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A MATHEMATICAL MODEL OF THE HUMAN BODY

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FOREWORD

This report was prepared by Ernest P. Hanavan, Jr., Captain, USAF in partial fulfillment of the requirements for the Master of Science Degree in Engineering at the USAF Institute of Technology in 1964. The topic was suggested by Donald D. Mueller, Captain, USAF, Crew Stations Branch, Human Engineering Division, Behavioral Sciences Laboratory, Aerospace Medical Research Laboratories, and fulfills a requirement under Project No. 7184, "Human Performance in Advanced Systems," Task No. 718405, "Design Criteria for Crew Stations in Advanced Systems." The work was initiated in June 1963 and was completed in August 1964.

Special acknowledgement is made to Captain Mueller, Crew Stations Branch, and to Mr. Charles E. Clauser, Anthropology Branch, Human Engineering Division, for their sincere interest, suggestions, and guidance throughout this study. Also, thanks are extended to Mr. H. T. E. Hertzberg and Mr. M. Alexander, Anthropology Branch, for their many suggestions and literature guidance.

This technical report has been reviewed and is approved.

WALTER F. GRETHER, PhD
Technical Director
Behavioral Sciences Laboratory

ABSTRACT

A mathematical model for predicting the inertial properties of a human body in various positions has been developed. Twenty-five standard anthropometric dimensions are used in the model to predict an individual's center of gravity, moments and products of inertia, principal moments, and principal axes. The validity of the model was tested by comparing its predictions with experimental data from 66 subjects. The center of gravity was generally predicted within 0.7 inches and moments of inertia within 10 percent. The principal vertical axis was found to deviate from the longitudinal axis of the body by as much as 50 degrees, depending on the body position assumed. A generalized computer program to calculate the inertial properties of a subject in any body position is presented. The inertial properties of five composite subjects in each of 31 body positions is offered as a design guide. IBM 7094 digital computer programs are appended.

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I. Introduction

Subject

The subject of this study is the inertial properties of the human body. These inertial properties are:

a. the location of the center of mass

b. the moments of inertia and products of inertia about axes through the center of mass

c. the principal moments of inertia about the principal axes through the center of mass

d. the orientation of the principal axes

Center of gravity is used interchangeably with center of mass in this study.

Purpose

The purpose of this study is to design a mathematical model to predict the inertial properties of the human body in any fixed body position and to use this mathematical model to develop a design guide. The design guide can be used to establish preliminary design specifications requiring knowledge of the inertial properties of the human body in selected body positions.

Background

Without man, the exploration and utilization of space is meaningless. An analysis of man's ability to perform maintenance, supply, rescue, and operational tasks in the weightless environment of space is essential. An important factor in the performance of the orbital worker is his ability to move about at will from one position to another. Outside a space vehicle, this mobility can be provided by a personal propulsion device such as a Self-Maneuvering Unit (Ref 13: IV-18). Knowledge of the inertial properties of the human body in any body position is necessary to achieve the optimum design for such a unit.

Operation of the thrusters of a Self-Maneuvering Unit produces a rotational torque if the thrust vector does not pass through the center of mass of the system. Sometimes the thrust misalignment is caused by unbalanced thrust from several nozzles or from misaligned nozzles. This can occur when translational motion is commanded. At other times, the misaligned thrust is intentional, as when a change of pitch, roll, or yaw attitude is commanded.

If the torque is about a principal axis of the system, the rotation will be about the principal axis alone. The principal axes of a rigid body are those axes through the center of mass for which the products of inertia vanish (Ref 17: 88). A torque about a principal axis produces rotation about that axis alone. A torque about some axis other than a principal axis will produce rotation about more than one axis. This cross-coupling effect is caused by one or more of the products of inertia having values other than zero.

Cross-coupling wastes fuel and makes it more difficult for the stabilization unit to maintain body attitude. Therefore, it is essential that the principal axes of the system be known to achieve the optimum design of a Self-Maneuvering Unit. The first step in determining the principal axes of the system is to find the principal axes of the human body. Until now, no study has been made of the principal axes of the human body.

Braune and Fischer dissected three frozen cadavers and determined the centers of gravity and moments of inertia of the various body segments (Ref 3). Fischer later dissected another cadaver, increasing the sample to four (Ref 9). Dempster dissected eight cadavers and collected similar data during a study of the motion of the body limbs (Ref 5). Barter used the data gathered by Braune, Fischer, and Dempster to derive a set of regression equations for the weight of the body segments (Ref 1: 6). Swearingen determined the centers of gravity of living subjects in 67 different body positions (Ref 29). King investigated the locus of the center of gravity for a variety of body positions (Ref 22). Santschi, Du Bois, and Omoto determined the center of gravity and moments of inertia of 66 living subjects in eight selected body positions (Ref 27: 33-54).

Whitsett designed a mathematical model of the human body to analyze some dynamic response characteristics of weightless man (Ref 30: 2-9). Gray modified Whitsett's model and compared the results obtained using his model with the available experimental data (Ref 12: 31-36). Models of the human body have been used to analyze self-maneuvering for the orbital worker (Ref 28: 14-18), and self-rotation techniques for weightless man (Ref 24: 22-24). Other models were designed to assist in the development of zero-gravity propulsion devices (Ref 10: 19), and to analyze the feasibility of a Self-Maneuvering Unit for orbital maintenance workers (Ref 13: II 31-46).

Scope

This study is concerned with a personalized mathematical model of the human body based on an experimentally determined distribution of mass and the anthropometric data of the individual person. It is beyond the scope of this study to consider:

a. the assymetrical location of internal organs of the body

b. the variation of the inertial properties during a change of body position or a change of body weight

c. The variation of the inertial properties while the body is subjected to external forces which displace tissue from the rest position

Within these limitations, the mathematical model will predict the inertial properties of an individual person in any fixed body position.

Assumptions

The following assumptions have been made in the design of the mathematical model:

a. the human body can be represented by a set of rigid bodies of simple geometric shape and uniform density

b. the regression equations for segment weights are valid over the spectrum of body weight in the Air Force population

c. the limbs move about fixed pivot points when the body changes position

The first assumption is the essence of an analytical determination of the inertial properties of the human body using a mathematical model. The validity of the assumption is dependent upon the accuracy with which the model reproduces the inertial properties as determined by experimental tests.

The second assumption is dictated by current knowledge. Although the regression equations for segment weights are based on a limited sample, they represent the best source of information on the distribution of body weight.

The last assumption is made to simplify the configuration of the model. Very little quantitative information is available about the motion of the limbs since the joints of the body are extremely complex. For simplicity, fixed hinge points are chosen to represent the instantaneous centers of motion for the limbs.

Development

The problem of designing and evaluating a mathematical model of the human body is divided into four phases:

a. design of a personalized mathematical model

b. analysis of the model

c. description of a generalized computer program for calculation of the inertial properties of any subject in any body position

d. development of a design guide

The first phase is covered in Chapter II. A model is designed using the regression equations and anthropometric dimensions of the individual subject. Segment characteristics, length, radii, moments of inertia, center of gravity, and hinge point are defined.

In the second phase, the results obtained using the model are compared with experimental results (Ref 27: 33-54). The method of calculation and analysis of results, made with an IBM 7094 digital computer, are contained in Chapter III.

The third phase is described in Chapter IV. A generalized computer program is described which utilizes the model to determine the inertial properties of any subject in any body position.

The last phase is the development of a design guide in Chapter V. Five composite subjects are defined by using the fifth, twenty-fifth, fiftieth, seventy-fifth, and ninety-fifth percentile anthropometric dimensions of the Air Force flying population (Ref 15: 11-76). The inertial properties are calculated for 31 selected body positions.

II. The Model

Introduction

The personalized mathematical model is made up of 15 simple geometric solids numbered as indicated in Fig. 1. Each solid represents a segment of the body. These segments are:

1. head
2. upper torso
3. lower torso
4. right hand
5. left hand
6. right upper arm
7. left upper arm
8. right forearm
9. left forearm
10. right upper leg
11. left upper leg
12. right lower leg
13. left lower leg
14. right foot
15. left foot

The dimensions and properties of the body segments are calculated using the anthropometric dimensions of the individual subject. Thus, the model is truly personalized. These dimensions and properties are assigned brief symbols which will appear throughout this paper in capital letters. Stature is referred to as STAT. These symbols and their units are defined in Appendix B. When more than one segment can share the same symbol, the segment is identified by a subscript of the symbol. The segment weight of the lower torso is SW(3). The

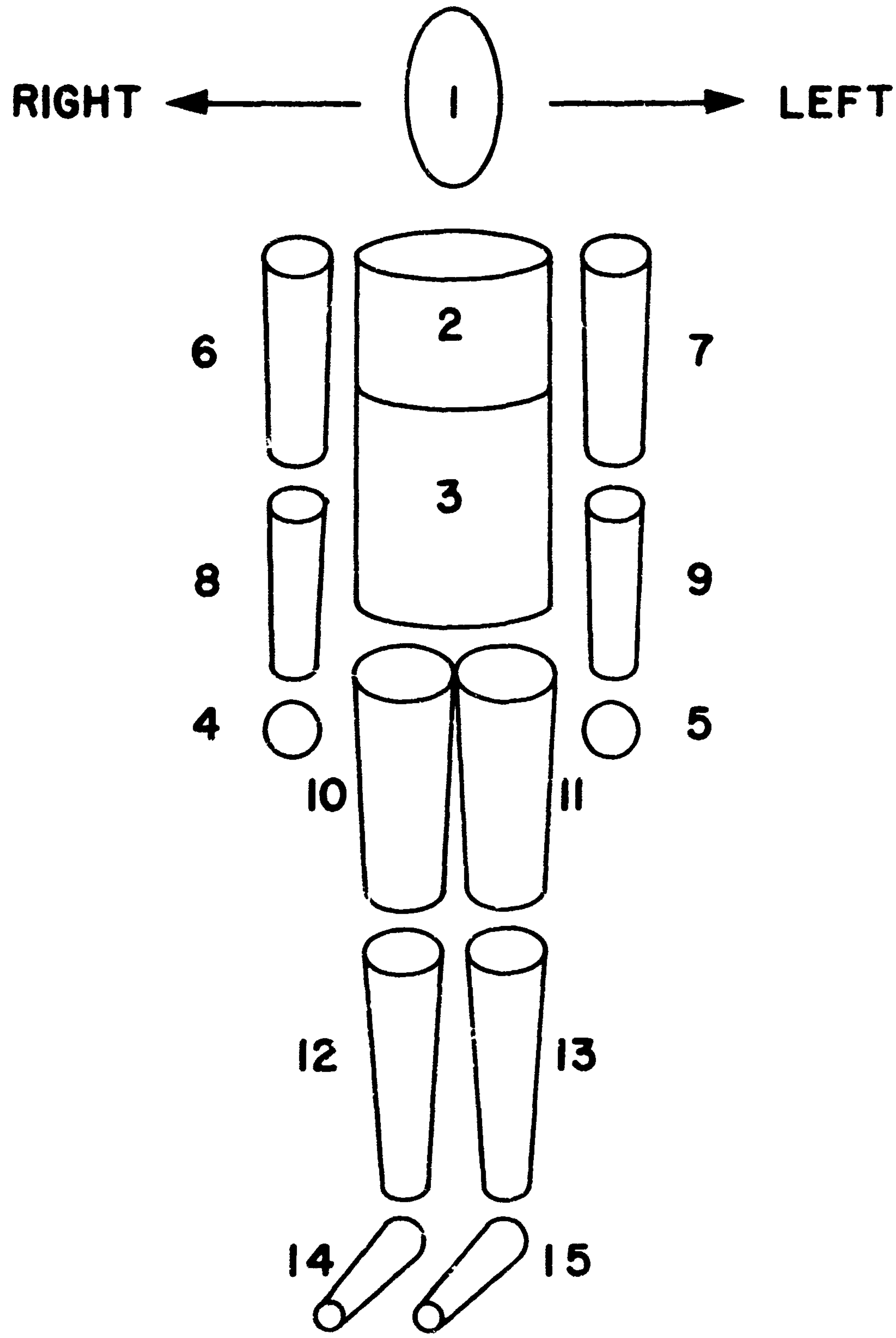


FIG. 1
THE MATHEMATICAL MODEL

subscripts correspond to the segment numbers in Fig. 1. The use of symbols and subscripts is in accordance with IBM FORTRAN programming practice (Ref 19). Inertial properties of the individual segments are calculated with respect to the center of mass of the segment. The coordinate system used is a right-handed Cartesian coordinate system whose origin is at the center of mass of the segment. The orientation of the axes of these coordinate systems is shown in the individual figures describing each segment. These figures are adjacent to the text describing the individual segment.

Body motion is restricted to motion of the arms and legs. The major consideration has been toward applications concerning manned operations in space where the limited mobility of a full pressure suit restricts motion of the head, upper torso, and lower torso. This does not affect the validity of the model. If mobility of these segments is desired, the computer programs can easily be modified to provide this mobility.

Anthropometric Dimensions

The anthropometric dimensions used in the design of the model were selected from those taken in the experimental study (Ref 27: 14). A total of 25 dimensions are needed to define the parameters of the model. These dimensions and the symbols used for them in the computer programs are listed in Table I. All dimensions are taken with standard anthropometric instruments in accordance with the descriptions

TABLE I

Anthropometric Dimensions

Symbol	Dimension
ANKC	Ankle Circumference
AXILC	Axillary Arm Circumference
BUTTD	Buttock Depth
CHESB	Chest Breadth
CHESD	Chest Depth
ELBC	Elbow Circumference
FISTC	Fist Circumference
FOARL	Forearm Length (Lower Arm Length)
FOOTL	Foot Length
GKNEC	Knee Circumference
HEADC	Head Circumference
HIPB	Hip Breadth
SHLDH	Shoulder Height (Acromial Height)
SITH	Sitting Height
SPHYH	Sphyrion Height
STAT	Stature
SUBH	Substernale Height
THIHC	Thigh Circumference
TIBH	Tibiale Height
TROCH	Trochanteric Height
UPARL	Upper Arm Length
W	Weight
WAISB	Waist Breadth
WAISD	Waist Depth
WRISC	Wrist Circumference

in Appendix A.

Regression Equations

The weight distribution among the segments of the model is determined by the regression equations devised by Barter (Ref 1: 6). The symbols used in the equations and their units are defined in Appendix B. The regression equations are:

$$HNT = .47\,W + 12.0 \tag{1a}$$

$$BUA = .08\,W - 2.9 \tag{1b}$$

$$BFO = .04\,W - 0.5 \tag{1c}$$

$$BH = .01\,W + 0.7 \tag{1d}$$

$$BUL = .18\,W + 3.2 \tag{1e}$$

$$BLL = .11\,W - 1.9 \tag{1f}$$

$$BF = .02\,W + 1.5 \tag{1g}$$

The calculated weight represented by the sum of these equations does not always equal the input body weight. To compensate for this small deviation, the difference is determined and then distributed proportionally over the segments. The calculated weight then is exactly equal to the input weight.

The per cent of body weight represented by each of the terms on the left side of Eq (1) is shown in Fig. 2 for body weights from 120 to 240 lb. The curves in Fig. 2 are based on the corrected segment weights.

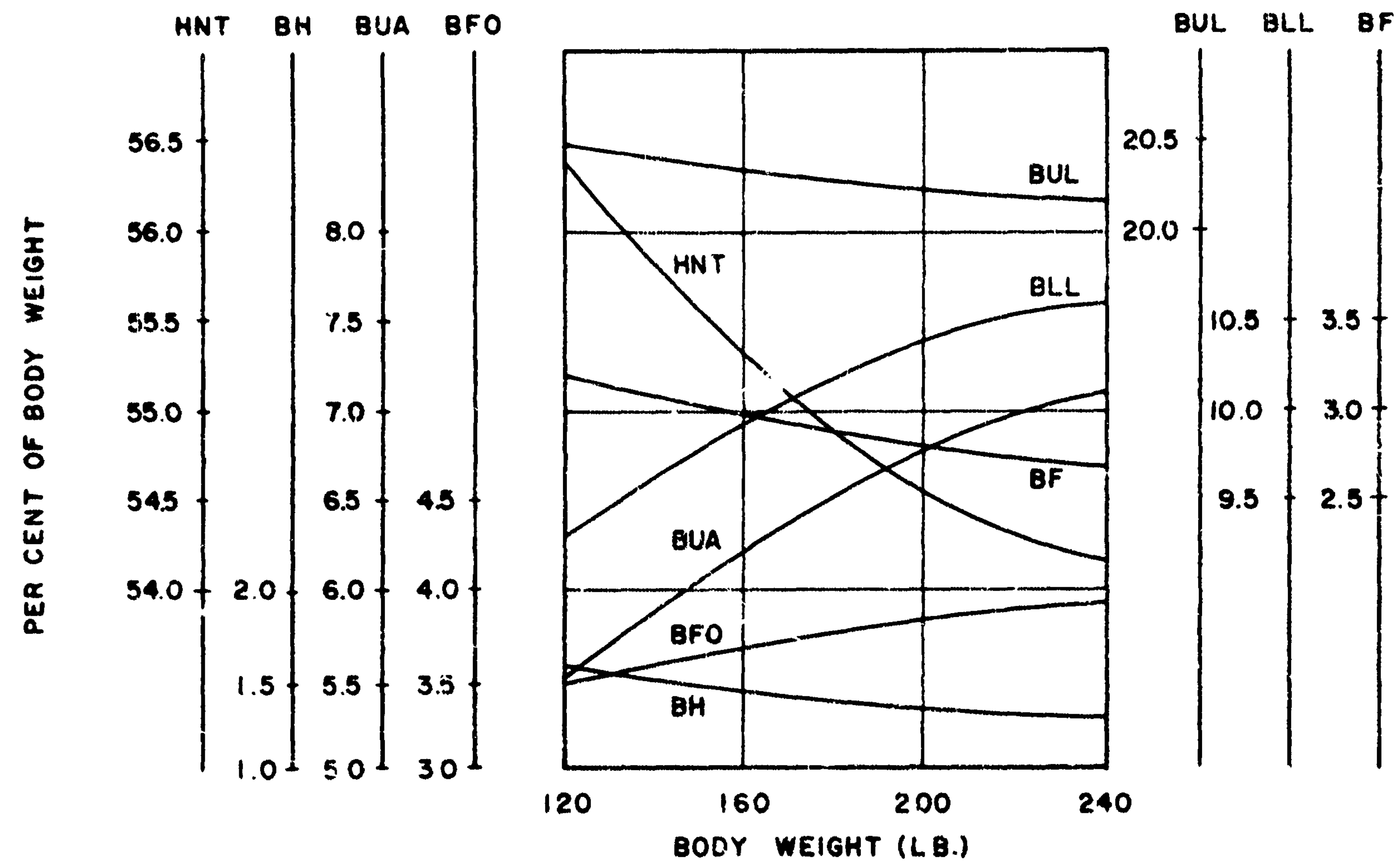


FIG. 2
DISTRIBUTION OF BODY WEIGHT

Head

The head of the model is a right circular ellipsoid of revolution as shown in Fig. 3. The cross section is a circle when the cutting plane is parallel to the X-Y plane and an ellipse when the cutting plane is perpendicular to the X-Y plane. The dimensions and properties of the head are:

$$R = .5\ (\ STAT - SHLDH\ ) \tag{2a}$$

$$RR = \frac{HEADC}{2\ PI} \tag{2b}$$

$$SL = (\ STAT - SHLDH\ ) \tag{2c}$$

$$ETA = .5 \tag{2d}$$

$$SW = .079\ W \tag{2e}$$

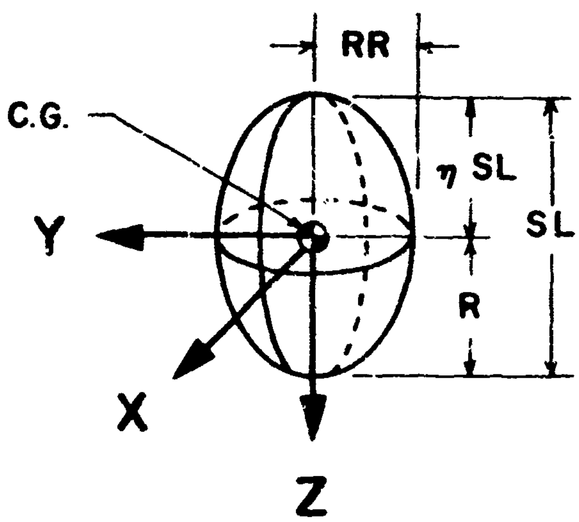


FIG. 3
HEAD OF MODEL

$$SM = SW/32.2 \tag{2f}$$

$$DELTA = \frac{SW}{4\ R\ (RR)^2} \tag{2g}$$

$$SIXX = .2\ SM\ (\ (R)^2 + (RR)^2\ ) \tag{2h}$$

$$SIYY = SIXX \tag{2i}$$

$$SIZZ = .4\ SM\ (RR)^2 \tag{2j}$$

Upper Torso

The upper torso of the model is a right elliptical cylinder as shown in Fig. 4. The cross section is an ellipse when the cutting plane is parallel to the X-Y plane. The total torso weight is obtained by subtracting the weight of the head, SW(1), from the weight of the head, neck, and trunk. The weight of the upper torso is calculated by splitting

