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ANTHROPOMETRIC RELATIONSHIPS OF BODY AND BODY SEGMENT MOMENTS OF INERTIA

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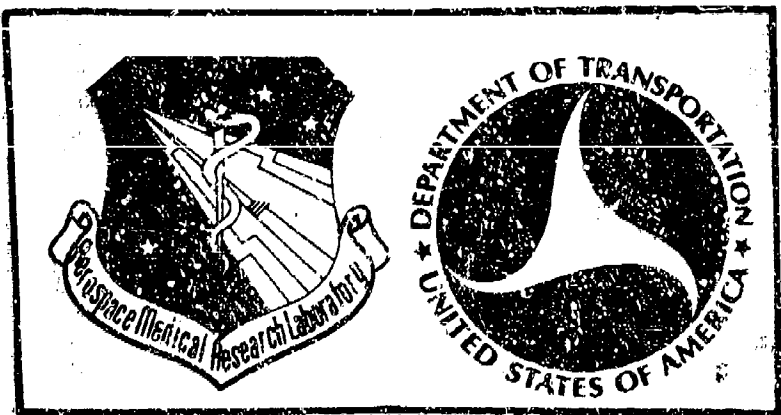
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FOR THE COMMANDER


CHARLES BATES, JR.

Chief

Human Engineering Division

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| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report documents the results of a study aimed at demonstrating that mass distribution properties of the human body and its segments can be predicted from anthropometric dimensions. Investigators combined stereophotometric and anthropometric techniques to measure 31 male subjects. Bodies were photographically segmented into 24 parts and their volume, centers of volume and principal moments of inertia established stereometrically. Principal moments were measured about three principal axes of inertia which | | | |

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20. ABSTRACT (cont'd)

were established with reference to anatomical axis systems based on easily located body landmarks.

Seventy-five body size variables were measured anthropometrically and an additional 10 dimensions were derived from the measured variables. Multiple regression equations were devised for the total body and for each segment using the most highly correlated variables on each segment, and stature and weight for determining volume and principal moments of inertia.

Included is a brief review of the literature with emphasis on earlier studies by authors which provide the rationale for the reliability of the stereophotometric method in determining mass distribution properties of living subjects. The data analysis section provides tables illustrating each of the segments and their axis systems, the segmental data established in this study, and a series of regression equations estimating volume and principal moments from anthropometric measurements.

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PREFACE

The work reported here is the result of a joint effort of a number of organizations. Funding was provided, in part, through an interagency agreement, No. DOT-HS-6-01332, between the National Highway Traffic Safety Administration (NHTSA) of the Department of Transportation and the Air Force Aerospace Medical Research Laboratory (AFAMRL). Mr. Arnold K. Johnson acted as contract technical manager for the NHTSA and Mr. C. E. Clauser as principal investigator for the AFAMRL. The biostereometrics work was conducted at the Biostereometrics Laboratory under Air Force contract F33615-76-C-0529 with the Texas Institute for Rehabilitation and Research; Mr. C. E. Clauser acted as contract monitor and Dr. R. E. Herron as principal investigator.

A significant part of the initial planning and validation of the study was carried out in the Federal Aviation Administration's Civil Aeromedical Laboratory (CAMI) in Oklahoma City, Oklahoma. The authors are deeply indebted to Mr. Richard Chandler and Mr. Joe Young, Protection and Survival Branch, CAMI, for their outstanding assistance and cooperation during this phase of the study. Dr. H. M. Reynolds, now of Michigan State University, also assumed a significant role in this phase of the work.

The authors also wish to acknowledge the outstanding work of the members of the Biostereometrics Laboratory who contributed to this effort, in particular: Dr. Herron for his understanding and support of the study; Ms. Marge Gordon for her administrative support; Ms. Cheryl Mittenberger who handled data acquisition; and Mr. John Hugg and Dr. Daniel Sheffer who assisted with the photographic process.

Computer programs for analyzing and formatting the data were developed by Mr. Thomas Churchill of the Anthropology Research Project (ARP). Other staff members of ARP who contributed hundreds of painstaking hours to the editorial preparation of the report were Ilse Tebbetts, Kathy Robinette and Jane Reese. In this connection, too, the authors wish to thank Edmund Churchill and Dr. Melvin Warrick for reading and critical commentary which helped guide the choice of material presented in this report.

Gary Ball of Ball Graphics was responsible for the clear and detailed illustrations which accompany the presentation of the data in Chapter III.

We gratefully acknowledge the skill and labor devoted to this study by all those named above and by other colleagues and co-workers too numerous to be listed who contributed so generously to our work.

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INTRODUCTION

The intent of this research was to establish the relationship between human body size and its mass distribution properties. Stereophotometric and anthropometric techniques were combined to measure a group of 31 living male subjects with the object of arriving at a means of estimating volume and moments of inertia of the body and its parts from anthropometric dimensions. Numerous anthropometric measurements were taken and various combinations of dimensions were used in predictive equations to obtain those variables which provided the best estimates of the mass distribution characteristics which had been stereophotometrically determined.

In our previous two studies of the mass distribution properties of man (Clauser et al., 1969; Chandler et al., 1975), all subject specimens were cadavers. This work provided interim data until such time as we could develop methods and procedures for making similar assessments on the living. In the second of these studies, a double blind investigation was designed, in which stereophotometric assessments of mass distribution were made and compared to measurements empirically determined. An evaluation of results indicated that an acceptable level of correspondence existed between the two measurement techniques. This indicated that the stereophotometric method could be used to obtain estimates of mass distribution parameters from living subjects and provided us with a means for testing and validating the hypothesis that moments of inertia of separate parts of the body might be predicted from relevant dimensions of these parts.

This study demonstrates that body size and moments of inertia are related and the correlations can be used to develop regression equations for predicting mass distribution characteristics. The establishment of reliable predictive equations suggests that more difficult, expensive and time-consuming empirical measurements and modeling calculations can be eliminated. Further, if anthropometry can be used to estimate mass distribution properties, then, for the first time, large-scale population data could be obtained for those groups for whom sufficient anthropometry is available.

Chapter I

HISTORICAL PERSPECTIVES

Despite the attention of investigators over the past 200 years, the problem of accurately measuring the mass distribution properties of the human body remains almost as knotty today as it did in 1679 when the earliest recorded work described a scheme for ascertaining the center of mass of nude men by stretching them on a platform balanced on a knife edge (Borelli, 1679). While weight, volume, center of mass and moments of inertia of the whole body can be measured in a number of ingenious ways on living human beings, comparable information for segments of the body can be empirically measured only on cadavers. The expense and difficulties of research involving the use of cadavers and their dissection into component parts and the complexity involved in the design and development of the measuring apparatus have severely limited these investigations to small sample sizes from which data cannot be safely universalized. Additionally, cadavers do not approximate living persons of the same size. Research has demonstrated that supine and standing height differ and that cadavers lose weight progressively after death (probably through loss of body fluids). While sufficient fluid can be injected into a cadaver to simulate "normal" appearance, increases in various circumferential measurements are so variable as to make this method quite unsatisfactory in predicting living body size accurately (Todd and Lindala, 1928).

Live subjects were used by Weber and Weber (1836) to determine the center of mass by moving a body on a platform until it balanced and then reversing the body and repeating the procedure. The mean position between the two balance points was a more accurate approximation of center of mass than that obtained from Borelli's single measurement technique.

Some 25 years later Harless (1860) extended the Webers' experiments to studies of center of mass on body segments with a view to determining the center of mass along the long axis of as many movable body parts as possible. Harless cut the bodies of two cadavers into 18 parts. The volume of each segment was calculated from the mass using a postulated specific gravity of 1.066. Harless later provided further verification of his findings when he weighed 44 segment extremities from seven male and female corpses first in air and then in water. From these data he concluded that sex and age were significant factors in the variability of the specific gravity of segments of the human body.

While the list of investigations in this field is very long, perhaps the best known and most often cited are the studies of Braune and Fischer (1889 and 1892), Dempster (1955), Clauser et al. (1969), and Chandler et al. (1975).

Although sample sizes have of necessity been small, various researchers have undertaken the development of equations with a view toward applying known cadaver data to living bodies. Barter (1957), using data from Braune and Fischer, and from Dempster, prepared a series of equations for predicting segment weights from body weight. These have been used extensively by designers and engineers, despite limitations clearly specified by Barter.

In 1969 Clauser et al. determined weight, volume and center of mass on 14 body segments from each of 13 cadavers. They developed a series of multi-step regression equations aimed at predicting segment variables from anthropometric dimensions. Weight of the trunk segment, for example, was found to be best predicted by weight, trunk length and chest circumference measurements obtained from the whole body.

If the static mass distribution variables of the human body have presented tangled problems, its dynamic properties have formed a massive Gordian knot which investigators have not yet cut. As long ago as 1892, Braune and Fischer enlarged on earlier studies to include investigation of moments of inertia as well as volume, mass and center of mass. Using two adult male cadavers, they measured moments of inertia about the longitudinal axis and one axis perpendicular to the longitudinal axis of 11 segments. Dempster expanded these experiments still further by using segments from eight cadavers, and measuring moments of inertia about two parallel transverse axes. Others (notably, Santschi et al., 1963 and Ignazi et al., 1972, using live subjects; Liu and Wickstrom, 1973, using a torso segment), measured moments of inertia about as many as three axes. None of these investigators, however, found the principal axes of inertia from which principal moments of inertia are determined, although it has often been mistakenly assumed that results of one or more of these studies did provide these basic data.

The inertia tensor of a rigid body may be determined relative to any origin and any coordinate system orientation. Since there is an infinite number of such choices, there is an infinite number of possible inertia tensors for a given body. However, for a given origin, a unique inertia tensor exists for a non-symmetric body, which represented in matrix form has only nonzero diagonal elements. These elements are the principal moments of inertia of the body, and for each of these there is a corresponding principal axis of rotation. These principal axes form an orthogonal set, and are aligned with the axes of the coordinate system in which the inertia tensor is in diagonal form.

Observation of the general symmetry of a body may provide some insight into the approximate orientation of the principal axes. However, the actual determination of principal axes must be carried out analytically - generally using measured products and moments of inertia. These were measured for the first time by Chandler et al. in 1975 using the intact bodies and, subsequently, 14 dismembered segments of six adult male cadavers. The measured moments of inertia of the intact specimens were compared to findings from five live subjects of comparable weight and stature measured in an earlier study (Santschi et al., 1963) and a satisfactory level of agreement was found. Nevertheless, as the authors of the Chandler study pointed out, investigators were still not much closer to establishing population estimates for inertial properties.

The search for more widely applicable means of measuring mass distribution properties had also been pursued for many years by investigators attempting a more simplified approach to the problem. Long before the widespread use of high-speed computers, researchers were drawn to the possibilities of analytical and geometric modeling and approximating.

Harless (1860) verified the use of various geometrical forms as analogues of human body parts by comparing their volume and center of mass measurements with those obtained on body segments of a cadaver. Von Meyer (1863, 1873) studied the movement of center of mass in the body with changes in its positions by reducing the head, torso and appendages to elemental ellipsoids and spheres.

Modern day research by investigators such as Clauser, reported by Simons and Gardner (1960), Whitsett (1962), Hanavan (1964), Wooley (1972), and Bartz and Gianotti (1973), to name but a few, has been aimed at the development of mathematical man models, chiefly for use in astronaut maneuvering simulation and in auto-crash research. Three-dimensional models, based on anthropometric data, have also been developed.

While mathematical modeling, through decades of trial and error and modification of geometric shapes, has produced reasonably usable analogues, its limitations are apparent. Both two- and three-dimensional models now in use are statistical representations of 5th, 50th and 95th percentile "persons" and, as such, do not accurately represent the body proportions of actual people since percentiles are not additive and it is impossible to assemble models from percentile values without manipulating some body part or parts (McConville and Churchill, 1976; Robinette and Churchill, 1979). Furthermore, even in mathematical modeling, verification of calculations on which mass distribution properties of segments are based can only be made from cadaver data.

Interest has focussed in the past decade on a sophisticated new technique which shows considerable promise as an accurate means of measuring mass distribution properties on living human beings and their segments. This technique, known variously as stereophotometrics, biostereometrics and photostereogrammetry, involves three-dimensional photography of the subject by cameras placed at strategic locations. The coordinates of a given number of points on the body serve as input to a digital computer which can then "recreate" the body or any of its photographed parts in all its geometric subtlety. This method, if proven accurate, would greatly refine the mathematical modeling procedures in current use since it can be used, for example, to measure and simulate the shape of an actual living head which is, after all, a good deal more irritatingly irregular than a sphere.

Stereophotometrics was first applied to a study of mass distribution by Dr. Robin Herron of the Biostereometrics Laboratory at the Texas Institute for Research and Rehabilitation (Herron et al., 1974). In that investigation periods of oscillation were measured and moments of inertia computed for three subjects riding a pendulum. Stereophotometric records were then made of the same subjects and their mass distribution properties calculated. The periods of oscillation were determined and a comparison with the measured periods revealed a close agreement.

Recognizing the possibilities of this method, Clauser saw the opportunity for a further test of its validity in conjunction with the Chandler et al. study (1975) of mass distribution on six cadavers and their segments. A double blind study ensued and preliminary results, reported by McConville and Clauser (1976), showed a high degree of correlation between findings

obtained by the stereophotometric technique and those obtained by direct measurement of the cadaver segments, even to the extent of validating one suspected data point obtained through direct measurement.

In the study to be described here, investigators made further use of the stereophotometric technique to determine the relationship between the anthropometry of the body and its segments and mass distribution characteristics of living subjects.

Chapter II

STUDY DESIGN

This study was conducted in several phases and involved a considerable amount of planning and groundwork at several locations before the actual measurement of subjects began. The planning stage included the establishment of primary segments and planes of segmentation, selection of body-size dimensions to be measured and establishment of the anatomical axis systems for the body and its segments.

A pretest, using one subject, was designed and carried out to further develop and refine the techniques to be used and to further validate the stereophotometric assessment of human body moments of inertia. A reasonably representative sample was then selected.

In the test itself each subject was anthropometrically measured and marked with the landmarks to be used for photography. Stereophotometric photographs of each subject were then obtained.

Analytic procedures included: stereophotometric assessment of volume, principal moments and principal axes of inertia for the total body and its segments; preparation of a regression analysis of the anthropometry with the volume and moments of inertia; and analysis of the resulting data to determine whether body size measurements can accurately predict mass distribution parameters.

SEGMENTATION

The primary body segments used in this study were defined by using planes of segmentation similar to those used in our previous studies (Clauser et al., 1969; Chandler et al., 1975). The delineation of some additional segments was made possible because segmentation can be achieved more simply by photography than on cadavers. The segments defined were:

- | | |
|----------------------------|----------------------------|
| 1. Head | 14. Right Calf |
| 2. Neck | 15. Right Foot |
| 3. Thorax | 16. Left Flap |
| 4. Abdomen | 17. Left Thigh minus Flap |
| 5. Pelvis | 18. Left Calf |
| 6. Right Upper Arm | 19. Left Foot |
| 7. Right Forearm | 20. Right Forearm and Hand |
| 8. Right Hand | 21. Left Forearm and Hand |
| 9. Left Upper Arm | 22. Right Thigh |
| 10. Left Forearm | 23. Left Thigh |
| 11. Left Hand | 24. Torso |
| 12. Right Flap | 25. Total Body |
| 13. Right Thigh minus Flap | |

Segments 20-25 are summations of previously tabulated individual segments.

The planes of segmentation,* illustrated in Figure 1, were identified and located in the following ways:

- Head plane: passes through the left and right gonial points and nuchale.†
- Neck plane: a compound plane in which a horizontal plane originates at cervicale and passes anteriorly parallel with the standing surface. A second plane originates at the lower of the two clavical landmarks, rises 45° from the horizontal and passes diagonally superiorly-posteriorly until it intersects with the horizontal plane.
- Thorax plane: originates at the 10th rib mid-spine landmark and passes through the torso parallel with the standing surface.
- Abdominal plane: originates at the higher of the two ilio-cristale landmarks and passes through the torso parallel with the standing surface.
- Hip plane: originates at the center of the crotch and passes laterally midway between the anterior superior iliac spine and the trochanteric landmarks along the lines of the right and left inguinal ligaments.
- Thigh flap plane: originates at the gluteal furrow landmark and passes through the thigh parallel to the standing surface.
- Knee plane: passes through the lateral femoral epicondyle landmark parallel to the standing surface.
- Ankle plane: originates at the sphyrion landmark and passes through the ankle parallel to the standing surface.
- Shoulder plane: originates at the acromion landmark and passes downward through the anterior and posterior scye creases at the level of the axilla.
- Elbow plane: originates at the olecranon landmark and passes through the medial and lateral humeral epicondyle landmarks.
- Wrist plane: originates at the ulnar and radial styloid landmark and passes through the wrist perpendicular to the long axis of the forearm.

* All planes are described with reference to the body in the erect standing position.

† Definitions of all the body landmarks are given in Appendix A.



Figure 1. Total body segmentation scheme.

AXIS SYSTEMS

A segmental axis system was established for the total body and for each of the 24 segments. These were right-hand orthogonal systems based on palpable, largely bony, landmarks and were used to provide a consistent reference for the principal axes systems independent of body segment position. The principal axes could then be located with respect to the anatomical axes, thus permitting duplication of measurements on other subject populations and comparison between subjects. This represents a major step forward from past investigations in which principal axes were located with reference to fixed points in the laboratory.

It should be noted that three landmarks are used to establish the original plane, two additional landmarks establish a plane perpendicular to the first, and a single additional landmark is used to establish a plane perpendicular to both. The origin of each axis system is the common point of intersection of the three planes with +Z being from the origin towards the head, +X being from the origin towards the front of the body and +Y being from the origin towards the left of the body.

The landmarks used to establish the axis system for each segment are as follows:

1. Head Axis: XY plane - right and left tragion and right infraorbitale
YZ plane - right and left tragion
XZ plane - sellion
2. Neck Axis: XZ plane - Adam's apple (midpoint of the anterior triangle at the level of the thyroid cartilage), cervicale and suprasternale
XY plane - one-half the distance between the right clavicale and cervicale and the left clavicale and cervicale
YZ plane - cervicale
3. Thorax Axis: XZ plane - suprasternale, cervicale and at mid-spine at level of 10th rib
YZ plane - cervicale and 10th rib level at mid-spine
XY plane - 10th rib level at mid-spine

4. Abdomen Axis: XY plane - right and left 10th rib and at mid-spine at level of 10th rib
YZ plane - right and left 10th rib
XZ plane - 10th rib mid-spine
5. Pelvic Axis: YZ plane - right and left anterior superior iliac spine and symphysis
XY plane - right and left anterior superior iliac spine
XZ plane - mid-spine at level of posterior superior iliac spine
6. Right Upper Arm: YZ plane - acromion and right and left humeral epicondyles
9. Left Upper Arm
XZ plane - lateral epicondyle and acromion
XY plane - acromion
7. Right Forearm: YZ plane - distal end of the ulnar and radial styloid processes and radiale
10. Left Forearm
20. Right Forearm and Hand
21. Left Forearm and Hand
XZ plane - distal end of the ulnar styloid process and radiale
XY plane - radiale
8. Right Hand: YZ plane - dactylion and the lateral aspect of the metacarpal-phalangeal joint of digits II and V
11. Left Hand
XY plane - the lateral aspect of the metacarpal-phalangeal joint of digits II and V
XZ plane - metacarpale III
12. Right Flap YZ plane - trochanterion and right and left lateral femoral epicondyles
13. Right Thigh minus Flap
16. Left Flap
17. Left Thigh minus Flap XZ plane - lateral femoral epicondyles and trochanterion
22. Right Thigh
23. Left Thigh
XY plane - trochanterion

- 14. Right Calf: YZ plane - tibiale, sphyrion and the lateral malleolus
- 18. Left Calf
 - XZ plane - sphyrion and tibiale
 - XY plane - tibiale
- 15. Right Foot: XY plane - metatarsal-phalangeal I and V landmarks
- 19. Left Foot
 - and the posterior calcaneus
 - XZ plane - tip of digit II and posterior calcaneus
 - YZ plane - metatarsal-phalangeal I landmark

Total Body: the same as pelvis

A PRELIMINARY TEST

In a pretest designed to refine and further validate the techniques to be used in the forthcoming study, investigators empirically established the moments of inertia for one subject about two axes in the sitting position and one axis in the supine position and compared these results with those obtained from the stereophotometric assessment. The subject was seated in a special specimen holder, which assured a fixed posture during the measurement of moments. The seated-specimen holder with the subject restraint systems of foam blocks and tape is illustrated in Figure 2.



Figure 2. Subject seated and restrained in specimen holder

After the subject was properly positioned in the specimen holder, the center of mass of the composite was located by suspension and the torsion pendulum specimen mounting plate affixed to the specimen holder at the center of mass. This procedure is illustrated in Figure 3 in which a manikin is shown in the specimen holder during a trial run.

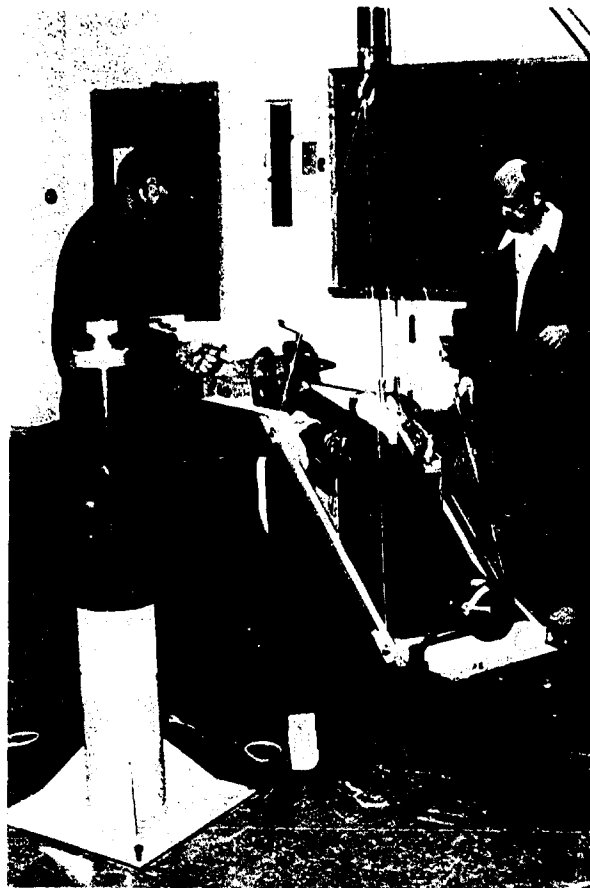


Figure 3. Establishing the center of gravity of the subject and specimen holder.

The composite (subject and holder) was then mounted on the torsion pendulum* and the periods of oscillation were measured (see Figure 4). A minimum of 15 counts were made and averaged for each axis. The subject was removed from the holder and the process repeated for the empty specimen holder.

The proposed surface dimensions were measured on the subject, targets were fixed to the body to indicate landmarks for segmentation and segment axis systems, and the stereophotographs were made. This opportunity was taken to evaluate the various segmentation planes proposed for the study. The principal moments of inertia were then estimated by stereophotometric assessment (the method used is described below) and compared to those measured on the pendulum. The results of this comparison are given in the table below.

* Manufactured by Space Electronics, Inc., Model XR-250.

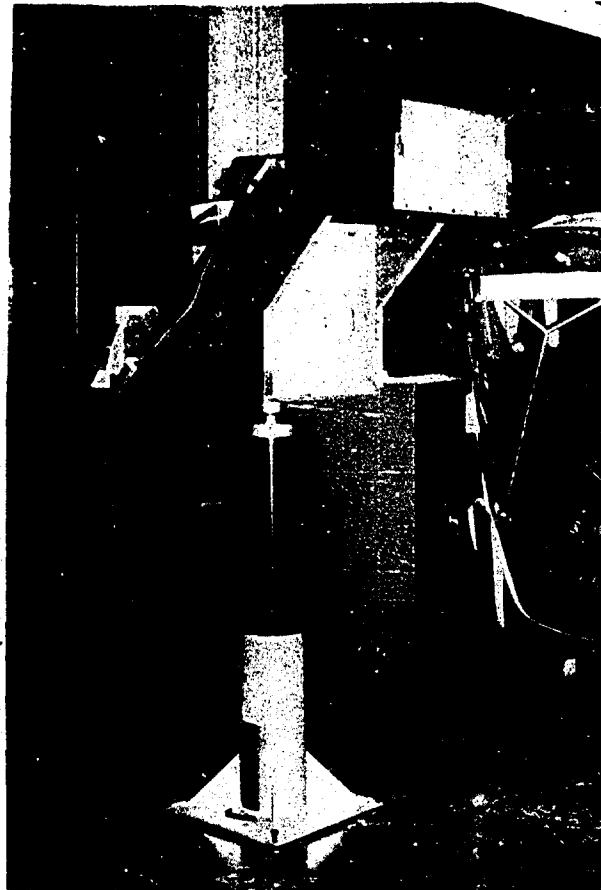


Figure 4. Subject and holder mounted on torsion pendulum.

TABLE 1

COMPARISON OF MEASURED VALUES WITH STEREOPHOTOMETRICALLY
 ESTIMATED VALUES FOR PRINCIPAL MOMENTS OF INERTIA
 (in gm cm²)

| <u>Position</u> | <u>Axis</u> | <u>Measured I₀</u> | <u>Stereo- photometric Estimated I₀</u> | <u>Δ</u> | <u>Δ%</u> |
|-----------------|-------------|-------------------------------|--|-----------|-----------|
| Sitting | Z | 38,299,252 | 33,333,924 | 4,965,328 | -12.96% |
| Sitting | Y | 77,192,067 | 74,068,259 | 3,123,808 | - 4.05% |
| Supine | X | 182,934,444 | 180,956,256 | 1,978,188 | - 1.08% |

The disagreement between the two measures ranged from a low of approximately one percent for the supine X axis to a high of approximately 13 percent for the sitting Z axis. The latter has the smaller moment of inertia, is a posture which is most difficult to define analytically in terms of segment orientation, and as a result is subject to the largest relative error in terms

of both its empirical determination as well as its stereophotometric estimation. From this evaluation we concluded that the degree of correspondence of the stereophotometrically estimated moments were sufficiently high with those empirically determined to pursue the planned investigation. This was believed particularly true since all data developed in this study are from subjects in a standing position which is analogous to the supine position.

THE SAMPLE

The sampling strategy was designed to select a small sample of test subjects who are representative of the population of interest (in this case, the U.S. Air Force male flying population specifically, and the U.S. adult male population in general). In most cases a sampling strategy is designed to use either random or matched samples with the intent of gathering descriptive data applicable to the population. In this study we were concerned with finding useful relationships between body size measurements and measurements of mass distribution properties from which population statements can be made. Our primary aim was to obtain a valid correlational analysis for a wide range of body sizes within a workable sample size. From a variety of possible sampling strategies, we elected to use a W-shaped sample (Churchill and McConville, 1976) based on the dimensions of stature and weight. Our intent was to draw ten subjects from each of three discontinuous height/weight strata of the population. These categories were to represent the lower 15%, the middle 20% and the upper 15% of the height/weight distribution found in the 1967 USAF survey of rated officers (Churchill et al., 1977).

In actuality the subject pool did not yield sufficient persons to meet the strict requirements of each category defined by the theoretical sampling strategy. The actual sample is shown plotted on a height/weight bivariate distribution of the USAF flying population (Table 2). The size categories from which the subjects were to be drawn are indicated by the heavy black lines. It will be noted that the actual sample (indicated by ★) deviates from the sample strategy in that the three subgroups of the sample do not show the marked discontinuity in the height/weight distribution that was originally sought but that, as planned, the sample represents a wide range of body sizes with good representation from the extreme ends of the distribution which are the areas most critical to the solution of design problems. Further, as will be shown in Chapter III, "Data Analysis," the average height and weight of the subjects in this sample closely reflect those of the larger USAF population.

MEASURING AND MARKING

After selection, the subjects were measured for some 75 body dimensions shown on the data sheet reproduced in Figure 5.* After measurements had been completed, targets were placed on each body landmark to facilitate detection during the stereophotometric assessment. Landmarks located on the coronal planes, or sides, of the subjects were marked with three-dimensional

* Measurement descriptions appear in Appendix A.

Subject No. _____ Date _____
 Name _____ Age _____
 Highest known weight _____ Usual weight _____ Recent weight change _____
 Weight at 16 years _____ Weight at 23 years _____

| | | | |
|----------------------------|-------|---------------------------------------|-------|
| Weight | _____ | Midhigh Depth | _____ |
| Stature | _____ | Calf Depth | _____ |
| Cervicale Height | _____ | Ankle Breadth | _____ |
| Tragion Height | _____ | Foot Length | _____ |
| Mastoid Height | _____ | Foot Breadth | _____ |
| Acromion Height | _____ | Axillary Arm Depth | _____ |
| Suprasternale Height | _____ | Biceps Depth (relaxed) | _____ |
| Thelion Height | _____ | Midforearm Breadth | _____ |
| Tenth Rib Height | _____ | Wrist Breadth (bone) | _____ |
| Iliac Crest Height | _____ | Hand Length | _____ |
| Omphalion Height | _____ | Hand Breadth | _____ |
| Ant Sup Iliac Spine Ht | _____ | Meta III-Dactylion Lgth | _____ |
| Symphysion Height | _____ | Sitting Height | _____ |
| Trochanterion Height | _____ | Head Length | _____ |
| Gluteal Furrow Height | _____ | Head Breadth | _____ |
| Tibiale Height | _____ | Elbow Br Rt _____ Lt _____ | |
| Fibulare Height | _____ | Knee Br Rt _____ Lt _____ | |
| Sphyrion Height | _____ | Head Circumference | _____ |
| Acromion-Radiale Length | _____ | Neck Circumference | _____ |
| Radiale-Styilion Length | _____ | Chest Circumference | _____ |
| Neck Breadth | _____ | Tenth Rib Circumference | _____ |
| Biacromial Breadth | _____ | Waist Circumference | _____ |
| Chest Breadth | _____ | Buttock Circumference | _____ |
| Tenth Rib Breadth | _____ | Upper Thigh Circumference | _____ |
| Waist Breadth | _____ | Midhigh Circumference | _____ |
| *Bicristale Breadth (bone) | _____ | Knee Circumference | _____ |
| Bispinous Breadth | _____ | Calf Circ Rt _____ Lt _____ | |
| Bitrochanterion Breadth | _____ | Ankle Circumference | _____ |
| Hip Breadth | _____ | Arch Circumference | _____ |
| Buttock Depth | _____ | Ball of Foot Circ | _____ |
| Gluteal Furrow Depth | _____ | Axillary Arm Circ | _____ |

Figure 5. Data blank.

* This dimension was measured but later eliminated in the data analysis.

ANTHROPOMETRY--DATA SHEET
 MASS DISTRIBUTION OF MALES (continued)

Biceps Circ Relaxed
 Rt _____ Lt _____
 Biceps Circ Flexed
 Rt _____ Lt _____
 Elbow Circumference _____
 Midforearm Circumference _____

Wrist Circumference _____
 Hand Circumference _____
 Triceps Skinfold _____
 Subscapular Skinfold _____
 Suprailiac Skinfold _____
 Biceps Skinfold _____

LANDMARKS

| | |
|------------------------------|---|
| Nuchale | |
| Cervicale | |
| Tenth Rib Level - Midspine | |
| Post Sup Iliac - Midspine | |
| Left Gluteal Furrow | |
| Right Gluteal Furrow | |
| Lt Post Calcaneus | |
| Rt Post Calcaneus | |
| Left Acromion | o |
| Right Acromion | o |
| Lt Posterior Scye | |
| Rt Posterior Scye | |
| Left Olecranon | |
| Lt Medial Humeral Epicon | o |
| Right Radiale | o |
| Right Olecranon | |
| Rt Medial Humeral Epicon | o |
| Left Tenth Rib | o |
| Right Tenth Rib | o |
| Left Iliocristale | o |
| Right Iliocristale | o |
| Left Trochanterion | o |
| Right Trochanterion | o |
| Sellion | |
| Right Infraorbitale | |
| Left Infraorbitale | |
| Right Tragion | o |
| Left Tragion | o |
| Right Gonion | o |
| Left Gonion | o |
| Adam's Apple (Mid-thyr Cart) | |
| Right Clavicale | |
| Left Clavicale | |
| Suprasternale | |
| Rt Anterior Scye | |
| Left Anterior Scye | |
| Rt Lat Humeral Epicondyle | o |
| Right Radiale | o |
| Lt Lat Humeral Epicondyle | o |

| | |
|------------------------------|---|
| Left Radiale | o |
| Rt Ulnar Styloid | o |
| Rt Radial Styloid | o |
| Rt Metacarpale V | o |
| Rt Metacarpale III | |
| Rt Metacarpale II | o |
| Left Radial Styloid | o |
| Left Ulnar Styloid | o |
| Lt Metacarpale II | o |
| Lt Metacarpale III | |
| Lt Metacarpale V | o |
| Rt Ant Sup Iliac Spine | |
| Lt Ant Sup Iliac Spine | |
| Symphysion | |
| Rt Lat Femoral Epicondyle | o |
| Right Fibulare | o |
| Right Infrapatella | |
| Rt Medial Femoral Epicondyle | o |
| Right Tibiale | o |
| Lt Medial Femoral Epicondyle | o |
| Left Tibiale | o |
| Left Infrapatella | |
| Left Lat Femoral Epicondyle | o |
| Left Fibulare | o |
| Right Lateral Malleolus | o |
| Right Medial Malleolus | o |
| Right Sphyrion | o |
| Right Metatarsal V | o |
| Right Metatarsal I | o |
| Left Medial Malleolus | o |
| Left Sphyrion | o |
| Left Lateral Malleolus | o |
| Left Metatarsal V | o |
| Left Metatarsal I | o |
| Right Dactylion | |
| Left Dactylion | |
| Right Toe II | |
| Left Toe II | |

Figure 5. (cont'd)

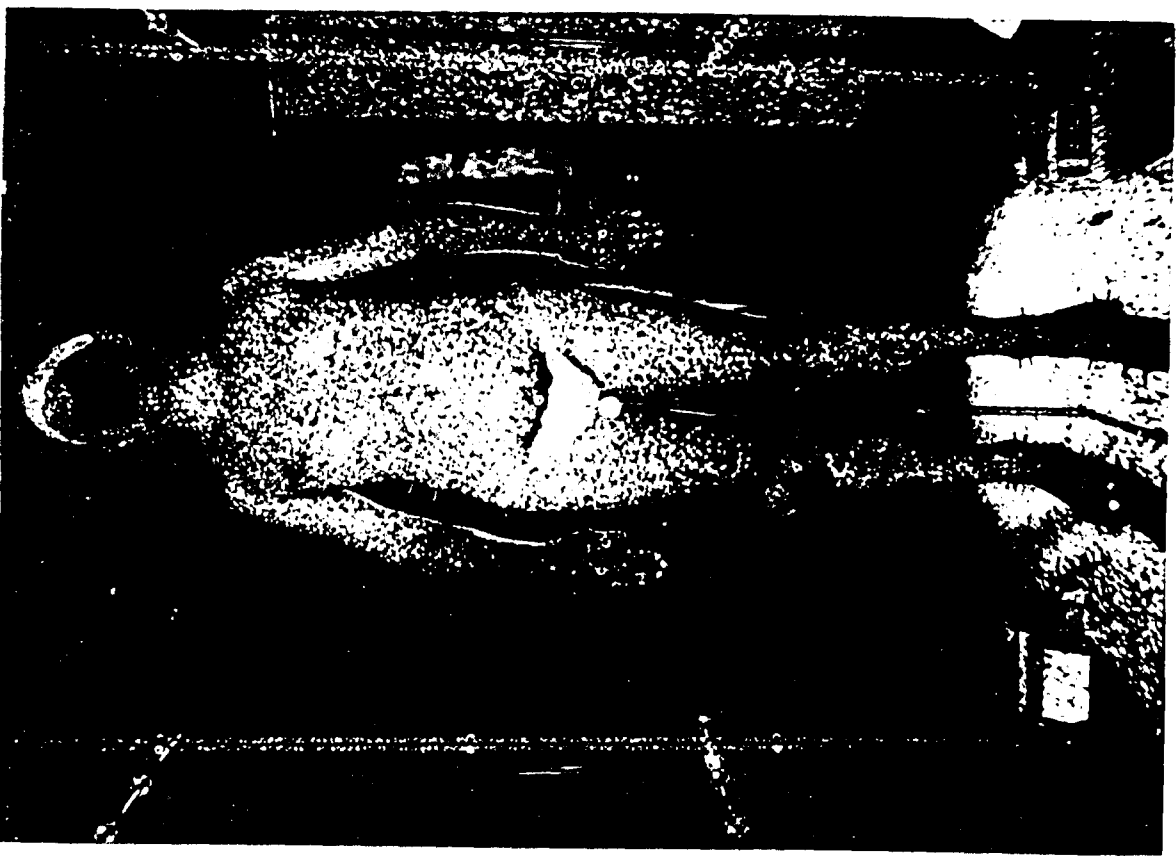
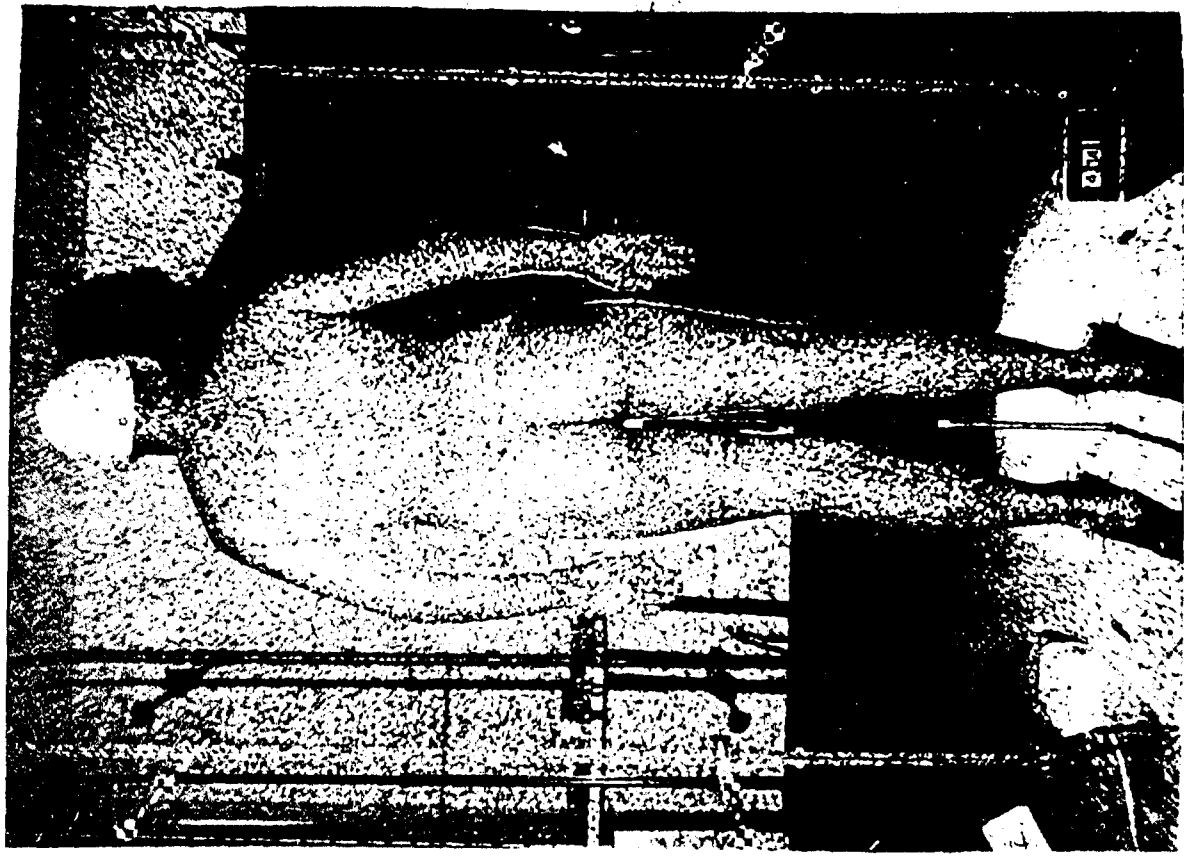


Figure 6. Type image obtained by the stereophotographic process.

off-sets so as to be visible in the stereometric photos of front and back views. They can be seen most clearly around the right wrist in Figure 6. All the landmarks are listed on the second page of the data sheet (Figure 5) with the symbol (o) denoting the use of off-sets.

