetry in particular, is currently underway at the Biostereometric Laboratory in Houston, Texas (Herron, 1974).

Dempster (1955) essentially duplicated the Braune and Fischer measurement technique on segments from eight cadavers to provide moments of inertia about two parallel transverse axes. A moment of inertia about a transverse axis passing through the center of mass was measured for all segments. The second moment of inertia was measured about a parallel axis that passed through the proximal joint centers for all limbs, the hip joint centers for both the trunk (with and without shoulders) and the abdominal-pelvic region, the sternoclavicular joints for the shoulders, the 7th cervical vertebral body for the head and neck, and the 12th thoracic vertebral body for the thorax. Dempster's work in conjunction with that of Braune and Fischer has provided investigators in biomechanics with data on the inertial properties of man; however, these data are incomplete because they represent only the inertial properties about axes parallel to those measured.

Santschi, DuBois, and Omoto (1963) measured three moments of inertia about three orthogonal axes defined as the intersection of the three anatomical planes of the body. The momental ellipsoid of inertia was not defined but the three moments of inertia were measured about axes that passed through the subject's center of mass. The center of mass was located in three dimensions as distances along the z-axis from the vertex, along the x-axis from the back plane, and along the y-axis as one-half the distance between the right and left anterior superior iliac spines. Sixty-six living male subjects representative of the Air Force population were measured in eight body positions. DuBois et al. (1964) continued this work on 19 subjects to investigate the effects of a full-pressure suit on the inertial properties of the body. Again, three moments of inertia were measured, but these were not related to the body in three-dimensional space nor were they examined to see how well they represented the principal moments of inertia about the principal axes.

Bouisset and Pertuzon (1968) measured a moment of inertia about the humero-ulnar joint of the combined forearm and hand by a quick release method. This method had been developed earlier by Fenn, Brody and Petrilli (1931) for the leg. Data are presented on 11 living subjects, and the authors conclude that the technique is reliable. However, they do not define the parameters of the momental ellipsoid of inertia about the body segment of interest.

Liu, LaBorde, and Van Buskirk (1971) measured three moments of inertia about the three principal geometric axes of transverse sections cut from one unembalmed male cadaver. The axes were assumed to represent the principal axes "...since their products of inertia are approximately zero" [sic] (p. 652). Liu and

Wickstrom (1973) continued this work by measuring the inertial properties of sections taken from the torsos of one unembalmed and seven embalmed cadavers. Again, the measured axes were assumed to represent the principal axes.

Becker (1972) was the first to attempt to measure the momental ellipsoid of inertia (six cadaver heads and three cadaver head and neck segments) by using a least squares procedure on 10 measured moments of inertia and 12 vector locations of the center of mass.

Ignazi et al. (1972) measured three moments of inertia about three anatomical axes that were defined relative to the feet and pelvis in three-dimensional space. These are the first reported data relating the measured moments of inertia to the body in three-dimensional space. However, the principal moments of inertia or the principal axes were not determined.

In summary, previous studies have demonstrated the difficulty of defining the three-dimensional mass distribution properties of biological specimens. Table 1 lists all the studies reviewed in this section together with the kind and size of sample and the number of axes measured. Basically, two studies in Table 1--Braune and Fischer (1892) and Dempster (1955)--have been used almost exclusively to provide data on the inertial properties of the human body. Neither of these studies defined the momental ellipsoid of inertia for the whole body nor any of its segments.

TABLE 1. SUMMARY OF INERTIAL INVESTIGATIONS

	Subjects		Axes
	Cadavers	Living	Measured
Braune and Fischer (1892)	2		2
Weinbach (1938)		8	1
Dempster (1955)	8 (Incomplete)		2
Santschi et al. (1963)		66	3
DuBois et al. (1964)		19	3
Bouisset and Pertuzon (1968)		11	1
Liu et al. (1971)	1 (Torso only)		3
Ignazi et al. (1972)		11	3
Becker (1972)	9 (Head and neck only)		10
Liu and Wickstrom (1973)	8 (Torso only)		3

As indicated in Section I, with the development of modern-day high-speed computers, mathematical modeling provided great promise for simulating dynamic crash environments. The concept of mathematically modeling the body as a series of geometric forms was suggested, however, in the 19th century. Harless (1860) verified the use of regular geometric forms as analogues of segments of the human body by a comparison of the volume and center of mass calculations with measurements obtained on a single cadaver. He concluded that the computed values for such analogues gave results within the range of variability of such measurements on cadavers.

Hermann Von Meyer, also in the mid-19th century (1863, 1873), used the concept of mathematical modeling in his investigation of the statics and mechanics of the human body. Von Meyer attempted to ascertain the location of the center of mass of the body in a three-dimensional space and to study its movement with changes in body position. He determined the centers of mass of the segments of the body by reducing the head, torso, and appendages to simple geometric shapes (ellipsoids and sphere); then, by combining or linking them in space, he computed the common center of mass of the whole body.

Amar (1920), continued this approach in a study of human locomotion by considering the trunk to approximate a cylinder and the appendages to approximate frustums of cones. Using the segment mass/body weight ratios reported by Fischer (1906), Amar computed the segmental moments of inertia for a 65-kilogram man.

The widespread availability of high-speed computers in recent years has intensified the interest in the development of mathematical models of the human body. In 1960, Simmons and Gardner developed a man-model by approximating the body segments as uniform geometric shapes. They assumed the appendages, neck, and torso to approximate cylinders and the head to approximate a sphere. Using Barter's (1957) equations for mass of the individual segments, they computed the inertial parameters for the geometric forms and calculated the total-body moments of inertia. This work, in many respects most elementary, was the genesis of much present modeling activity.

Whitsett (1962), in a study of the dynamic response of weightless man, refined the model developed by Simmons and Gardner by increasing the number of body segments from 8 to 14 and using additional geometric shapes to approximate more closely the shapes of the various body segments. Whitsett's 14 segments include a head, a torso, two upper arms, two lower arms, two hands, two upper legs, two lower legs, and two feet. The head is modeled as one ellipsoid, the hands as spheres, the upper arms and legs and lower arms and legs as frustums of right circular cones, and the feet as rectangular parallelepipeds (Figure 8). In developing his model, Whitsett assumed that, ideally,

> "...(1) [the human body] consists of a finite number of masses (or segments) and a finite number of degrees of freedom (hinge points);
>
> (2) segments are rigid and homogeneous;
>
> (3) each segment can be represented by a geometric body which closely approximates the segment's shape, mass, and center of mass, length and average density.
>
> The dynamic properties of these rigid, homogeneous, geometric, bodies can be exactly determined." (Page 6.)

The physical properties incorporated by Whitsett into the model included the size data from Hertzberg et al. (1954), the mass properties fr~ the regression equations of Barter (1957) and the center-of-mass and segment-density data from Dempster (1955). The equations for the mass moments of inertia were standard for the particular geometric forms used; only the

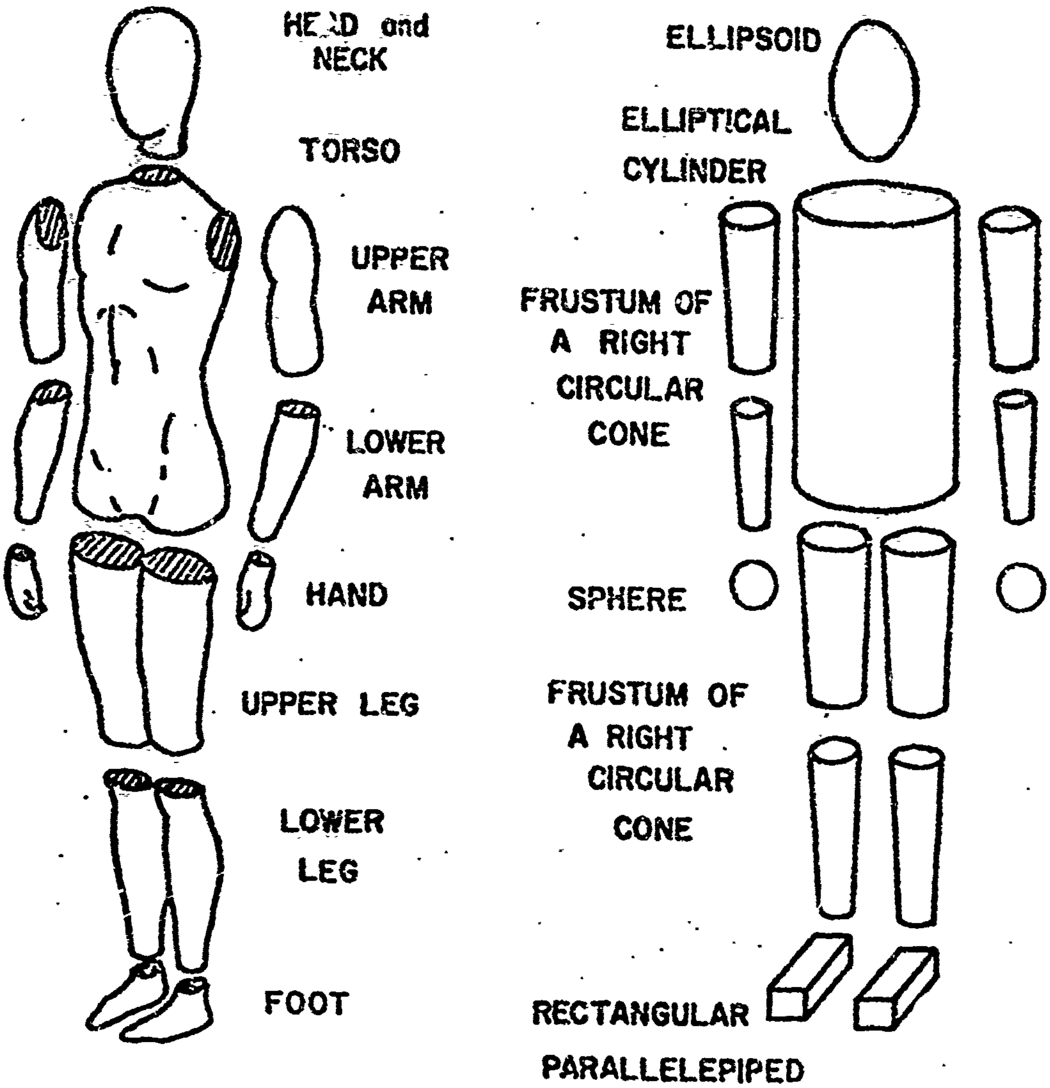


FIGURE 8. SEGMENTED MAN AND MODEL. AFTER WHITSETT (1962).

mass moment of inertia equation for the frustum of a right circular cone needed to be derived.

After developing the model, an analysis was made to determine which segments had the greatest effect on the total body moments of inertia, the approximation errors that result from representing the segments by geometric bodies, and the simplification that could be made in representing the segments without a significant loss in accuracy. Whitsett determined that, in general, the segment moments of inertia cannot be neglected, particularly about the z-axis; however, the segment moments for the smaller segments (hands, feet, lower arms) contribute little. He concluded that special care, however, must be used in computing the moments of inertia for the torso because of its major contribution to total-body moments. On the basis of his findings, Whitsett suggested a simplified method of computing moments of inertia for any body position.

Whitsett then attempted to validate his model by recording on film a free-floating subject in an aircraft flying a Keplerian trajectory. He then compared the body motion under zero gravity to that predicted from his model. The maximum impact-free periods were found insufficient to demonstrate conclusively the validity of the theoretical formulation.

Kulwicki et al. (1962) developed a simplified model composed of six right circular cylinders (two arms, two legs, torso, and head) to evaluate the effectiveness of selected movements in producing rotation in a zero gravity environment.

Gray (1963), in an analytical study of man's inertial properties, presented a method of predicting the inertial properties of a body of any size and in any fixed position by using a model to simulate the mass distribution properties. With this model, the inertial tensor of any body in any conceivable position could be computed by assigning appropriate dimensions and body segment masses.

Gray modified the existing Whitsett model in a number of respects. Because of the difference in density of the upper torso and lower torso, Gray divided the torso into two elliptical cylinders of the same cross section but of different densities. The foot, a rectangular parallelepiped in the original model, became a frustum of a right circular cone because this was believed to approximate more closely the mass distribution of the foot. Gray then outlined the coordinate transformations necessary to relate the moments and products of inertia of the various segments to a single set of axes. He then calculated the inertial properties of three specific men (a small-, an average-, and a large-size individual) in six different body positions and compared the resulting moments of inertia and center-of-mass locations to the empirical data detailed by Santschi _et al._ (1963). Gray was disappointed in the results of the comparison of the model's predicted values with the measured values and concluded that although the method used in his modeling was suitable, the model itself must be refined to represent more precisely the mass and the mass distribution of man.

In 1964, Hanavan published the results of a study to (1) design a personalized mathematical man model, (2) analyze the model, (3) prepare a generalized computer routine for calculating the inertial properties of any subject in any body position, and (4) develop a design handbook for a series of percentile body forms in 31 body positions. The model was made up of 15 simple geometric forms hinged at the end of each of the primary segments. While the torso was considered as two linked segments and the head as a third linked segment, they lacked motion. Hanavan, in a manner similar to that used by Gray, defined the body posture by assigning Euler angles to each of the segments and then calculated the inertial dyadic tensor and the center-of-mass locations for a specific body in specific positions. Hanavan used as input the mass predictive equations of Barter (1957). To validate his model, Hanavan used the anthropometry measured by Santschi et al. (1963) to define the size of the geometric segments. The moments of inertia and the center of mass for each segment were calculated and the results transferred to a total-body center of mass. The model's total-body moments of inertia and center-of-mass locations were then compared to Santschi's data on 66 subjects.

Hanavan found that the total-body moments of inertia I_{xx} and I_{yy} were predicted in half the cases within 10 percent of the experimental data, and the moment of inertia I_{zz} was predicted in half the cases within 20 percent of the experimental data.

The prediction of center-of-mass location in the z-axis was found to be very good, with one-half the values falling within seven-tenths of an inch of the experimental data. The center-of-mass locations in the x- and y-axes were difficult to compare in a similar fashion because of the method used by Santschi et al. to report these locations.

Hanavan's second method of model evaluation was to compare the segment center-of-mass locations and densities with the experimental results published by Dempster (1955). He found these comparisons to be good, with the poorest results being predicted from the model for the hand and foot segments.

Tieber and Lindemuth (1965) used a modified version of the basic Hanavan model in their study and analysis of the inertial properties of the pressure-suited subject and an astronaut-maneuvering system. The inertial properties were calculated by determining the individual inertial properties of each component of the system (the man, the pressure suit, the life-support pack, and the maneuvering unit) and then combining them into a single composite system.

A number of modifications were made to the Hanavan 15-segment model. The use of a new series of regression equations for predicting segment mass produced a significant redistribution in body weight. This, in turn, caused the model to reflect a poorer agreement in the computed and experimental center-of-mass and moments-of-inertia data. In general, it was found that the computed moments of inertia were less than the experimental properties; therefore, the procedure was one of increasing these computed moments. The model was, therefore, modified to improve the calculated results to bring them more in line with the experimental dat: addition to the improvement in the calculated results, + lifications that were incorporated were a logical attempt to improve the representation of the body-size data in the model.

Wooley (1972) was at the same time working to simplify this model. Wooley combined the head with the trunk, the hands with the forearms, and the feet with the calves. This simplification was based on the assumption that the distal segments (hands and feet) are relatively small in mass and do not move an appreciable amount relative to their attached segment. Wooley checked his model results against the experimental data of Santschi <u>et al</u>. and found the agreement similar in terms of error to that which had been obtained by Hanavan.

In addition to his modification of the model, Wooley prepared a series of regression equations for predicting the moments of inertia of body segments from a man's body weight. These results were evaluated against values of segment moments of inertia measured by Dempster (1955) about a transverse axis through the center of mass. The average error between the theoretical values and measured values was within 10 percent of the measured value. Wooley concluded: "...the regression equations can be a useful tool in computing segment inertial properties, with only a knowledge of the total body mass of a particular subject" (p. 43).

In 1966, Kurzhals established a series of regression equations for predicting the pivot points and center-of-mass coordinates for use in the Wooley model.

The Barter regression equation for computing segment mass from total-body weight, the moments-of-inertia regression equations of Wooley, and the segment mass center and pivot points location regression equations of Kurzhals have been incorporated into a modified Hanavan man model by the Martin Marietta Corporation. This mathematical "Model of Man" is currently being used in astronaut maneuvering simulation and is being revised based on results obtained from crew-motion studies performed by NASA and its various contractors (Wudell et al. 1970). The model has the advantage and limitation of a single input, body weight, from which all other necessary segmental parameters are computed. It does, of course, lack the personalization that Hanavan and also Tieber and Lindemuth attempted to incorporate into their man models.

In the preceding review of modeling endeavors, the impetus has centered in the aerospace industry; yet, a parallel effort focusing on the use of mathematical models to generate input data for predicting occupant behavior in auto crash simulations has taken place in the automotive industry. The interest, however, has been directed toward statistical representations of the population, such as the 50th-percentile male model, rather than the personalized approach reported previously in the aerospace industry. Apparently, many of the models in this area have been derived from the work of D. A. Lepley, as reported in "A Mathematical Model for Calculating the Moments of Inertia of Individual Body Segments" (Bartz and Gianotti, 1973), which has not been released for publication by General Motors.

Patten (1969) and Patten and Theiss (1970) modeled the human body as 12 segments by using a segmented trunk with a lower torso (half sphere), a middle torso (right circular cylinder), an upper torso (two concentric right circular cylinders), a combined head and neck (ellipsoid of revolution and right circular cylinder), upper legs (frustum of right circular cone), and lower legs and arms (right circular cylinders). Segment mass and moments of inertia have been calculated and integrated into the program for a 5th-percentile female, a 50th-percentile male, and a 95th-percentile male based on anthropometric data in the literature. These calculations were compared with appropriate data in the literature on cadavers, living subjects, anthropomorphic dummies, and mathematical models. The authors conclude that there is reasonable agreement between their model and other comparable data.

Continuing in this approach to generate occupant data for crash victim simulation models, Bartz and Gianotti (1973) changed the shape of the segment models to ellipsoids. They developed a 15-segment model that calculates link dimensions, contact surface dimensions and a two-dimensional location of the "eye-point" and "H-point." Using anthropometric data and Motor Vehicle Manufacturers Association two-dimensional template for a 50th-percentile male and 5th-percentile female, the authors calculated these occupant parameters for a 95th-percentile male, a 50th-percentile male, a 50th-percentile female, 5th-percentile female, and 50-pound and 30-pound unisex children. Like Patten and Theiss, the authors compared their model results with data in the literature on measured moments of inertia for cadavers (Becker, 1972; Dempster, 1955; Hodgson et al. 1972), living subjects (Drillis and Contini, 1966; Santschi, DuBois and Omoto, 1963), anthropomorphic dummies (Bartz, 1971; Bartz and Butler, 1972), and another model previously discussed (Hanavan, 1964). The data presented are significant in that the simplified ellipsoid model appears to have the same magnitude of error as found in the model developed by Hanavan (1964).

Analogous to Whitsett, who attempted to validate his model on movements of the living body in a gravity-free environment, Robbins et al. (1971) reported on the validation of a two-dimensional crash-victim model developed at the University of Michigan. The results of the model predicted the dynamic behavior of living subjects, and these results were compared with actual test results of living subjects on the Daisy Decelerator, Holloman Air Force Base. To generate the input data, classical and nonclassical anthropometric measurements were taken on the subjects, range-of-motion measurements were made, and leg strength was measured. Mass was calculated from Barter's (1957) regression equations and the principal moments of inertia were calculated for the segments modeled as shapes similar to those of Hanavan (1964). As a result of this comparison, the authors concluded that the crash-victim model had sufficient accuracy to be used as an analytical tool.

Mathematical modeling depends on data that precisely define the geometric shape of each body segment. The present study is designed to develop data on the shape and mass distribution of each principal body segment as biological input data for biomechanical modeling.

Section III. METHODS AND TECHNIQUES

The methods and techniques used in this investigation were similar in many respects to those used in the previous study of the weight, volume, and center of mass of segments of the human body by Clauser et al. (1969). Changes necessitated by the current study, however, warrant a discussion of exactly how the subject material was selected and treated.

Because the availability of human cadavers in good overall condition is limited, the task of subject selection is difficult under the best of circumstances. The task of obtaining the best specimens possible for the investigation was accomplished through the full cooperation of the Health Sciences Center of the University of Oklahoma.

The guiding criterion in selecting the six male cadavers was their physical condition. Specimens that exhibited congenital anomalies, major surgical alterations, general or localized structural atrophy, excessive wasting, or obesity were not considered. The cause of death of one subject was listed as pulmonary embolism; death of all others was attributed to cardiovascular embarrassment.

Each of the six cadavers selected was weighed, its stature measured, and its Ponderal Index ($H/\sqrt[3]{W}$) calculated. The Ponderal Index and visual observations were used to select three pairs of specimens of similar body configuration (subjects 1 and

4, 2 and 5, 3 and 6). One member of each pair was treated as a standing subject (subjects 1, 2 and 3 approximating the anatomical position), the other as a seated subject in the inertial measurement procedures.

All cadavers had been embalmed by the gravity-flow method with a standard solution. Cadavers 1 and 6 had been stored for a period of time in vats of formaldehyde and subsequently placed in sealed bags and stored in a cold, dry environment. Cadavers 2, 3, 4, and 5 had been placed in plastic bags after embalming and stored in a cold, dry environment for at least 1 year. Each cadaver was X-rayed to detect gross joint anomalies. None was revealed. The specimens were shaved.

Next, a series of anthropometric measurements was taken. As landmarks are often difficult to locate accurately on a cadaver by palpation, fluoroscopy and X-ray were used to verify their locations.* The landmarks used are listed with a brief description of each in Appendix B. Each cadaver was measured in a supine position in a manner similar to that reported by Clauser _et al_. The 116 dimensions measured by using conventional anthropometric instruments and techniques are described in Appendix C.

After the anthropometry had been completed, planes of segmentation were established. The techniques of dismemberment

* For a general discussion of anatomical terminology, see Francis, Carl C., _Introduction to Human Anatomy_, Fifth edition. The C. V. Mosley Co:St. Louis 1968.

were similar to those described by Clauser et al. for the shoulder, wrist, ankle, elbow, hip, and knee for the standing cadavers (subjects 1, 2 and 3). These planes of segmentation are illustrated as roentgenographic tracings in Figures 9, 10, 11, 12a, 13a, and 14a. The plane of segmentation of the neck was radically different from that previously used and was employed to maintain continuity of the vertebral column as an integrated unit. In this approach, the neck is considered a functional part of the torso and thus separation of the head from the supporting neck structure is required. To accomplish this, a compound cut was made as opposed to the simple planar disarticulation of the other joints. The initial cut started on the posterior neck surface, continued anteriorly in a transverse plane to pass through the occipital condyles, and terminated at the anterior-superior surface of the first cervical vertebra. The second cut passed through the anterior neck surface, continued in a superior-posterior direction tangential to the mandibular angle surfaces, and terminated by intersecting the initial transverse plane cut. A roentgenographic tracing of this plane of segmentation is illustrated in Figure 15.

In order to treat half the sample in a seated position, modification of the planes of segmentation at the elbow, hip and knee joints was required. Dissecting out these joints to permit full range of joint motion and proper positioning (á la Harless and Dempster), was rejected because of the associated fluid and

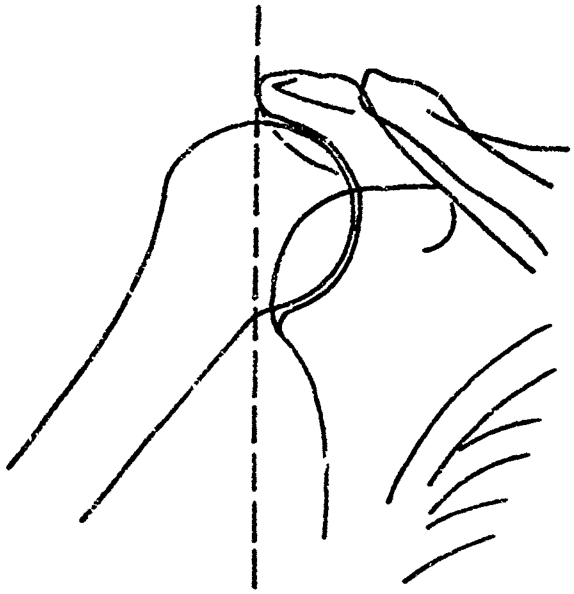


FIGURE 9. COMPOSITE TRACING FROM ROENTGENOGRAMS OF THE SHOULDER PLANES OF SEGMENTATION.

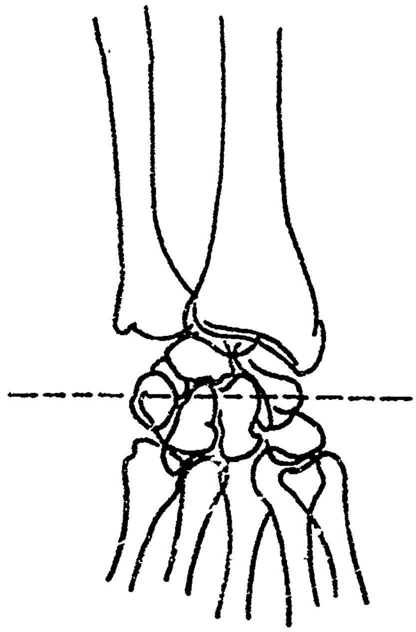


FIGURE 10. COMPOSITE TRACING FROM ROENTGENOGRAMS OF THE WRIST PLANES OF SEGMENTATION.

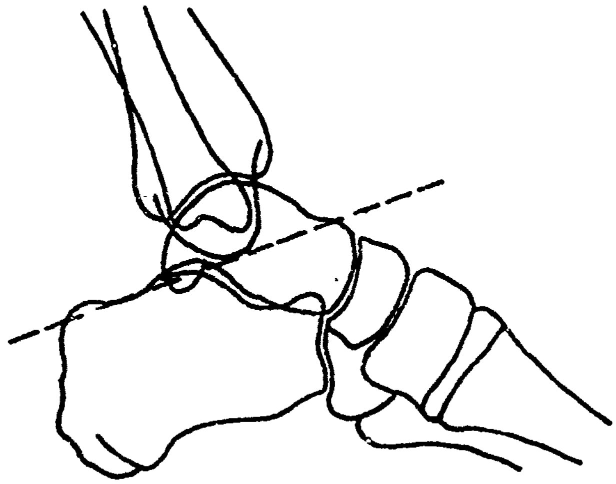


FIGURE 11. COMPOSITE TRACING FROM ROENTGENOGRAMS OF THE ANKLE PLANES OF SEGMENTATION.

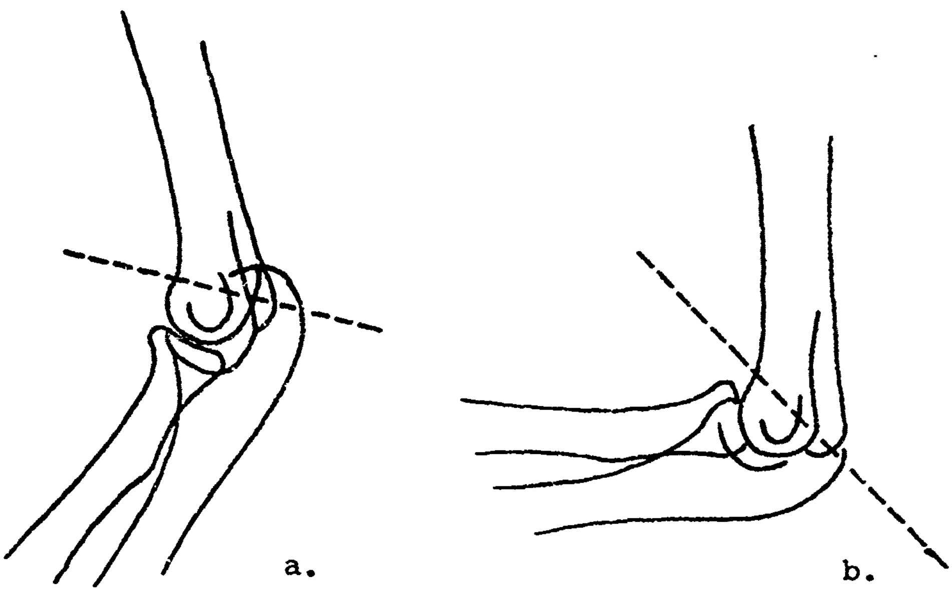


FIGURE 12. COMPOSITE TRACING FROM ROENTGENOGRAMS OF THE ELBOW PLANES OF SEGMENTATION (a) THE SPECIMEN STANDING WITH ELBOW EXTENDED, AND (b) THE SEATED SPECIMEN WITH ELBOW FLEXED.

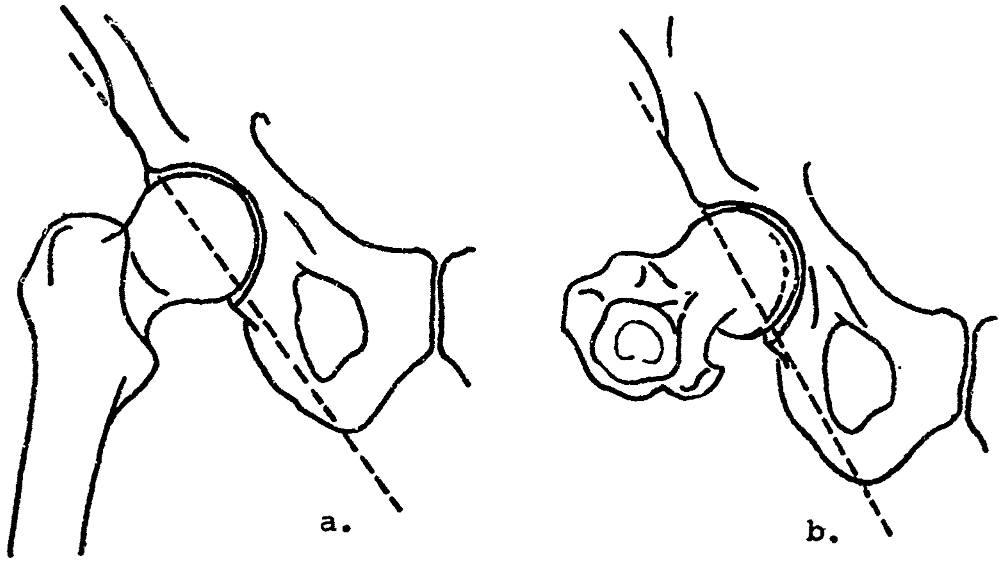


FIGURE 13. COMPOSITE TRACING FROM ROENTGENOGRAMS OF THE HIP PLANES OF SEGMENTATION OF (a) THE STANDING SPECIMEN, AND (b) THE SEATED SPECIMEN.

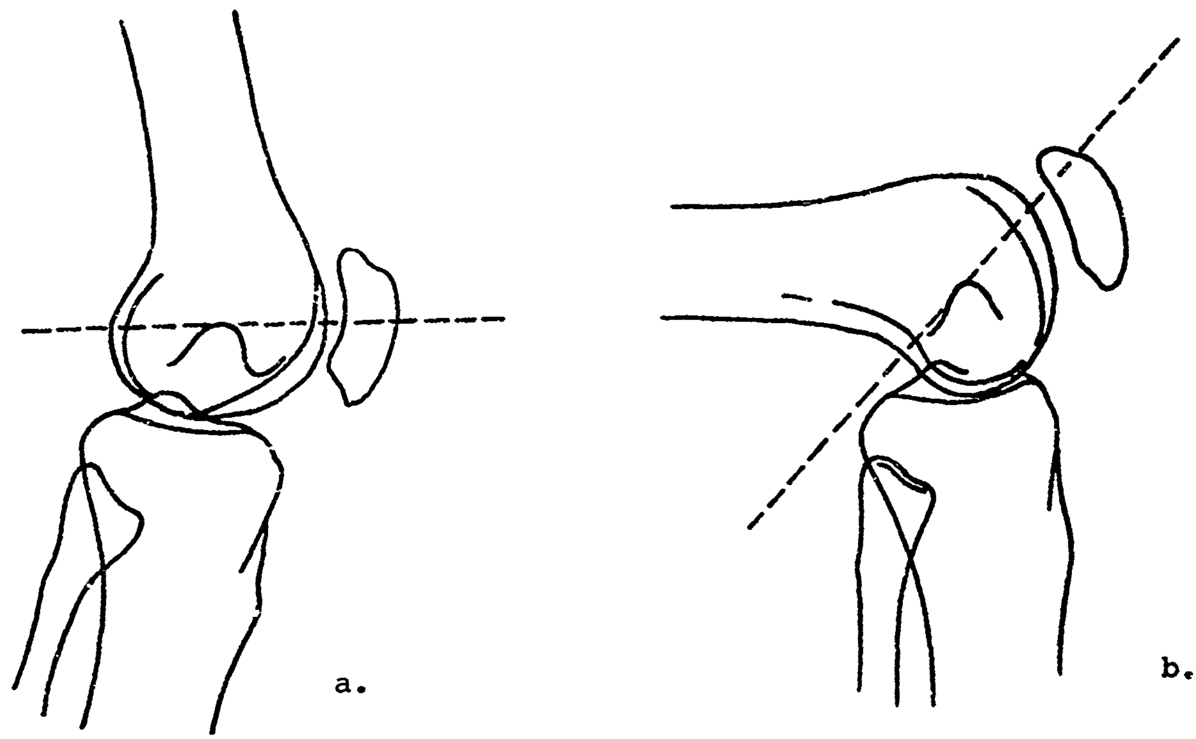


FIGURE 14. COMPOSITE TRACINGS FROM ROENTGENOGRAMS OF THE KNEE PLANES OF SEGMENTATION OF (a) THE STANDING SPECIMEN, AND (b) THE SEATED SPECIMEN.