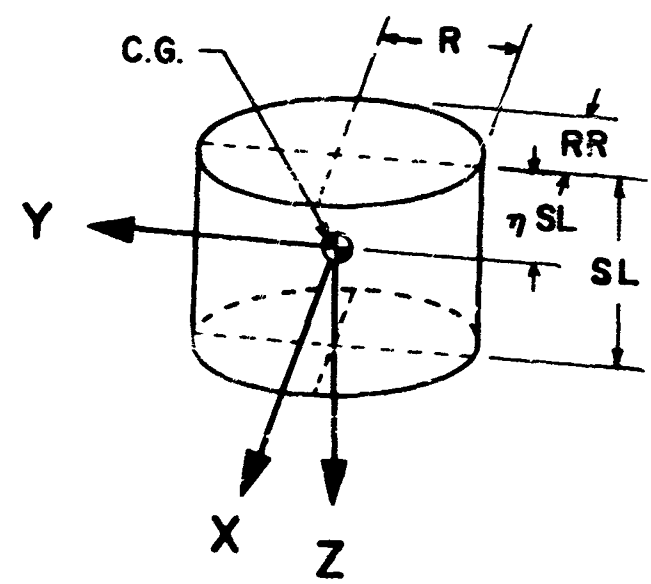


FIG. 4
UPPER TORSO OF MODEL

the total torso weight between the upper and lower torso according to the ratio of the densities of the two segments (Ref 5: 195). The dimensions and properties of the upper torso are:

$$R = .5\ CHESB \quad (3a)$$

$$RR = .25\ (\ CHESD + WAISD\ ) \quad (3b)$$

$$SL = SHLDH - SUBH \quad (3c)$$

$$ETA = .5 \quad (3d)$$

$$v_2 = \text{upper torso volume} = PI\ R\ RR\ SL \quad (3e)$$

$$v_3 = \text{lower torso volume} \quad (3f)$$

$$DELTA = \frac{HNT - SW(1)}{v_2 + \frac{1.01}{.92} v_3} \quad (3g)$$

$$SW = DELTA\ v_2 \quad (3h)$$

$$SM = SW/32.2 \quad (3i)$$

$$SIXX = SM\ (\ 3(R)^2 + (SL)^2\ ) \quad (3j)$$

$$SIYY = SM\ (\ 3(RR)^2 + (SL)^2\ ) \quad (3k)$$

$$SIZZ = SM\ (\ (R)^2 + (RR)^2\ ) \quad (3l)$$

Lower Torso

The lower torso of the model is a right elliptical cylinder as shown in Fig. 5. The cross section is an ellipse when the cutting plane is parallel to the X-Y plane. The dimensions and properties of the lower torso are:

$$R = .5\ HIPB \quad (4a)$$

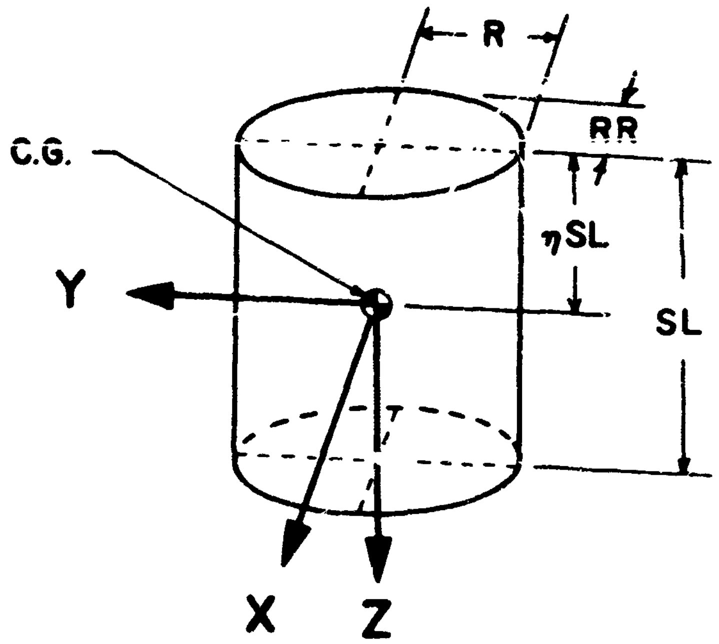


FIG. 5
LOWER TORSO OF MODEL

$$RR = .25 \ (\ WAISD + BUTTD \ ) \qquad (4b)$$

$$SL = SITH - (\ STAT - SUBH \ ) \qquad (4c)$$

$$ETA = .5 \qquad (4d)$$

$$v_3 = \text{lower torso volume} = PI \ R \ RR \ SL \qquad (4e)$$

$$SW = HNT - SW(1) - SW(2) \qquad (4f)$$

$$SM = SW/32.2 \qquad (4g)$$

$$DELTA = \frac{SW}{PI \ R \ RR \ SL} \qquad (4h)$$

$$SIXX = SM \ (\ 3(R)^2 + (SL)^2 \ ) \qquad (4i)$$

$$SIYY = SM \ (\ 3(RR)^2 + (SL)^2 \ ) \qquad (4j)$$

$$SIZZ = SM \ (\ (R)^2 + (RR)^2 \ ) \qquad (4k)$$

Hand

The hand of the model is a sphere as shown in Fig. 6. The dimensions and properties of the hand are:

$$R = \frac{FISTC}{2\ PI} \tag{5a}$$

$$RR = R \tag{5b}$$

$$SL = 2\ R \tag{5c}$$

$$ETA = .5 \tag{5d}$$

$$SW = .5\ BH \tag{5e}$$

$$SM = SW/32.2 \tag{5f}$$

$$DELTA = \frac{3\ SW}{4\ PI\ (R)^3} \tag{5g}$$

$$SIXX = .4\ SM\ (R)^2 \tag{5h}$$

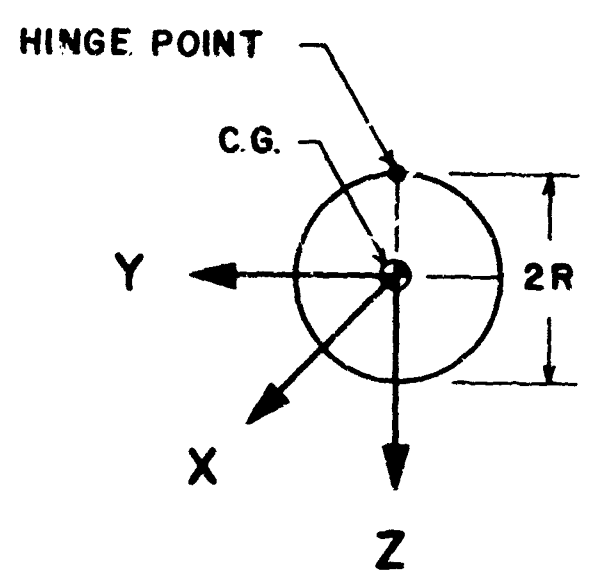


FIG. 6
HAND OF MODEL

SIYY = SIXX (5i)

SIZZ = SIXX (5j)

<u>Upper Arm</u>

The upper arm is a frustum of a right circular cone as shown in Fig. 7. The cross section is a circle when the cutting plane is parallel to the X-Y plane. The dimensions and properties of the upper arm are:

$$R = \frac{AXELC}{2\ PI} \tag{6a}$$

$$RR = \frac{ELBC}{2\ PI} \tag{6b}$$

$$SL = UPARL \tag{6c}$$

$$SW = .5\ BUA \tag{6d}$$

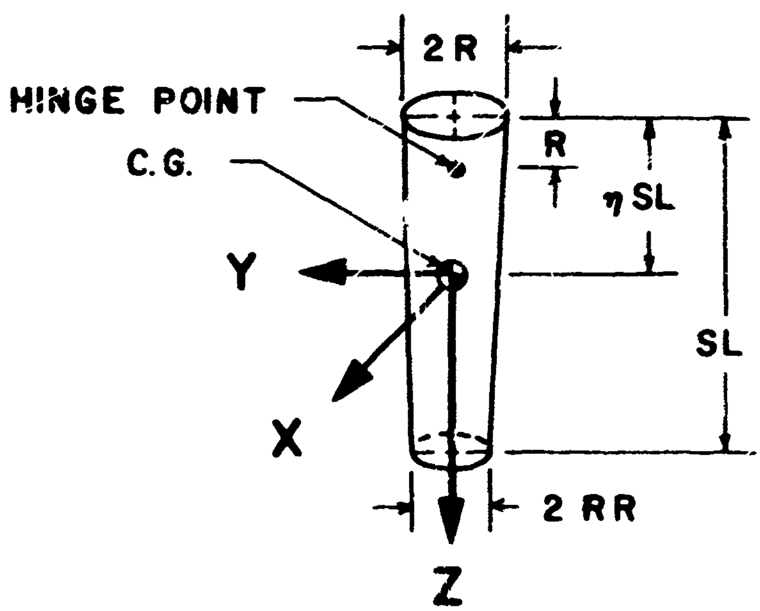


FIG. 7
UPPER ARM OF MODEL

$$SM = SW/32.2 \tag{6e}$$

Since the upper arm and the remaining segments of the model are frusta of right circular cones, the properties of each are described together in a later section.

Forearm

The forearm of the model is a frustum of a right circular cone as shown in Fig. 8. The cross section is a circle when the cutting plane is parallel to the X-Y plane. The dimensions and properties of the forearm are:

$$R = ELBC \tag{7a}$$

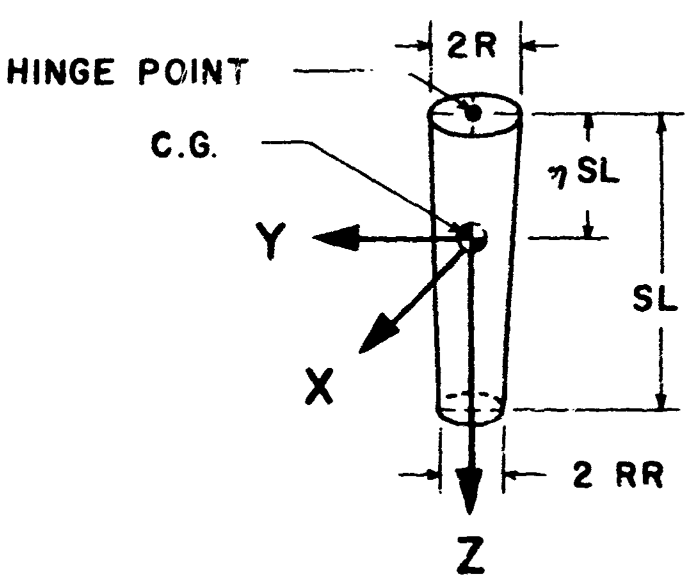


FIG. 8
FOREARM OF MODEL

$$RR = \frac{WRISC}{2\ PI} \tag{7b}$$

$$SL = FOARL \tag{7c}$$

$$SW = .5\ BFO \tag{7d}$$

$$SM = SW/32.2 \tag{7e}$$

Upper Leg

The upper leg of the model is a frustum of a right circular cone as shown in Fig. 9. The cross section is a circle when the cutting plane is parallel to the X-Y plane. The dimensions and properties of the upper leg are:

$$R = \frac{THIHC}{2\ PI} \tag{8a}$$

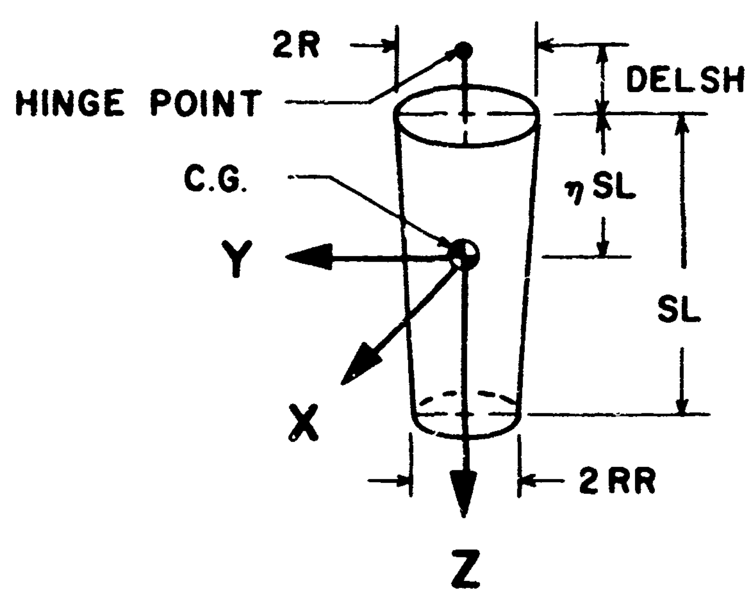


FIG. 9
UPPER LEG OF MODEL

$$RR = \frac{GKNEC}{2\ PI} \qquad (8b)$$

$$SL = STAT - SITH - TIBH \qquad (8c)$$

$$DELSH = SITH - (\ STAT - TROCH\ ) \qquad (8d)$$

$$SW = .5\ BUL \qquad (8e)$$

$$SM = SW/32.2 \qquad (8f)$$

Lower Leg

The lower leg of the model is a frustum of a right circular cone as shown in Fig. 10. The cross section is a circle when the cutting plane is parallel to the X-Y plane. The dimensions and properties of the

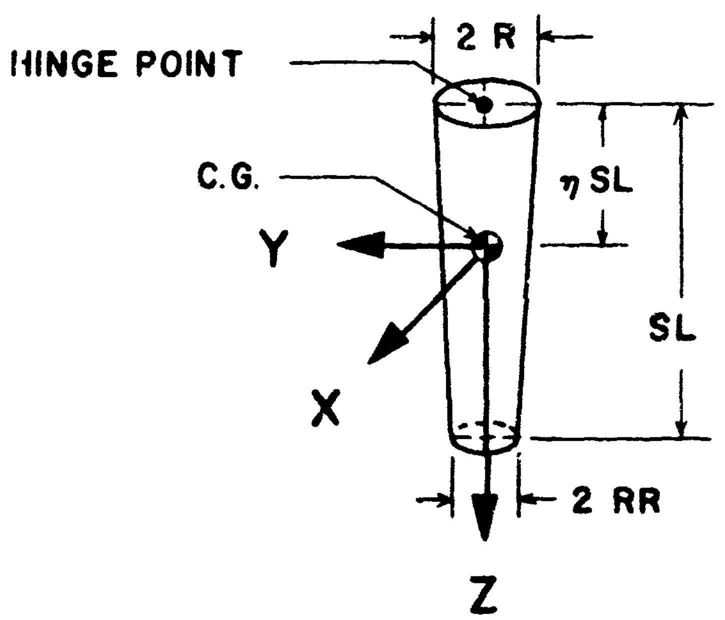


FIG. 10
LOWER LEG OF MODEL

lower leg are:

$$R = \frac{GKNEC}{2\ PI} \qquad (9a)$$

$$RR = \frac{ANKC}{2\ PI} \qquad (9b)$$

$$SL = TIBH - SPHYH \qquad (9c)$$

$$SW = .5\ BLL \qquad (9d)$$

$$SM = SW/32.2 \qquad (9e)$$

Foot

The foot of the model is a frustum of a right circular cone as shown in Fig. 11. The cross section is a circle when the cutting plane is parallel to the X-Y plane. The dimensions and properties of the

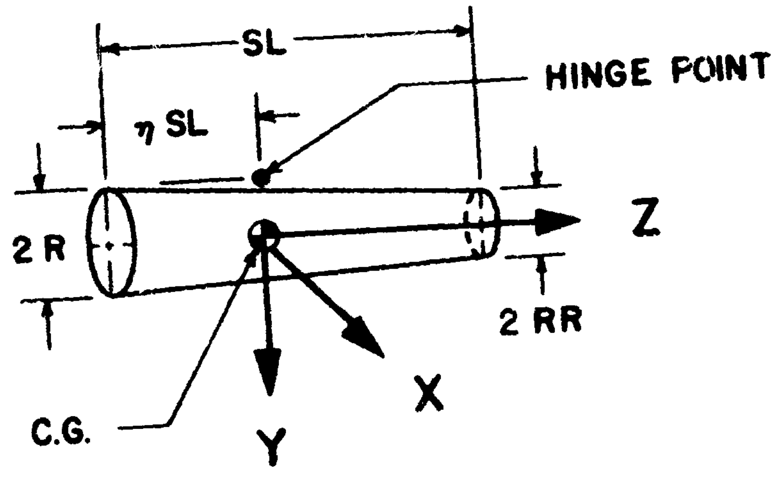


FIG. 11
FOOT OF MODEL

foot are:

$$R = .5\ SPHYH \tag{10a}$$

$$SL = FOOTL \tag{10b}$$

$$ETA = .429 \tag{10c}$$

$$SW = .5\ BF \tag{10d}$$

$$SM = SW/32.2 \tag{10e}$$

The small radius, RR, is such that the center of gravity of the foot is located at a distance of .429 SL from the larger end.