THE STEREPHOTOMETRIC PHOTOGRAPHS

Two pairs of cameras, set up as shown in Figure 7, were used to record the antero-posterior view of each subject. Control stands (at the subject's sides) provide a "datum" or reference plane which is common to the imagery

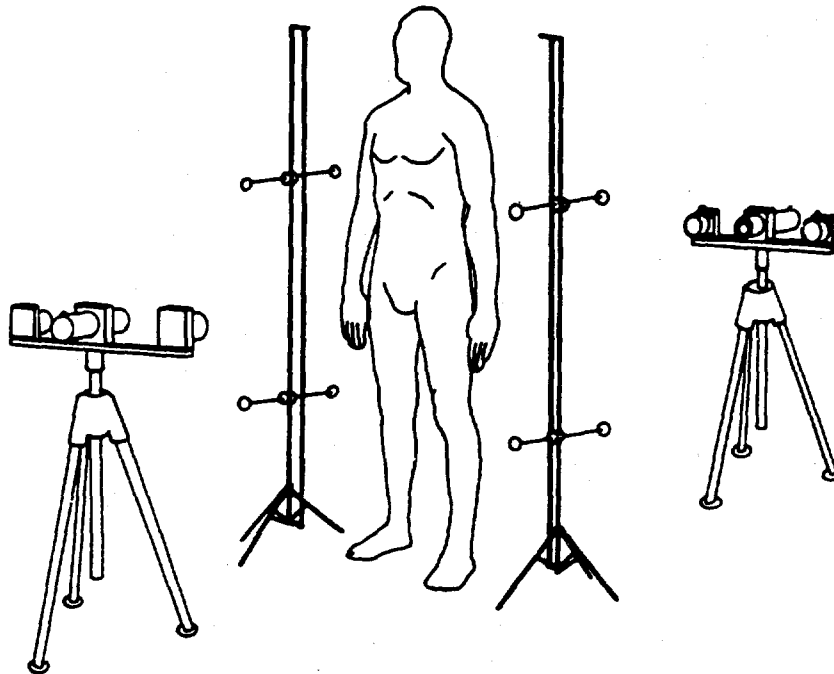


Figure 7. Stereo camera array.*

from each of the opposing stereometric cameras. This permits the analogue transformation of coordinates from each view (i.e., from either front or rear cameras) into a single coordinate system. Control points marked on the body surface in areas common (visible) to both anterior and posterior photographs provide a means for joining the two sets of data points. On opposite sides of the subject, stands support a vertically suspended pair of steel tapes graduated in English and metric units. Perpendicular to the surfaces of the tapes on each side, steel rods of known lengths extend in both directions. High contrast markers affixed to the rods provide points for determining scale at four widely spaced locations in the image space.

* Modified from Herron et al., 1976.

The stereo cameras are Hasselblad SWC units modified to improve their quality of imagery. Kodak 'M' glass plates (2½" x 0.05") coated with a panchromatic emulsion rated at an effective exposure index of 250 ASA were developed immediately after exposure, before the subject was released, to determine if the imagery was of the desired quality.

For measurements on the Kern PG-2 stereo plotter, all plates were enlarged by a factor of 3.86 onto Kodak aerographic duplicating film with an Estar thick base. The resulting images are similar to those illustrated in Figure 6. The stippling was projected on the body at the time the pictures were taken to increase skin contrast.

The three-dimensional image is viewed through the optics of the stereo plotter and the image of a lighted dot manipulated to indicate the elevation at points on the surface of the stereo image. By recording the position of the floating mark in three directions, the XYZ coordinates of a series of points on the surface are determined.

The coordinates for computation were read for points along parallel cross sections normal to the vertical or laboratory fixed axis. An attachment on the plotter prevents Z axis movement of the base carriage. The Z coordinate is fixed at the uppermost visible level of the segment which corresponds to an even mark on the steel tapes of the control cage. The model is then scanned (from left to right) and a series of XY coordinate points are read with a common Z coordinate. The Z coordinate is then repositioned along the tape until the next interval is found, another series of coordinates is then read, and so on, until the entire segment has been covered. In this study the interval between cross sections was 2.54 cm, except for the head, hands, feet and abdomen segments where the interval was 1.27. The distance between two consecutive points along the perimeter of the cross section ranges from 0.1 to 1.2 cm, with an average of approximately 0.7 cm at object scale. After all segments were read, the data were arranged for processing in the computer.

The individual data points are distributed along cross sections approximately normal to the long axis of the segments. Line segments connecting these points provide a complete cross section of the segment. Given a cross section and assuming constant density, the volume, center of volume, and principal moments and axes of inertia can be calculated. The analytic procedures used in these calculations have been described in detail in a previous publication (Herron et al., 1976).

Thus, the output from the stereophotometric assessment for each subject includes for the total body and each of the primary body segments an estimate of volume, center of volume, principal moments and axes of inertia. These data were then used in the correlational analysis.

There are indications that the stereophotometric technique consistently overestimates values -- in some cases by as much as 5%. The reason for this is unknown and is the subject of continuing investigation. Evidence of this phenomenon in this study is indicated by the lower-than-anticipated volumes for total body density of our subjects as calculated from measured weight and stereophotometrically determined volume (range = .94 - .99; \bar{x} = .96; SD = .01). From a series of skinfold dimensions measured on each subject,

more biologically realistic body densities were calculated ($\bar{x} = 1.06$; $SD = .01$). These values, however, are estimates of body densities based on studies where lung and, in some cases, gut gases were subtracted. Therefore, treating the density of the total body and its segments as unity (1.0), as was done in this study, is somewhat compensated for by the fact that, for human engineering purposes, inclusion of the normal gas contents of the body is appropriate.

We also recognize that the center of volume as reported in this study is not coincident with the center of mass of the body or of its segments. Mid-volume of a limb segment is distal to its center of mass (Clauser et al., 1969). While it is important to recognize that an error of constant direction is inherent in using mid-volume to approximate the center of mass, the use of mid-volume is believed to be valid for all practical purposes addressed in this study.

The computer programs developed to calculate many of the data reported in this study were designed so that alternate densities are easily substituted. Table 3 lists data from two studies describing the densities of intact cadavers and their segments. Data describing densities of the torso and its components are not considered as reliable as the values reported for head and limb segments. This is because the gas contents of cadaver torsos are so variable. It is possible to assign density values other than unity and to recompute mass distribution parameters of each segment by simply multiplying the segment volumes by appropriate density values.

TABLE 3
 DENSITIES OF THE TOTAL BODY OF CADAVERS
 AND THEIR SEGMENTS

| | DEMPSTER (1955) | | CLAUSER et al. (1969) | |
|-----------------|-----------------|-----------|-----------------------|-----------|
| | <u>Mean</u> | <u>SD</u> | <u>Mean</u> | <u>SD</u> |
| Total Body | | | 1.042 | .018 |
| Head | | | 1.071 | |
| Neck and torso | | | 1.023 | .032 |
| Head and neck | 1.11 | .012 | | |
| Thorax | 0.92 | .056 | | |
| Abdomino-pelvic | 1.01 | .014 | | |
| Thigh | 1.05 | .008 | 1.045 | .017 |
| Calf | 1.09 | .015 | 1.085 | .014 |
| Foot | 1.10 | .056 | 1.085 | .014 |
| Arm | 1.07 | .027 | 1.058 | .025 |
| Forearm | 1.13 | .037 | 1.099 | .018 |
| Hand | 1.16 | .110 | 1.108 | .019 |
| Torso-limbs | 1.07 | .016 | | |

Chapter III

DATA ANALYSIS

The material presented in this report is statistical and was obtained from data gathered from 31 subjects. The basic data used in compiling these results consisted of both directly measured and stereophotometrically derived body parameters. In the latter category a number of dimensions and other body characterizing quantities were calculated and compiled.

In all, fourteen tables of data were generated and compiled for each subject. These tables are listed in Appendix C. Only the results considered central to the overall study objectives are presented in the main body of this report. Information for obtaining the remaining data is given in Appendix C.

The data analysis reported here is from two sources: (1) the 87 variables of body size obtained by conventional anthropometry, and (2) the 25 segmental and total body variables of volume and the principal moments and axes of inertia obtained from the stereophotometric technique. Prior to the beginning of the analysis, the data were subjected to extensive editing to identify values which could, on the basis of their distributions, be considered as aberrant. These were then screened to determine if they could be erroneous and corrected where necessary. The editing process, described in detail in Kikta and Churchill (1978), also served to indicate when segment axes were reversed. This occurred when segment shapes were sufficiently symmetrical to yield approximately equal principal moments of inertia with a consequent indeterminacy over which quadrant the principal axis lay in. In certain body segments, such as the forearm and calf, the shapes are sufficiently symmetric to make the X and Y moments, for all practical purposes, essentially identical. In such cases, the segments were rotated about the Z axis to provide consistent alignment to one another.

The primary descriptive statistics (means, standard deviations, etc.) were computed for all variables. It should be noted that the sampling strategy used may have a marked effect on one or more of these descriptive statistics. In this case the attempt to emphasize representation from the extreme ends of the distribution results in a sample which closely reflects mean values of the larger USAF population but whose standard deviations are much larger--as would be expected in assembling a test population which contains a disproportionate number of unusually large and small subjects. The height/weight summary statistics for the sample compare to those of the USAF 1967 survey population as follows:

| | Sample (n=31) | | USAF 1967 (n=2420) | |
|-------------|---------------|-----------|--------------------|-----------|
| | <u>Mean</u> | <u>SD</u> | <u>Mean</u> | <u>SD</u> |
| Height (cm) | 177.49 | 9.63 | 177.34 | 6.19 |
| Weight (lb) | 170.38 | 28.93 | 173.60 | 21.44 |

While the deviations in the mean values for height and weight are relatively small (0.15 cm and 3.22 lb) on the order of 0.08% and 1.85%,

respectively, the differences between standard deviations are quite large. The difference in the standard deviations of height is +3.44 cm or +55.57%; the sample SD for weight is 7.49 pounds or 34.93% larger than the USAF population value.

As with many non-random sampling procedures, the one used here creates a problem in the statistical analysis. It appears that while the mean values are comparable, the standard deviations tend to be inflated. Our concern is with determining and documenting the relationships that exist between the measures of body size as represented by the anthropometry and the mass distribution parameters as represented by the measures of volume, principal moments and principal axes of inertia. For these purposes, we believe that the inflated standard deviations do not present a problem.

Summary statistics for the anthropometry of the study sample are presented in Table 4. Variables #2 through #77 were measured on the subjects and variables #78 through #87 were derived from the measured variables as:

- (78) Head Ht = (3) Stature minus (6) Mastoid Ht
- (79) Neck Lgth = (6) Mastoid Ht minus (4) Cervicale Ht
- (80) Torso Lgth = (4) Cervicale Ht minus (16) Gluteal Furrow Ht
- (81) Thorax Lgth = (4) Cervicale Ht minus (10) Tenth Rib Ht
- (82) Abdomen Lgth = (10) Tenth Rib Ht minus (11) Iliac Crest Ht
- (83) Pelvic Lgth = (11) Iliac Crest Ht minus (16) Gluteal Furrow Ht
- (84) Thigh Flap Lgth = (13) Ant Sup Iliac Spine Ht minus
(16) Gluteal Furrow Ht
- (85) Thigh Lgth = (15) Trochanteric Ht minus (17) Tibiale Ht
- (86) Calf Lgth = (17) Tibiale Ht minus (19) Sphyrion Ht
- (87) Forearm-Hand Lgth = (21) Radiale-Stylion Lgth plus
(41) Hand Lgth

The volume, principal moments and axes of inertia are reported for each segment and for the total body in Tables 5 through 29 which follow. These results are presented in a two-page format for each body segment. Results for the head segment are given in Table 5. At the top of the left-hand page is a line drawing of the segment. Two axis systems are shown on the line drawing; the first, the X_a, Y_a, Z_a , is the anatomical axis system based on the skeletal landmarks. The second axis system, X_p, Y_p, Z_p , the principal axes of inertia, is depicted originating at the center of volume of the segment with its orientation illustrating the general relationship of this axis system to the anatomical axis system.

TABLE 4

DESCRIPTIVE STATISTICS FOR ANTHROPOMETRIC VARIABLES (n=31)*

| NO. | VARIABLE NAME | MEAN | STD DEV | V-I† | V-II† | V† |
|-----|--------------------|---------|---------|------|-------|-------|
| 1 | AGE | 27.45 | 5.64 | 1.22 | 4.57 | 20.6% |
| 2 | WEIGHT | 1703.84 | 289.30 | .56 | 2.44 | 17.0% |
| 3 | STATURE | 1774.90 | 96.27 | .18 | 1.77 | 5.4% |
| 4 | CERVICALE HT | 1526.59 | 92.81 | .22 | 1.80 | 6.1% |
| 5 | TRACION HT | 1638.10 | 94.78 | .14 | 1.81 | 5.8% |
| 6 | MASTOID HT | 1608.35 | 93.56 | .14 | 1.75 | 5.8% |
| 7 | ACROMIAL HT | 1448.19 | 93.42 | .15 | 1.81 | 6.5% |
| 8 | SUPRASTERNALE HT | 1443.90 | 85.52 | .08 | 1.90 | 5.9% |
| 9 | THELION HT | 1287.97 | 76.50 | .09 | 1.96 | 5.9% |
| 10 | TENTH RIB HT | 1123.52 | 71.88 | .16 | 1.95 | 6.4% |
| 11 | ILIAC CREST HT | 1073.45 | 69.70 | .05 | 2.02 | 6.5% |
| 12 | OMPHALION HT | 1065.23 | 69.63 | .15 | 1.97 | 6.5% |
| 13 | ANT SUP ILIAC SF H | 997.94 | 65.69 | .11 | 2.07 | 6.6% |
| 14 | SYMPH HT | 914.77 | 61.23 | .12 | 1.91 | 6.7% |
| 15 | TROCHANTERION HT | 943.58 | 63.90 | .17 | 1.95 | 6.8% |
| 16 | GLUTEAL FURROW HT | 815.13 | 57.81 | .00 | 1.98 | 7.1% |
| 17 | TIBIAL HT | 478.10 | 34.24 | .05 | 2.46 | 7.2% |
| 18 | FIBULAR HT | 479.19 | 34.90 | .41 | 2.19 | 7.3% |
| 19 | SPHYRION HT | 70.74 | 6.82 | .26 | 2.68 | 9.6% |
| 20 | ACROMIAL-RAD LN | 333.94 | 24.59 | -.20 | 1.92 | 7.4% |
| 21 | RADIAL-STYLION LN | 270.45 | 18.15 | .23 | 1.96 | 6.7% |
| 22 | NECK BREADTH | 122.87 | 8.66 | .76 | 2.73 | 7.1% |
| 23 | BIACROMIAL BREADTH | 415.84 | 23.28 | .04 | 2.21 | 5.6% |
| 24 | CHEST BREADTH | 331.94 | 21.42 | .10 | 2.56 | 6.5% |
| 25 | 10TH RIB BREADTH | 298.45 | 23.28 | -.29 | 2.27 | 7.8% |
| 26 | WAIST BREADTH | 312.29 | 27.10 | -.12 | 2.22 | 8.7% |
| 27 | BISPINOUS BREADTH | 222.94 | 21.67 | -.20 | 3.43 | 9.7% |
| 28 | BITROCHANTERIC BR | 317.61 | 19.60 | .25 | 2.79 | 6.2% |
| 29 | HIP BREADTH | 346.23 | 23.31 | .32 | 3.30 | 6.7% |
| 30 | BUTTOCK DEPTH | 240.84 | 20.84 | .60 | 2.60 | 8.7% |
| 31 | GLUTEAL FURROW DPT | 193.84 | 14.42 | .18 | 2.53 | 7.4% |
| 32 | MIDTHIGH DEPTH | 174.03 | 10.00 | .69 | 2.46 | 5.7% |
| 33 | CALF DEPTH | 120.23 | 6.85 | .74 | 3.23 | 5.7% |
| 34 | ANKLE BREADTH | 59.00 | 4.29 | .02 | 1.93 | 7.3% |
| 35 | FOOT LENGTH | 266.13 | 16.44 | .61 | 3.30 | 6.2% |
| 36 | FOOT BREADTH | 104.94 | 5.85 | .28 | 2.30 | 5.6% |
| 37 | AXILLARY ARM DEPTH | 124.90 | 12.47 | .42 | 4.33 | 10.0% |
| 38 | BICEPS DPTH (RELX) | 108.26 | 11.40 | .98 | 4.54 | 10.5% |
| 39 | MIDFOREARM BREADTH | 79.48 | 6.72 | .11 | 5.15 | 8.5% |
| 40 | WRIST BREADTH | 55.42 | 3.71 | .51 | 2.70 | 6.7% |
| 41 | HAND LENGTH | 189.39 | 10.40 | .53 | 2.85 | 5.5% |
| 42 | HAND BREADTH | 86.35 | 4.88 | .24 | 2.43 | 5.7% |
| 43 | META-3-DACTY LNPTH | 109.42 | 6.48 | .47 | 4.26 | 5.9% |
| 44 | SITTING HT | 930.13 | 47.02 | .24 | 2.32 | 5.1% |
| 45 | HEAD LENGTH | 199.32 | 8.01 | -.26 | 3.11 | 4.0% |

* Age in years, weight in tenths of pounds and all others in mm with the exception of skinfold measurements given in tenths of mm.

† V-I and V-II are measures of the symmetry and kurtosis of the distribution; V is the coefficient of variation

TABLE 4 (cont'd)

| NO. | VARIABLE NAME | MEAN | STD DEV | V-I† | V-II† | V† |
|-----|--------------------|--------|---------|-------|-------|-------|
| 46 | HEAD BREADTH | 153.23 | 5.18 | -.27 | 2.16 | 3.4% |
| 47 | ELBOW BREADTH RT | 70.90 | 4.45 | .51 | 2.35 | 6.3% |
| 48 | ELBOW BREADTH LF | 70.48 | 4.29 | .49 | 2.58 | 6.1% |
| 49 | KNEE BREADTH RT | 96.39 | 5.67 | .13 | 2.81 | 5.9% |
| 50 | KNEE BREADTH LF | 95.68 | 5.79 | .41 | 3.21 | 6.1% |
| 51 | HEAD CIRC | 572.74 | 14.33 | .38 | 2.17 | 2.5% |
| 52 | NECK CIRC | 376.71 | 26.98 | .61 | 2.54 | 7.2% |
| 53 | CHEST CIRC | 965.13 | 75.69 | .31 | 2.45 | 7.8% |
| 54 | 10TH RIB CIRC | 821.48 | 71.56 | .14 | 2.14 | 8.7% |
| 55 | WAIST CIRC | 857.00 | 78.79 | .01 | 2.09 | 9.2% |
| 56 | BUTTOCK CIRC | 952.87 | 63.90 | .29 | 2.41 | 6.7% |
| 57 | UPPER THIGH CIRC | 570.23 | 39.70 | .31 | 2.69 | 7.0% |
| 58 | MIDTHIGH CIRC | 528.97 | 30.05 | .77 | 3.05 | 5.7% |
| 59 | KNEE CIRC | 374.10 | 24.99 | .39 | 2.36 | 6.7% |
| 60 | CALF CIRC RT | 379.55 | 20.76 | .67 | 2.66 | 5.5% |
| 61 | CALF CIRC LF | 374.23 | 32.05 | -1.62 | 9.66 | 8.6% |
| 62 | ANKLE CIRC | 224.29 | 12.88 | .21 | 2.51 | 5.7% |
| 63 | ARCH CIRC | 260.06 | 24.50 | 3.19 | 15.88 | 9.4% |
| 64 | BALL OF FOOT CIRC | 257.32 | 23.93 | 2.93 | 14.00 | 9.3% |
| 65 | AXILLARY ARM CIRC | 319.10 | 26.20 | .54 | 3.60 | 8.2% |
| 66 | BICEPS CIRC RLX RT | 300.90 | 25.79 | 1.33 | 5.79 | 8.6% |
| 67 | BICEPS CIRC RLX LF | 298.45 | 24.93 | 1.19 | 5.14 | 8.4% |
| 68 | ELBOW CIRC | 265.74 | 18.47 | .52 | 2.99 | 7.0% |
| 69 | MIDFOREARM CIRC | 234.16 | 15.55 | .62 | 4.78 | 6.6% |
| 70 | WRIST CIRC | 169.94 | 10.44 | .48 | 2.95 | 6.1% |
| 71 | HAND CIRC | 208.68 | 10.84 | .16 | 2.54 | 5.2% |
| 72 | TRICEPS SKINFOLD | 94.35 | 26.02 | .43 | 2.93 | 27.6% |
| 73 | SUBSCAPULAR SKINF | 120.97 | 52.39 | 1.62 | 5.16 | 43.3% |
| 74 | SUPRAILIAC SKINF | 152.42 | 61.45 | .46 | 2.20 | 40.3% |
| 75 | BICEPS SKINFOLD | 37.42 | 17.36 | 1.80 | 6.28 | 46.4% |
| 76 | BICEPS CIRC FLEX R | 322.74 | 25.70 | 1.23 | 5.30 | 8.0% |
| 77 | BICEPS CIRC FLEX L | 319.29 | 25.50 | 1.45 | 6.26 | 8.0% |
| 78 | HEAD HT | 166.55 | 7.75 | .37 | 2.44 | 4.7% |
| 79 | NECK LENGTH | 81.77 | 11.71 | .18 | 4.69 | 14.3% |
| 80 | TORSO LENGTH | 711.45 | 39.79 | .47 | 2.12 | 5.6% |
| 81 | THORAX LENGTH | 403.06 | 26.86 | .21 | 2.61 | 6.7% |
| 82 | ABDOMEN LENGTH | 50.06 | 12.57 | .82 | 3.64 | 25.1% |
| 83 | PELVIC LENGTH | 258.32 | 16.66 | .10 | 3.26 | 6.4% |
| 84 | THIGH FLAP LENGTH | 182.81 | 16.20 | .24 | 2.50 | 8.9% |
| 85 | THIGH LENGTH | 465.49 | 34.19 | .13 | 1.76 | 7.3% |
| 86 | CALF LENGTH | 407.35 | 30.52 | -.03 | 2.75 | 7.5% |
| 87 | FOREARM-HAND LNPTH | 459.84 | 27.18 | .32 | 2.32 | 5.9% |

Adjacent to the sketch is a tabulation of the range, mean and standard deviation of selected measured dimensions--in this case, head length, breadth, circumference, and height. Following this are similar statistics for the segment volume. Below the sketch are given the range, mean and standard deviation for the location of the center of volume from the anatomical axis origin in the X_a , Y_a , and Z_a notation. The mean and standard deviation are similarly given for the location of the center of volume from a number of anatomical landmarks, once again using the notation of the anatomical axis, X_a , Y_a , and Z_a . For example, the third and fourth lines of this set of data in Table 5 show that the origin of the principal axis of inertia lies .85 cm behind, essentially equally distant between and 3.13 cm above the left and right tragion landmarks.

The range, mean and standard deviation for the principal moments of inertia are then listed and are followed by the mean and standard rotational deviation in degrees of the principal axis of inertia with respect to the orientation of the anatomical axis system. (Computations used to arrive at the mean and standard rotational deviation of the principal axis systems are discussed in Appendix B.) The first line of the principal axes tabulation indicates that the mean X principal axis lies 36.13° from the anatomical X axis, 86.95° from the anatomical Y axis and 54.04° from the anatomical Z axis.

The second page of the table is devoted to a series of regression equations for predicting volume and principal moments of inertia from various anthropometric dimensions. The first section of the table tabulates the regression equations using stature and weight as predictor values. While these anthropometric variables do not necessarily provide the best estimates possible, they are provided because both stature and weight are generally known or readily obtainable for most populations of interest. These regressions are given in the form:

$$\text{Predicted Variable} = \text{Coefficient} \cdot \text{Stature} \pm \text{Coefficient} \cdot \text{Weight} \pm \text{Constant}$$

The multiple correlation coefficient (R) and the standard error of estimate (SE EST) are given on the extreme right of the line. The standard error of estimate is given as a percent of the predicted variable mean value rather than in its more usual numerical value.

These regression equations are followed by a series of multistep regression equations which use stature, weight and other segmental anthropometric variables as predictors. These regressions were obtained using a standard type of BMD stepwise regression computer program which selects those body dimensions from a given set having the maximum power to predict a given segment volume or principal moment of inertia. The initial anthropometric variable is selected on the basis of having the largest correlation coefficient with the predicted variable and then partial correlation coefficients are computed from which the variable having the second greatest predictive power is selected. The process can be continued to select the next predictor and so on. The predictive equations presented here were restricted to three steps or less as they are cumbersome to use beyond a three-step level and have

rapidly decreasing efficiency (in terms of prediction) after a certain level is reached. In some instances, a second or third step equation will not be listed as it was found to offer no practical advantage over the previous one- or two-step equation. The cut-off point in terms of the number of steps to be reported was based on the continued decrease in the resulting standard error of estimate.

The body size variables considered in the development of these equations were restricted to those measured directly on the segment involved plus stature and weight. The latter were included because as measures of overall mass distribution they may be better predictors than any other single variable.

In theory, the predictive powers of the regression equations should be improved by raising the anthropometric variables to their fourth power before initiating the stepwise analysis. In reality, the improvement obtained was essentially insignificant with the increase of the multiple correlation coefficient averaging $+0.009$ with a standard deviation ± 0.007 . Such a low level of improvement in the results does not warrant increasing the complexity of the regression equation with a power function and was therefore dropped from further consideration.

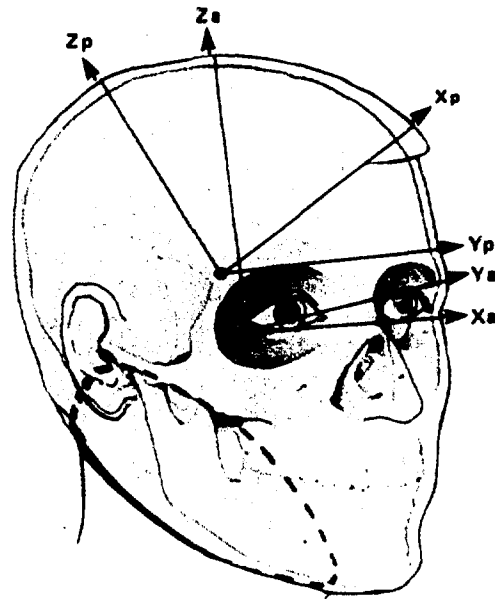
This data format is repeated for each of the 25 separate segments.