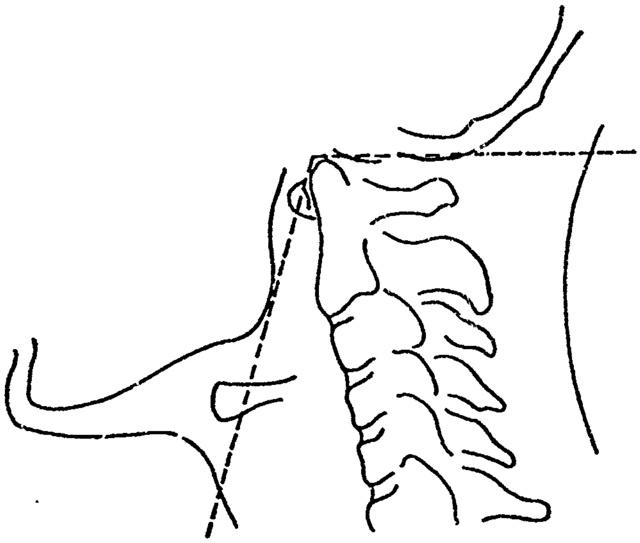


FIGURE 15. COMPOSITE TRACING FROM ROENTGENOGRAMS OF THE NECK PLANES OF SEGMENTATION.

tissue losses that would result. Limited joint movement was achieved, however, by extensive joint massage and manipulation, but the limbs would not remain in the desired position without the constant application of force. Therefore, the cadavers were strapped in an acceptable position to rigid boards. The use of the positioning boards with heavy-duty web straps allowed application of considerable tension to the various segments of the body to achieve segment orientation. The standing and seated positioning boards are illustrated in Figure 16. After positioning, planes of segmentation were established on the

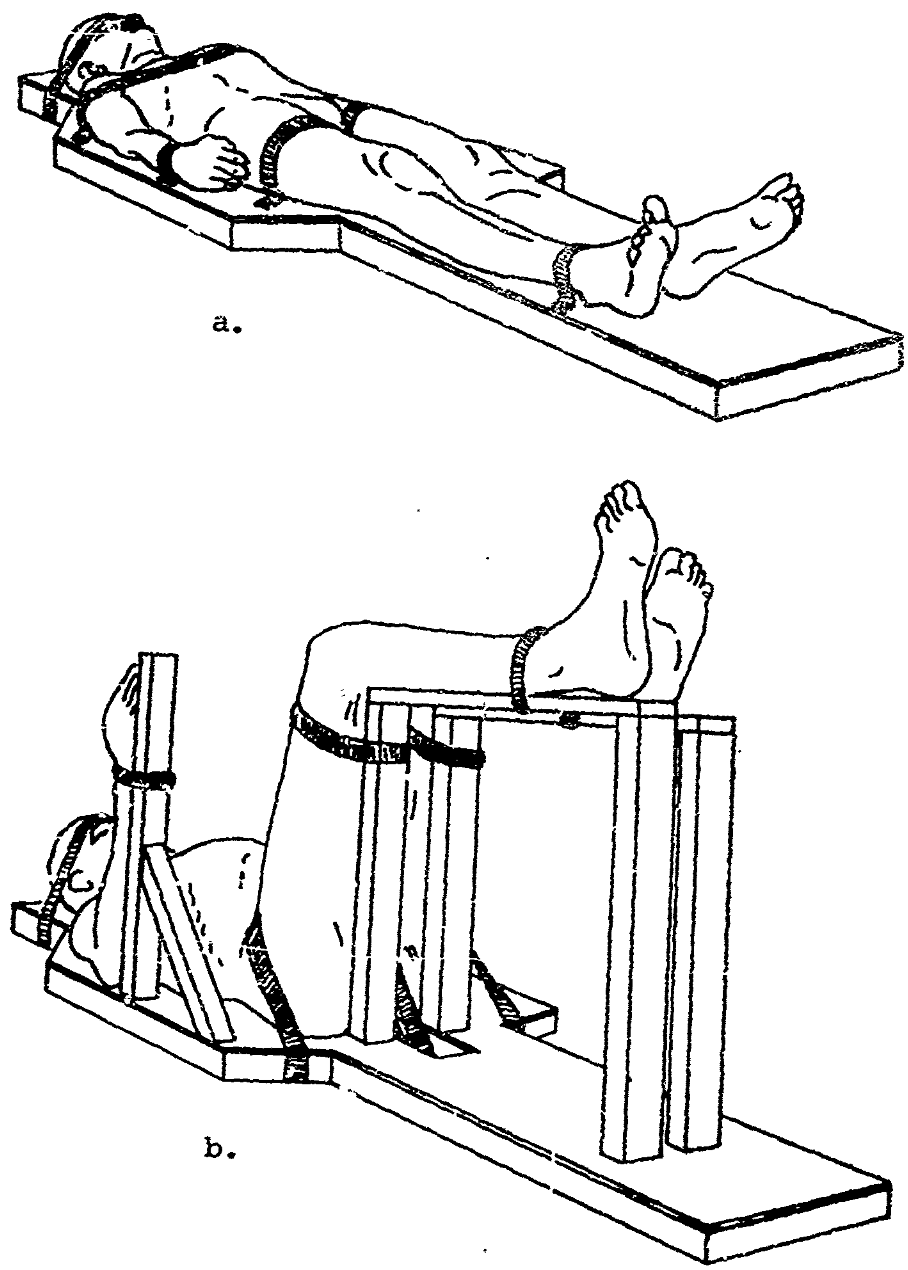


FIGURE 16. STANDING (a) AND SEATED (b) SPECIMEN POSITIONING BOARD WITH SPECIMEN IN PLACE.

flexed elbow (Figure 12b), hip (Figure 13b), and knee (Figure 14b) approximating those made on the extended joints with regard to the bony structure of the joints.

After placement or alignment of the specimens on the positioning board, the planes of segmentation were rechecked to insure that they passed approximately through a center of joint rotation. Three tick marks were then made on each segmentation line. The intersection of these tick marks with the segmentation line established three points that defined the location of the cut plane between two adjacent links in three-dimensional space. The positioning boards were then moved to an environmental chamber maintained at -29°C.

The subjects were frozen to form a rigid body for inertial body measurements and to retard fluid loss after segmentation. To reduce sublimation (Hower, 1970), all specimens were processed as quickly as possible and maintained in constant-temperature freezers. Weight loss was monitored repeatedly by weighing each specimen immediately after segmentation and then by periodically reweighing it throughout the course of the experiment.

After the cadavers were completely frozen, their orientation in three-dimensional space was documented. A whole-body 3-D anthropometer (Figure 17) was designed and fabricated to locate anthropometric and anatomical points in three dimensions. This instrument consisted of two graduated pointers mounted above (1) and below (2) the level of the positioning

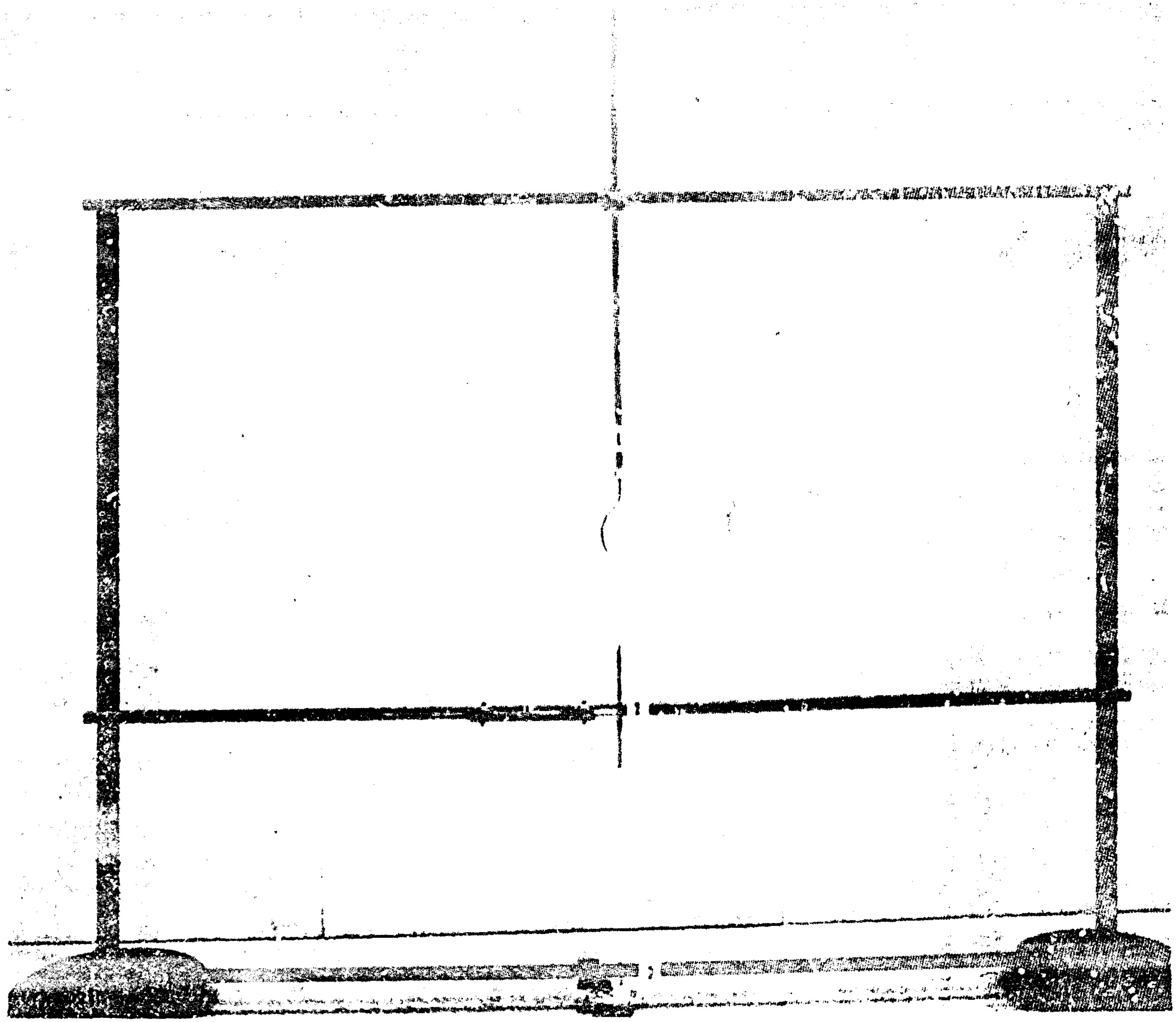


FIGURE 17. WHOLE-BODY 3-D ANTHROPOMETER.

board on a movable frame and a marking device (3) mounted at floor level in line with the two pointers. The procedure for using this device was to fix drawing velum to hardboard sheets on the floor beneath the specimen (which was held off the floor by the positioning board), move the pointer to a landmark on the specimen, and then transfer the point to the velum by use of the marker. The mark on the velum established the point in space with regard to the y- and z-planes of an external reference system and the level of the x-coordinate was read from the graduated pointers. This value was also noted on the velum so that the three coordinates for a landmark could be read or measured from the velum.

This procedure concluded the initial anatomical preparation of the specimens.

The next step was to measure the inertial properties of each intact cadaver. Calculation of the inertial tensor requires the mass, center of mass, and six moments of inertia about some point with a known spatial reference to the center of mass of the specimen.

Since each specimen to be measured was geometrically irregular and nonhomogeneous, an orthogonal axis system was established, external to the specimen, by the use of a specimen holder which defined the axis system.

Each of the specimen holders was in the form of a rectangular box made of 1-inch-thick styrofoam with tongue-and-groove construction. The top and sides of the box were glued together for additional rigidity, and the base of the box served as a platform to which each segment was mounted. When the segment was securely mounted, the base was taped to the box (Figure 18). This light, rigid specimen holder also afforded thermal isolation for the frozen specimen.

One corner of the specimen holder was designated as the origin of the measurement axis system and the swing axis was established with reference to it. This axis system is illustrated in Figure 19 with the six swing axes indicated in parentheses.

The specimen holder was designed to be suspended by two precisely positioned strings that acted as flexures for each swing axis.* For a specimen other than the total body, torso and thigh, the strings were attached directly to the appropriate box wall. The weight of a smaller segment did not deflect the styrofoam specimen holder to a significant degree, whereas the weight of the total body, torso or thigh produced a significant deformation of the box when the strings were attached to a wall. For each of these larger segments, the strings were attached directly to the specimen and the specimen holder was used as a horizontal spacer and locator for the string attachment points.

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* For a complete description of measurement methodology and techniques, see Reynolds, 1974.

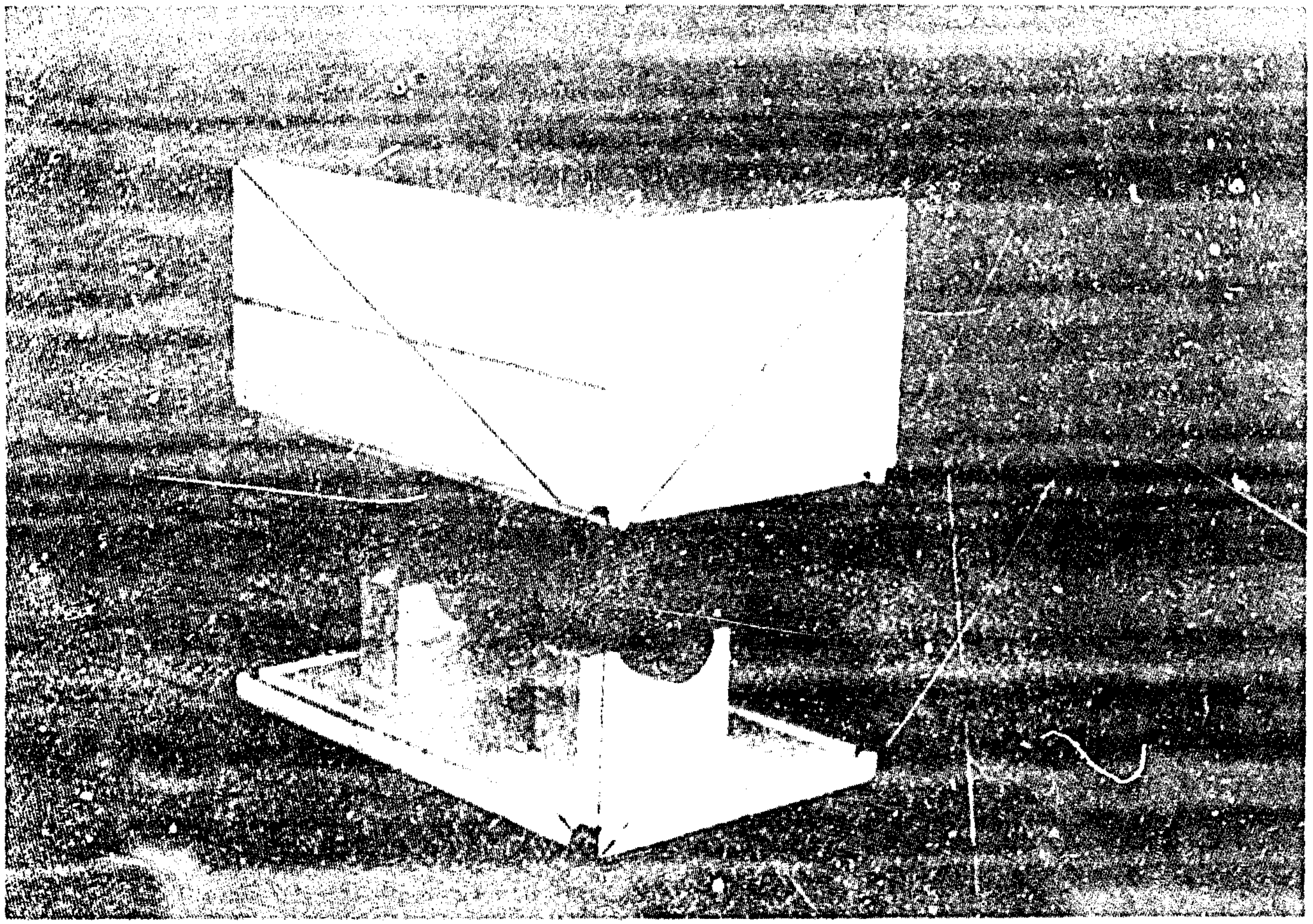

FIGURE 18. SPECIMEN HOLDER WITH MOUNTED SPECIMEN.

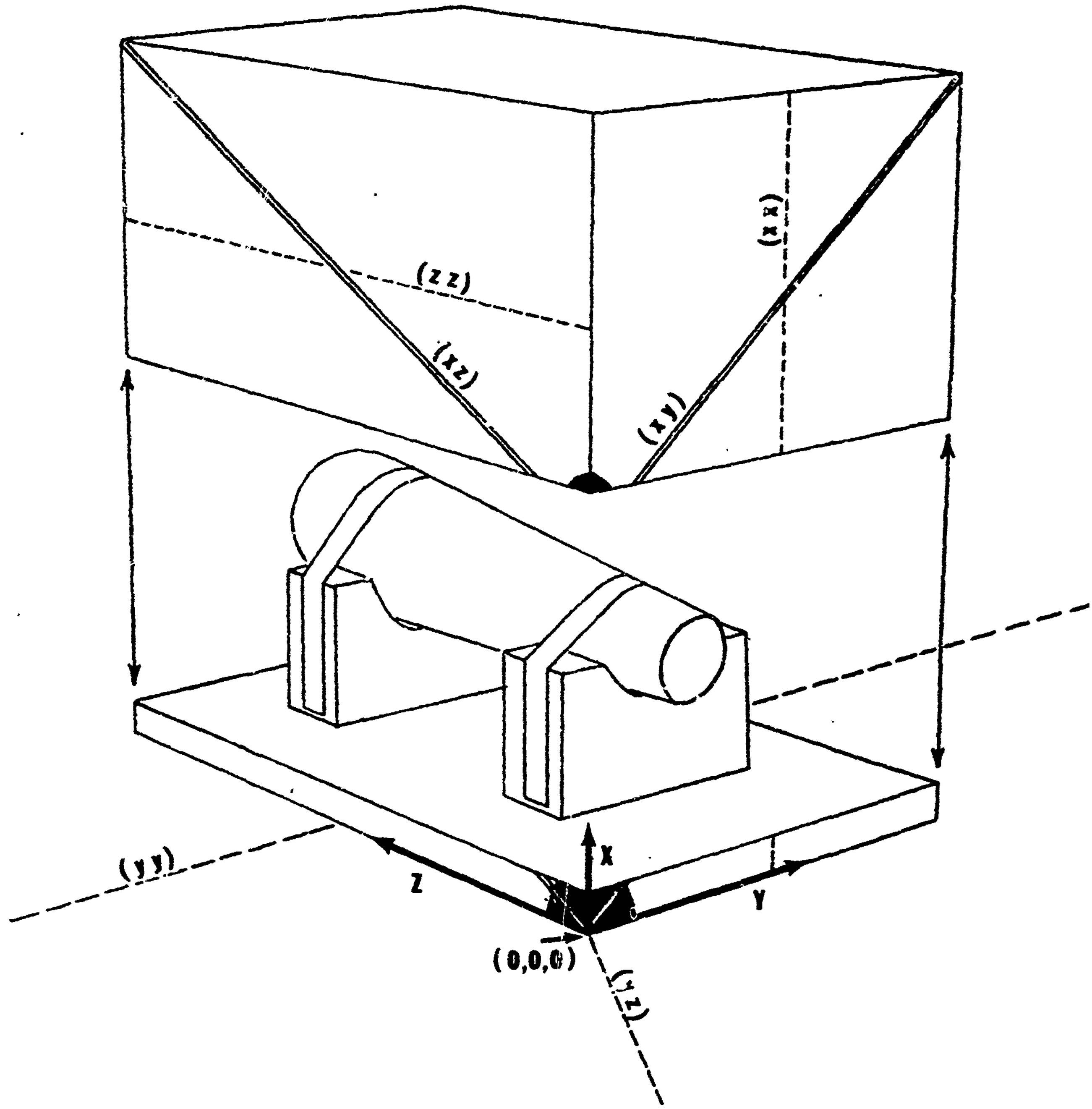

FIGURE 19. SPECIMEN HOLDER AND MEASUREMENT-AXIS SYSTEM. THE SIX SWING AXES ARE INDICATED WITH A TWO-LETTER DESIGNATION.

In all cases, the specimen holder was suspended from a rigid stand (Figure 20). Each string was passed through a clamp that formed a pivot about which the pendulum swung, and all clamps had been precisely aligned relative to the gravitational vector. Thus, as the box was swung in six axes, utilizing two clamp positions with respect to the horizontal direction, the specimen box remained within a three-dimensional orthogonal axis system (Figure 21).

To achieve the desired accuracy of measurement, it was necessary to limit the size and mass of the specimen holder relative to each biological specimen. This was accomplished by constructing specimen holders in various sizes so that for each specimen there would be a minimum-size holder. The mass, center of mass, and moments of inertia of each specimen holder were measured so that they could be subtracted from the composite (specimen plus specimen holder) measurements and calculations.

All the measurements, anatomical and biomechanical, were then made relative to the box reference axis system. Because any change in the specimen mass relative to the specimen holder during the measurement process would affect the results, it was necessary that movement be controlled. Internal movement in the specimen, either muscle-mass movement or fluid shift, was adequately controlled by freezing the specimen in a predetermined and described position. External movement

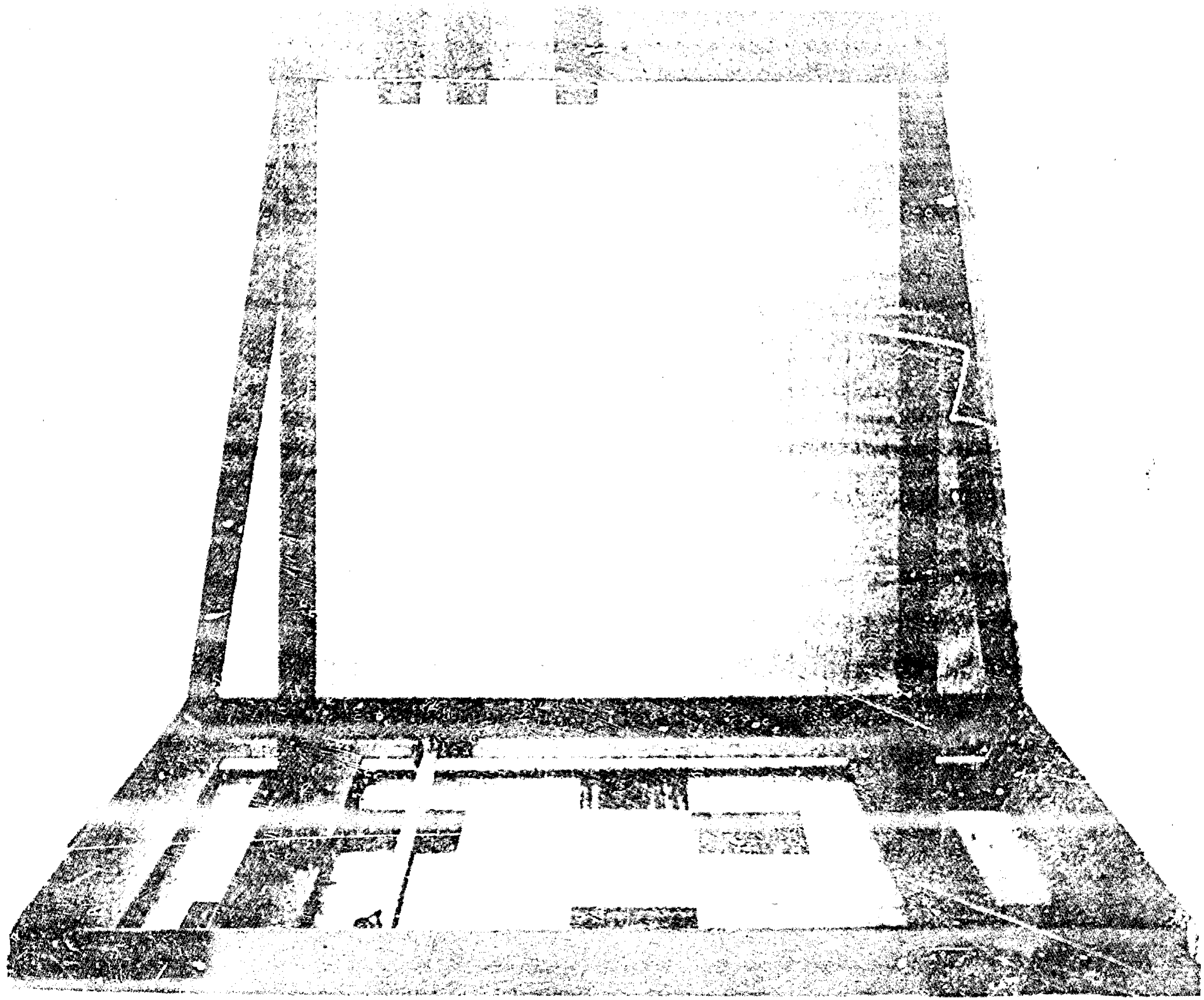

FIGURE 20. STAND FROM WHICH SPECIMEN HOLDERS WERE SWUNG.

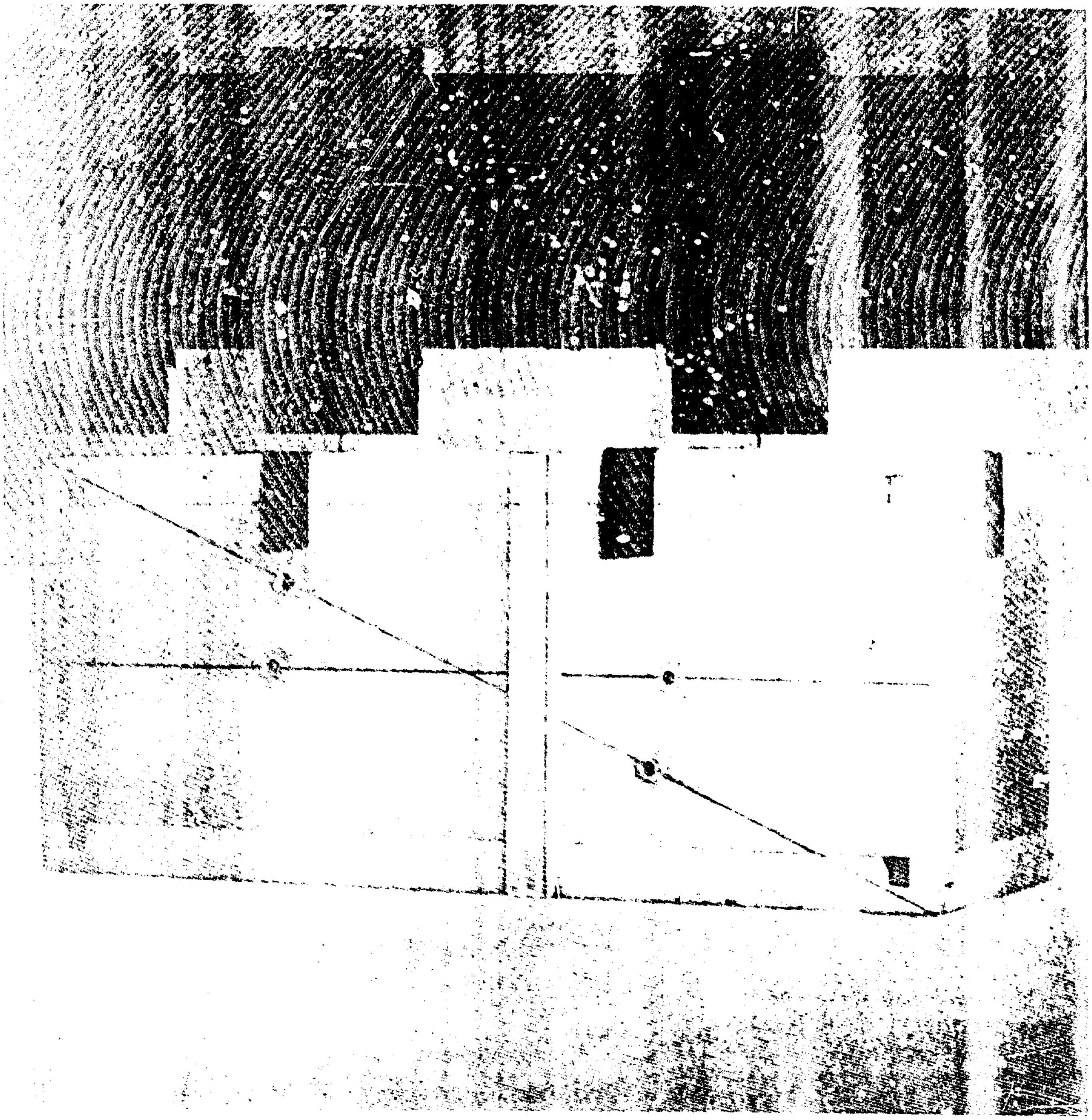

FIGURE 21. SPECIMEN HOLDER IN PLACE FOR MOMENT OF INERTIA MEASUREMENT (YZ AXES).

was controlled by securely mounting the specimen to the specimen holder.

The calculation of moments of inertia requires measurement of gravity, mass, the effective length of the pendulum, and the period of oscillation.

The gravitational constant was measured locally and found to be 978.8794 cm/sec^2.

Mass for the total body was measured on a platform balance graduated in 5-gram divisions and the segments on Mettler balances in hundredths or thousandths of a gram divisions.

The length of the pendulum was composed of two measures. The first component was the length of the flexure. The second component was the distance from the axis on the outer plane of the specimen holder to the center of mass of the empty holder or to the center of mass of the holder with the specimen mounted in place.

The distance to the center of mass of either the empty or composite specimen holder configuration from the swing axis was measured by a photographic suspension method (Eshbach, 1936; Reynolds, 1974).

The period of oscillation was timed by a Hewlett-Packard Universal Counter, Model 5325B. The counter was triggered manually for a period of 50 cycles of the pendulum. The period was measured twice for each swing axis by two observers and repeated until the time was reproduced between observers within 6 x 10^{-3} seconds and only after the total angular displacement of the swing was less than 10°.

These measures were then applied to appropriate equations discussed in the Introduction and the six moments of inertia and three products of inertia calculated.

An error analysis of the calculations for the moments of inertia was made, and accuracy limits for measurements of mass, pendulum length, and time established. Mass as measured by the appropriate Mettler balance for a particular segment produced negligible errors in the inertial measurements. The photographic system developed for measuring pendulum length, specifically the length from the specimen holder to the center of mass, measured length in three dimensions with an accuracy of ± 0.05 cm of the total pendulum length. Time, the period of oscillation for a single cycle, was calculated with an accuracy of 1.2 x 10^{-4} seconds based on an average of 50 cycles.

The inertial-measuring system was evaluated by using a solid aluminum bar, which was measured six times. The principal moments of inertia of a homogeneous parallelepiped with physical properties of 26.075 cm in length, 10.196 cm in width, 1.275 cm in depth, and 923.42 gm in weight are I_{xx}= 60319 gm-cm^2, I_{yy}= 52445 gm-cm^2, and I_{zz}= 8124 gm-cm^2. The results of the six measurements of the principal moments and their deviation from the theoretical values are shown in Table 2.

TABLE 2. DEVIATION OF THE MEASURED MOMENTS FROM THE THEORETICAL VALUES

	% I_{xx}	% I_{yy}	% I_{zz}
Trial 1	-1.5	-1.3	-5.6
2	-3.4	+3.1	+0.4
3	+2.1	-2.1	+3.8
4	-2.7	-0.3	-0.5
5	-0.3	-2.4	-0.9
6	-0.6	-2.2	-10.4
$\lvert\bar{X}\rvert$	$\lvert 1.77\rvert$	$\lvert 1.90\rvert$	$\lvert 3.61\rvert$

These results indicate that the system measures the principal moments of inertia with a reasonable degree of accuracy.

After the inertial measurements of the total body and each segment were made and before the specimen was removed from the specimen holder, another set of three-dimensional measurements was taken. Since the measurements of center of mass and moments of inertia utilized the specimen holder as an integral part of the measurement apparatus, spatial location of the specimen relative to the holder was necessary.