Conical Segment Properties

The upper arms, forearms, upper legs, lower legs, and feet are frusta of right circular cones. These segments have properties given by a common set of formulae:

$$DELTA = \frac{3\ SW}{SL\ (\ (R)^2 + R\ (RR) + (RR)^2\ )\ PI} \tag{11a}$$

$$MU = \mu = RR/R \tag{11b}$$

$$SIGMA = \sigma = 1 + \mu + \mu^2 \tag{11c}$$

$$ETA = \frac{1 + 2\mu + 3\mu^2}{4\sigma} \tag{11d}$$

$$AA = \frac{9}{20\ PI}\ \frac{1 + \mu^2 + \mu^3 + \mu^4}{\sigma^2} \tag{11e}$$

$$BB = \frac{3}{80}\ \frac{1 + 4\mu + 10\mu^2 + 4\mu^3 + \mu^4}{\sigma^2} \tag{11f}$$

$$SIXX = \frac{AA\ (SM)^2}{DELTA\ SL} + BB\ SM\ (SL)^2 \tag{11g}$$

$$SIYY = SIXX \tag{11h}$$

$$SIZZ = \frac{2\ AA\ (SM)^2}{DELTA\ SL} \tag{11i}$$

Detailed derivation of these formulae is presented in Appendix C.

<u>Hinge Points and Sockets</u>

The model has articulated extremities. Each of the moveable segments moves about an instantaneous center of motion defined by a hinge point and a socket. The hinge point is in the moving segment or attached to it by a massless extension. The socket is in the adjacent segment or attached to it by a massless extension. The hinge point acts like a ball joint, moving within the socket.

The hinge point of the hand is indicated in Fig. 6. The socket for the hand hinge point is located at the lower end of the forearm, on the center line, where the radius of the cross section is RR.

The hinge point of the upper arm is indicated in Fig. 7. The socket for the upper arm hinge point is external to the upper torso in the Y-Z plane of the upper torso. It is located at a distance, R(6), from the top of the upper torso and at the same distance from the side of the upper torso.

The hinge point of the forearm is indicated in Fig. 8. The socket for the forearm hinge point is located at the lower end of the upper arm, on the center line, where the radius of the cross section is RR.

The hinge point of the upper leg is indicated in Fig. 9. The socket for the upper leg hinge point is internal to the lower torso in the Y-Z plane of the lower torso. It is located at a distance, DELSH, from the bottom of the lower torso, and at a distance, R(10), from the side of the lower torso.

The hinge point of the lower leg is indicated in Fig. 10. The socket for the lower leg hinge point is located at the lower end of the upper leg, on the center line, where the radius of the cross section is RR.

The hinge point of the foot is indicated in Fig. 11. The socket for the foot hinge point is located at the lower end of the lower leg, on the center line, where the radius of the cross section is RR.

Euler Angles

Body position is described by specifying two Euler angles for each of the moveable segments of the body. No Euler angles are needed for the head, upper torso, and lower torso since these segments are not allowed to move. Two Euler angles are sufficient because the moveable segments are volumes of revolution and are therefore symmetrical about their longitudinal axis. The two angles, elevation and azimuth, define the orientation of the segments with respect to the torso. The sense of these angles is shown in Fig. 12. The elevation angle, THETA(I, 1), varies from 0 to 180 degrees. The azimuth angle, THETA(I, 2), varies from 0 to 360 degrees. These angles determine the transformation matrix which relates the local coordinate system of

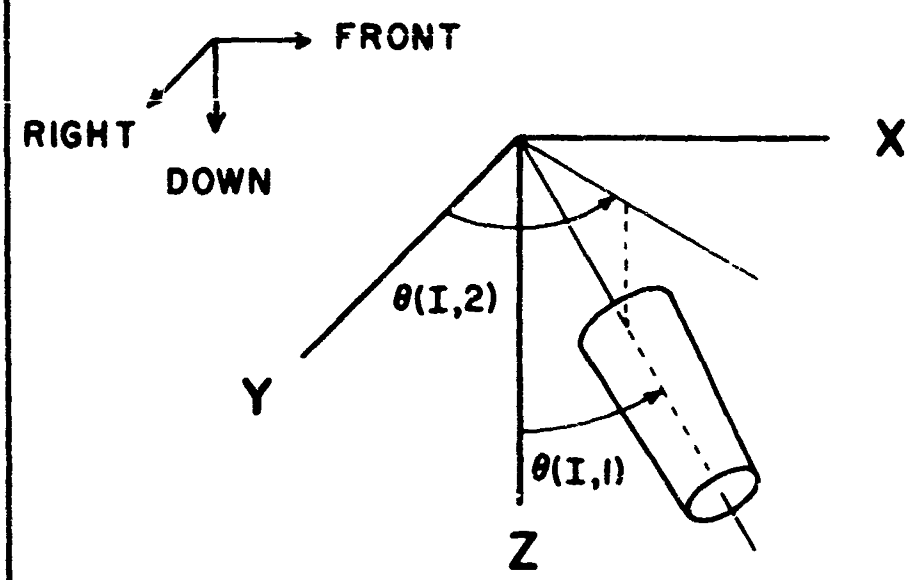


FIG. 12
EULER ANGLES

each segment to the body coordinate system at the center of mass of the body.

<u>Summary</u>

The personalized mathematical model is made up of 15 simple geometric solids. The dimensions and properties of the body segments are calculated using the anthropometric dimensions of the individual subject. The weight distribution among the segments of the model is determined by regression equations based on experimental results. The model has articulated extremities, allowing these segments full range of movement. Body position is described by a pair of Euler angles for each of the moveable segments.

III. Analysis of Model

Introduction

The essence of an analytical determination of the inertial properties of the human body using a mathematical model is the assumption that the human body can be represented by a set of rigid bodies of simple geometric shape and uniform density. The properties and parameters of the model were explained in Chapter II. Proof of the validity of the assumption lies in an analysis of the results achieved with the mathematical model compared to experimental data.

The experimental data, with which the mathematical model results are compared, was collected by North American Aviation under contract from the 6570th Aerospace Medical Research Laboratories. In addition, a second study conducted under another contract to North American Aviation provides data for a supplementary comparison of results.

The analysis of the model is divided into six sections:

a. N. A. A. body positions

b. N. A. A. axes

c. N. A. A. data

d. computer program MODEL

e. comparison of results

f. supplementary comparison of results

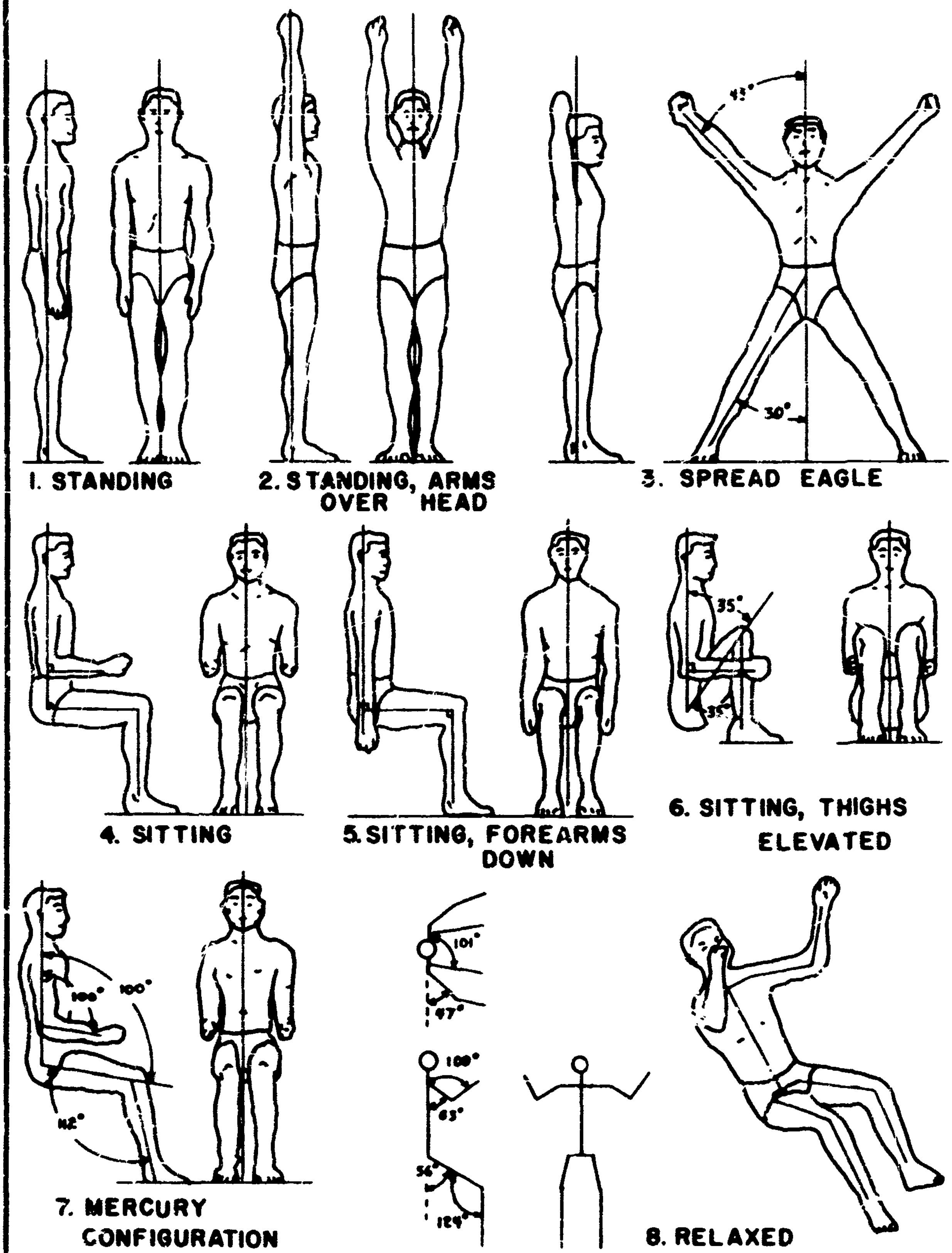


FIG. 13

BODY POSITIONS FOR N.A.A. STUDY

(FROM REF 27:9)

N. A. A. Body Positions

The eight body positions used by North American Aviation in the experimental study are shown in Fig. 13. A complete description of the positions is contained in Appendix D (Ref 27: 8). Position six, sitting with thighs elevated, is a difficult position for a subject to assume. The buttocks tend to move forward, away from the back plane, as the legs are raised, and the lower part of the spine follows this motion by curving forward. It is doubtful that this position has a very high degree of reproducibility or accuracy. Position eight, the relaxed position, is not adequately defined for use in an analytical study. The relationship between the upper arm and the forearm is not completely described, hence the position can not be considered in this study.

N. A. A. Axes

The axis system selected by North American Aviation is a right-handed Cartesian coordinate system. The axes are shown in Fig. 14. This system is similar to the coordinate system generally used in aircraft stability and control analysis. The X location of the center of gravity, XNAA, is measured along the X-axis from the back plane (Ref 27: 7). The Y location of the center of gravity, YNAA, is measured along the Z-axis from the top of the head. Center of gravity calculations for the model are made in this coordinate system to simplify comparison of results between the model and the experimental data.

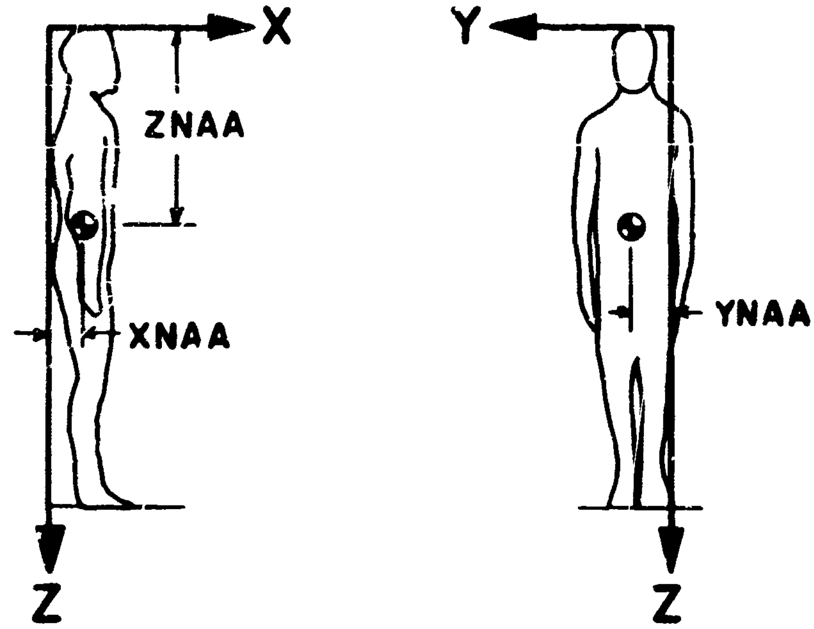


FIG. 14
N.A.A. AXES

N.A.A. Data

The North American Aviation study contains data on the centers of gravity and moments of inertia of 66 subjects in the 8 body positions. Fifty anthropometric dimensions of each subject are included. A total of 6468 data bits are presented (Ref 27: 33-54). Only 25 of the anthropometric dimensions of each subject are required to design the personalized mathematical model of each subject.

One of the measurements, BIACD, was not taken correctly and can not be used. Several individual errors in measurement or recording are apparent upon close examination of the data. Discovery of these errors made it advisable to check the remaining data thoroughly before using it to evaluate the accuracy of the mathematical model. The center of gravity and moment of inertia data were analyzed by a special computer program. Compatibility of the data bits was checked by a series of 60 comparison tests. A total of 3960 individual comparisons were made and 18 failures were noted. The measurement and compatibility failures are recorded for permanent reference.

Computer Program MODEL

The analysis of the mathematical model is accomplished by an IBM 7094 digital computer program, MODEL. This original program uses the design of the mathematical model to calculate the inertial properties of the 66 subjects in 7 body positions. Seventeen major designs and innumerable minor design modifications were tried during development of the final design of the mathematical model. The computer program is written in FORTRAN II language (Ref 18 and 19), but it has also been translated into FORTRAN IV language (Ref 20 and 21). A listing of the program in FORTRAN II is given in Appendix E. MODEL consists of a main program and seven subroutines. The main program controls the flow of information and logic. Each subroutine performs a step in determining the inertial properties or in comparing the results with the experimental data.

Main Program. The main program reads into the computer memory the input data for the subjects, one at a time. The subroutines are called in the proper order to calculate the inertial properties for the seven positions, in sequence. This process is repeated until the calculations have been made for all 66 subjects. An analysis of the results is then performed by SUBROUTINE ANALYZ.

SUBROUTINE DESIGN Total body weight is distributed among the body segments by the regression equations. The segment dimensions are calculated using the anthropometric dimensions. Segment center of gravity and moments of inertia are determined. Hinge points for the upper arms and upper legs are established. When execution of the subroutine is completed, control is returned to the main program.

SUBROUTINE EULER. Euler angles of the moveable segments are defined for the body position being considered. The sine and cosine of these angles are calculated. When execution of the subroutine is completed, control is returned to the main program.

SUBROUTINE MODMOM. Matrix methods are used to determine the location of the center of gravity of the body in the position being considered (Ref 26). Similarly, the moments and products of inertia, which form the inertia tensor, are calculated. The numerical differences and percentage differences between the experimental data and the calculated values are determined. These errors are arranged in an array for analysis by SUBROUTINE ANALYZ. SUBROUTINE EMMPY is called to perform matrix multiplication. SUBROUTINE EIGEN is called to calculate the principal moments of inertia, and to determine the orientation of the principal axes. When execution of the subroutine is completed, control is returned to the main program.

SUBROUTINE HMMPY. This subroutine is a modification of a standard matrix multiplication subroutine. Two matrices of three rows and three columns each are multiplied together. The result of this multiplication is returned to the routine which called SUBROUTINE HMMPY.

SUBROUTINE EIGEN. This subroutine is a modification of a special subroutine written by Mr. H. E. Petersen, Analysis Branch, Digital Computation Division, Research and Technology Division, Wright-Patterson Air Force Base, Ohio. The subroutine diagonalizes any real, symmetric matrix using the Jacoby method. The computation procedure is similar to that devised by Householder (Ref 16: 23-27). The eigenvalues and eigenvectors are calculated by making successive orthogonal transformations to reduce the off-diagonal terms to zero. The eigenvalues of the inertia tensor, which is a real, symmetric matrix, are the principal moments of inertia. The eigenvectors are the direction cosines of the principal axes.