TABLE 5

HEAD

| ANTHROPOMETRY | | | | |
|---------------|------------|-------|------|--|
| OF SEGMENT | RANGE | MEAN | S.D. | |
| HEAD LGTH | 17.8- 21.6 | 19.93 | .80 | |
| HEAD BR | 14.2- 16.1 | 15.32 | .52 | |
| HEAD CIRC | 55.2- 60.4 | 57.27 | 1.43 | |
| HEAD HT | 15.3- 18.2 | 16.65 | .77 | |

| HEAD VOLUME | | | |
|---------------|-------|-------|--|
| RANGE | MEAN | S. D. | |
| 3,795 - 5,069 | 4,369 | 295 | |



LOCATION OF THE CENTER OF VOLUME FROM THE ANATOMICAL AXIS ORIGIN

| | RANGE | MEAN | S.D. | |
|--------|-------------|------|------|--|
| X-AXIS | -1.79 - .53 | -.85 | .49 | |
| Y-AXIS | -.75 - .60 | .01 | .31 | |
| Z-AXIS | 2.07 - 4.05 | 3.13 | .48 | |

LOCATION OF THE CENTER OF VOLUME FROM ANATOMICAL LANDMARKS

| | X-MEAN | X-S.D. | Y-MEAN | Y-S.D. | Z-MEAN | Z-S.D. |
|-----------------|--------|--------|--------|--------|--------|--------|
| NUCHALE | 8.77 | .76 | -.54 | .59 | 6.07 | .98 |
| SELLION | -9.88 | .40 | .01 | .31 | 1.29 | .77 |
| LEFT TRAGION | -.85 | .49 | -7.57 | .36 | 3.13 | .48 |
| RIGHT TRAGION | -.85 | .49 | 7.62 | .32 | 3.13 | .48 |
| R INFRAORBITALE | -8.08 | .36 | 3.27 | .35 | 3.13 | .48 |

THE PRINCIPAL MOMENTS OF INERTIA

| | RANGE | MEAN | S.D. | |
|--------|-------------------|---------|--------|--|
| X-AXIS | 155,880 - 260,023 | 204,117 | 25,449 | |
| Y-AXIS | 174,248 - 310,090 | 232,888 | 31,815 | |
| Z-AXIS | 122,517 - 191,634 | 150,832 | 15,571 | |

PRINCIPAL AXES OF INERTIA WITH RESPECT TO ANATOMICAL AXES
 COSINE MATRIX EXPRESSED IN DEGREES

| | X | Y | Z | STO. DEV. OF ROT. |
|---|--------|-------|-------|-------------------|
| X | 36.13 | 86.95 | 54.04 | X = 2.31 |
| Y | 93.75 | 3.75 | 90.02 | Y = 6.89 |
| Z | 125.88 | 92.19 | 35.96 | Z = 4.31 |

HEAD: REGRESSION EQUATIONS

| HEAD VOLUME AND MOMENTS FROM STATURE AND WEIGHT | | | | | | |
|---|---------|--------|----------|------|----|-------|
| | STATURE | WEIGHT | CONSTANT | R | SE | EST* |
| VOLUME = | 6.84 + | 2.05 + | 2,806 | .414 | | 6.4% |
| X MOMENT = | 859 + | 86 + | 36,972 | .416 | | 11.7% |
| Y MOMENT = | 1,097 + | 103 + | 20,735 | .419 | | 12.8% |
| Z MOMENT = | 216 + | 168 + | 83,847 | .437 | | 9.6% |

| HEAD VOLUME FROM: | | | |
|-------------------|-----------|------------|-----------|
| HEAD CIRC | HEAD LGTH | CONSTANT | R SE EST |
| 160.01 | | - 4,800.09 | .776 4.3% |
| 216.18 - | 121.84 | - 5,593.60 | .798 4.2% |

| HEAD X MOMENT FROM: | | | |
|---------------------|---------|-----------|-----------|
| HEAD CIRC | HEAD BR | CONSTANT | R SE EST |
| 13,491 | | - 568,894 | .759 8.3% |
| 11,639 + | 10,605 | - 625,049 | .783 8.0% |

| HEAD Y MOMENT FROM: | | | |
|---------------------|--|-----------|-----------|
| HEAD CIRC | | CONSTANT | R SE EST |
| 17,924 | | - 794,181 | .807 8.2% |

| HEAD Z MOMENT FROM: | | | |
|---------------------|-----------|-----------|-----------|
| HEAD CIRC | HEAD LGTH | CONSTANT | R SE EST |
| 8,493 | | - 335,264 | .780 6.6% |
| 11,857 - | 7,320 | - 382,935 | .809 6.3% |

*SE EST EXPRESSED AS A PERCENTAGE OF THE MEAN

MOMENTS IN GM CM SQUARED
 VOLUMES IN CUBIC CM
 SKINFOLDS IN MM
 WEIGHT IN POUNDS
 ALL OTHER VALUES AND DISTANCES IN CM

TABLE 6

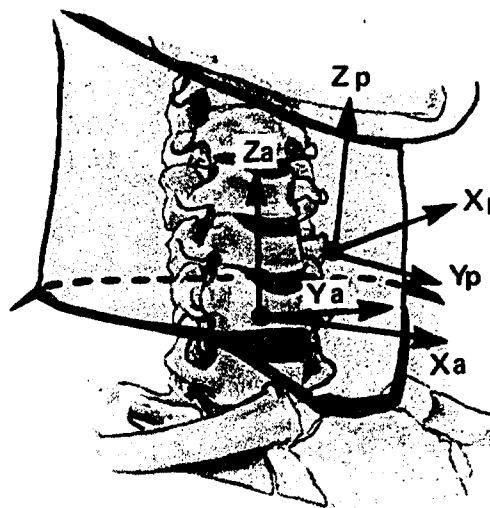
NECK

ANTHROPOMETRY

| OF SEGMENT | RANGE | MEAN | S. D. |
|------------|------------|-------|-------|
| NECK CIRC | 33.7- 43.7 | 37.67 | 2.70 |
| NECK BR | 10.9- 14.3 | 12.29 | .87 |
| NECK LGTH | 4.8- 11.5 | 8.18 | 1.17 |

NECK VOLUME

| RANGE | MEAN | S. D. |
|-------------|-------|-------|
| 721 - 1,552 | 1,043 | 182 |



LOCATION OF THE CENTER OF VOLUME FROM THE ANATOMICAL AXIS ORIGIN

| | RANGE | MEAN | S. D. |
|--------|-------------|------|-------|
| X-AXIS | 4.17 - 7.31 | 5.72 | .71 |
| Y-AXIS | -1.29 - .59 | -.18 | .41 |
| Z-AXIS | 3.93 - 6.05 | 4.98 | .44 |

LOCATION OF THE CENTER OF VOLUME FROM ANATOMICAL LANDMARKS

| | X-MEAN | X-S. D. | Y-MEAN | Y-S. D. | Z-MEAN | Z-S. D. |
|------------------|--------|---------|--------|---------|--------|---------|
| CERVICALE | 5.72 | .71 | -.18 | .41 | 4.98 | .44 |
| LEFT CLAVICALE | -7.16 | .80 | -2.54 | .46 | 4.96 | .52 |
| RIGHT CLAVICALE | -7.38 | .84 | 2.26 | .58 | 5.00 | .46 |
| MID THYROID CART | -6.24 | .56 | -.18 | .41 | -.66 | 1.06 |
| SUPRATERNALE | -6.28 | .81 | -.18 | .41 | 6.09 | .66 |

THE PRINCIPAL MOMENTS OF INERTIA

| | RANGE | MEAN | S. D. |
|--------|-----------------|--------|-------|
| X-AXIS | 9,205 - 33,649 | 16,824 | 5,277 |
| Y-AXIS | 10,163 - 36,754 | 20,250 | 5,782 |
| Z-AXIS | 13,986 - 49,238 | 25,057 | 7,345 |

PRINCIPAL AXES OF INERTIA WITH RESPECT TO ANATOMICAL AXES
 COSINE MATRIX EXPRESSED IN DEGREES

| | X | Y | Z | STD. DEV. OF ROT. |
|---|-------|-------|-------|-------------------|
| X | 12.75 | 80.08 | 82.08 | X = 9.37 |
| Y | 99.29 | 10.54 | 34.92 | Y = 7.92 |
| Z | 98.65 | 86.48 | 9.34 | Z = 11.84 |

NECK: REGRESSION EQUATIONS

NECK VOLUME AND MOMENTS FROM STATURE AND WEIGHT

| | STATURE | WEIGHT | CONSTANT | R | SE EST* |
|------------|---------|--------|----------|------|---------|
| VOLUME = | -5.50 + | 6.32 + | 943 | .749 | 12.0% |
| X MOMENT = | -142 + | 173 + | 12,401 | .723 | 22.4% |
| Y MOMENT = | -222 + | 212 + | 23,551 | .741 | 19.9% |
| Z MOMENT = | -361 + | 301 + | 37,865 | .778 | 19.1% |

NECK VOLUME FROM:

| NECK CIRC | WEIGHT | NECK BR | CONSTANT | R | SE EST |
|-----------|--------|---------|----------|------|--------|
| 52.99 | | - | 954.51 | .785 | 11.0% |
| 36.89 + | 1.83 | - | 659.40 | .803 | 10.8% |
| 11.37 + | 2.03 + | 83.40 - | 756.87 | .823 | 10.4% |

NECK X MOMENT FROM:

| NECK BR | WEIGHT | NECK LGTH | CONSTANT | R | SE EST |
|---------|--------|-----------|----------|------|--------|
| 4,752 | | - | 41,620 | .780 | 20.0% |
| 3,336 + | 60 | - | 34,491 | .815 | 18.8% |
| 3,125 + | 64 + | 597 - | 37,472 | .825 | 18.7% |

NECK Y MOMENT FROM:

| NECK CIRC | WEIGHT | NECK BR | CONSTANT | R | SE EST |
|-----------|--------|---------|----------|------|--------|
| 1,583 | | - | 39,417 | .738 | 19.6% |
| 945 + | 73 | - | 27,718 | .767 | 19.0% |
| 190 + | 78 + | 2,467 - | 30,602 | .785 | 18.6% |

NECK Z MOMENT FROM:

| NECK CIRC | NECK BR | WEIGHT | CONSTANT | R | SE EST |
|-----------|---------|--------|----------|------|--------|
| 2,250 | | - | 59,779 | .827 | 16.8% |
| 1,206 + | 3,663 | - | 65,463 | .850 | 16.0% |
| 532 + | 3,939 + | 68 - | 54,971 | .864 | 15.6% |

*SE EST EXPRESSED AS A PERCENTAGE OF THE MEAN

MOMENTS IN GM CM SQUARED

VOLUMES IN CUBIC CM

SKINFOLDS IN MM

WEIGHT IN POUNDS

ALL OTHER VALUES AND DISTANCES IN CM

TABLE 7

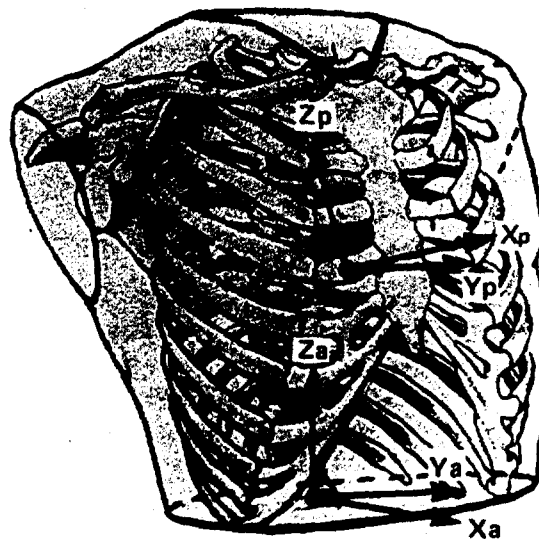
THORAX

ANTHROPOMETRY

| OF SEGMENT | RANGE | MEAN | S.D. |
|------------------|------------|-------|------|
| CHEST CIR | 82.6-113.8 | 96.51 | 7.57 |
| CHEST BR | 28.4- 37.9 | 33.19 | 2.14 |
| THORAX L | 35.2- 46.5 | 40.31 | 2.69 |
| 10 RIB BR | 24.6- 33.6 | 29.85 | 2.33 |
| 10 RIB C | 70.1- 95.7 | 82.15 | 7.16 |
| SUBSCAP SKINFOLD | 7.0- 28.0 | 12.10 | 5.24 |

THORAX VOLUME

| RANGE | MEAN | S. D. |
|-----------------|--------|-------|
| 16,452 - 35,321 | 24,385 | 4,649 |



LOCATION OF THE CENTER OF VOLUME FROM THE ANATOMICAL AXIS ORIGIN

| | RANGE | MEAN | S.D. |
|--------|---------------|-------|------|
| X-AXIS | 4.22 - 7.07 | 5.80 | .73 |
| Y-AXIS | -.54 - .49 | .13 | .27 |
| Z-AXIS | 17.12 - 21.98 | 19.99 | 1.20 |

LOCATION OF THE CENTER OF VOLUME FROM ANATOMICAL LANDMARKS

| | X-MEAN | X-S.D. | Y-MEAN | Y-S.D. | Z-MEAN | Z-S.D. |
|-------------------|--------|--------|--------|--------|--------|--------|
| CERVICALE | 5.80 | .73 | .13 | .27 | -21.62 | 1.76 |
| 10TH RIB MIDSPINE | 5.80 | .73 | .13 | .27 | 18.99 | 1.20 |
| LEFT ACROMIALE | 3.32 | 1.55 | -20.16 | 1.27 | -15.23 | 1.92 |
| RIGHT ACROMIALE | 1.82 | 1.99 | 20.75 | 1.06 | -14.23 | 1.62 |
| SUPRATERNALE | -6.07 | .68 | .13 | .27 | -14.23 | 1.04 |

THE PRINCIPAL MOMENTS OF INERTIA

| | RANGE | MEAN | S.D. |
|--------|-----------------------|-----------|-----------|
| X-AXIS | 2,724,311 - 8,323,236 | 4,774,889 | 1,497,622 |
| Y-AXIS | 1,913,036 - 6,344,398 | 3,512,342 | 1,140,605 |
| Z-AXIS | 1,505,047 - 5,301,733 | 2,959,363 | 944,269 |

PRINCIPAL AXES OF INERTIA WITH RESPECT TO ANATOMICAL AXES
 COSINE MATRIX EXPRESSED IN DEGREES

| | X | Y | Z | |
|---|--------|-------|-------|----------------------------|
| X | 14.43 | 90.50 | 75.58 | STD. DEV. OF ROT. X = 4.31 |
| Y | 90.06 | 2.22 | 87.79 | STD. DEV. OF ROT. Y = 2.85 |
| Z | 104.43 | 92.16 | 14.60 | STD. DEV. OF ROT. Z = 2.74 |

THORAX: REGRESSION EQUATIONS

THORAX VOLUME AND MOMENTS FROM STATURE AND WEIGHT

| | STATURE | WEIGHT | CONSTANT | R | SE | EST* |
|------------|-----------|----------|-----------|------|----|------|
| VOLUME = | -22.71 + | 163.68 + | 524 | .976 | | 4.3% |
| X MOMENT = | 8,183 + | 47,484 - | 4,768,961 | .965 | | 8.5% |
| Y MOMENT = | 3,738 + | 36,636 - | 3,393,924 | .958 | | 9.6% |
| Z MOMENT = | -14,325 + | 36,254 - | 675,725 | .980 | | 6.6% |

THORAX VOLUME FROM:

| WEIGHT | CHEST CIR | THORAX LGTH | CONSTANT | R | SE | EST |
|----------|-----------|-------------|-----------|------|----|------|
| 156.80 | | - | 2,334.31 | .976 | | 4.2% |
| 109.92 + | 189.96 | - | 12,676.98 | .981 | | 3.8% |
| 75.01 + | 236.12 + | 316.66 - | 23,943.81 | .987 | | 3.2% |

THORAX X MOMENT FROM:

| WEIGHT | THORAX LGTH | CHEST BR | CONSTANT | R | SE | EST |
|----------|-------------|-----------|------------|------|----|------|
| 49,963 | | - | 3,738,760 | .965 | | 8.4% |
| 39,681 + | 138,438 | - | 7,565,763 | .977 | | 7.0% |
| 32,621 + | 143,486 + | 104,738 - | 10,043,411 | .979 | | 6.7% |

THORAX Y MOMENT FROM:

| WEIGHT | THORAX LGTH | STATURE | CONSTANT | R | SE | EST |
|----------|-------------|----------|-----------|------|----|------|
| 37,768 | | - | 2,923,320 | .958 | | 9.5% |
| 28,924 + | 119,075 | - | 6,215,043 | .973 | | 7.8% |
| 33,058 + | 136,460 - | 17,912 - | 4,440,692 | .974 | | 7.7% |

THORAX Z MOMENT FROM:

| WEIGHT | CHEST CIR | THORAX LGTH | CONSTANT | R | SE | EST |
|----------|-----------|-------------|-----------|------|----|------|
| 31,916 | | - | 2,479,038 | .978 | | 6.8% |
| 20,483 + | 46,325 | - | 5,001,216 | .986 | | 5.6% |
| 15,461 + | 52,965 + | 45,554 - | 6,622,028 | .988 | | 5.1% |

*SE EST EXPRESSED AS A PERCENTAGE OF THE MEAN

MOMENTS IN GM CM SQUARED

VOLUMES IN CUBIC CM

SKINFOLDS IN MM

WEIGHT IN POUNDS

ALL OTHER VALUES AND DISTANCES IN CM

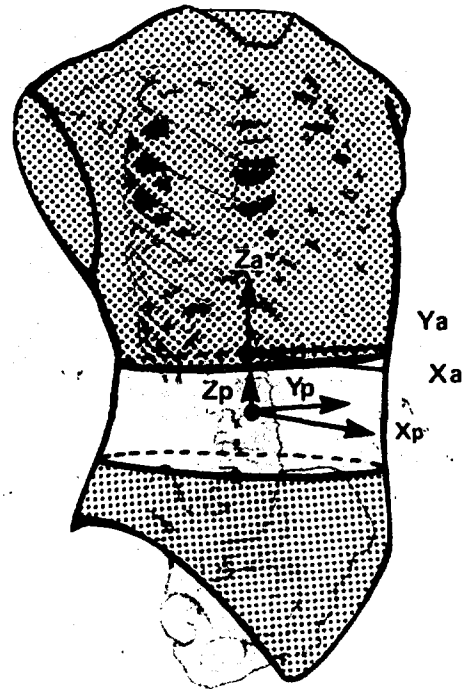
TABLE 8

ABDOMEN

ANTHROPOMETRY

| OF SEGMENT | RANGE | MEAN | S.D. |
|--------------------|------------|-------|------|
| ABDOMEN L | 3.0- 8.2 | 5.01 | 1.26 |
| WAIST CIR | 72.3- 99.7 | 85.70 | 7.88 |
| 10 RIB BR | 24.6- 33.6 | 29.85 | 2.33 |
| 10 RIB C | 70.1- 95.7 | 82.15 | 7.16 |
| WAIST BR | 26.1- 35.6 | 31.23 | 2.71 |
| SUPRAIL'C SKINFOLD | | | |
| | 6.0- 28.0 | 15.24 | 6.14 |

| ABDOMEN VOLUME | | | |
|----------------|-------|-------|--|
| RANGE | MEAN | S. D. | |
| 915 - 3,912 | 2,339 | 693 | |



LOCATION OF THE CENTER OF VOLUME FROM THE ANATOMICAL AXIS ORIGIN

| | RANGE | MEAN | S.D. |
|--------|---------------|-------|------|
| X-AXIS | -4.82 - 1.54 | -0.40 | 1.14 |
| Y-AXIS | -2.57 - 2.25 | .50 | .86 |
| Z-AXIS | -3.65 - -1.15 | -2.42 | .67 |

LOCATION OF THE CENTER OF VOLUME FROM ANATOMICAL LANDMARKS

| | X-MEAN | X-S.D. | Y-MEAN | Y-S.D. | Z-MEAN | Z-S.D. |
|------------------|--------|--------|--------|--------|--------|--------|
| L ILIOCRISTALE | .09 | 1.03 | -15.69 | 1.27 | 2.15 | .64 |
| R ILIOCRISTALE | .28 | 1.26 | 16.17 | 1.43 | 2.63 | .82 |
| LEFT 10TH RIB | -.40 | 1.14 | -15.00 | 1.26 | -2.42 | .67 |
| RIGHT 10TH RIB | -.40 | 1.14 | 15.21 | 1.33 | -2.42 | .67 |
| P S IL'C MDSPINE | 11.09 | 1.09 | .59 | .89 | 5.72 | 1.58 |

THE PRINCIPAL MOMENTS OF INERTIA

| | RANGE | MEAN | S.D. |
|--------|------------------|---------|---------|
| X-AXIS | 45,129 - 327,248 | 156,228 | 66,349 |
| Y-AXIS | 20,339 - 207,761 | 86,397 | 41,900 |
| Z-AXIS | 64,711 - 465,963 | 235,236 | 102,995 |

PRINCIPAL AXES OF INERTIA WITH RESPECT TO ANATOMICAL AXES
COSINE MATRIX EXPRESSED IN DEGREES

| | X | Y | Z | STD. DEV. OF ROT. |
|---|-------|-------|-------|-------------------|
| X | 2.61 | 91.47 | 92.15 | X = 1.75 |
| Y | 88.51 | 1.61 | 89.38 | Y = 4.64 |
| Z | 87.86 | 90.68 | 2.24 | Z = 4.36 |

ABDOMEN: REGRESSION EQUATIONS

ABDOMEN VOLUME AND MOMENTS FROM STATURE AND WEIGHT

| | STATURE | WEIGHT | CONSTANT | R | SE EST* |
|------------|----------|---------|----------|------|---------|
| VOLUME = | -23.05 + | 19.42 + | 3,121 | .536 | 25.9% |
| X MOMENT = | -2,124 + | 2,218 + | 155,225 | .698 | 31.5% |
| Y MOMENT = | -1,838 + | 1,481 + | 160,313 | .662 | 37.6% |
| Z MOMENT = | -3,865 + | 3,625 + | 303,513 | .705 | 32.1% |

ABDOMEN VOLUME FROM:

| ABDOMEN LGTH | WAIST CIR | WEIGHT | CONSTANT | R | SE EST |
|--------------|-----------|--------|----------|------|--------|
| 396.95 | | + | 354.65 | .720 | 20.9% |
| 298.13 + | 44.39 | - | 2,955.60 | .861 | 15.6% |
| 290.54 + | 70.58 - | 7.97 - | 3,803.99 | .875 | 15.1% |

ABDOMEN X MOMENT FROM

| WAIST CIR | ABDOMEN LGTH | SUPRAIL'C SKINFOLD | CONSTANT | R | SE EST |
|-----------|--------------|--------------------|----------|------|--------|
| 6,993 | | - | 443,070 | .830 | 24.1% |
| 5,743 + | 22,063 | - | 446,249 | .918 | 17.5% |
| 4,678 + | 21,771 + | 1,717 - | 379,651 | .922 | 17.3% |

ABDOMEN Y MOMENT FROM

| 10 RIB C | ABDOMEN LGTH | SUPRAIL'C SKINFOLD | CONSTANT | R | SE EST |
|----------|--------------|--------------------|----------|------|--------|
| 4,789 | | - | 306,792 | .818 | 28.4% |
| 3,807 + | 14,797 | - | 300,104 | .915 | 20.2% |
| 2,659 + | 14,558 + | 1,746 - | 231,263 | .929 | 18.9% |

ABDOMEN Z MOMENT FROM

| WAIST CIR | ABDOMEN LGTH | SUPRAIL'C SKINFOLD | CONSTANT | R | SE EST |
|-----------|--------------|--------------------|----------|------|--------|
| 11,075 | | - | 713,850 | .847 | 23.7% |
| 9,103 + | 34,803 | - | 718,864 | .936 | 16.0% |
| 7,198 + | 34,280 + | 3,071 - | 599,736 | .942 | 15.5% |

*SE EST EXPRESSED AS A PERCENTAGE OF THE MEAN

MOMENTS IN GM CM SQUARED

VOLUMES IN CUBIC CM

SKINFOLDS IN MM

WEIGHT IN POUNDS

ALL OTHER VALUES AND DISTANCES IN CM

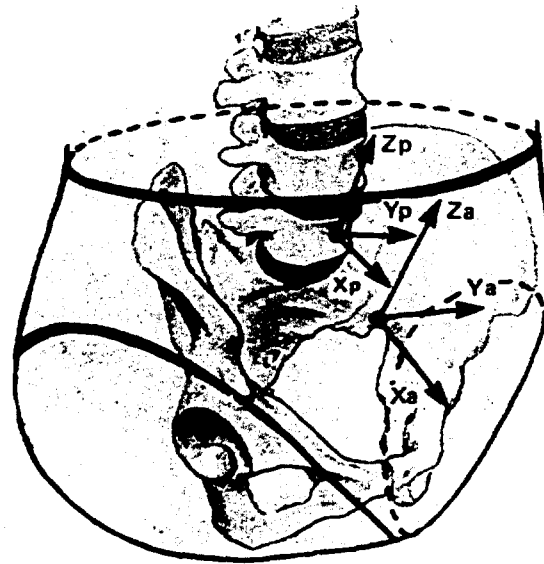
TABLE 9

PELVIS

ANTHROPOMETRY

| OF SEGMENT | RANGE | MEAN | S.D. |
|--------------------|------------|-------|------|
| BUTTOCK C | 84.1-109.0 | 95.29 | 6.39 |
| BUTT'K DP | 20.6- 29.1 | 24.08 | 2.08 |
| BISPIN BR | 16.8- 27.0 | 22.29 | 2.17 |
| PELVIC L | 21.9- 29.7 | 25.83 | 1.67 |
| HIP BR | 30.0- 40.8 | 34.62 | 2.33 |
| SUPRAIL'C SKINFOLD | 6.0- 28.0 | 15.24 | 6.14 |

| PELVIS VOLUME | | MEAN | S. D. |
|----------------|--|--------|-------|
| RANGE | | | |
| 7,148 - 16,400 | | 11,390 | 2,565 |



LOCATION OF THE CENTER OF VOLUME FROM THE ANATOMICAL AXIS ORIGIN

| | RANGE | MEAN | S. D. |
|--------|----------------|-------|-------|
| X-AXIS | -10.02 - -6.96 | -8.18 | .82 |
| Y-AXIS | -.73 - .74 | .05 | .36 |
| Z-AXIS | -1.57 - 5.18 | 1.07 | 1.17 |

LOCATION OF THE CENTER OF VOLUME FROM ANATOMICAL LANDMARKS

| | X-MEAN | X-S.D. | Y-MEAN | Y-S.D. | Z-MEAN | Z-S.D. |
|------------------|--------|--------|--------|--------|--------|--------|
| LEFT ASIS | -8.18 | .82 | -11.16 | 1.06 | 1.07 | 1.17 |
| RIGHT ASIS | -8.18 | .82 | 11.28 | 1.17 | 1.07 | 1.17 |
| POS SUP ILIAC MS | 7.17 | 1.20 | .05 | .36 | -8.30 | 1.08 |
| SYMPHYSION | -8.18 | .82 | .13 | .52 | 9.71 | 1.37 |

THE PRINCIPAL MOMENTS OF INERTIA

| | RANGE | MEAN | S. D. |
|--------|---------------------|-----------|---------|
| X-AXIS | 442,667 - 1,737,411 | 993,154 | 357,943 |
| Y-AXIS | 426,544 - 1,722,636 | 909,728 | 349,198 |
| Z-AXIS | 491,319 - 2,066,561 | 1,148,135 | 435,481 |

PRINCIPAL AXES OF INERTIA WITH RESPECT TO ANATOMICAL AXES
 COSINE MATRIX EXPRESSED IN DEGREES

| | X | Y | Z | STD. DEV. OF ROT. |
|---|-------|--------|-------|-------------------|
| X | 11.57 | 100.31 | 84.80 | X = 3.24 |
| Y | 79.62 | 10.38 | 90.26 | Y = 12.49 |
| Z | 95.07 | 88.81 | 5.21 | Z = 10.35 |

PELVIS: REGRESSION EQUATIONS

PELVIS VOLUME AND MOMENTS FROM STATURE AND WEIGHT

| | STATURE | HEIGHT | CONSTANT | R | SE EST* |
|------------|-----------|----------|----------|------|---------|
| VOLUME = | -68.97 + | 98.98 + | 6,765 | .887 | 10.7% |
| X MOMENT = | -10,283 + | 14,215 + | 396,174 | .904 | 15.9% |
| Y MOMENT = | -10,851 + | 13,750 + | 492,711 | .876 | 19.2% |
| Z MOMENT = | -14,684 + | 17,498 + | 772,875 | .877 | 18.8% |

PELVIS VOLUME FROM:

| BUTTOCK C | SUPRAIL 'C SKINFOLD | BUTT 'K DP | CONSTANT | R | SE EST |
|-----------|------------------------|------------|-----------|------|--------|
| 362.75 | | - | 23,179.36 | .904 | 9.8% |
| 279.79 + | 138.28 | - | 17,375.21 | .940 | 7.9% |
| 192.98 + | 103.29 + | 392.86 - | 18,838.43 | .954 | 7.1% |

PELVIS X MOMENT FROM:

| BUTTOCK C | SUPRAIL 'C SKINFOLD | BUTT 'K DP | CONSTANT | R | SE EST |
|-----------|------------------------|------------|-----------|------|--------|
| 51,216 | | - | 3,887,706 | .914 | 14.8% |
| 40,473 + | 17,907 | - | 3,136,095 | .945 | 12.2% |
| 30,171 + | 13,754 + | 46,623 - | 3,214,802 | .955 | 11.3% |

PELVIS Y MOMENT FROM:

| BUTT 'K DP | HEIGHT | SUPRAIL 'C SKINFOLD | CONSTANT | R | SE EST |
|------------|---------|------------------------|-----------|------|--------|
| 152,381 | | - | 2,762,656 | .909 | 16.2% |
| 101,293 + | 4,516 | - | 2,301,000 | .935 | 14.1% |
| 79,999 + | 4,294 + | 11,786 - | 1,929,018 | .947 | 13.0% |

PELVIS Z MOMENT FROM:

| BUTT 'K DP | BUTTOCK C | SUPRAIL 'C SKINFOLD | CONSTANT | R | SE EST |
|------------|-----------|------------------------|-----------|------|--------|
| 191,408 | | - | 3,464,807 | .916 | 15.5% |
| 115,988 + | 29,237 | - | 4,433,412 | .945 | 12.8% |
| 89,240 + | 26,661 + | 16,528 - | 3,794,526 | .960 | 11.2% |

*SE EST EXPRESSED AS A PERCENTAGE OF THE MEAN

MOMENTS IN GM CM SQUARED

VOLUMES IN CUBIC CM

SKINFOLDS IN MM

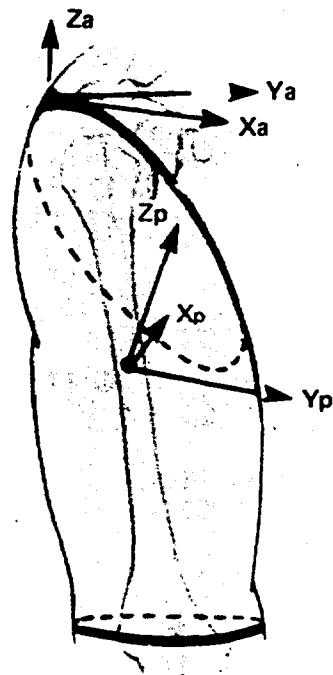
HEIGHT IN POUNDS

ALL OTHER VALUES AND DISTANCES IN CM

TABLE 10

RIGHT UPPER ARM

| ANTHROPOMETRY | | | | |
|----------------------|------------|-------|-------|--|
| OF SEGMENT | RANGE | MEAN | S. D. | |
| AX ARM C | 26.8- 39.5 | 31.91 | 2.62 | |
| BICEPS C RELAXED | | | | |
| | 26.3- 39.2 | 30.09 | 2.58 | |
| BICEPS C FLEXED | | | | |
| | 28.3- 41.1 | 32.27 | 2.57 | |
| ACROMIAL-RADIAL LGTH | | | | |
| | 28.3- 37.1 | 33.39 | 2.46 | |
| ELBOW CIR | 23.1- 31.4 | 26.57 | 1.85 | |
| BICEPS DP -RELAXED | | | | |
| | 9.3- 14.5 | 10.83 | 1.14 | |
| ELBOW BR | 6.4- 8.1 | 7.09 | .44 | |
| BICEPS SF | 2.0- 10.0 | 3.74 | 1.74 | |
| TRICEP SF | 5.0- 16.5 | 9.44 | 2.60 | |
| AX ARM DP | 9.6- 16.3 | 12.49 | 1.25 | |



| RIGHT UPPER ARM VOLUME | | | |
|------------------------|-------|-------|--|
| RANGE | MEAN | S. D. | |
| 1,259 - 3,150 | 1,955 | 389 | |

| LOCATION OF THE CENTER OF VOLUME FROM THE ANATOMICAL AXIS ORIGIN | | | | |
|--|-----------------|--------|-------|--|
| | RANGE | MEAN | S. D. | |
| X-AXIS | -2.14 - -.92 | -1.60 | .34 | |
| Y-AXIS | -4.04 - -2.28 | -3.05 | .41 | |
| Z-AXIS | -20.53 - -14.28 | -17.18 | 1.53 | |

| LOCATION OF THE CENTER OF VOLUME FROM ANATOMICAL LANDMARKS | | | | | | |
|--|--------|---------|--------|---------|--------|---------|
| | X-MEAN | X-S. D. | Y-MEAN | Y-S. D. | Z-MEAN | Z-S. D. |
| RIGHT ACROMIALE | 1.60 | .34 | 3.05 | .41 | -17.18 | 1.53 |
| RIGHT OLECRANON | 4.00 | .38 | -2.07 | .62 | 13.55 | 1.11 |
| R MED HUM EPICON | 1.60 | .34 | -5.06 | .55 | 14.08 | 1.18 |
| R LAT HUM EPICON | 1.60 | .34 | 3.05 | .41 | 14.42 | 1.09 |
| RIGHT RADIALE | 1.90 | .60 | 2.46 | .67 | 15.76 | 1.17 |

| THE PRINCIPAL MOMENTS OF INERTIA | | | |
|----------------------------------|------------------|---------|--------|
| | RANGE | MEAN | S. D. |
| X-AXIS | 57,846 - 250,155 | 127,515 | 42,915 |
| Y-AXIS | 61,213 - 276,453 | 135,568 | 46,612 |
| Z-AXIS | 12,235 - 60,858 | 25,859 | 9,412 |

PRINCIPAL AXES OF INERTIA WITH RESPECT TO ANATOMICAL AXES
 COSINE MATRIX EXPRESSED IN DEGREES

| | X | Y | Z | |
|---|-------|--------|-------|----------------------------|
| X | 25.63 | 115.53 | 87.92 | STD. DEV. OF ROT. X = 1.29 |
| Y | 64.39 | 26.56 | 96.58 | STD. DEV. OF ROT. Y = 1.85 |
| Z | 89.03 | 83.17 | 6.90 | STD. DEV. OF ROT. Z = 9.24 |

RIGHT UPPER ARM: REGRESSION EQUATIONS

RIGHT UPPER ARM VOLUME AND MOMENTS FROM STATURE AND WEIGHT

| | STATURE | WEIGHT | CONSTANT | R | SE EST* |
|------------|---------|---------|----------|------|---------|
| VOLUME = | -2.14 + | 13.25 + | 76 | .937 | 7.2% |
| X MOMENT = | 934 + | 1,094 - | 224,626 | .932 | 12.6% |
| Y MOMENT = | 627 + | 1,304 - | 198,020 | .929 | 13.2% |
| Z MOMENT = | -338 + | 391 + | 19,102 | .900 | 16.4% |

RIGHT UPPER ARM VOLUME FROM:

| WEIGHT | BICEPS C FLEXED R | ACROMIAL-RADIAL L | CONSTANT | R | SE EST |
|--------|-------------------|-------------------|----------|------|--------|
| 12.61 | | | 193.15 | .936 | 7.1% |
| 7.59 + | 68.34 | | 1,545.38 | .970 | 5.0% |
| 2.54 + | 84.86 + | 52.47 - | 2,970.77 | .983 | 3.9% |

RIGHT UPPER ARM X MOMENT FROM:

| WEIGHT | ACROMIAL-RADIAL L | BICEPS C FLEXED R | CONSTANT | R | SE EST |
|--------|-------------------|-------------------|----------|------|--------|
| 1,377 | | | 107,147 | .928 | 12.8% |
| 880 + | 6,795 | | 249,297 | .949 | 11.0% |
| 159 + | 9,700 + | 6,912 - | 446,887 | .973 | 8.1% |

RIGHT UPPER ARM Y MOMENT FROM:

| WEIGHT | TRICEP SF | AX ARM DP | CONSTANT | R | SE EST |
|---------|-----------|-----------|----------|------|--------|
| 1,494 | | | 119,075 | .927 | 13.1% |
| 1,639 - | 3,566 | | 110,117 | .944 | 11.7% |
| 1,335 - | 3,932 + | 9,157 - | 169,440 | .955 | 10.7% |

RIGHT UPPER ARM Z MOMENT FROM:

| BICEPS C FLEXED R | AX ARM C | ACROMIAL-RADIAL L | CONSTANT | R | SE EST |
|-------------------|----------|-------------------|----------|------|--------|
| 3,468 | | | 86,144 | .947 | 11.9% |
| 1,986 + | 1,613 | | 89,749 | .967 | 9.6% |
| 1,985 + | 1,201 + | 653 - | 98,396 | .975 | 8.5% |

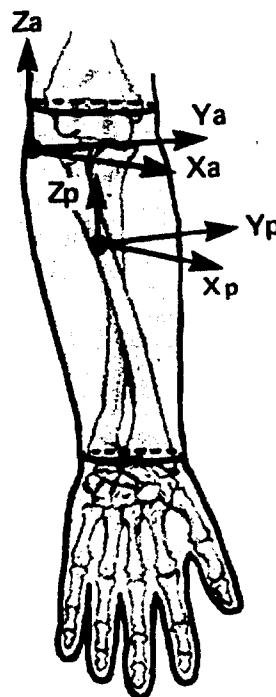
*SE EST EXPRESSED AS A PERCENTAGE OF THE MEAN

MOMENTS IN GM CM SQUARED
 VOLUMES IN CUBIC CM
 SKINFOLOS IN MM
 WEIGHT IN POUNDS
 ALL OTHER VALUES AND DISTANCES IN CM

TABLE 11

RIGHT FOREARM

| ANTHROPOMETRY OF SEGMENT | | | |
|--------------------------|-------|-------|--|
| RANGE | MEAN | S. D. | |
| RADIAL-STYLION LGTH | | | |
| 24.1- 30.9 | 27.05 | 1.81 | |
| ELBOW BR 6.4- 8.1 | 7.09 | .44 | |
| ELBOW CIR 23.1- 31.4 | 26.57 | 1.85 | |
| MIDFOREARM CIRC | | | |
| 20.5- 28.4 | 23.42 | 1.56 | |
| MIDFOREARM BREADTH | | | |
| 6.1- 10.0 | 7.95 | .67 | |
| WRIST CIR 15.3- 19.8 | 16.99 | 1.04 | |
| WRIST BR 4.9- 6.4 | 5.54 | .37 | |



| RIGHT FOREARM VOLUME | | | |
|----------------------|-------|-------|--|
| RANGE | MEAN | S. D. | |
| 1,018 - 2,170 | 1,396 | 247 | |

LOCATION OF THE CENTER OF VOLUME FROM THE ANATOMICAL AXIS ORIGIN

| | RANGE | MEAN | S. D. |
|--------|----------------|--------|-------|
| X-AXIS | -2.27 - .07 | -.97 | .61 |
| Y-AXIS | 2.63 - 4.14 | 3.22 | .33 |
| Z-AXIS | -11.86 - -8.87 | -10.37 | .76 |