For the total body, the whole-body 3-D anthropometer previously described was used to locate the specimen in space with reference to the specimen holder axis system. For the segments, a simplified version of this device was fabricated. The segment 3-D anthropometer consisted of a pointer and a graduated bar mounted on a movable base (Figure 22). This measuring instrument utilized the basic concept of the whole-body 3-D anthropometer. The specimen holder base was located

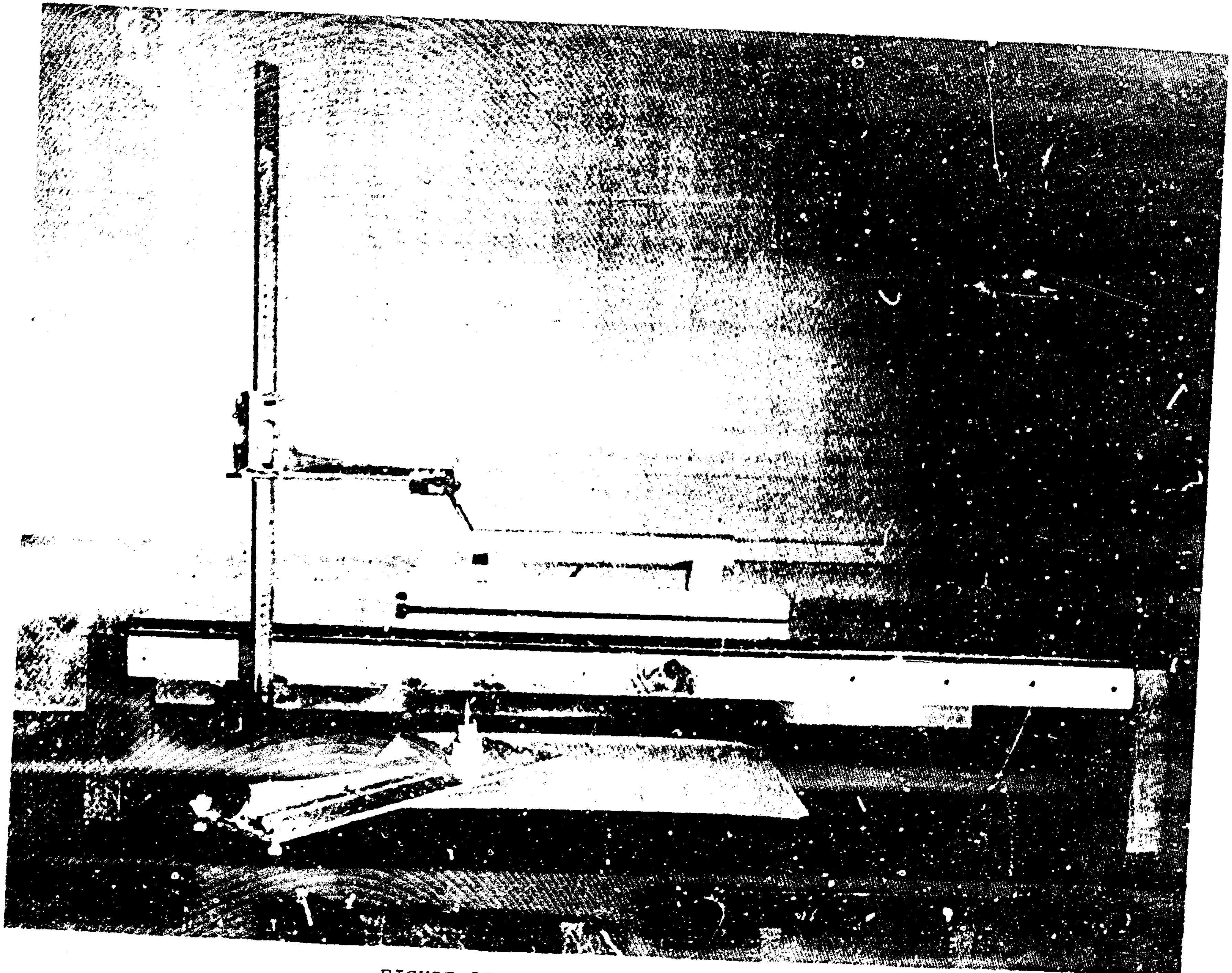

FIGURE 22. SEGMENT 3-D ANTHROPOMETER.

with reference to one specific corner (0,0,0), which represented the origin of the orthogonal axis system of all inertial measurements. All cut-plane tick marks, selected anatomical landmarks, segment orientation points and a center of joint rotation* on the cut bone surface were then located in this coordinate system. This procedure completed the inertial measurement sequence of the study.

The final step in the study was to measure the volume of each segment. Segment volume was measured by weighing the segments in a 30% alcohol solution cooled to -20°C (Figure 23).

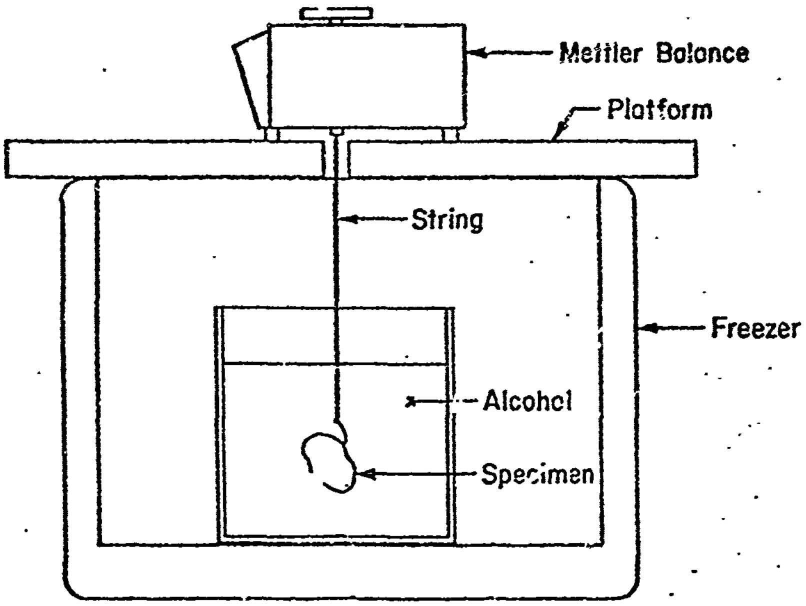

FIGURE 23. SCHEMATIC OF UNDER ALCOHOL WEIGHING DEVICE.

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* There is, of course, no single center of joint rotation. All planes of segmentation, except for the head, were selected to pass through an estimated location of the mean center of joint rotation. The centroid landmarks were located on each cut surface (plane of segmentation) at our estimated anatomical center of each joint.

The cooled solution kept the specimen from thawing and retarded the condensation of ice on the specimen. The volume was determined by the formula

$$V = \frac{W_{air} - W_{alcohol}}{D_{alcohol}} \tag{79}$$

where W_{air} was the weight in grams of the body segment, $W_{alcohol}$ was the weight of the body segment in the alcohol solution, and $D_{alcohol}$ was the density of the alcohol solution at -20°C.*

* Densities of the torsos of the cadavers are low and do not accurately reflect densities of torsos of the living which are corrected for residual lung volume and intestinal gas. Cadaver torsos contain large amounts of air in the thoracic and abdominal cavities owing to the collapse of organs.

Section IV. DATA SUMMARY

The results of this investigation are presented as a series of tables. The presentation and summary of the extensive series of observations and measurements made throughout the course of the study pose some difficulty because of the quantity of data. The data are organized so that the variables of primary interest to the majority of users are tabulated for each segment and for the whole body as individual pages. Additional data, conventional anthropometry (Appendix D), and three-dimensional anthropometry (Appendix E), are given separately for each specimen.

The two-page format of the data summaries in this section is identical for each segment. The top of the left-hand page lists the segment name followed by a sketch illustrating the segment axis system. This is not the measurement axis system described earlier (page 49) but one devised to relate the moments of inertia and their directional angles to the anatomical landmarks and center of mass of the segments. Though desirable, it was impractical within the scope of this study to establish an inertial axis system within which the total body and each segment could be located. An axis system was, therefore, defined relative to each segment. The axial systems described below were devised to permit a comparable alignment of the specimen for data presentation and summary. The segmental axis systems are right-hand orthogonal axes as follows:

1. Head. The y-axis was established as a line passing through the right and left tragion landmarks. The x-axis was established as a perpendicular to the y-axis originating from the mid-point of a line between the right and left infraorbitale landmarks. This aligned the heads in the Frankfort plane. The z-axis was established normal to the x- and y-axes.

2. Torso. The z-axis was established as a line passing through the proximal centroid (the center of the exposed spinal cord at the level of C-1) and the distal axis point (a point located on the perineum in the mid-sagittal plane). The x-axis was established as a perpendicular to the z-axis passing through the suprasternale landmark. The y-axis was normal to the x- and z-axes.

3. Upper Arm, Right and Left. The z-axis was established as a line passing through the proximal centroid (center of the exposed ball of the humerus) and the distal centroid (center of the exposed epicondyles of the humerus). The x-axis was established as a perpendicular to the z-axis passing through a mark made on the anterior surface of the biceps brachii at approximately midsegment. The y-axis was normal to the x- and z-axes.

4. Forearm, Right and Left. The z-axis was established as a line passing through the proximal centroid (a location like that of the distal centroid of the upper arm) and the distal centroid (the center of the cut surface of the capitate). The

x-axis was established as a perpendicular to the z-axis passing through a mark made on the lateral surface of the forearm at about midsegment. The y-axis was normal to the x- and z- axes. The forearms of these specimens were all in some degree of rotation from the anatomical position. The axis system for this segment was, therefore, the least anatomically consistent system.

5. Hand, Right and Left. The hands were in various "relaxed" positions--fingers curved with some thenar adduction. The z-axis was established as a line passing from the proximal centroid (like the distal centroid of the forearm) to a mark made on the dorsal surface at the distal end of the first phalanx of digit III. The x-axis was established as a perpendicular to the z-axis passing through metacarpale III. The y-axis was established normal to the x- and z-axes.

6. Thigh, Right and Left. The z-axis was established as a line passing through the proximal centroid (the center of the exposed head of the femur) and the distal centroid (the center of the exposed epicondyles of the femur just anterior to the intercondyloid fossa of the femur). The x-axis was established as a perpendicular to the z-axis passing through a mark made on the anterior surface of the thigh at about midsegment. The y-axis was normal to the x- and z-axes.

7. Calf, Right and Left. The z-axis was established as a line passing through the proximal centroid (a location like that of the distal centroid of the thigh) and the distal centroid

(the center of the exposed talus). The x-axis was established as a perpendicular passing through a mark made on the anterior surface of the calf at about midsegment. The y-axis was normal to the x- and z-axes.

8. Foot, Right and Left. The z-axis was established as a line passing through the heel point (a mark made on the posterior surface of the heel in line with the anterior point) and the anterior point (the tip of the second toe).* The x-axis was established as a perpendicular to the z-axis arising from a mark made on the dorsal surface of the foot. The y-axis was normal to the x- and z-axes.

9. Whole Body. The z-axis was established as a line through the vertex landmark parallel to the surface of the back plane. The x-axis was established as a perpendicular to the z-axis passing through the suprasternale landmark. The y-axis was normal to the x- and z-axes.

The data reported in this section are, therefore, the results obtained after the measured data had been rotated and transferred from the measurement axes system with its origin at one corner of the specimen holder base to the segment axes system with its origin at the center of mass of the segment.

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* The z-axis was purposefully established in a direction that is not consistent relative to the anatomical position of the other segments. It is felt that for modeling purposes, the z-axis consistently following the long axis of the segment would be most convenient.

Following the sketch illustrating the segmental axes system is a series of selected anthropometric dimensions for the segment. The principal moments of inertia are listed at the bottom of the page. The listings of the anthropometry and principal moments of inertia contain a tabulation of individual data values for each specimen as well as the means and standard deviations of the six specimens. <u>These data cannot be construed to reflect population parameters.</u> <u>It is not possible to reflect such parameters from the limited number of specimens examined in this study.</u>

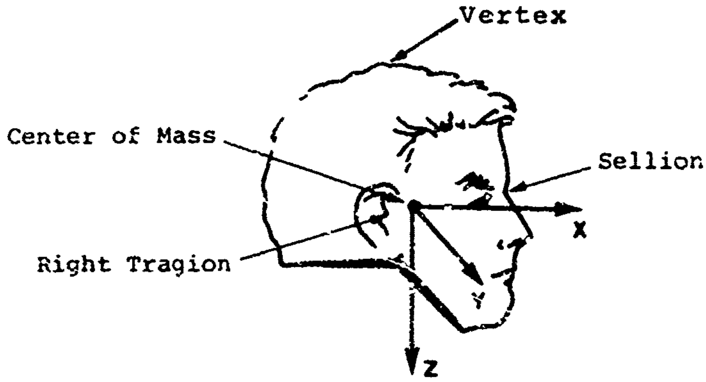
The right-hand page of the data summary is headed by a listing of the directional angles of the principal moments of inertia. The alpha, beta, and gamma values designate the deviations in degrees of the principal axes of the moments of inertia from the referenced segment axes system. The alpha value indicates the angular deviation from the x-axis, the beta value from the y-axis, and the gamma value from the z-axis. These data are, in general, more variable than anticipated and they are probably, in part, an artifact of the variability of the segmental axis system rather than solely a function of the variability of the mass distribution characteristics of the segments themselves. The torso (Table 4), for example, appears to have minimal variation in the directional angles of the principal moments. The axis system of the torso was developed relative to stable, well defined bony landmarks as opposed, for example, to the forearms which in addition to their inconsistent anatomical positions lack sufficient stable landmarks.

Following the listing of the directional angles are the x-, y-, and z-coordinates of selected landmark locations referenced from the center of mass. In Table 3, the Right Tragion landmark location for subject 1 is designated as x=0.4 cm, y=7.6 cm, and z=1.6 cm. This would indicate that with the head oriented in the segment axes system, the Right Tragion landmark is located 0.4 cm anteriorly, 7.6 cm laterally to the right, and 1.6 cm superiorly from the center of mass of the head. Conversely, when the direction signs of these coefficients are reversed, the center of mass can be specified with respect to the landmark. Below the landmark location coefficients are listed the link length (proximal to distal centroid) or the segment length (a centroid to a landmark or a landmark to a landmark) and the location of the center of mass as a ratio of this length. The center of mass, however, does not necessarily lie on the axis passing through the proximal and distal centroid points.

The last section of the data summary describes the relationships of total body weight with segment weights and principal moments of inertia and segment volumes with segment weight and principal moments of inertia. Correlation coefficients (r) and regression equations are given to document these relationships. These are given for the convenience of the reader, but, again, cannot be considered to reliably estimate population parameters.

The final table in this section (Table 17) provides similar but less complete data for the whole body of the six specimens.

TABLE 3. HEAD DATA



Anthropometry

Subject:	1	2	3	4	5	6	$\bar{X}$	SD
Weight (gm)	4025	4152	4821	3358	4105	3471	3958.3	483.0
Volume (ml)	3818	3973	4410	3199	3898	3413	3785.2	392.1
Density	1.055	1.046	1.096	1.052	1.055	1.030	1.056	.020
Head Circ (cm)	56.9	58.2	59.1	54.7	57.8	56.4	57.18	1.41
Head Length (cm)	20.0	20.7	20.9	19.2	20.1	23.4	20.72	1.32
Head Breadth (cm)	15.3	15.0	15.4	15.2	15.4	16.0	15.38	0.31
Menton to Vertex (cm)	23.1	24.2	22.4	22.3	25.0	21.8	23.13	1.13
Mastoid to Vertex (cm)	16.5	15.3	15.8	15.1	16.9	15.0	15.76	0.72

Principal Moments of Inertia (x 10^3 gm-cm^2)

Subject:	1	2	3	4	5	6	$\bar{X}$	SD
I_{xx}	181	141	251	133	152	167	170.8	42.8
I_{yy}	144	207	182	108	197	145	164.0	37.9
I_{zz}	207	232	277	146	231	112	200.8	61.2

Directional Angles of Principal Moments of Inertia (degrees)

	Subject:	1	2	3	4	5	6
I_{xx}	alpha	61	139	57	56	133	47
	beta	52	90	65	63	85	97
	gamma	129	132	137	134	13[illegible]	136
I_{yy}	alpha	144	131	144	141	135	105
	beta	88	100	88	91	110	160
	gamma	127	43	125	129	53	115
I_{zz}	alpha	110	97	103	107	102	133
	beta	38	10	24	26	20	75
	gamma	59	82	69	70	73	132

Landmark Locations from Center of Mass (cm)

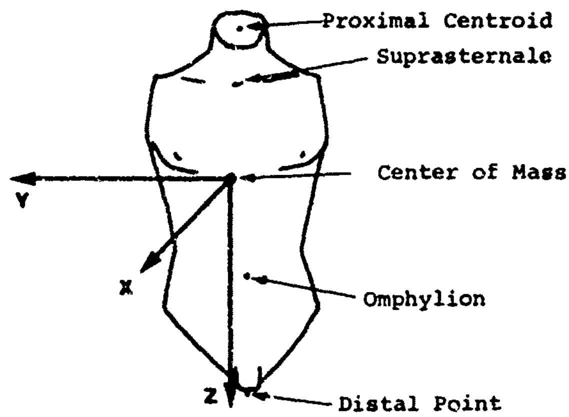
		1	2	3	4	5	6
Rt Tragion	x	0.4	-.4	-.9	0	0.4	-.2
	y	7.6	7.6	7.8	7.6	7.8	8.1
	z	1.6	2.4	2.1	2.8	2.7	2.3
Lt Tragion	x	0.4	-.4	-.9	0	0.4	-.2
	y	-7.2	-7.6	-7.8	-7.1	-7.3	-7.0
	z	1.6	2.4	2.1	2.8	2.7	2.8
Sellion	x	10.0	9.9	9.8	9.5	9.5	9.2
	y	0.2	-.2	0	-.4	0	0.5
	z	-.8	-.1	0	0.4	0.8	2.8
Segment Length		16.2	15.1	15.5	14.9	15.8	14.3
CM from Vertex		10.2	10.6	10.5	9.4	10.4	9.8
Ratio (%)		63	70	58	63	66	68

Regression Equations*

					r	$Se_{(est)}$
Segment Weight	=	0.032	Body Wt	+ 1,906	.873	288
" I_{xx}	=	2.129	" "	+ 32,030	.720	33,217
" I_{yy}	=	1.676	" "	+ 54,918	.639	32,598
" I_{zz}	=	3.186	" "	- 6,846	.753	45,033
Segment Weight	=	1.223	Seg Vol	- 639	.992	72
" I_{xx}	=	71.289	" "	- 99,078	.716	33,413
" I_{yy}	=	67.587	" "	- 91,812	.766	27,265
" I_{zz}	=	133.055	" "	-302,860	.934	24,479

* Weight in gm, moments in gm-cm², volume in ml

TABLE 4. TORSO DATA



Anthropometry

Subject:	1	2	3	4	5	6	$\overline{X}$	SD
Weight (gm)	30631	41060	46182	26928	28005	31262	33994.58	7123.58
Volume (ml)	36772	46301	50683	33887	33721	36487	39641.60	6488.70
Density	0.833	0.887	0.911	0.792	0.831	0.857	0.853	0.039
Torso Length (cm)	65.6	69.5	71.7	67.0	61.8	63.1	66.44	3.44
Chest Circ (cm)	94.0	101.4	105.5	83.1	89.5	93.2	94.45	7.37
Waist Circ (cm)	81.3	87.3	93.3	73.5	78.3	81.2	82.48	6.34
Buttock Circ (cm)	88.4	90.0	101.1	84.4	88.5	87.1	89.92	5.29
Chest Breadth (cm)	33.4	37.9	37.0	29.0	34.1	32.8	34.03	2.92
Buttock Breadth (cm)	33.5	34.6	37.6	33.0	36.5	33.8	34.83	1.67

Principal Moments of Inertia (x 10^3 gm-cm^2)

Subject:	1	2	3	4	5	6	$\overline{X}$	SD
I_{xx}	14436	20449	23142	13555	12464	13116	16,193.7	4,079.0
I_{yy}	9315	14320	18063	9022	6635	7902	10,876.3	4,004.4
I_{zz}	2643	5008	6194	2302	3022	3541	3,785.1	1,381.0

Directional Angles of Principal Moments of Inertia (degrees)

	Subject:	1	2	3	4	5	6
I_{xx}	alpha	39	42	35	39	47	48
	beta	129	132	125	130	137	138
	gamma	94	92	92	90	89	85
I_{yy}	alpha	52	48	56	51	44	42
	beta	39	42	35	40	47	48
	gamma	95	96	98	95	98	92
I_{zz}	alpha	85	84	84	87	85	93
	beta	88	86	85	86	83	85
	gamma	6	7	8	5	8	6

Landmark Locations from Center of Mass (cm)

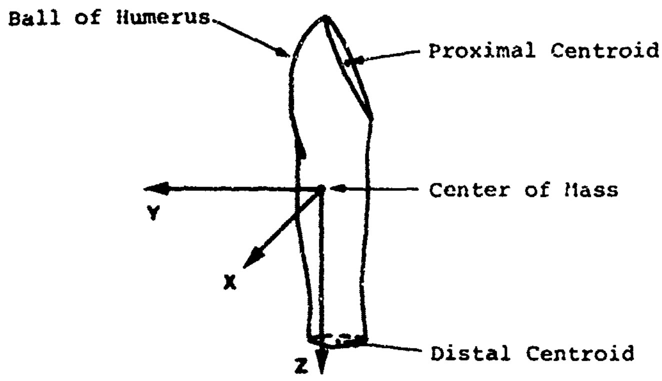
Suprasternale	x	12.5	11.9	12.8	14.0	12.0	15.4
	y	-.2	-.8	-.3	-.1	-1.5	-.9
	z	-20.6	-22.7	-22 6	-22.4	-19.7	-19.0
Omphylion	x	12.9	17.1	16.4	12.7	12.5	--
	y	-.7	-2.0	0.4	0.0	-.5	--
	z	12.6	16.0	15.5	11.6	10.9	--
Segment Lg		76.8	81.9	83.5	76.9	70.2	68.1
CM from PC		41.0	42.9	45.1	38.3	36.1	36.1
Ratio (%)		53	52	54	50	51	53

Regression Equations *

						<u>r</u>	$Se_{(est)}$
Segment Weight	=	0.532	Body Wt	-	706	.987	1,405
" I_{xx}	=	296.900	" "	-	3,156,034	.961	1,379,341
" I_{yy}	=	284.493	" "	-	7,664,880	.938	1,698,647
" I_{zz}	=	102.507	" "	-	2,895,524	.980	335,644
Segment Weight	=	1.095	Torso Vol	-	9,410	.997	637
" I_{xx}	=	621.812	" "	-	8,456,005	.989	733,465
" I_{yy}	=	601.400	" "	-	12,964,208	.974	1,100,518
" I_{zz}	=	205.205	" "	-	4,349,563	.964	448,759

* Weight in gm, moments in gm-cm^2, volume in ml

TABLE 5. UPPER ARM (RIGHT) DATA



Anthropometry

Subject:	1	2	3	4	5	6	$\bar{X}$	SD
Weight (gm)	1794	1941	2248	1538	1815	1719	1842.5	218.0
Volume (ml)	1782	1935	2298	1562	1788	1724	1848.2	229.4
Density	1.007	1.003	.981	.983	1.012	0.997	0.997	0.012
Acromial-Radiale Lg (cm)	33.1	35.2	33.7	33.8	31.5	32.4	33.28	1.16
Ball-Humerus-Rad Lg (cm)	30.6	31.8	31.1	32.1	28.3	29.2	30.52	1.36
Axillary Arm Circ (cm)	31.2	29.5	35.7	24.8	30.1	33.4	30.78	3.39
Biceps Circ (cm)	30.3	28.8	36.6	25.0	30.4	29.7	30.13	3.42
Elbow Circ (cm)	29.5	29.0	32.5	27.2	28.6	28.0	29.13	1.67
Elbow Breadth (cm)	7.0	7.1	8.9	7.8	7.2	8.2	7.70	0.68

Principal Moments of Inertia ($\times 10^3$ gm·cm^2)

Subject:	1	2	3	4	5	6	$\bar{X}$	SD
I_{xx}	136	122	158	136	120	125	133.0	12.9
I_{yy}	126	160	140	134	117	120	132.7	14.4
I_{zz}	20	21	34	16	22	19	22.0	5.9

Directional Angles of Principal Moments of Inertia (degrees)

	Subject:	1	2	3	4	5	6
I_{xx}	alpha	150	136	108	31	105	91
	beta	60	48	19	120	15	2
	gamma	85	79	84	93	88	88
I_{yy}	alpha	119	133	161	60	164	175
	beta	150	137	109	30	105	91
	gamma	86	88	86	90	87	85
I_{zz}	alpha	84	81	85	88	86	85
	beta	89	96	94	91	91	93
	gamma	6	11	7	2	4	6

Landmark Locations from Center of Mass (cm)

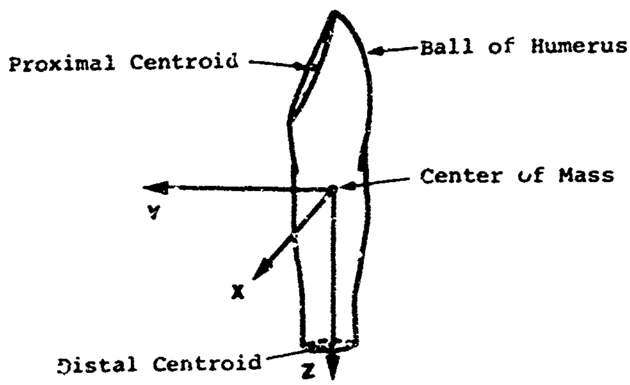
Ball of Humerus	x	0.2	-.6	0.5	-.8	1.0	1.8
	y	3.6	3.9	2.5	2.8	3.9	3.6
	z	-15.0	-16.0	-16.1	-14.1	[illegible]	-14.4
Proximal Centroid	x	1.3	0.8	1.2	1.5	1.5	1.9
	y	1.3	0.6	-.1	-.2	1.9	1.0
	z	-14.8	-14.6	-14.0	-14.3	-14.1	-14.4
Distal Centroid	x	1.3	0.8	1.2	1.5	1.5	1.9
	y	1.3	0.6	-.1	-.2	1.9	1.0
	z	14.2	13.9	12.8	15.6	13.0	13.7
Link Length		29.0	28.5	26.8	29.9	27.0	28.0
CM from PC		14.9	14.6	14.1	14.4	14.3	14.5
Ratio (%)		[illegible]	51	52	48	53	52

Regression Equations*

							$\underline{r}$	$Se_{(est)}$
Segment Weight	=	0.016	Body Wt		+	809	.960	74
" I_{xx}	=	0.535	"	"	+	98,150	.547	13,230
" I_{yy}	=	0.661	"	"	+	89,662	.607	13,979
" I_{zz}	=	0.400	"	"	-	4,018	.690	3,306
Segment Weight	=	0.946	Seg Vol		+	95	.995	27
" I_{xx}	=	34.736	"	"	+	68,833	.617	12,440
" I_{yy}	=	25.896	"	"	+	84,858	.413	16.021
" I_{zz}	=	25.080	"	"	-	24,303	.970	1,772

* Weight in gm, moments in gm-cm^2, volume in ml

TABLE 6. UPPER ARM (LEFT) DATA



Anthropometry

Subject:	1	2	3	4	5	6	$\bar{X}$	SD
Weight (gm)	1887	2103	2404	1536	1580	1819	1888.2	299.1
Volume (ml)	1824	2096	2436	1533	1562	1777	1871.2	313.9
Density	1.035	1.004	0.988	1.002	1.010	1.025	1.012	.015
Acromial-Radiale Lg (cm)	33.9	35.6	35.1	33.8	31.2	32.4	33.67	1.50
Ball of Humerus-Rad Lg (cm)	32.1	32.1	31.3	30.9	29.5	29.5	30.9	1.08
Axillary Arm Circ (cm)	29.7	31.1	35.4	25.0	30.4	31.5	30.52	3.06
Biceps Circ (cm)	29.6	30.0	34.9	26.2	28.8	30.0	29.92	2.58
Elbow Circ (cm)	27.6	29.3	30.8	27.1	26.0	28.3	28.18	1.55
Elbow Breadth (cm)	7.0	7.3	9.3	7.3	7.9	7.7	7.75	0.75

Principal Moments of Inertia (x 10^3 gm-cm^2)

Subject:	1	2	3	4	5	6	$\bar{X}$	SD
I_{xx}	146	191	198	141	105	132	152.1	32.5
I_{yy}	132	172	162	134	99	127	137.7	24.1
I_{zz}	23	27	37	12	17	22	22.8	7.9

Directional Angles of Principal Moments of Inertia (degrees)

Subject:		1	2	3	4	5	6
I_{xx}	alpha	113	102	162	148	86	74
	beta	157	168	107	122	176	163
	gamma	88	86	86	89	87	86
I_{yy}	alpha	23	13	72	58	5	16
	beta	112	102	163	148	86	74
	gamma	93	94	89	89	90	92
I_{zz}	alpha	86	85	87	90	90	88
	beta	89	87	88	88	87	86
	gamma	4	6	4	2	2	4

Landmark Locations from Center of Mass (cm)

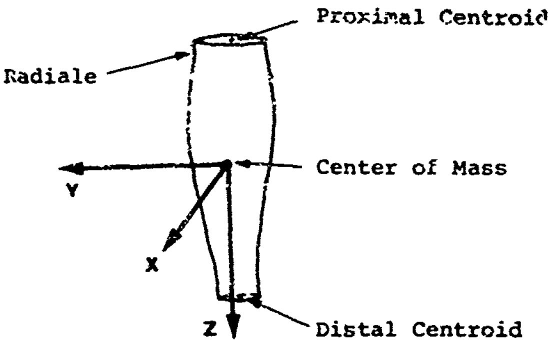
Ball of Humerus	x	1.4	-.4	-.7	2.2	-.6	2.2
	y	-3.9	-3.8	-3.6	-2.9	-3.0	-3.2
	z	-14.7	-15.1	-14.1	-15.9	-15.3	-14.4
Proximal Centroid	x	1.4	0.5	0.6	1.8	0.1	0.7
	y	-.6	-.6	0.2	-.4	-.8	0
	z	-14.4	-14.8	-14.5	-15.5	-14.1	-13.4
Distal Centroid	x	1.4	0.5	0.6	1.8	0.1	0.7
	y	-.6	-.6	0.2	-.4	-.8	0
	z	13.8	15.6	14.6	14.4	12.6	14.1
Link Length		28.2	30.5	29.1	29.8	26.7	27.6
CM from PC		14.4	14.9	14.5	15.6	14.1	13.4
Ratio (%)		51	49	50	52	53	49

Regression Equations*

						r	Se (est)
Segment Weight	=	0.022	Body	Wt	+ 485	.951	113
" I_{xx}	=	2.096	"	"	+15,569	.850	20,993
" I_{yy}	=	1.352	"	"	+49,572	.741	19,802
" I_{zz}	=	.567	"	"	-14,171	.947	3,105
Segment Weight	=	0.949	Seg	Vol	+ 112	.996	31
" I_{xx}	=	92.989	"	"	-21,864	.897	17,645
" I_{yy}	=	61.584	"	"	+22,465	.802	17,604
" I_{zz}	=	24.702	"	"	-23,429	.981	1,899

* Weight in gm, moments in gm cm^2, volume in ml

TABLF 7. FOREARM (RIGHT) DATA



Anthropometry

Subject:	1	2	3	4	5	6	$\bar{X}$	SD
Weight (gm)	971	1293	1624	796	1011	985	1113.2	271.1
Volume (ml)	914	1241	1556	754	948	957	1061.7	263.7
Density	1.061	1.017	1.035	1.051	1.066	1.029	1.043	0.018
Radiale-Stylion Lg (cm)	26.8	28.2	27.0	26.5	25.0	24.3	26.30	1.30
Elbow Circ (cm)	29.5	29.0	32.5	27.2	28.6	28.0	29.13	1.67
Forearm Circ (cm)	28.0	28.1	32.5	26.1	28.0	28.2	28.48	1.94
Wrist Circ (cm)	17.4	16.9	19.5	14.9	16.5	17.7	17.15	1.38
Wrist Breadth (cm)	5.5	6.0	6.2	6.0	6.1	6.3	6.02	0.25

Principal Moments of Inertia (x 10^3 gm·cm^2)

Subject:	1	2	3	4	5	6	$\bar{X}$	SD
I_{xx}	54	99	94	45	59	50	66.9	21.4
I_{yy}	52	94	90	45	55	51	64.5	19.7
I_{zz}	6	13	16	4	7	7	8.8	4.2

Directional Angles of Principal Moments of Inertia (degrees)

	Subject:	1	2	3	4	5	6
I_{xx}	alpha	31	155	97	110	145	62
	beta	120	114	7	20	125	28
	gamma	87	92	90	93	93	91
I_{yy}	alpha	59	65	173	159	55	152
	beta	31	154	97	109	145	62
	gamma	93	90	89	83	89	88
I_{zz}	alpha	91	92	88	85	93	87
	beta	85	91	89	84	91	90
	gamma	5	2	2	8	3	3

Landmark Locations from Center of Mass (cm)