The seven positions described in SUBROUTINE EULER have a plane of symmetry in the X-Z plane. The products of inertia, I_{xy} and I_{yz}, are both zero and the orientation of the principal axes is described by the angle, PSI, whose positive sense is indicated in Fig. 15. The principal axes, X'Y'Z', are related to the body axes, XYZ, by the angle PSI. In positions 1, 2, and 3 the Y-Z plane is also a plane of symmetry. In this case, the remaining product of inertia, I_{xz}, is also

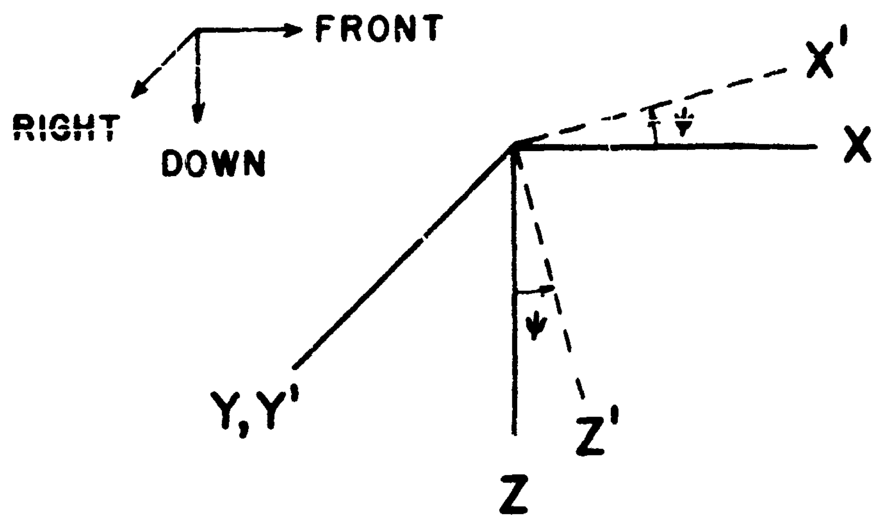


FIG. 15
PRINCIPAL AXES

zero, the moments of inertia already calculated are the principal moments, and the body axes are the principal axes. When execution of the subroutine is completed, control is returned to SUBROUTINE MODMOM.

SUBROUTINE OUTPUT. Experimental data, calculated values, numerical differences, percentage differences, principal moments, and direction angles of the principal axes are written on the normal output tape. Anthropometric dimensions, segment dimensions, and segment properties are written on another output tape, called the master tape. Output control parameters allow the user to select both, either, or neither of these two sets of output data. When the execution of the subroutine is completed, control is returned to the main program.

SUBROUTINE ANALYZ. The error array constructed in SUBROUTINE MODMOM is systematically scanned to produce a numerical histogram suitable for error analysis. The medians and averages are calculated. The histogram, the medians, and the averages are written on the normal output tape. When execution of the subroutine is completed, control is returned to the main program.

Comparison of Results

The results obtained using the mathematical model can be compared with the experimental data in these categories:

a. anthropologic parameters

b. center of gravity

c. moment of inertia about X-axis

d. moment of inertia about Y-axis

e. moment of inertia about Z-axis

Anthropologic Parameters. Two anthropologic parameters can be used as figures of merit for the mathematical model. They are the segment center of gravity location and the segment specific gravity.

A comparison of the segment center of gravity results for the 66 subjects is presented in Table II. The center of gravity location is expressed in per cent of segment length. The high, low, and average values for the model are shown with the experimental value obtained by

TABLE II

LOCATION OF CENTER OF GRAVITY[1]

BODY SEGMENT	MODEL			EXPERIMENT[2]
	HIGH	LOW	AVE	
HEAD AND TORSO	73.2	61.3	64.5	60.4
UPPER ARM	49.6	44.6	47.3	43.6
FOREARM	45.0	39.8	42.8	43.0
UPPER LEG	45.3	42.0	43.7	43.3
LOWER LEG	47.6	39.8	41.6	43.3

[1] DISTANCE FROM UPPER END IN % OF SEGMENT LENGTH

[2] FROM REF 5:194

dissection of cadavers (Ref 5: 194). No experimental data is available for the head, upper torso, or hand in the closed position. The foot is not included because the experimental value was used as an input in the design of the model. This was necessary to overcome a deficiency in anthropometric data for the foot in comparison with the data available for the other segments. The locations of the center of gravity of the segments represented by frusta of right circular cones are dependent solely on the geometry of the segment. The very small deviation between the model and the experimental results indicates that the shape and size of these segments approximate the body segment very well. The center of gravity of the head and torso combined is dependent mainly on the distribution of weight between the head and the torso. The results for the combination are very good in view of the fact that this parameter is difficult to determine experimentally.

The second figure of merit is the segment specific gravity. A comparison of the segment specific gravity results for the 66 subjects is presented in Table III. The specific gravity reflects the effect of the weight distribution from the regression equations and the size of the model segments. The segments which show the greatest deviation from the experimental data are the hand and the foot. These two segments are the weak segments of the model since the information used in their design is not as extensive as that used in the design of the other segments.

The average results are within approximately ten per cent of the

TABLE III

SPECIFIC GRAVITY OF BODY SEGMENTS

BODY SEGMENT	MODEL			EXPERIMENT[1]
	HIGH	LOW	AVE.	
HEAD	1.47	.90	1.15	1.11
UPPER TORSO	1.00	.72	.84	.92
LOWER TORSO	1.10	.80	.92	1.01
HAND	1.72	1.02	1.29	1.17
UPPER ARM	1.22	.79	.97	1.07
FOREARM	1.56	1.04	1.30	1.13
UPPER LEG	1.32	.88	1.13	1.05
LOWER LEG	1.44	.83	1.19	1.09
FOOT	2.14	1.12	1.62	1.09

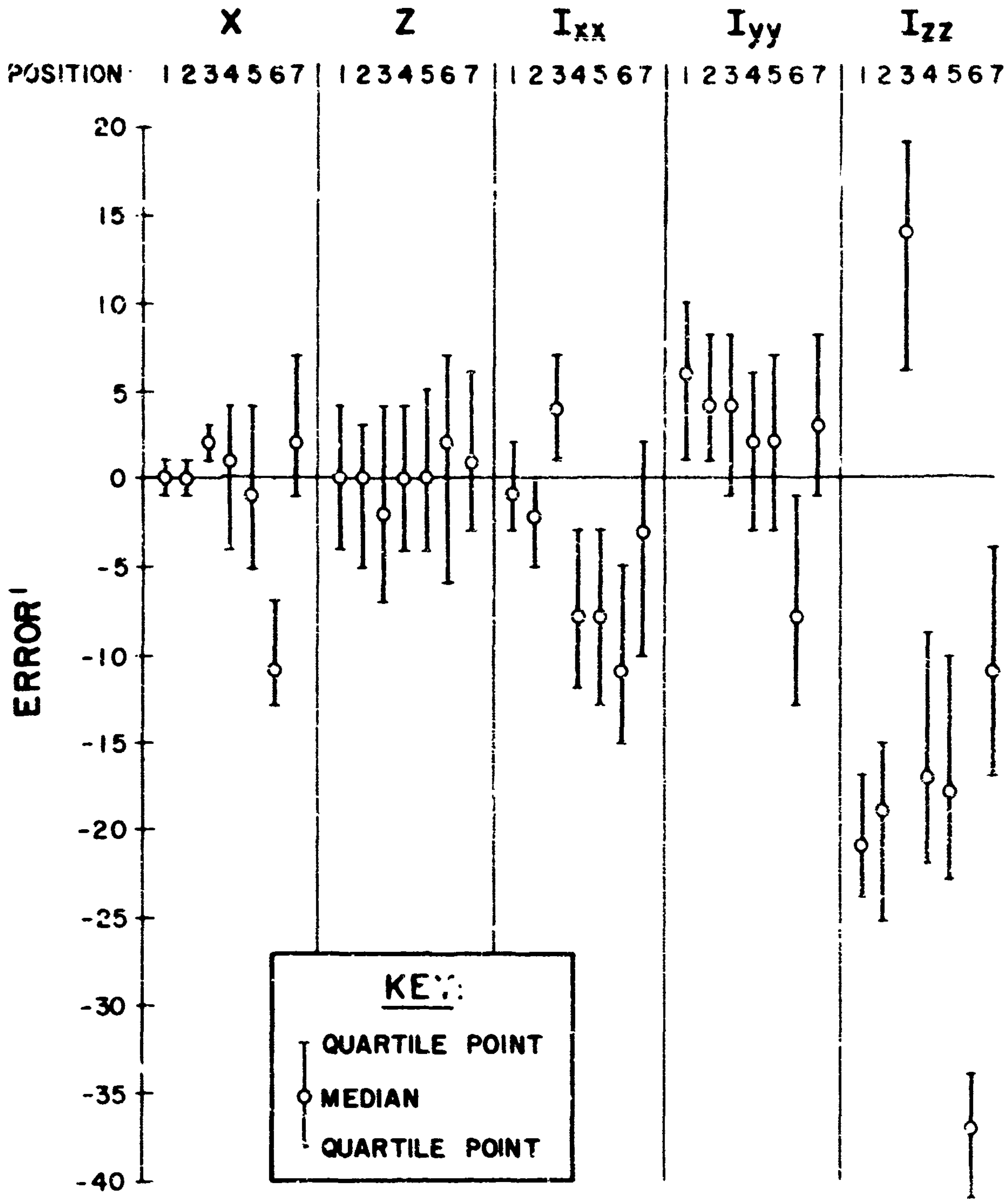
[1] FROM REF 5:195-196

experimental data. This is exceptionally good considering the number of parameters involved in the calculations and the assumptions of simple geometric shape and uniform density. The effect of irregularity of segment shapes, such as in the biceps, calves, and knees, can not be duplicated by a geometric solid of revolution which has a straight line as generatrix.

The larger error in the hand and foot does not affect the other calculations appreciably. The error is in the calculated segment volume which affects only the local moments of inertia. The contribution made by the local moments of inertia of the hand and foot is very small in comparison to the total moments of inertia of the body. It can be shown that the predominant factors in the body moments of inertia are the parallel axis transfer terms.

Center of Gravity. The comparison of center of gravity results can be divided into two sections. The North American Aviation study did not determine the Y location of the center of gravity by experiment, so only the X location and the Z location need be discussed. The error distribution for the seven positions is shown in Fig. 16. The median of the errors and the two quartile points are marked. Fifty per cent of the errors fall between the quartile points, by definition.

The X location of the center of gravity for position one is determined by a least squares curve fit of the experimental data based on WAISD as the independent variable. This is necessary



¹ C.G. ERROR IN TENTHS OF INCHES, MOMENT OF INERTIA ERROR IN % OF EXPERIMENTAL VALUE

FIG. 16

ERROR DISTRIBUTION (66 SUBJECTS)

because no information is available to locate the back plane with respect to an anthropometric landmark used in the study. Polynomials of degree 1 through 12 were tried and the first order equation proved to be the best. The X location for the remaining positions is calculated by perturbation techniques with respect to the standing position.

Examination of the calculated results and the pictures of the experimental apparatus (Ref 27: 17-20) reveal that the subjects were not restrained properly in position number three. The arms were secured against the back plane instead of having the wrist axes parallel to the Y-Z plane, as prescribed in the description of the position. This causes the values predicted by the model to be larger than the experimental data. This effect is evident in Fig. 16. The observation made earlier, about the difficulty of attaining position number six with a high degree of reproducibility or accuracy, is borne out by the results. The model conforms to the position exactly, but a human subject can not do so. The effect is that the predicted values are smaller than the experimental data. This can be seen in Fig. 16. Other than these discrepancies, one half of the predicted values generally falls within five tenths of an inch of the experimental data.

The Z location of the center of gravity is predicted by the model very well. No significant discrepancies appear in the results. One half of the predicted values generally falls within seven tenths of an inch of the experimental data.

Moment of Inertia About X-axis. The error distribution of I_{xx} is shown in Fig. 16. The median of the errors and the quartile points are marked. No significant discrepancies can be discerned from the results. One half of the predicted values generally falls within 10 per cent of the experimental data.

Moment of Inertia About Y-axis. The error distribution of I_{yy} is shown in Fig. 16. The median of the errors and the quartile points are marked. The effect of the error in predicting the X location of the center of gravity in position six is evident. The smaller predicted value for the X location of the center of gravity lowers the moment of inertia about the Y-axis. This makes I_{yy} smaller than the experimental data. Other than this discrepancy, one half of the predicted values falls within 10 per cent of the experimental data.

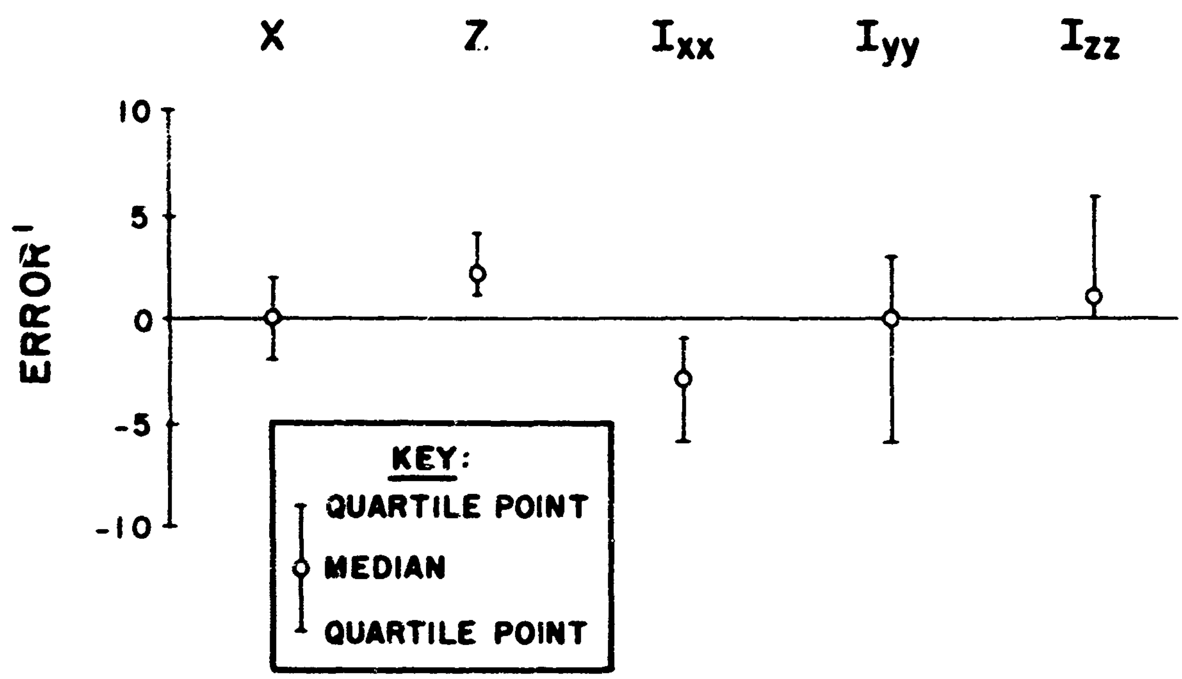
Moment of Inertia About Z-axis. The error distribution of I_{zz} is shown in Fig. 16. The median of the errors and the quartile points are marked. The effect of the error in predicting the X location of the center of gravity in positions 3 and 6 is evident. The error produced in the moment of inertia about the Z-axis follows the trend of the error in the X location of the center of gravity. In general, the errors in I_{zz} are markedly greater than the errors in the other moments of inertia. This is attributable to the fact that I_{zz} is generally an order of magnitude smaller than I_{xx} and I_{yy}. A small numerical error becomes a much larger percentage error. Other than the discrepancies noted, one half of the predicted values generally falls within 20 per cent of the experimental data.

Supplementary Comparison of Results

A second experimental study completed recently is the basis for a supplementary comparison of results. North American Aviation investigated the center of gravity location and moments of inertia of 19 subjects in the seated position (Ref 8). The primary purpose of the study was to determine the effect of a pressure suit on the inertial properties of the human body. Experimental runs were made with the subject nude, as well as in the pressure suit. The data from the runs with the subject nude can be compared with results using the mathematical model. Again, each subject's anthropometric dimensions are used to design a personalized mathematical model. A comparison of the results is presented in Fig. 17.

The center of gravity location, represented by X and Z, is comparable to the results achieved in the first study. One half of the predicted values falls within five tenths of an inch of the experimental data.

The moment of inertia results for I_{xx} and I_{yy} are also comparable to the results achieved in the first study The results for I_{zz}, however, are significantly different. The median error in the first study is about 15 per cent below the experimental data. The median error in the second study is nearly zero. The effect of an order of magnitude difference in I_{zz}, as compared to the other two moments of inertia, is



[1] C.G. ERROR IN TENTHS OF INCHES, MOMENT OF INERTIA ERROR IN % OF EXPERIMENTAL VALUE

FIG. 17

ERROR DISTRIBUTION (19 SUBJECTS)

again clear. The exact position of the body is critical when determining I_{zz}. Variation of position of body segments in the X direction affects I_{zz} directly. This small variation has a greater relative effect on I_{zz} than it has on X or I_{yy}. Careful scrutiny of the pictures of the experimental apparatus for the first study shows that the body positions were not held precisely (Ref 27: 19). The mathematical model, on the other hand, places the subject in the exact position desired. The results using the model are probably of comparable accuracy in I_{zz} as in the other two moments of inertia. The errors in experimental procedure obscure this accuracy since I_{zz} is much smaller than I_{xx} and I_{yy}.

Summary

The body positions and axes used by North American Aviation are discussed. Errors in measurement of anthropometric dimensions and compatibility errors in the experimental data are pointed out. Computer program MODEL is explained.

The segment center of gravity location and segment specific gravity for the model are very good. The weak segments are the hand and the foot. The center of gravity prediction generally falls within five tenths of an inch of the experimental data in the X direction and within seven tenths of an inch of the experimental data in the Z direction. The moment of inertia about the Z-axis, I_{zz}, is very sensitive to small variations in body position. It is generally an order of magnitude smaller than the other moments of inertia. The moments of inertia generally fall within 10 per cent of the experimental data. Supplementary comparison of results verifies these accuracies.

IV. Generalized Computer Program

Computer Program APMOD

The design of the mathematical model is incorporated into a generalized computer program, APMOD. The function of this program is to calculate the inertial properties of any human subject in any body position. The program is written in FORTRAN II for the IBM 7094 digital computer, but is also available in FORTRAN IV. A listing of the FORTRAN II program is given in Appendix F. A listing of the FORTRAN IV version is given in Appendix G. The program consists of a main program and six subroutines. The main program controls the flow of information and logic. Each subroutine performs a step in determining the inertial properties.

Input Data

Two output control parameters are read into the computer memory at the beginning of execution. The same type of output control is used in this program as was used in MODEL. The 25 anthropometric dimensions of a subject are read into memory from the input tape. The inertial properties are calculated from these dimensions. Approximately one second is required for execution of the calculation for each subject. New sets of data are called for until the list of subjects is exhausted. Lack of new data terminates execution.