LOCATION OF THE CENTER OF VOLUME FROM ANATOMICAL LANDMARKS

| | X-MEAN | X-S. D. | Y-MEAN | Y-S. D. | Z-MEAN | Z-S. D. |
|------------------|--------|---------|--------|---------|--------|---------|
| RIGHT OLECRANON | 3.52 | .50 | 1.66 | .84 | -12.89 | .83 |
| R MED HUM EPICON | 4.41 | .77 | -1.89 | 1.07 | -11.79 | .70 |
| R RADIAL STYLOID | -.97 | .61 | -3.41 | .35 | 16.51 | 1.20 |
| R ULNAR STYLOID | -.97 | .61 | 3.22 | .33 | 16.42 | 1.15 |
| RIGHT RADIALE | -.97 | .61 | 3.22 | .33 | -10.37 | .76 |

THE PRINCIPAL MOMENTS OF INERTIA

| | RANGE | MEAN | S. D. |
|--------|------------------|--------|--------|
| X-AXIS | 47,484 - 150,408 | 85,854 | 26,092 |
| Y-AXIS | 48,904 - 154,810 | 87,411 | 26,639 |
| Z-AXIS | 7,544 - 28,153 | 12,784 | 4,108 |

PRINCIPAL AXES OF INERTIA WITH RESPECT TO ANATOMICAL AXES
 COSINE MATRIX EXPRESSED IN DEGREES

| | X | Y | Z | |
|---|-------|-------|-------|-----------------------------|
| X | 7.61 | 82.48 | 88.85 | STD. DEV. OF ROT. X = .90 |
| Y | 97.48 | 7.68 | 91.70 | STD. DEV. OF ROT. Y = 2.61 |
| Z | 91.36 | 88.46 | 2.05 | STD. DEV. OF ROT. Z = 13.32 |

RIGHT FOREARM: REGRESSION EQUATIONS

| RIGHT FOREARM VOLUME AND MOMENTS FROM STATURE AND WEIGHT | | | | | | |
|--|---------|--------|----------|------|-------|------|
| | STATURE | WEIGHT | CONSTANT | R | SE | EST* |
| VOLUME = | -2.06 + | 8.40 + | 329 | .912 | 7.5% | |
| X MOMENT = | 905 + | 537 - | 166,237 | .910 | 13.1% | |
| Y MOMENT = | 867 + | 566 - | 162,961 | .909 | 13.1% | |
| Z MOMENT = | -142 + | 167 + | 9,488 | .885 | 15.5% | |

| RIGHT FOREARM VOLUME FROM: | | | | | | |
|----------------------------|-----------|-----------------------|----------|------|------|-----|
| ELBOW CIR | WRIST CIR | RADIAL - STYLION L | CONSTANT | R | SE | EST |
| 126.30 | | - | 1,963.77 | .944 | 5.9% | |
| 85.56 + | 81.95 | - | 2,273.27 | .959 | 5.2% | |
| 67.38 + | 76.39 + | 28.10 - | 2,453.90 | .968 | 4.7% | |

| RIGHT FOREARM X MOMENT FROM: | | | | | | |
|------------------------------|-----------|-----------|----------|------|-------|-----|
| RADIAL - STYLION L | WRIST CIR | ELBOW CIR | CONSTANT | R | SE | EST |
| 13,043 | | - | 266,304 | .907 | 13.0% | |
| 8,557 + | 11,249 | - | 336,437 | .964 | 8.4% | |
| 7,476 + | 6,807 + | 3,694 - | 329,986 | .970 | 7.8% | |

| RIGHT FOREARM Y MOMENT FROM: | | | | | | |
|------------------------------|-----------|-----------|----------|------|-------|-----|
| RADIAL - STYLION L | WRIST CIR | ELBOW CIR | CONSTANT | R | SE | EST |
| 13,288 | | - | 271,362 | .905 | 13.2% | |
| 8,644 + | 11,647 | - | 343,975 | .963 | 8.5% | |
| 7,515 + | 7,008 + | 3,858 - | 337,239 | .970 | 7.8% | |

| RIGHT FOREARM Z MOMENT FROM: | | | | | | |
|------------------------------|--------------------|----------|----------|------|-------|-----|
| ELBOW CIR | MIDFOREARM CIRC | WRIST BR | CONSTANT | R | SE | EST |
| 2,074 | | - | 42,371 | .932 | 11.8% | |
| 1,653 + | 730 | - | 48,283 | .954 | 10.0% | |
| 1,355 + | 782 + | 1,953 - | 52,297 | .962 | 9.2% | |

*SE EST EXPRESSED AS A PERCENTAGE OF THE MEAN

MOMENTS IN GM CM SQUARED
 VOLUMES IN CUBIC CM
 SKINFOLDS IN MM
 WEIGHT IN POUNDS
 ALL OTHER VALUES AND DISTANCES IN CM

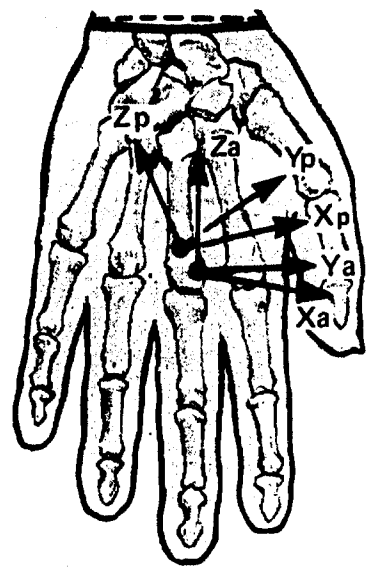
TABLE 12

RIGHT HAND

ANTHROPOMETRY

| OF SEGMENT | RANGE | MEAN | S.D. |
|----------------------|------------|-------|------|
| HAND LGTH | 17.3- 21.7 | 18.94 | 1.04 |
| HAND BR | 7.8- 9.8 | 8.64 | .49 |
| HAND CIRC | 18.7- 23.5 | 20.87 | 1.08 |
| META-III-DACTYL LGTH | 9.5- 12.9 | 10.94 | .65 |

| RIGHT HAND VOLUME | | MEAN | S. D. |
|-------------------|-----|------|-------|
| RANGE | | | |
| 410 - | 677 | 512 | 69 |



LOCATION OF THE CENTER OF VOLUME FROM THE ANATOMICAL AXIS ORIGIN

| | RANGE | MEAN | S. D. |
|--------|-------------|------|-------|
| X-AXIS | -1.76 - .03 | -.75 | .39 |
| Y-AXIS | -1.01 - .12 | -.46 | .28 |
| Z-AXIS | .75 - 1.92 | 1.31 | .32 |

LOCATION OF THE CENTER OF VOLUME FROM ANATOMICAL LANDMARKS

| | X-MEAN | X-S.D. | Y-MEAN | Y-S.D. | Z-MEAN | Z-S.D. |
|------------------|--------|--------|--------|--------|--------|--------|
| R RADIAL STYLOID | .45 | .82 | -1.77 | .43 | -6.98 | .44 |
| R ULNAR STYLOID | -.90 | .87 | 4.63 | .56 | -6.33 | .53 |
| R METACARPALE V | -.75 | .39 | 5.08 | .26 | 1.31 | .32 |
| R METACARPALE II | -.75 | .39 | -4.21 | .26 | 1.31 | .32 |
| RIGHT DACTYLION | -.75 | .39 | -.99 | .77 | 12.07 | .70 |

THE PRINCIPAL MOMENTS OF INERTIA

| | RANGE | MEAN | S. D. |
|--------|----------------|--------|-------|
| X-AXIS | 8,549 - 20,711 | 12,821 | 3,043 |
| Y-AXIS | 6,757 - 17,217 | 10,498 | 2,504 |
| Z-AXIS | 2,759 - 6,678 | 4,093 | 956 |

PRINCIPAL AXES OF INERTIA WITH RESPECT TO ANATOMICAL AXES
 COSINE MATRIX EXPRESSED IN DEGREES

| | X | Y | Z | STD. DEV. OF ROT. |
|---|--------|-------|-------|-------------------|
| X | 13.44 | 79.13 | 82.19 | X = 4.12 |
| Y | 101.75 | 13.30 | 83.85 | Y = 4.21 |
| Z | 96.43 | 97.57 | 9.96 | Z = 3.36 |

RIGHT HAND: REGRESSION EQUATIONS

RIGHT HAND VOLUME AND MOMENTS FROM STATURE AND WEIGHT

| | STATURE | WEIGHT | CONSTANT | R | SE | EST* |
|------------|---------|--------|----------|------|-------|------|
| VOLUME = | 1.69 + | 1.60 - | 62 | .888 | 6.4% | |
| X MOMENT = | 133 + | 48 - | 18,865 | .852 | 12.9% | |
| Y MOMENT = | 124 + | 34 - | 17,258 | .847 | 13.1% | |
| Z MOMENT = | 12 + | 26 - | 2,404 | .884 | 11.3% | |

RIGHT HAND VOLUME FROM:

| WEIGHT | HAND CIRC | META-THREE DACTYL L | CONSTANT | R | SE | EST |
|--------|-----------|------------------------|----------|------|------|-----|
| 2.12 | | | 151.11 | .883 | 6.5% | |
| 1.18 + | 31.16 | | 340.70 | .930 | 5.2% | |
| .95 + | 24.58 + | 30.29 - | 494.22 | .954 | 4.3% | |

RIGHT HAND X MOMENT FROM:

| WEIGHT | META-THREE DACTYL L | HAND CIRC | CONSTANT | R | SE | EST |
|--------|------------------------|-----------|----------|------|-------|-----|
| 88 | | | 2,133 | .834 | 13.3% | |
| 59 + | 2,059 | | 19,619 | .901 | 10.7% | |
| 37 + | 1,752 + | 852 - | 30,452 | .918 | 9.9% | |

RIGHT HAND Y MOMENT FROM:

| HAND LGTH | HAND CIRC | CONSTANT | R | SE | EST |
|-----------|-----------|----------|------|-------|-----|
| 2,060 | | 28,437 | .855 | 12.6% | |
| 1,390 + | 1,113 | 39,028 | .941 | 8.3% | |

RIGHT HAND Z MOMENT FROM:

| HAND CIRC | WEIGHT | META-THREE DACTYL L | CONSTANT | R | SE | EST |
|-----------|--------|------------------------|----------|------|-------|-----|
| 787 | | | 12,354 | .891 | 10.8% | |
| 454 + | 16 | | 8,045 | .935 | 8.6% | |
| 380 + | 13 + | 340 - | 9,771 | .951 | 7.7% | |

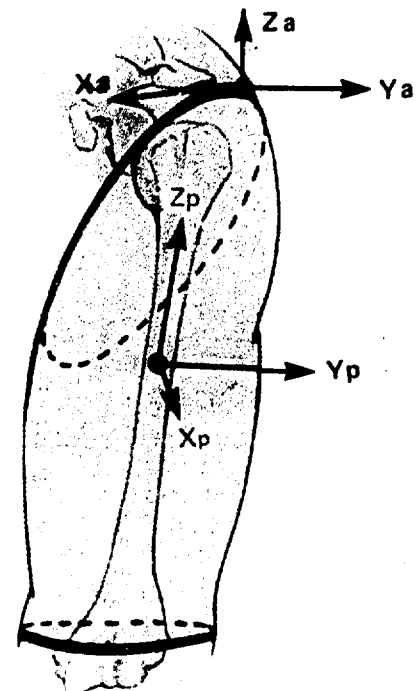
*SE EST EXPRESSED AS A PERCENTAGE OF THE MEAN

MOMENTS IN GM CM SQUARED
 VOLUMES IN CUBIC CM
 SKINFOLDS IN MM
 WEIGHT IN POUNDS
 ALL OTHER VALUES AND DISTANCES IN CM

TABLE 13

LEFT UPPER ARM

| ANTHROPOMETRY | | | | |
|----------------------|------------|-------|-------|--|
| OF SEGMENT | RANGE | MEAN | S. D. | |
| AX ARM C | 26.8- 39.5 | 31.91 | 2.62 | |
| BICEPS C RELAXED L | 26.0- 37.9 | 29.85 | 2.49 | |
| BICEPS C FLEXED L | 27.8- 40.8 | 31.93 | 2.55 | |
| ACROMIAL-RADIAL LGTH | 28.3- 37.1 | 33.39 | 2.46 | |
| ELBOW CIR | 23.1- 31.4 | 26.57 | 1.85 | |
| BICEPS DP -RELAXED | 9.3- 14.5 | 10.83 | 1.14 | |
| ELBW BR L | 6.3- 8.0 | 7.05 | .43 | |
| BICEPS SF | 2.0- 10.0 | 3.74 | 1.74 | |
| TRICEP SF | 5.0- 16.5 | 9.44 | 2.60 | |
| AX ARM DP | 9.6- 16.3 | 12.49 | 1.25 | |



| LEFT UPPER ARM VOLUME | | | |
|-----------------------|-------|-------|--|
| RANGE | MEAN | S. D. | |
| 1,259 - 3,142 | 1,918 | 387 | |

| LOCATION OF THE CENTER OF VOLUME FROM THE ANATOMICAL AXIS ORIGIN | | | | |
|--|-----------------|--------|-------|--|
| | RANGE | MEAN | S. D. | |
| X-AXIS | .97 - 2.58 | 1.69 | .31 | |
| Y-AXIS | -4.36 - -1.80 | -2.96 | .41 | |
| Z-AXIS | -20.64 - -14.32 | -17.26 | 1.48 | |

| LOCATION OF THE CENTER OF VOLUME FROM ANATOMICAL LANDMARKS | | | | | | |
|--|--------|---------|--------|---------|--------|---------|
| | X-MEAN | X-S. D. | Y-MEAN | Y-S. D. | Z-MEAN | Z-S. D. |
| LEFT ACROMIALE | 1.69 | .31 | -2.96 | .41 | -17.26 | 1.48 |
| LEFT OLECRANON | 4.01 | .41 | 2.04 | .62 | 13.48 | 1.03 |
| L MED HUM EPICON | 1.69 | .31 | 5.02 | .67 | 14.00 | .95 |
| L LAT HUM EPICON | 1.69 | .31 | -2.96 | .41 | 14.31 | 1.07 |
| LEFT RADIALE | 1.95 | .63 | -2.52 | .45 | 15.85 | 1.02 |

| THE PRINCIPAL MOMENTS OF INERTIA | | | |
|----------------------------------|------------------|---------|--------|
| | RANGE | MEAN | S. D. |
| X-AXIS | 59,653 - 260,924 | 122,994 | 42,716 |
| Y-AXIS | 63,336 - 284,018 | 129,924 | 46,288 |
| Z-AXIS | 12,028 - 58,303 | 24,785 | 9,237 |

| PRINCIPAL AXES OF INERTIA WITH RESPECT TO ANATOMICAL AXES | | | | |
|---|--------|-------|-------|-----------------------------|
| COSINE MATRIX EXPRESSED IN DEGREES | | | | |
| | X | Y | Z | |
| X | 41.50 | 48.82 | 94.25 | STD. DEV. OF ROT. X = 1.30 |
| Y | 131.49 | 42.05 | 95.62 | STD. DEV. OF ROT. Y = 1.89 |
| Z | 90.54 | 82.97 | 7.05 | STD. DEV. OF ROT. Z = 11.14 |

LEFT UPPER ARM: REGRESSION EQUATIONS

LEFT UPPER ARM VOLUME AND MOMENTS FROM STATURE AND WEIGHT

| | STATURE | WEIGHT | CONSTANT | R | SE | EST* |
|------------|---------|---------|----------|------|-------|------|
| VOLUME = | -8.09 + | 14.66 + | 856 | .918 | 8.3% | |
| X MOMENT = | 279 + | 1,251 - | 139,781 | .905 | 15.3% | |
| Y MOMENT = | -15 + | 1,454 - | 115,179 | .906 | 15.6% | |
| Z MOMENT = | -432 + | 408 + | 31,947 | .888 | 17.7% | |

LEFT UPPER ARM VOLUME FROM:

| BICEPS C RELAXED L | ACROMIAL- RADIAL L | AX ARM C | CONSTANT | R | SE | EST |
|-----------------------|-----------------------|----------|----------|------|------|-----|
| 145.18 | | - | 2,408.15 | .936 | 7.2% | |
| 114.02 + | 53.00 | - | 3,249.82 | .975 | 4.7% | |
| 81.99 + | 43.63 + | 40.01 - | 3,258.72 | .961 | 4.1% | |

LEFT UPPER ARM X MOMENT FROM:

| WEIGHT | BICEPS C FLEXED L | ACROMIAL- RADIAL L | CONSTANT | R | SE | EST |
|--------|----------------------|-----------------------|----------|------|-------|-----|
| 1,336 | | - | 104,640 | .905 | 15.0% | |
| 915 + | 5,960 | - | 223,117 | .930 | 13.3% | |
| 242 + | 8,054 + | 7,191 - | 415,301 | .950 | 11.4% | |

LEFT UPPER ARM Y MOMENT FROM:

| WEIGHT | BICEPS C FLEXED L | ACROMIAL- RADIAL L | CONSTANT | R | SE | EST |
|--------|----------------------|-----------------------|----------|------|-------|-----|
| 1,449 | | - | 117,028 | .906 | 15.4% | |
| 946 + | 7,133 | - | 258,828 | .936 | 13.0% | |
| 288 + | 9,180 + | 7,028 - | 446,640 | .953 | 11.4% | |

LEFT UPPER ARM Z MOMENT FROM:

| BICEPS C RELAXED L | AX ARM C | ACROMIAL- RADIAL L | CONSTANT | R | SE | EST |
|-----------------------|----------|-----------------------|----------|------|-------|-----|
| 3,565 | | - | 81,445 | .962 | 10.4% | |
| 2,562 + | 1,069 | - | 85,655 | .972 | 9.1% | |
| 2,572 + | 807 + | 401 - | 90,996 | .975 | 8.8% | |

*SE EST EXPRESSED AS A PERCENTAGE OF THE MEAN

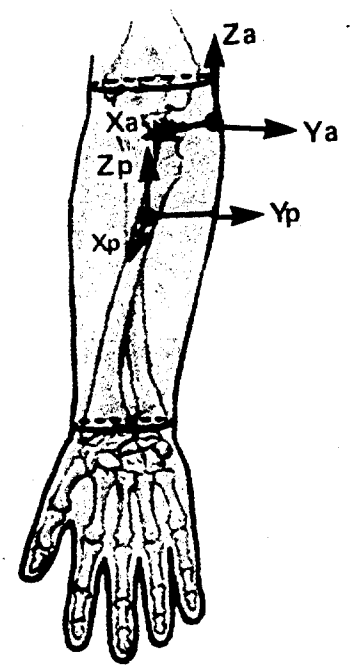
MOMENTS IN GM CM SQUARED
 VOLUMES IN CUBIC CM
 SKINFOLDS IN MM
 WEIGHT IN POUNDS
 ALL OTHER VALUES AND DISTANCES IN CM

TABLE 14

LEFT FOREARM

| ANTHROPOMETRY OF SEGMENT | | | |
|--------------------------|-------|-------|--|
| RANGE | MEAN | S. D. | |
| RAOIAL-STYLION LGTH | | | |
| 24.1- 30.9 | 27.05 | 1.81 | |
| ELBOW BR L | | | |
| 6.3- 8.0 | 7.05 | .43 | |
| ELBOW CIR | | | |
| 23.1- 31.4 | 26.57 | 1.85 | |
| MIDFOREARM CIRC | | | |
| 20.5- 28.4 | 23.42 | 1.56 | |
| MIDFOREARM BREADTH | | | |
| 6.1- 10.0 | 7.95 | .67 | |
| WRIST CIR | | | |
| 15.3- 19.8 | 16.99 | 1.04 | |
| WRIST BR | | | |
| 4.9- 6.4 | 5.54 | .37 | |

| LEFT FOREARM VOLUME | | | |
|---------------------|-------|-------|--|
| RANGE | MEAN | S. D. | |
| 971 - 1,951 | 1,335 | 224 | |



LOCATION OF THE CENTER OF VOLUME FROM THE ANATOMICAL AXIS ORIGIN

| | RANGE | MEAN | S. D. | |
|--------|----------------|--------|-------|--|
| X-AXIS | -2.41 - .13 | -0.88 | .67 | |
| Y-AXIS | -4.13 - -2.46 | -3.30 | .34 | |
| Z-AXIS | -12.02 - -9.08 | -10.31 | .75 | |

LOCATION OF THE CENTER OF VOLUME FROM ANATOMICAL LANDMARKS

| | X-MEAN | X-S. D. | Y-MEAN | Y-S. D. | Z-MEAN | Z-S. D. |
|------------------|--------|---------|--------|---------|--------|---------|
| LEFT OLECRANON | 3.47 | .54 | -1.49 | .95 | -12.99 | .80 |
| L MED HUM EPICON | 4.28 | .76 | 2.05 | 1.15 | -11.87 | .93 |
| L RADIAL STYLOID | -0.88 | .67 | 3.32 | .47 | 16.32 | 1.08 |
| L ULNAR STYLOID | -0.88 | .67 | -3.30 | .34 | 16.11 | 1.23 |
| LEFT RADIALE | -0.88 | .67 | -3.30 | .34 | -10.31 | .75 |

THE PRINCIPAL MOMENTS OF INERTIA

| | RANGE | MEAN | S. D. | |
|--------|------------------|--------|--------|--|
| X-AXIS | 46,540 - 126,191 | 81,918 | 22,822 | |
| Y-AXIS | 47,918 - 131,353 | 84,184 | 23,538 | |
| Z-AXIS | 6,868 - 24,006 | 11,773 | 3,587 | |

PRINCIPAL AXES OF INERTIA WITH RESPECT TO ANATOMICAL AXES
 COSINE MATRIX EXPRESSED IN DEGREES

| | X | Y | Z | |
|---|--------|-------|-------|-----------------------------|
| X | 20.80 | 69 29 | 88.10 | STD. DEV. OF ROT. X = 1.73 |
| Y | 110.75 | 20 77 | 89.09 | STD. DEV. OF ROT. Y = 2.14 |
| Z | 91.46 | 91 52 | 2.11 | STD. DEV. OF ROT. Z = 13.26 |

LEFT FOREARM: REGRESSION EQUATIONS

| LEFT FOREARM VOLUME AND MOMENTS FROM STATURE AND WEIGHT | | STATURE | WEIGHT | CONSTANT | R | SE EST* |
|---|---|---------|--------|----------|------|---------|
| VOLUME | = | - .93 + | 7.30 + | 257 | .905 | 7.4% |
| X MOMENT | = | 938 + | 431 - | 158,022 | .921 | 11.2% |
| Y MOMENT | = | 891 + | 470 - | 154,021 | .922 | 11.2% |
| Z MOMENT | = | -105 + | 140 + | 6,431 | .884 | 14.7% |

| LEFT FOREARM VOLUME FROM: | | ELBOW CIR | WEIGHT | MIDFOREARM CIRC | CONSTANT | R | SE EST |
|---------------------------|--|-----------|---------|-----------------|----------|------|--------|
| 110.60 | | | | | 1,606.56 | .911 | 7.0% |
| 61.51 + | | 3.50 | | | 896.61 | .933 | 6.3% |
| 37.24 + | | 3.73 + | 36.42 - | | 1,143.53 | .951 | 5.5% |

| LEFT FOREARM X MOMENT FROM: | | WEIGHT | ELBW BR L | RADIAL - STYLION L | CONSTANT | R | SE EST |
|-----------------------------|--|----------|-----------|--------------------|----------|------|--------|
| 715 | | | | | 39,973 | .907 | 11.9% |
| 479 + | | 21,590 | | | 150,848 | .947 | 9.2% |
| 339 + | | 16,239 + | 3,917 - | | 195,325 | .963 | 7.9% |

| LEFT FOREARM Y MOMENT FROM: | | WEIGHT | ELBW BR L | RADIAL - STYLION L | CONSTANT | R | SE EST |
|-----------------------------|--|----------|-----------|--------------------|----------|------|--------|
| 740 | | | | | 41,884 | .909 | 11.8% |
| 496 + | | 22,258 | | | 156,190 | .950 | 9.1% |
| 359 + | | 17,015 + | 3,838 - | | 199,778 | .964 | 7.9% |

| LEFT FOREARM Z MOMENT FROM: | | ELBOW CIR | MIDFOREARM CIRC | WEIGHT | CONSTANT | R | SE EST |
|-----------------------------|--|-----------|-----------------|--------|----------|------|--------|
| 1,758 | | | | | 34,987 | .905 | 13.2% |
| 1,368 + | | 677 | | | 40,467 | .930 | 11.6% |
| 708 + | | 715 + | 46 - | | 31,531 | .944 | 10.6% |

*SE EST EXPRESSED AS A PERCENTAGE OF THE MEAN

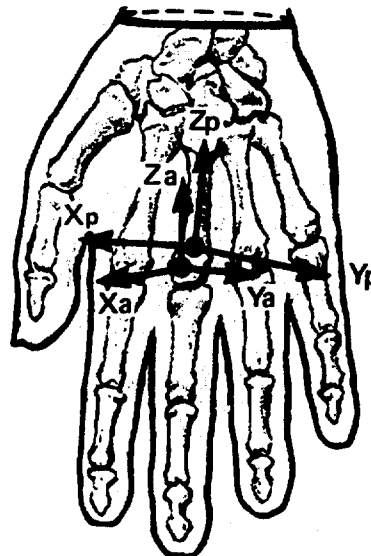
MOMENTS IN GM CM SQUARED
 VOLUMES IN CUBIC CM
 SKINFOLDS IN MM
 WEIGHT IN POUNDS
 ALL OTHER VALUES AND DISTANCES IN CM

TABLE 15

LEFT HAND

| ANTHROPOMETRY | | | | |
|----------------------|------------|-------|------|--|
| OF SEGMENT | RANGE | MEAN | S.D. | |
| HAND LGTH | 17.3- 21.7 | 18.94 | 1.04 | |
| HAND BR | 7.8- 9.8 | 8.64 | .49 | |
| HAND CIRC | 18.7- 23.5 | 20.87 | 1.08 | |
| META-III-DACTYL LGTH | 9.5- 12.9 | 10.94 | .65 | |

| LEFT HAND VOLUME | | | | |
|------------------|------|------|--|--|
| RANGE | MEAN | S.D. | | |
| 414 - 678 | 512 | 65 | | |



LOCATION OF THE CENTER OF VOLUME FROM THE ANATOMICAL AXIS ORIGIN

| | RANGE | MEAN | S.D. | |
|--------|-------------|------|------|--|
| X-AXIS | -2.23 - .22 | -.91 | .45 | |
| Y-AXIS | -.09 - .90 | .45 | .26 | |
| Z-AXIS | .14 - 2.04 | 1.14 | .39 | |

LOCATION OF THE CENTER OF VOLUME FROM ANATOMICAL LANDMARKS

| | X-MEAN | X-S.D. | Y-MEAN | Y-S.D. | Z-MEAN | Z-S.D. |
|------------------|--------|--------|--------|--------|--------|--------|
| L RADIAL STYLOID | .44 | .80 | 1.77 | .43 | -6.96 | .49 |
| L ULNAR STYLOID | -1.14 | .85 | -4.58 | .52 | -6.32 | .69 |
| L METACARPALE V | -.91 | .45 | -5.00 | .29 | 1.14 | .39 |
| L METACARPALE II | -.91 | .45 | 4.19 | .31 | 1.14 | .39 |
| LEFT DACTYLION | -.91 | .45 | 1.15 | .73 | 12.11 | .74 |

THE PRINCIPAL MOMENTS OF INERTIA

| | RANGE | MEAN | S.D. | |
|--------|----------------|--------|-------|--|
| X-AXIS | 8,994 - 22,850 | 12,909 | 3,096 | |
| Y-AXIS | 7,420 - 19,157 | 10,604 | 2,589 | |
| Z-AXIS | 2,816 - 6,090 | 4,051 | 883 | |

PRINCIPAL AXES OF INERTIA WITH RESPECT TO ANATOMICAL AXES
 COSINE MATRIX EXPRESSED IN DEGREES

| | X | Y | Z | |
|---|-------|--------|-------|----------------------------|
| X | 17.08 | 105.20 | 82.41 | STD. DEV. OF ROT. X = 3.14 |
| Y | 73.96 | 17.17 | 95.94 | STD. DEV. OF ROT. Y = 4.79 |
| Z | 95.69 | 82.21 | 9.66 | STD. DEV. OF ROT. Z = 3.94 |

LEFT HAND: REGRESSION EQUATIONS

LEFT HAND VOLUME AND MOMENTS FROM STATURE AND WEIGHT

| | STATURE | WEIGHT | CONSTANT | R | SE EST* |
|------------|---------|--------|----------|------|---------|
| VOLUME = | 2.18 + | 1.23 - | 83 | .845 | 7.1% |
| X MOMENT = | 181 + | 27 - | 23,856 | .802 | 14.8% |
| Y MOMENT = | 167 + | 17 - | 21,834 | .795 | 15.3% |
| Z MOMENT = | 22 + | 19 - | 3,028 | .837 | 12.3% |

LEFT HAND VOLUME FROM WEIGHT META-THREE HAND CIRC DACTYL L

| | META-THREE DACTYL L | HAND CIRC | CONSTANT | R | SE EST |
|--------|---------------------|-----------|----------|------|--------|
| 1.89 | | + | 190.47 | .834 | 7.2% |
| 1.18 + | 50.26 | - | 236.34 | .919 | 5.2% |
| .76 + | 44.26 + | 16.61 - | 447.67 | .933 | 4.9% |

LEFT HAND X MOMENT FROM: HAND LGTH HAND CIRC META-THREE DACTYL L

| | HAND LGTH | HAND CIRC | META-THREE DACTYL L | CONSTANT | R | SE EST |
|---------|-----------|-----------|---------------------|----------|------|--------|
| 2,531 | | | - | 34,935 | .850 | 12.8% |
| 1,878 + | | 1,084 | - | 45,250 | .905 | 10.6% |
| 1,341 + | | 871 + | 1,345 - | 45,301 | .919 | 10.0% |

LEFT HAND Y MOMENT FROM: HAND LGTH HAND CIRC META-THREE DACTYL L

| | HAND LGTH | HAND CIRC | META-THREE DACTYL L | CONSTANT | R | SE EST |
|---------|-----------|-----------|---------------------|----------|------|--------|
| 2,139 | | | - | 29,817 | .859 | 12.7% |
| 1,663 + | | 789 | - | 37,326 | .900 | 11.0% |
| 1,177 + | | 597 + | 1,217 - | 37,372 | .916 | 10.3% |

LEFT HAND Z MOMENT FROM: HAND CIRC META-THREE DACTYL L WEIGHT

| | HAND CIRC | META-THREE DACTYL L | WEIGHT | CONSTANT | R | SE EST |
|-------|-----------|---------------------|--------|----------|------|--------|
| 715 | | | - | 10,886 | .877 | 10.7% |
| 518 + | | 518 | - | 12,421 | .925 | 8.6% |
| 382 + | | 449 + | 8 - | 10,123 | .936 | 8.1% |

*SE EST EXPRESSED AS A PERCENTAGE OF THE MEAN

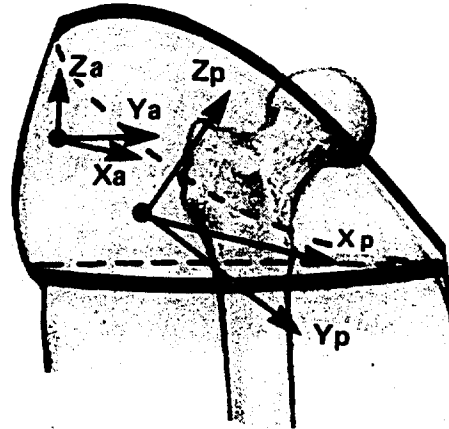
MOMENTS IN GM CM SQUARED
 VOLUMES IN CUBIC CM
 SKINFOLDS IN MM
 WEIGHT IN POUNDS
 ALL OTHER VALUES AND DISTANCES IN CM

TABLE 16

RIGHT FLAP

ANTHROPOMETRY

| OF SEGMENT | RANGE | MEAN | S. D. |
|-------------------|------------|-------|-------|
| THIGH FLAP LENGTH | 15.2- 21.9 | 18.28 | 1.62 |
| BUTTOCK C | 84.1-109.0 | 95.29 | 6.39 |
| BUTT'K DP | 20.6- 29.1 | 24.08 | 2.08 |
| BISPIN BR | 16.8- 27.0 | 22.29 | 2.17 |
| HIP BR | 30.0- 40.8 | 34.62 | 2.33 |
| UPPER THIGH CIRC | 49.9- 65.7 | 57.02 | 3.97 |



| RIGHT FLAP VOLUME | RANGE | MEAN | S. D. |
|-------------------|---------------|-------|-------|
| | 2,385 - 4,967 | 3,440 | 673 |

LOCATION OF THE CENTER OF VOLUME FROM THE ANATOMICAL AXIS ORIGIN

| | RANGE | MEAN | S. D. |
|--------|---------------|-------|-------|
| X-AXIS | -3.24 - 1.70 | -0.22 | 1.12 |
| Y-AXIS | 5.67 - 7.37 | 6.40 | .48 |
| Z-AXIS | -9.64 - -6.04 | -7.54 | 1.00 |

LOCATION OF THE CENTER OF VOLUME FROM ANATOMICAL LANDMARKS

| | X-MEAN | X-S. D. | Y-MEAN | Y-S. D. | Z-MEAN | Z-S. D. |
|------------------|--------|---------|--------|---------|--------|---------|
| R TROCHANTERION | -0.22 | 1.12 | 6.40 | .48 | -7.54 | 1.00 |
| RIGHT ASIS | -8.33 | 1.03 | -0.51 | 1.27 | -13.31 | 1.25 |
| R GLUTEAL FURROW | 8.51 | .85 | -2.28 | 1.60 | 6.51 | .63 |
| SCROTAL | 3.57 | 1.68 | -10.03 | 1.06 | 4.54 | 1.09 |
| SYMPHYSION | -10.49 | 2.13 | -11.54 | 1.56 | -4.96 | 1.02 |

THE PRINCIPAL MOMENTS OF INERTIA

| | RANGE | MEAN | S. D. |
|--------|-------------------|---------|--------|
| X-AXIS | 64,941 - 214,974 | 119,598 | 40,266 |
| Y-AXIS | 82,409 - 277,713 | 154,832 | 49,483 |
| Z-AXIS | 109,565 - 358,229 | 202,044 | 64,923 |

PRINCIPAL AXES OF INERTIA WITH RESPECT TO ANATOMICAL AXES
COSINE MATRIX EXPRESSED IN DEGREES

| | X | Y | Z | |
|---|-------|-------|--------|----------------------------|
| X | 7.94 | 82.23 | 91.60 | STD. DEV. OF ROT. X = 4.89 |
| Y | 96.72 | 44.37 | 133.58 | STD. DEV. OF ROT. Y = 6.63 |
| Z | 94.20 | 46.68 | 43.63 | STD. DEV. OF ROT. Z = 8.75 |

RIGHT FLAP: REGRESSION EQUATIONS

RIGHT FLAP VOLUME AND MOMENTS FROM STATURE AND WEIGHT

| | STATURE | WEIGHT | CONSTANT | R | SE | EST* |
|------------|----------|---------|----------|------|-------|------|
| VOLUME = | -23.15 + | 27.48 + | 2,867 | .890 | 9.2% | |
| X MOMENT = | -1,201 + | 1,590 + | 61,862 | .889 | 16.0% | |
| Y MOMENT = | -1,924 + | 2,113 + | 136,174 | .908 | 13.8% | |
| Z MOMENT = | -2,261 + | 2,738 + | 136,854 | .925 | 12.6% | |