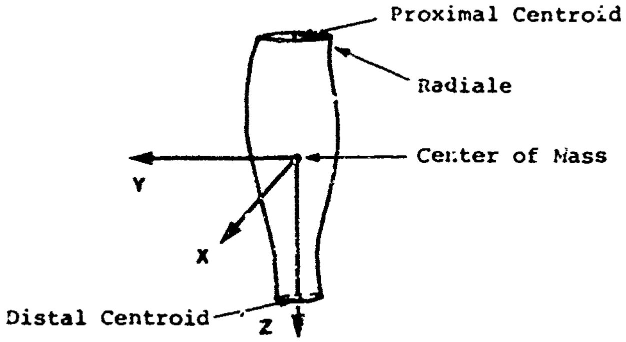
Proximal Centroid	x	-.1	0	0.4	0.6	0	0.1
	y	1.0	0	0.3	0.3	-.6	0.2
	z	-11.0	-12.0	-11.0	-9.9	-11.5	-10.0
Radiale	x	3.6	-4.1	-2.3	-3.3	-3.4	-3.2
	y	-1.0	1.9	-2.9	-.2	0.7	0.9
	z	-9.3	-10.0	-9.6	-10.2	-9.1	-9.3
Distal Centroid	x	-.1	0	0.4	0.6	0	0.1
	y	1.0	0	0.3	0.3	-.6	0.2
	z	14.2	17.6	15.7	15.6	15.1	15.0
Link Length		25.2	29.6	26.7	25.5	26.6	25.0
CM from PC		11.0	12.0	11.0	9.9	11.5	10.0
Ratio (%)		44	40	41	39	43	40

Regression Equations*

						r	$Se_{(est)}$
Segment Weight	= 0.020	Body Wt		-	218	.994	35
" I_{xx}	= 1.508	"	"		-31,431	.929	9,747
" I_{yy}	= 1.397	"	"		-26,562	.938	8,357
" I_{zz}	= 0.313	"	"		-11,645	.994	557
Segment Weight	= 1.027	Seg Vol		+	22	.999	14
" I_{xx}	= 73.143	"	"		-10,787	.899	11,494
" I_{yy}	= 67.817		"		- 7,531	.909	10,025
" I_{zz}	= 15.657	"	"		- 7,858	.992	631

* Weight in gm, moments in gm-cm^2, volume in ml

TABLE 8. FOREARM (LEFT) DATA



Anthropometry

Subject:	1	2	3	4	5	6	$\bar{X}$	SD
Weight (gm)	1002	1170	1418	839	957	1149	1088.8	185.4
Volume (ml)	916	1115	1370	789	903	1077	1028.2	188.0
Density	1.094	1.050	1.037	1.059	1.061	1.067	1.061	0.017
Radiale-Stylion Lg (cm)	25.7	28.2	25.2	26.5	25.5	24.5	25.93	1.18
Elbow Circ (cm)	27.6	29.3	30.8	27.1	26.0	28.3	28.18	1.55
Forearm Circ (cm)	24.4	28.2	31.5	26.1	26.1	28.5	27.47	2.27
Wrist Circ (cm)	16.7	16.7	18.6	15.4	16.0	18.5	16.98	1.19
Wrist Breadth (cm)	5.6	6.0	5.9	6.0	5.8	7.0	6.05	0.45

Principal Moments of Inertia (x 10^3 gm-cm^2)

Subject:	1	2	3	4	5	6	$\bar{X}$	SD
I_{xx}	67	80	75	49	54	64	64.7	10.6
I_{yy}	62	81	73	49	52	61	63.0	11.4
I_{zz}	6	11	14	5	6	9	8.6	3.2

Directional Angles of Principal Moments of Inertia (degrees)

	Subject:	1	2	3	4	5	6
I_{xx}	alpha	116	132	34	159	73	149
	beta	154	138	125	111	164	59
	gamma	90	88	90	93	90	95
I_{yy}	alpha	154	42	56	69	17	121
	beta	64	131	35	159	73	148
	gamma	94	85	87	88	85	85
I_{zz}	alpha	86	92	92	93	95	91
	beta	91	86	92	90	91	83
	gamma	176	4	2	4	5	7

Landmark Locations from Center of Mass (cm)

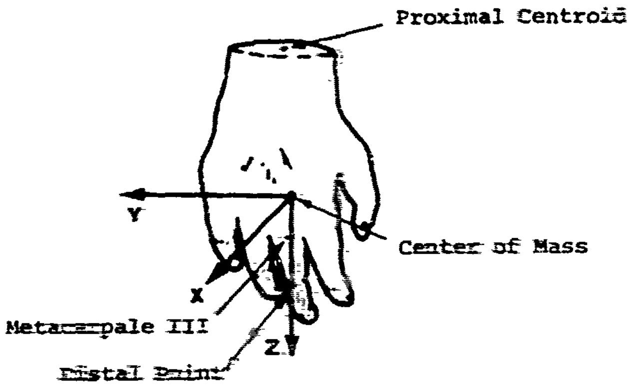
Proximal Centroid	x	0.7	0.1	0.1	0.4	-.5	-.8
	y	-.3	1.0	0.6	0.3	-.4	1.3
	z	-10.8	-12.2	-10.2	-10.3	-10.5	-11.5
Radiale	x	-2.8	-3.7	-3.9	-3.8	-4.3	-4.3
	y	-.8	1.2	-2.6	-.3	0	-.5
	z	-10.5	-11.0	-8.8	-9.6	-9.2	-9.6
Distal Centroid	x	0.7	0.1	0.1	0.4	-.5	-.8
	y	-.3	1.0	0.6	0.3	-.4	1.3
	z	15.9	17.2	14.7	15.1	14.8	14.5
Link Length		26.6	29.4	24.9	25.4	25.3	26.1
CM from PC		10.8	12.2	10.2	10.3	10.5	11.6
Ratio (%)		41	42	41	40	41	45

Regression Equations*

							r	$Se_{(est)}$
Segment Weight		=	0.013	Body	Wt	+ 246	.920	89
"	I_{xx}	=	0.659	"	"	+21,806	.819	7,478
"	I_{yy}	=	0.727	"	"	+15,672	.841	7,554
"	I_{zz}	=	0.230	"	"	- 6,[illegible]36	.943	1,311
Segment Weight		=	0.984	Seg	Vol	+ 77	.997	16
"	I_{xx}	=	44.578	"	"	+18,905	.789	8,004
"	I_{yy}	=	47.411	"	"	+14,283	.781	8,718
"	I_{zz}	=	16.949	"	"	- 8,856	.991	531

* Weight in gm, moments in gm-cm^2, volume in ml

TABLE 9. HAND (RIGHT) DATA



Anthropometry

Subject:	1	2	3	4	5	6	$\bar{X}$	SD
Weight (gm)	[illegible]	490	[illegible]	320	355	302	400.4	90.9
Volume (ml)	345	461	[illegible]	295	327	288	371.0	84.3
Density	[illegible]	1.062	1.087	1.077	1.088	1.056	1.079	0.017
Stylion-Meta III Lg (cm)	[illegible]	8.7	9.2	8.0	8.1	8.0	8.33	0.46
Hand Circ (cm)	[illegible]	23.1	24.1	20.0	20.0	20.2	21.38	1.62
Hand Breadth (cm)	[illegible]	9.5	9.5	8.4	8.2	8.3	8.68	0.58

Principal Moments of Inertia (x 10^3 gm-cm^2)

Subject:	1	2	3	4	5	6	$\bar{X}$	SD
I_{xx}	6.7	10.1	10.3	7.0	7.0	4.1	7.54	2.14
I_{yy}	5.7	9.0	8.8	4.8	5.2	3.6	6.15	2.02
I_{zz}	1.7	3.9	3.9	1.6	1.0	0.9	2.15	1.27

Directional Angles of Principal Moments of Inertia (degrees)

Subject:		1	2	3	4	5	6
I_{xx}	alpha	20	19	151	32	35	49
	beta	108	108	62	58	58	135
	gamma	81	84	89	86	77	74
I_{yy}	alpha	74	73	118	121	123	54
	beta	18	18	150	31	33	45
	gamma	82	86	100	93	88	67
I_{zz}	alpha	101	97	95	95	101	118
	beta	95	92	99	89	99	95
	gamma	12	7	10	4	14	28

Landmark Locations from Center of Mass (cm)

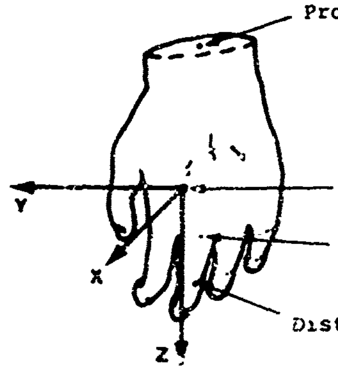
Proximal Centroid	x	0.5	0.6	-.1	0.6	0.5	0.5
	y	0.2	0.4	1.1	1.1	0.8	-.3
	z	-6.2	-6.6	-6.2	-6.1	-6.5	-5.7
Meta III	x	3.3	4.1	2.7	2.1	3.1	2.9
	y	0.2	0.4	1.1	1.1	0.8	-.3
	z	1.7	1.1	3.0	1.9	1.4	0.9
Distal Point	x	0.5	0.6	-.1	0.6	0.5	0.5
	y	0.2	0.4	1.1	1.1	0.8	-.3
	z	6.1	5.6	6.8	7.0	6.0	4.1
Proximal to Distal Point		12.3	12.2	13.0	13.1	12.5	9.8
CM from PC		6.2	6.7	6.3	6.3	6.5	5.7
Ratio (%)		50	54	49	48	52	59

Regression Equations*

						r	$Se_{(est)}$
Segment Weight	=	0.007	Body Wt	-	30	.959	32
" I_{xx}	=	0.129	" "	-	850	.795	1,590
" I_{yy}	=	0.134	" "	-	2,599	.880	1,174
" I_{zz}	=	0.085	" "	-	3,401	.889	711
Segment Weight	=	1.077	Seg Vol	+	1	.997	8
" I_{xx}	=	23.160	" "	-	1,051	.912	1,074
" I_{yy}	=	23.173	" "	-	2,443	.968	616
" I_{zz}	=	14.349	" "	-	3,172	.955	461

* Weight in gm, moments in gm·cm^2, volume in ml

TABLE 10. HAND (LEFT) DATA



Anthropometry

Subject:	1	2	3	4	5	6	$\bar{X}$	SD
Weight (gm)	324	409	497	328	351	332	373.7	62.1
Volume (ml)	298	383	463	305	325	302	346.1	59.8
Density	1.091	1.068	1.072	1.075	1.080	1.098	1.081	0.011
Stylion-Meta III Lg (cm)	7.9	8.5	9.2	7.2	7.9	7.6	8.05	0.64
Hand Circ (cm)	20.7	22.3	22.4	21.3	19.5	20.5	21.12	1.02
Hand Breadth (cm)	8.0	9.1	9.3	8.3	7.9	8.0	8.43	0.56

Principal Moments of Inertia (x 10^3 gm-cm^2)

Subject	1	2	3	4	5	6	$\bar{X}$	SD
I_{xx}	5.3	7.6	9.3	7.1	6.2	5.6	6.88	1.36
I_{yy}	4.5	7.5	7.7	5.1	4.9	3.7	5.57	1.51
I_{zz}	1.6	1.2	3.2	2.1	1.5	1.1	1.79	0.70

Directional Angles of Principal Moments of Inertia (degrees)

Subject:		1	2	3	4	5	#6
I_{xx}	alpha	55	13	176	19	39	5
	beta	40	98	86	71	52	90
	gamma	74	80	95	91	86	84
I_{yy}	alpha	139	84	94	109	127	91
	beta	51	11	176	19	39	7
	gamma	100	85	90	93	99	84
I_{zz}	alpha	108	100	95	91	99	96
	beta	96	94	90	87	85	96
	gamma	19	11	4	4	11	9

Landmark Locations from Center of Mass (cm)

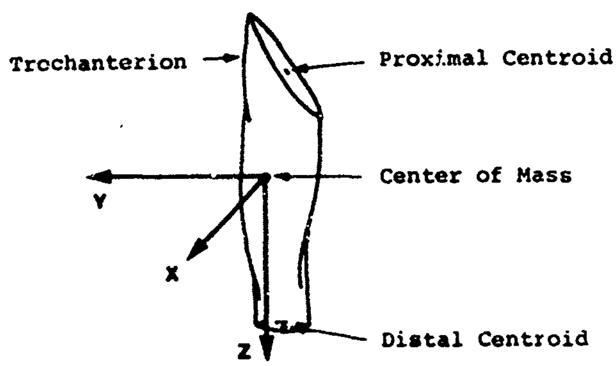
Proximal Centroid	x	0.7	0.9	0.6	0.4	0.4	0.3
	y	-.8	-.3	-.3	-.9	-.7	-.6
	z	-5.7	-6.6	-6.3	-6.4	-6.2	-5.7
Meta III	x	2.8	3.7	2.7	3.2	3.4	3.2
	y	-.8	-.3	-.3	-.9	-.7	-.6
	z	2.2	1.3	2.1	1.0	1.0	1.4
Distal Point	x	0.7	0.9	0.6	0.4	0.4	0.3
	y	-.8	-.3	-.3	-.9	-.7	-.6
	z	4.0	6.3	6.9	6.5	6.3	6.1
Proximal to Distal Point		9.7	13.0	13.2	12.8	12.4	11.8
CM from PC		5.8	6.7	6.4	6.4	6.2	5.8
Ratio (%)		60	52	48	50	50	49

Regression Equations*

							r	Se(est)
Segment Weight	=	0.005	Body Wt	+	76		.967	19
" I_{xx}	=	0.083	" "	+	1,437		.808	983
" I_{yy}	=	0.100	" "	-	920		.869	918
" I_{zz}	=	0.028	" "	-	6		.520	734
Segment Weight	=	1.039	Seg Vol	+	14		.999	3
" I_{xx}	=	21.015	" "	-	397		.923	644
" I_{yy}	=	22.895	" "	-	2,354		.905	787
" I_{zz}	=	7.802	" "	-	908		.666	641

* Weight in gm, moments in gm-cm^2, volume in ml

TABLE 11. THIGH (RIGHT) DATA



Anthropometry

Subject:	1	2	3	4*	5	6	$\bar{X}$	SD
Weight (cm)	5601	7294	9770	4133*	6812	5532	6523.3	1768.4
Volume (ml)	5518	7180	9567	4014	6673	5575	6420.9	1725.4
Density	1.021	1.016	1.021	1.034	1.022	0.995	1.018	0.012
Thigh Length (cm)	44.8	49.4	44.0	48.6	44.1	44.0	45.82	2.50
Upper Thigh Circ (cm)	46.0	48.2	59.0	42.3	49.3	49.2	49.0	5.08
Mid-Thigh Circ (cm)	37.8	44.0	54.5	34.2	44.9	43.0	43.07	6.34
Knee Circ (cm)	36.7	37.2	39.3	34.8	38.1	36.1	37.03	1.43
Knee Breadth (cm)	10.1	10.5	12.1	10.0	10.8	10.5	10.67	0.69

Principal Moments of Inertia (x 10^3 gm cm^2)

Subject:	1	2	3	4*	5	6	$\bar{X}$	SD
I_{xx}	1034	1341	1720	663*	1190	876	1137.3	338.8
I_{yy}	1086	1429	1604	683*	1307	839	1157.9	323.3
I_{zz}	171	191	520	68*	206	193	224.9	139.6

* These values appear to be erroneous, but they are reported for completeness of the data.

Directional Angles of Principal Moments of Inertia (degrees)

	Subject:	1	2	3	4	5	6
I_{xx}	alpha	12	45	41	34	10	47
	beta	101	134	49	123	79	136
	gamma	95	94	92	95	91	99
I_{yy}	alpha	79	46	131	57	101	46
	beta	14	44	41	33	13	46
	gamma	84	90	87	86	83	91
I_{zz}	alpha	87	87	87	88	88	83
	beta	98	92	91	96	96	96
	gamma	8	2	3	6	7	9

Landmark Locations from Center of Mass (cm)

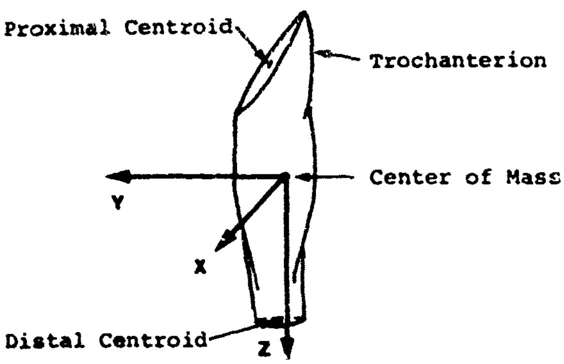
		1	2	3	4	5	6
Proximal Centroid	x	1.1	0.8	1.2	2.2	0.1	0.7
	y	-1.9	-1.3	-1.0	-2.0	-2.0	-.7
	z	-16.7	-18.1	-16.9	-13.6	-14.8	-13.6
Trochanterion	x	3.2	4.1	0.2	4.2	5.7	2.0
	y	5.6	6.9	8.3	4.9	6.2	8.0
	z	-16.1	-18.3	-15.7	-16.1	-15.3	-18.9
Distal Centroid	x	1.1	0.8	1.2	2.2	0.1	0.7
	y	-1.9	-1.3	-1.0	-2.0	-2.0	-.7
	z	24.7	26.3	24.3	24.8	26.2	23.3
Link Length		41.4	44.4	41.2	38.4	41.0	37.0
CM from PC		16.9	18.2	17.0	13.9	15.0	13.7
Ratio (%)		41	41	41	36	37	37

Regression Equations*

								r	$Se_{(est)}$
Segment	Weight	=	0.126	Body	Wt	-	1,688	.941	734
"	I_{xx}	=	24.102	"	"	-	433,522	.939	142,340
"	I_{yy}	=	21.186	"	"	-	222,796	.865	198,494
"	I_{zz}	=	9.262	"	"	-	378,738	.876	82,545
Segment	Weight	=	1.024	Seg	Vol	-	54	.999	75
"	I_{xx}	=	193.702	"	"	-	106,453	.986	68,137
"	I_{yy}	=	174.924	"	"	+	34,777	.934	141,955
"	I_{zz}	=	75.608	"	"	-	260,549	.934	61,027

* Weight in gm, moments in gm-cm^2, volume in ml

TABLE 12. THIGH (LEFT) DATA



Anthropometry

Subject:	1	2	3	4	5	6	$\bar{X}$	SD
Weight (gm)	5839	8082	9899	5008	6090	5733	6775.1	1684.3
Volume (ml)	5646	7989	9711	4899	6096	5530	6645.0	1673.3
Density	1.035	1.013	1.020	1.017	1.001	1.038	1.021	0.012
Thigh Length (cm)	45.1	49.1	44.8	47.1	44.2	41.9	45.37	2.48
Upper Thigh Length (cm)	47.3	50.5	58.0	39.9	46.4	48.7	48.47	5.39
Mid-Thigh Length (cm)	37.5	46.0	55.5	33.4	43.2	41.6	42.53	6.36
Knee Circ (cm)	36.5	36.8	40.1	34.1	36.5	34.4	36.42	1.97
Knee Breadth (cm)	9.9	10.5	12.0	10.2	11.0	10.2	10.63	0.70

Principal Moments of Inertia (x 10^3 gm-cm^2)

Subject:	1	2	3	4	5	6	$\bar{X}$	SD
I_{xx}	964	1490	1620	1049	929	857	1151.4	293.2
I_{yy}	942	1651	1751	1120	972	892	1221.2	347.4
I_{zz}	132	247	358	138	197	203	212.5	76.2

Directional Angles of Principal Moments of Inertia (degrees)

	Subject:	1	2	3	4	5	6
I_{xx}	alpha	107	25	17	15	135	135
	beta	19	114	107	106	45	45
	gamma	100	88	86	89	93	87
I_{yy}	alpha	163	65	73	75	135	135
	beta	107	26	20	17	135	135
	gamma	89	100	100	98	88	84
I_{zz}	alpha	91	88	90	88	92	83
	beta	81	80	79	81	87	87
	gamma	10	11	11	9	4	8

Landmark Locations from Center of Mass (cm)

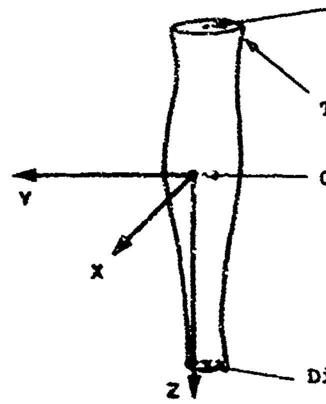
Proximal Centroid	x	0.7	0.8	0.7	1.4	1.6	0.6
	y	1.2	1.0	1.2	2.2	2.3	1.0
	z	-17.2	-18.2	-16.7	-16.4	-14.0	-14.4
Trochanterion	x	3.0	-.2	3.2	3.5	5.7	-.4
	y	-6.7	-7.9	-7.3	-6.8	-6.0	-6.4
	z	-16.8	-18.4	-15.4	-15.9	-15.7	-17.8
Distal Centroid	x	0.7	0.8	0.7	1.4	1.6	0.6
	y	1.2	1.0	1.2	2.2	2.3	1.0
	z	2[illegible].2	26.2	24.3	28.0	23.4	22.7
Link Length		40.5	44.4	41.0	44.4	37.4	37.1
CM from PC		17.3	18.3	16.7	16.6	14.3	14.5
Ratio (%)		43	41	41	37	38	39

Regression Equations*

								r	$Se_{(est)}$
Segment Weight		=	0.127	Body Wt		- 1,511		.997	106
"	I_{xx}	=	20.310	"	"	-172,235		.915	145,022
"	I_{yy}	=	23.633	"		-319,070		.898	186,889
"	I_{zz}	=	5.404	"	"	-139,702		.937	32,621
Segment Weight		=	1.006	Seg Vol		+ 93		.999	90
"	I_{xx}	=	161.212	"	"	+ 80,151		.920	140,573
"	I_{yy}	=	188.229	"	"	- 29,614		.907	179,449
"	I_{zz}	=	43.021	"	"	- 73,388		.945	30,472

* Weight in gm, moments in gm-cm^2, volume in ml

TABLE 13. CALF (RIGHT) DATA



Anthropometry

Subject:	1	2	3	4	5	6	$\bar{X}$	SD
Weight (gm)	2182	2876	3779	2251	2744	2282	2685.7	553.9
Volume (ml)	2056	2727	3522	2140	2596	2161	2533.5	506.5
Density	1.062	1.054	1.073	1.052	1.057	1.057	1.059	0.007
Calf Length (cm)	34.4	40.5	36.8	38.2	38.5	36.8	37.53	1.87
Knee Circ (cm)	36.7	37.2	39.3	34.8	38.1	36.1	37.03	1.43
Calf Circ (cm)	28.6	31.0	38.5	27.4	31.7	30.7	31.32	3.53
Ankle Circ (cm)	19.4	21.0	22.5	19.5	20.5	20.4	20.55	1.04
Ankle Breadth (cm)	6.8	7.2	7.8	6.6	6.9	6.9	7.03	0.39

Principal Moments of Inertia (x 10^3 gm-cm^2)

Subject:	1	2	3	4	5	6	$\bar{X}$	SD
I_{xx}	310	534	480	336	384	303	391.3	87.4
I_{yy}	290	493	507	348	402	317	392.8	83.0
I_{zz}	35	23	60	13	24	18	29.1	15.6

Directional Angles of Principal Moments of Inertia (degrees)

Subject:		1	2	3	4	5	6
I_{xx}	alpha	2	21	34	48	29	7
	beta	94	69	124	138	61	84
	gamma	89	90	89	90	87	87
I_{yy}	alpha	86	111	56	42	119	96
	beta	5	21	34	48	29	6
	gamma	92	87	89	88	90	89
I_{zz}	alpha	91	89	92	91	93	93
	beta	88	92	90	92	91	91
	gamma	2	2	2	2	3	3

Landmark Locations from Center of Mass (cm)

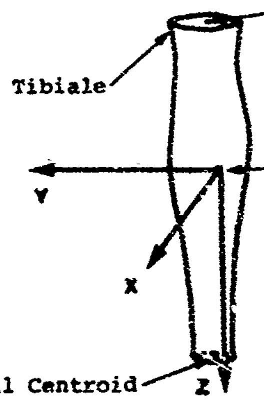
Proximal Centroid	x	0.7	0	0.7	-.3	0.8	0.4
	y	-.8	-1.3	-2.3	-.6	-.7	-1.0
	z	-16.4	-19.2	-17.3	-17.5	-18.1	-16.8
Tibiale	x	-.8	-2.5	-3.0	1.7	-.2	-2.2
	y	-5.3	-5.2	-6.2	-4.6	-5.7	-5.6
	z	-13.4	-15.3	-13.7	-14.2	-15.5	-12.8
Distal Centroid	x	0.7	0	0.7	-.3	0.8	0.4
	y	-.8	-1.3	-2.3	-.6	-.7	-1.0
	z	22.5	26.5	23.8	24.3	24.1	23.6
Link Length		38.1	45.7	41.1	41.8	42.2	40.4
CM from PC		16.5	19.3	17.4	17.5	18.1	16.9
Ratio (%)		42	42	42	42	43	42

Regression Equations*

								r	$Se_{(est)}$
Segment Weight		=	0.038	Body Wt		+	179	.917	271
"	I_{xx}	=	5.434	"	"	+	37,127	.821	61,086
"	I_{yy}	=	5.341	"	"	+	44,749	.850	53,568
"	I_{zz}	=	0.940	"	"	-	32,220	.795	11,597
Segment Weight		=	1.093	Seg Vol		-	84	.999	16
"	I_{xx}	=	135.509	"	"	+	47,990	.785	66,252
"	I_{yy}	=	147.572	"	"	+	18,949	.901	44,152
"	I_{zz}	=	23.929	"	"	-	31,573	.776	12,054

* Weight in gm, moments in gm-cm^2, volume in ml

TABLE 14. CALF (LEFT) DATA



Anthropometry

Subject:	1	2	3	4	5	6	$\bar{X}$	SD
Weight (gm)	2288	3039	3794	2056	2510	2345	2671.9	584.9
Volume (ml	2086	2296	3548	1915	2410	2136	2498.3	564.1
Density	1.097	1.049	1.069	1.074	1.043	1.098	1.071	0.021
Calf Length (cm)	33.7	40.4	36.4	39.1	38.6	38.3	37.75	2.16
Knee Circ (cm)	36.6	36.8	40.1	34.1	36.5	34.4	36.42	1.97
Calf Circ (cm)	29.3	32.4	39.2	27.5	30.3	29.8	31.42	3.77
Ankle Circ (cm)	19.6	21.0	22.7	19.4	20.2	19.4	20.38	1.18
Ankle Breadth (cm)	6.7	7.2	7.7	7.0	6.9	6.4	6.98	0.41

Principal Moments of Inertia (x 10^3 gm-cm^2)

Subject	1	2	3	4	5	6	$\bar{X}$	SD
I_{xx}	283	560	497	307	392	331	394.9	101.7
I_{yy}	286	526	477	324	379	345	389.6	85.0
I_{zz}	25	37	52	11	30	17	28.6	13.5

Directional Angles of Principal Moments of Inertia (degrees)

		Subject: 1	2	3	4	5	6
I_{xx}	alpha	55	75	57	9	48	46
	beta	35	17	34	98	42	136
	gamma	89	89	91	87	88	91
I_{yy}	alpha	145	165	147	82	138	44
	beta	55	75	56	9	48	46
	gamma	91	90	88	87	90	89
I_{zz}	alpha	91	91	89	95	92	91
	beta	91	90	90	93	91	92
	gamma	2	0	3	6	2	2

Landmark Locations from Center of Mass (cm)

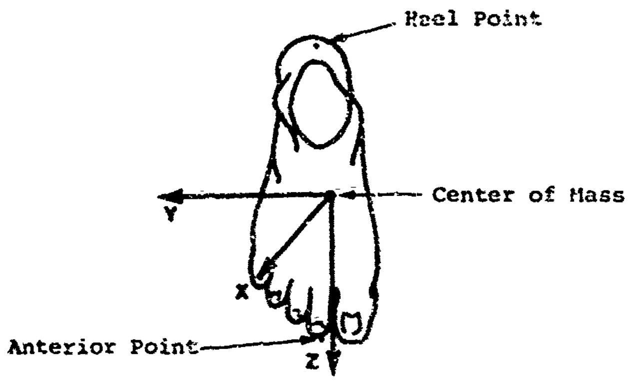
Proximal Centroid	x	1.0	0.9	1.3	-.3	0.4	0
	y	1.6	1.0	1.3	0.3	0.1	0.2
	z	-15.8	-18.9	-16.3	-15.9	-18.4	-16.9
Tibiale	x	-1.4	-.1	-3.1	1.6	1.5	0.3
	y	5.5	5.3	5.5	5.3	4.5	4.9
	z	-12.6	-15.1	-12.1	-15.7	-16.1	-13.2
Distal Centroid	x	1.0	0.9	1.3	-.3	0.4	0
	y	1.6	1.0	1.3	0.3	0.1	0.2
	z	22.2	26.8	24.3	23.8	24.0	24.7
Link Length		38.1	45.7	40.6	39.7	42.4	41.6
CM from PC		16.0	19.0	16.4	15.9	18.4	16.9
Ratio (%)		42	42	40	40	43	41

Regression Equations*

							r	$Se_{(est.)}$
Segment	Weight	=	0.044	Body Wt	-	178	.987	114
"	I_{xx}	=	6.434	"	"	-24,410	.835	68,487
"	I_{yy}	=	5.350	"	"	+40,974	.831	57,972
"	I_{zz}	=	.969	"	"	-34,567	.947	5,330
Segment	Weight	=	1.034	Seg Vol	+	89	.997	55
"	I_{xx}	=	134.032	"	"	+10,063	.854	64,749
"	I_{yy}	=	127.806	"	"	+70,322	.848	55,225
"	I_{zz}	=	23.163	"	"	-29,253	.966	4,261

* Weight in gm, moments in gm-cm^2, volume in ml

TABLE 15. FOOT (RIGHT) DATA



Anthropometry

Subject:	1	2	3	4	5	6	$\bar{X}$	SD
Weight (gm)	791	1029	958	730	859	657	837.2	127.6
Volume (ml)	723	990	883	695	813	595	783.0	129.4
Density	1.095	1.039	1.086	1.054	1.057	1.107	1.073	0.024
Foot Length (cm)	24.1	26.8	23.9	24.3	24.3	22.6	24.33	1.25
L. Malleolus Ht (cm)	6.6	6.8	4.8	7.6	6.1	6.2	6.35	0.85
Foot Breadth (cm)	8.4	9.7	10.2	9.0	9.0	8.6	9.15	0.62
Arch Circ (cm)	25.4	28.0	27.7	24.5	27.8	23.5	26.15	1.77
Ball of Foot Circ (cm)	22.0	25.7	24.8	21.8	23.2	20.8	23.05	1.72

Principal Moments of Inertia ($\times 10^3$ gm$\cdot$cm^2)

Subject:	1	2	3	4	5	6	$\bar{X}$	SD
I_{xx}	30.7	46.7	39.3	27.8	33.2	24.0	33.62	7.51
I_{yy}	28.8	41.7	34.8	25.7	31.0	20.4	30.40	6.73
I_{zz}	5.6	10.8	9.4	4.5	7.5	4.2	7.01	2.47

Directional Angles of Principal Moments of Inertia (degrees)

	Subject:	1	2	3	4	5	6
I_{xx}	alpha	11	73	11	35	30	44
	beta	81	20	82	56	61	48
	gamma	83	80	84	84	81	73
I_{yy}	alpha	100	163	99	124	120	133
	beta	11	73	9	35	31	43
	gamma	89	90	88	85	85	89
I_{zz}	alpha	96	93	96	93	96	97
	beta	92	100	93	9[illegible]	99	98
	gamma	6	11	6	8	11	11

Landmark Locations from Center of Mass (cm)

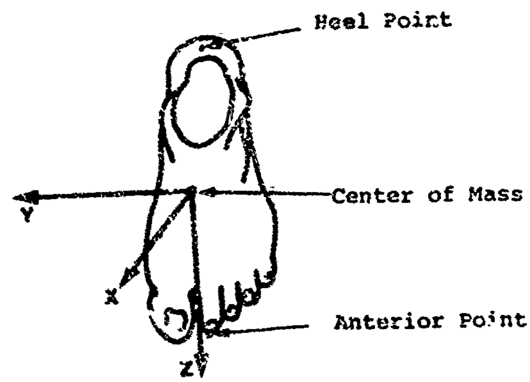
Heel Point	x	-1.9	-1.1	-1.1	-.2	-1.9	-1.8
	y	0	-.8	0.1	-.3	-.6	-.4
	z	-9.8	-11.3	-10.1	-10.7	-10.5	-9.4
Tip of Digit I	x	2.1	0.4	-1.1	0	-1.7	-2.8
	y	-1.9	-2.2	-1.8	-1.9	-2.2	-1.4
	z	13.8	14.5	13.2	13.5	13.6	12.9
Anterior Point	x	-1.9	-1.1	-1.1	-.2	-1.9	-1.8
	y	0	-.8	.1	-.3	-.6	-.6
	z	13.2	13.5	12.6	13.2	12.9	12.7
Heel to Ant Pt		23.0	24.8	22.7	23.9	23.3	22.1
CM to Ant Pt		13.3	13.6	12.7	13.2	13.0	12.8
Ratio (%)		58	55	56	55	56	58

Regression Equations*

					r	$Se_{(est)}$
Segment Weight	=	0.008	Body Wt	+ 343	.784	97
" I_{xx}	=	.433	" "	+ 5,371	.762	5,950
" I_{yy}	=	.355	" "	+ 7,[illegible]96	.696	5,912
" I_{zz}	=	.153	" "	+ 2,989	.819	1,741
Segment Weight	=	0.979	Seg Vol	+ 70	.993	18
" I_{xx}	=	57.250	" "	-11,214	.987	1,463
" I_{yy}	=	51.547	" "	- 9,963	.992	1,019
" I_{zz}	=	18.703	" "	7,635	.978	627