Subroutines

The six subroutines used in APMOD are similar in form to the subroutines used in MODEL. The COMMON and DIMENSION statements have been altered because no experimental data are needed in this program. SUBROUTINE DESIGN performs the same functions in this program as the similar subroutine does in MODEL. SUBROUTINE EULER must be provided by the user. Memory space is allocated for seven body positions. The Euler angles for the moveable segments must be coded into executable statements like those in SUBROUTINE EULER of MODEL. SUBROUTINE MODMOM is similar in form to the subroutine in MODEL, but all calculations necessary to compare the results with experimental data have been deleted. The remaining functions of the subroutine are unaltered. SUBROUTINE HMMPY and SUBROUTINE EIGEN are identical to the subroutines used in MODEL. SUBROUTINE OUTPUT provides for normal output and master tape output under the control of output parameters. Normal output includes the location of the center of gravity, the moments and products of inertia, the principal moments, and the orientation of the principal axes. The master tape output includes the anthropometric dimensions, the segment dimensions, and the segment properties.

Summary

Computer program APMOD calculates the inertial properties of any human subject in any body position. The 25 anthropometric dimensions of the subject are used to calculate the inertial properties using the personalized mathematical model. Calculations can be made for any number of subjects in seven body positions specified by the user. Normal output and master tape output are provided under control of output parameters.

V. Design Guide

Introduction

The mathematical model is used to develop a design guide. The design guide can be used to establish preliminary design specifications requiring knowledge of the inertial properties of the human body in selected body positions. The design guide is intended to be a basic reference from which individual users can obtain approximate values of the inertial properties of the human body in selected body positions. An example of one use of the design guide has already been alluded to in the introduction to this study. The design of a Self-Maneuvering Unit requires knowledge of the inertial properties of the human body. The design guide provides inertial properties for the designer to use in optimizing the design of the unit to minimize cross-coupling.

Five composite subjects are defined by using the fifth, twenty-fifth, fiftieth, seventy-fifth, and ninety-fifth percentile anthropometric dimensions of the Air Force flying population (Ref 15: 11-76). The inertial properties of these composite subjects are calculated for 31 selected body positions.

Calculations are made by a computer program, GUIDE, written in FORTRAN II language for the IBM 7094 digital computer. A listing of this program is given in Appendix H. The program consists of a main program and four subroutines. The program is very similar to computer program, APMOD, described earlier. The main program, however, also produces the output, eliminating the need for a separate subroutine. SUBROUTINE DESIGN, SUBROUTINE EULER, and SUBROUTINE HMMPY perform the same functions as the corresponding subroutines in APMOD. SUBROUTINE MODMOM combines the functions of its counterpart subroutine in APMOD and SUBROUTINE EIGEN. This is possible because the positions being considered are symmetrical so that the principal moments of inertia can be calculated directly.

Input Data

The 25 anthropometric dimensions for the five composite subjects are obtained from the survey of the Air Force flying population (Ref 15). Some of the dimensions can not be obtained directly since they were not taken during the survey. These dimensions are calculated by regression equations using various dimensions from the survey as independent variables. The independent variables were chosen on the basis of high correlation factor and low value of standard deviation. Eight such regression equations are required to complete the set of anthropometric dimensions.

Different composite percentile subjects can be used in the computer program. Provision is made for making calculations on five composite subjects defined by percentile anthropometric dimensions. Should other percentiles, other than those selected for this study, be required, the appropriate anthropometric dimensions can be used. The five percentiles selected were chosen because they represent the spectrum of body sizes generally considered in the design of systems involving the human body.

Body Positions

The 31 body positions selected for the design guide are shown in Fig. 18. All positions have a plane of symmetry in the X-Z plane. The Euler angles required for each of the moveable segments are defined in the same manner as those used in computer program MODEL. The positive sense of these angles is indicated in Fig. 12. The angles are defined by executable statements of SUBROUTINE EULER in Appendix H.

The 31 body positions cover the regime of permissible positions of the body in a full pressure suit representative of the state of the art. The possible range of values of the moments of inertia are also covered, consistent with the limitation that the position must be realistic with respect to current pressure suit mobility. The six basic configurations of the upper half of the body are:

a. arms at attention
b. arms directly overhead
c. arms spread in cruciform position
d. arms extended in front of body
e. arms bent 90° at elbow, forearms in front of body
f. upper arms at shoulder level, forearms extended in front of body

The five basic configurations of the lower half of the body are:

a. standing

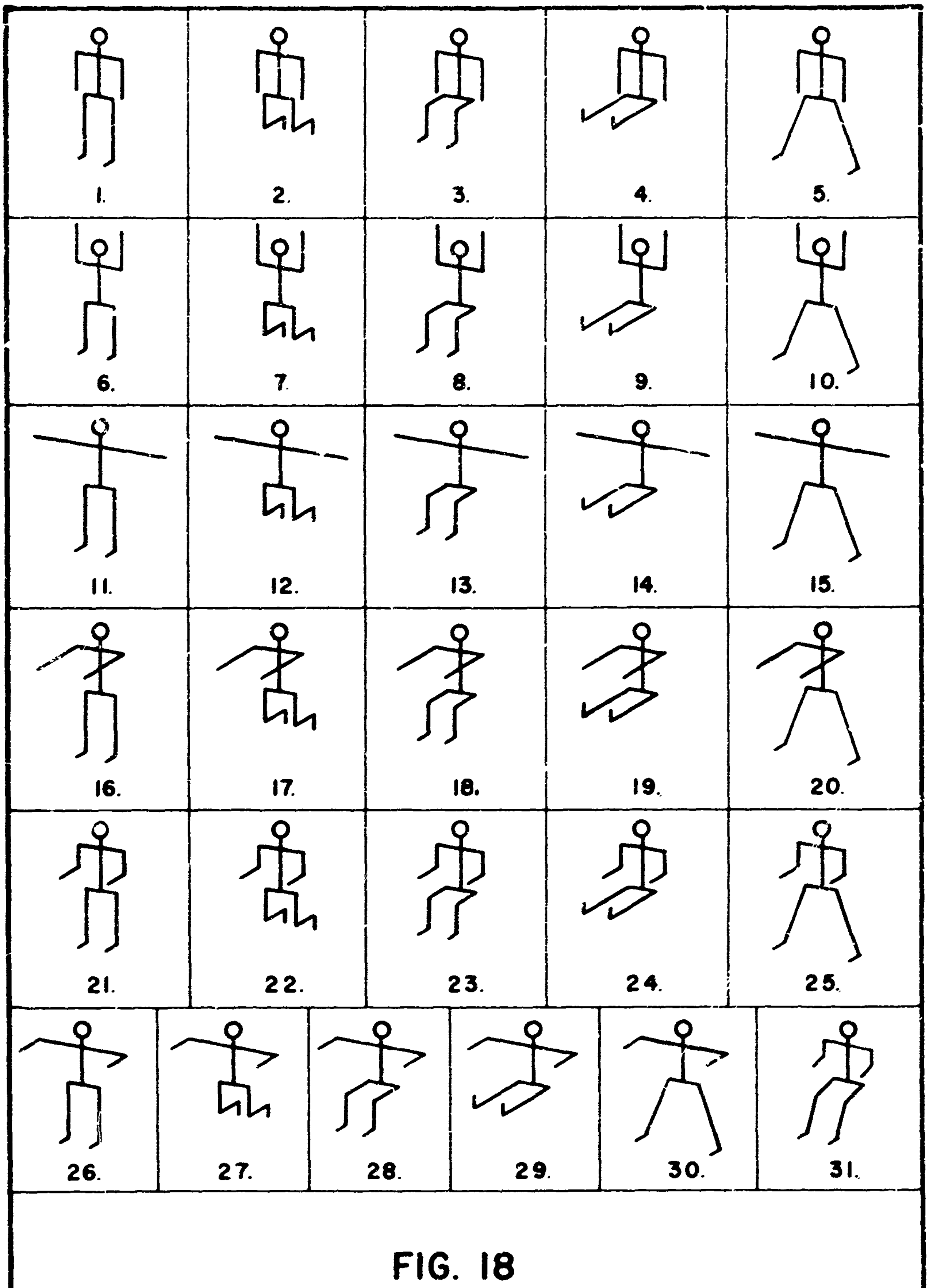


FIG. 18
BODY POSITIONS FOR DESIGN GUIDE

b. kneeling
c. sitting
d. sitting, legs extended forward
e. standing, legs at 30°

All combinations of the upper body and lower body configurations are included, making a total of 30 body positions. The last position is the Mercury configuration examined earlier (Ref 27: 8). The inertial properties of the five composite subjects are calculated for these 31 body positions.

Output Data

All output is written on the normal output tape. The output data include the anthropometric dimensions, the location of the center of gravity, the moments and products of inertia about axes through the center of gravity, the principal moments of inertia about the principal axes through the center of gravity, and the orientation of the principal axes. The output data is presented in Table IV.

The 25 anthropometric dimensions are arranged by percentile. The brief symbols for the anthropometric dimensions are defined in Appendix B. The center of gravity is described by X and Z, the location in the X direction and the Z direction, respectively. The center of gravity location in the X direction is measured from the back plane. The center of gravity location in the Z direction is measured from the top of the head. The axis system for these calculations is shown in Fig. 14.

The moments and products of inertia form the inertia tensor for the subject. The body positions selected for the design guide have a plane of symmetry in the X-Z plane. In this case, two of the products of inertia, I_{xy} and I_{yz}, are zero. The inertia tensor is then determined by the moments of inertia and the non-zero product of inertia, I_{xz}.

The orientation of the principal axes is conveniently described by a single angle, THETA. The positive sense of this angle, and the orientation of the principal axes are indicated in Fig. 15. The moments of inertia about the principal axes through the center of gravity complete the list of output data.

TABLE IV

ANTHROPOMETRIC DATA OF MODELS

	PERCENTILE				
	5	25	50	75	95
WEIGHT	132.5	148.7	161.9	176.6	200.3
STAT	65.2	67.5	69.1	70.7	73.1
SHLDH	52.8	55.0	56.6	58.0	60.2
SUBH	45.6	47.4	48.7	50.1	52.1
TROCH	32.6	35.0	36.1	37.3	39.0
TIBH	16.6	17.4	18.0	18.7	19.6
UPARL	12.7	13.1	13.5	13.8	14.4
FOARL	10.2	10.6	10.9	11.2	11.6
CHESD	8.0	8.6	9.0	9.6	10.4
WAISD	6.7	7.3	7.9	8.5	9.5
BUTTD	7.6	8.2	8.8	9.4	10.2
CHESB	10.8	11.5	12.0	12.5	13.4
WAISB	9.4	10.0	10.6	10.2	12.3
HIPB	12.1	12.7	13.2	13.7	14.4
AXILC	10.9	11.8	12.4	13.2	14.4
ELBC	9.9	10.5	10.9	11.4	12.0
WRISC	6.3	6.6	6.8	7.1	7.5
FISTC	10.7	11.2	11.6	11.9	12.4
THIHC	19.6	21.2	22.4	23.6	25.3
GKNEC	13.2	13.8	14.3	14.9	15.6
ANKC	8.1	8.6	8.9	9.3	9.8
SPHYH	2.7	2.8	2.9	3.1	3.2
FOOTL	9.8	10.2	10.5	10.8	11.3
SITH	33.8	35.1	36.0	36.8	38.0
HEADC	21.5	22.1	22.5	22.9	23.5

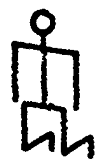
WEIGHT IN LB., DIMENSIONS IN INCHES.

POSITION 1

1.

	C.G.		INERTIA TENSOR					PRINCIPAL MOMENTS		
O/C	X	Z	IXX	IYY	IZZ	IXZ	THETA	IXX	IYY	IZZ
5	3.16	29.9	6.44	6.14	0.45	0.	-0.	6.44	6.14	0.45
25	3.26	30.8	7.85	7.46	0.57	0.	-0.	7.85	7.46	0.57
50	3.35	31.5	9.02	8.57	0.67	0.	-0.	9.02	8.57	0.67
75	3.44	32.1	10.29	9.76	0.80	0.	-0.	10.29	9.76	0.80
95	3.59	33.0	12.62	11.94	1.04	0.	-0.	12.62	11.94	1.04

POSITION 2



2.

	C.G.		INERTIA TENSOR					PRINCIPAL MOMENTS		
O/C	X	Z	IXX	IYY	IZZ	IXZ	THETA	IXX	IYY	IZZ
5	2.13	28.9	4.97	4.97	0.75	0.58	-7.7	5.05	4.97	0.67
25	2.16	29.7	6.04	6.03	0.94	0.71	-7.8	6.14	6.03	0.84
50	2.22	30.3	6.95	6.93	1.11	0.82	-7.8	7.06	6.93	0.99
75	2.27	30.9	7.91	7.88	1.31	0.94	-7.9	8.04	7.88	1.18
95	2.36	31.8	9.68	9.62	1.67	1.16	-8.1	9.84	9.62	1.51

POSITION 3

3.

	C.G.		INERTIA TENSOR					PRINCIPAL MOMENTS		
O/O	X	Z	IXX	IYY	IZZ	IXZ	THETA	IXX	IYY	IZZ
5	6.75	26.3	3.22	3.90	1.44	-1.12	25.8	3.76	3.90	0.90
25	7.36	26.7	3.72	4.71	1.94	-1.38	28.6	4.47	4.71	1.19
50	7.61	27.2	4.27	5.41	2.27	-1.58	28.8	5.14	5.41	1.40
75	7.87	27.7	4.85	6.17	2.65	-1.80	29.2	5.86	6.17	1.64
95	8.26	28.3	5.93	7.55	3.34	-2.20	29.8	7.19	7.55	2.09

ALL POSITIONS ARE SYMMETRIC (IXY,IYZ ARE ZERO),
X,Z IN INCHES, IXX,IYY,IZZ,IXZ IN SLUG-FT-FT, THETA IN DEG.

POSITION 4

4.

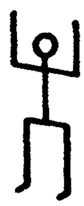
	C.G.		INERTIA TENSOR					PRINCIPAL MOMENTS		
O/C	X	Z	IXX	IYY	IZZ	IXZ	THETA	IXX	IYY	IZZ
5	7.79	25.3	2.48	4.20	2.48	-0.97	45.0	3.45	4.20	1.51
25	8.45	25.6	2.66	5.17	3.26	-1.14	49.9	4.22	5.17	1.90
50	8.74	26.1	3.29	5.96	3.79	-1.31	50.4	4.87	5.96	2.21
75	9.04	26.5	3.73	6.81	4.42	-1.47	51.5	5.59	6.81	2.56
95	9.49	27.1	4.55	8.37	5.54	-1.78	52.7	6.90	8.37	3.20

POSITION 5

5.

	C.G.		INERTIA TENSOR					PRINCIPAL MOMENTS		
O/C	X	Z	IXX	IYY	IZZ	IXZ	THETA	IXX	IYY	IZZ
5	3.16	29.3	6.73	5.37	1.50	0.	-0.	6.73	5.37	1.50
25	3.26	30.1	8.25	6.48	1.95	0.	-0.	8.25	6.48	1.95
50	3.35	30.7	9.49	7.44	2.28	0.	-0.	9.49	7.44	2.28
75	3.44	31.3	10.86	8.46	2.67	0.	-0.	10.86	8.46	2.67
95	3.59	32.2	13.33	10.34	3.36	0.	-0.	13.33	10.34	3.36

POSITION 6

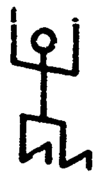


6.

	C.G.		INERTIA TENSOR					PRINCIPAL MOMENTS		
O/C	X	Z	IXX	IYY	IZZ	IXZ	THETA	IXX	IYY	IZZ
5	3.16	27.6	8.38	8.07	0.45	0.	-0.	8.38	8.07	0.45
25	3.26	28.4	10.19	9.81	0.57	0.	-0.	10.19	9.81	0.57
50	3.35	29.0	11.75	11.30	0.67	0.	-0.	11.75	11.30	0.67
75	3.44	29.6	13.39	12.86	0.80	0.	-0.	13.39	12.86	0.80
95	3.59	30.4	16.39	15.71	1.04	0.	-0.	16.39	15.71	1.04

ALL POSITIONS ARE SYMMETRIC (IXY,IYZ ARE ZERO),
X,Z IN INCHES, IXX,IYY,IZZ,IXZ IN SLUG-FT-FT, THETA IN DEG.

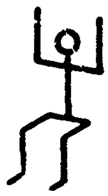
POSITION 7



7.

	C.G.		INERTIA TENSOR					PRINCIPAL MOMENTS		
O/O	X	Z	IXX	IYY	IZZ	IXZ	THETA	IXX	IYY	IZZ
5	2.13	26.6	6.77	6.77	0.75	0.65	-6.1	6.84	6.77	0.68
25	2.16	27.3	8.22	8.21	0.94	0.80	-6.2	8.31	8.21	0.85
50	2.22	27.3	9.48	9.46	1.11	0.92	-6.2	9.58	9.46	1.01
75	2.27	28.4	10.78	10.75	1.31	1.05	-6.3	10.90	10.75	1.19
95	2.36	29.1	13.17	13.11	1.67	1.30	-6.4	13.31	13.11	1.53

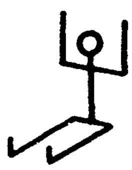
POSITION 8



8.

	C.G.		INERTIA TENSOR					PRINCIPAL MOMENTS		
O/O	X	Z	IXX	IYY	IZZ	IXZ	THETA	IXX	IYY	IZZ
5	6.75	24.0	4.68	5.36	1.44	-1.36	20.0	5.17	5.36	0.95
25	7.36	24.3	5.44	6.43	1.94	-1.69	22.0	6.12	6.43	1.26
50	7.61	24.7	6.26	7.40	2.27	-1.95	22.1	7.05	7.40	1.47
75	7.87	25.1	7.09	8.41	2.65	-2.22	22.5	8.02	8.41	1.73
95	8.26	25.7	8.63	10.25	3.34	-2.73	23.0	9.79	10.25	2.19

POSITION 9

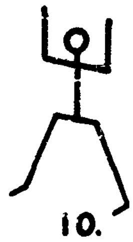


9.

	C.G.		INERTIA TENSOR					PRINCIPAL MOMENTS		
O/O	X	Z	IXX	IYY	IZZ	IXZ	THETA	IXX	IYY	IZZ
5	7.79	23.0	3.80	5.53	2.48	-1.27	31.3	4.58	5.53	1.71
25	8.45	23.2	4.41	6.72	3.26	-1.54	34.8	5.48	6.72	2.19
50	8.74	23.6	5.08	7.75	3.79	-1.77	35.0	6.33	7.75	2.55
75	9.04	24.0	5.75	8.83	4.42	-2.01	35.9	7.20	8.83	2.96
95	9.49	24.5	6.98	10.79	5.54	-2.46	36.9	8.82	10.79	3.70

ALL POSITIONS ARE SYMMETRIC (IXY,IYZ ARE ZERO),
X,Z IN INCHES, IXX,IYY,IZZ,IXZ IN SLUG-FT-FT, THETA IN DEG.