RIGHT FLAP VOLUME FROM:

| BUTTOCK C | THIGH FLAP LENGTH | UPPER THIGH CIRC | CONSTANT | R | SE | EST |
|-----------|-------------------|------------------|----------|------|------|-----|
| 95.98 | | - | 5,706.73 | .911 | 8.2% | |
| 77.96 + | 130.87 | - | 6,384.79 | .948 | 6.4% | |
| 47.57 + | 132.36 + | 51.92 - | 6,475.07 | .95 | 6.2% | |

RIGHT FLAP X MOMENT FROM:

| BUTTOCK C | THIGH FLAP LENGTH | WEIGHT | CONSTANT | R | SE | EST |
|-----------|-------------------|--------|----------|------|-------|-----|
| 5,690 | | - | 422,657 | .903 | 14.7% | |
| 4,554 + | 8,255 | - | 465,426 | .945 | 11.4% | |
| 2,554 + | 8,487 + | 462 - | 357,800 | .952 | 10.9% | |

RIGHT FLAP Y MOMENT FROM:

| BUTTOCK C | THIGH FLAP LENGTH | BUTT'K DP | CONSTANT | R | SE | EST |
|-----------|-------------------|-----------|----------|------|-------|-----|
| 7,123 | | - | 523,965 | .920 | 12.8% | |
| 6,156 + | 7,026 | - | 560,369 | .940 | 11.3% | |
| 4,102 + | 8,691 + | 6,647 - | 555,366 | .951 | 10.4% | |

RIGHT FLAP Z MOMENT FROM:

| BUTTOCK C | THIGH FLAP LENGTH | UPPER THIGH CIRC | CONSTANT | R | SE | EST |
|-----------|-------------------|------------------|----------|------|-------|-----|
| 9,522 | | - | 705,396 | .937 | 11.4% | |
| 8,372 + | 8,355 | - | 748,683 | .953 | 10.0% | |
| 5,187 + | 8,511 + | 5,442 - | 758,144 | .961 | 9.4% | |

*SE EST EXPRESSED AS A PERCENTAGE OF THE MEAN

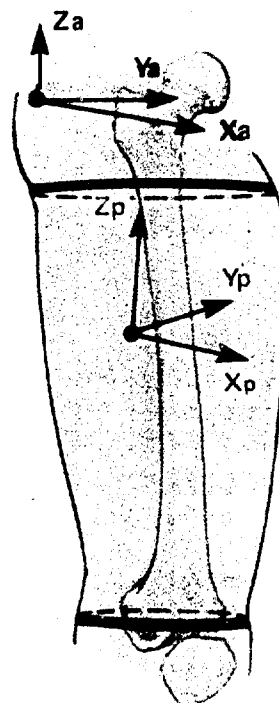
MOMENTS IN GM CM SQUARED
 VOLUMES IN CUBIC CM
 SKINFOLDS IN MM
 WEIGHT IN POUNDS
 ALL OTHER VALUES AND DISTANCES IN CM

TABLE 17

RIGHT THIGH MINUS FLAP

| ANTHROPOMETRY | | | |
|------------------|------------|-------|------|
| OF SEGMENT | RANGE | MEAN | S.D. |
| THIGH L | 41.4- 53.1 | 46.55 | 3.42 |
| BUTTOCK C | 84.1-109.0 | 95.29 | 6.39 |
| BUTT'K DP | 20.6- 29.1 | 24.08 | 2.08 |
| UPPER THIGH CIRC | | | |
| | 49.9- 65.7 | 57.02 | 3.97 |
| MIDTHIGH CIRC | | | |
| | 47.8- 60.1 | 52.90 | 3.01 |
| MIDTHIGH DEPTH | | | |
| | 15.9- 19.7 | 17.40 | 1.00 |
| KNEE CIRC | 33.5- 43.1 | 37.41 | 2.50 |

| RIGHT THIGH MINUS FLAP VOLUME | | | |
|-------------------------------|---------------|-------|-------|
| | RANGE | MEAN | S.D. |
| | 4,928 - 8,903 | 6,444 | 1,110 |



LOCATION OF THE CENTER OF VOLUME FROM THE ANATOMICAL AXIS ORIGIN

| | RANGE | MEAN | S.D. |
|--------|-----------------|--------|------|
| X-AXIS | -.91 - 2.36 | .86 | .75 |
| Y-AXIS | 5.79 - 8.38 | 6.87 | .54 |
| Z-AXIS | -30.92 - -23.33 | -26.56 | 2.09 |

LOCATION OF THE CENTER OF VOLUME FROM ANATOMICAL LANDMARKS

| | X-MEAN | X-S.D. | Y-MEAN | Y-S.D. | Z-MEAN | Z-S.D. |
|------------------|--------|--------|--------|--------|--------|--------|
| R TROCHANTERION | .86 | .75 | 6.87 | .54 | -26.56 | 2.09 |
| R LAT FEM CONDYL | .86 | .75 | 6.87 | .54 | 17.55 | 1.52 |
| R MED FEM CONDYL | .86 | .75 | -4.47 | .52 | 18.73 | 1.59 |
| RIGHT TIBIALE | -.39 | .97 | -2.87 | .62 | 20.98 | 1.54 |
| RIGHT FIBULARE | -.22 | 1.37 | 6.35 | .71 | 20.13 | 1.64 |

THE PRINCIPAL MOMENTS OF INERTIA

| | RANGE | MEAN | S.D. |
|--------|---------------------|---------|---------|
| X-AXIS | 345,474 - 999,616 | 603,733 | 193,349 |
| Y-AXIS | 361,418 - 1,020,188 | 622,730 | 197,547 |
| Z-AXIS | 145,950 - 401,339 | 232,604 | 65,646 |

PRINCIPAL AXES OF INERTIA WITH RESPECT TO ANATOMICAL AXES
 COSINE MATRIX EXPRESSED IN DEGREES

| | X | Y | Z | |
|---|--------|-------|-------|-----------------------------|
| X | 12.04 | 79.48 | 95.78 | STD. DEV. OF ROT. X = 1.44 |
| Y | 100.74 | 10.87 | 91.66 | STD. DEV. OF ROT. Y = 2.51 |
| Z | 84.63 | 87.30 | 6.02 | STD. DEV. OF ROT. Z = 14.17 |

RIGHT THIGH MINUS FLAP: REGRESSION EQUATIONS

RIGHT THIGH MINUS FLAP VOLUME AND MOMENTS FROM STATURE AND WEIGHT

| | STATURE | WEIGHT | CONSTANT | R | SE EST* |
|------------|----------|---------|-----------|------|---------|
| VOLUME = | 58.34 + | 17.83 - | 6,949 | .949 | 5.6% |
| X MOMENT = | 15,627 + | 1,108 - | 2,358,876 | .931 | 12.1% |
| Y MOMENT = | 16,044 + | 1,121 - | 2,416,120 | .934 | 11.8% |
| Z MOMENT = | 1,013 + | 1,834 - | 259,580 | .945 | 9.5% |

RIGHT THIGH MINUS FLAP VOLUME FROM:

| STATURE | MDTHIGH C | THIGH LGTH | CONSTANT | R | SE EST |
|---------|-----------|------------|-----------|------|--------|
| 107.10 | | - | 12,565.68 | .929 | 6.5% |
| 69.11 + | 156.19 | - | 14,086.59 | .966 | 4.6% |
| 46.66 + | 156.99 + | 69.99 - | 13,397.57 | .971 | 4.3% |

RIGHT THIGH MINUS FLAP X MOMENT FROM:

| STATURE | THIGH LGTH | MDTHIGH C | CONSTANT | R | SE EST |
|----------|------------|-----------|-----------|------|--------|
| 18,658 | | - | 2,707,982 | .929 | 12.1% |
| 11,919 + | 21,188 | - | 2,497,060 | .944 | 11.0% |
| 7,738 + | 21,481 + | 16,808 - | 2,657,796 | .958 | 9.7% |

RIGHT THIGH MINUS FLAP Y MOMENT FROM:

| STATURE | THIGH LGTH | MDTHIGH C | CONSTANT | R | SE EST |
|----------|------------|-----------|-----------|------|--------|
| 19,110 | | - | 2,769,242 | .931 | 11.8% |
| 12,236 + | 21,454 | - | 2,555,672 | .946 | 10.7% |
| 8,257 + | 21,737 + | 16,200 - | 2,710,598 | .958 | 9.6% |

RIGHT THIGH MINUS FLAP Z MOMENT FROM:

| WEIGHT | MDTHIGH C | STATURE | CONSTANT | R | SE EST |
|---------|-----------|---------|----------|------|--------|
| 2,140 | | - | 132,107 | .943 | 9.5% |
| 1,265 + | 9,661 | - | 494,084 | .968 | 7.4% |
| 857 + | 9,908 + | 1,275 - | 663,819 | .971 | 7.1% |

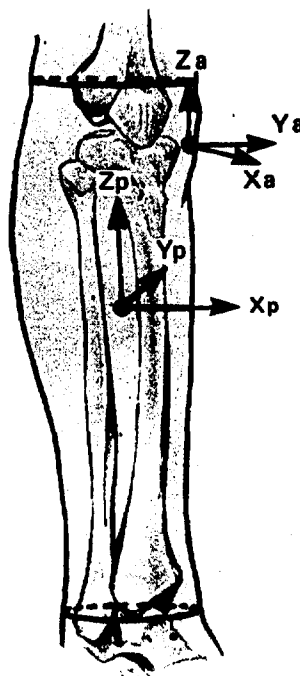
*SE EST EXPRESSED AS A PERCENTAGE OF THE MEAN

MOMENTS IN GM CM SQUARED
 VOLUMES IN CUBIC CM
 SKINFOLDS IN MM
 WEIGHT IN POUNDS
 ALL OTHER VALUES AND DISTANCES IN CM

TABLE 18

RIGHT CALF

| ANTHROPOMETRY | | | | |
|---------------|------------|-------|-------|--|
| OF SEGMENT | RANGE | MEAN | S. D. | |
| CALF LGTH | 34.3- 47.4 | 40.74 | 3.05 | |
| CALF CIRC | 35.0- 42.7 | 37.95 | 2.08 | |
| ANKLE CIR | 19.6- 25.1 | 22.43 | 1.29 | |
| KNEE CIRC | 33.5- 43.1 | 37.41 | 2.50 | |
| ANKLE BR | 5.1- 6.6 | 5.90 | .43 | |
| KNEE BR | 8.6- 10.9 | 9.64 | .57 | |
| CALF DP | 11.0- 13.7 | 12.02 | .69 | |



| RIGHT CALF VOLUME | | | |
|-------------------|-------|-------|--|
| RANGE | MEAN | S. D. | |
| 2,869 - 5,212 | 3,848 | 629 | |

LOCATION OF THE CENTER OF VOLUME FROM THE ANATOMICAL AXIS ORIGIN

| | RANGE | MEAN | S. D. | |
|--------|-----------------|--------|-------|--|
| X-AXIS | -2.87 - -.11 | -1.25 | .68 | |
| Y-AXIS | -6.49 - -4.85 | -5.76 | .40 | |
| Z-AXIS | -18.47 - -12.02 | -15.15 | 1.51 | |

LOCATION OF THE CENTER OF VOLUME FROM ANATOMICAL LANDMARKS

| | X-MEAN | X-S. D. | Y-MEAN | Y-S. D. | Z-MEAN | Z-S. D. |
|-----------------|--------|---------|--------|---------|--------|---------|
| RIGHT SPHYRION | -1.25 | .68 | -5.76 | .40 | 25.53 | 1.92 |
| RIGHT TIBIALE | -1.25 | .68 | -5.76 | .40 | -15.15 | 1.51 |
| RIGHT FIBULARE | -4.34 | .96 | 2.89 | .86 | -15.31 | 1.27 |
| R MED MALLEOLUS | -.89 | .81 | -5.87 | .49 | 23.73 | 1.89 |
| R LAT MALLEOLUS | -1.25 | .68 | 1.97 | .37 | 25.61 | 2.04 |

THE PRINCIPAL MOMENTS OF INERTIA

| | RANGE | MEAN | S. D. | |
|--------|-------------------|---------|---------|--|
| X-AXIS | 341,549 - 967,680 | 570,006 | 175,026 | |
| Y-AXIS | 346,305 - 979,884 | 578,473 | 176,883 | |
| Z-AXIS | 38,846 - 108,162 | 66,072 | 17,807 | |

PRINCIPAL AXES OF INERTIA WITH RESPECT TO ANATOMICAL AXES

COSINE MATRIX EXPRESSED IN DEGREES

| | X | Y | Z | STD. DEV. OF ROT. |
|---|--------|-------|-------|-------------------|
| X | 40.74 | 49.28 | 88.95 | X = 1.19 |
| Y | 130.74 | 40.75 | 89.21 | Y = 1.11 |
| Z | 90.28 | 91.28 | 1.31 | Z = 6.86 |

RIGHT CALF: REGRESSION EQUATIONS

RIGHT CALF VOLUME AND MOMENTS FROM STATURE AND WEIGHT

| | STATURE | WEIGHT | CONSTANT | R | SE | EST* |
|------------|----------|---------|-----------|------|-------|------|
| VOLUME = | 26.72 + | 11.84 - | 2,912 | .933 | 6.1% | |
| X MOMENT = | 12,323 + | 1,702 - | 1,907,428 | .941 | 10.7% | |
| Y MOMENT = | 12,429 + | 1,730 - | 1,922,497 | .941 | 10.7% | |
| Z MOMENT = | 291 + | 477 - | 66,811 | .920 | 10.9% | |

RIGHT CALF VOLUME FROM:

| WEIGHT | CALF C RT | CALF LGTH | CONSTANT | R | SE | EST |
|---------|-----------|-----------|----------|------|------|-----|
| 19.93 | | | 451.56 | .917 | 6.6% | |
| 11.30 + | 150.24 | | 3,786.04 | .964 | 4.5% | |
| 8.48 + | 133.42 + | 51.31 - | 4,755.85 | .980 | 3.4% | |

RIGHT CALF X MOMENT FROM:

| STATURE | CALF DP | ANKLE CIR | CONSTANT | R | SE | EST |
|----------|----------|-----------|-----------|------|-------|-----|
| 16,979 | | | 2,443,792 | .934 | 11.2% | |
| 12,519 + | 85,244 | | 2,675,111 | .961 | 8.8% | |
| 10,851 + | 65,309 + | 26,079 - | 2,723,962 | .967 | 8.2% | |

RIGHT CALF Y MOMENT FROM:

| STATURE | CALF DP | ANKLE CIR | CONSTANT | R | SE | EST |
|----------|----------|-----------|-----------|------|-------|-----|
| 17,161 | | | 2,467,648 | .934 | 11.1% | |
| 12,671 + | 85,827 | | 2,700,549 | .961 | 8.8% | |
| 11,005 + | 65,921 + | 26,041 - | 2,749,329 | .967 | 8.2% | |

RIGHT CALF Z MOMENT FROM:

| CALF C RT | WEIGHT | CALF LGTH | CONSTANT | R | SE | EST |
|-----------|--------|-----------|----------|------|------|-----|
| 8,111 | | | 242,153 | .945 | 8.9% | |
| 5,029 + | 276 | | 172,074 | .983 | 5.1% | |
| 4,830 + | 243 + | 607 - | 183,552 | .986 | 4.8% | |

*SE EST EXPRESSED AS A PERCENTAGE OF THE MEAN

MOMENTS IN GM CM SQUARED
 VOLUMES IN CUBIC CM
 SKINFOLDS IN MM
 WEIGHT IN POUNDS
 ALL OTHER VALUES AND DISTANCES IN CM

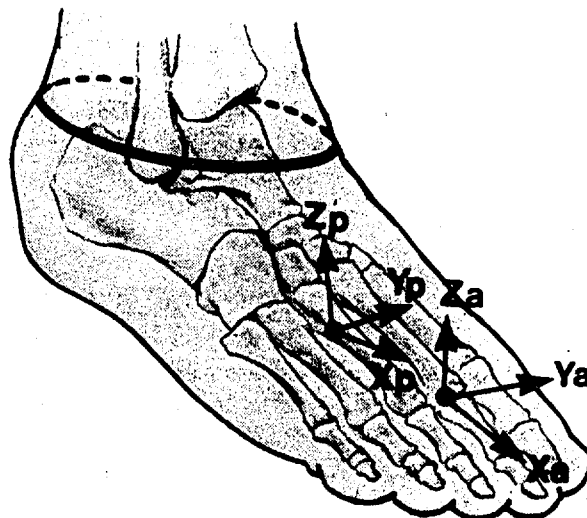
TABLE 19

RIGHT FOOT

ANTHROPOMETRY

| OF SEGMENT | RANGE | MEAN | S. D. |
|-------------------|------------|-------|-------|
| FOOT LGTH | 24.2- 31.3 | 26.61 | 1.64 |
| FOOT BR | 9.3- 11.7 | 10.49 | .59 |
| SPHYRN HT | 5.8- 8.7 | 7.07 | .68 |
| ANKLE CIR | 19.6- 25.1 | 22.43 | 1.29 |
| ARCH CIRC | 22.6- 37.5 | 26.01 | 2.45 |
| BALL OF FOOT CIRC | 22.6- 36.6 | 25.73 | 2.39 |

| RIGHT FOOT VOLUME | | MEAN | S. D. |
|-------------------|--|------|-------|
| RANGE | | | |
| 748 - 1,368 | | 976 | 155 |



LOCATION OF THE CENTER OF VOLUME FROM THE ANATOMICAL AXIS ORIGIN

| | RANGE | MEAN | S. D. |
|--------|---------------|-------|-------|
| X-AXIS | -9.60 - -6.62 | -7.79 | .69 |
| Y-AXIS | -.81 - .44 | -.14 | .35 |
| Z-AXIS | -1.32 - -.05 | -.66 | .26 |

LOCATION OF THE CENTER OF VOLUME FROM ANATOMICAL LANDMARKS

| | X-MEAN | X-S. D. | Y-MEAN | Y-S. D. | Z-MEAN | Z-S. D. |
|-----------------|--------|---------|--------|---------|--------|---------|
| RIGHT SPHYRION | 5.57 | .50 | -4.22 | .42 | -2.17 | .53 |
| R METATARSAL V | -5.69 | .74 | 5.73 | .36 | -.66 | .26 |
| R METATARSAL I | -7.79 | .69 | -4.96 | .37 | -.66 | .26 |
| RIGHT TOE II | -14.94 | 1.16 | -.14 | .35 | -1.83 | .59 |
| R POS CALCANEUS | 11.56 | .71 | -.14 | .35 | -.66 | .26 |

THE PRINCIPAL MOMENTS OF INERTIA

| | RANGE | MEAN | S. D. |
|--------|-----------------|--------|--------|
| X-AXIS | 5,160 - 13,363 | 8,221 | 2,122 |
| Y-AXIS | 26,845 - 83,410 | 43,056 | 12,504 |
| Z-AXIS | 28,156 - 86,390 | 45,509 | 12,911 |

PRINCIPAL AXES OF INERTIA WITH RESPECT TO ANATOMICAL AXES
 COSINE MATRIX EXPRESSED IN DEGREES

| | X | Y | Z | |
|---|-------|-------|-------|----------------------------|
| X | 9.35 | 85.95 | 81.04 | STD. DEV. OF ROT. X = 7.03 |
| Y | 95.18 | 8.76 | 82.95 | STD. DEV. OF ROT. Y = 2.04 |
| Z | 98.35 | 97.75 | 11.44 | STD. DEV. OF ROT. Z = 1.40 |

RIGHT FOOT: REGRESSION EQUATIONS

RIGHT FOOT VOLUME AND MOMENTS FROM STATURE AND WEIGHT

| | STATURE | WEIGHT | CONSTANT | R | SE EST* |
|------------|---------|--------|----------|------|---------|
| VOLUME = | 9.31 + | 1.87 - | 994 | .907 | 6.9% |
| X MOMENT = | 110 + | 30 - | 16,550 | .895 | 11.9% |
| Y MOMENT = | 948 + | 71 - | 137,353 | .882 | 14.2% |
| Z MOMENT = | 954 + | 86 - | 138,369 | .889 | 13.4% |

RIGHT FOOT VOLUME FROM:

| STATURE | ANKLE CIR | SPHYRN HT | CONSTANT | R | SE EST |
|---------|-----------|-----------|----------|------|--------|
| 14.42 | | | 1,582.84 | .895 | 7.2% |
| 8.25 + | 59.29 | | 1,816.89 | .948 | 5.3% |
| 6.58 + | 47.41 + | 65.77 - | 1,720.30 | .972 | 3.9% |

RIGHT FOOT X MOMENT FROM:

| ANKLE CIR | SPHYRN HT | STATURE | CONSTANT | R | SE EST |
|-----------|-----------|---------|----------|------|--------|
| 1,471 | | | 24,734 | .893 | 11.8% |
| 1,054 + | 1,269 | | 24,404 | .948 | 8.5% |
| 691 + | 1,018 + | 77 - | 28,110 | .971 | 6.5% |

RIGHT FOOT Y MOMENT FROM:

| FOOT L | SPHYRN HT | ANKLE CIR | CONSTANT | R | SE EST |
|---------|-----------|-----------|----------|------|--------|
| 7,184 | | | 148,034 | .945 | 9.7% |
| 6,072 + | 4,666 | | 151,582 | .967 | 7.6% |
| 4,965 + | 3,580 + | 2,233 - | 164,452 | .977 | 6.6% |

RIGHT FOOT Z MOMENT FROM:

| FOOT L | ANKLE CIR | SPHYRN HT | CONSTANT | R | SE EST |
|---------|-----------|-----------|----------|------|--------|
| 7,446 | | | 152,559 | .948 | 9.2% |
| 5,426 + | 3,303 | | 172,814 | .970 | 7.1% |
| 5,149 + | 2,627 + | 2,896 - | 170,875 | .978 | 6.3% |

*SE EST EXPRESSED AS A PERCENTAGE OF THE MEAN

MOMENTS IN GM CM SQUARED
 VOLUMES IN CUBIC CM
 SKINFOLDS IN MM
 WEIGHT IN POUNDS
 ALL OTHER VALUES AND DISTANCES IN CM

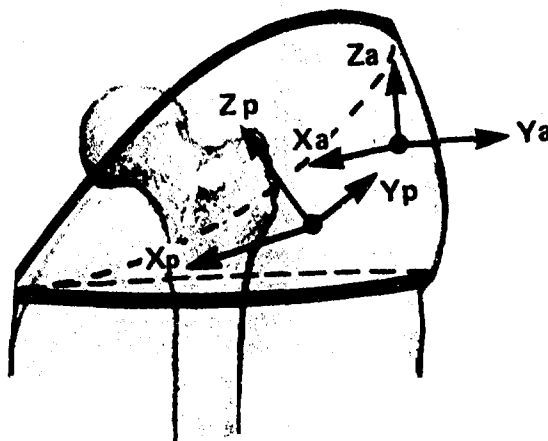
TABLE 20

LEFT FLAP

ANTHROPOMETRY

| OF SEGMENT | RANGE | MEAN | S.D. |
|-------------------|------------|-------|------|
| THIGH FLAP LENGTH | 15.2- 21.9 | 18.28 | 1.62 |
| BUTTOCK C | 84.1-109.0 | 95.29 | 6.39 |
| BUTT'K DP | 20.6- 29.1 | 24.08 | 2.08 |
| BISPIN BR | 16.8- 27.0 | 22.29 | 2.17 |
| HIP BR | 30.0- 40.8 | 34.62 | 2.33 |
| UPPER THIGH CIRC | 49.9- 65.7 | 57.02 | 3.97 |

| LEFT FLAP VOLUME | RANGE | MEAN | S.D. |
|------------------|---------------|-------|------|
| | 2,479 - 5,019 | 3,356 | 655 |



LOCATION OF THE CENTER OF VOLUME FROM THE ANATOMICAL AXIS ORIGIN

| | RANGE | MEAN | S.D. |
|--------|---------------|-------|------|
| X-AXIS | -1.56 - 2.42 | .27 | 1.04 |
| Y-AXIS | -8.24 - -5.18 | -6.40 | .73 |
| Z-AXIS | -9.99 - -6.21 | -7.82 | .92 |

LOCATION OF THE CENTER OF VOLUME FROM ANATOMICAL LANDMARKS

| | X-MEAN | X-S.D. | Y-MEAN | Y-S.D. | Z-MEAN | Z-S.D. |
|------------------|--------|--------|--------|--------|--------|--------|
| L TROCHANTERION | .27 | 1.04 | -6.40 | .73 | -7.82 | .92 |
| LEFT ASIS | -8.16 | 1.01 | -5.56 | 1.32 | -13.20 | 1.08 |
| L GLUTEAL FURROW | 8.87 | .81 | 2.35 | 1.43 | 6.43 | .61 |
| SCROTAL | 2.57 | 1.76 | 10.14 | 1.11 | 4.53 | .80 |
| SYMPHYSION | -11.63 | 2.23 | 10.28 | 1.61 | -4.93 | 1.17 |

THE PRINCIPAL MOMENTS OF INERTIA

| | RANGE | MEAN | S.D. |
|--------|-------------------|---------|--------|
| X-AXIS | 69,992 - 221,069 | 114,720 | 39,234 |
| Y-AXIS | 90,333 - 280,231 | 151,283 | 48,207 |
| Z-AXIS | 117,336 - 360,795 | 195,930 | 61,717 |

PRINCIPAL AXES OF INERTIA WITH RESPECT TO ANATOMICAL AXES
COSINE MATRIX EXPRESSED IN DEGREES

| | X | Y | Z | STD. DEV. OF ROT. |
|---|-------|--------|-------|-------------------|
| X | 6.27 | 84.81 | 86.48 | X = 4.06 |
| Y | 96.18 | 44.22 | 46.44 | Y = 6.30 |
| Z | 88.95 | 133.75 | 43.77 | Z = 8.14 |

LEFT FLAP: REGRESSION EQUATIONS

LEFT FLAP VOLUME AND MOMENTS FROM STATURE AND WEIGHT

| | STATURE | WEIGHT | CONSTANT | R | SE EST* |
|------------|----------|---------|----------|------|---------|
| VOLUME = | -25.64 + | 27.74 + | 3,180 | .896 | 9.0% |
| X MOMENT = | -1,475 + | 1,628 + | 99,038 | .884 | 16.5% |
| Y MOMENT = | -1,804 + | 2,051 + | 121,919 | .915 | 13.3% |
| Z MOMENT = | -2,166 + | 2,611 + | 135,447 | .927 | 12.2% |

LEFT FLAP VOLUME FROM BUTTOCK C THIGH FLAP LENGTH

| | BISPIN BR | CONSTANT | R | SE EST |
|---------|-----------|----------|----------|-----------|
| 94.44 | - | 5,643.72 | .921 | 7.7% |
| 83.03 + | 82.87 | 6,073.07 | .937 | 7.0% |
| 95.26 + | 86.74 - | 63.62 - | 5,890.51 | .952 6.3% |

LEFT FLAP X MOMENT FROM: HIP BR THIGH FLAP LENGTH BUTT'K DP

| | BISPIN BR | CONSTANT | R | SE EST |
|----------|-----------|----------|---------|------------|
| 15,312 | - | 415,068 | .910 | 14.4% |
| 13,348 + | 5,075 | 440,008 | .926 | 13.3% |
| 10,898 + | 5,477 + | 3,795 - | 454,036 | .938 12.5% |

LEFT FLAP Y MOMENT FROM: BUTTOCK C BISPIN BR THIGH FLAP LENGTH

| | BISPIN BR | CONSTANT | R | SE EST |
|---------|-----------|----------|---------|------------|
| 6,944 | - | 510,509 | .921 | 12.7% |
| 7,923 - | 4,878 | 494,972 | .937 | 11.5% |
| 7,309 - | 5,052 + | 4,715 - | 518,845 | .947 10.8% |

LEFT FLAP Z MOMENT FROM: BUTTOCK C BISPIN BR THIGH FLAP LENGTH

| | BISPIN BR | CONSTANT | R | SE EST |
|----------|-----------|----------|---------|-----------|
| 9,052 | - | 666,769 | .937 | 11.2% |
| 10,103 - | 5,239 | 650,082 | .949 | 10.3% |
| 9,407 - | 5,437 + | 5,345 - | 677,146 | .956 9.7% |

*SE EST EXPRESSED AS A PERCENTAGE OF THE MEAN

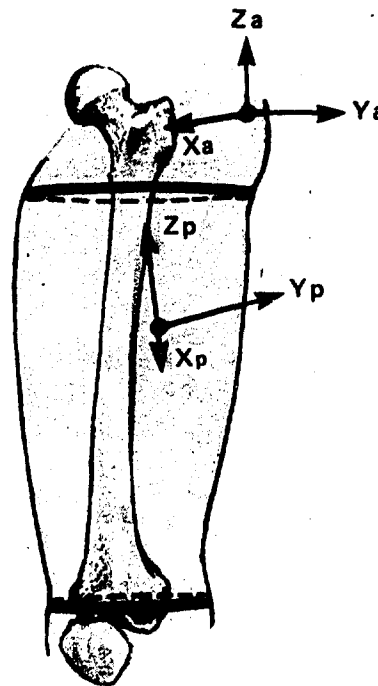
MOMENTS IN GM CM SQUARED
 VOLUMES IN CUBIC CM
 SKINFOLDS IN MM
 WEIGHT IN POUNDS
 ALL OTHER VALUES AND DISTANCES IN CM

TABLE 21

LEFT THIGH MINUS FLAP

| ANTHROPOMETRY OF SEGMENT | | | |
|--------------------------|------------|-------|-------|
| | RANGE | MEAN | S. D. |
| THIGH L | 41.4- 53.1 | 46.55 | 3.42 |
| BUTTOCK C | 84.1-109.0 | 95.29 | 6.39 |
| BUTT* K DP | 20.6- 29.1 | 24.08 | 2.08 |
| UPPER THIGH CIRC | | | |
| | 49.9- 65.7 | 57.02 | 3.97 |
| MIDHIGH CIRC | | | |
| | 47.8- 60.1 | 52.90 | 3.01 |
| MIDHIGH DEPTH | | | |
| | 15.9- 19.7 | 17.40 | 1.00 |
| KNEE CIRC | 33.5- 43.1 | 37.41 | 2.50 |

| LEFT THIGH MINUS FLAP VOLUME | | | |
|------------------------------|---------------|-------|-------|
| | RANGE | MEAN | S. D. |
| | 4,720 - 8,896 | 6,289 | 1,096 |



| LOCATION OF THE CENTER OF VOLUME FROM THE ANATOMICAL AXIS ORIGIN | | | | |
|--|-----------------|--------|-------|--|
| | RANGE | MEAN | S. D. | |
| X-AXIS | -0.04 - 2.22 | .94 | .59 | |
| Y-AXIS | -7.93 - -5.28 | -6.53 | .61 | |
| Z-AXIS | -31.18 - -23.61 | -26.68 | 1.88 | |

| LOCATION OF THE CENTER OF VOLUME FROM ANATOMICAL LANDMARKS | | | | | | |
|--|--------|---------|--------|---------|--------|---------|
| | X-MEAN | X-S. D. | Y-MEAN | Y-S. D. | Z-MEAN | Z-S. D. |
| L TROCHANTERION | .94 | .59 | -6.53 | .61 | -26.68 | 1.88 |
| L LAT FEM CONDYL | .94 | .59 | -6.53 | .61 | 17.33 | 1.34 |
| L MED FEM CONDYL | .94 | .59 | 4.75 | .46 | 19.31 | 1.45 |
| LEFT TIBIALE | -.25 | 1.10 | 2.95 | .84 | 21.53 | 1.46 |
| LEFT FIBULARE | .09 | .93 | -6.34 | .76 | 20.20 | 1.55 |

| THE PRINCIPAL MOMENTS OF INERTIA | | | |
|----------------------------------|---------------------|---------|---------|
| | RANGE | MEAN | S. D. |
| X-AXIS | 320,299 - 1,006,732 | 574,638 | 180,235 |
| Y-AXIS | 333,853 - 1,061,071 | 604,723 | 188,113 |
| Z-AXIS | 132,397 - 397,493 | 224,983 | 65,342 |

| PRINCIPAL AXES OF INERTIA WITH RESPECT TO ANATOMICAL AXES | | | |
|---|--------|-------|-------|
| COSINE MATRIX EXPRESSED IN DEGREES | | | |
| | X | Y | Z |
| X | 29.05 | 61.27 | 93.94 |
| Y | 118.37 | 28.83 | 85.30 |
| Z | 84.29 | 92.24 | 6.14 |

STD. DEV. OF ROT. X = 1.72
 STD. DEV. OF ROT. Y = 2.35
 STD. DEV. OF ROT. Z = 11.17

LEFT THIGH MINUS FLAP: REGRESSION EQUATIONS

LEFT THIGH MINUS FLAP VOLUME AND MOMENTS FROM STATURE AND WEIGHT

| | STATURE | WEIGHT | CONSTANT | R | SE EST* |
|------------|----------|---------|-----------|------|---------|
| VOLUME = | 51.91 + | 18.69 - | 6,110 | .928 | 6.7% |
| X MOMENT = | 13,654 + | 1,223 - | 2,057,227 | .912 | 13.4% |
| Y MOMENT = | 14,059 + | 1,361 - | 2,122,558 | .914 | 13.1% |
| Z MOMENT = | 996 + | 1,780 - | 255,005 | .923 | 11.5% |

LEFT THIGH MINUS FLAP VOLUME FROM:

| WEIGHT | MDTHIGH C | STATURE | CONSTANT | R | SE EST |
|---------|-----------|---------|-----------|------|--------|
| 34.42 | | | 424.18 | .908 | 7.4% |
| 20.34 + | 155.44 | | 5,399.70 | .932 | 6.5% |
| 2.29 + | 166.36 + | 56.31 - | 12,897.46 | .954 | 5.5% |

LEFT THIGH MINUS FLAP X MOMENT FROM:

| STATURE | MDTHIGH C | THIGH LGTH | CONSTANT | R | SE EST |
|----------|-----------|------------|-----------|------|--------|
| 16,998 | | | 2,442,457 | .908 | 13.4% |
| 12,159 + | 19,899 | | 2,636,222 | .931 | 11.8% |
| 8,582 + | 20,026 + | 11,148 - | 2,526,483 | .936 | 11.6% |

LEFT THIGH MINUS FLAP Y MOMENT FROM:

| STATURE | MDTHIGH C | THIGH LGTH | CONSTANT | R | SE EST |
|----------|-----------|------------|-----------|------|--------|
| 17,781 | | | 2,551,381 | .910 | 13.1% |
| 12,566 + | 21,444 | | 2,760,187 | .935 | 11.4% |
| 8,954 + | 21,572 + | 11,259 - | 2,649,357 | .939 | 11.2% |

LEFT THIGH MINUS FLAP Z MOMENT FROM:

| WEIGHT | MDTHIGH C | STATURE | CONSTANT | R | SE EST |
|---------|-----------|---------|----------|------|--------|
| 2,081 | | | 129,645 | .921 | 11.5% |
| 1,136 + | 10,435 | | 520,616 | .951 | 9.3% |
| 726 + | 10,683 + | 1,278 - | 690,845 | .954 | 9.2% |