* Weight in gm, moments in gm-cm^2, volume in ml

TABLE 16. FOOT (LEFT) DATA



Anthropometry

Subject:	1	2	3	4	5	6	$\bar{X}$	SD
Weight (gm)	807	1074	974	726	763	671	835.7	142.2
Volume (ml)	728	1035	891	686	724	630	782.3	138.1
Density	1.109	1.038	1.092	1.057	1.055	1.065	1.069	0.024
Foot Length (cm)	24.3	25.8	23.6	24.1	24.0	23.1	24.15	0.83
L. Malleolus Ht (cm)	5.7	5.6	5.1	6.6	7.9	5.1	6.00	0.99
Foot Breadth (cm)	8.5	9.9	10.1	9.0	8.8	9.1	9.23	0.58
Arch Circ (cm)	26.0	28.2	27.8	24.4	26.8	24.0	26.20	1.58
Ball of Foot Circ (cm)	22.0	26.2	25.0	22.5	23.0	20.9	23.27	1.80

Principal Moments of Inertia (x 10^3 gm·cm^2)

Subject:	1	2	3	4	5	6	$\bar{X}$	SD
I_{xx}	35.7	46.0	36.9	28.1	28.7	23.4	33.13	7.40
I_{yy}	29.6	44.5	34.2	25.1	27.1	22.1	30.43	7.34
I_{zz}	5.5	11.3	9.2	5.2	8.0	6.1	7.54	2.20

Directional Angles of Principal Moments of Inertia (degrees)

	Subject:	1	2	3	4	5	6
I_{xx}	alpha	21	43	10	37	16	29
	beta	107	48	83	53	106	119
	gamma	77	85	82	84	88	85
I_{yy}	alpha	106	132	96	127	74	62
	beta	163	42	6	37	17	29
	gamma	97	96	91	94	94	86
I_{zz}	alpha	76	97	99	97	91	97
	beta	88	89	89	90	86	92
	gamma	165	7	9	8	4	7

Landmark Locations from Center of Mass (cm)

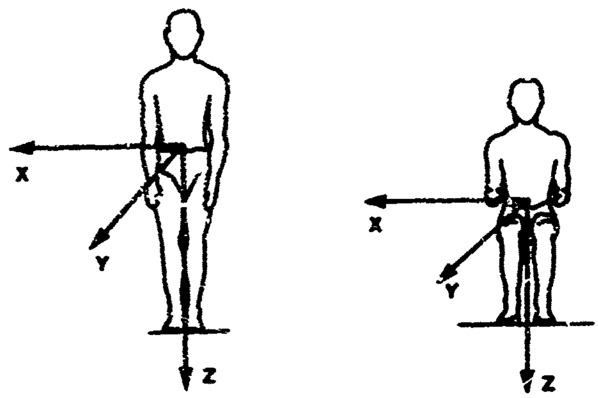
Heel Point	x	-1.6	-1.0	-1.2	0.1	-2.2	-1.1
	y	0.1	0.7	0.3	0.2	0.7	0.6
	z	-10.0	-11.4	-10.1	-10.6	-10.2	-9.9
Tip of Digit I	x	-2.5	0.1	-.8	-1.1	-2.3	-1.8
	y	2.3	2.3	2.8	2.1	2.8	2.0
	z	13.6	13.7	12.6	13.5	13.1	12.9
Anterior Point	x	-1.6	-1.0	-1.2	0.1	-2.2	-1.1
	y	0.1	0.7	0.3	0.2	0.7	0.6
	z	13.0	13.9	12.8	12.9	12.4	13.2
Heel to Ant Pt		23.0	25.3	22.9	23.5	22.5	23.1
CM to Ant Pt		13.1	13.9	12.9	12.9	12.6	13.2
Ratio (%)		57	55	56	55	56	57

Regression Equations*

			r	Se (est)
Segment Weight	= 0.009 Body Wt	+ 253	.831	97
" I_{xx}	= 0.371 " "	+ 8,974	.661	6,796
" I_{yy}	= 0.391 " "	+ 4,959	.703	6,396
" I_{zz}	= 0.130 " "	− 946	.782	1,677
Segment Weight	= 1.018 Seg Vol	+ 39	.991	24
" I_{xx}	= 50.313 " "	− 6,233	.941	3,074
" I_{yy}	= 52.318 " "	−10,500	.986	1,514
" I_{zz}	= 14.527 " "	− 3,824	.914	1,091

* Weight in gm, moments in gm-cm^2, volume in ml

TABLE 17. WHOLE-BODY DATA



Standing Specimen (Subjects 1, 2 and 3)	Seated Specimen (Subjects 4, 5 and 6)

Anthropometry

Subject:	1	2	3	4	5	6	$\bar{X}$	SD
Age (Years)	65	45	47	58	61	50	54.3	7.4
Weight (kg)	58.7	76.15	89.15	50.62	58.08	58.34	65.173	13.205
Stature (cm)	167.8	181.7	174.2	175.9	168.8	164.5	172.15	5.75
Trochanterion Ht (cm)	85.8	97.0	86.7	93.8	90.2	86.5	89.98	4.16
CM-Vertex (cm)	69.2	73.8	74.0	--	--	--	72.33	2.22
	--	--	--	67.8	65.6	60.3	64.57	3.15
CM-Vertex/Stature Ratio (%)	41.2	40.6	42.5	--	--	--	41.43	0.73
	--	--	--	38.5	38.9	36.7	38.03	0.96

Principal Moments of Inertia (x 10^3 gm-cm^2)

		1	2	3	4	5	6	$\bar{X}$	SD
I_{xx}	(Standing)	98,807	150,886	169,127	--	--	--	133,967.0	45,391.4
	(Seated)	--	--	--	70,858	64,125	66,937	67,306.7	3,087.0
I_{yy}	(Standing)	89,223	125,580	141,888	--	--	--	118,897.0	24,611.9
	(Seated)	--	--	--	66,023	69,801	60,726	65,516.7	4,161.4
I_{zz}	(Standing)	11,644	17,424	22,388	--	--	--	17,152.0	4,908.7
	(Seated)	--	--	--	11,385	17,445	15,825	14,885.0	2,864.1

Directional Angles of Principal Moments of Inertia (degrees)

		1	2	3	4	5	6
I_{xx}	alpha	6	21	17	25	31	26
	beta	85	69	73	110	117	76
	gamma	37	87	88	106	105	111
I_{yy}	alpha	95	110	107	71	63	102
	beta	5	21	17	20	27	15
	gamma	91	89	92	95	95	82
I_{zz}	alpha	93	92	92	73	75	67
	beta	90	93	89	91	92	93
	gamma	4	3	2	17	16	23

Section V. CONCLUSIONS

A study of the moments of inertia of the intact body and body segments of six adult male cadavers was conducted and the results reported. The study design did not attempt to provide a statistically valid sampling for establishing population estimates of these parameters, and no attempt should be made to use the results reported as such. Differences between the principal moments of inertia of the cadavers used in this study and living human beings of like size, shape, and weight are, of course, unknown. A comparison of the measured moments of inertia of our intact specimens with the measured moments of inertia of standing and seated living subjects of similar stature and weight reported by Santschi *et al*. (1963) is shown in Table 18. The data selected for comparison were from those five of the sixty-six subjects reported by Santschi *et al*. who were closest in stature and weight to our specimens. Subject 4 has been deleted from this comparison as there was no comparable subject in the Santschi series. The numbers in the table are the differences between the moments of inertia (unrotated) of the cadavers and that of the matched live subjects expressed as a ratio of the former. These differences, in general, show a satisfactory level of agreement.

TABLE 18. COMPARISON OF MOMENTS OF INERTIA

Subject Match	1 & 19	2 & 1	3 & 17	5 & 65	6 & 39
Stature (cm)	167.8/ 171.7	181.7/ 183.4	174.2/ 175.5	168.8/ 170.4	164.5/ 165.9
Weight (kg)	63.2/ 62.9	77.2/ 78.9	90.4/ 92.6	63.3/ 64.8	69.2/ 70.0
$I_{(xx)}$*	-4.15	-1.01	5.81	6.79	1.97
$I_{(yy(}$*	-1.89	-4.50	4.43	7.89	1.15
$I_{(zz)}$*	15.18	18.68	28.16	0.32	-1.55

* Deviation as percent of cadaver value.

Differences between the principal moments of inertia of our specimens and the segments of living human beings of like sex, size, shape and weight are unknown, but they are believed to be small though the torso may well be an exception. Attempts to extrapolate the results reported here to women and children are most likely invalid owing to differences in the amount and distribution of various tissues between men, women, and children. The principal moments of inertia of segments of the body as reported in this study cannot, without considerable caution, be compared with measured moments of inertia data of body segments reported by other investigators since their measurements were often made about different axes.

The results of this investigation permit a number of general conclusions:

(1) The relationships of the segment principal moments of inertia to body weight and segment volumes are

high with the latter providing, in general, the best predictors of moments of inertia.

(2) The principal moments I_{xx} and I_{yy} are approximately of the same magnitude for the major limb segments with the principal moment I_{zz} being approximately 20 percent or less of the I_{xx} values.

(3) The direction angles of the principal moments tend to approximate but are not identical to our segment-reference axis system.

(4) For most segments, the differences in the principal moments of inertia between the seated and standing subjects are small and fall within sample variability. While shifts in muscle tissue associated with joint movement could not be duplicated in our specimens, the results of this tissue displacement on the moments of inertia are believed to be slight and the estimates for segment moments of inertia in one orientation are usable in any other segment orientation for purposes of modeling.

(5) The results of this investigation are useful in improving existing mathematical models of the human body by providing empirical values

against which the moments of inertia of
various geometric shapes and sizes
may be tested.

APPENDIX A

COMPARISON OF THEORETICAL AND EMPIRICAL MOMENTS

It was of considerable interest to determine how well the computed moments of inertia obtained from mathematical models relate to the principal moments of inertia of body segments determined empirically. The previously described Hanavan (1964) model, as modified by Tieber and Lindemuth (1965), was used to generate the calculated moments of inertia used in this comparison. It was necessary to make certain changes in the model before a segment-to-segment comparison could be made. The major change necessary was in the treatment of the torso as a single unit rather than two units, as had been done by Hanavan.

As the model was personalized, the individual anthropometric values of the six specimens were used in calculating the weights and principal moments of inertia of the segments. In Table 19 the deviation of the predicted value from the measured value is presented as a ratio of the measured value; for example, the first entry, 11.5 percent, indicates that the predicted value of head weight for subject 1 is 11.5 percent greater than the measured value. Table 19 consists of four sections: Section A gives comparisons of segment weight; section B, comparisons of the principal moments I_{xx}; section C, comparisons of the principal moments I_{yy}; and section D, comparisons of the principal moments I_{zz}. Each section lists the segment being compared, the six specimen comparisons, and the average deviation of the predicted value, disregarding the arithmetic sign. This is, of course, a more rigorous comparison than if the sign were considered where the deviations in excess of or less than the measured values would tend to cancel each other.

The comparisons of measured segment weights with those predicted by using regression equations are, in some instances, poor (Table 19 A). The least accurate prediction of weight was for the head segment; however, this was not unexpected as the regression equation used for predicting head weight is based on a different plane of segmentation than that used in this study. The prediction of hand weight also showed a poor level of agreement to measured weight. These differences are in part a function of the small weight of the hand segments and in part a function of the large differences associated with one specimen, subject 6. In general, this subject's weights show the poorest overall level of agreement with predicted values.

The comparisons shown in Table 19 B, C, D indicate that the model is a poor vehicle for predicting the segmental moments of inertia, as some predicted values were as much as 300 percent greater than the measured values. In order to determine if the deviations of the predicted weights were a principal source of

TABLE 19. COMPARISON OF MEASURED WITH PREDICTED SEGMENT WEIGHT AND MOMENTS OF INERTIA

(Deviation in Percent of Predicted Value from Measured Value)

A. Segment Weight

Subject:	1	2	3	3	5	6	$\lvert\bar{\Delta}\rvert$
Head	11.5	21.8	8.1	24.8	12.9	26.4	17.6
Torso	- 2.7	- 3.1	- 0.7	- 4.8	- 2.9	-10.3	4.1
Rt Up Arm	- 2.9	3.5	10.3	-21.1	- 9.5	7.5	9.2
Lt Up Arm	- 7.7	- 4.4	3.1	-21.0	3.9	1.6	7.0
Rt Forearm	- 0.7	- 7.9	- 5.3	16.1	5.5	26.5	10.3
Lt Forearm	- 2.4	1.7	8.5	10.2	11.5	8.5	7.1
Rt Hand	7.2	- 1.0	- 0.7	24.7	19.0	70.7	20.6
Lt Hand	26.5	18.6	10.4	21.4	20.4	56.0	25.6
Rt Thigh	2.6	4.6	- 2.7	9.4	-10.5	7.5	6.2
Lt Thigh	- 1.6	- 5.6	- 4.0	- 9.7	0.1	3.7	4.1
Rt Calf	5.8	9.2	- 1.7	6.9	4.6	8.7	6.2
Lt Calf	1.0	3.3	- 2.1	17.1	14.3	5.8	7.3
Rt Foot	10.3	5.8	16.0	17.5	8.1	29.0	14.5
Lt Foot	8.1	1.4	14.1	18.2	21.6	26.4	9.2

B. I_{xx}

Subject:	1	2	3	4	5	6	$\lvert\bar{\Delta}\rvert$
Head	69.5	146.6	38.7	104.6	111.9	49.3	86.8
Torso	-47.2	-39.0	-30.6	-48.7	-44.0	-41.7	41.1
Rt Up Arm	12.5	49.8	38.3	-22.7	2.2	14.7	23.4
Lt Up Arm	4.5	- 4.3	10.8	-25.1	16.7	9.1	11.8
Rt Forearm	4.7	-21.8	- 5.6	16.8	- 3.2	25.5	12.9
Lt Forearm	-15.7	- 2.5	19.1	7.2	5.0	- 1.6	8.5
Rt Hand	-51.1	-54.4	-47.4	-53.7	-53.5	0.8	43.5
Lt Hand	-38.5	-39.4	-42.1	-54.2	-48.1	-26.2	41.4
Rt Thigh	- 2.0	20.1	- 0.9	35.0	-12.0	10.7	13.5
Lt Thigh	5.1	8.1	5.3	-14.7	12.7	13.1	9.8
Rt Calf	-31.8	-25.8	-22.6	-17.0	-13.5	-12.2	20.5
Lt Calf	-25.3	-29.2	-25.2	- 9.1	-15.2	-19.6	20.6
Rt Foot	38.5	35.1	35.2	52.4	39.2	54.7	42.5
Lt Foot	19.1	36.9	44.1	50.8	60.8	59.2	45.2

TABLE 19. (Continued)

C. I_{yy}

	Subject: 1	2	3	4	5	6	$\overline{\lvert\Delta\rvert}$
Head	112.8	67.4	90.7	152.1	63.3	72.0	93.1
Torso	-26.9	-28.4	-26.0	-34.4	-18.7	22.0	26.1
Rt Up Arm	21.1	14.4	56.6	-21.2	5.1	20.0	23.1
Lt Up Arm	15.4	6.1	34.9	-21.0	24.4	13.3	19.2
Rt Forearm	9.2	-17.2	- 1.7	16.0	4.0	23.4	11.9
Lt Forearm	- 8.6	- 4.7	21.0	8.6	9.0	3.4	9.2
Rt Hand	-42.3	-48.4	-38.2	-32.1	-37.3	16.1	35.7
Lt Hand	-26.5	-38.3	-30.0	-36.1	-34.6	12.0	29.6
Rt Thigh	- 6.8	12.8	6.3	31.0	-19.9	15.6	15.4
Lt Thigh	7.5	- 2.4	- 2.6	-20.1	7.7	8.8	8.2
Rt Calf	-27.1	-19.6	-26.6	-19.9	-17.4	-16.2	21.1
Lt Calf	-26.2	-24.7	-22.0	-13.8	-12.4	-22.9	20.3
Rt Foot	47.7	51.3	53.0	64.4	48.8	82.5	57.9
Lt Foot	43.5	41.6	55.6	68.9	70.2	68.6	58.1

D. I_{zz}

	Subject: 1	2	3	4	5	6	$\overline{\lvert\Delta\rvert}$
Head	-29.1	-25.2	-33.4	-12.7	-32.0	26.5	26.5
Torso	2.5	-13.8	-14.8	-12.0	-12.2	-32.0	14.5
Rt Up Arm	- 5.5	5.9	3.1	-33.3	-21.2	15.6	14.1
Lt Up Arm	-16.2	-17.9	- 2.6	-10.0	4.0	- 0.5	8.5
Rt Forearm	21.4	-28.8	-14.0	43.0	- 0.2	33.6	23.5
Lt Forearm	20.1	-16.3	- 2.9	20.9	10.6	- 1.2	12.0
Rt Hand	96.5	17.4	40.4	110.1	222.8	364.7	142.0
Lt Hand	101.1	296.3	70.5	53.1	112.2	266.2	149.9
Rt Thigh	-25.3	0.2	-35.4	18.0	-26.3	-25.4	21.8
Lt Thigh	- 3.1	-22.2	- 6.3	-41.5	-23.1	-29.2	20.9
Rt Calf	-24.9	64.9	-15.1	91.6	46.6	48.9	48.7
Lt Calf	7.7	0.9	- 1.6	131.3	19.9	59.2	36.8
Rt Foot	-28.6	-38.9	-39.3	9.4	-28.5	- 7.4	25.4
Lt Foot	-27.0	-41.3	-38.2	-4.6	-33.1	-36.1	30.0

error in predicting the segmental moments of inertia, the actual measured weights were used as inputs in the model. The results of this comparison are shown in Table 20. In this table only the mean absolute deviation as a percent of the measured value is compared as opposed to the individual segment and specimen values in the previous table. The columns labeled O list the absolute mean deviation of the original model and are compared in this table with similar values from the modified model where actual segment weights are used (columns labeled I). This comparison shows some improvement over the original model, but many differences, predicted minus measured, still remain unacceptably large. This would suggest that the principal source of error in the prediction of segment moments of inertia is not associated with the prediction of segment weights but in the model itself.

The model was, therefore, further modified by the redefinition of the lengths of the head and torso. Because the head segmentation plane was considerably higher in this experiment than in previous studies, the head segment was, in effect, shortened and what would be anatomically the neck was added to the torso segment length. The upper arms, forearms, thighs, calves, and feet (which in the original model were treated as the frustra of a right circular cone) were modified to become right elliptical cylinders. The hands were left unchanged. The model was rerun with these modifications and the results are shown in Table 20 in the columns labeled II. There is some improvement with these modifications in many instances, except for the head segment. The head was, therefore, changed in the model from an ellipsoid to a sphere and the results of this modification are shown in the columns labeled III. This modification brought about a significant improvement in the predicted-versus-measured moments of the head, and the model now begins to show a reasonable level of correspondence to the empirical data.

TABLE 20. COMPARISON OF THE ORIGINAL MODEL AND THE MODIFIED MATHEMATICAL MODELS

(Average Deviation in Percent of Predicted Value from Measured Value)

	I_{xx}				I_{yy}				I_{zz}			
	O	I	II	III	O	I	II	III	O	I	II	III
Head	86.8	58.8	238.3	20.9	93.1	64.6	251.1	17.4	26.5	30.6	179.7	30.6
Torso	41.1	38.6	7.4	--	26.1	22.8	26.9	--	14.5	12.0	12.0	--
Rt Up Arm	23.4	17.9	18.7	--	23.1	17.5	16.9	--	14.1	7.9	7.9	--
Lt Up Arm	11.8	8.6	9.2	--	19.2	14.5	13.9	--	8.5	13.8	13.7	--
Rt Forearm	12.9	4.8	7.4	--	11.9	4.4	5.4	--	23.5	14.4	12.0	--
Lt Forearm	8.5	13.0	15.2	--	9.2	11.4	11.7	--	12.0	10.3	9.3	--
Rt Hand	43.5	53.4	--	--	35.7	42.8	--	--	142.0	92.5	--	--
Lt Hand	41.4	49.9	--	--	29.6	37.8	--	--	149.9	112.5	--	--
Rt Thigh	13.5	8.2	9.9	--	15.4	10.7	10.6	--	21.8	20.2	20.7	--
Lt Thigh	9.8	11.2	14.0	--	8.2	10.0	10.0	--	20.9	21.6	22.4	--
Rt Calf	20.5	24.6	12.3	--	21.1	25.3	17.2	--	48.7	41.7	38.3	--
Lt Calf	20.6	24.7	12.4	--	20.3	24.5	16.2	--	36.8	31.2	29.2	--
Rt Foot	42.5	24.7	37.4	--	57.9	37.9	45.0	--	25.4	32.4	13.2	--
Lt Foot	45.2	27.0	40.0	--	58.1	38.3	45.4	--	30.0	38.7	12.8	--

APPENDIX B

LANDMARK DESCRIPTIONS

Landmarks were used in the anthropometry of the cadavers. The purpose of the anthropometry was to describe the physical size of the cadavers for comparison with other samples and for the gathering of input data for modeling. The cadavers were measured with the body in a supine position, the head in the Frankfort plane (relative) and firmly in contact with a headboard, the legs extended, the torso and head aligned, and the arms extended naturally at the sides with the palms facing medially.

Landmarks are often located with reference to a bony structure; that is, the terminal point of a long bone, a bony protuberance, etc. The use of these reference points does not imply that the landmarks are located on the bone itself but only at that particular level on the skin which overlies the bony reference points.

This convention does not pose a serious problem with traditional anthropometry, as the measurements are normally made only in a single plane. Because both traditional and three-dimensional anthropometry were utilized in this investigation, it must be clearly understood that when a bony reference is used as a landmark, the actual point of measurement lies on the surface of the skin some distance away from the actual bony reference.

The study required the use of nontraditional landmarks for establishing the orientation of the body and its segments in three-dimensional space. Three tick marks were drawn on each plane of segmentation previously inscribed on the cadavers. These marks were subsequently located in three-dimensional space and permit the mathematical reassembly of the parts into the whole. The tick marks generally were made on the anterior, medial, and lateral aspects of the elbow, wrist, knee, and ankle planes of segmentation; on the anterior, superior, and posterior surfaces of the shoulder and hip segmentation planes; and on the anterior, posterior, and right or left aspects of the planes of segmentation of the head. Although the names given to the tick marks have reference to anatomical or anthropometric aspects, they were chosen primarily for their mnemonic powers. The locations of these marks are summarized in Table 20.

The anthropometric and anatomical landmarks used in this study are defined as follows:

TABLE 20. GENERAL ANATOMICAL ORIENTATION OF SEGMENT PLANE TICK MARKS

Plane Ticks*		Segmentation Planes: Neck	Shoulder	Elbow	Wrist	Hip	Knee	Ankle
A,CN,E,H,K,S,W	– 1	Anterior	Anterior	Anterior	Anterior	Anterior	Anterior	Anterior
A,CN,E,H,K,S,W	– 2	Left	Superior	Medial	Medial	Superior	Medial	Medial
A,E,F,H,K,S,W	– 3	Left	Posterior	Lateral	Lateral	Posterior	Lateral	Lateral
F,W	– 4	Posterior	---	---	Posterior	---	---	---
F	– 5	Right	---	---	---	---	---	---
CN	– 6	Right	---	---	---	---	---	---

* A = Ankle Plane
CN = Chin-Neck Plane
E = Elbow Plane
F = Frankfort Plane
H = Hip Plane
K = Knee Plane
S = Shoulder Plane
W = Wrist Plane

Acromion: The lateral point on the lateral margin of the acromial process of the scapula.

Anterior Iliospinale: The inferior point of the anterior superior iliac spine.

Ball of Foot: The distal point on the sole of the foot between metatarsals I and V.

Ball of Humerus: A point between the superior portions of the intertubercular sulcus of the humerus.

Big Toe: The tip of the big toe.

Chin Point: The anterior point in the mid-sagittal plane of the chin.

Chin/Neck Intersect: A point in the mid-sagittal plane at the intersection of chin and neck. (The intersection of the chin and neck is located by sliding a small rod along the inferior surface of the chin until it meets the vertical plane of the neck.)

Clavicale: A point on the most imminent prominence of the anterior superior aspect of the medial end of the clavical (after Snyder, 1972).

Dactylion: The tip of digit III.

Distal Centroid: A point on the distal cut surface of a segment approximating a center of joint rotation.

Distal Point: The farthest point on the edge of the inferior plane of segmentation.

Fibulare: The superior point of the proximal head of the fibula.

Glabella: The anterior point of the forehead between the brow ridges in the mid-sagittal plane.

Hip Reference Point, Right and Left: An arbitrary point placed on each buttock to help establish a posterior reference plane.

Iliac Crest: The superior point on the crest of the ilium in the mid-axillary line.

Infraorbitale: The lowest point on the inferior margin of the orbit.

Lateral Malleolus: The lateral point on the lateral malleolus.

Lumbar Vertebra 5: The tip of the spinous process of the fifth lumbar vertebra.

Mastoid: The lowest point of the apex of the mastoid process.

Menton: The lowest point of the tip of the chin in the mid-sagittal plane.

Metacarpale III: A point on the dorsal sulcus between the third metacarpal and its articulating phalanx.

Mid-anterior Plane Point: A point located on the anterior surface of a segment and about halfway between its ends.

Mid-forearm: A point midway between the radiale and stylion landmarks.

Mid-lateral Plane Point: A point located on the lateral surface of a segment and about halfway between its ends.

Mid-medial Plane Point: A point located on the medial surface of a segment and about halfway between its ends.

Mid-patella: A point on the anterior surface of the patella midway between its superior and inferior margins.

Mid-posterior Plane Point: A point located on the posterior surface of a segment and about halfway between its ends.

Mid-thigh: A point on the medial aspect of the thigh midway between the crotch level and the tibiale landmark.

Occipital Point: A point in the mid-sagittal plane located on the occiput.

Olecranon: The superior point of the proximal head of the ulna.

Proximal Centroid: A point located on the proximal cut surface of a segment approximating a center of joint rotation.

Proximal Point: The nearest point on the edge of the superior plane of segmentation.

Radiale: The superior point on the medial margin of the head of the radius.

Sellion: The point in the mid-sagittal plane of the greatest indentation of the nasal root depression.

Sphyrion: The inferior point of the tibia.

Sphyrion, Fibular: The inferior point of the fibula.

Stylion: The inferior point of the styloid process of the radius.

Superior Head Plane Point: A point located on the top of the head in the mid-sagittal plane in line with the right and left tragion landmarks.

Suprasternale: The lowest point on the margin of the jugular notch of the sternum.

Symphysion: A point in the mid-sagittal plane on the superior margin of the pubic symphysis.

Tenth Rib: The lowest point on the inferior margin of the 10th rib.

Thelion: The center of the nipple.

Thoracic Vertebra 1: The superior tip of the spinous process of the first thoracic vertebra.

Thoracic Vertebra 12: The superior point of the tip of the spinous process of the 12th thoracic vertebra.

Tibial, Lateral: The superior point on the border of the lateral condyle of the tibia just lateral to the patella ligament.

Tibiale: The superior point on the medial margin of the head of the tibia.

Torso Plane Point, Left: A point located on the left mid-axillary line at the level of omphylion.

Tragion: The deepest point of the notch located immediately superior to the tragus of the ear.

Trochanterion: The superior point of the greater trochanter of the femur.

Ulnar Styloid: The inferior point of the styloid process of the ulna.

Vertex: The highest point on the top of the head when the head is oriented in the Frankfort plane.

APPENDIX C

DESCRIPTIONS OF ANTHROPOMETRIC DIMENSIONS

Acromion Height: Cadaver supine, with its head oriented in the Frankfort plane (relative) and firmly touching the headboard of the measuring table. With an anthropometer, measure the horizontal distance from the headboard to the acromion landmark.*

Acromion-Radiale Length: With a beam caliper, measure the distance along the long axis of the upper arm between the acromion and radiale landmarks.

Age: As recorded on the coroner's report.

Ankle Breadth: With a sliding caliper, measure on the ankle the maximum distance between the medial and lateral malleoli.

Ankle Circumference: With a tape perpendicular to the long axis of the lower leg, measure the minimum circumference of the ankle.

Anterior-Superior Iliac Spine Height: Cadaver supine, with its head oriented in the Frankfort plane (relative) and firmly touching the headboard of the measuring table. With an anthropometer, measure the horizontal distance from the headboard to the anterior iliospinale landmark.

Arch Circumference: With a tape perpendicular to the long axis of the foot and passing over the highest point in the arch, measure the circumference of the arch of the foot.

Arm Circumference, Axillary: With a tape perpendicular to the long axis of the upper arm and passing just below the lowest point of the axilla, measure the circumference of the arm.

Ball of Foot Circumference: With a tape passing over the metatarsal-phalangeal joints I and V, measure the circumference of the foot.

Ball of Foot-Vertex Length: Cadaver supine, with its head oriented in the Frankfort plane (relative) and firmly touching the headboard of the measuring table. With an anthropometer, measure the horizontal distance from the headboard to the mid-ball of the foot.

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* All dimensions measured from the headboard are reported as subtractions from Stature

Ball of Humerus-Radiale Length: With a beam caliper, measure the distance along the axis of the upper arm between the superior portion of the intertubercular sulcus of the humerus and the radiale landmark.

Biacromial Breadth: With a beam caliper, measure the horizontal distance between the right and left acromion landmarks.

Biceps Circumference: With a tape perpendicular to the long axis of the upper arm, measure the circumference of the upper arm at the level of the maximum anterior prominence of the biceps brachii.

Bicristal Breadth (Bone): With a body caliper, measure the horizontal distance between the right and left ilia, exerting sufficient pressure to compress the tissue overlying the bone.

Bispinous Breadth: With a beam caliper, measure the distance between the right and left anterior iliospinale landmark.

Bitrochanteric Breadth (Bone): With a body caliper, measure the horizontal distance between the maximum protrusions of the right and left greater trochanters, exerting sufficient pressure to compress the tissue overlying the femurs.

Buttock Depth: With an anthropometer, measure the vertical distance from the measuring table to the anterior surface of the torso at the level of symphysion.

Calf Circumference: With a tape perpendicular to the long axis of the lower leg, measure the maximum circumference of the calf.

Calf Length: A dimension calculated by subtracting sphyrion height from tibiale height.

Cervicale Height: The horizontal distance between the headboard and cervicale. This dimension is computed from the difference between top of head to thelion and the horizontal distance between thelion and cervicale.

Chest Breadth: With a beam caliper, measure the horizontal breadth of the chest at the level of thelion.

Chest Circumference: With a tape passing over the nipples and perpendicular to the long axis of the trunk, measure the circumference of the chest.

Chest Depth: With an anthropometer, measure the vertical distance from the measuring table to the anterior surface of the body at the level of thelion.

Chin/Neck Intersect Height: Cadaver supine, with its head oriented in the Frankfort plane (relative) and firmly touching the headboard of the measuring table. With an anthropometer, measure the horizontal distance from the headboard to the chin/neck intersect.

Crotch Height: Cadaver supine, with its head oriented in the Frankfort plane (relative) and firmly touching the headboard of the measuring table. With an anthropometer, measure the horizontal distance between the headboard and the lowest point of the crotch between the scrotum and the right leg.

Elbow Breadth: With a spreading caliper, measure the maximum breadth across the humeral epicondyles.

Elbow Circumference: With a tape passing over the olecranon process of the ulna and into the crease of the elbow, measure the circumference of the elbow.

Fibulare Height: Cadaver supine, with its head oriented in the Frankfort plane (relative) and firmly touching the headboard of the measuring table. With an anthropometer, measure the horizontal distance from the headboard to the fibulare landmark.

Foot Breadth: With a sliding caliper, measure on the foot the breadth across the distal ends of metatarsus I and V.

Foot Length: With a beam caliper, measure on the foot the distance from the dorsal surface of the heel to the tip of the longest toe.

Forearm Circumference: With a tape perpendicular to the long axis of the forearm, measure the maximum circumference of the forearm.

Hand Breadth: With a sliding caliper, measure the breadth of the hand across the distal ends of metacarpus II and V.

Hand Circumference: With a tape passing around the metacarpal-phalangeal joints, measure the circumference of the hand.

Hand Depth: With a sliding caliper, measure the depth of the hand at metacarpale III.

Head Breadth: With a spreading caliper, measure the maximum horizontal breadth of the head.

Head Circumference: With the tape passing above the brow ridges and parallel to the Frankfort plane (relative), measure the maximum circumference of the head.

Hip Breadth: With a beam caliper, measure the horizontal distance across the greatest lateral protrusion of the hips.

Hip Circumference: With a tape passing over the greatest lateral protrusion of the hips and in a plane perpendicular to the long axis of the trunk, measure the circumference of the hips.

Iliac Crest Height: Cadaver supine, with its head oriented in the Frankfort plane (relative) and firmly touching the headboard of the measuring table. With an anthropometer, measure the horizontal distance from the headboard to the iliac crest in the mid-axillary line.

Knee Breadth: With a spreading caliper, measure the maximum breadth of the knee across the femoral epicondyles.

Knee Circumference: With a tape perpendicular to the long axis of the leg and passing over the middle of the patella, measure the circumference of the knee.

Malleolus Height, Lateral: Cadaver supine, with its head oriented in the Frankfort plane (relative) and firmly touching the headboard of the measuring table. With an anthropometer, measure the horizontal distance from the headboard to the lateral malleolus landmark.