POSITION 10



10.

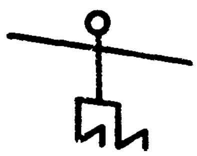
	C.G.		INERTIA TENSOR					PRINCIPAL MOMENTS		
O/C	X	Z	IXX	IYY	IZZ	IXZ	THETA	IXX	IYY	IZZ
5	3.16	27.0	8.58	7.22	1.50	0.	-0.	8.58	7.22	1.50
25	3.26	27.7	10.49	8.72	1.95	0.	-0.	10.49	8.72	1.95
50	3.35	28.3	12.10	10.04	2.28	0.	-0.	12.10	10.04	2.28
75	3.44	28.8	13.81	11.41	2.67	0.	-0.	13.81	11.41	2.67
95	3.59	29.6	16.92	13.92	3.36	0.	-0.	16.92	13.92	3.36

POSITION 11

11.

	C.G.		INERTIA TENSOR					PRINCIPAL MOMENTS		
O/C	X	Z	IXX	IYY	IZZ	IXZ	THETA	IXX	IYY	IZZ
5	3.16	28.8	7.92	6.61	1.45	0.	-0.	7.92	6.61	1.45
25	3.26	29.6	9.65	8.05	1.79	0.	-0.	9.65	8.05	1.79
50	3.35	30.2	11.13	9.26	2.09	0.	-0.	11.13	9.26	2.09
75	3.44	30.8	12.71	10.55	2.44	0.	-0.	12.71	10.55	2.44
95	3.59	31.7	15.61	12.90	3.07	0.	-0.	15.61	12.90	3.07

POSITION 12

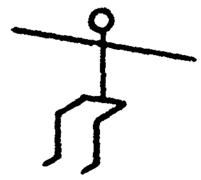


12.

	C.G.		INERTIA TENSOR					PRINCIPAL MOMENTS		
O/C	X	Z	IXX	IYY	IZZ	IXZ	THETA	IXX	IYY	IZZ
5	2.13	27.7	6.38	5.37	1.76	0.62	-7.5	6.46	5.37	1.68
25	2.16	28.5	7.77	6.54	2.16	0.76	-7.5	7.87	6.54	2.06
50	2.22	29.1	8.96	7.52	2.53	0.87	-7.6	9.07	7.52	2.41
75	2.27	29.6	10.21	8.55	2.94	1.00	-7.7	10.35	8.55	2.81
95	2.36	30.5	12.52	10.44	3.70	1.23	-7.8	12.69	10.44	3.53

ALL POSITIONS ARE SYMMETRIC (IXY,IYZ ARE ZERO),
X,Z IN INCHES, IXX,IYY,IZZ,IXZ IN SLUG-FT-FT, THETA IN DEG.

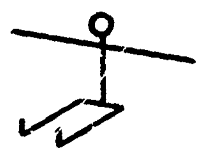
POSITION 13



13.

	C.G.		INERTIA TENSOR					PRINCIPAL MOMENTS		
O/O	X	Z	IXX	IYY	IZZ	IXZ	THETA	IXX	IYY	IZZ
5	6.75	25.2	4.46	4.14	2.45	-1.24	25.4	5.05	4.14	1.86
25	7.36	25.5	5.21	4.98	3.16	-1.53	28.1	6.03	4.98	2.34
50	7.61	26.0	6.01	5.73	3.69	-1.76	28.3	6.96	5.73	2.74
75	7.87	26.4	6.84	6.52	4.28	-2.01	28.8	7.95	6.52	3.18
95	8.26	27.0	8.38	7.97	5.38	-2.46	29.3	9.76	7.97	3.99

POSITION 14



14.

	C.G.		INERTIA TENSOR					PRINCIPAL MOMENTS		
O/C	X	Z	IXX	IYY	IZZ	IXZ	THETA	IXX	IYY	IZZ
5	7.79	24.1	3.65	4.37	3.49	-1.12	42.9	4.69	4.37	2.45
25	8.45	24.4	4.27	5.36	4.48	-1.34	47.2	5.72	5.36	3.03
50	8.74	24.3	4.93	6.18	5.21	-1.54	47.6	6.62	6.18	3.53
75	9.04	25.2	5.61	7.06	6.05	-1.74	48.6	7.59	7.06	4.07
95	9.43	25.8	6.87	8.65	7.58	-2.12	49.7	9.37	8.65	5.07

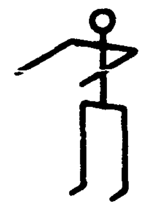
POSITION 15

15.

	C.G.		INERTIA TENSOR					PRINCIPAL MOMENTS		
O/O	X	Z	IXX	IYY	IZZ	IXZ	THETA	IXX	IYY	IZZ
5	3.16	28.1	8.16	5.80	2.50	0.	-0.	8.16	5.80	2.50
25	3.26	28.9	10.01	7.01	3.17	0.	-0.	10.01	7.01	3.17
50	3.35	29.5	11.54	8.06	3.70	0.	-0.	11.54	8.06	3.70
75	3.44	30.1	13.20	9.17	4.30	0.	-0.	13.20	9.17	4.30
95	3.59	30.9	16.23	11.20	5.39	0.	-0.	16.23	11.20	5.39

ALL POSITIONS ARE SYMMETRIC (IXY,IYZ ARE ZERO),
X,Z IN INCHES, IXX,IYY,IZZ,IXZ IN SLUG-FT-FT, THETA IN DEG.

POSITION 16



16.

	C.G.		INERTIA TENSOR					PRINCIPAL MOMENTS		
O/C	X	Z	IXX	IYY	IZZ	IXZ	THETA	IXX	IYY	IZZ
5	4.32	28.8	6.92	7.11	0.94	0.48	-4.6	6.96	7.11	0.90
25	4.46	29.6	8.43	8.64	1.15	0.59	-4.6	8.48	8.64	1.11
50	4.59	30.2	9.71	9.93	1.35	0.68	-4.6	9.76	9.93	1.29
75	4.71	30.8	11.08	11.31	1.57	0.77	-4.6	11.14	11.31	1.51
95	4.91	31.7	13.58	13.83	1.97	0.94	-4.6	13.66	13.83	1.90

POSITION 17

17.

	C.G.		INERTIA TENSOR					PRINCIPAL MOMENTS		
O/C	X	Z	IXX	IYY	IZZ	IXZ	THETA	IXX	IYY	IZZ
5	3.29	27.7	5.38	5.94	1.32	1.07	-13.9	5.64	5.94	1.05
25	3.36	28.5	6.55	7.21	1.61	1.30	-13.9	6.87	7.21	1.29
50	3.46	29.1	7.54	8.29	1.86	1.50	-14.0	7.91	8.29	1.51
75	3.54	29.6	8.58	9.43	2.18	1.71	-14.1	9.01	9.43	1.75
95	3.68	30.5	10.49	11.51	2.74	2.10	-14.2	11.03	11.51	2.21

POSITION 18

18.

	C.G.		INERTIA TENSOR					PRINCIPAL MOMENTS		
O/C	X	Z	IXX	IYY	IZZ	IXZ	THETA	IXX	IYY	IZZ
5	7.91	25.2	3.45	4.39	1.70	-0.87	22.4	3.81	4.39	1.34
25	8.56	25.5	3.99	5.25	2.21	-1.10	25.6	4.52	5.25	1.68
50	8.85	26.0	4.59	6.04	2.57	-1.27	25.7	5.20	6.04	1.96
75	9.13	26.4	5.21	6.86	2.99	-1.45	26.3	5.93	6.86	2.27
95	9.58	27.0	6.35	8.36	3.74	-1.79	27.0	7.26	8.36	2.83

ALL POSITIONS ARE SYMMETRIC (IXY,IYZ ARE ZERO),
X,Z IN INCHES, IXX,IYY,IZZ,IXZ IN SLUG-FT-FT, THETA IN DEG.

POSITION 19

19.

O/C	C.G. X	C.G. Z	Inertia Tensor IXX	Inertia Tensor IYY	Inertia Tensor IZZ	Inertia Tensor IXZ	THETA	Principal Moments IXX	Principal Moments IYY	Principal Moments IZZ
5	8.95	24.1	2.65	4.56	2.67	-0.79	45.4	3.45	4.56	1.87
25	9.65	24.4	3.05	5.55	3.45	-0.96	50.8	4.23	5.55	2.27
50	9.98	24.8	3.51	6.38	4.00	-1.09	51.3	4.87	6.38	2.64
75	10.30	25.2	3.98	7.28	4.64	-1.24	52.5	5.59	7.28	3.02
95	10.81	25.8	4.64	8.91	5.80	-1.52	53.8	6.91	8.91	3.73

POSITION 20

20.

O/C	C.G. X	C.G. Z	Inertia Tensor IXX	Inertia Tensor IYY	Inertia Tensor IZZ	Inertia Tensor IXZ	THETA	Principal Moments IXX	Principal Moments IYY	Principal Moments IZZ
5	4.32	28.1	7.16	6.30	1.99	0.46	-5.1	7.20	6.30	1.95
25	4.46	28.9	8.79	7.60	2.54	0.56	-5.1	8.83	7.60	2.49
50	4.57	29.5	10.12	8.74	2.96	0.65	-5.1	10.18	8.74	2.90
75	4.71	30.1	11.57	9.94	3.43	0.74	-5.1	11.64	9.94	3.37
95	4.91	30.9	14.20	12.13	4.29	0.90	-5.1	14.28	12.13	4.21

POSITION 21

21.

O/C	C.G. X	C.G. Z	Inertia Tensor IXX	Inertia Tensor IYY	Inertia Tensor IZZ	Inertia Tensor IXZ	THETA	Principal Moments IXX	Principal Moments IYY	Principal Moments IZZ
5	3.50	29.6	6.45	6.22	0.54	0.04	-0.4	6.45	6.22	0.54
25	3.61	30.5	7.85	7.57	0.67	0.05	-0.4	7.85	7.57	0.67
50	3.71	31.1	9.03	8.69	0.79	0.06	-0.4	9.03	8.69	0.79
75	3.81	31.7	10.31	9.91	0.94	0.07	-0.4	10.31	9.91	0.94
95	3.97	32.6	12.64	12.12	1.21	0.09	-0.4	12.64	12.12	1.21

ALL POSITIONS ARE SYMMETRIC (IXY,IYZ ARE ZERO),
X,Z IN INCHES, IXX,IYY,IZZ,IXZ IN SLUG-FT-FT, THETA IN DEG.

POSITION 22

22.

	C.G.		INERTIA TENSOR					PRINCIPAL MOMENTS		
C/C	X	Z	IXX	IYY	IZZ	IXZ	THETA	IXX	IYY	IZZ
5	2.47	28.5	4.95	5.05	0.86	0.63	-8.5	5.05	5.05	0.77
25	2.51	29.4	6.03	6.14	1.07	0.77	-8.6	6.14	6.14	0.95
50	2.57	30.0	6.93	7.05	1.25	0.88	-8.7	7.06	7.05	1.12
75	2.63	30.5	7.89	8.03	1.47	1.01	-8.8	8.05	8.03	1.32
95	2.74	31.4	9.65	9.80	1.87	1.25	-8.9	9.85	9.80	1.68

POSITION 23

23.

	C.G.		INERTIA TENSOR					PRINCIPAL MOMENTS		
C/C	X	Z	IXX	IYY	IZZ	IXZ	THETA	IXX	IYY	IZZ
5	7.09	26.0	3.15	3.85	1.46	-1.14	26.8	3.73	3.85	0.88
25	7.71	26.4	3.63	4.63	1.95	-1.41	29.6	4.44	4.63	1.15
50	7.97	26.3	4.17	5.32	2.28	-1.62	29.8	5.10	5.32	1.35
75	8.23	27.3	4.74	6.07	2.66	-1.85	30.3	5.82	6.07	1.58
95	8.64	28.0	5.79	7.41	3.35	-2.26	30.9	7.14	7.41	2.00

POSITION 24

24.

	C.G.		INERTIA TENSOR					PRINCIPAL MOMENTS		
C/C	X	Z	IXX	IYY	IZZ	IXZ	THETA	IXX	IYY	IZZ
5	8.13	24.9	2.39	4.11	2.48	-1.01	46.2	3.45	4.11	1.42
25	8.80	25.3	2.75	5.05	3.25	-1.21	50.8	4.23	5.05	1.77
50	9.10	25.7	3.16	5.81	3.77	-1.38	51.2	4.88	5.81	2.06
75	9.40	26.1	3.59	6.65	4.40	-1.56	52.3	5.60	6.65	2.38
95	9.87	26.7	4.37	8.16	5.51	-1.89	53.4	6.92	8.16	2.97

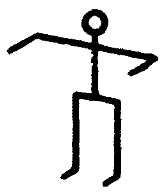
ALL POSITIONS ARE SYMMETRIC (IXY,IYZ ARE ZERO),
X,Z IN INCHES, IXX,IYY,IZZ,IXZ IN SLUG-FT-FT, THETA IN DEG.

POSITION 25

25.

0/0	C.G. X	C.G. Z	INERTIA TENSOR IXX	IYY	IZZ	IXZ	THETA	PRINCIPAL MOMENTS IXX	IYY	IZZ
5	3.50	29.0	6.71	5.44	1.59	0.04	-0.4	6.71	5.44	1.59
25	3.61	29.8	8.24	6.57	2.06	0.05	-0.4	8.24	6.57	2.06
50	3.71	30.4	9.49	7.54	2.40	0.05	-0.4	9.49	7.54	2.40
75	3.81	31.0	10.85	8.59	2.80	0.06	-0.4	10.85	8.59	2.80
95	3.97	31.4	13.32	10.48	3.52	0.07	-0.4	13.32	10.48	3.52

POSITION 26



26.

0/0	C.G. X	C.G. Z	INERTIA TENSOR IXX	IYY	IZZ	IXZ	THETA	PRINCIPAL MOMENTS IXX	IYY	IZZ
5	3.50	28.8	7.48	6.70	1.10	0.14	-1.3	7.49	6.70	1.10
25	3.61	29.6	9.12	8.15	1.36	0.17	-1.3	9.13	8.15	1.36
50	3.71	30.2	10.52	9.37	1.60	0.20	-1.3	10.52	9.37	1.60
75	3.81	30.3	12.01	10.68	1.87	0.22	-1.3	12.01	10.68	1.87
95	3.97	31.7	14.75	13.06	2.38	0.27	-1.3	14.76	13.06	2.37

POSITION 27

27.

0/0	C.G. X	C.G. Z	INERTIA TENSOR IXX	IYY	IZZ	IXZ	THETA	PRINCIPAL MOMENTS IXX	IYY	IZZ
5	2.47	27.7	5.94	5.48	1.47	0.75	-9.2	6.06	5.48	1.30
25	2.51	28.5	7.24	6.66	1.76	0.91	-9.2	7.39	6.66	1.61
50	2.57	29.1	8.35	7.67	2.06	1.05	-9.3	8.52	7.67	1.89
75	2.63	29.6	9.51	8.72	2.41	1.20	-9.4	9.71	8.72	2.21
95	2.74	30.5	11.66	10.64	3.04	1.49	-9.5	11.91	10.64	2.30

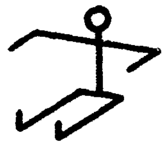
ALL POSITIONS ARE SYMMETRIC (IXY, IYZ ARE ZERO),
X,Z IN INCHES, IXX,IYY,IZZ,IXZ IN SLUG-FT-FT, THETA IN DEG.

POSITION 28

28.

	C.G.		INERTIA TENSOR					PRINCIPAL MOMENTS		
O/O	X	Z	IXX	IYY	IZZ	IXZ	THETA	IXX	IYY	IZZ
5	7.09	25.2	4.02	4.15	2.02	-1.13	24.3	4.53	4.15	1.51
25	7.71	25.5	4.68	4.99	2.64	-1.41	27.1	5.40	4.99	1.92
50	7.97	26.0	5.40	5.74	3.09	-1.62	27.2	6.23	5.74	2.25
75	8.23	26.4	6.14	6.53	3.59	-1.85	27.7	7.11	6.53	2.62
95	8.64	27.0	7.52	7.98	4.52	-2.27	28.3	8.74	7.98	3.30

POSITION 29



29.

	C.G.		INERTIA TENSOR					PRINCIPAL MOMENTS		
O/O	X	Z	IXX	IYY	IZZ	IXZ	THETA	IXX	IYY	IZZ
5	8.13	24.1	3.71	4.37	3.04	-1.02	42.6	4.15	4.37	2.10
25	8.80	24.4	3.74	5.35	3.94	-1.23	47.3	5.07	5.35	2.60
50	9.10	24.8	4.32	6.16	4.58	-1.41	47.6	5.87	6.16	3.04
75	9.40	25.2	4.91	7.04	5.33	-1.60	48.7	6.73	7.04	3.51
95	9.37	25.3	6.01	8.62	6.68	-1.95	49.9	8.32	8.62	4.37

POSITION 30

30.

	C.G.		INERTIA TENSOR					PRINCIPAL MOMENTS		
O/O	X	Z	IXX	IYY	IZZ	IXZ	THETA	IXX	IYY	IZZ
5	3.53	28.1	7.72	5.89	2.15	0.14	-1.4	7.73	5.89	2.15
25	3.61	28.9	9.47	7.12	2.75	0.16	-1.4	9.48	7.12	2.74
50	3.71	29.5	10.93	8.18	3.21	0.19	-1.4	10.94	8.18	3.20
75	3.81	30.1	12.52	9.31	3.73	0.21	-1.4	12.51	9.31	3.73
95	3.97	30.9	15.37	11.36	4.69	0.26	-1.4	15.38	11.36	4.69

ALL POSITIONS ARE SYMMETRIC (IXY,IYZ ARE ZERO).
X,Z IN INCHES, IXX,IYY,IZZ,IXZ IN SLUG-FT-FT, THETA IN DEG.

POSITION 31

31.

	C.G.		INERTIA TENSOR					PRINCIPAL MOMENTS		
O/O	X	Z	IXX	IYY	IZZ	IXZ	THETA	IXX	IYY	IZZ
5	7.25	26.6	3.55	4.38	1.59	-1.41	27.6	4.29	4.38	0.85
25	7.67	27.1	4.13	5.30	2.12	-1.77	30.1	5.16	5.30	1.09
50	8.13	27.6	4.75	6.09	2.47	-2.03	30.3	5.93	6.09	1.28
75	8.40	28.1	5.40	6.94	2.88	-2.32	30.7	6.78	6.94	1.50
95	8.82	28.3	6.59	8.49	3.62	-2.85	31.2	8.32	8.49	1.90

ALL POSITIONS ARE SYMMETRIC (IXY,IYZ ARE ZERO),
X,Z IN INCHES, IXX,IYY,IZZ,IXZ IN SLUG-FT-FT, THETA IN DEG.