*SE EST EXPRESSED AS A PERCENTAGE OF THE MEAN

MOMENTS IN GM CM SQUARED

VOLUMES IN CUBIC CM

SKINFOLOS IN MM

WEIGHT IN POUNDS

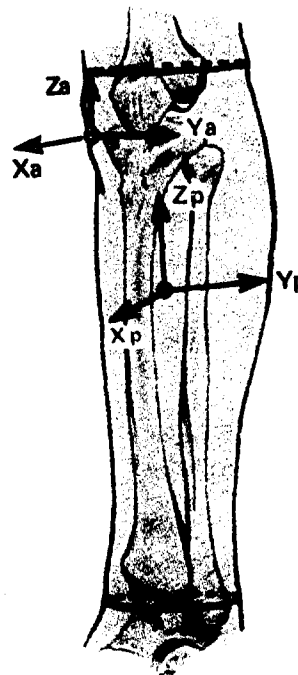
ALL OTHER VALUES AND DISTANCES IN CM

TABLE 22

LEFT CALF

ANTHROPOMETRY

| OF SEGMENT | RANGE | MEAN | S. D. |
|------------|------------|-------|-------|
| CALF LGTH | 34.3- 47.4 | 40.74 | 3.05 |
| CALF C LF | 24.6- 43.1 | 37.42 | 3.21 |
| ANKLE CIR | 19.6- 25.1 | 22.43 | 1.29 |
| KNEE CIRC | 33.5- 43.1 | 37.41 | 2.50 |
| ANKLE BR | 5.1- 6.6 | 5.90 | .43 |
| KNEE BR L | 8.5- 11.1 | 9.57 | .58 |
| CALF DF | 11.0- 13.7 | 12.02 | .69 |



| LEFT CALF VOLUME | | MEAN | S. D. |
|------------------|--|-------|-------|
| RANGE | | | |
| 2,788 - 5,239 | | 3,842 | 670 |

LOCATION OF THE CENTER OF VOLUME FROM THE ANATOMICAL AXIS ORIGIN

| | RANGE | MEAN | S. D. |
|--------|-----------------|--------|-------|
| X-AXIS | -3.98 - .68 | -1.13 | .91 |
| Y-AXIS | 3.26 - 6.83 | 5.64 | .58 |
| Z-AXIS | -17.78 - -12.31 | -14.65 | 1.44 |

LOCATION OF THE CENTER OF VOLUME FROM ANATOMICAL LANDMARKS

| | X-MEAN | X-S. D. | Y-MEAN | Y-S. D. | Z-MEAN | Z-S. D. |
|-----------------|--------|---------|--------|---------|--------|---------|
| LEFT SPHYRION | -1.13 | .91 | 5.64 | .58 | 25.75 | 2.01 |
| LEFT TIBIALE | -1.13 | .91 | 5.64 | .58 | -14.65 | 1.44 |
| LEFT FIBULARE | -4.55 | .91 | -3.00 | 1.00 | -15.14 | 1.36 |
| L MED MALLEOLUS | -.92 | .87 | 5.67 | .57 | 23.80 | 2.01 |
| L LAT MALLEOLUS | -.97 | .81 | -1.95 | .33 | 25.88 | 2.07 |

THE PRINCIPAL MOMENTS OF INERTIA

| | RANGE | MEAN | S. D. |
|--------|---------------------|---------|---------|
| X-AXIS | 337,925 - 1,020,043 | 580,501 | 184,925 |
| Y-AXIS | 344,001 - 1,039,896 | 589,841 | 187,723 |
| Z-AXIS | 37,375 - 112,646 | 66,419 | 19,681 |

PRINCIPAL AXES OF INERTIA WITH RESPECT TO ANATOMICAL AXES
 COSINE MATRIX EXPRESSED IN DEGREES

| | X | Y | Z | |
|---|-------|-------|-------|-----------------------------|
| X | 7.46 | 97.46 | 89.83 | STD. DEV. OF ROT. X = .73 |
| Y | 82.54 | 7.62 | 91.54 | STD. DEV. OF ROT. Y = 1.48 |
| Z | 89.97 | 88.45 | 1.55 | STD. DEV. OF ROT. Z = 10.47 |

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LEFT CALF: REGRESSION EQUATIONS

LEFT CALF VOLUME AND MOMENTS FROM STATURE AND WEIGHT

| | STATURE | HEIGHT | CONSTANT | R | SE EST* |
|------------|----------|---------|-----------|------|---------|
| VOLUME = | 30.50 + | 11.88 - | 3,596 | .930 | 6.6% |
| X MOMENT = | 14,369 + | 1,352 - | 2,200,471 | .945 | 10.8% |
| Y MOMENT = | 14,600 + | 1,366 - | 2,234,460 | .944 | 10.8% |
| Z MOMENT = | 346 + | 512 - | 82,292 | .910 | 12.7% |

LEFT CALF VOLUME FROM

| HEIGHT | ANKLE CIR | CALF LGTH | CONSTANT | R | SE EST |
|---------|-----------|-----------|----------|------|--------|
| 21.12 | | | 243.84 | .912 | 7.3% |
| 13.94 + | 201.19 | | 3,039.35 | .941 | 6.1% |
| 11.36 + | 166.59 + | 51.72 - | 3,930.21 | .955 | 5.4% |

LEFT CALF X MOMENT FROM:

| STATURE | CALF DP | CALF LGTH | CONSTANT | R | SE EST |
|----------|----------|-----------|-----------|------|--------|
| 18,068 | | | 2,626,569 | .941 | 11.0% |
| 13,745 + | 82,628 | | 2,850,791 | .963 | 8.9% |
| 10,693 + | 83,844 + | 10,801 - | 2,761,441 | .967 | 8.5% |

LEFT CALF Y MOMENT FROM:

| STATURE | CALF DP | CALF LGTH | CONSTANT | R | SE EST |
|----------|----------|-----------|-----------|------|--------|
| 18,337 | | | 2,665,012 | .940 | 11.0% |
| 13,917 + | 84,489 | | 2,894,285 | .963 | 8.8% |
| 10,754 + | 85,745 + | 11,155 - | 2,802,009 | .967 | 8.5% |

LEFT CALF Z MOMENT FROM:

| HEIGHT | CALF DP | CALF C LF | CONSTANT | R | SE EST |
|--------|----------|-----------|----------|------|--------|
| 617 | | | 38,708 | .907 | 12.7% |
| 361 + | 13,253 | | 154,207 | .946 | 10.0% |
| 238 + | 10,638 + | 1,416 - | 165,043 | .957 | 9.0% |

*SE EST EXPRESSED AS A PERCENTAGE OF THE MEAN

MOMENTS IN GM CM SQUARED
 VOLUMES IN CUBIC CM
 SKINFOLDS IN MM
 WEIGHT IN POUNDS
 ALL OTHER VALUES AND DISTANCES IN CM

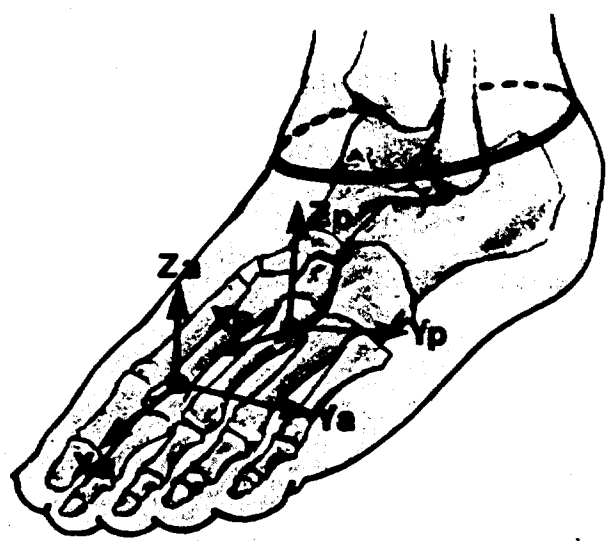
TABLE 23

LEFT FOOT

ANTHROPOMETRY

| OF SEGMENT | RANGE | MEAN | S.D. |
|-------------------|------------|-------|------|
| FOOT LGTH | 24.2- 31.3 | 26.61 | 1.64 |
| FOOT BR | 9.3- 11.7 | 10.49 | .59 |
| SPHYRN HT | 5.8- 8.7 | 7.07 | .68 |
| ANKLE CIR | 19.6- 25.1 | 22.43 | 1.29 |
| ARCH CIRC | 22.6- 37.5 | 26.01 | 2.45 |
| BALL OF FOOT CIRC | 22.6- 36.6 | 25.73 | 2.39 |

| LEFT FOOT VOLUME | | MEAN | S. D. |
|------------------|--|------|-------|
| RANGE | | | |
| 700 - 1,333 | | 952 | 161 |



LOCATION OF THE CENTER OF VOLUME FROM THE ANATOMICAL AXIS ORIGIN

| | RANGE | MEAN | S. D. |
|--------|---------------|-------|-------|
| X-AXIS | -9.49 - -6.47 | -7.60 | .70 |
| Y-AXIS | -.49 - .88 | .01 | .31 |
| Z-AXIS | -.96 - -.11 | -.57 | .23 |

LOCATION OF THE CENTER OF VOLUME FROM ANATOMICAL LANDMARKS

| | X-MEAN | X-S.D. | Y-MEAN | Y-S.D. | Z-MEAN | Z-S.D. |
|-----------------|--------|--------|--------|--------|--------|--------|
| LEFT SPHYRION | 5.84 | .63 | 4.22 | .50 | -2.06 | .49 |
| L METATARSAL V | -5.52 | .63 | -5.77 | .38 | -.57 | .23 |
| L METATARSAL I | -7.60 | .70 | 4.77 | .34 | -.57 | .23 |
| LEFT TOE II | -14.68 | 1.13 | .01 | .31 | -1.69 | .58 |
| L POS CALCANEUS | 11.59 | .74 | .01 | .31 | -.57 | .23 |

THE PRINCIPAL MOMENTS OF INERTIA

| | RANGE | MEAN | S. D. |
|--------|-----------------|--------|--------|
| X-AXIS | 4,666 - 12,497 | 7,756 | 2,162 |
| Y-AXIS | 25,344 - 80,854 | 41,654 | 12,514 |
| Z-AXIS | 26,601 - 83,364 | 43,753 | 12,870 |

PRINCIPAL AXES OF INERTIA WITH RESPECT TO ANATOMICAL AXES
 COSINE MATRIX EXPRESSED IN DEGREES

| | X | Y | Z | STD. DEV. OF ROT. X = |
|---|-------|-------|-------|-----------------------|
| X | 8.97 | 92.17 | 81.30 | 7.49 |
| Y | 87.21 | 4.83 | 93.94 | 1.83 |
| Z | 98.52 | 85.69 | 9.56 | 1.38 |

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LEFT FOOT: REGRESSION EQUATIONS

LEFT FOOT VOLUME AND MOMENTS FROM STATURE AND WEIGHT

| | STATURE | WEIGHT | CONSTANT | R | SE | EST* |
|------------|---------|--------|----------|------|-------|------|
| VOLUME = | 8.37 + | 2.32 - | 930 | .897 | 7.7% | |
| X MOMENT = | 100 + | 34 - | 15,824 | .878 | 13.8% | |
| Y MOMENT = | 851 + | 101 - | 126,715 | .873 | 15.2% | |
| Z MOMENT = | 838 + | 118 - | 125,144 | .876 | 14.7% | |

LEFT FOOT VOLUME FROM ANKLE CIR

| | STATURE | SPHYRN HT | CONSTANT | R | SE | EST |
|---------|---------|-----------|----------|------|------|-----|
| 114.23 | | - | 1,606.99 | .914 | 7.0% | |
| 72.61 + | 7.17 | - | 1,947.15 | .953 | 5.3% | |
| 65.11 + | 6.11 + | 41.49 - | 1,886.22 | .963 | 4.8% | |

LEFT FOOT X MOMENT FROM: ANKLE CIR

| | STATURE | SPHYRN HT | CONSTANT | R | SE | EST |
|---------|---------|-----------|----------|------|-------|-----|
| 1,557 | | - | 27,121 | .928 | 10.6% | |
| 1,104 + | 78 | - | 30,821 | .953 | 8.8% | |
| 1,000 + | 63 + | 578 - | 29,972 | .963 | 8.0% | |

LEFT FOOT Y MOMENT FROM: FOOT LGTH ANKLE CIR

| | ANKLE CIR | WEIGHT | CONSTANT | R | SE | EST |
|---------|-----------|--------|----------|------|-------|-----|
| 7,083 | | - | 146,761 | .931 | 11.2% | |
| 4,870 + | 3,619 | - | 168,955 | .959 | 8.8% | |
| 4,475 + | 2,686 + | 74 - | 150,104 | .964 | 8.4% | |

LEFT FOOT Z MOMENT FROM: FOOT LGTH ANKLE CIR

| | ANKLE CIR | WEIGHT | CONSTANT | R | SE | EST |
|---------|-----------|--------|----------|------|-------|-----|
| 7,291 | | - | 150,195 | .932 | 10.9% | |
| 4,963 + | 3,807 | - | 173,542 | .962 | 8.4% | |
| 4,529 + | 2,782 + | 81 - | 152,824 | .967 | 7.9% | |

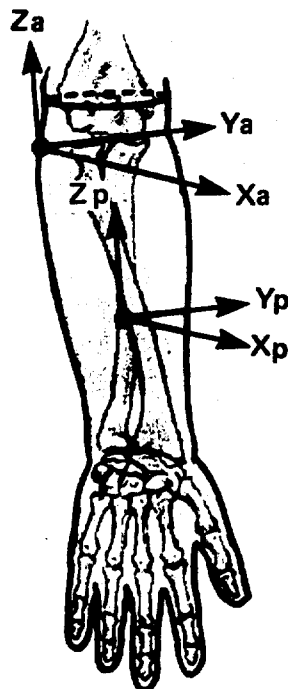
*SE EST EXPRESSED AS A PERCENTAGE OF THE MEAN

MOMENTS IN GM CM SQUARED
 VOLUMES IN CUBIC CM
 SKINFOLDS IN MM
 WEIGHT IN POUNDS
 ALL OTHER VALUES AND DISTANCES IN CM

TABLE 24

RIGHT FOREARM PLUS HAND

| ANTHROPOMETRY | | | |
|--------------------|------------|-------|------|
| OF SEGMENT | RANGE | MEAN | S.D. |
| ELBOW CIR | 23.1- 31.4 | 26.57 | 1.85 |
| MIDFOREARM CIRC | 20.5- 28.4 | 23.42 | 1.56 |
| MIDFOREARM BREADTH | 6.1- 10.0 | 7.95 | .67 |
| WRIST CIR | 15.3- 19.8 | 16.99 | 1.04 |
| HAND LGTH | 17.3- 21.7 | 18.94 | 1.04 |
| HAND BR | 7.8- 9.8 | 8.64 | .49 |
| HAND CIRC | 18.7- 23.5 | 20.87 | 1.08 |
| FOREARM-HAND LGTH | 41.6- 52.6 | 45.98 | 2.72 |



| RIGHT FOREARM PLUS HAND VOLUME | | | |
|--------------------------------|-------|------|--|
| RANGE | MEAN | S.D. | |
| 1,429 - 2,847 | 1,907 | 312 | |

LOCATION OF THE CENTER OF VOLUME FROM THE ANATOMICAL AXIS ORIGIN

| | RANGE | MEAN | S.D. | |
|--------|-----------------|--------|------|--|
| X-AXIS | -1.97 - -.35 | -1.00 | .41 | |
| Y-AXIS | 2.83 - 4.51 | 3.44 | .35 | |
| Z-AXIS | -19.16 - -14.98 | -16.60 | .98 | |

LOCATION OF THE CENTER OF VOLUME FROM ANATOMICAL LANDMARKS

| | X-MEAN | X-S.D. | Y-MEAN | Y-S.D. | Z-MEAN | Z-S.D. |
|------------------|--------|--------|--------|--------|--------|--------|
| RIGHT OLECRANON | 3.49 | .69 | 1.87 | .84 | -19.12 | 1.10 |
| R RADIAL STYLOID | -1.00 | .41 | -3.20 | .33 | 10.28 | 1.03 |
| R ULNAR STYLOID | -1.00 | .41 | 3.44 | .35 | 10.19 | .95 |
| RIGHT RADIALE | -1.00 | .41 | 3.44 | .35 | -16.60 | .98 |
| RIGHT DACTYLION | 1.21 | 1.71 | -.02 | 1.73 | 28.88 | 1.80 |

THE PRINCIPAL MOMENTS OF INERTIA

| | RANGE | MEAN | S.D. | |
|--------|-------------------|---------|--------|--|
| X-AXIS | 186,186 - 509,822 | 303,670 | 82,880 | |
| Y-AXIS | 185,168 - 506,682 | 302,342 | 82,535 | |
| Z-AXIS | 10,661 - 36,501 | 17,327 | 5,160 | |

PRINCIPAL AXES OF INERTIA WITH RESPECT TO ANATOMICAL AXES
 COSINE MATRIX EXPRESSED IN DEGREES

| | X | Y | Z | |
|---|-------|-------|-------|-----------------------------|
| X | 6.06 | 96.06 | 90.10 | STD. DEV. OF ROT. X = 1.33 |
| Y | 83.94 | 6.21 | 88.66 | STD. DEV. OF ROT. Y = 2.67 |
| Z | 90.04 | 91.35 | 1.35 | STD. DEV. OF ROT. Z = 17.03 |

RIGHT FOREARM PLUS HAND: REGRESSION EQUATIONS

RIGHT FOREARM + HAND VOLUME AND MOMENTS FROM STATURE AND WEIGHT

| | STATURE | WEIGHT | CONSTANT | R | SE EST* |
|------------|---------|---------|----------|------|---------|
| VOLUME = | - .36 + | 10.01 + | 267 | .918 | 6.7% |
| X MOMENT = | 4,086 + | 1,316 - | 645,877 | .913 | 11.5% |
| Y MOMENT = | 4,058 + | 1,316 - | 642,117 | .913 | 11.5% |
| Z MOMENT = | -139 + | 200 + | 7,973 | .892 | 13.9% |

RIGHT FOREARM PLUS HAND VOLUME FROM:

| ELBOW CIR | WRIST CIR | RADIAL - STYLION L | CONSTANT | R | SE EST |
|-----------|-----------|-----------------------|----------|------|--------|
| 158.86 | | - | 2,318.30 | .941 | 5.6% |
| 100.95 + | 116.49 | - | 2,758.25 | .959 | 4.8% |
| 73.43 + | 108.08 + | 42.54 - | 3,031.69 | .973 | 4.0% |

RIGHT FOREARM PLUS HAND X MOMENT FROM:

| FOREARM- HAND LGTH | WRIST CIR | HAND CIRC | CONSTANT | R | SE EST |
|-----------------------|-----------|-----------|-----------|------|--------|
| 28,050 | | - | 986,648 | .920 | 10.9% |
| 19,439 + | 31,774 | - | 1,130,677 | .963 | 7.6% |
| 17,987 + | 19,561 + | 17,373 - | 1,219,356 | .971 | 6.9% |

RIGHT FOREARM PLUS HAND Y MOMENT FROM:

| FOREARM- HAND LGTH | WRIST CIR | HAND CIRC | CONSTANT | R | SE EST |
|-----------------------|-----------|-----------|-----------|------|--------|
| 27,946 | | - | 983,154 | .920 | 10.9% |
| 19,372 + | 31,635 | - | 1,126,554 | .963 | 7.6% |
| 17,932 + | 19,524 + | 17,228 - | 1,214,491 | .971 | 6.9% |

RIGHT FOREARM PLUS HAND Z MOMENT FROM:

| ELBOW CIR | MIDFOREARM CIRC | WEIGHT | CONSTANT | R | SE EST |
|-----------|--------------------|--------|----------|------|--------|
| 2,599 | | - | 51,797 | .930 | 11.1% |
| 2,094 + | 877 | - | 58,898 | .950 | 9.6% |
| 1,329 + | 921 + | 53 - | 48,551 | .959 | 8.9% |

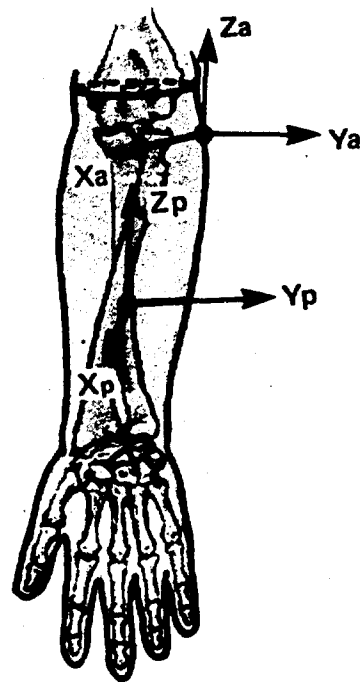
*SE EST EXPRESSED AS A PERCENTAGE OF THE MEAN

MOMENTS IN GM CM SQUARED
 VOLUMES IN CUBIC CM
 SKINFOLDS IN MM
 WEIGHT IN POUNDS
 ALL OTHER VALUES AND DISTANCES IN CM

TABLE 25

LEFT FOREARM PLUS HAND

| ANTHROPOMETRY OF SEGMENT | | | |
|--------------------------|------------|-------|------|
| | RANGE | MEAN | S.D. |
| ELBOW CIR | 23.1- 31.4 | 26.57 | 1.85 |
| MIDFOREARM CIRC | 20.5- 28.4 | 23.42 | 1.56 |
| MIDFOREARM BREADTH | 6.1- 10.0 | 7.95 | .67 |
| WRIST CIR | 15.3- 19.8 | 16.99 | 1.04 |
| HAND LGTH | 17.3- 21.7 | 18.94 | 1.04 |
| HAND BR | 7.8- 9.8 | 8.64 | .49 |
| HAND CIRC | 18.7- 23.5 | 20.87 | 1.08 |
| FOREARM-HAND LGTH | 41.6- 52.6 | 45.98 | 2.72 |



| LEFT FOREARM PLUS HAND VOLUME | | | |
|-------------------------------|---------------|-------|------|
| | RANGE | MEAN | S.D. |
| | 1,384 - 2,599 | 1,847 | 284 |

| LOCATION OF THE CENTER OF VOLUME FROM THE ANATOMICAL AXIS ORIGIN | | | | |
|--|-----------------|--------|------|--|
| | RANGE | MEAN | S.D. | |
| X-AXIS | -2.21 - .01 | -.95 | .54 | |
| Y-AXIS | -4.41 - -2.81 | -3.48 | .36 | |
| Z-AXIS | -19.62 - -15.00 | -16.67 | .96 | |

| LOCATION OF THE CENTER OF VOLUME FROM ANATOMICAL LANDMARKS | | | | | | |
|--|--------|--------|--------|--------|--------|--------|
| | X-MEAN | X-S.D. | Y-MEAN | Y-S.D. | Z-MEAN | Z-S.D. |
| LEFT OLECRANON | 3.40 | .65 | -1.62 | 1.03 | -19.35 | 1.06 |
| L RADIAL STYLOID | -.95 | .54 | 3.14 | .48 | 9.96 | .96 |
| L ULNAR STYLOID | -.95 | .54 | -3.48 | .36 | 9.75 | 1.08 |
| LEFT RADIALE | -.95 | .54 | -3.48 | .36 | -16.67 | .96 |
| LEFT DACTYLION | 1.05 | 1.53 | -.14 | 1.89 | 28.55 | 1.79 |

| THE PRINCIPAL MOMENTS OF INERTIA | | | |
|----------------------------------|-------------------|---------|--------|
| | RANGE | MEAN | S.D. |
| X-AXIS | 181,313 - 478,092 | 292,937 | 75,877 |
| Y-AXIS | 180,204 - 474,831 | 291,156 | 75,259 |
| Z-AXIS | 9,901 - 31,348 | 16,319 | 4,542 |

| PRINCIPAL AXES OF INERTIA WITH RESPECT TO ANATOMICAL AXES | | | |
|---|-------|--------|-------|
| COSINE MATRIX EXPRESSED IN DEGREES | | | |
| | X | Y | Z |
| X | 32.87 | 122.87 | 89.71 |
| Y | 57.13 | 32.88 | 90.79 |
| Z | 89.81 | 89.18 | .84 |

STD. DEV. OF ROT. X = 1.45
 STD. DEV. OF ROT. Y = 2.38
 STD. DEV. OF ROT. Z = 15.47

LEFT FOREARM PLUS HAND: REGRESSION EQUATIONS

| LEFT FOREARM + HAND VOLUME AND MOMENTS FROM STATURE AND WEIGHT | | | | | | |
|--|---------|--------|----------|------|-------|------|
| | STATURE | WEIGHT | CONSTANT | R | SE | EST* |
| VOLUME = | 1.25 + | 8.53 + | 173 | .906 | 6.7% | |
| X MOMENT = | 4,326 + | 991 - | 643,803 | .906 | 11.3% | |
| Y MOMENT = | 4,335 + | 970 - | 643,567 | .907 | 11.3% | |
| Z MOMENT = | -83 + | 164 + | 3,136 | .887 | 13.3% | |

| LEFT FOREARM PLUS HAND VOLUME FROM: | | | | | | |
|-------------------------------------|-----------|-----------------|----------|------|------|-----|
| WEIGHT | ELBW BR L | MIDFOREARM CIRC | CONSTANT | R | SE | EST |
| 8.90 | | | 330.10 | .906 | 6.6% | |
| 6.20 + | 247.17 | | 939.25 | .941 | 5.4% | |
| 5.29 + | 202.30 + | 44.10 - | 1,502.76 | .959 | 4.6% | |

| LEFT FOREARM PLUS HAND X MOMENT FROM: | | | | | | |
|---------------------------------------|----------|-------------------|-----------|------|-------|-----|
| FOREARM-HAND LGTH | HAND BR | META-III-DACTYL L | CONSTANT | R | SE | EST |
| 25,650 | | | 886,970 | .919 | 10.4% | |
| 19,059 + | 57,113 | | 1,074,944 | .961 | 7.4% | |
| 14,724 + | 51,181 + | 28,026 - | 1,129,994 | .974 | 6.2% | |

| LEFT FOREARM PLUS HAND Y MOMENT FROM: | | | | | | |
|---------------------------------------|----------|-------------------|-----------|------|-------|-----|
| FOREARM-HAND LGTH | HAND BR | META-III-DACTYL L | CONSTANT | R | SE | EST |
| 25,468 | | | 880,366 | .920 | 10.3% | |
| 19,019 + | 55,882 | | 1,064,289 | .961 | 7.4% | |
| 14,763 + | 50,058 + | 27,514 - | 1,118,333 | .973 | 6.3% | |

| LEFT FOREARM PLUS HAND Z MOMENT FROM: | | | | | | |
|---------------------------------------|---------|-----------------|----------|------|-------|-----|
| ELBOW CIRC | HAND BR | MIDFOREARM CIRC | CONSTANT | R | SE | EST |
| 2,230 | | | 43,010 | .907 | 11.9% | |
| 1,625 + | 3,055 | | 53,184 | .933 | 10.4% | |
| 1,387 + | 2,652 + | 553 - | 56,315 | .943 | 9.8% | |

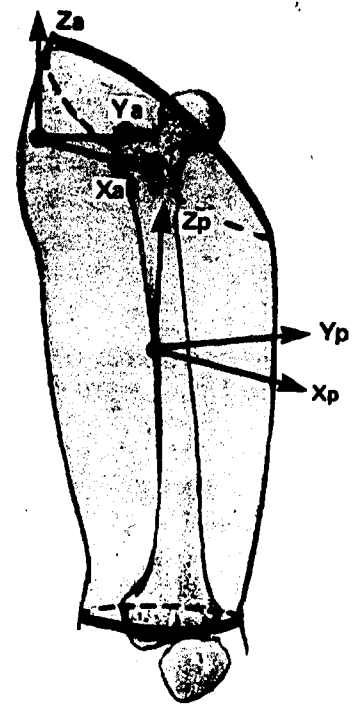
*SE EST EXPRESSED AS A PERCENTAGE OF THE MEAN

MOMENTS IN GM CM SQUARED
 VOLUMES IN CUBIC CM
 SKINFOLDS IN MM
 WEIGHT IN POUNDS
 ALL OTHER VALUES AND DISTANCES IN CM

TABLE 26

RIGHT THIGH

| ANTHROPOMETRY OF SEGMENT | | | | |
|--------------------------|------------|-------|-------|--|
| | RANGE | MEAN | S. D. | |
| THIGH L | 41.4- 53.1 | 46.55 | 3.42 | |
| UPPER THIGH CIRC | 49.9- 65.7 | 57.02 | 3.97 | |
| MIDTHIGH C | 47.8- 60.1 | 52.90 | 3.01 | |
| MIDTHIGH DEPTH | 15.9- 19.7 | 17.40 | 1.00 | |
| KNEE CIRC | 33.5- 43.1 | 37.41 | 2.50 | |
| KNEE BR | 8.6- 10.9 | 9.64 | .57 | |
| GLUT F DP | 16.3- 22.7 | 19.38 | 1.44 | |



| RIGHT THIGH VOLUME | | | |
|--------------------|----------------|-------|-------|
| | RANGE | MEAN | S. D. |
| | 7,365 - 13,604 | 9,884 | 1,690 |

LOCATION OF THE CENTER OF VOLUME FROM THE ANATOMICAL AXIS ORIGIN

| | RANGE | MEAN | S. D. | |
|--------|-----------------|--------|-------|--|
| X-AXIS | -1.62 - 2.11 | .48 | .86 | |
| Y-AXIS | 5.75 - 8.01 | 6.71 | .48 | |
| Z-AXIS | -23.10 - -17.54 | -19.95 | 1.68 | |

LOCATION OF THE CENTER OF VOLUME FROM ANATOMICAL LANDMARKS

| | X-MEAN | X-S. D. | Y-MEAN | Y-S. D. | Z-MEAN | Z-S. D. |
|------------------|--------|---------|--------|---------|--------|---------|
| R TROCHANTERION | .48 | .86 | 6.71 | .48 | -19.95 | 1.68 |
| R LAT FEM CONDYL | .48 | .86 | 6.71 | .48 | 24.16 | 1.83 |
| R MED FEM CONDYL | .48 | .86 | -4.63 | .49 | 25.33 | 1.96 |
| RIGHT TIBIALE | -.77 | 1.08 | -3.03 | .59 | 27.59 | 1.86 |
| RIGHT FIBULARE | -.59 | 1.47 | 6.18 | .69 | 26.73 | 1.96 |

THE PRINCIPAL MOMENTS OF INERTIA

| | RANGE | MEAN | S. D. | |
|--------|---------------------|-----------|---------|--|
| X-AXIS | 869,712 - 2,568,235 | 1,550,818 | 475,281 | |
| Y-AXIS | 913,263 - 2,715,546 | 1,632,836 | 496,707 | |
| Z-AXIS | 257,123 - 721,262 | 418,835 | 122,850 | |

PRINCIPAL AXES OF INERTIA WITH RESPECT TO ANATOMICAL AXES

COSINE MATRIX EXPRESSED IN DEGREES

| | X | Y | Z | |
|---|-------|-------|-------|----------------------------|
| X | 9.23 | 80.81 | 89.13 | STD. DEV. OF ROT. X = .82 |
| Y | 99.20 | 9.27 | 88.90 | STD. DEV. OF ROT. Y = 1.63 |
| Z | 90.68 | 91.23 | 1.41 | STD. DEV. OF ROT. Z = 9.60 |

RIGHT THIGH: REGRESSION EQUATIONS

| RIGHT THIGH VOLUME AND MOMENTS FROM STATURE AND WEIGHT | | | | | | |
|--|---|----------|---------|-----------|------|---------|
| | | STATURE | WEIGHT | CONSTANT | R | SE EST* |
| VOLUME = | = | 35.19 + | 45.30 - | 4,083 | .962 | 4.8% |
| X MOMENT = | = | 28,839 + | 6,407 - | 4,659,953 | .953 | 9.6% |
| Y MOMENT = | = | 28,559 + | 7,298 - | 4,679,995 | .957 | 9.2% |
| Z MOMENT = | = | -1,587 + | 4,537 - | 72,496 | .957 | 8.9% |

| RIGHT THIGH VOLUME FROM: | | | | | | |
|--------------------------|--|---------|-----------|------------|-----------|-----------|
| | | WEIGHT | MDTHIGH C | THIGH LGTH | CONSTANT | R SE EST |
| | | 55.96 | | + | 347.73 | .958 5.0% |
| | | 35.47 + | 226.30 | - | 8,131.49 | .978 3.7% |
| | | 24.80 + | 241.40 + | 94.37 - | 11,499.63 | .984 3.2% |

| RIGHT THIGH X MOMENT FROM: | | | | | | |
|----------------------------|--|----------|-----------|------------|-----------|------------|
| | | STATURE | MDTHIGH C | THIGH LGTH | CONSTANT | R SE EST |
| | | 46,365 | | - | 6,678,946 | .939 10.7% |
| | | 31,602 + | 60,709 | - | 7,270,091 | .969 7.8% |
| | | 16,713 + | 61,238 + | 46,410 - | 6,813,237 | .961 6.3% |

| RIGHT THIGH Y MOMENT FROM: | | | | | | |
|----------------------------|--|----------|-----------|------------|-----------|------------|
| | | STATURE | MDTHIGH C | THIGH LGTH | CONSTANT | R SE EST |
| | | 48,522 | | - | 6,979,742 | .940 10.5% |
| | | 32,860 + | 64,404 | - | 7,606,871 | .972 7.4% |
| | | 17,848 + | 64,938 + | 46,791 - | 7,146,259 | .982 6.0% |

| RIGHT THIGH Z MOMENT FROM: | | | | | | |
|----------------------------|--|---------|-----------|------------------|-----------|-----------|
| | | WEIGHT | MDTHIGH C | UPPER THIGH CIRC | CONSTANT | R SE EST |
| | | 4,056 | | - | 272,336 | .955 8.8% |
| | | 2,447 + | 17,772 | - | 938,226 | .979 6.2% |
| | | 1,660 + | 15,421 + | 8,005 - | 1,136,123 | .984 5.5% |

*SE EST EXPRESSED AS A PERCENTAGE OF THE MEAN

MOMENTS IN GM CM SQUARED

VOLUMES IN CUBIC CM

SKINFOLDS IN MM

WEIGHT IN POUNDS

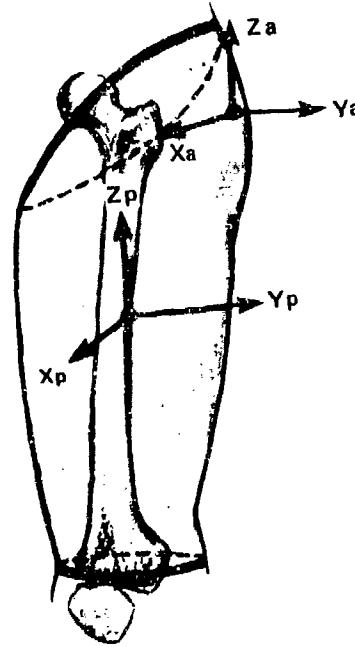
ALL OTHER VALUES AND DISTANCES IN CM

TABLE 27

LEFT THIGH

| ANTHROPOMETRY | | | | |
|------------------|------------|-------|------|--|
| OF SEGMENT | RANGE | MEAN | S.D. | |
| THIGH L | 41.4- 53.1 | 46.55 | 3.42 | |
| UPPER THIGH CIRC | | | | |
| | 49.9- 65.7 | 57.02 | 3.97 | |
| MIDTHIGH CIRC | | | | |
| | 47.8- 60.1 | 52.90 | 3.01 | |
| MIDTHIGH DEPTH | | | | |
| | 15.9- 19.7 | 17.40 | 1.00 | |
| KNEE CIRC | 33.5- 43.1 | 37.41 | 2.50 | |
| KNEE BR L | 8.5- 11.1 | 9.57 | .58 | |
| GLUT F DP | 16.3- 22.7 | 19.38 | 1.44 | |

| LEFT THIGH VOLUME | | | |
|-------------------|-------|-------|--|
| RANGE | MEAN | S.D. | |
| 7,241 - 13,565 | 9,645 | 1,661 | |



LOCATION OF THE CENTER OF VOLUME FROM THE ANATOMICAL AXIS ORIGIN

| | RANGE | MEAN | S.D. | |
|--------|-----------------|--------|------|--|
| X-AXIS | - .46 - 2.29 | .71 | .72 | |
| Y-AXIS | -8.00 - -5.26 | -6.49 | .63 | |
| Z-AXIS | -23.34 - -17.82 | -20.12 | 1.53 | |