Mastoid Height: Cadaver supine, with its head oriented in the Frankfort plane (relative) and firmly touching the headboard of the measuring table. With an anthropometer, measure the horizontal distance from the headboard to the apex of the mastoid process.

Menton Height: Cadaver supine, with its head oriented in the Frankfort plane (relative) and firmly touching the headboard of the measuring table. With an anthropometer, measure the horizontal distance from the headboard to the menton landmark.

Metacarpale III-Dactylion Length: With a sliding caliper parallel to the long axis of digit III, measure the distance from the metacarpale III landmark to the tip of the middle finger.

Mid-Forearm Circumference: With a tape perpendicular to the long axis of the forearm and midway between the radiale and the ulnar styloid landmarks, measure the circumference of the forearm.

Mid-Thigh Circumference: With a tape perpendicular to the long axis of the leg and at a level midway between the trochanterion and tibiale landmarks, measure the circumference of the thigh.

Mid-Torso Circumference: With a tape passing over the torso at the level of the tip of the xiphoid process and perpendicular to the long axis of the trunk, measure the circumference of the torso.

Neck Breadth: With a beam caliper, measure the maximum horizontal breadth of the neck.

Neck Circumference: With a tape in a plane perpendicular to the axis of the neck and passing over the laryngeal prominence (Adam's Apple), measure the circumference of the neck.

Neck Depth: With a beam caliper, measure the maximum depth of the neck perpendicular to the long axis of the neck.

Olecranon-Stylion Length: With a beam caliper parallel to the long axis of the flexed forearm, measure the distance from the proximal portion of the olecranon process to the tip of the styloid process of the ulna.

Omphalion Height: Cadaver supine, with its head oriented in the Frankfort plane (relative) and firmly touching the headboard of the measuring table. With an anthropometer, measure the horizontal distance between the headboard and omphalion.

Radiale-Stylion Length: With a beam caliper parallel to the long axis of the forearm, measure the distance between radiale and the stylion landmark.

Sphyrion Height: Cadaver supine, with its head oriented in the Frankfort plane (relative) and firmly touching the headboard of the measuring table. With an anthropometer, measure the horizontal distance from the headboard to the sphyrion landmark.

Sphyrion Height, Fibular: Cadaver supine, with its head oriented in the Frankfort plane (relative) and firmly touching the headboard of the measuring table. With an anthropometer, measure the horizontal distance from the headboard to the fibular sphyrion landmark.

Stature: A derived dimension calculated by taking the average of right and left ball of foot to vertex lengths.

Stylion-Dactylion Length: With a sliding caliper parallel to the forearm-hand axis, measure the distance between the stylion and dactylion landmarks.

Stylion-Meta III Length: With a sliding caliper parallel to the forearm-hand axis, measure the distance between the stylion and metacarpale III landmarks.

Suprasternale Height: Cadaver supine, with it head oriented in the Frankfort plane (relative) and firmly touching the headboard of the measuring table. With an anthropometer, measure the horizontal distance between the headboard and suprasternale landmark.

Tenth Rib Height: Cadaver supine, with its head oriented in the Frankfort plane (relative) and firmly touching the headboard of the measuring table. With an anthropometer, measure the horizontal distance from the headboard to the 10th rib landmark.

Thelion Height: Cadaver supine, with its head oriented in the Frankfort plane (relative) and firmly touching the headboard of the measuring table. With an anthropometer, measure the horizontal distance from the headboard to the thelion.

Thigh Length: A derived dimension calculated by subtracting tibiale height from trochanterion height.

Tibiale Height: Cadaver supine, with its head oriented in the Frankfort plane (relative) and firmly touching the headboard of the measuring table. With an anthropometer, measure the horizontal distance from the headboard to the lateral tibial landmark.

Tragion Height: Cadaver supine, with its head oriented in the Frankfort plane (relative) and firmly touching the headboard of the measuring table. With an anthropometer, measure the horizontal distance from the headboard to the tragion landmark.

Trochanterion Height: Cadaver supine, with its head oriented in the Frankfort plane (relative) and firmly touching the headboard of the measuring table. With an anthropometer, measure the horizontal distance from the headboard to the trochanterion landmark.

Torso Length: A dimension calculated by subtracting trochanterion height from chin/neck intersect height.

Torso Segment Length: A dimension calculated by subtracting trochanterion height from one half the value of mastoid height plus menton height.

Upper Thigh Circumference: With a tape perpendicular to the long axis of the leg and passing just below the lowest point of the gluteal furrow, measure the circumference of the thigh.

Waist Breadth: With a beam caliper, measure the horizontal breadth of the body at the level of the omphalion.

Waist Circumference: With a tape passing over the umbilicus and perpendicular to the long axis of the trunk, measure the circumference of the waist.

Waist Depth: With an anthropometer, measure the vertical distance between the measuring table and the anterior surface of the body at the level of the omphalion.

Weight: Body weighed with scales read to the nearest gram.

Wrist Breadth: With a spreading caliper, measure the maximum breadth of the forearm across the radial and the ulnar styloid processes.

Wrist Circumference: With a tape perpendicular to the long axis of the forearm, measure the minimum circumference of the wrist proximal to the radial and ulnar styloid processes.

APPENDIX D

CONVENTIONAL ANTHROPOMETRY

ANTHROPOMETRY *

VARIABLE NAME	SUBJECT 1	SUBJECT 2	SUBJECT 3	SUBJECT 4	SUBJECT 5	SUBJECT 6
WEIGHT	58.7	76.2	89.2	50.6	58.1	58.3
TRAGION HT	155.2	168.8	161.6	163.9	154.6	151.7
MASTOID HT	151.3	166.4	158.4	160.8	151.9	149.5
MENTON HT	144.7	157.5	151.8	153.6	143.8	142.7
CHIN/NECK HT	142.8	156.2	150.1	152.4	142.8	140.6
STATURE	167.8	181.7	174.2	175.9	168.8	164.5
CERVICALE HT	140.6	157.0	147.8	152.5	142.9	137.0
ACROMION HT	143.4	159.5	153.3	152.7	142.4	143.0
SUPRASTERNALE HT	135.6	149.6	142.9	144.3	136.4	135.9
THELION HT	124.1	136.4	132.5	131.4	124.0	123.7
10TH RIB HT	105.3	117.2	112.3	116.8	109.1	102.9
OMPHALION HT	101.5	110.3	103.9	119.4	105.0	98.9
ILIAC CREST HT	100.5	110.9	100.9	107.4	104.3	99.4
ANT SUP ILIAC SPINE HT	91.3	102.9	93.0	98.3	94.7	90.8
TROCHANTERION HT	85.7	96.9	86.7	93.8	90.1	86.5
CROTCH HT	75.2	85.1	77.8	82.7	79.0	74.8
FIBULA HT	39.4	46.7	41.3	44.4	43.5	42.1
TIBIALE HT	40.8	47.7	42.3	45.9	46.0	43.5
LATERAL TIBIAL HT	41.3	48.7	43.3	46.4	45.7	44.4
LATERAL MALLEOLUS HT	6.1	6.2	4.9	7.1	7.0	5.6
LATERAL SPHYRION HT	5.1	4.6	3.3	5.8	6.1	4.6
MEDIAL SPHYRION HT	6.8	7.3	5.7	7.3	7.4	6.0
CHEST DEPTH	20.3	21.7	22.7	19.1	19.3	22.2
WAIST DEPTH	16.8	21.3	21.5	16.9	19.1	10.5
BUTTOCK DEPTH	17.9	18.7	19.5	16.7	14.9	16.2
HEAD BREADTH	15.3	15.0	15.4	15.2	15.4	16.0
HEAD LENGTH	20.0	20.7	20.9	19.2	20.1	23.4
ELBOW BREADTH	7.0	7.2	9.1	7.5	7.5	7.9
WRIST BREADTH	5.5	6.0	6.0	6.0	5.9	6.6
HAND DEPTH AT META III	3.0	3.3	3.5	2.8	3.0	3.0
KNEE BREADTH	10.0	10.5	12.0	10.1	10.9	10.3
NECK BREADTH	13.7	12.6	15.1	10.4	11.2	13.9
NECK DEPTH	18.9	14.3	15.0	13.3	13.0	13.3
BIACROMION BREADTH	33.0	35.8	32.9	30.4	36.0	34.2
CHEST BREADTH	33.4	37.9	37.0	29.0	34.1	32.8
WAIST BREADTH	29.9	30.6	33.1	27.9	29.5	30.2
BISPINOUS BREADTH	21.6	24.3	21.4	20.2	23.1	0.0
HIP BREADTH	33.5	34.6	37.6	33.0	36.5	33.8
BALL OF FOOT L	167.7	181.7	174.2	175.9	168.8	164.4
ACROMION-RADIALE L	33.5	35.4	34.4	33.8	31.3	32.4

* BILATERAL MEASUREMENTS ARE PRESENTED IN THIS TABLE AS THE AVERAGE OF THE RIGHT AND LEFT MEASURED VALUES.
WEIGHT IS IN KILOGRAMS, ALL OTHER DIMENSIONS ARE IN CENTIMETERS.
ABBREVIATIONS CIRC=CIRCUMFERENCE, ANT SUP=ANTERIOR SUPERIOR, HT=HEIGHT, META=METACARPALE, L=LENGTH.

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ANTHROPOMETRY *

VARIABLE NAME	SUBJECT 1	SUBJECT 2	SUBJECT 3	SUBJECT 4	SUBJECT 5	SUBJECT 6
BALL HUMEROUS-RADIALE L	31.3	31.9	31.2	31.5	28.9	29.3
RADIALE-STYLION L	26.3	28.2	26.1	26.5	25.2	24.4
OLECRANON-ULNA STYLIOD L	27.3	30.6	28.5	28.6	28.3	27.1
BICRISTAL BREADTH	27.9	29.3	29.1	26.8	28.6	27.5
BITROCHANTERION BREADTH	31.8	32.7	35.1	31.3	32.5	30.7
STYLION-META III L	7.9	8.6	9.2	7.6	8.0	7.8
STYLION-DACTYLION L	0.0	0.0	0.0	18.0	0.0	0.0
HAND BREADTH	8.1	9.3	9.4	8.3	8.0	8.1
ANKLE BREADTH	6.8	7.2	7.8	6.8	6.9	6.6
HEAD CIRC	56.9	58.2	59.1	54.7	57.8	56.4
NECK CIRC	43.7	42.0	49.1	38.4	37.7	41.5
CHEST CIRC	94.0	101.4	105.5	83.1	89.5	93.2
MID TORSO CIRC	93.5	95.6	100.0	79.6	84.9	90.5
WAIST CIRC	81.3	87.3	93.3	73.5	78.3	81.2
HIP CIRC	88.4	90.0	101.1	84.4	88.5	87.1
UPPER THIGH CIRC	46.6	49.3	58.5	41.1	47.8	48.9
MID THIGH CIRC	37.6	45.0	54.0	33.8	44.0	42.3
KNEE CIRC	36.6	37.0	39.7	34.4	37.3	35.2
CALF CIRC	28.9	31.7	38.8	27.4	31.0	30.2
ANKLE CIRC	19.5	21.0	22.6	19.4	20.3	19.9
AXILLARY ARM CIRC	30.4	30.3	35.5	24.9	30.2	32.4
BICEPS CIRC	29.9	29.4	35.7	25.6	29.6	29.8
ELBOW CIRC	28.5	29.1	31.6	27.1	27.3	28.1
FOREARM CIRC	26.2	28.1	32.0	26.1	27.0	28.3
MID-FOREARM CIRC	20.0	20.7	28.3	18.2	22.1	25.0
WRIST CIRC	17.0	16.8	19.0	15.1	16.3	18.1
HAND CIRC	20.8	22.7	23.2	20.6	19.7	20.3
META III-DACTYLION L	0.0	12.4	0.0	0.0	10.8	10.7
FOOT L	24.2	26.3	23.8	24.2	24.1	22.8
FOOT BREADTH	8.4	9.8	10.1	9.0	8.9	8.8
ARCH CIRC	25.7	28.1	27.7	24.4	27.3	23.8
BALL OF FOOT CIRC	22.0	25.9	24.9	22.1	23.1	20.8
TORSO L	49.8	52.6	56.2	50.5	46.3	49.4
THIGH L	44.9	49.2	44.4	47.8	44.1	42.9
CALF L	34.0	40.4	36.6	38.6	38.5	37.5
L OF TORSO SEGMENT (MOD)	65.5	69.5	71.6	67.0	61.7	63.0

* BILATERAL MEASUREMENTS ARE PRESENTED IN THIS TABLE AS THE AVERAGE OF THE RIGHT AND LEFT MEASURED VALUES.
WEIGHT IS IN KILOGRAMS, ALL OTHER DIMENSIONS ARE IN CENTIMETERS.
ABBREVIATIONS CIRC=CIRCUMFERENCE, ANT SUP=ANTERIOR SUPERIOR, HT=HEIGHT, META=METACARPALE, L=LENGTH.

APPENDIX E

SEGMENTAL THREE-DIMENSIONAL ANTHROPOMETRY

SEGMENT NAME - HEAD

VARIABLE NAME	********* STANDING SUBJECTS ******** SUBJECT 1	SUBJECT 2	SUBJECT 3	********** SEATED SUBJECTS ********* SUBJECT 4	SUBJECT 5	SUBJECT 6
WEIGHT (GRAMS)	4024.	4152.	4821.	3361.	4104.	3471.
VOLUME (ML)	3818.	3973.	4410.	3199.	3898.	2413.
DENSITY (GRAMS PER ML)	1.055	1.046	1.096	1.052	1.055	1.030

********* 3-D SURFACE POINT LOCATION FROM CENTER OF MASS (CM) **********

VERTEX X	-1.2	-0.4	1.3	-1.1	-1.4	-2.2
VERTEX Y	-0.2	-0.3	0.4	0.2	0.3	2.6
VERTEX Z	-10.2	-10.6	-10.5	-9.4	-10.4	-9.8
PLANE POINT X	0.0	1.5	-0.1	1.6	0.7	0.9
PLANE POINT Y	-0.1	-0.2	0.3	0.1	-0.3	1.1
PLANE POINT Z	-10.4	-10.3	-10.3	-9.2	-10.2	-9.4
TRAGION, LEFT X	0.4	-0.4	-0.9	0.0	0.4	-0.2
TRAGION, LEFT Y	-7.2	-7.6	-7.8	-7.1	-7.3	-7.0
TRAGION, LEFT Z	1.6	2.4	2.1	2.8	2.7	2.0
INFRAORBITALE, LEFT X	8.6	7.9	8.3	8.3	8.2	7.9
INFRAORBITALE, LEFT Y	-3.1	-4.0	-3.5	-2.9	-3.0	-2.7
INFRAORBITALE, LEFT Z	1.5	2.5	2.0	2.9	2.7	2.7
SELLION X	10.0	9.9	9.8	9.5	9.6	9.6
SELLION Y	0.2	-0.2	0.0	-0.4	0.0	0.8
SELLION Z	-0.8	-0.1	0.0	0.4	0.8	1.2
FRANKFORT 4 X	-3.4	-5.8	-4.8	-4.0	-3.7	-4.2
FRANKFORT 4 Y	-6.8	-5.8	-7.3	-5.0	-5.4	-6.5
FRANKFORT 4 Z	6.2	4.7	5.0	5.6	5.9	4.1
CHIN/NECK 2 X	2.5	0.4	3.0	1.9	2.2	2.3
CHIN/NECK 2 Y	-5.8	-6.7	-6.3	-4.2	-5.0	-6.1
CHIN/NECK 2 Z	9.3	8.7	10.6	9.7	10.3	8.6
ANTERIOR CHIN X	10.2	10.0	11.4	8.4	9.9	9.3
ANTERIOR CHIN Y	0.1	0.5	0.5	0.4	0.5	0.5
ANTERIOR CHIN Z	11.5	12.5	11.2	11.9	12.3	10.9
TRAGION, RIGHT X	0.4	-0.4	-0.9	0.0	0.4	-0.2
TRAGION, RIGHT Y	7.6	7.6	7.8	7.6	7.8	8.1
TRAGION, RIGHT Z	1.6	2.4	2.1	2.8	2.7	2.8
INFRAORBITALE, RIGHT X	9.1	8.6	8.4	8.4	8.5	9.1
INFRAORBITALE, RIGHT Y	3.6	3.3	3.5	4.3	3.2	4.0
INFRAORBITALE, RIGHT Z	1.7	2.3	2.2	2.6	2.8	3.0

VARIABLE NAME	SUBJECT 1	SUBJECT 2	SUBJECT 3	SUBJECT 4	SUBJECT 5	SUBJECT 6
	********* STANDING SUBJECTS ********			********** SEATED SUBJECTS *********		
FRANKFORT 5 X	-3.4	-5.6	-6.6	-4.7	-3.0	-5.5
FRANKFORT 5 Y	6.7	6.4	6.3	5.4	6.9	6.2
FRANKFORT 5 Z	6.1	4.5	5.5	5.3	5.0	5.0
CHIN/NECK 6 X	1.8	0.4	2.4	1.5	2.1	1.2
CHIN/NECK 6 Y	7.0	7.5	7.2	5.6	6.4	7.1
CHIN/NECK 6 Z	8.7	7.8	9.6	8.7	9.9	8.0
FRANKFORT 3 X	-8.9	-10.3	-10.2	-7.7	-7.4	-9.0
FRANKFORT 3 Y	0.4	0.5	-0.8	1.1	3.4	0.9
FRANKFORT 3 Z	5.8	4.2	4.6	5.2	5.4	4.3
CHIN-OCCIPITAL X	-7.2	-7.5	-8.0	-6.9	-7.1	-7.0
CHIN-OCCIPITAL Y	-0.2	0.7	0.6	-1.1	-0.4	1.5
CHIN-OCCIPITAL Z	-7.7	-8.4	-8.6	-8.4	-7.9	-7.0

********* MOMENTS OF INERTIA (GMCM**2) **********

IXX	180581.	140847.	250666.	133241.	151802.	167464.
IYY	143805.	207475.	182309.	108166.	197006.	145353.
IZZ	207387.	232109.	277168.	145556.	230703.	111762.

********* DIRECTION ANGLES (DEG) **********

X ALPHA	61.	139.	57.	56.	133.	47.
X BETA	52.	90.	65.	63.	85.	97.
X GAMMA	129.	132.	137.	134.	137.	136.
Y ALPHA	143.	131.	144.	141.	135.	105.
Y BETA	88.	100.	88.	91.	110.	160.
Y GAMMA	127.	43.	125.	129.	53.	115.
Z ALPHA	110.	97.	103.	107.	102.	133.
Z BETA	38.	10.	24.	26.	20.	75.
Z GAMMA	59.	82.	69.	70.	73.	132.

SEGMENT NAME - TORSO

VARIABLE NAME	********* STANDING SUBJECTS ********			********** SEATED SUBJECTS *********		
	SUBJECT 1	SUBJECT 2	SUBJECT 3	SUBJECT 4	SUBJECT 5	SUBJECT 6
WEIGHT (GRAMS)	30630.	41060.	46182.	26828.	28005.	31262.
VOLUME (ML)	36772.	46301.	50683.	33887.	33721.	36487.
DENSITY (GRAMS PER ML)	0.833	0.887	0.911	0.792	0.831	0.857

********* 3-D SURFACE POINT LOCATION FROM CENTER OF MASS (CM) **********

	SUBJECT 1	SUBJECT 2	SUBJECT 3	SUBJECT 4	SUBJECT 5	SUBJECT 6
PROXIMAL POINT X	-1.3	4.9	-2.8	2.4	0.0	12.2
PROXIMAL POINT Y	-0.1	-0.5	-1.6	-0.4	-0.4	3.9
PROXIMAL POINT Z	-36.6	-39.7	-38.3	-40.1	-35.8	-33.6
PROXIMAL CENTROID X	6.1	5.5	4.6	9.0	6.4	10.6
PROXIMAL CENTROID Y	-0.2	-0.8	-0.3	-0.1	-1.5	-0.9
PROXIMAL CENTROID Z	-36.3	-39.4	-38.6	-39.7	-34.7	-33.7
CHIN/NECK 1 X		14.5	13.4	15.9	13.2	18.4
CHIN/NECK 1 Y		-0.9	0.5	-0.1	-1.2	-2.5
CHIN/NECK 1 Z		-31.9	-30.3	-31.8	-27.6	-24.4
CHIN/NECK 2 X	9.9	8.3	10.6	12.3	9.4	13.6
CHIN/NECK 2 Y	-5.9	-8.1	-6.6	-4.6	-7.0	-7.9
CHIN/NECK 2 Z	-33.1	-36.4	-33.2	-35.9	-31.4	-29.1
FRANKFORT 3 X	4.2	1.7	3.0	5.0	4.3	7.8
FRANKFORT 3 Y	-6.7	-6.7	-7.8	-4.9	-7.5	-7.3
FRANKFORT 3 Z	-36.3	-39.2	-38.3	-40.1	-36.0	-33.6
FRANKFORT 4 X	-1.3	-2.5	-2.8	2.4	0.5	4.0
FRANKFORT 4 Y	-0.1	-0.5	-1.6	-0.4	1.2	0.1
FRANKFORT 4 Z	-36.6	-38.8	-38.3	-40.1	-35.9	-34.2
CHIN/NECK 6 X	9.2	8.8	9.1	11.1	9.3	14.8
CHIN/NECK 6 Y	7.2	6.3	7.4	5.5	4.8	5.4
CHIN/NECK 6 Z	-34.0	-36.7	-34.6	-36.9	-31.7	-30.7
FRANKFORT 5 X	3.6	2.2	0.3	4.8	3.8	8.6
FRANKFORT 5 Y	6.7	5.5	4.8	4.3	4.6	5.1
FRANKFORT 5 Z	-36.4	-39.3	-38.3	-40.1	-36.2	-34.1
SHOULDER 1, LEFT X	8.3	6.6	7.3	9.4	9.4	9.4
SHOULDER 1, LEFT Y	-16.7	-17.3	-16.6	-13.3	-17.2	-17.3
SHOULDER 1, LEFT Z	-22.8	-23.2	-26.9	-24.0	-19.1	-20.3
SHOULDER 2, LEFT X	4.0	2.4	3.5	5.3	3.6	4.9
SHOULDER 2, LEFT Y	-15.6	-17.3	-16.7	-13.5	-19.7	-16.8
SHOULDER 2, LEFT Z	-30.2	-32.7	-32.6	-32.8	-26.3	-27.9

VARIABLE NAME	********* STANDING SUBJECTS ******** SUBJECT 1	SUBJECT 2	SUBJECT 3	********** SEATED SUBJECTS ********* SUBJECT 4	SUBJECT 5	SUBJECT 6
SHOULDER 3, LEFT X	-5.1	-6.7	-5.1	-2.4	-1.0	-3.7
SHOULDER 3, LEFT Y	-6.6	-20.3	-18.4	-14.4	-20.7	-16.2
SHOULDER 3, LEFT Z	-22.4	-28.4	-29.6	-27.3	-23.1	-20.8
CLAVICALE, LEFT X	12.5	11.5	12.3	13.6	11.8	15.0
CLAVICALE, LEFT Y	-1.6	-1.7	-1.4	-1.5	-2.6	-2.7
CLAVICALE, LEFT Z	-21.4	-23.4	-23.8	-23.4	-20.8	-19.6
SUPRASTERNALE X	12.5	11.9	12.8	14.0	12.0	15.4
SUPRASTERNALE Y	-0.2	-0.8	-0.3	-0.1	-1.5	-0.9
SUPRASTERNALE Z	-20.6	-22.7	-22.6	-22.4	-19.7	-19.0
OMPHYLION X	12.9	17.1	16.4	12.7	12.5	
OMPHYLION Y	-0.7	-2.0	0.4	0.0	-0.5	
OMPHYLION Z	12.6	16.0	15.5	11.6	10.9	
MID LEFT PLANE X	4.6	4.1	4.8	5.2	3.9	1.4
MID LEFT PLANE Y	-15.9	-16.8	-17.1	-15.5	-15.6	-15.8
MID LEFT PLANE Z	14.8	17.1	15.1	11.7	11.0	8.4
HIP 1, LEFT X	13.3	13.3	13.8	12.1	9.8	10.8
HIP 1, LEFT Y	-7.2	-10.5	-7.0	-6.1	-10.2	-9.5
HIP 1, LEFT Z	31.4	29.6	33.4	29.0	23.9	25.0
HIP 2, LEFT X	6.5	-2.3	6.5	4.4	-0.6	-4.1
HIP 2, LEFT Y	-15.6	-15.3	-16.1	-16.9	-17.3	-15.7
HIP 2, LEFT Z	19.3	20.3	20.6	19.4	17.4	17.3
HIP 3, LEFT X	-1.4	-4.2	-5.2	-3.6	-4.6	-7.5
HIP 3, LEFT Y	-6.8	-9.0	-12.0	-8.7	-15.2	-12.2
HIP 3, LEFT Z	33.4	29.9	28.4	28.0	10.3	22.8
DISTAL AXIS POINT X	6.1	5.5	4.6	9.0	6.4	10.6
DISTAL AXIS POINT Y	-0.2	-0.8	-0.3	-0.1	-1.5	-0.9
DISTAL AXIS POINT Z	40.5	42.5	44.9	37.3	35.5	34.5
DISTAL POINT X	6.1	5.5	4.6	2.4	2.0	1.7
DISTAL POINT Y	-0.2	-0.8	-0.3	1.0	0.2	1.1
DISTAL POINT Z	40.5	42.5	44.9	38.8	36.6	37.9
HIP 1, RIGHT X	11.8	13.8	13.0	11.9	11.9	6.0
HIP 1, RIGHT Y	4.3	8.2	10.4	9.3	7.4	12.1
HIP 1, RIGHT Z	35.4	28.1	34.6	28.1	14.7	19.6
HIP 2, RIGHT X	4.7	5.3	5.2	2.7	3.2	-1.5
HIP 2, RIGHT Y	14.3	14.7	15.3	14.2	16.7	16.8
HIP 2, RIGHT Z	18.3	19.3	21.5	21.0	16.3	14.5

VARIABLE NAME	********* STANDING SUBJECTS ******** SUBJECT 1	SUBJECT 2	SUBJECT 3	********** SEATED SUBJECTS ********* SUBJECT 4	SUBJECT 5	SUBJECT 6
HIP 3, RIGHT X	-2.0	-2.4	-6.1	-4.2	-3.4	-6.8
HIP 3, RIGHT Y	9.2	9.4	9.5	8.6	11.6	13.1
HIP 3, RIGHT Z	26.1	28.6	30.3	28.9	24.0	22.9
CLAVICALE, RIGHT X	12.9	11.6	12.3	13.7	12.1	15.7
CLAVICALE, RIGHT Y	1.4	0.3	1.3	1.5	-0.5	0.7
CLAVICALE, RIGHT Z	-21.7	-24.0	-24.0	-23.2	-21.1	-19.8
SHOULDER 1, RIGHT X	8.4	11.6	6.6	8.6	12.1	13.0
SHOULDER 1, RIGHT Y	14.1	14.3	16.4	18.7	14.1	15.8
SHOULDER 1, RIGHT Z	-22.2	-22.7	-26.6	-23.0	-19.7	-17.7
SHOULDER 2, RIGHT X	4.5	9.3	3.8	4.6	7.2	10.2
SHOULDER 2, RIGHT Y	15.0	16.3	15.7	16.6	16.5	17.3
SHOULDER 2, RIGHT Z	-29.2	-30.2	-33.3	-30.6	-27.1	-26.0
SHOULDER 3, RIGHT X	-4.2	-0.6	-6.4	-2.9	0.4	1.2
SHOULDER 3, RIGHT Y	15.8	21.2	18.8	15.0	18.7	17.3
SHOULDER 3, RIGHT Z	-22.5	-25.6	-23.7	-26.1	-21.3	-22.6
CERVICALE X	-4.9	-4.3	-6.6	0.6	-2.6	-0.9
CERVICALE Y	0.9	0.0	-0.8	1.0	-1.1	0.0
CERVICALE Z	-24.7	-28.4	-27.9	-30.9	-27.0	-24.2
MID RIGHT PLANE X	5.8	7.7	4.8	6.0	7.2	5.8
MID RIGHT PLANE Y	14.1	14.3	16.7	13.4	13.7	14.8
MID RIGHT PLANE Z	12.9	16.4	15.8	12.7	11.6	9.4

********* MOMENTS OF INERTIA (GMCM**2) **********

IXX	14436211.	20448977.	23142328.	13554588.	12464273.	13115587.
IYY	9315234.	14320269.	18062716.	9022039.	6635201.	7902188.
IZZ	2643447.	5007909.	6194000.	2301722.	3022393.	3541070.

********* DIRECTION ANGLES (DEG) **********

X ALPHA	39.	42.	34.	39.	47.	48.
X BETA	129.	132.	125.	129.	137.	138.
X GAMMA	94.	92.	92.	90.	89.	85.
Y ALPHA	52.	48.	56.	50.	44.	42.
Y BETA	39.	42.	35.	40.	47.	48.
Y GAMMA	95.	96.	98.	95.	98.	92.

SEGMENT NAME - TORSO

VARIABLE NAME	********* STANDING SUBJECTS ********			********** SEATED SUBJECTS *********		
	SUBJECT 1	SUBJECT 2	SUBJECT 3	SUBJECT 4	SUBJECT 5	SUBJECT 6
Z ALPHA	85.	84.	84.	87.	85.	93.
Z BETA	88.	86.	85.	86.	83.	85.
Z GAMMA	6.	7.	8.	5.	8.	6.

VARIABLE NAME	********* STANDING SUBJECTS ******** SUBJECT 1	SUBJECT 2	SUBJECT 3	********** SEATED SUBJECTS ********* SUBJECT 4	SUBJECT 5	SUBJECT 6
WEIGHT (GRAMS)	1794.	1941.	2248.	1538.	1815.	1719.
VOLUME (ML)	1782.	1935.	2298.	1562.	1788.	1724.
DENSITY (GRAMS PER ML)	1.007	1.003	0.981	0.983	1.012	0.997

********* 3-D SURFACE POINT LOCATION FROM CENTER OF MASS (CM) **********

SHOULDER 1 X	4.9	5.7	6.0	5.5	6.7	5.7
SHOULDER 1 Y	1.7	1.6	0.0	-0.4	2.2	0.0
SHOULDER 1 Z	-12.2	-13.7	-12.9	-12.0	-10.5	-10.8
SHOULDER 2 X	-0.8	0.6	1.3	-0.3	-0.4	0.7
SHOULDER 2 Y	1.2	2.1	1.2	1.3	1.9	2.6
SHOULDER 2 Z	-17.9	-19.5	-17.8	-18.3	-17.4	-17.8
SHOULDER 3 X	-5.0	-7.1	-5.4	-6.4	-5.6	-6.5
SHOULDER 3 Y	-4.8	-2.9	-3.7	-3.0	-3.8	-1.4
SHOULDER 3 Z	-10.0	-11.4	-5.3	-11.9	-10.8	-13.0
PROXIMAL CENTROID X	1.3	0.8	1.2	1.5	1.5	1.9
PROXIMAL CENTROID Y	1.3	0.6	-0.1	-0.2	1.9	1.0
PROXIMAL CENTROID Z	-14.8	-14.6	-14.0	-14.3	-14.1	-14.4
PROXIMAL POINT X	-0.8	-1.2	-0.7	-0.3	-0.4	-1.6
PROXIMAL POINT Y	1.2	1.5	0.9	1.3	1.9	2.0
PROXIMAL POINT Z	-17.9	-19.3	-17.9	-18.3	-17.4	-17.9
BALL OF HUMEROUS X	0.2	-0.6	0.5	-0.8	1.0	1.8
BALL OF HUMEROUS Y	3.6	3.9	2.5	2.8	3.9	3.6
BALL OF HUMEROUS Z	-15.0	-16.0	-16.1	-14.1	-14.0	-14.4
MID ANTERIOR X	4.7	5.5	6.1	3.9	4.9	4.6
MID ANTERIOR Y	1.3	0.6	-0.1	-0.2	1.9	1.0
MID ANTERIOR Z	-0.8	-2.0	-1.9	1.7	-0.6	-3.2
MID MEDIAL X				0.2		
MID MEDIAL Y				-4.6		
MID MEDIAL Z				2.4		
MID POSTERIOR X	-4.6	-4.7	-6.1		-3.7	-3.5
MID POSTERIOR Y	-1.2	-2.3	1.3		-0.9	-1.1
MID POSTERIOR Z	0.9	-1.4	-0.8		-0.2	-1.0
MID LATERAL X	-0.3	-1.2	1.2	-0.9	-1.7	-1.2
MID LATERAL Y	3.8	3.6	4.6	3.7	3.9	4.6
MID LATERAL Z	-0.3	[illegible]	-1.2	1.8	-0.5	-1.4

SEGMENT NAME - UPPER ARM, RIGHT

VARIABLE NAME	********* STANDING SUBJECTS ********			********** SEATED SUBJECTS *********		
	SUBJECT 1	SUBJECT 2	SUBJECT 3	SUBJECT 4	SUBJECT 5	SUBJECT 6
ELBOW 1 X	5.3	3.5	6.1	4.0	3.7	4.2
ELBOW 1 Y	1.1	4.5	1.1	-3.2	3.7	2.4
ELBOW 1 Z	12.0	12.7	11.1	11.7	7.5	8.3
ELBOW 2 X	3.7	3.4	3.5	1.2	3.0	2.1
ELBOW 2 Y	-3.0	-3.1	-5.1	-3.5	-1.5	-2.4
ELBOW 2 Z	12.9	13.9	11.4	16.1	14.6	15.6
ELBOW 3 X	-0.2	-2.6	-0.2	3.1	-0.7	0.3
ELBOW 3 Y	4.4	-1.1	3.7	4.0	3.9	4.0
ELBOW 3 Z	14.7	15.1	13.5	12.8	13.4	14.0
DISTAL CENTROID X	1.3	0.8	1.2	1.5	1.5	1.9
DISTAL CENTROID Y	1.3	0.6	-0.1	-0.2	1.9	1.0
DISTAL CENTROID Z	14.2	13.9	12.8	15.6	13.0	13.7
DISTAL POINT X	-2.1	0.6	-0.9	-0.2	0.4	1.4
DISTAL POINT Y	1.9	-3.9	-4.0	-0.5	0.4	0.0
DISTAL POINT Z	15.7	14.8	13.3	18.3	16.3	16.6

********* MOMENTS OF INERTIA (GMCM**2) **********

	SUBJECT 1	SUBJECT 2	SUBJECT 3	SUBJECT 4	SUBJECT 5	SUBJECT 6
IXX	135746.	122045.	158279.	136489.	?17.	125407.
IYY	126129.	159729.	139771.	133881.	.53.	119848.
IZZ	20382.	21266.	34490.	15624.	887.	18644.