VI. Concluding Statements and Recommendations for Future Study

Concluding Statements

A mathematical model to predict the inertial properties of the human body in any fixed body position is within the state of the art. The 15 segment model is personalized by using 25 anthropometric dimensions of the individual subject. The dimensions and properties of the segments are calculated using the regression equations and the anthropometric dimensions.

The results obtained using the model are compared with the experimental data collected by North American Aviation on 66 living subjects. The location of the center of gravity is generally predicted within 0.7 inches. The moments of inertia are generally predicted within 10 per cent.

The design guide contains the inertial properties of 5 composite percentile subjects in 31 body positions. These results emphasize the importance of the principal axes. In some positions, the principal axes are rotated as much as 45 degrees from the body axes. This much difference may affect the performance of a Self-Maneuvering Unit drastically. Extensive cross-coupling can waste considerable amounts of fuel as the stabilization package compensates for spurious rotations resulting from the cross-coupling.

Recommendations for Future Study

It is recommended that further investigation be pursued to accomplish the following objectives:

a. improve the mathematical model

b. determine the products of inertia of the human body by experiment

c. improve the regression equations for segment weights

d. conduct a new study of the anthropometry of flying personnel

The mathematical model can be improved by redesigning the hand and the foot so that the specific gravity of each segment is closer to the experimental value. In addition, modifications can be made in the basic computer program to include external loads on the model such as tools, pressure suit, or life support equipment.

The products of inertia of the human body can be determined by variation of the compound pendulum techniques used to determine the center of gravity and moments of inertia. The principal moments and principal axes can then be calculated. These calculations would also provide further validation of the mathematical model.

Dissection of more cadavers is necessary to improve the regression equations. Samples in the upper end of the weight spectrum are essential to increase the accuracy of the equations.

The requirements for anthropometric dimensions in the design of the mathematical model should be considered when selecting measurements for a new anthropometry study. Some dimensions not included in the 1950 study are necessary for the current version of the mathematical model. Other dimensions will be required for improvement of the model. These dimensions should be taken in the new survey.

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Appendix A

Description of Anthropometric Dimensions

The 25 anthropometric dimensions described below are some of the dimensions taken during the North American Aviation study (Ref 27: 55-59). Reference is made to the source of each description. The 1950 survey of Air Force flying personnel is given precedence in selecting a source.

1. Ankle Circumference: Subject stands. Holding the tape slightly above the projections of the ankle bones, measure the minimum circumference of the right ankle (Ref 15: 37).

2. Axillary Arm Circumference: Subject stands, right arm initially raised and then lowered after the tape is in place. Holding the tape in a horizontal plane and as high as possible in the armpit, measure the circumference of the upper arm (Ref 15: 38).

3. Buttock Depth: Subject stands erect. Holding the anthropometer horizontally at the subject's right side, measure the depth of the buttocks at the level of the greatest rearward protrusion (Ref 15: 33).

4. Chest Breadth: Subject stands erect with arms initially raised and then lowered after the anthropometer is placed. Measure the chest breadth at the level of the nipples, during normal breathing (Ref 15: 30).

5. Chest Depth: Subject stands erect with arms initially raised and then lowered after the anthropometer is placed. Holding the anthropometer horizontally on the subject's right side, at the level of the nipples, measure the chest depth during normal breathing (Ref 15: 32).

6. Elbow Circumference: Subject stands with right arm extended.

Measure the elbow circumference holding the tape over the olecranon (Ref 27: 56).

7. Fist Circumference: Subject makes a tight fist with right hand, thumb lying across the end of the fist. Measure the fist circumference with tape passing over the thumb and the knuckles (Ref 15: 56).

8. Forearm Length (Lower Arm Length): Subject stands with right arm extended at side. Using the anthropometer, measure the distance along the axis of the lower arm between radiale and stylion (Ref 27: 57).

9. Foot Length: Subject stands with right foot in the foot box, weight equally distributed, foot just touching the side and rear walls, and long axis of the foot parallel to the side wall. Using the scale on the base of the foot box, measure the length of the foot along the long axis (Ref 15: 48).

10. Knee Circumference: Subject stands. Measure the right knee circumference at the mid-patella level holding the tape in a horizontal plane (Ref 27: 57).

11. Head Circumference: With tape passing above (not including) the brow ridges, measure the maximum circumference of the head (Ref 15: 71).

12. Hip Breadth: Subject stands erect. Holding the anthropometer horizontally, measure the maximum breadth of the hips (Ref 15: 31).

13. Shoulder Height (Acromial Height): Subject stands erect. Using the anthropometer, measure the vertical distance from the floor to the right acromion (Ref 15: 14).

14. Sitting Height: Subject sits erect, head oriented in the Frankfort plane and feet resting on a surface so that knees are bent at about right angles. Using the anthropometer, measure the vertical distance from the sitting surface to the top of the head by placing the anthropometer firmly against the scalp (Ref 15: 20).

15. Sphyrion Height: Subject stands erect with legs slightly apart. Using the measuring block, measure the vertical distance from the floor to sphyrion (Ref 27: 35).

16. Stature: Subject stands with head oriented in the Frankfort plane. Using the anthropometer, measure the vertical distance from the

floor to the top of the head by placing the anthropometer firmly against scalp (Ref 15: 11).

17. Substernale Height: Subject stands erect. Using the anthropometer, measure the vertical distance from the floor to the substernale point at the lower edge of the breastbone (Ref 15: 15).

18. Thigh Circumference: Subject stands with legs slightly apart. Holding the tape in a horizontal plane just below the lowest point in the gluteal furrow, measure the circumference of the right thigh (Ref 15: 36).

19. Tibiale Height: Subject stands erect with legs slightly apart. Using the anthropometer, measure the vertical distance from the floor to the right tibiale (Ref 27: 58).

20. Trochanteric Height: Subject stands erect. Using the anthropometer, measure the vertical distance from the floor to the trochanterion on the right side (Ref 27: 59).

21. Upper Arm Length: Subject stands with right arm extended at side. Using the anthropometer, measure the distance along the axis of the upper arm, between the acromion and the radiale (Ref 27: 59).

22. Weight: Weigh nude subject on standard medical type scales (Ref 15: 11).

23. Waist Breadth: Subject stands erect with abdomen relaxed. Using the anthropometer, measure the minimum horizontal distance between the points marking the most lateral indentation in the abdomenal region (Ref 15: 31).

24. Waist Depth: Subject stands erect with abdomen relaxed. Holding the anthropometer horizontally on the subject's right side, measure the anterior to posterior distance of the abdomen at the level of the most lateral indentation waist points (Ref 15: 32).

25. Wrist Circumference: Right arm and hand extended. Passing the tape just proximal of the styloid process of the ulna, measure the minimum circumference of the wrist (Ref 15: 40).

FOARC	FOREARM CIRCUMFERENCE	IN
FOARL	FOREARM LENGTH	IN
FOOTL	FOOT LENGTH	IN
G	INTERMEDIATE CALCULATION VARIABLE	
GAMMA(J,K)	PRINCIPAL AXIS DIRECTION ANGLE	DEGREE
GKNEC	KNEE CIRCUMFERENCE	IN
H(I,J)	SEGMENT H.P. COORDINATE(BODY AXES)	IN
HEADC	HEAD CIRCUMFERENCE	IN
HIPB	HIP BREADTH	IN
HNT	WEIGHT OF HEAD, NECK AND TRUNK	LB
I	SEGMENT NUMBER INDICATOR	
II	DUMMY DO-LOOP OPERATOR	
IJ	COMPUTED GO-TO OPERATOR	
J	AXES INDICATOR	
JJ	DUMMY DO-LOOP OPERATOR	
K	BODY POSITION INDICATOR	
LM	ERROR SYMBOL, MATRIX MULTIPLICATION	
L1	OUTPUT SENSE LIGHT CONTROL	
L2	OUTPUT SENSE LIGHT CONTROL	
MADD	INTERMEDIATE CALCULATION VARIABLE	
MD	INTERMEDIATE CALCULATION VARIABLE	
MOSAIC(M,M)	ERROR ARRAY ANALYSIS	
N	SUBJECT NUMBER	
NC	CYCLE INDICATOR	
NERROR(N,M)	ERROR ARRAY	
NI(2,M)	ERROR ARRAY MEDIANS AND AVERAGES	
NO	CYCLE INDICATOR	
NS(N)	SUBJECT NUMBER SEQUENCE ARRAY	
O(3,3)	TRANSFORMATION MATRIX	
OT(3,3)	TRANSFORMATION MATRIX TRANSPOSE	
PDIX(K)	MODEL IXX DIFF (PER CENT OF NAA)	PER CENT
PDIY(K)	MODEL IYY DIFF (PER CENT OF NAA)	PER CENT
PDIZ(K)	MODEL IZZ DIFF (PER CENT OF NAA)	PER CENT
PI	3.1415927	
PMOM(J,K)	PRINCIPAL MOMENTS	SLUG-FT-FT
R(I)	SEGMENT RADIUS (LARGER)	IN
RR(I)	SEGMENT RADIUS (SMALLER)	IN
SHLDH	SHOULDER HEIGHT	IN
SIGMA(I)	SEGMENT PARAMETER (CONICAL)	
SINT(I,JJ)	SEGMENT EULER ANGLE SINE	
SITH	SITTING HEIGHT	IN
SIXX(I)	SEGMENT IXX	SLUG-IN-IN
SIYY(I)	SEGMENT IYY	SLUG-IN-IN
SIZZ(I)	SEGMENT IZZ	SLUG-IN-IN
SL(I)	SEGMENT LENGTH	IN
SM(I)	SEGMENT MASS	SLUG
SPHYH	SPHYRION HEIGHT	IN
STAT	STATURE	IN
SUBH	SUBSTERNALE HEIGHT	IN
SUPH	SUPRASTERNALE HEIGHT	IN
SW(I)	SEGMENT WEIGHT	LB
SW23	WEIGHT OF TORSO	LB
THETA(I,JJ)	SEGMENT EULER ANGLE	RAD
THIHC	THIGH CIRCUMFERENCE	IN

TIBH	TIBIALE HEIGHT	IN
TROCH	TROCHANTERIC HEIGHT	IN
TWOPI	2.*PI	
UPARL	UPPER ARM LENGTH	IN
W	SUBJECT WEIGHT	LB
WAISB	WAIST BREADTH	IN
WAISD	WAIST DEPTH	IN
WDIFF	WEIGHT DIFFERENCE	LB
WR	WEIGHT RATIO	
WR1	WEIGHT CORRECTION FACTOR	
WRISC	WRIST CIRCUMFERENCE	IN
X(I,J)	SEGMENT C.G. COORDINATE(BODY AXES)	IN
XCG(I,J,K)	SEGMENT C.G. COORDINATE(C.G. AXES)	IN
XDIFF(K)	MODEL C.G. DIFFERENCE (X)	IN
XMCD(K)	MODEL C.G. LOCATION (X)	IN
XIXX(K)	NAA IXX	SLUG-FT-FT
XIYY(K)	NAA IYY	SLUG-FT-FT
XIZZ(K)	NAA IZZ	SLUG-FT-FT
XNAA(K)	NAA C.G. LOCATION (X)	IN
Y(I)	SEGMENT C.G. LOCATION (TO R END)	IN
YDIFF(K)	MODEL C.G. DIFFERENCE (Y)	IN
YMCD(K)	MODEL C.G. LOCATION (Y)	IN
YNAA(K)	NAA C.G. LOCATION (Y)	IN
YY(I)	SEGMENT C.G. LOCATION (TO HINGE)	IN
ZDIFF(K)	MODEL C.G. DIFFERENCE (Z)	IN
ZMCD(K)	MODEL C.G. LOCATION (Z)	IN
ZNAA(K)	NAA C.G. LOCATION (Z)	IN

Appendix C

Properties of a Frustum of a Right Circular Cone

The right circular cone in Fig. 19 and the frustum of a right circular cone in Fig. 20 are related by:

$$h = h_1 - h_2 \tag{C-1}$$

and:

$$\frac{h_1}{R} = \frac{h_2}{RR} = \frac{h}{R - RR} \tag{C-2}$$

Then:

$$h_1 = h \frac{R}{R - RR} \tag{C-3}$$

and:

$$h_2 = h \frac{RR}{R - RR} \tag{C-4}$$

The centroid of the frustum is given by:

$$x = \frac{h}{4} \frac{R^2 + 2R\,(RR) + 3\,(RR)^2}{R^2 + R\,(RR) + (RR)^2} \tag{C-5}$$

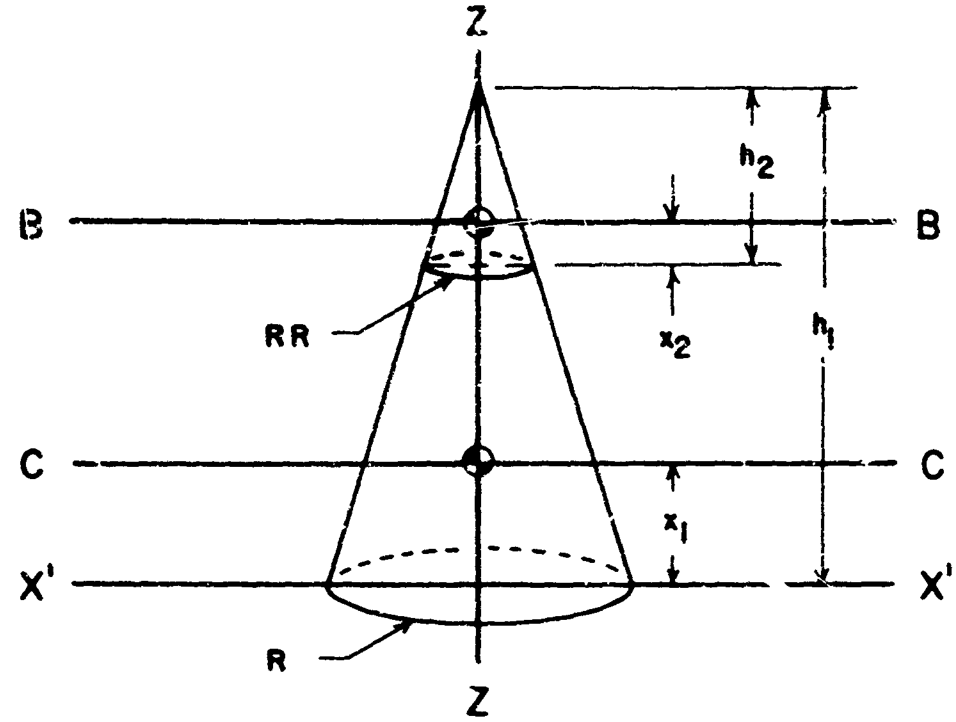

FIG. 19
RIGHT CIRCULAR CONES

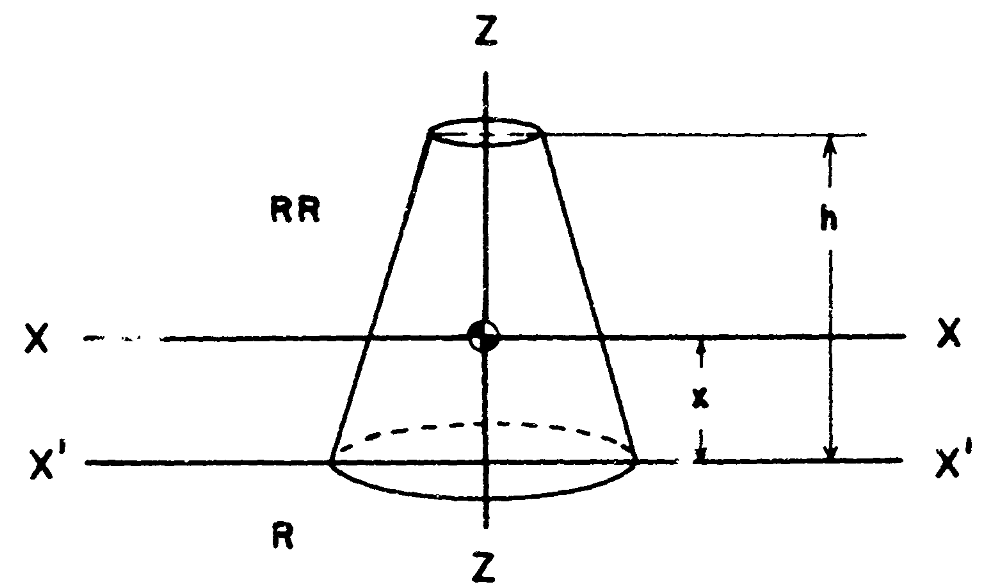

FIG. 20
FRUSTUM OF RIGHT CIRCULAR CONE

Let:

$$\mu = \frac{RR}{R} \tag{C-6}$$

and:

$$\sigma = 1 + \mu + \mu^2 \tag{C-7}$$

and:

$$\eta = \frac{x}{h} \tag{C-8}$$

Substituting equations C-5, C-6, and C-7 into the above equation, we have:

$$\eta = \frac{1 + 2\mu + 3\mu^2}{4\sigma} \tag{C-9}$$

The mass of the cone of altitude, h_1, and density, ρ, is given by:

$$M_1 = \rho \frac{PI}{3} R^2 h_1 \tag{C-10}$$

The mass of the cone of altitude, h_2, and density, ρ, is given by:

$$M_2 = \rho \frac{PI}{3} (RR)^2 h_2 \tag{C-11}$$

Substituting equation C-3 into C-10 and equation C-4 into C-11, we have:

$$M_1 = \rho \frac{PI}{3} \frac{R^3}{R - RR} h \qquad \text{(C-12)}$$

and:

$$M_2 = \rho \frac{PI}{3} \frac{(RR)^3}{R - RR} h \qquad \text{(C-13)}$$

The mass of the frustum of altitude, h, and density, ρ, is then:

$$M = M_1 - M_2 \qquad \text{(C-14)}$$

Substituting equations C-12 and C-13 into the above equation and simplifying by using equations C-6 and C-7, we have:

$$M = \rho \frac{PI}{3} R^2 h \sigma \qquad \text{(C-15)}$$

Substituting equations C-15 and C-6 into equations C-12 and C-13:

$$M_1 = \frac{M}{\sigma} \frac{R}{R - RR} \qquad \text{(C-16)}$$

and:

$$M_2 = \frac{M}{\sigma} \frac{RR}{R - RR} \mu^2 \qquad \text{(C-17)}$$

The cone of altitude, h_1, has moment of inertia about the axis, C-C, through the center of mass given by:

$$I_{cc} = \frac{3}{20} M_1 \left(R^2 + \frac{h_1^2}{4}\right) \qquad \text{(C-18)}$$