LOCATION OF THE CENTER OF VOLUME FROM ANATOMICAL LANDMARKS

| | X-MEAN | X-S.D. | Y-MEAN | Y-S.D. | Z-MEAN | Z-S.D. |
|------------------|--------|--------|--------|--------|--------|--------|
| L TROCHANTERION | .71 | .72 | -6.49 | .63 | -20.12 | 1.53 |
| L LAT FEM CONDYL | .71 | .72 | -6.49 | .63 | 23.89 | 1.63 |
| L MED FEM CONDYL | .71 | .72 | 4.80 | .48 | 25.87 | 1.74 |
| LEFT TIBIALE | -.48 | 1.24 | 2.99 | .90 | 28.09 | 1.74 |
| LEFT FIBULARE | -.14 | 1.04 | -6.30 | .77 | 26.76 | 1.89 |

THE PRINCIPAL MOMENTS OF INERTIA

| | RANGE | MEAN | S.D. |
|--------|---------------------|-----------|---------|
| X-AXIS | 859,103 - 2,601,263 | 1,487,046 | 451,768 |
| Y-AXIS | 914,120 - 2,724,962 | 1,568,980 | 471,551 |
| Z-AXIS | 250,660 - 713,153 | 404,963 | 119,266 |

PRINCIPAL AXES OF INERTIA WITH RESPECT TO ANATOMICAL AXES
 COSINE MATRIX EXPRESSED IN DEGREES

| | X | Y | Z | STD. DEV. OF ROT. |
|---|--------|-------|-------|-------------------|
| X | 10.43 | 79.59 | 90.53 | X = .93 |
| Y | 100.42 | 10.43 | 90.53 | Y = 1.75 |
| Z | 89.58 | 89.38 | .75 | Z = 8.63 |

LEFT THIGH: REGRESSION EQUATIONS

| LEFT THIGH VOLUME AND MOMENTS FROM STATURE AND WEIGHT | | | | | |
|---|----------|---------|-----------|------|---------|
| | STATURE | WEIGHT | CONSTANT | R | SE EST* |
| VOLUME = | 26.26 + | 46.43 - | 2,929 | .950 | 5.6% |
| X MOMENT = | 21,773 + | 7,688 - | 3,687,770 | .935 | 11.2% |
| Y MOMENT = | 21,577 + | 8,474 - | 3,704,865 | .939 | 10.7% |
| Z MOMENT = | -1,134 + | 4,249 - | 117,848 | .948 | 9.7% |

| LEFT THIGH VOLUME FROM: | | | | | |
|-------------------------|-----------|---------|-----------|------|--------|
| WEIGHT | MDTHIGH C | STATURE | CONSTANT | R | SE EST |
| 54.39 | | | 376.96 | .948 | 5.6% |
| 34.19 + | 223.04 | | 7,979.95 | .968 | 4.5% |
| 23.83 + | 229.31 + | 32.33 - | 12,284.45 | .971 | 4.3% |

| LEFT THIGH X MOMENT FROM: | | | | | |
|---------------------------|----------|-----------|-----------|------|--------|
| WEIGHT | STATURE | MDTHIGH C | CONSTANT | R | SE EST |
| 14,283 | | | 946,750 | .915 | 12.5% |
| 7,688 + | 21,773 | | 3,687,770 | .935 | 11.2% |
| 1,465 + | 23,443 + | 63,128 - | 6,263,299 | .957 | 9.3% |

| LEFT THIGH Y MOMENT FROM: | | | | | |
|---------------------------|-----------|----------|-----------|------|--------|
| WEIGHT | MDTHIGH C | STATURE | CONSTANT | R | SE EST |
| 15,009 | | | 988,567 | .921 | 11.9% |
| 9,532 + | 60,483 | | 3,254,750 | .940 | 10.6% |
| 2,066 + | 65,002 + | 23,297 - | 6,356,847 | .960 | 8.8% |

| LEFT THIGH Z MOMENT FROM: | | | | | |
|---------------------------|-----------|------------------|----------|------|--------|
| WEIGHT | MDTHIGH C | UPPER THIGH CIRC | CONSTANT | R | SE EST |
| 3,906 | | | 260,547 | .947 | 9.6% |
| 2,523 + | 15,266 | | 832,539 | .966 | 7.9% |
| 1,865 + | 13,299 + | 6,699 - | 998,137 | .970 | 7.5% |

*SE EST EXPRESSED AS A PERCENTAGE OF THE MEAN

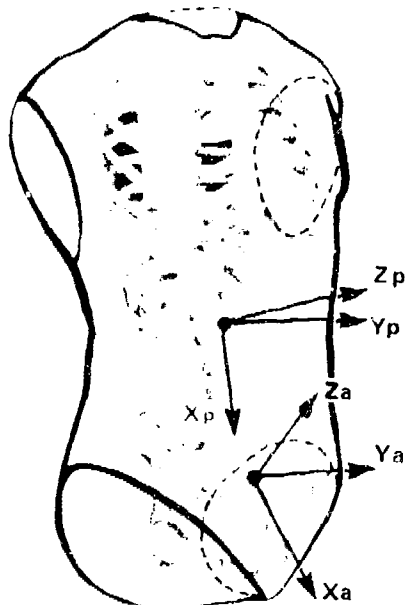
MOMENTS IN GM CM SQUARED
 VOLUMES IN CUBIC CM
 SKINFOLDS IN MM
 WEIGHT IN POUNDS
 ALL OTHER VALUES AND DISTANCES IN CM

TABLE 28

TORSO

ANTHROPOMETRY

| OF SEGMENT | RANGE | MEAN | S.D. |
|------------------|------------|-------|------|
| CHEST CIR | 82.6-113.8 | 96.51 | 7.57 |
| CHEST BR | 28.4- 37.9 | 33.19 | 2.14 |
| SUBSCAP SKINFOLD | | | |
| | 7.0- 28.0 | 12.10 | 5.24 |
| WAIST CIR | 72.3- 99.7 | 85.70 | 7.88 |
| BUTTOCK C | 84.1-109.0 | 95.29 | 6.39 |
| BUTT'K DP | 20.6- 29.1 | 24.08 | 2.08 |
| HIP BR | 30.0- 40.8 | 34.62 | 2.33 |
| TORSO L | 64.9- 78.9 | 71.15 | 3.98 |



TORSO VOLUME

| RANGE | MEAN | S. D. |
|-----------------|--------|-------|
| 26,236 - 53,062 | 38,115 | 7,346 |

LOCATION OF THE CENTER OF VOLUME FROM THE ANATOMICAL AXIS ORIGIN

| | RANGE | MEAN | S. D. |
|--------|---------------|-------|-------|
| X-AXIS | -6.78 - 2.49 | -1.89 | 2.28 |
| Y-AXIS | -1.73 - 1.72 | .09 | .81 |
| Z-AXIS | 18.98 - 25.61 | 21.41 | 1.57 |

LOCATION OF THE CENTER OF VOLUME FROM ANATOMICAL LANDMARKS

| | X-MEAN | X-S.D. | Y-MEAN | Y-S.D. | Z-MEAN | Z-S.D. |
|--------------|--------|--------|--------|--------|--------|--------|
| CERVICALE | -5.83 | 3.32 | -1.14 | 1.59 | -32.46 | 2.48 |
| LEFT ASIS | -1.89 | 2.28 | -11.12 | 1.38 | 21.41 | 1.57 |
| RIGHT ASIS | -1.89 | 2.28 | 11.31 | 1.31 | 21.41 | 1.57 |
| SUPRATERNALE | -13.97 | 2.53 | .24 | 1.21 | -21.17 | 2.14 |
| SYMPHYSION | -1.89 | 2.28 | .16 | 1.03 | 30.05 | 1.95 |

THE PRINCIPAL MOMENTS OF INERTIA

| | RANGE | MEAN | S. D. |
|--------|------------------------|------------|-----------|
| X-AXIS | 8,045,156 - 23,787,262 | 14,386,049 | 4,322,462 |
| Y-AXIS | 7,433,074 - 21,894,753 | 13,003,769 | 3,958,326 |
| Z-AXIS | 2,252,535 - 7,194,668 | 4,375,485 | 1,413,519 |

PRINCIPAL AXES OF INERTIA WITH RESPECT TO ANATOMICAL AXES
 COSINE MATRIX EXPRESSED IN DEGREES

| | X | Y | Z | STD. DEV. OF ROT. |
|---|-------|-------|--------|-------------------|
| X | 15.62 | 92.74 | 105.36 | X = 2.39 |
| Y | 87.38 | 2.74 | 90.81 | Y = 5.75 |
| Z | 74.62 | 89.92 | 15.38 | Z = 2.30 |

TORSO: REGRESSION EQUATIONS

TORSO VOLUME AND MOMENTS FROM STATURE AND WEIGHT

| | STATURE | WEIGHT | CONSTANT | R | SE | EST* |
|------------|-----------|-----------|------------|------|----|------|
| VOLUME = | -114.73 + | 282.09 + | 10,411 | .976 | | 4.3% |
| X MOMENT = | 2,815 + | 143,580 - | 10,579,720 | .967 | | 8.0% |
| Y MOMENT = | -830 + | 131,633 - | 9,279,222 | .960 | | 8.8% |
| Z MOMENT = | -31,690 + | 57,416 + | 216,703 | .983 | | 6.2% |

TORSO VOLUME FROM:

| WEIGHT | SUBSCAP SKINFOLD | WAIST BR | CONSTANT | R | SE | EST |
|----------|------------------|----------|-----------|------|----|------|
| 247.34 | | - | 4,031.67 | .974 | | 4.4% |
| 220.55 + | 265.73 | - | 2,681.51 | .987 | | 3.2% |
| 173.70 + | 195.32 + | 640.81 - | 13,840.00 | .991 | | 2.7% |

TORSO X MOMENT FROM:

| WEIGHT | TORSO LGTH | BUTT *K DP | CONSTANT | R | SE | EST |
|----------|------------|------------|------------|------|----|------|
| 144,433 | | - | 10,225,320 | .967 | | 7.8% |
| 83,641 + | 470,625 | - | 33,327,869 | .978 | | 6.5% |
| 52,834 + | 521,549 + | 412,663 - | 41,644,194 | .985 | | 5.5% |

TORSO Y MOMENT FROM:

| WEIGHT | SUBSCAP SKINFOLD | TORSO LGTH | CONSTANT | R | SE | EST |
|-----------|------------------|------------|------------|------|----|------|
| 131,382 | | - | 9,383,727 | .960 | | 8.6% |
| 117,157 + | 141,080 | - | 8,666,906 | .973 | | 7.3% |
| 73,814 + | 117,589 + | 353,884 - | 26,158,116 | .980 | | 6.4% |

TORSO Z MOMENT FROM:

| WEIGHT | SUBSCAP SKINFOLD | CHEST BR | CONSTANT | R | SE | EST |
|----------|------------------|-----------|-----------|------|----|------|
| 47,818 | | - | 3,772,674 | .979 | | 6.8% |
| 43,478 + | 43,040 | - | 3,553,988 | .988 | | 5.3% |
| 35,609 + | 40,008 + | 128,070 - | 6,428,388 | .992 | | 4.2% |

*SE EST EXPRESSED AS A PERCENTAGE OF THE MEAN

MOMENTS IN GM CM SQUARED

VOLUMES IN CURIC CM

SKINFOLDS IN MM

WEIGHT IN POUNDS

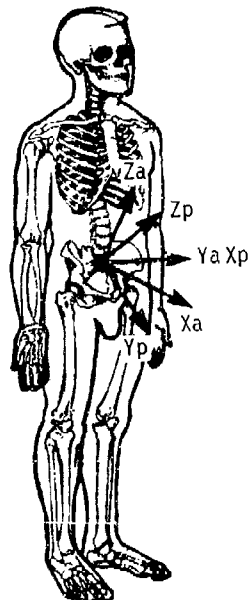
ALL OTHER VALUES AND DISTANCES IN CM

TABLE 29

TOTAL BODY

ANTHROPOMETRY

| OF SEGMENT | RANGE | MEAN | S.D. |
|--------------------|-------------|--------|-------|
| STATURE | 162.3-194.3 | 177.49 | 9.63 |
| WEIGHT | 127.0-233.3 | 170.38 | 28.93 |
| 10 RIB BR | 24.6- 33.6 | 29.85 | 2.33 |
| 10 RIB C | 70.1- 95.7 | 82.15 | 7.16 |
| SUBSCAP SKINFOLD | | | |
| | 7.0- 28.0 | 12.10 | 5.24 |
| WAIST CIR | 72.3- 99.7 | 85.70 | 7.88 |
| SUPRAIL'C SKINFOLD | | | |
| | 6.0- 28.0 | 15.24 | 6.14 |
| BUTTOCK C | 84.1-109.0 | 95.29 | 6.39 |



| TOTAL BODY VOLUME | | | |
|-------------------|--------|--------|--|
| RANGE | MEAN | S.D. | |
| 59,484 -108,203 | 80,302 | 13,356 | |

LOCATION OF THE CENTER OF VOLUME FROM THE ANATOMICAL AXIS ORIGIN

| | RANGE | MEAN | S.D. |
|--------|----------------|-------|------|
| X-AXIS | -11.42 - -6.40 | -8.69 | 1.38 |
| Y-AXIS | -.90 - .96 | .04 | .49 |
| Z-AXIS | -2.30 - 8.16 | 3.02 | 1.87 |

LOCATION OF THE CENTER OF VOLUME FROM ANATOMICAL LANDMARKS

| | X-MEAN | X-S.D. | Y-MEAN | Y-S.D. | Z-MEAN | Z-S.D. |
|-----------------|--------|--------|--------|--------|--------|--------|
| CERVICALE | -12.63 | 4.72 | -.19 | 2.17 | -50.85 | 3.77 |
| LEFT ASIS | -8.69 | 1.38 | -11.17 | 1.13 | 3.02 | 1.87 |
| RIGHT ASIS | -8.69 | 1.38 | 11.27 | 1.22 | 3.02 | 1.87 |
| SUPRASTERNAL F. | -20.76 | 3.93 | .20 | 1.79 | -39.56 | 3.58 |
| SYMPHYSION | -8.69 | 1.38 | .11 | .62 | 11.66 | 1.97 |

THE PRINCIPAL MOMENTS OF INERTIA

| | RANGE | MEAN | S.D. |
|--------|--------------------------|-------------|------------|
| X-AXIS | 88,439,435 - 203,043,411 | 135,395,337 | 34,042,243 |
| Y-AXIS | 83,399,023 - 188,134,006 | 126,366,113 | 31,577,709 |
| Z-AXIS | 8,116,878 - 24,100,314 | 14,432,630 | 4,235,469 |

PRINCIPAL AXES OF INERTIA WITH RESPECT TO ANATOMICAL AXES
 COSINE MATRIX EXPRESSED IN DEGREES

| | X | Y | Z | |
|---|-------|-------|--------|----------------------------|
| X | 20.86 | 90.23 | 110.85 | STD. DEV. OF ROT. X = 2.09 |
| Y | 89.76 | .24 | 90.01 | STD. DEV. OF ROT. Y = 5.32 |
| Z | 69.15 | 90.08 | 20.85 | STD. DEV. OF ROT. Z = 1.79 |

TOTAL BODY: REGRESSION EQUATIONS

TOTAL BODY VOLUME AND MOMENTS FROM STATURE AND WEIGHT

| | STATURE | WEIGHT | CONSTANT | R | SE EST* |
|------------|-------------|-----------|-------------|------|---------|
| VOLUME = | 13.63 + | 456.54 + | 88 | .998 | 1.1% |
| X MOMENT = | 1,732,353 + | 619,298 - | 277,625,773 | .993 | 3.0% |
| Y MOMENT = | 1,750,747 + | 526,985 - | 274,187,835 | .994 | 2.9% |
| Z MOMENT = | -40,033 + | 155,980 - | 5,049,460 | .983 | 5.5% |

TOTAL BODY VOLUME FROM:

| WEIGHT | 10 RIB BR | STATURE | CONSTANT | R | SE EST |
|----------|-----------|---------|-----------|------|--------|
| 460.67 | | + | 1,803.68 | .998 | 1.1% |
| 430.84 + | 420.32 | - | 5,638.59 | .998 | 1.0% |
| 409.52 + | 483.85 + | 55.49 - | 13,748.96 | .999 | .9% |

TOTAL BODY X MOMENT FROM:

| WEIGHT | STATURE | 10 RIB C | CONSTANT | R | SE EST |
|-----------|-------------|-----------|---------------|------|--------|
| 1,144,005 | | | - 59,543,098 | .972 | 6.0% |
| 619,298 + | 1,732,353 | | - 277,625,773 | .993 | 3.0% |
| 871,021 + | 1,508,892 - | 837,316 - | 212,111,197 | .996 | 2.3% |

TOTAL BODY Y MOMENT FROM:

| STATURE | WEIGHT | 10 RIB C | CONSTANT | R | SE EST |
|-------------|-----------|-----------|---------------|------|--------|
| 3,192,171 | | | - 440,242,306 | .973 | 5.8% |
| 1,750,747 + | 526,985 | | - 274,187,835 | .994 | 2.9% |
| 1,560,581 + | 741,201 - | 712,555 - | 218,434,961 | .996 | 2.4% |

TOTAL BODY Z MOMENT FROM:

| WEIGHT | SUBSCAP SKINFOLD | STATURE | CONSTANT | R | SE EST |
|-----------|------------------|----------|--------------|------|--------|
| 143,854 | | | - 10,089,161 | .983 | 5.6% |
| 149,092 - | 51,948 | | - 10,353,108 | .984 | 5.4% |
| 168,452 - | 66,272 - | 59,146 - | 2,979,880 | .985 | 5.3% |

*SE EST EXPRESSED AS A PERCENTAGE OF THE MEAN

MOMENTS IN GM CM SQUARED
 VOLUMES IN CUBIC CM
 SKINFOLDS IN MM
 WEIGHT IN POUNDS
 ALL OTHER VALUES AND DISTANCES IN CM

Chapter IV

CONCLUSIONS

The results of this study demonstrate that mass distribution properties can be estimated with a high degree of confidence from the anthropometric measures of the body and that such estimates can be made using various regression equations for both individuals and populations.

One method of judging the effectiveness of a regression equation is to determine if it reduces the variability of the estimate to a significant degree. For example, if it were necessary to estimate the volume of the head of a particular individual without knowing any of that person's dimensions, a "best estimate" would be the arithmetic mean of the sample using the standard deviation to establish the confidence limits of the estimate. Given dimensional information about the individual, the regression value becomes a "best estimate" and the standard error of estimate is used to establish the confidence limits. We can compare the standard error of estimate of a given regression with the standard deviation to determine the level of improvement in the prediction. In this study, such a comparison indicates that the standard error of estimate is generally one-third or less as large as the corresponding standard deviation, an appreciable reduction in the confidence limits. Such computations for the head and neck segments show the least overall improvement (on the order of 35 - 47 percent reduction) with the torso and total body demonstrating the most improvement (on the order of 80 - 95 percent reduction). The remainder of the segments show reduction in the standard errors of the estimate over the standard deviation ranging from approximately 60 to 80 percent. There is no difference in these comparisons between the segmental volumes and the principal moments of inertia.

In the selection of anthropometric variables for inclusion in the regression equation, a measure of mass (weight, circumference or skinfold) was generally the first dimension selected, a component of linearity the second, with a segment breadth or depth selected third. The major exception to this pattern was for the stepwise regression variable selected for the appendages when stature or a measure of segment length was selected first for the I_{xx} and I_{yy} moment predictions. The variables for predicting the segment volumes and I_{zz} principal moments were most frequently measures of mass with measurements of linearity only being selected second or, more commonly, third in the equation. As volume and moments are strongly related to mass, it is not surprising that the anthropometric measures of weight and circumference should appear most frequently in the predictive equations.

The alignment of the principal axes of inertia did not coincide closely with the anatomical axes systems. This is not unexpected as the anatomical axes systems were selected with less regard for the shape of the segment than for the presence of bony, palpable landmarks which could be located with some accuracy from subject to subject. However, for a large number of segments, excellent alignment between the principal axes of inertia and the segmental anatomical axes is achieved by a minor rotation of the anatomical axis system about a single axis. This means that, for practical purposes,

the location of the principal axes could be envisioned by construction of the anatomical axes and the appropriate rotation empirically determined in this study. No anthropometric measurement or combination of body or segment measurements provide usable predictions of the orientation of the principal axes of inertia to the anatomical axis. The mean values as presented in Tables 5-29 (principal axes of inertia with respect to anatomical axes) are the best estimates of the orientation of the principal axes.

There is not, unfortunately, a major body of data available to compare with the results of this investigation. We can test the segment volume and moments of inertia results against the limited data obtained in the few studies in which cadavers were used and the total body volume and moments against the equally limited data from living subjects. Such comparisons are not as telling as we would like them to be since in the first instance we are comparing the data for living subjects with data for embalmed cadaveric segments and, in the second, comparing principal moments with those obtained for similar but undefined axes.

Table 30 compares results of this study with mean values for the moments of inertia for body segments determined in previous investigations. The values from Chandler (1975) and Becker (1972) are for principal moments about the center of mass and the values from Dempster (1955) were determined about an undefined X-Y axis through the center of gravity. In general, the values from this study are almost consistently larger than those obtained in previous investigations. These differences could, however, be primarily a result of comparing data obtained on cadavers with those obtained on the living.

TABLE 30

SEGMENTAL MOMENTS OF INERTIA (gmcm² x 10³)

| | Chandler et al. | | | Dempster I _{x-y} * | Becker | | | This Study | | |
|--------------|-----------------|-----------------|-----------------|--------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| | I _{xx} | I _{yy} | I _{zz} | | I _{xx} | I _{yy} | I _{zz} | I _{xx} | I _{yy} | I _{zz} |
| Head | 174 | 164 | 203 | - | 199 | 221 | 134 | 204 | 233 | 150 |
| Torso | 16,194 | 10,876 | 3,785 | 18,400 | - | - | - | 14,386 | 13,004 | 4,375 |
| Upper Arm Rt | 135 | 133 | 20 | 142 | - | - | - | 128 | 136 | 26 |
| Lt | 152 | 138 | 23 | 139 | - | - | - | 123 | 130 | 25 |
| Forearm Rt | 67 | 65 | 9 | 56 | - | - | - | 86 | 87 | 13 |
| Lt | 65 | 63 | 9 | 55 | - | - | - | 82 | 84 | 11 |
| Hand Rt | 8 | 6 | 2 | 5 | - | - | - | 13 | 10 | 4 |
| Lt | 7 | 6 | 2 | 4 | - | - | - | 13 | 11 | 4 |
| Thigh Rt | 1,137 | 1,158 | 225 | 1,100 | - | - | - | 1,551 | 1,633 | 419 |
| Lt | 1,151 | 1,221 | 213 | 1,080 | - | - | - | 1,487 | 1,569 | 405 |
| Calf Rt | 391 | 393 | 29 | 430 | - | - | - | 570 | 578 | 66 |
| Lt | 395 | 390 | 29 | 416 | - | - | - | 581 | 590 | 66 |
| Foot Rt | 32 | 31 | 7 | 31 | - | - | - | 46 | 43 | 8 |
| Lt | 33 | 30 | 8 | 29 | - | - | - | 44 | 42 | 8 |
| Total Body | 133,970 | 118,897 | 17,125 | - | - | - | - | 135,395 | 126,368 | 14,433 |

* This axis is undefined except to say that it is perpendicular to the long axis and passes through the center of mass.

In the second comparison shown in Table 31, the total body principal moments from this study are compared with the results obtained by others for an aligned, but not necessarily principal, axis through the center of gravity. Again, the results of this study are of a larger magnitude than reported by others. These results could be a function of the somewhat taller and heavier subjects used in this study, or, they could be a result of our measuring the principal and largest, as opposed to a lesser, moment about an undefined axis.

TABLE 31

TOTAL BODY MOMENTS OF INERTIA ($\text{gmcm}^2 \times 10^3$)

| | n | I_{xx} | | I_{yy} | | I_{zz} | |
|------------|----|-----------|--------|-----------|--------|-----------|-------|
| | | \bar{x} | SD | \bar{x} | SD | \bar{x} | SD |
| Santschi | 66 | 130,035 | 21,823 | 116,467 | 20,240 | 12,777 | 2,488 |
| Ignazi | 11 | 123,827 | 20,319 | 115,145 | 19,916 | 11,191 | 2,922 |
| This Study | 31 | 135,395 | 34,042 | 126,368 | 31,578 | 14,433 | 4,385 |

A companion study of women has been initiated and data analysis is currently in progress. It is hoped that data from both these studies will furnish the impetus for further validation of this relatively uncomplicated approach to the determination of human mass distribution properties.

Appendix A

DEFINITION OF TERMS AND LANDMARKS

ABDOMINAL: pertaining to the abdomen, particularly the region below the rib cage and above the pelvis.

ACROMION: the bony process which forms the lateral extension of the scapular spine.

ACROMION LANDMARK: the most lateral point on the lateral edge of the acromial process of the scapula. A point on the tip of the shoulder.

ADAM'S APPLE LANDMARK: the anterior point in the mid-sagittal plane of the thyroid cartilage.

ANTERIOR: pertaining to the front of the body; as opposed to posterior.

ANTERIOR SUPERIOR ILIAC SPINE LANDMARK: the most prominent point on the anterior superior spine of the ilium.

AXILLA: the armpit.

BI: a prefix relating to each of two symmetrically paired points.

BICEPS (BRACHII M.): the large muscle on the anterior side of the upper arm.

BICEPS LANDMARK: the most superior point on the biceps muscle when the upper arm is held horizontal and the biceps is flexed.

CERVICALE LANDMARK: the superior tip of the spine of the 7th cervical vertebra.

CLAVICALE LANDMARK: the point on the most eminent prominence of the superior aspect of the medial end of each clavicle.

CLAVICLE: the long bone extending from the upper border of the sternum laterally and posteriorly to the acromion of the scapula; the collarbone.

DACTYLION: the tip of the middle finger.

DIGIT (I - V): a finger or toe, numbered sequentially from the thumb or big toe (digit I).

DISTAL: the end of a body segment furthest from the torso; the opposite of proximal.

DORSAL: pertaining to the back or the posterior surface.

EPICONDYLE: an eminence upon a bone above its rounded projection which is usually for articulation.

FEMORAL EPICONDYLE LANDMARKS: the lateral point on the lateral epicondyle and the medial point on the medial epicondyle of each femur.

FEMUR: the long bone of the thigh.

FIBULA: the smaller of the two long bones of the calf or lower leg.

FIBULAR LANDMARK: the superior point of the fibula.

FRANKFORT PLANE: the standard horizontal plane of orientation of the head, containing tragion and the lowest point of the orbit. This is closely approximated when the subject looks directly forward with his line of vision parallel with the floor.

GLABELLA LANDMARK: the most anterior point of the forehead between the brow ridges, in the mid-sagittal plane.

GLUTEAL FURROW: the furrow formed by the protrusion of the buttock beyond the back of the leg.

GLUTEAL FURROW LANDMARK: the most inferior point of the gluteal furrow.

GONIAL ANGLE: the obtuse angle at the back of the lower jaw formed by the intersection of the vertical and horizontal portions of the jaw.

GONION LANDMARK: the inferior posterior tip of the right and left gonial angles, the most prominent point on the angle of the jaw.

HUMERAL EPICONDYLE LANDMARKS: the lateral point on the lateral epicondyle and the medial point on the medial epicondyle of each humerus.

ILIAC CREST: the superior rim of the ilium or pelvic bone.

ILIOCRISTALE LANDMARK: the most superior point of the iliac crest in the mid-axillary line.

ILIUM: the upper one of three bones composing either lateral half of the pelvis.

INFERIOR: lower, nearer to the feet.

INFRAORBITALE: the lowest point on the inferior margin of the orbit or eye socket.

INFRAPATELLA LANDMARK: the inferior point on the patella while it is in the relaxed position.

INGUINAL LIGAMENT: the ligament which extends from the anterior superior iliac spine to the pubic tubercle and forms the groin crease.

LATERAL: lying away from the mid-sagittal line of the body; opposed to medial.

MALLEOLUS LANDMARK: the bony protrusion, either lateral or medial, of the ankle.

MASTOID: the bony eminence on the inferior posterior aspect of the temporal bone behind the ear.

MASTOID LANDMARK: the most inferior point of the mastoid process.

MEDIAL: lying near the mid-sagittal plane of the body; opposed to lateral.

METACARPALE: the joint or juncture of a bone of the palm (metacarpal) with the first bone (phalanx) of the finger. Numbered sequentially I (thumb) through V (little finger).

METACARPALE III LANDMARK: the distal palpable point on the metacarpal bone of the third digit on the posterior surface of the hand.

METACARPALE-PHALANGEAL LANDMARKS (II and V): the lateral prominent point on the lateral surface of the second metacarpal and the medial prominent point on the medial surface of the fifth metacarpal.

METATARSAL: a bone in the instep of the foot. Numbered sequentially I (big toe) through V (little toe).

METATARSAL-PHALANGEAL LANDMARKS (I and V): the medial point on the head of the metatarsus I and the lateral point on the head of metatarsus V.

MID-AXILLARY LINE: the vertical line which originates at the apex of the axilla.

MID-SAGITTAL PLANE: the vertical plane which divides the body into right and left halves.

NUCHALE LANDMARK: the lowest point in the mid-sagittal plane of the occiput that can be palpated among the nuchal muscles. This point is often visually obscured by hair.

OCCIPUT: the bone at the back of the skull; the region of the back of the head.

OLECRANON: the large bony process at the upper end of the ulna, one of the two long bones of the forearm.

OLECRANON LANDMARK: the posterior point on the olecranon.

OMPHALION: the mid-point of the umbilicus or navel.

PATELLA: the kneecap.

PHALANX: (plural, phalanges) a bone of the fingers or toes.

POSTERIOR: pertaining to the back of the body; opposed to anterior.

POSTERIOR CALCANEUS LANDMARKS: the posterior point on each heel.

POSTERIOR SUPERIOR ILIAC SPINE LANDMARK: the point on the mid-spine made at the level of the posterior superior iliac spines.

PROXIMAL: the end of a body segment nearest the torso; opposed to distal.

RADIALE STYLOID LANDMARK: the point at the distal tip of the radius.

RADIALE LANDMARK: the highest point on the proximal head of the radius, near the mid-point of the elbow joint on the posterior side of the arm.

RADIUS: one of the two bones of the lower arm. This bone extends from the lateral side of the elbow to the wrist at the base of the thumb.

SCAPULA: the large flat triangular bone forming the back of the shoulder; the shoulder blade.

SCYE LANDMARKS: the point marking the upper end of the axillary fold, either right or left, anterior or posterior, which is the skin furrow formed by the juncture of the upper arm and torso.

SELLION LANDMARK: the greatest indentation of the nasal root depression in the mid-sagittal plane.

SPHYRION LANDMARK: the most distal point on the medial side of the tibia.

STERNUM: the breastbone.

STYLION: see ULNAR-STYLOID LANDMARK.

STYLOID PROCESS: a bony protuberance resembling a stylus. On the radius and ulna this occurs at the distal end of the bone.

SUB: a prefix denoting under or beneath.

SUPERIOR: higher, nearer to the head; as opposed to inferior.

SUPRA: a prefix denoting above or superior to.

SUPRASTERNALE LANDMARK: the lowest point in the notch in the upper edge of the breastbone.

SYMPHYSION LANDMARK: the lowest point on the superior border of the pubic symphysis, the anterior juncture of the pelvic bones.

TENTH RIB LANDMARKS: the inferior point on the inferior border of each tenth rib. The mid-spine landmark is at this level but marked on the mid-spine.

THELION: the mid-point of the nipple.

TIBIALE LANDMARK: the uppermost point on the medial superior border of the tibia.

TOE II LANDMARK: the anterior point of the second digit of each foot.

TRAGION LANDMARK: the point located at the notch just above the tragus of the ear. This point corresponds approximately to the upper edge of the ear hole.

TRAGUS: the small cartilaginous flap of flesh in front of the ear hole.

TRICEPS LANDMARK: with the right elbow flexed 90°, the level on the back of the upper arm halfway between acromion and the tip of the elbow.

TRICEPS M: the large muscle on the back of the upper arm.

TROCHANTER: a large prominence of a bone for the attachment of rotator muscles.

TROCHANTERION LANDMARK: the superior point on the greater trochanter of the femur.

ULNA: one of the two bones of the lower arm; this bone runs from the tip of the elbow to the wrist on the same side as the little finger.

ULNAR STYLOID LANDMARK: the most distal point on the ulna.

UMBILICUS: the navel.

VENTRAL: the front surface; opposed to dorsal.

VERTEX: the top of the head in the mid-sagittal plane when the head is held in the Frankfort plane.

ZYGOMATIC ARCH: the bony arch extending horizontally along the side of the head from the cheekbone (malar) nearly to the external ear.

MEASUREMENT DESCRIPTIONS*

Abdomen Segment Length (82): a dimension calculated by subtracting iliac crest height from tenth rib height.

Acromion Height (7): subject stands erect, feet together, with head oriented in the Frankfort plane. With an anthropometer, measure the vertical distance from the floor to the acromion landmark.

Acromion-Radiale Length (20): with a beam caliper, measure the distance along the long axis of the upper arm between the acromion and radiale landmarks.

Ankle Breadth (34): with a sliding caliper, measure on the ankle the maximum distance between the medial and lateral malleoli.

Ankle Circumference (62): with a tape perpendicular to the long axis of the lower leg, measure the minimum circumference of the ankle.

Anterior-Superior Iliac Spine Height (13): subject stands erect, heels together, with head oriented in the Frankfort plane. With an anthropometer, measure the vertical distance from the floor to the anterior superior iliac spine landmark.

Arch Circumference (63): subject stands with his weight equally distributed on both feet. 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 foot at the arch.

Axillary Arm Circumference (65): 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.

Axillary Arm Depth (37): subject stands erect, arms hanging relaxed at sides. With the beam caliper, measure the horizontal distance from the anterior to the posterior surface of the upper arm at the axilla level.

Ball of Foot Circumference (64): subject stands with weight equally distributed on both feet. With a tape passing over the metatarsal-phalangeal joints I and V, measure the circumference of the foot.

Biacromial Breadth (23): subject stands with upper arms hanging relaxed and forearms and hands extended forward horizontally. With a beam caliper, measure the horizontal distance between the right and left acromion landmarks.

* All measurements were taken with the subjects' arms in a relaxed position at their sides, rather than in the anatomical position, and all unilateral measurements were taken on the right sides, unless otherwise specified.

Biceps Circumference Flexed, Right and Left (76/77): subject stands, upper arm raised so that its long axis is horizontal, elbow flexed 90°, biceps strongly contracted, and fist tightly clenched. With a tape perpendicular to the long axis of the upper arm, measure the circumference of the upper arm at the level of the biceps landmark.

Biceps Circumference Relaxed, Right and Left (66/67): subject stands erect, arms hanging relaxed at his sides. With a tape perpendicular to the long axis of the upper arm, measure the circumference of the upper arm at the level of the biceps landmark.

Biceps Depth (38): subject stands erect, arms hanging relaxed at his sides. With the sliding caliper, measure the horizontal distance from the anterior to the posterior surface of the upper arm at the level of the biceps landmark.

Biceps Skinfold (75): subject stands erect, arms hanging relaxed at his sides. With the Lange skinfold caliper, measure a thickness of a fold of skin and subcutaneous tissue parallel to the long axis of the right upper arm at the level of the biceps landmark.

Bispinous Breadth (27): subject stands erect, heels together. With a beam caliper, measure the distance between the right and left anterior superior iliac spine landmarks.

Bitrochanteric Breadth (Bone) (28): subject stands erect with his heels together. 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 Circumference (56): subject stands erect with his heels together. With a tape passing over the greatest posterior protrusion of the buttocks, and in a plane perpendicular to the long axis of the trunk, measure the circumference of the hips.