********* DIRECTION ANGLES (DEG) **********

	SUBJECT 1	SUBJECT 2	SUBJECT 3	SUBJECT 4	SUBJECT 5	SUBJECT 6
X ALPHA	150.	136.	108.	30.	105.	91.
X BETA	60.	48.	19.	120.	15.	2.
X GAMMA	85.	79.	84.	93.	88.	88.
Y ALPHA	119.	133.	161.	60.	164.	175.
Y BETA	150.	137.	109.	30.	105.	91.
Y GAMMA	86.	88.	86.	90.	87.	85.
Z ALPHA	84.	81.	85.	88.	86.	85.
Z BETA	89.	95.	94.	91.	91.	93.
Z GAMMA	6.	11.	7.	2.	4.	6.

SEGMENT NAME - UPPER ARM, LEFT

VARIABLE NAME	********* STANDING SUBJECTS ******** SUBJECT 1	SUBJECT 2	SUBJECT 3	********** SEATED SUBJECTS ********* SUBJECT 4	SUBJECT 5	SUBJECT 6
WEIGHT (GRAMS)	1887.	2103.	2404.	1536.	1580.	1819.
VOLUME (ML)	1824.	2096.	2436.	1533.	1562.	1777.
DENSITY (GRAMS PER ML)	1.035	1.004	0.988	1.002	1.010	1.025
********* 3-D SURFACE POINT LOCATION FROM CENTER OF MASS (CM) **********						
SHOULDER 1 X	5.2	6.5	5.6	5.0	5.1	5.2
SHOULDER 1 Y	-0.6	-0.6	-1.9	-0.4	-2.2	0.8
SHOULDER 1 Z	-10.4	-11.1	-13.3	-11.0	-11.6	-10.6
SHOULDER 2 X	-0.4	-0.3	1.0	0.5	-2.0	1.0
SHOULDER 2 Y	-1.4	-1.1	-1.7	-1.2	-0.8	-1.5
SHOULDER 2 Z	-17.2	-18.8	-18.0	-19.1	-17.0	-17.2
SHOULDER 3 X	-6.0	-7.2	-5.1	-6.1	-5.1	-7.4
SHOULDER 3 Y	4.8	3.0	3.7	3.4	1.9	2.2
SHOULDER 3 Z	-8.2	-11.9	-13.7	-13.5	-13.0	-9.4
PROXIMAL CENTROID X	1.4	0.5	0.6	1.8	0.1	0.7
PROXIMAL CENTROID Y	-0.6	-0.6	0.2	-0.4	-0.8	0.0
PROXIMAL CENTROID Z	-14.4	-14.8	-14.3	-15.5	-14.1	-13.4
PROXIMAL POINT X	0.7	-1.6	-0.2	-0.2	-0.4	1.0
PROXIMAL POINT Y	-1.9	-0.7	-1.1	-0.8	-1.7	-1.5
PROXIMAL POINT Z	-17.2	-18.5	-18.2	-19.3	-17.2	-17.2
BALL OF HUMEROUS X	1.4	-0.4	-0.7	2.2	-0.6	2.2
BALL OF HUMEROUS Y	-3.9	-3.8	-3.6	-2.9	-3.0	-3.2
BALL OF HUMEROUS Z	-14.7	-15.1	-14.1	-15.9	-15.3	-14.4
MID ANTERIOR X	4.8	4.9	6.2	3.9	4.7	4.2
MID ANTERIOR Y	-0.6	-0.6	0.2	-0.4	-0.8	0.0
MID ANTERIOR Z	0.8	0.1	0.7	-1.1	-2.4	-0.1
MID POSTERIOR X	-5.4	-5.2	-6.0	-2.8	-4.3	-3.6
MID POSTERIOR Y	1.1	1.8	1.9	2.1	2.0	0.6
MID POSTERIOR Z	0.6	0.9	0.2	-0.4	-2.6	0.0
MID LATERAL X	-0.8	-1.6	-1.5	-1.5	-1.5	-0.7
MID LATERAL Y	-3.8	-3.5	-4.5	-3.8	-3.3	-4.9
MID LATERAL Z	0.8	0.1	0.5	-1.1	-2.4	0.5

VARIABLE NAME	********* STANDING SUBJECTS ********			********** SEATED SUBJECTS *********		
	SUBJECT 1	SUBJECT 2	SUBJECT 3	SUBJECT 4	SUBJECT 5	SUBJECT 6
ELBOW 1 X	5.0	4.0	4.4	3.6	1.9	3.6
ELBOW 1 Y	0.0	-3.2	-2.5	-2.8	-3.9	-2.6
ELBOW 1 Z	12.8	14.5	13.3	10.3	8.3	8.8
ELBOW 2 X	2.2	2.9	3.0	4.2	4.8	0.3
ELBOW 2 Y	4.3	4.1	4.0	1.9	0.1	4.0
ELBOW 2 Z	13.7	15.7	14.7	11.6	9.6	15.0
ELBOW 3 X	0.3	-1.2	-1.2	1.2	-2.3	0.9
ELBOW 3 Y	-4.4	-3.6	-3.7	-4.5	-5.4	-4.2
ELBOW 3 Z	14.1	15.4	14.4	13.4	10.9	14.0
DISTAL CENTROID X	1.4	0.5	0.6	1.8	0.1	0.7
DISTAL CENTROID Y	-0.6	-0.6	0.2	-0.4	-0.8	0.0
DISTAL CENTROID Z	13.8	15.6	14.6	14.4	12.6	14.1
DISTAL POINT X	-2.4	2.9	-0.2	-0.3	-0.9	-1.1
DISTAL POINT Y	-0.9	4.1	4.5	-0.4	1.8	1.1
DISTAL POINT Z	15.0	15.7	15.3	17.8	15.5	16.8

********* MOMENTS OF INERTIA (GMCM**2) **********

IXX	146121.	191072.	197653.	140909.	105299.	131808.
IYY	132330.	172340.	162290.	133541.	98772.	126955.
IZZ	23002.	27434.	36508.	11583.	16590.	21652.

********* DIRECTION ANGLES (DEG) **********

X ALPHA	113.	102.	162.	148.	86.	74.
X BETA	157.	168.	107.	122.	176.	163.
X GAMMA	88.	86.	86.	89.	87.	86.
Y ALPHA	23.	13.	72.	58.	5.	16.
Y BETA	112.	102.	163.	148.	86.	74.
Y GAMMA	93.	94.	89.	89.	90.	92.
Z ALPHA	86.	85.	87.	90.	90.	88.
Z BETA	89.	87.	88.	88.	87.	86.
Z GAMMA	4.	5.	4.	2.	2.	4.

SEGMENT NAME - FOREARM, RIGHT

VARIABLE NAME	SUBJECT 1	SUBJECT 2	SUBJECT 3	SUBJECT 4	SUBJECT 5	SUBJECT 6
	********* STANDING SUBJECTS ********			********** SEATED SUBJECTS *********		
WEIGHT (GRAMS)	971.	1292.	1624.	796.	1011.	985.
VOLUME (ML)	914.	1241.	1556.	754.	948.	957.
DENSITY (GRAMS PER ML)	1.061	1.017	1.035	1.051	1.066	1.029

********* 3-D SURFACE POINT LOCATION FROM CENTER OF MASS (CM) **********

VARIABLE NAME	SUBJECT 1	SUBJECT 2	SUBJECT 3	SUBJECT 4	SUBJECT 5	SUBJECT 6
ELBOW 1 X	-0.6	0.7	-3.7	1.5	-0.8	4.5
ELBOW 1 Y	-5.4	4.9	3.6	4.8	5.8	2.7
ELBOW 1 Z	-9.8	-11.3	-9.7	-7.4	-7.8	-8.4
ELBOW 2 X	-4.6	-2.9	2.8	7.6	3.8	2.1
ELBOW 2 Y	-3.9	-2.6	5.3	-1.8	-0.7	-3.3
ELBOW 2 Z	-9.8	-12.1	-9.5	-8.2	-11.1	-11.0
ELBOW 3 X	2.7	3.6	-1.4	-2.5	-2.9	-2.9
ELBOW 3 Y	0.8	-1.9	-2.8	3.8	0.3	1.3
ELBOW 3 Z	-11.1	-12.2	-11.9	-8.7	-11.3	-10.4
PROXIMAL CENTROID X	-0.1	0.0	0.4	0.6	0.0	0.1
PROXIMAL CENTROID Y	1.0	0.0	0.3	0.3	-0.6	0.2
PROXIMAL CENTROID Z	-11.0	-12.0	-11.0	-9.9	-11.5	-10.0
PROXIMAL POINT X	-0.6	1.8	0.8	-1.0	0.3	-1.3
PROXIMAL POINT Y	2.7	-4.0	-3.9	-3.1	-2.6	-3.2
PROXIMAL POINT Z	-11.3	-12.5	-12.4	-12.3	-12.7	-11.6
RADIALE X	3.6	-4.1	-2.3	-3.3	-3.4	-3.2
RADIALE Y	-1.0	1.9	-2.9	-0.2	0.7	0.9
RADIALE Z	-9.3	-10.0	-9.6	-10.2	-9.1	-9.3
MID ANTERIOR X	2.9		5.1			3.1
MID ANTERIOR Y	1.0		0.3			0.2
MID ANTERIOR Z	0.5		1.0			1.7
MID MEDIAL X	-3.6	-1.1		-0.9	0.5	-3.1
MID MEDIAL Y	-1.2	-3.4		-2.5	-3.5	-0.3
MID MEDIAL Z	1.2	2.7		0.5	1.2	1.5
MID POSTERIOR X		-3.5	-4.5	-2.8	-3.4	
MID POSTERIOR Y		0.0	0.5	0.3	-0.6	
MID POSTERIOR Z		1.9	0.6	0.4	2.0	
MID LATERAL X	1.8	0.8	0.4	1.5	-0.6	-0.2
MID LATERAL Y	-2.9	3.9	4.6	2.9	3.6	4.1
MID LATERAL Z	1.2	1.8	1.3	0.5	2.0	2.0

SEGMENT NAME - FOREARM, RIGHT

VARIABLE NAME	********* STANDING SUBJECTS ********			**** ****** SEATED SUBJECTS *********		
	SUBJECT 1	SUBJECT 2	SUBJECT 3	SUBJECT 4	SUBJECT 5	SUBJECT 6
RADIAL STYLOID X	0.6	2.7	-0.6	1.9	-0.6	1.8
RADIAL STYLOID Y	-2.0	2.1	3.4	2.9	2.4	3.2
RADIAL STYLOID Z	13.6	17.4	15.9	16.0	15.0	13.8
WRIST 1 X	-0.1	2.8	-1.2	3.2	0.3	1.2
WRIST 1 Y	-2.0	2.1	2.5	2.7	2.1	3.3
WRIST 1 Z	14.7	17.8	16.3	15.4	15.9	14.7
WRIST 2 X	-2.5	1.2	2.9			2.7
WRIST 2 Y	0.7	-2.5	1.2			-1.0
WRIST 2 Z	14.1	17.1	13.9			13.7
WRIST 3 X	1.3	-2.3	-0.8	-0.1	-1.7	-1.3
WRIST 3 Y	1.1	-0.5	-1.5	1.1	-0.9	0.0
WRIST 3 Z	14.6	18.1	16.2	16.2	16.2	15.3
WRIST 4 X				-0.1	0.6	0.5
WRIST 4 Y				-2.1	-2.0	-3.0
WRIST 4 Z				15.0	14.3	14.5
DISTAL CENTROID X	-0.1	0.0	0.4	0.6	0.0	0.1
DISTAL CENTROID Y	1.0	0.0	0.3	0.3	-0.6	0.2
DISTAL CENTROID Z	14.2	17.6	15.7	15.6	15.1	15.0
DISTAL POINT X	1.0	-0.4	-1.5	0.8	-1.8	-1.2
DISTAL POINT Y	3.4	2.4	0.6	2.2	0.5	0.9
DISTAL POINT Z	14.3	18.4	16.5	16.1	16.4	15.5

********* MOMENTS OF INERTIA (GMCM**2) **********

IXX	53769.	99103.	94083.	45121.	58650.	50492.
IYY	51543.	93642.	90327.	45414.	54563.	51338.
IZZ	5878.	12535.	16085.	4161.	7102.	6828.

********* DIRECTION ANGLES (DEG) **********

X ALPHA	31.	155.	97.	110.	145.	62.
X BETA	120.	115.	7.	20.	125.	28.
X GAMMA	87.	91.	90.	93.	93.	91.
Y ALPHA	59.	65.	173.	159.	55.	151.
Y BETA	31.	155.	97.	109.	145.	62.
Y GAMMA	93.	90.	89.	83.	89.	88.

VARIABLE NAME	********** STANDING SUBJECTS ********			********** SEATED SUBJECTS *********		
	SUBJECT 1	SUBJECT 2	SUBJECT 3	SUBJECT 4	SUBJECT 5	SUBJECT 6
Z ALPHA	91.	92.	88.	85.	93.	87.
Z BETA	85.	90.	89.	84.	91.	90.
Z GAMMA	5.	2.	2.	8.	3.	3.

VARIABLE NAME	********* STANDING SUBJECTS ******** SUBJECT 1	SUBJECT 2	SUBJECT 3	********** SEATED SUBJECTS ********* SUBJECT 4	SUBJECT 5	SUBJECT 6
WEIGHT (GRAMS)	1002.	1170.	1418.	838.	956.	1148.
VOLUME (ML)	916.	1115.	1370.	789.	903.	1077.
DENSITY (GRAMS PER ML)	1.094	1.050	1.037	1.059	1.061	1.067
********* 3-D SURFACE POINT LOCATION FROM CENTER OF MASS (CM) **********						
ELBOW 1 X	1.7	-3.6	3.8	-1.6	3.5	-1.6
ELBOW 1 Y	-4.2	-4.0	-3.1	-4.6	-3.7	-5.1
ELBOW 1 Z	-10.0	-10.8	-10.0	-8.3	-8.2	-7.6
ELBOW 2 X	5.5	4.1	3.2	3.0	3.3	3.4
ELBOW 2 Y	-0.5	-3.0	3.6	-2.9	0.1	1.2
ELBOW 2 Z	-10.0	-10.8	-10.3	-9.2	-11.8	-11.1
ELBOW 3 X	-2.6	-3.6	-2.3	-3.9	-1.7	-4.4
ELBOW 3 Y	0.0	1.4	-3.4	-1.2	-4.8	-1.8
ELBOW 3 Z	-11.4	-12.3	-10.3	-9.6	-6.0	-9.8
PROXIMAL CENTROID X	0.7	0.1	0.1	0.4	-0.5	-0.8
PROXIMAL CENTROID Y	-0.3	1.0	0.6	0.3	-0.4	1.3
PROXIMAL CENTROID Z	-10.8	-12.2	-10.2	-10.3	-10.5	-11.5
PROXIMAL POINT X	-1.5	-0.4	-0.0	0.9	0.4	-0.5
PROXIMAL POINT Y	3.0	3.4	4.4	3.7	2.5	2.5
PROXIMAL POINT Z	-12.1	-12.9	-10.7	-12.0	-13.1	-12.2
RADIALE X	-2.8	-3.7	-3.9	-3.8	-4.3	-4.3
RADIALE Y	-0.8	1.2	-2.6	-0.3	0.0	-0.5
RADIALE Z	-10.5	-11.0	-8.8	-9.6	-9.2	-9.6
MID ANTERIOR X	3.0		3.6	2.2	2.8	
MID ANTERIOR Y	-0.3		0.6	0.3	-0.4	
MID ANTERIOR Z	2.8		1.8	2.1	0.7	
MID MEDIAL X	-2.6	0.1				1.4
MID MEDIAL Y	0.5	3.9				4.3
MID MEDIAL Z	2.4	2.4				2.6
MID POSTERIOR X		-3.8	-4.5	-2.8	-3.2	-2.6
MID POSTERIOR Y		1.0	-1.1	1.4	1.3	1.3
MID POSTERIOR Z		2.9	1.0	1.6	0.9	3.5
MID LATERAL X	-0.5	-1.4	0.7	-1.1	-0.9	-0.6
MID LATERAL Y	-3.6	-2.8	-4.4	-3.0	-3.3	-3.3
MID LATERAL Z	2.1	2.9	1.2	2.0	1.2	3.8

VARIABLE NAME	********* STANDING SUBJECTS ******** SUBJECT 1	SUBJECT 2	SUBJECT 3 ********	********** SEATED SUBJECTS ********* SUBJECT 4	SUBJECT 5	SUBJECT 6 *********
RADIAL STYLOID X	1.5	-0.7	3.0	0.4	0.3	-0.3
RADIAL STYLOID Y	-3.0	-1.5	-1.0	-2.9	-3.3	-2.2
RADIAL STYLOID Z	15.3	15.9	15.1	14.7	14.5	14.6
WRIST 1 X	-1.6	-1.2	3.6	1.2	0.9	-1.7
WRIST 1 Y	0.5	2.5	-0.3	-3.0	-3.1	2.6
WRIST 1 Z	15.8	17.9	14.9	14.7	14.7	15.2
WRIST 2 X	2.5	0.0	1.3	2.2	2.1	2.4
WRIST 2 Y	-2.7	-1.6	2.7	0.0	0.3	0.9
WRIST 2 Z	15.6	17.4	13.6	14.0	13.8	14.0
WRIST 3 X	0.6		-1.2	-1.7	-1.6	
WRIST 3 Y	3.0		-1.0	0.0	-1.3	
WRIST 3 Z	15.7		15.5	16.3	15.6	
WRIST 4 X		2.7			-1.0	0.2
WRIST 4 Y		-0.6			2.3	4.2
WRIST 4 Z		16.4			14.8	14.7
DISTAL CENTROID X	0.7	0.1	0.1	0.4	-0.5	-0.8
DISTAL CENTROID Y	-0.3	1.0	0.6	0.3	-0.4	1.3
DISTAL CENTROID Z	15.9	17.2	14.7	15.1	14.8	14.5
DISTAL POINT X	-1.6	1.0	1.0	-1.2	-1.5	-1.3
DISTAL POINT Y	0.8	-0.5	-1.8	2.2	-0.8	3.3
DISTAL POINT Z	16.0	18.5	16.1	16.4	15.7	15.1

********* MOMENTS OF INERTIA (GMCM**2) **********

IXX	66809.	79549.	74527.	49139.	54025.	64400.
IYY	61567.	81393.	73376.	48503.	52064.	61287.
IZZ	5942.	10665.	14256.	4919.	6412.	9233.

********* DIRECTION ANGLES (DEG) **********

X ALPHA	116.	132.	34.	159.	73.	149.
X BETA	154.	138.	124.	111.	164.	59.
X GAMMA	90.	88.	90.	93.	90.	95.
Y ALPHA	154.	42.	56.	69.	17.	121.
Y BETA	64.	131.	35.	159.	73.	148.
Y GAMMA	94.	85.	87.	83.	85.	85.

SEGMENT NAME - FOREARM, LEFT

VARIABLE NAME	********* STANDING SUBJECTS ********			********** SEATED SUBJECTS *********		
	SUBJECT 1	SUBJECT 2	SUBJECT 3	SUBJECT 4	SUBJECT 5	SUBJECT 6
Z ALPHA	86.	92.	92.	93.	95.	91.
Z BETA	91.	86.	92.	90.	91.	83.
Z GAMMA	176.	4.	2.	4.	5.	7.

SEGMENT NAME - HAND, RIGHT

VARIABLE NAME	SUBJECT 1	SUBJECT 2	SUBJECT 3	SUBJECT 4	SUBJECT 5	SUBJECT 6
	********* STANDING SUBJECTS ********			********** SEATED SUBJECTS *********		
WEIGHT (GRAMS)	383.	490.	553.	320.	355.	302.
VOLUME (ML)	345.	461.	509.	295.	327.	288.
DENSITY (GRAMS PER ML)	1.105	1.062	1.087	1.077	1.088	1.056
********* 3-D SURFACE POINT LOCATION FROM CENTER OF MASS (CM) **********						
WRIST 1 X	0.5	-0.4	1.6	1.8	0.9	-0.2
WRIST 1 Y	-2.7	-2.9	-1.7	-1.4	-1.8	-3.5
WRIST 1 Z	-6.5	-6.9	-6.5	-6.3	-6.7	-5.5
WRIST 2 X	-2.1	-2.4	-2.4	-2.1		-1.9
WRIST 2 Y	-0.3	1.3	1.0	2.4		0.9
WRIST 2 Z	-6.3	-6.8	-6.0	-6.1		-5.8
WRIST 3 X	1.9	1.6	2.6	2.1	2.2	2.5
WRIST 3 Y	0.6	2.4	2.3	1.8	1.6	0.0
WRIST 3 Z	-6.1	-6.4	-6.2	-5.9	-6.6	-5.8
WRIST 4 X				-0.9	-1.2	0.5
WRIST 4 Y				3.5	3.2	3.0
WRIST 4 Z				-5.8	-6.0	-5.9
PROXIMAL CENTROID X	0.5	0.6	-0.1	0.6	0.5	0.5
PROXIMAL CENTROID Y	0.2	0.4	1.1	1.1	0.8	-0.3
PROXIMAL CENTROID Z	-6.2	-6.6	-6.2	-6.1	-6.5	-5.7
PROXIMAL POINT X	-0.4	-0.4	0.8	0.8	2.0	1.7
PROXIMAL POINT Y	3.4	-2.9	4.7	-1.9	2.2	-2.5
PROXIMAL POINT Z	-6.0	-6.9	-5.9	-6.6	-6.3	-5.6
METACARPALE III X	3.3	4.1	2.7	2.1	3.1	2.9
METACARPALE III Y	0.2	0.4	1.1	1.1	0.8	-0.3
METACARPALE III Z	1.7	1.1	3.0	1.9	1.4	0.9
MID LATERAL X	1.8	2.4	1.5	1.7	2.0	1.0
MID LATERAL Y	-3.2	-3.6	-3.5	-2.6	-3.2	-3.4
MID LATERAL Z	1.0	1.5	-1.4	2.4	0.4	1.3
MID MEDIAL X	0.6	0.7	0.2	-1.9	-0.1	0.5
MID MEDIAL Y	4.3	4.9	5.4	3.7	4.2	3.7
MID MEDIAL Z	0.3	0.3	0.4	1.2	0.1	0.6
DISTAL CENTROID X	0.5	0.6	-0.1	0.6	0.5	0.5
DISTAL CENTROID Y	0.2	0.4	1.1	1.1	0.8	-0.3
DISTAL CENTROID Z	6.1	5.6	6.8	7.0	6.0	4.1

SEGMENT NAME - HAND, RIGHT

VARIABLE NAME	SUBJECT 1	SUBJECT 2	SUBJECT 3	SUBJECT 4	SUBJECT 5	SUBJECT 6
	********* STANDING SUBJECTS		*********	********** SEATED SUBJECTS		*********
DACTYLION X	-5.3	-5.9	-4.8	-4.4	-4.5	-6.1
DACTYLION Y	-0.2	0.2	-0.2	-0.4	0.6	-0.5
DACTYLION Z	7.4	7.6	4.1	8.5	8.7	4.4
********* MOMENTS OF INERTIA (GMCM**2) **********						
IXX	6702.	10142.	10290.	7046.	6970.	4098.
IYY	5686.	8963.	8750.	4803.	5167.	3559.
IZZ	1669.	3943.	3854.	1551.	1003.	889.
********* DIRECTION ANGLES (DEG) **********						
X ALPHA	20.	19.	151.	32.	35.	49.
X BETA	108.	108.	61.	58.	58.	135.
X GAMMA	81.	84.	89.	86.	77.	74.
Y ALPHA	74.	73.	118.	121.	123.	54.
Y BETA	18.	18.	150.	31.	33.	45.
Y GAMMA	82.	86.	100.	93.	88.	67.
Z ALPHA	101.	97.	94.	95.	101.	118.
Z BETA	95.	91.	99.	89.	99.	95.
Z GAMMA	12.	7.	10.	4.	14.	28.

SEGMENT NAME - HAND, LEFT

VARIABLE NAME	********* STANDING SUBJECTS ******** SUBJECT 1	SUBJECT 2	SUBJECT 3	********** SEATED SUBJECTS ********* SUBJECT 4	SUBJECT 5	SUBJECT 6
WEIGHT (GRAMS)	324.	409.	497.	328.	351.	331.
VOLUME (ML)	298.	383.	463.	305.	325.	302.
DENSITY (GRAMS PER ML)	1.091	1.068	1.072	1.075	1.080	1.098
********* 3-D SURFACE POINT LOCATION FROM CENTER OF MASS (CM) **********						
WRIST 1 X	0.1	0.5	-1.4	0.2	0.1	0.5
WRIST 1 Y	2.6	2.6	2.8	2.5	2.5	2.9
WRIST 1 Z	-5.8	-6.4	-6.2	-6.2	-5.9	-5.2
WRIST 2 X		-1.9	-2.1	-2.1	-1.6	-2.3
WRIST 2 Y		0.8	-1.2	-0.7	-0.6	-0.2
WRIST 2 Z		-6.4	-5.8	-6.4	-5.6	-5.5
WRIST 3 X	2.4	2.6	2.6	2.4	0.5	1.7
WRIST 3 Y	-1.8	-1.3	-0.1	-0.9	-3.3	-1.6
WRIST 3 Z	-5.7	-6.9	-6.6	-6.4	-6.4	-5.9
WRIST 4 X	-0.1			-0.6		-0.1
WRIST 4 Y	-3.6			-3.3		-3.3
WRIST 4 Z	-5.6			-6.5		-6.0
PROXIMAL CENTROID X	0.7	0.9	0.6	0.4	0.4	0.3
PROXIMAL CENTROID Y	-0.8	-0.3	-0.3	-0.9	-0.7	-0.6
PROXIMAL CENTROID Z	-5.7	-6.6	-6.3	-6.4	-6.2	-5.7
PROXIMAL POINT X	2.0	0.9	2.6	0.9	1.9	0.5
PROXIMAL POINT Y	-3.1	-3.5	-0.1	-3.7	-2.5	2.9
PROXIMAL POINT Z	-5.5	-7.1	-6.6	-6.4	-6.6	-5.2
METACARPALE III X	2.8	3.7	2.7	3.2	3.4	3.2
METACARPALE III Y	-0.8	-0.3	-0.3	-0.9	-0.7	-0.6
METACARPALE III Z	2.3	1.3	2.1	1.0	1.0	1.4
MID LATERAL X	2.9	1.2	1.2	1.7	1.7	2.4
MID LATERAL Y	2.0	3.4	3.6	2.8	2.9	2.5
MID LATERAL Z	-1.6	2.1	0.6	1.6	1.7	1.8
MID MEDIAL X	1.0	0.3	0.0	0.2	0.7	-0.6
MID MEDIAL Y	-4.8	-4.3	-4.6	-4.7	-4.6	-4.2
MID MEDIAL Z	1.1	1.5	0.5	0.0	0.2	0.7
DISTAL CENTROID X	0.7	0.9	0.3	0.4	0.4	0.3
DISTAL CENTROID Y	-0.8	-0.3	-0.3	-0.9	-0.7	-0.6
DISTAL CENTROID Z	4.0	6.3	6.9	6.5	6.3	6.1

VARIABLE NAME	STANDING SUBJECTS SUBJECT 1	SUBJECT 2	SUBJECT 3	SEATED SUBJECTS SUBJECT 4	SUBJECT 5	SUBJECT 6
DACTYLION X		-5.3	-4.9	-3.4	-4.8	-5.0
DACTYLION Y		-1.2	-1.2	-1.0	0.2	0.4
DACTYLION Z		8.3	7.3	9.7	7.6	7.7

********* MOMENTS OF INERTIA (GMCM**2) *********

IXX	5330.	7635.	9346.	7113.	6243.	5599.
IYY	4465.	7498.	7728.	5099.	4948.	5688.
IZZ	1631.	1168.	3174.	2128.	1526.	1128.

********* DIRECTION ANGLES (DEG) *********

Y ALPHA	55.	13.	176.	19.	39.	5.
X BETA	40.	98.	86.	71.	52.	90.
X GAMMA	74.	80.	95.	91.	86.	84.
Y ALPHA	139.	84.	94.	109.	127.	[illegible]
Y BETA	51.	11.	176.	19.	39.	7.
Y GAMMA	100.	85.	90.	93.	99.	64.
Z ALPHA	108.	100.	94.	91.	99.	96.
Z BETA	96.	94.	90.	87.	85.	96.
Z GAMMA	19.	11.	4.	4.	11.	9.

VARIABLE NAME	********* STANDING SUBJECTS ******** SUBJECT 1	SUBJECT 2	SUBJECT 3	********** SEATED SUBJECTS ********* SUBJECT 4	SUBJECT 5	SUBJECT 6
WEIGHT (GRAMS)	5601.	7204.	9770.	4133.	6812.	5532.
VOLUME (ML)	5518.	7180.	9567.	4014.	6673.	5575.
DENSITY (GRAMS PER ML)	1.021	1.016	1.021	1.034	1.022	C.995

********* 3-D SURFACE POINT LOCATION FROM CENTER OF MASS (CM) *********

HIP 1 X	3.3	7.2	10.3	5.3	4.2	8.3
HIP 1 Y	-7.3	-3.5	-2.8	-4.4	-3.9	3.3
HIP 1 Z	-10.4	-19.8	-14.8	-8.9	-10.1	-16.1
HIP 2 X	1.0	4.4	2.4	8.8	12.1	9.1
HIP 2 Y	5.6	6.4	6.7	0.7	2.2	8.5
HIP 2 Z	-26.4	-20.9	-26.4	-19.0	-20.5	-24.9
HIP 3 X	-8.5	-7.0	-9.3	-2.4	2.1	-0.4
HIP 3 Y	-1.6	3.1	-0.3	2.1	4.1	7.0
HIP 3 Z	-14.0	-17.9	-18.4	-22.0	-24.4	-25.8
PROXIMAL CENTROID X	1.1	0.8	1.2	2.2	0.1	0.7
PROXIMAL CENTROID Y	-1.9	-1.3	-1.0	-2.0	-2.0	-0.7
PROXIMAL CENTROID Z	-16.7	-18.1	-16.9	-13.6	-14.8	-13.6
PROXIMAL POINT X	-2.7	2.5	-5.0	-4.3	-6.7	-1.1
PROXIMAL POINT Y	6.1	7.4	7.5	1.7	2.3	6.6
PROXIMAL POINT Z	-26.6	-28.9	-27.7	-21.5	-22.9	-25.9
TROCHANTERION X	3.2	4.1	-0.2	4.2	5.7	2.0
TROCHANTERION Y	5.6	6.9	8.3	4.9	6.2	8.0
TROCHANTERION Z	-16.1	-18.3	-15.7	-16.1	-15.3	-18.9
MID ANTERIOR X	6.2	6.7	8.4	5.5	6.2	6.2
MID ANTERIOR Y	-1.9	-1.3	-1.0	-2.0	-2.0	-0.7
MID ANTERIOR Z	5.2	6.2	2.9	6.8	4.0	1.9
MID MEDIAL X	-2.4	-1.7	0.1	-2.0	-1.5	-0.3
MID MEDIAL Y	-8.0	-7.0	-10.2	-5.1	-7.7	-7.8
MID MEDIAL Z	5.3	6.7	3.4	7.3	4.0	1.9
MID LATERAL X	1.2		1.1	-0.2	0.3	1.3
MID LATERAL Y	4.2		7.7	3.5	4.3	6.3
MID LATERAL Z	6.4		3.4	7.9	6.3	4.0
KNEE 1 X	6.7	6.6	7.1	6.2	3.3	3.3
KNEE 1 Y	-2.7	-1.5	-0.4	-2.8	-3.2	-2.2
KNEE 1 Z	25.1	26.9	24.6	26.6	28.5	25.7

SEGMENT NAME - THIGH, RIGHT

VARIABLE NAME	********* STANDING SUBJECTS ********* SUBJECT 1	SUBJECT 2	SUBJECT 3	********** SEATED SUBJECTS ********* SUBJECT 4	SUBJECT 5	SUBJECT 6
KNEE 2 X	-0.4	-2.5	0.6	0.0	-1.7	-2.5
KNEE 2 Y	-7.8	-6.0	-7.3	-6.3	-6.5	-6.0
KNEE 2 Z	24.7	26.2	24.9	25.1	26.8	21.7
KNEE 3 X	0.1	-1.8	-0.9	2.1	2.3	2.0
KNEE 3 Y	3.2	4.7	4.9	3.2	2.6	3.6
KNEE 3 Z	24.3	25.2	23.7	23.8	25.2	24.3
DISTAL CENTROID X	1.1	0.0	1.2	2.2	0.1	0.7
DISTAL CENTROID Y	-1.9	-2.3	-1.0	-2.0	-2.0	-0.7
DISTAL CENTROID Z	24.7	26.3	24.3	24.8	26.2	23.3
DISTAL POINT X	-2.0	6.8	0.6	6.2	2.4	3.7
DISTAL POINT Y	-7.3	-5.0	-7.3	-2.8	-4.4	1.2
DISTAL POINT Z	24.9	26.3	24.9	26.6	28.5	25.5
MID POSTERIOR X		-7.4				
MID POSTERIOR Y		0.5				
MID POSTERIOR Z		5.9				

********* MOMENTS OF INERTIA (GMCM**2) **********

IXX	1033745.	1341170.	1720483.	662573.	1189735.	876017.
IYY	1086422.	1428504.	1603829.	682530.	1307321.	839048.
IZZ	171488.	191394.	519984.	68185.	205507.	192952.