Buttock Depth (30): subject stands erect, heels together. With a beam caliper, measure the horizontal distance from the anterior to the posterior surface of the torso at the level of the maximum protrusion of the buttocks.

Calf Circumference, Right and Left (60/61): subject stands, weight evenly distributed on both feet. With a tape perpendicular to the long axis of the lower leg, measure the maximum circumference of each calf.

Calf Depth (33): subject stands erect, weight evenly distributed on both feet. With the beam caliper, measure the horizontal distance from the anterior to the posterior surface of the right calf at the level of maximum calf circumference.

Calf Segment Length (86): a dimension calculated by subtracting sphyrion height from tibiale height.

Cervicale Height (4): subject stands erect, heels together, with head in the Frankfort plane. With an anthropometer, measure the vertical distance from the floor to the cervicale landmark.

Chest Breadth (24): subject stands erect, with heels together, head in the Frankfort plane. With a beam caliper, measure the horizontal breadth of the chest at the level of right thelion. The measurement is made at the mid-point of quiet respiration.

Chest Circumference (53): subject stands erect, heels together, head in the Frankfort plane. With a tape passing over the nipples and perpendicular to the long axis of the trunk, measure the circumference of the chest. The measurement is made at the mid-point of quiet respiration.

Elbow Breadth, Right and Left (47/48): subject stands with elbows flexed about 110°. With a spreading caliper, measure the maximum breadth across the humeral epicondyles.

Elbow Circumference (68): subject stands with arms hanging relaxed at his sides. With a tape passing over the olecranon process of the ulna and into the crease of the elbow, measure the circumference of the elbow.

Fibular Height (18): subject stands erect with heels together, weight evenly distributed on both feet. With an anthropometer, measure the vertical distance from the floor to the fibular landmark.

Foot Breadth (36): subject stands with his weight equally distributed on both feet. With a slicing caliper, measure the breadth of the foot across the metatarsal-phalangeal joints I and V.

Foot Length (35): subject stands with his weight equally distributed on both feet. With a beam caliper, measure on the foot the distance from the posterior point of the heel to the tip of the longest toe.

Foot Segment Length: see FOOT LENGTH.

Forearm-Hand Segment Length (87): a dimension calculated by adding radiale-styilion length and hand length.

Gluteal Furrow Depth (31): subject stands erect with heels together, weight evenly distributed on both feet. With the beam caliper, measure the horizontal distance from the anterior to the posterior surface of the right thigh at the gluteal furrow landmark.

Gluteal Furrow Height (16): subject stands erect with heels together, weight evenly distributed on both feet. With an anthropometer, measure the vertical distance from the standing surface to the right gluteal furrow landmark.

Hand Breadth (42): subject positions hand with fingers together and extended, and thumb slightly abducted. With a sliding caliper, measure the breadth of the hand across the metacarpal-phalangeal joints II and V.

Hand Circumference (71): subject positions hand with the fingers together and extended and thumb slightly abducted. With a tape passing around the metacarpal-phalangeal joints II and V, measure the circumference of the hand.

Hand Length (41): subject positions hand with fingers together and extended. With a sliding caliper, measure the length of the hand from the distal wrist crease to the tip of digit III.

Hand Segment Length: see HAND LENGTH.

Head Breadth (46): with a spreading caliper, measure the maximum horizontal breadth of the head.

Head Circumference (51): with the tape passing above the brow ridges and parallel to the Frankfort plane, measure the maximum circumference of the head.

Head Length (45): with the spreading caliper, measure in the mid-sagittal plane the maximum length of the head between the glabella landmark and the occiput.

Head Segment Height (78): a dimension calculated by subtracting mastoid height from stature.

Hip Breadth (29): subject stands erect with his heels together. With a beam caliper, measure the horizontal distance across the greatest lateral protrusion of the hips.

Iliac Crest Height (11): subject stands erect with heels together, weight evenly distributed on both feet. With an anthropometer, measure the vertical distance from the floor to the iliac crest landmark.

Knee Breadth, Right and Left (49/50): subject sits, knees flexed about 90°. With a spreading caliper, measure the maximum breadth of the knee across the femoral epicondyles.

Knee Circumference (59): subject stands erect. 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. The subject is instructed not to lock his patella.

Lower Arm Segment Length: see RADIALE-STYLION LENGTH.

Mastoid Height (6): subject stands erect, heels together, head in the Frankfort plane. With an anthropometer, measure the vertical distance from the floor to the mastoid landmark.

Metacarpale III-Dactylion Length (43): subject extends his fingers. 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 (69): subject stands erect, arms hanging relaxed at his sides. 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-forearm Breadth (39): subject stands erect, arms hanging relaxed at his sides. With the sliding caliper, measure the horizontal distance from the anterior to the posterior surface of the lower arm at a level midway between the radiale and the ulnar styloid landmarks.

Mid-thigh Circumference (58): subject stands erect, feet slightly apart, weight evenly distributed on both feet. With a tape perpendicular to the long axis of the leg and at the level midway between the trochanterion and tibiale landmarks, measure the circumference of the thigh.

Mid-thigh Depth (32): subject stands erect, heels together, weight evenly distributed on both feet. With the beam caliper, measure the horizontal distance from the anterior to the posterior surface of the thigh at the level midway between the trochanterion and tibiale landmarks.

Neck Breadth (22): subject stands with head in the Frankfort plane. With a beam caliper, measure the maximum horizontal breadth of the neck, superior to the trapezius muscles.

Neck Circumference (52): subject stands with head in the Frankfort plane. With a tape in a plane perpendicular to the long axis of the neck and passing over the laryngeal prominence (Adam's apple), measure the circumference of the neck.

Neck Segment Length (79): a dimension calculated by subtracting cervicale height from mastoid height.

Omphalion Height (12): subject stands erect, heels together, head in the Frankfort plane. With an anthropometer, measure the vertical distance from the floor to omphalion. The subject must not pull in his stomach.

Pelvic Segment Length (83): a dimension calculated by subtracting gluteal furrow height from the higher of the two iliocristale landmarks.

Radiale-Styilion Length (21): with a beam caliper parallel to the long axis of the forearm, measure the distance between the radiale and the ulnar-styloid landmarks.

Sitting Height (44): subject sits erect, head in the Frankfort plane. With the anthropometer, measure the vertical distance from the sitting surface to the top of the head.

Sphyrion Height (19): subject stands erect, feet slightly apart, weight evenly distributed on both feet. With the measuring block, measure the vertical distance from the standing surface to the sphyrion landmark.

Stature (3): subject stands erect, heels together, head in the Frankfort plane. With an anthropometer, measure the vertical distance from the floor to the top of the head.

Subscapular Skinfold (73): subject stands. With a Lange skinfold caliper, measure the thickness of a fold of skin and subcutaneous tissue just below the inferior angle of the right scapula and parallel to the tension lines of the skin.

Suprailiac Skinfold (74): subject stands. With a Lange skinfold caliper, measure the thickness of a fold of skin and subcutaneous tissue in the right mid-axillary line at the level of the crest of the ilium and parallel to the border of the crest.

Suprasternale Height (8): subject stands erect, heels together, head in the Frankfort plane. With an anthropometer, measure the vertical distance from the floor to the suprasternale landmark.

Symphysion Height (14): subject stands erect, heels together, with head in the Frankfort plane. With an anthropometer, measure the vertical distance from the floor to the symphysion landmark.

Tenth Rib Circumference (54): subject stands erect, heels together, head in the Frankfort plane. With a tape passing over the torso at the level of the right tenth rib landmark and perpendicular to the long axis of the trunk, measure the circumference of the torso. The subject must not pull in his stomach.

Tenth Rib Height (10): subject stands erect, heels together, head in the Frankfort plane. With an anthropometer, measure the vertical distance from the floor to the right tenth rib landmark.

Tenth Rib Torso Breadth (25): subject stands erect, heels together, head in the Frankfort plane. With the beam caliper, measure the horizontal breadth of the torso at the level of the right tenth rib landmark.

Thelion Height (9): subject stands erect, heels together, head in the Frankfort plane. With an anthropometer, measure the vertical distance from the floor to the thelion.

Thigh Flap Segment Length (84): a dimension calculated by subtracting gluteal furrow height from trochanterion height.

Thigh Segment Length (85): a derived dimension calculated by subtracting tibiale height from trochanterion height.

Thorax Segment Length (81): a derived dimension calculated by subtracting tenth rib height from cervicale height.

Tibial Height (17): subject stands erect with heels together, weight evenly distributed on both feet. With an anthropometer, measure the vertical distance from the floor to the tibiale landmark.

Torso Segment Length (80): a derived dimension calculated by subtracting gluteal furrow height from cervicale height.

Tragion Height (5): subject stands erect, heels together, head in the Frankfort plane. With an anthropometer, measure the vertical distance from the floor to the tragion landmark.

Triceps Skinfold (72): subject stands. With a Lange skinfold caliper, measure the thickness of a fold of skin and subcutaneous tissue parallel to the long axis of the right upper arm at the level of the triceps landmark.

Trochanterion Height (15): subject stands erect with heels together. With an anthropometer, measure the vertical distance from the floor to the trochanterion landmark.

Upper Arm Segment Length: see ACROMION-RADIALE LENGTH.

Upper Thigh Circumference (57): subject stands with his legs apart. 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 (26): subject stands, heels together. With a beam caliper, measure the horizontal breadth of the body at the level of omphalion.

Waist Circumference (55): subject stands erect with heels together. With a tape passing over omphalion and perpendicular to the long axis of the trunk, measure the circumference of the waist. The subject must not pull in his stomach.

Weight (2): body weighed with scales read to the nearest quarter pound.

Wrist Breadth (Bone) (40): with a spreading caliper, measure the maximum breadth of the forearm across the radial and the ulnar styloid processes using sufficient pressure to compress the flesh.

Wrist Circumference (70): 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 B

STATISTICAL TREATMENT OF PRINCIPAL AXES

The description of inertial properties of a rigid body requires the specification of an inertia tensor, a coordinate system origin and the orientation with respect to which the tensor is calculated. A coordinate system may be chosen in which the inertia tensor has all off-diagonal elements equal to zero. This coordinate system is called the principal axis system and the diagonal elements of the inertia tensor are the principal moments of inertia. The alignment of the principal axis system depends on the mass distribution properties of the segment and, in the case of sets of human body segments, can be expected to have a distribution because of the variability in body shape from subject to subject.

The inertial distribution properties of the human body are essential for the analysis of any dynamics involving rotational motion of body segments. While, in principle, the equations describing such dynamics can be written using general inertia tensors, such an approach is most awkward. The usual procedure is to use principal moments and specify segment dimensions in the principal axis system of that segment.

This approach requires the specification of only the three principal moments and not the total 3 x 3 inertia tensor. However, it does require the additional specification of the segment principal axes alignments.

In the comparison of data for all 31 subjects, the principal moments, which are scalar quantities, were regressed against directly measured body dimensions. The resulting regression equations provide segment principal moments as a function of these dimensions.

The determination of corresponding principal axis systems, which consists of the specification of triads of orthogonal vectors, poses a more difficult problem. While individual vectors can be averaged to find a mean and a distribution around the mean, it does not necessarily follow that averages formed using respective axes of orthogonal sets will lead to an average orthogonal coordinate system.

That this approach indeed does not work in general can be easily demonstrated by trying to find the average of two orthogonal coordinate systems. Consider two coordinate systems both orthogonal, denoted by subscripts 1 and 2 in Figure B-1. Since each system is orthogonal

$$\hat{X}_1 \cdot \hat{Y}_1 = \hat{X}_1 \cdot \hat{Z}_1 = \hat{Y}_1 \cdot \hat{Z}_1 = 0 \quad (1)$$

Consider the sums

$$\vec{U}_1 = \hat{X}_1 + \hat{X}_2, \quad \vec{U}_2 = \hat{Y}_1 + \hat{Y}_2 \quad \text{and} \quad \vec{U}_3 = \hat{Z}_1 + \hat{Z}_2 \quad (2)$$

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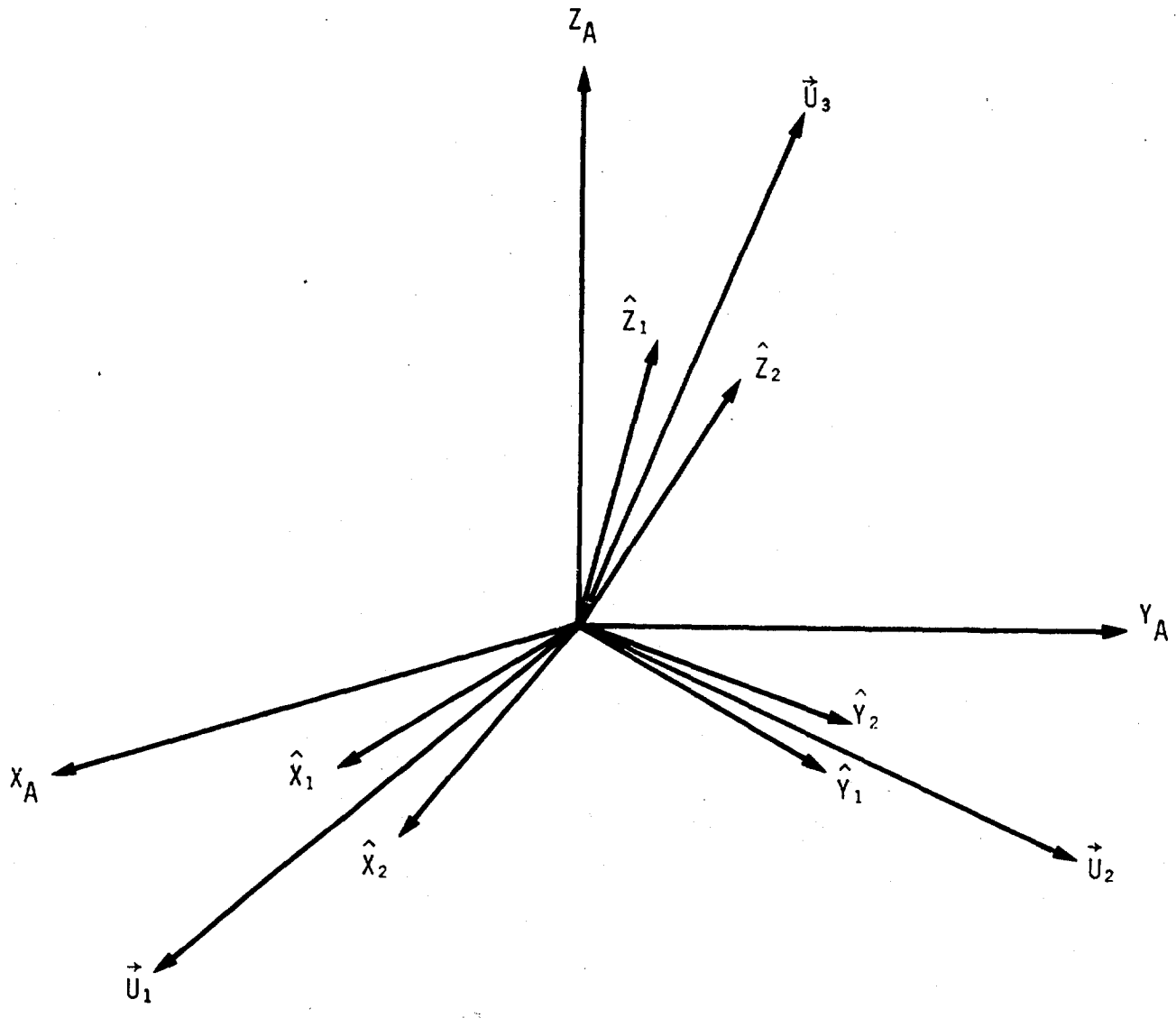


Figure B-1. An illustration of two orthogonal axis systems.

If \vec{U}_1, \vec{U}_2 and \vec{U}_3 formed an orthogonal set, then $\vec{U}_1 \cdot \vec{U}_2 = \vec{U}_1 \cdot \vec{U}_3 = \vec{U}_2 \cdot \vec{U}_3 = 0$,

however, consider the first term

$$\vec{U}_1 \cdot \vec{U}_2 = (\hat{X}_1 + \hat{X}_2) \cdot (\hat{Y}_1 + \hat{Y}_2) = \hat{X}_1 \cdot \hat{Y}_2 + \hat{X}_2 \cdot \hat{Y}_1 \quad (3)$$

where conditions (1) have been applied.

The system 2 vectors can be expressed in terms of the orthogonal system 1 unit vectors. Thus X_2 and Y_2 can be written in the form

$$\begin{aligned} \hat{X}_2 &= \alpha_{x_2x_1} \hat{X}_1 + \alpha_{x_2y_1} \hat{Y}_1 + \alpha_{x_2z_1} \hat{Z}_1 \\ \hat{Y}_2 &= \alpha_{y_2x_1} \hat{X}_1 + \alpha_{y_2y_1} \hat{Y}_1 + \alpha_{y_2z_1} \hat{Z}_1 \end{aligned} \quad (4)$$

where the α_{xy} is the cosine of the angle between the X and Y axes. Substituting these relations into equation (3) and using the properties from (1) we find

$$\vec{U}_1 \cdot \vec{U}_2 = \alpha_{x_2y_1} + \alpha_{y_2x_1} = \cos \angle X_2 Y_1 + \cos \angle Y_2 X_1 \quad (5)$$

Since, in general, this term will not be equal to zero, \vec{U}_1 and \vec{U}_2 are not in general orthogonal. If systems 1 and 2 are closely aligned, then the angles between X_2 and Y_1 , and Y_2 and X_1 will be close to $\pi/2$ and the cosine of these angles will be small, indicating that \vec{U}_1 and \vec{U}_2 are almost orthogonal.

The same analysis can be performed on $\vec{U}_1 \cdot \vec{U}_3$ and $\vec{U}_2 \cdot \vec{U}_3$ to show that these terms are also not generally equal to zero and therefore the summation of respective axes vectors does not lead to an orthogonal vector set. However, as indicated for $\vec{U}_1 \cdot \vec{U}_2$, if the summed axes are closely bunched, the resultant vectors are close to an orthogonal set. Since the final averaged axis system chosen had to be orthogonal, the following procedure was applied to generate an orthogonal system.

Taking N coordinate systems with respective axes vectors X_i, Y_i and Z_i , we formed the sums

$$\vec{U}'_1 = \sum_{i=1}^N \hat{X}_i, \quad \vec{U}'_2 = \sum_{i=1}^N \hat{Y}_i, \quad \vec{U}'_3 = \sum_{i=1}^N \hat{Z}_i \quad (6)$$

By taking dot products among these vectors, as we did for N=2 above, we can show again that they do not equal zero and thus do not form an orthogonal set of vectors. However, if the summed unit vectors are closely aligned, then these products will be small and \vec{U}'_1, \vec{U}'_2 and \vec{U}'_3 are close to an orthogonal set.

Since our intent is to find an average orthonormal principal axis system, an orthogonal set \vec{U}_1 , \vec{U}_2 and \vec{U}_3 is first obtained by taking

$$\begin{aligned}\vec{U}_1 &= \vec{U}'_1 \\ \vec{U}_2 &= \vec{U}'_2 - (\vec{U}'_1 \cdot \vec{U}'_2)\vec{U}'_1 \\ \vec{U}_3 &= \vec{U}_1 \times \vec{U}_2\end{aligned}\tag{7}$$

A second and third set of these orthogonal vector sets were generated by permutation of the indices 1→2 and 2→3, respectively. This was done to remove any sequencing bias introduced in the orthogonalization process defined by equation (7). These vectors were then normalized to unit vectors and the respective axes vectors (three for each axis) summed as in equation (6). The orthogonalization procedure described above was again applied and the total procedure repeated until

$$\hat{U}_1 \cdot \hat{U}_2; \hat{U}_1 \cdot \hat{U}_3; \hat{U}_2 \cdot \hat{U}_3 < .0001\tag{8}$$

In most cases this condition was satisfied by one pass through the orthogonalization process with only a few cases requiring two passes.

The average principal axis system alignment with respect to the anatomical axis system can be expressed by a cosine matrix, D_{pa} , which relates the components of a vector in the principal system to those in the anatomical system by

$$\vec{R}_p = D_{pa} \vec{R}_a\tag{9}$$

Also, each individual principal axis system can be related by $D_{pi\bar{p}}$ to the average principal system so that a vector in this system is related to the same vector in the average principal system by

$$\vec{R}_{pi} = D_{pi\bar{p}} \vec{R}_{\bar{p}}\tag{10}$$

If we choose an axis vector for \vec{R}_{pi} , for example \hat{X}_{pi} , then

$$\hat{X}_{pi} = \alpha_{xx} \hat{X}_{\bar{p}} + \alpha_{xy} \hat{Y}_{\bar{p}} + \alpha_{xz} \hat{Z}_{\bar{p}}$$

where α_{xx} , α_{xy} and α_{xz} are the projections of the unit vector \hat{X}_{pi} along the $\hat{X}_{\bar{p}}$, $\hat{Y}_{\bar{p}}$ and $\hat{Z}_{\bar{p}}$ axes, respectively. This is shown in Figure B-2.

To examine the distribution of the individual principal axes vectors about the average principal axes vectors, we take

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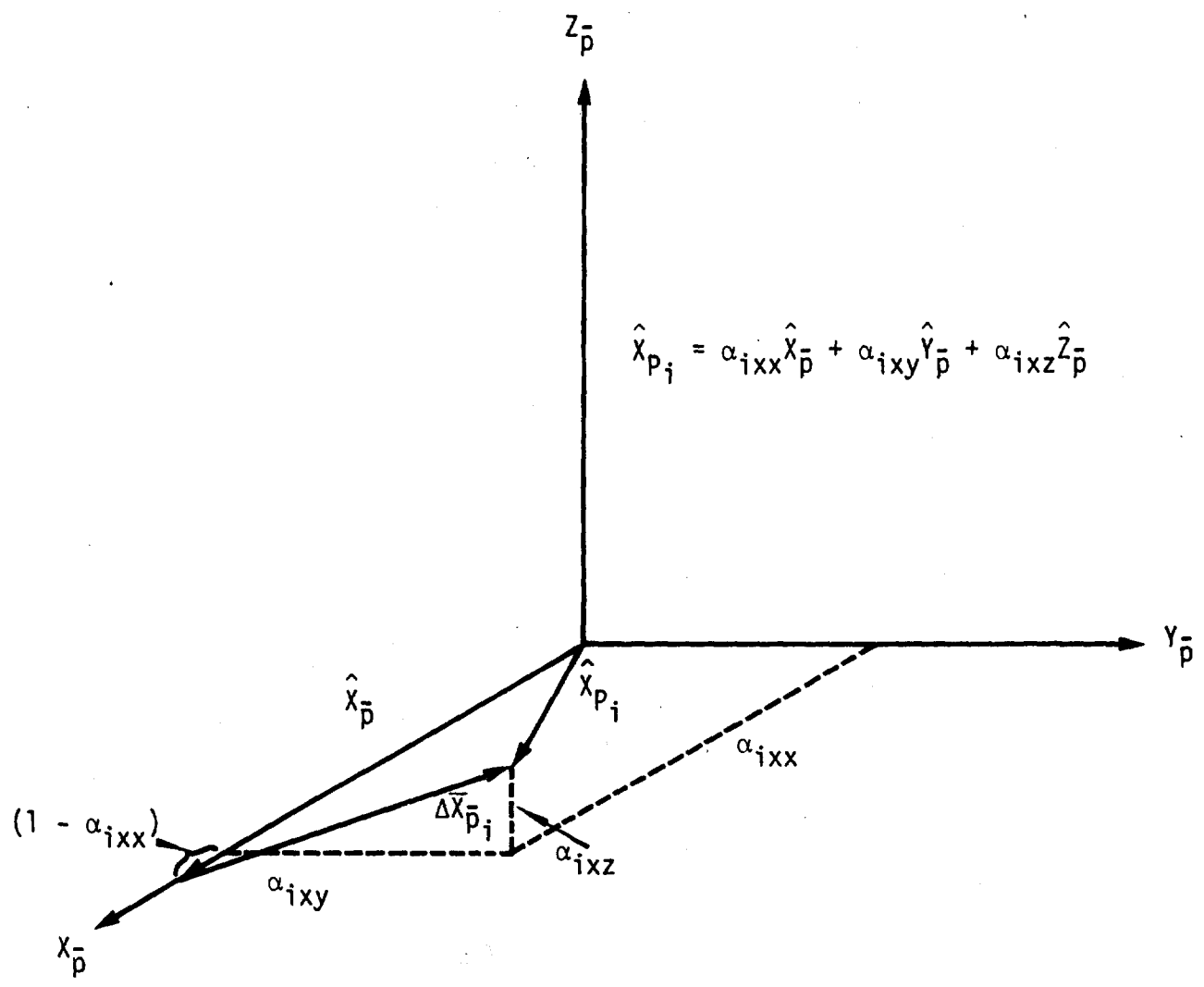


Figure B-2. A standard deviation unit vector (\hat{x}_{pi}).

$$\begin{aligned}
 \Delta \hat{x}_{Pi} &= \hat{x}_{Pi} - \hat{x}_{\bar{p}} = (\alpha_{ixx} - 1)\hat{x}_{\bar{p}} + \alpha_{ixy}\hat{y}_{\bar{p}} + \alpha_{ixz}\hat{z}_{\bar{p}} \\
 \Delta \hat{y}_{Pi} &= \hat{y}_{Pi} - \hat{y}_{\bar{p}} = \alpha_{iyx}\hat{x}_{\bar{p}} + (\alpha_{iyy} - 1)\hat{y}_{\bar{p}} + \alpha_{iyz}\hat{z}_{\bar{p}} \\
 \Delta \hat{z}_{Pi} &= \hat{z}_{Pi} - \hat{z}_{\bar{p}} = \alpha_{izx}\hat{x}_{\bar{p}} + \alpha_{izy}\hat{y}_{\bar{p}} + (\alpha_{izz} - 1)\hat{z}_{\bar{p}}
 \end{aligned}
 \tag{11}$$

which are expressed in the average principal axis system, and define

$$\sigma_{xx} = \frac{\sum_{i=1}^M (\Delta \hat{x}_{Pi})^2}{M}, \quad \sigma_{yy} = \frac{\sum_{i=1}^M (\Delta \hat{y}_{Pi})^2}{M}, \quad \sigma_{zz} = \frac{\sum_{i=1}^M (\Delta \hat{z}_{Pi})^2}{M}$$

(12)

$$\sigma_{yx} = \frac{\sum_{i=1}^M (\Delta \hat{x}_{Pi})^2}{M}, \quad \sigma_{xz} = \frac{\sum_{i=1}^M (\Delta \hat{x}_{Pi})^2}{M}, \quad \sigma_{zy} = \frac{\sum_{i=1}^M (\Delta \hat{y}_{Pi})^2}{M}$$

and $\sigma_{xy} = \sigma_{yx}$, $\sigma_{xz} = \sigma_{zx}$, and $\sigma_{yz} = \sigma_{zy}$.

These are standard deviations defining the distribution of individual principal axes unit vectors about the respective average principal axes. They may be depicted graphically as shown in Figure B-3, where the σ_{xy} , σ_{xz} and σ_{yz} standard deviations can be viewed as defining ellipsoidal cones about each average principal axis.

Due to the orthogonality of the individual principal axis systems for every vector contributing a data point along one axis there are two other data points along the other two axes whose relative positions are determined by the orthogonality condition. This results, as also shown above, in

$$\sigma_{xy} = \sigma_{yx}; \quad \sigma_{xz} = \sigma_{zx} \quad \text{and} \quad \sigma_{yz} = \sigma_{zy}, \quad \text{as well as} \quad \sigma_{xx} = \sigma_{yy} = \sigma_{zz} = \sigma.$$

The standard deviation cones can also be specified in terms of conical angles $\sigma_{rot x}$, $\sigma_{rot y}$ and $\sigma_{rot z}$, which are defined by

$$\begin{aligned}
 \sigma_{rot x} &= \tan^{-1} \frac{\sigma_{zy}}{1-\sigma} \\
 \sigma_{rot y} &= \tan^{-1} \frac{\sigma_{xz}}{1-\sigma} \\
 \sigma_{rot z} &= \tan^{-1} \frac{\sigma_{yx}}{1-\sigma}
 \end{aligned}
 \tag{13}$$

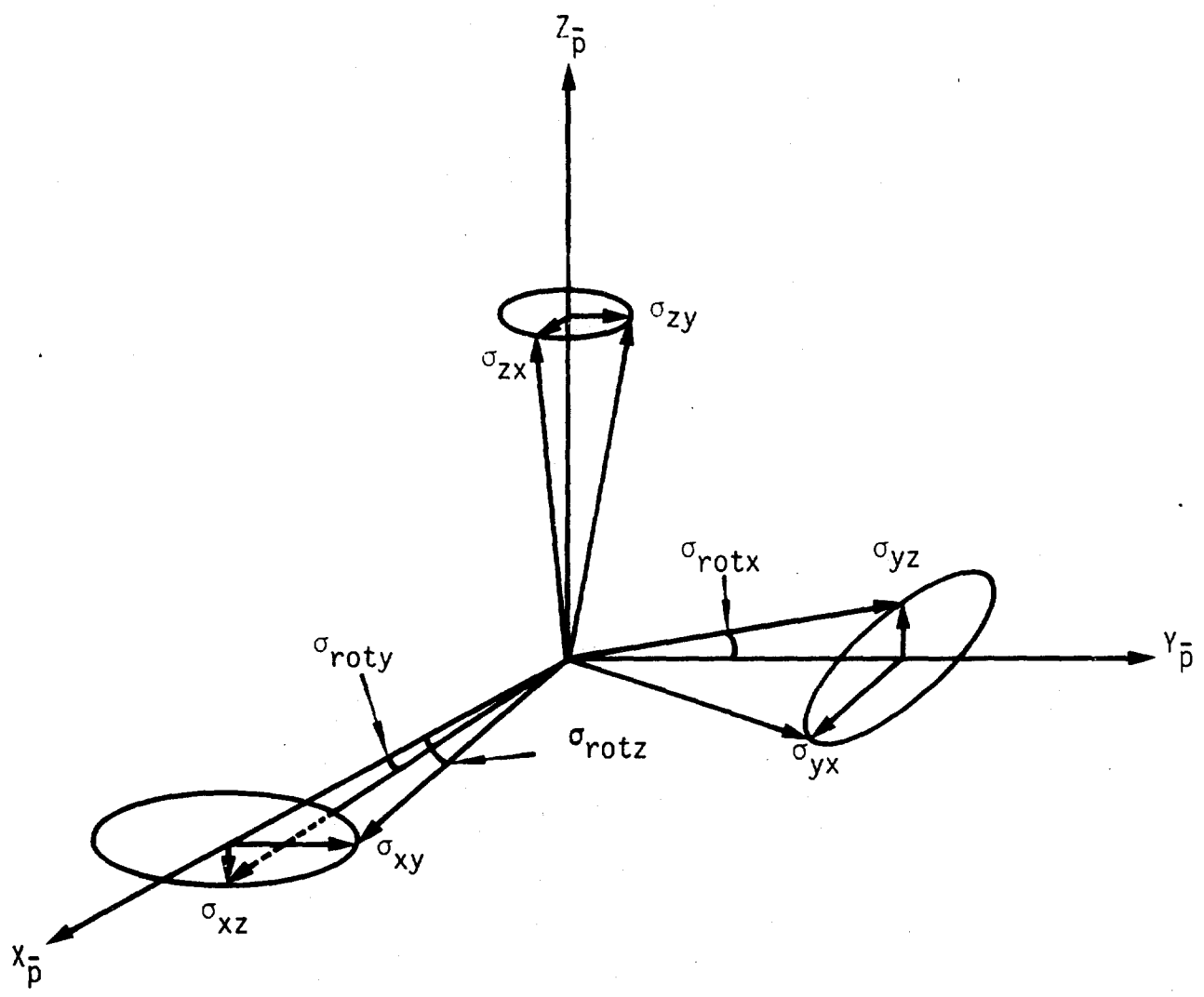


Figure B-3. Ellipsoidal cones depicting the standard deviation of individual principal axes about average principal axes.

Appendix C

SOURCE DATA AVAILABLE TO USERS

The material presented in the main body of this report is statistical and was obtained from data gathered from 31 subjects. The basic data used in compiling these results consisted of both directly measured and stereophotometrically derived body parameters. In the latter category a number of dimensions and other body characterizing quantities were calculated and compiled. Some of these quantities were directly compiled for the 31 subjects and the statistical results presented in the main body of the report. Others were intermediate results or considered not to be central to the overall study objectives.

In all, fourteen tables of data were generated and compiled for each subject. These tables contain the following data:

TABLE 1:

Body landmarks, as listed in Figure 5 in the main text of this report, specified in the Global Axes X_G, Y_G, Z_G system.

TABLE 2:

The calculated volume, percentage of total body volume and center of volume with respect to the Global Axes X_G, Y_G, Z_G of the 24 body segments and the total body.

TABLE 3:

The principal moments of inertia taken with respect to the center of volume of the body segments and the total body.

TABLE 4:

The direction cosines and the equivalent angles specifying the segment Principal Axes X_p, Y_p, Z_p orientation with respect to the Global Axes X_G, Y_G, Z_G for the 24 segments and the total body.

TABLE 5:

The origins of the segment Anatomical Axes X_A, Y_A, Z_A with respect to the Global Axes X_G, Y_G, Z_G for the 24 segments and the total body. The total body Anatomical Axes X_A, Y_A, Z_A system is taken to coincide with that defined for the pelvis.

TABLE 6:

The direction cosines and the equivalent angles specifying the segment Anatomical Axes X_A , Y_A , Z_A orientation with respect to the Global Axes X_G , Y_G , Z_G for the 24 body segments and the total body. The total body Anatomical Axes X_A , Y_A , Z_A system is taken to coincide with that defined for the pelvis.

TABLE 7:

The landmarks specified in Table 1 of this list are associated with a segment and the Anatomical Axes X_A , Y_A , Z_A origins are given in the segment Principal Axes X_p , Y_p , Z_p system for that respective segment the origin of which is at the segment volume center for the 24 body segments and the total body. Landmarks which define the Anatomical Axes X_A , Y_A , Z_A for each segment are separately listed with each segment.

TABLE 8:

The centers of volume with respect to the total body Principal Axes X_p , Y_p , Z_p system for the 24 segments and the total body.

TABLE 9:

The origins of the segment Anatomical Axes X_A , Y_A , Z_A systems with respect to the total body Principal Axes X_p , Y_p , Z_p system for the 24 segments and the total body.

TABLE 10:

The landmarks specified in Table 1 of this list and associated with a segment and the centers of volume are given in the segment Anatomical Axes X_A , Y_A , Z_A system for each respective segment for the 24 body segments and the total body. Landmarks which define the Anatomical Axes X_A , Y_A , Z_A for each segment are separately listed for each segment.

TABLE 11:

The centers of volume with respect to the total body Anatomical Axes X_A , Y_A , Z_A system for the 24 segments and the total body.

TABLE 12:

The origins of the Anatomical Axes X_A , Y_A , Z_A with respect to the total body Anatomical Axes X_A , Y_A , Z_A for the 24 segments.

TABLE 13:

The direction cosines and the equivalent angles specifying the segment Anatomical Axes X_A, Y_A, Z_A orientation with respect to the segment Principal Axes X_p, Y_p, Z_p for the 24 body segments and the total body.

TABLE 14:

The inertia tensors taken with respect to the segment volume center and along the Global Axes X_G, Y_G, Z_G for the 24 body segments and the total body.

These data are on magnetic tape at the Air Force Aerospace Medical Research Laboratory and are available, upon request, to interested users.

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