********* DIRECTION ANGLES (DEG) **********

X ALPHA	12.	45.	41.	34.	10.	47.
X BETA	101.	134.	49.	123.	79.	136.
X GAMMA	95.	94.	92.	95.	91.	99.
Y ALPHA	79.	45.	131.	57.	101.	44.
Y BETA	14.	44.	41.	33.	13.	46.
Y GAMMA	84.	90.	87.	86.	83.	91.
Z ALPHA	87.	87.	87.	88.	87.	83.
Z BETA	98.	92.	91.	96.	96.	96.
Z GAMMA	8.	3.	3.	6.	7.	9.

VARIABLE NAME	********* STANDING SUBJECTS ******** SUBJECT 1	SUBJECT 2	SUBJECT 3	********** SEATED SUBJECTS ********* SUBJECT 4	SUBJECT 5	SUBJECT 6
WEIGHT (GRAMS)	5839.	8082.	9899.	5008.	6090.	5732.
VOLUME (ML)	5646.	7989.	9711.	4899.	6096.	5530.
DENSITY (GRAMS PER ML)	1.035	1.013	1.020	1.017	1.001	1.038
********* 3-D SURFACE POINT LOCATION FROM CENTER OF MASS (CM) **********						
HIP 1 X	4.2	7.7	8.9	7.4	5.8	5.6
HIP 1 Y	6.0	0.8	3.3	1.6	3.1	1.3
HIP 1 Z	-15.4	-17.9	-15.6	-12.7	-10.5	-9.5
HIP 2 X	4.4	-6.7	2.9	9.9	9.7	7.2
HIP 2 Y	-5.4	-6.4	-7.0	-1.4	-3.1	-5.1
HIP 2 Z	-25.9	-28.0	-27.0	-20.4	-21.9	-16.3
HIP 3 X	-5.6	-9.9	-9.1	-4.0	5.1	-3.0
HIP 3 Y	-6.1	0.1	-2.8	0.0	-4.0	-5.2
HIP 3 Z	-19.0	-18.7	-19.6	-23.5	-24.7	-25.2
PROXIMAL CENTROID X	0.7	0.8	0.7	1.4	1.6	0.6
PROXIMAL CENTROID Y	1.2	1.0	1.2	2.2	2.3	1.0
PROXIMAL CENTROID Z	-17.2	-18.2	-16.7	-16.4	-14.0	-14.4
PROXIMAL POINT X	3.2	-3.5	-3.9	-4.5	5.1	2.3
PROXIMAL POINT Y	-6.7	-6.8	-9.0	-0.3	-4.0	-8.6
PROXIMAL POINT Z	-26.1	-29.0	-27.7	-23.5	-24.7	-25.5
TROCHANTERION X	3.0	-0.2	3.2	3.5	5.7	-0.4
TROCHANTERION Y	-6.7	-7.9	-7.3	-6.8	-6.0	-6.4
TROCHANTERION Z	-16.8	-18.4	-15.4	-15.9	-15.7	-17.8
MID ANTERIOR X	6.1	7.1	8.1	4.9	6.6	
MID ANTERIOR Y	1.2	1.0	1.2	2.2	2.3	
MID ANTERIOR Z	4.7	3.1	1.6	7.7	4.0	
MID MEDIAL X	-3.6	0.6	-1.2	-2.6	-2.0	-0.5
MID MEDIAL Y	6.0	8.4	9.3	4.8	7.2	8.0
MID MEDIAL Z	4.8	3.8	1.5	8.8	4.6	2.5
MID LATERAL X	0.8	1.1	0.9	0.5		-1.0
MID LATERAL Y	-5.2	-6.4	-8.2	-4.5		-6.6
MID LATERAL Z	5.3	3.6	2.9	8.5		4.4
KNEE 1 X	7.4	7.0	7.1	5.6	4.8	4.7
KNEE 1 Y	1.6	-1.0	1.6	3.6	3.6	-0.2
KNEE 1 Z	23.5	26.5	24.5	29.8	24.8	25.1

SEGMENT NAME - THIGH, LEFT

VARIABLE NAME	SUBJECT 1	SUBJECT 2	SUBJECT 3	SUBJECT 4	SUBJECT 5	SUBJECT 6
	********* STANDING SUBJECTS ********			********** SEATED SUBJECTS *********		
KNEE 2 X	-1.1	1.2	-1.0	-2.7	-2.7	2.0
KNEE 2 Y	6.5	6.1	7.4	6.2	6.3	5.5
KNEE 2 Z	23.7	26.7	24.7	28.0	22.7	23.0
KNEE 3 X	-0.8	-1.1	0.3	3.3	-3.9	-0.2
KNEE 3 Y	-4.2	-4.5	-4.5	-1.4	1.4	-3.8
KNEE 3 Z	23.2	26.7	24.0	28.0	21.5	22.8
DISTAL CENTROID X	0.7	0.8	0.7	1.4	1.6	0.6
DISTAL CENTROID Y	1.2	1.0	1.2	2.2	2.3	1.0
DISTAL CENTROID Z	23.2	20.2	24.5	28.0	23.4	22.7
DISTAL POINT X	5.9	6.1	2.0	5.6	3.9	4.7
DISTAL POINT Y	3.6	-2.2	6.3	3.6	9.7	-0.2
DISTAL POINT Z	23.6	26.6	24.8	29.8	24.4	25.1
MID POSTERIOR X					-3.9	-4.3
MID POSTERIOR Y					-2.8	1.0
MID POSTERIOR Z					6.5	3.3

********* MOMENTS OF INERTIA (GMCM**2) **********

IXX	963855.	1489667.	1520005.	1048578.	928908.	857474.
IYY	942489.	1650753.	1750953.	1119506.	971799.	891582.
IZZ	132187.	246618.	358294.	137591.	196977.	203280.

********* DIRECTION ANGLES (DEG) **0*******

X ALPHA	107.	24.	17.	15.	135.	135.
X BETA	19.	114.	107.	106.	45.	45.
X GAMMA	100.	88.	86.	89.	93.	86.
Y ALPHA	163.	65.	73.	74.	135.	135.
Y BETA	107.	26.	20.	17.	135.	135.
Y GAMMA	89.	100.	100.	98.	88.	84.
Z ALPHA	91.	87.	90.	88.	92.	83.
Z BETA	80.	80.	79.	81.	87.	87.
Z GAMMA	10.	11.	13.	8.	4.	8.

VARIABLE NAME	STANDING SUBJECTS SUBJECT 1	SUBJECT 2	SUBJECT 3	SEATED SUBJECTS SUBJECT 4	SUBJECT 5	SUBJECT 6
WEIGHT (GRAMS)	2192.	2876.	3779.	2251.	2744.	2282.
VOLUME (ML)	2056.	2727.	3522.	2140.	2596.	2161.
DENSITY (GRAMS PER ML)	1.062	1.054	1.073	1.052	1.057	1.057

********* 3-D SURFACE POINT LOCATION FROM CENTER OF MASS (CM) **********

KNEE 1 X	6.9	6.3	5.9	4.5	3.8	3.9
KNEE 1 Y	-2.6	-4.7	-6.4	-0.4	-1.6	-2.9
KNEE 1 Z	-16.0	-19.1	-16.9	-21.0	-20.8	-19.5
KNEE 2 X	-1.1	-3.9	-3.5	0.2	-0.1	-3.5
KNEE 2 Y	-5.9	-5.6	-7.2	-5.4	-5.9	-5.2
KNEE 2 Z	-16.0	-18.6	-16.7	-18.0	-18.7	-15.7
KNEE 3 X	1.5	-0.2	3.9	-0.2	2.2	3.7
KNEE 3 Y	4.5	4.4	2.7	4.5	3.9	2.7
KNEE 3 Z	-16.9	-19.7	-18.0	-17.4	-18.2	-17.7
PROXIMAL CENTROID X	0.7	0.0	0.7	-0.3	0.8	0.4
PROXIMAL CENTROID Y	-0.8	-1.3	-2.3	-0.6	-0.7	-1.0
PROXIMAL CENTROID Z	-16.4	-19.2	-17.3	-17.5	-18.1	-16.8
PROXIMAL POINT X	-4.6	0.7	2.9	4.4	4.6	3.0
PROXIMAL POINT Y	-2.6	4.1	3.4	0.4	0.9	-3.9
PROXIMAL POINT Z	-16.6	-19.7	-18.0	-20.9	-20.8	-19.3
TIBIALE X	-0.8	-2.5	-3.0	1.7	-0.2	-2.2
TIBIALE Y	-5.3	-5.2	-6.2	-4.6	-5.7	-5.6
TIBIALE Z	-13.4	-15.3	-13.7	-14.2	-15.5	-12.8
LATERAL TIBIALE X		1.9	3.9	-0.1	1.4	4.3
LATERAL TIBIALE Y		3.9	3.0	4.8	4.5	2.2
LATERAL TIBIALE Z		-16.2	-14.8	-13.9	-15.3	-14.7
MID ANTERIOR X	2.8	4.5	5.2	3.9	4.6	4.3
MID ANTERIOR Y	-0.8	-1.3	-2.3	-0.6	-0.7	-1.0
MID ANTERIOR Z	2.2	0.2	2.5	-1.1	0.1	1.3
MID MEDIAL X	-2.5	-1.7	-2.6	-1.1	-0.8	-1.9
MID MEDIAL Y	-2.6	-3.6	-4.5	-4.3	-4.5	-3.7
MID MEDIAL Z	1.9	0.5	2.5	-1.1	0.0	1.3
MID LATERAL X	0.0	1.3	3.7	0.8	1.1	0.7
MID LATERAL Y	5.1	4.0	4.2	4.3	5.2	4.6
MID LATERAL Z	2.1	0.5	2.0	-1.0	-0.2	1.4

VARIABLE NAME	********* STANDING SUBJECTS ******** SUBJECT 1	SUBJECT 2	SUBJECT 3	********** SEATED SUBJECTS ********* SUBJECT 4	SUBJECT 5	SUBJECT 6
LATERAL MALLEOLUS X	1.3	1.4	2.1	-0.2	1.1	-0.5
LATERAL MALLEOLUS Y	2.5	2.0	1.2	2.5	3.1	2.4
LATERAL MALLEOLUS Z	22.3	25.5	23.6	23.6	23.0	22.7
ANKLE 1 X	3.8	4.7	4.8	5.1	5.0	4.4
ANKLE 1 Y	-3.4	-4.3	-5.4	-1.2	-3.1	-2.3
ANKLE 1 Z	22.2	26.4	24.0	23.7	23.5	23.5
ANKLE 2 X	-3.0	-3.5	-2.1	-1.6	-3.4	-2.2
ANKLE 2 Y	-2.0	-2.8	-3.9	-3.4	-3.6	-3.0
ANKLE 2 Z	22.0	25.8	23.2	24.4	23.1	20.9
ANKLE 3 X	1.0	2.0	2.4	-2.4	1.9	-0.3
ANKLE 3 Y	2.3	1.0	0.8	2.1	2.4	2.1
ANKLE 3 Z	23.0	26.3	24.5	24.4	23.8	24.2
DISTAL CENTROID X	0.7	0.0	0.7	-0.3	0.8	0.4
DISTAL CENTROID Y	-0.8	-1.3	-2.3	-0.6	-0.7	-1.0
DISTAL CENTROID Z	22.5	26.5	23.8	24.3	24.1	23.6
DISTAL POINT X	-0.6	0.4	1.8	-5.1	0.4	-0.6
DISTAL POINT Y	2.5	2.0	1.3	-0.9	3.0	2.1
DISTAL POINT Z	23.0	27.0	24.5	24.9	24.1	24.2

********* MOMENTS OF INERTIA (GMCM**2) **********

IXX	309872.	534070.	480431.	336418.	384068.	302982.
IYY	289628.	492707.	506582.	348408.	402251.	317387.
IZZ	35460.	22826.	60453.	13064.	24390.	18123.

********* DIRECTION ANGLES (DEG) **********

X ALPHA	2.	21.	34.	48.	29.	7.
X BETA	94.	69.	124.	138.	61.	84.
X GAMMA	89.	90.	89.	90.	87.	87.
Y ALPHA	86.	111.	56.	42.	119.	96.
Y BETA	5.	21.	34.	48.	29.	6.
Y GAMMA	92.	87.	89.	88.	90.	89.
Z ALPHA	91.	89.	92.	91.	93.	93.
Z BETA	88.	92.	90.	92.	91.	91.
Z GAMMA	2.	2.	2.	2.	3.	3.

VARIABLE NAME	********* STANDING SUBJECTS ******** SUBJECT 1	SUBJECT 2	SUBJECT 3	********** SEATED SUBJECTS ********* SUBJECT 4	SUBJECT 5	SUBJECT 6
WEIGHT (GRAMS)	2288.	3039.	3794.	2056.	2510.	2345.
VOLUME (ML)	2086.	2896.	3548.	1915.	2410.	2136.
DENSITY (GRAMS PER ML)	1.097	1.049	1.069	1.074	1.043	1.098

********* 3-D SURFACE POINT LOCATION FROM CENTER OF MASS (CM) **********

KNEE 1 X	7.2	6.8	6.4	4.5	3.1	4.0
KNEE 1 Y	4.2	3.1	5.7	-0.7	0.5	0.4
KNEE 1 Z	-15.3	-19.0	-16.0	-20.6	-21.3	-19.7
KNEE 2 X	-2.1	-1.3	-3.5	-0.8	-2.0	0.5
KNEE 2 Y	5.8	5.6	6.2	5.4	5.1	5.0
KNEE 2 Z	-15.4	-18.8	-15.6	-17.2	-17.0	-17.2
KNEE 3 X	2.1	1.9	4.1	1.6	1.3	-0.7
KNEE 3 Y	-4.1	-4.2	-3.5	-4.0	-5.1	-5.1
KNEE 3 Z	-16.3	-19.1	-17.1	-16.9	-18.6	-17.4
PROXIMAL CENTROID X	1.0	0.9	1.3	-0.3	0.4	0.0
PROXIMAL CENTROID Y	1.6	1.0	1.3	0.3	0.1	0.2
PROXIMAL CENTROID Z	-15.8	-18.9	-16.3	-15.9	-18.4	-16.9
PROXIMAL POINT X	-0.1	-3.4	3.1	4.1	2.5	4.0
PROXIMAL POINT Y	-4.2	-2.5	-4.3	0.3	2.9	0.4
PROXIMAL POINT Z	-16.4	-19.0	-17.1	-20.7	-21.3	-19.7
TIBIALE X	-1.4	-0.1	-3.1	1.6	1.5	0.3
TIBIALE Y	5.5	5.3	5.5	5.3	4.5	4.9
TIBIALE Z	-12.6	-15.1	-12.1	-15.7	-16.1	-13.2
LATERAL TIBIALE X		3.9	3.7	1.8	3.5	3.6
LATERAL TIBIALE Y		-3.3	-3.8	-4.8	-4.1	-3.9
LATERAL TIBIALE Z		-16.2	-14.0	-12.8	-17.4	-14.1
MID ANTERIOR X	3.1	4.9	5.7	4.2	4.2	4.0
MID ANTERIOR Y	1.6	1.0	1.3	0.3	0.1	0.2
MID ANTERIOR Z	3.1	0.0	-0.2	0.8	0.8	-0.3
MID MEDIAL X	-2.5	-2.0	-2.4	-0.7	-0.3	-0.5
MID MEDIAL Y	2.1	3.6	4.8	3.8	4.5	3.6
MID MEDIAL Z	2.9	0.4	0.2	0.0	0.9	-0.5
MID LATERAL X	2.6	1.2	3.8	1.3	0.4	-0.4
MID LATERAL Y	-3.4	-5.3	-5.3	-3.8	-5.1	-4.9
MID LATERAL Z	4.3	-0.1	-0.4	0.1	0.3	-0.6

SEGMENT NAME - CALF, LEFT

VARIABLE NAME	********* STANDING SUBJECTS ******** SUBJECT 1	SUBJECT 2	SUBJECT 3	********** SEATED SUBJECTS ********* SUBJECT 4	SUBJECT 5	SUBJECT 6
LATERAL MALLEOLUS X	1.7	1.7	2.6	-1.2	0.3	-1.2
LATERAL MALLEOLUS Y	-2.2	-2.9	-2.1	-3.3	-3.0	-3.1
LATERAL MALLEOLUS Z	20.9	26.8	24.4	23.0	23.1	24.5
ANKLE 1 X	3.4	5.3	4.9	4.6	5.9	4.5
ANKLE 1 Y	3.3	4.1	4.6	-0.5	1.1	-0.3
ANKLE 1 Z	22.3	26.5	24.3	23.6	23.9	25.3
ANKLE 2 X	-3.4	-3.3	-2.2	0.2	-0.6	-1.4
ANKLE 2 Y	1.5	2.1	2.5	3.3	3.0	2.6
ANKLE 2 Z	21.4	25.8	23.5	23.3	23.5	23.7
ANKLE 3 X	1.3	1.1	3.1	-0.7	1.3	0.4
ANKLE 3 Y	-2.2	-2.6	-1.5	-2.9	-2.6	-2.5
ANKLE 3 Z	22.9	27.7	24.9	24.6	24.6	25.8
DISTAL CENTROID X	1.0	0.9	1.3	-0.3	0.4	0.3
DISTAL CENTROID Y	1.6	1.0	1.3	0.3	0.1	0.2
DISTAL CENTROID Z	22.2	26.8	24.3	23.8	24.0	24.7
DISTAL POINT X	3.7	2.3	3.1	-2.8	0.0	3.8
DISTAL POINT Y	2.0	-2.0	-1.5	-2.5	-2.6	-1.4
DISTAL POINT Z	22.7	27.7	24.9	24.6	24.6	25.7

********* MOMENTS OF INERTIA (GMCM**2) **********

IXX	282641.	559594.	497394.	307034.	391818.	330848.
IYY	286196.	526181.	476980.	323889.	379393.	345118.
IZZ	24723.	57288.	52118.	10821.	29804.	16948.

********* DIRECTION ANGLES (DEG) **********

X ALPHA	55.	75.	56.	9.	48.	46.
X BETA	35.	17.	34.	98.	42.	136.
X GAMMA	89.	89.	91.	86.	88.	91.
Y ALPHA	145.	165.	147.	82.	138.	44.
Y BETA	55.	75.	56.	9.	48.	46.
Y GAMMA	91.	90.	88.	87.	90.	88.
Z ALPHA	91.	91.	89.	95.	92.	91.
Z BETA	92.	90.	90.	93.	91.	92.
Z GAMMA	2.	0.	3.	6.	2.	2.

VARIABLE NAME	********* STANDING SUBJECTS ******** SUBJECT 1	SUBJECT 2	SUBJECT 3	********** SEATED SUBJECTS ********* SUBJECT 4	SUBJECT 5	SUBJECT 6
WEIGHT (GRAMS)	791.	1029.	958.	730.	859.	657.
VOLUME (ML)	723.	990.	883.	695.	813.	595.
DENSITY (GRAMS PER ML)	1.095	1.039	1.086	1.054	1.057	1.107

********* 3-D SURFACE POINT LOCATION FROM CENTER OF MASS (CM) **********

VARIABLE NAME	SUBJECT 1	SUBJECT 2	SUBJECT 3	SUBJECT 4	SUBJECT 5	SUBJECT 6
ANKLE 1 X	4.5	6.3	5.3	5.2	6.2	5.6
ANKLE 1 Y	-3.6	2.9	-2.2	-1.7	-1.2	-2.0
ANKLE 1 Z	-1.6	-0.7	-0.1	0.2	-1.4	-1.2
ANKLE 2 X	2.5	4.4	2.3	3.2	3.6	2.5
ANKLE 2 Y	-4.8	-1.1	-4.3	-3.1	-3.5	-2.5
ANKLE 2 Z	-4.1	-7.7	-5.9	-6.7	-5.9	-7.3
ANKLE 3 X	4.5	2.9	4.8	3.5	3.6	3.6
ANKLE 3 Y	1.1	5.4	1.9	2.7	3.4	2.6
ANKLE 3 Z	-6.1	-4.9	-5.3	-6.8	-4.6	-5.1
PROXIMAL POINT X	5.2	6.0	5.4	5.2	6.2	5.9
PROXIMAL POINT Y	-2.8	3.4	-1.4	-1.7	-0.7	-0.5
PROXIMAL POINT Z	-1.6	-0.6	-0.2	0.2	-1.1	-1.2
HEEL POINT X	-1.9	-1.1	-1.1	-0.2	-1.9	-1.8
HEEL POINT Y	0.0	-0.3	0.1	-0.3	-0.6	-0.4
HEEL POINT Z	-9.8	-11.3	-10.1	-10.7	-10.5	-9.4
MID ANTERIOR X	0.6	0.5	.1	0.6	0.4	-0.6
MID ANTERIOR Y	0.0	-0.8	0.1	-0.3	-0.6	-0.4
MID ANTERIOR Z	7.8	8.3	6.5	6.7	7.0	7.5
MID MEDIAL X	-2.2	0.9	-2.5	-1.1	-1.4	-1.4
MID MEDIAL Y	-3.5	-5.7	-4.0	-4.1	-4.8	-4.4
MID MEDIAL Z	7.2	7.3	6.8	7.4	6.1	6.6
MID LATERAL X	-0.2	-5.7	-0.5	-2.0	-1.9	-2.2
MID LATERAL Y	4.7	2.1	5.3	3.9	3.7	3.7
MID LATERAL Z	6.2	6.8	5.4	5.0	5.9	5.1
ANTERIOR POINT X	-1.9	-1.1	-1.1	-0.2	-1.9	-1.8
ANTERIOR POINT Y	0.0	-0.8	0.1	-0.3	-0.6	-0.4
ANTERIOR POINT Z	13.2	13.5	12.6	13.2	12.9	12.7
BIG TOE POINT X	-2.1	0.4	-1.1	0.0	-1.7	-2.8
BIG TOE POINT Y	-1.9	-2.2	-1.9	-1.9	-2.2	-1.4
BIG TOE POINT Z	13.8	14.5	13.2	13.5	13.6	12.9

SEGMENT NAME - FOOT, RIGHT

VARIABLE NAME	********* STANDING SUBJECTS ********			********** SEATED SUBJECTS *********		
	SUBJECT 1	SUBJECT 2	SUBJECT 3	SUBJECT 4	SUBJECT 5	SUBJECT 6
********* MOMENTS OF INERTIA (GMCM**2) **********						
IXX	30700.	46673.	39344.	27761.	33180.	24033.
IYY	23800.	41677.	34775.	25743.	31026.	20382.
IZZ	5648.	10838.	9395.	4496.	7496.	4184.
********* DIRECTION ANGLES (DEG) **********						
X ALPHA	11.	73.	11.	34.	30.	44.
X BETA	81.	20.	82.	56.	61.	46.
X GAMMA	83.	80.	84.	84.	81.	79.
Y ALPHA	100.	163.	99.	124.	120.	133.
Y BETA	11.	73.	9.	35.	31.	43.
Y GAMMA	89.	90.	88.	85.	85.	89.
Z ALPHA	96.	93.	96.	93.	96.	97.
Z BETA	92.	100.	93.	97.	99.	98.
Z GAMMA	6.	11.	6.	8.	11.	11.

SEGMENT NAME - FOOT, LEFT

VARIABLE NAME	********* STANDING SUBJECTS ******** SUBJECT 1	SUBJECT 2	SUBJECT 3	********** SEATED SUBJECTS ********* SUBJECT 4	SUBJECT 5	SUBJECT 6
WEIGHT (GRAMS)	80[illegible].	1074.	974.	726.	763.	671.
VOLUME (ML)	728.	1035.	891.	686.	724.	630.
DENSITY (GRAMS PER ML)	1.10[illegible]	1.038	1.092	1.057	1.055	1.065

********* 3-D SURFACE POINT LOCATION FROM CENTER OF MASS (CM) *********

ANKLE 1 X	5.7	6.5	6.2	4.9	5.8	5.4
ANKLE 1 Y	2.3	2.5	1.5	1.8	-2.3	-1.0
ANKLE 1 Z	-1.6	-0.9	-0.8	0.1	-1.2	-0.9
ANKLE 2 X	2.3	2.2	2.9	3.[illegible]	3.5	3.0
ANKLE 2 Y	3.1	3.2	2.9	3.5	1.4	1.6
ANKLE 2 Z	-8.2	-8.6	-7.1	[illegible]	-6.5	-6.8
ANKLE 3 X	4.4	4.9	5.1	3.9	1.7	2.0
ANKLE 3 Y	-1.7	-2.7	-3.3	-2.5	-4.3	-3.6
ANKLE 3 Z	-7.6	-7.1	-4.8	-4.0	-5.0	-6.7
PROXIMAL POINT X	5.7	6.5	6.1	4.9	5.2	5.2
PROXIMAL POINT Y	2.3	2.5	0.4	1.8	-1.3	-1.8
PROXIMAL POINT Z	-1.6	-0.9	-0.8	0.1	-1.3	-1.0
HEEL POINT X	-1.6	-1.0	-1.2	0.1	-2.2	-1.1
HEEL POINT Y	0.1	0.7	0.3	0.2	0.7	0.6
HEEL POINT Z	-10.0	-11.4	-10.1	-10.6	-10.2	-9.9
MID ANTERIOR X	-0.5	0.2	-0.3	0.2	0.4	0.3
MID ANTERIOR Y	0.1	0.7	0.3	0.6	0.7	0.6
MID ANTERIOR Z	7.6	8.3	7.0	6.8	7.1	7.6
MID MEDIAL X	-2.6	-3.4	-2.2	-1.8	0.8	0.3
MID MEDIAL Y	4.0	4.3	4.7	4.2	4.7	4.3
MID MEDIAL Z	7.0	6.9	5.7	6.6	6.4	7.0
MID LATERAL X	-1.3	-0.9	-1.9	-1.3	-1.6	-3.3
MID LATERAL Y	-4.1	-4.2	-4.9	-3.8	-3.0	-3.1
MID LATERAL Z	6.9	7.5	6.2	6.5	6.5	7.4
ANTERIOR POINT X	-1.6	-1.0	-1.2	0.1	-2.2	-1.1
ANTERIOR POINT Y	0.1	0.7	0.3	0.2	0.7	0.6
ANTERIOR POINT Z	13.0	13.9	12.8	12.9	12.4	13.2
BIG TOE POINT X	-2.5	0.1	-0.8	-1.1	-2.3	-1.8
BIG TOE POINT Y	2.3	2.3	2.8	2.1	2.8	2.0
BIG TOE POINT Z	13.6	13.7	12.6	13.5	13.1	12.9

SEGMENT NAME - FOOT, LEFT

VARIABLE NAME	********* STANDING SUBJECTS ******** SUBJECT 1	SUBJECT 2	SUBJECT 3	********** SEATED SUBJECTS ********* SUBJECT 4	SUBJECT 5	SUBJECT 6
********* MOMENTS OF INERTIA (GMCM**2) **********						
IXX	35694.	46046.	36907.	28056.	28716.	23355.
IYY	29647.	44525.	34185.	25050.	27121.	22054.
IZZ	5519.	11275.	9235.	5[illegible]56.	8004.	6051.
********* DIRECTION ANGLES (DEG) **********						
X ALPHA	21.	43.	10.	37.	16.	29.
X BETA	107.	48.	83.	53.	106.	119.
X GAMMA	77.	85.	82.	84.	89.	85.
Y ALPHA	106.	131.	96.	127.	74.	[illegible]
Y BETA	163.	42.	6.	37.	[illegible]	29.
Y GAMMA	97.	96.	91.	94.	93.	86.
Z ALPHA	76.	97.	99.	97.	91.	97.
Z BETA	88.	89.	89.	90.	56.	52.
Z GAMMA	165.	7.	9.	8.	4.	6.

APPENDIX F

WHOLE-BODY THREE-DIMENSIONAL ANTHROPOMETRY

SEGMENT NAME - WHOLE BODY

VARIABLE NAME	SUBJECT 1	SUBJECT 2	SUBJECT 3	SUBJECT 4	SUBJECT 5	SUBJECT 6
	********* STANDING SUBJECTS ********			********** SEATED SUBJECTS *********		
WEIGHT (KILOGRAMS)	58.70	76.15	99.15	50.62	58.08	58.34
********* 3-D SURFACE POINT LOCATION FROM CENTER OF MASS (CM) **********						
VERTEX X	5.5	5.0	6.5	-4.2	-8.0	-7.6
VERTEX Y	-1.2	1.8	-2.9	-1.6	-1.1	1.5
VERTEX Z	-69.6	-73.8	-74.0	-67.2	-65.3	-60.5
ACROMION R X	3.0	1.8	0.2	-7.0	-8.8	-9.1
ACROMION R Y	13.6	20.7	12.7	15.7	17.2	19.6
ACROMION R Z	-45.8	-48.8	-53.4	-42.7	-39.7	-36.3
ACROMION L X	1.0	1.6	-0.9	-8.6	-5.9	-10.3
ACROMION L Y	-16.2	-16.2	-19.5	-15.9	-19.8	-14.5
ACROMION L Z	-47.5	-52.5	-52.2	-43.6	-34.2	-38.9
SUPRASTERNALE X	9.7	10.0	10.3	2.3	-10.3	0.1
SUPRASTERNALE Y	-1.2	1.8	-2.9	-1.6	-1.1	1.5
SUPRASTERNALE Z	-36.8	-41.1	-42.0	-34.5	-32.6	-31.3
WR 3 X	1.9	-3.1	0.9	17.9	20.8	16.9
WR 3 Y	33.6	41.5	34.9	24.0	22.8	33.1
WR 3 Z	7.1	11.7	-1.9	-7.6	-9.8	-4.3
WL 3 X	-2.4	1.4	0.9	21.5	19.5	17.6
WL 3 Y	-36.4	-44.9	-45.8	-24.7	-30.3	-27.5
WL 3 Z	8.0	6.5	1.4	-9.2	-10.0	-6.9
HR 2 X	0.5	-1.7	2.4	-7.3	-10.0	-12.9
HR 2 Y	14.5	15.1	13.1	14.2	17.0	18.0
HR 2 Z	1.3	1.9	3.4	9.0	3.2	7.1
HL 2 X	0.5	-5.3	2.0	-7.2	-10.4	-12.2
HL 2 Y	-15.6	-15.7	-17.6	-16.9	-17.4	-16.2
HL 2 Z	4.0	3.7	3.6	8.5	4.9	6.0
AR 3 X	-3.8	-5.6	-4.3	18.3	22.2	27.7
AR 3 Y	17.7	14.1	20.1	13.3	16.2	15.4
AR 3 Z	95.8	105.2	96.9	83.7	75.6	73.4
AL 3 X	-5.5	-3.9	-3.9	29.5	25.3	32.4
AL 3 Y	-20.3	-22.0	-19.8	-15.2	-16.7	-16.3
AL 3 Z	94.5	105.5	98.3	78.6	75.4	73.1

SEGMENT NAME - WHOLE BODY

VARIABLE NAME	SUBJECT 1	SUBJECT 2	SUBJECT 3	SUBJECT 4	SUBJECT 5	SUBJECT 6
	********* STANDING SUBJECTS ********			********** SEATED SUBJECTS *********		
********* MOMENTS OF INERTIA (GMCM**2) **********						
IXX	93806750.	150885991.	169127374.	70857620.	64125009.	66937210.
IYY	89223092.	125580448.	141988401.	66022862.	69801035.	60725729.
IZZ	11644431.	17424344.	22389491.	11385121.	17445286.	15825428.
********* DIRECTION ANGLES (DEG) **********						
X ALPHA	6.	21.	17.	25.	31.	26.
X BETA	85.	69.	73.	110.	117.	76.
X GAMMA	87.	87.	88.	106.	105.	111.
Y ALPHA	95.	110.	107.	71.	63.	102.
Y BETA	5.	21.	17.	20.	27.	15.
Y GAMMA	91.	89.	92.	95.	95.	82.
Z ALPHA	93.	92.	92.	73.	75.	67.
Z BETA	90.	92.	89.	91.	92.	93.
Z GAMMA	4.	3.	2.	17.	16.	23.

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