The parallel axis transfer theorem for moments of inertia:

$$I = I_{c.g.} + MD^2 \qquad \text{(C-19)}$$

Using equation C-18 in C-19, the moment of inertia about the axis, X'X', is given by:

$$I_{x'x'} = I_{cc} + M_1 x_1^2 \qquad \text{(C-20)}$$

where:

$$x_1 = .25\ h_1 \qquad \text{(C-21)}$$

The cone of altitude, h_2, has moment of inertia about the axis, B-B, through the center of mass given by:

$$I_{bb} = \frac{3}{20} M_2 \left((RR)^2 + \frac{h_2^2}{4} \right) \qquad \text{(C-22)}$$

Using equation C-22 in C-19, the moment of inertia about the axis, X'X', is given by:

$$I_{x'x'} = I_{bb} + M_2 \ (x_2 + h)^2 \qquad \text{(C-23)}$$

where:

$$x_2 = .25\ h_2 \tag{C-24}$$

The frustum of altitude, h, has moment of inertia about the axis, X'X', determined by the difference of the moments of inertia of the large and the small cone about the axis. The moment of inertia of the frustum is given by:

$$I_{x'x'} = I_{cc} + M_1 x_1^2 - I_{bb} - M_2 (x_2 + h)^2 \tag{C-25}$$

After rearranging by using equations C-3, C-4, C-6, C-7, C-16, and C-17, we have:

$$I_{x'x'} = M \left[\frac{3R^2}{20\sigma} (1 + \mu + \mu^2 + \mu^3 + \mu^4) + \frac{h^2}{10\sigma} (1 + 3\mu + 6\mu^2) \right] \tag{C-26}$$

Applying equation C-19 and using C-5 and C-15, we have:

$$I_{xx} = M \left[\frac{9}{20\ PI} \frac{1 + \mu + \mu^2 + \mu^3 + \mu^4}{\sigma^2} \frac{M}{\rho h} + \frac{3}{80} \frac{1 + 4\mu + 10\mu^2 + 4\mu^3 + \mu^4}{\sigma^2} h^2 \right] \tag{C-27}$$

Letting:

$$AA = \frac{9}{20\ PI} \frac{1 + \mu + \mu^2 + \mu^3 + \mu^4}{\sigma^2} \tag{C-28}$$

and:

$$BB = \frac{3}{80} \; \frac{1 + 4\,\mu + 10\,\mu^2 + 4\,\mu^3 + \mu^4}{\sigma^2} \qquad \text{(C-29)}$$

Equation C-27 can be written as:

$$I_{xx} = M \left[AA \left(\frac{M}{\rho h}\right) + BB\; h^2 \right] \qquad \text{(C-30)}$$

The moment of inertia of the frustum about the axis, Z-Z, through the center of mass is given by:

$$I_{zz} = \frac{3}{10} \; M \; \frac{R^5 - (RR)^5}{R^3 - (RR)^3} \qquad \text{(C-31)}$$

Using equations C-6, C-7, and C-15, we find:

$$I_{zz} = \frac{2M^2}{\rho h} \; \frac{9}{20\,PI} \; \frac{1 + \mu + \mu^2 + \mu^3 + \mu^4}{\sigma^2} \qquad \text{(C-32)}$$

This can be written as:

$$I_{zz} = \frac{2 \;\; AA \;\; M^2}{\rho h} \qquad \text{(C-33)}$$

Appendix D

Description of N. A. A. Body Positions

1. STANDING: Subject stands erect with head oriented in the Frankfort plane and with arms hanging naturally at the sides as when measuring stature (Ref 15: 11).

2. STANDING, ARMS OVER HEAD: Legs, torso, and head same as position 1; upper extremities raised over head, parallel to Z-axis; wrist axes parallel to X-axis; hands slightly clenched.

3. SPREAD EAGLE: Torso and head same as position 1: subject against plane parallel to Y-Z plane; arms at 45° with Z-axis, legs at 30° with Z-axis; wrist axes parallel to Y-Z plane; hands slightly clenched.

4. SITTING: Upper legs and forearms parallel to the X-axis; upper arms, lower legs and spine parallel to the Z-axis; soles parallel to X-Y plane; wrist axes parallel to Z-axis; head in Frankfort plane.

5. SITTING, FOREARMS DOWN: Same as position 4, except forearms parallel to Z-axis, wrist axes parallel to X-axis.

6. SITTING, THIGHS ELEVATED: Same as position 4, except upper leg angle approximately 35° with Y-Z plane.

7. MERCURY CONFIGURATION: Same as position 4, except 100° back-thigh angle, thigh-leg angle 112°, forearm parallel to thigh.

8. RELAXED (WEIGHTLESS): Position predicted to be assumed by a human relaxed in the weightless state.

APPENDIX E

COMPUTER PROGRAM MODEL (FORTRAN II)

```
C MODEL        MATHEMATICAL MODEL OF HUMAN BODY
      COMMON N,W,CW,ETA123
      COMMON SW,SM,SL,R,RR,Y,DELTA,AMU,AMUSQ,SIGMA,ETA,YY
      COMMON STAT,CERV,SHLDH,SUPH,SUBH,TROCH,TIBH,UPARL
      COMMON FOARL,CHESD,WAISD,BUTTD,CHESB,WAISB,HIPB,AXILC
      COMMON ELBC,FOARC,WRISC,FISTC,THIHC,GKNEC,ANKC,SPHYH
      COMMON FOOTL,BIACD,HEADC,BISPB,SITH,DELSH
      COMMON XNAA,YNAA,ZNAA,XIXX,XIYY,XIZZ
      COMMON SIXX,SIYY,SIZZ
      COMMON THETA,SINT,COST,D,E,F,O,OT
      COMMON H,X,XCG,CI
      COMMON XMOD,YMOD,ZMOD
      COMMON XDIFR,YDIFR,ZDIFR,CIXX,CIYY,CIZZ,DIXX,DIYY,DIZZ
      COMMON PDIX,PDIY,PDIZ
      COMMON ALPHA,BETA,GAMMA,PMOM
      COMMON NERROR,MOSAIC,NI,NS,L1,L2,K
      DIMENSION SW(15),SM(15),SL(15),R(15),RR(15),Y(15)
      DIMENSION DELTA(15),AMU(15),AMUSQ(15),SIGMA(15)
      DIMENSION ETA(15),YY(15)
      DIMENSION XNAA(7),YNAA(7),ZNAA(7)
      DIMENSION XIXX(7),XIYY(7),XIZZ(7)
      DIMENSION SIXX(15),SIYY(15),SIZZ(15)
      DIMENSION THETA(15,2),SINT(15,2),COST(15,2)
C                D(3,3),E(3,3),F(3,3) ARE DUMMY MATRICES
      DIMENSION D(3,3),E(3,3),F(3,3),O(3,3),OT(3,3)
      DIMENSION H(15,3),X(15,3),XCG(15,3,7),CI(3,3,7)
      DIMENSION XMOD(7),YMOD(7),ZMOD(7)
      DIMENSION XDIFR(7),YDIFR(7),ZDIFR(7)
      DIMENSION CIXX(7),CIYY(7),CIZZ(7)
      DIMENSION DIXX(7),DIYY(7),DIZZ(7)
      DIMENSION PDIX(7),PDIY(7),PDIZ(7)
      DIMENSION ALPHA(3,7),BETA(3,7),GAMMA(3,7),PMOM(3,7)
      DIMENSION NERROR(66,42),MOSAIC(43,43),NI(2,42),NS(66)
      READ INPUT TAPE 2,100,L1,L2
  100 FORMAT(2I5)
C     OUTPUT DESIRED
C     NORMAL     MASTER      CARD PUNCHED
C        NO        NO          0       0
C        NO        YES         0       1
C        YES       NO          1       0
C        YES       YES         1       1
      NC=1
    1 SENSE LIGHT 0
      IF(L1-1)3,2,3
```

```
  2 SENSE LIGHT 1
  3 IF(L2-1)5,4,4
  4 SENSE LIGHT 2
  5 READ INPUT TAPE 2,101,N,W
101 FORMAT(I5,4X,F6.1)
    READ INPUT TAPE 2,102,STAT,CERV,SHLDH,SUPH,SUBH,TROCH,
   1      TIBH,UPARL,FOARL,CHESD,WAISC,BUTTD,CHESB,WAISB,
   2      HIPB,AXILC,ELBC,FOARC,WRISC,FISTC,THIHC,GKNEC,
   3      ANKC,SPHYH,FOOTL,BIACD,HEADC,BISPB,SITH
102 FORMAT(14F5.1)
    READ INPUT TAPE 2,103,XNAA,ZNAA,XIXX,XIYY,XIZZ
103 FORMAT(7F5.0)
    NS(NC)=N
    CALL DESIGN
    DO 6 I=1,15
    DO 6 J=1,2
  6 THETA(I,J)=0.
    K=1
  7 CALL EULER
    CALL MODMOM
    K=K+1
    IF(K-8)7,8,7
  8 CALL OUTPUT
    IF(N-21)9,10,9
  9 NC=NC+1
    GO TO 1
 10 CALL ANALYZ
    CALL EXIT
     END


    SUBROUTINE DESIGN
    COMMON N,W,CW,ETA123
    COMMON SW,SM,SL,R,RR,Y,DELTA,AMU,AMUSQ,SIGMA,ETA,YY
    COMMON STAT,CERV,SHLDH,SUPH,SUBH,TROCH,TIBH,UPARL
    COMMON FOARL,CHESD,WAISD,BUTTD,CHESB,WAISB,HIPB,AXILC
    COMMON ELBC,FOARC,WRISC,FISTC,THIHC,GKNEC,ANKC,SPHYH
    COMMON FOOTL,BIACD,HEADC,BISPB,SITH,DELSH
    COMMON XNAA,YNAA,ZNAA,XIXX,XIYY,XIZZ
    COMMON SIXX,SIYY,SIZZ
    COMMON THETA,SINT,COST,D,E,F,O,OT
    COMMON H,X,XCG,CI
    COMMON XMOD,YMOD,ZMOD
    COMMON XDIFR,YDIFR,ZDIFR,CIXX,CIYY,CIZZ,DIXX,DIYY,DIZZ
    COMMON PDIX,PDIY,PDIZ
    COMMON ALPHA,BETA,GAMMA,PMOM
    COMMON NERROR,MOSAIC,NI,NS,L1,L2,K
    DIMENSION SW(15),SM(15),SL(15),R(15),RR(15),Y(15)
    DIMENSION DELTA(15),AMU(15),AMUSQ(15),SIGMA(15)
    DIMENSION ETA(15),YY(15)
    DIMENSION XNAA(7),YNAA(7),ZNAA(7)
    DIMENSION XIXX(7),XIYY(7),XIZZ(7)
    DIMENSION SIXX(15),SIYY(15),SIZZ(15)
```

```
      DIMENSION THETA(15,2),SINT(15,2),COST(15,2)
C               D(3,3),E(3,3),F(3,3) ARE DUMMY MATRICES
      DIMENSION D(3,3),E(3,3),F(3,3),O(3,3),OT(3,3)
      DIMENSION H(15,3),X(15,3),XCG(15,3,7),CI(3,3,7)
      DIMENSION XMOD(7),YMOD(7),ZMOD(7)
      DIMENSION XDIFR(7),YDIFR(7),ZDIFR(7)
      DIMENSION CIXX(7),CIYY(7),CIZZ(7)
      DIMENSION DIXX(7),DIYY(7),DIZZ(7)
      DIMENSION PDIX(7),PDIY(7),PDIZ(7)
      DIMENSION ALPHA(3,7),BETA(3,7),GAMMA(3,7),PMOM(3,7)
      DIMENSION NERROR(66,42),MOSAIC(43,43),NI(2,42),NS(66)
      PI=3.1415927
      TWOPI=2.*PI
      C1=PI/3.
      C2=62.427/1728.
C     DESIGN MODEL MAN BY USING ANTHROPOMETRIC DIMENSIONS
C     APPLY BARTER REGRESSION EQUATION TO SUBJECT WEIGHT
    1 HNT=(.47*W)+12.
      BUA=(.08*W)-2.9
      BFO=(.04*W)-.5
      BH=(.01*W)+.7
      BUL=(.18*W)+3.2
      BLL=(.11*W)-1.9
      BF=(.02*W)+1.5
      WDIFF=W-(HNT+BUA+BFO+BH+BUL+BLL+BF)
      WR=WDIFF/(HNT+BUA+BFO+BH+BUL+BLL+BF)
      WR1=1.+WR
C     DISTRIBUTE WDIFF PROPORTIONALLY OVER ALL SEGMENTS
    2 SW(1)=.079*W
      SW23=HNT*WR1-SW(1)
      SW(4)=BH*WR1/2.
      SW(6)=BUA*WR1/2.
      SW(8)=BFO*WR1/2.
      SW(10)=BUL*WR1/2.
      SW(12)=BLL*WR1/2.
      SW(14)=BF*WR1/2.
C     DEVELOPMENT OF HEAD
    3 I=1
      R(I)=(STAT-SHLDH)/2.
      RR(I)=HEADC/TWOPI
      DELTA(I)=SW(I)/RR(I)/RR(I)/R(I)/C1/4.
      SL(I)=2.*R(I)
      ETA(I)=.5
      Y(I)=R(I)
C     DEVELOPMENT OF TRUNK
      SL(2)=SHLDH-SUBH
      SL(3)=SITH-(STAT-SUBH)
      R(2)=CHESB/2.
      R(3)=HIPB/2.
      RR(2)=(CHESC+WAISD)/4.
      RR(3)=(WAISC+BUTTD)/4.
      ETA(2)=.5
      ETA(3)=.5
      Y(2)=ETA(2)*SL(2)
```

```
      Y(3)=ETA(3)*SL(3)
      DELTA(2)=SW23/PI/(R(2)*RR(2)*SL(2)
     1     +1.01/.92*R(3)*RR(3)*SL(3))
      DELTA(3)=1.01/.92*DELTA(2)
      SW(2)=DELTA(2)*R(2)*RR(2)*SL(2)*PI
      SW(3)=DELTA(3)*R(3)*RR(3)*SL(3)*PI
C     DEVELOPMENT OF HANDS
      I=4
    5 R(I)=FISTC/TWOPI
      RR(I)=R(I)
      SL(I)=2.*RR(I)
      ETA(I)=.5
      Y(I)=ETA(I)*SL(I)
      SW(I)=SW(4)
      DELTA(I)=SW(I)/R(I)/R(I)/R(I)/C1/4.
      IJ=I-3
      I=5
      GO TO (5,6),IJ
C     DEVELOPMENT OF UPPER ARMS
    6 IJ=1
      I=6
      R(I)=AXILC/TWOPI
      RR(I)=ELBC/TWOPI
      SL(I)=UPARL
      GO TO 20
C     DEVELOPMENT OF FOREARMS
    8 IJ=2
      I=8
      R(I)=ELBC/TWOPI
      RR(I)=WRISC/TWOPI
      SL(I)=FOARL
      GO TO 20
C     DEVELOPMENT OF UPPER LEGS
   10 IJ=3
      I=10
      R(I)=THIHC/TWOPI
      RR(I)=GKNEC/TWOPI
      SL(I)=STAT-SITH-TIBH
      GO TO 20
C     DEVELOPMENT OF LOWER LEGS
   12 IJ=4
      I=12
      R(I)=GKNEC/TWOPI
      RR(I)=ANKC/TWOPI
      SL(I)=TIBH-SPHYH
   20 G=R(I)*R(I)+R(I)*RR(I)+RR(I)*RR(I)
      DELTA(I)=SW(I)/SL(I)/G/C1
      AMU(I)=RR(I)/R(I)
      AMUSQ(I)=AMU(I)*AMU(I)
      SIGMA(I)=1.+AMU(I)+AMUSQ(I)
      ETA(I)=(1.+2.*AMU(I)+3.*AMUSQ(I))/SIGMA(I)/4.
      Y(I)=ETA(I)*SL(I)
      GO TO (8,10,12,14),IJ
C     DEVELOPMENT OF FEET
```

```
   14 I=14
      SL(I)=FOOTL
      ETA(I)=.429
      Y(I)=ETA(I)*SL(I)
      G=1.-2.*ETA(I)+SQRTF(ETA(I)*ETA(I)
     1     *(-12.)+12.*ETA(I)-2.)
      AMU(I)=(4.*ETA(I)-1.)/G
      AMUSQ(I)=AMU(I)*AMU(I)
      SIGMA(I)=1.+AMU(I)+AMUSQ(I)
      R(I)=SPHYH/2.
      RR(I)=AMU(I)*R(I)
      G=R(I)*R(I)+R(I)*RR(I)+RR(I)*RR(I)
      DELTA(I)=SW(I)/SL(I)/G/C1
   30 DO 31 I=7,15,2
      SW(I)=SW(I-1)
      DELTA(I)=DELTA(I-1)
      R(I)=R(I-1)
      RR(I)=RR(I-1)
      SL(I)=SL(I-1)
      AMU(I)=AMU(I-1)
      AMUSQ(I)=AMUSQ(I-1)
      SIGMA(I)=SIGMA(I-1)
      ETA(I)=ETA(I-1)
   31 Y(I)=Y(I-1)
   40 DO 41 I=1,5
      AMU(I)=0.
      AMUSQ(I)=0.
   41 SIGMA(I)=0.
C     CALCULATE SEGMENT MASS AND MASS DENSITY
C     CHECK SUM OF SEGMENT WEIGHTS EQUAL TO BODY WEIGHT
      CW=0.
   50 DO 51 I=1,15
      SM(I)=SW(I)/32.2
      DELTA(I)=DELTA(I)/32.2
   51 CW=CW+SW(I)
C     DETERMINATION OF LOCAL MOMENTS OF INERTIA OF SEGMENTS
C     HEAD
      I=1
      SIXX(I)=.2*SM(I)*(R(I)*R(I)+RR(I)*RR(I))
      SIYY(I)=SIXX(I)
      SIZZ(I)=.4*SM(I)*RR(I)*RR(I)
C     UPPER TORSO AND LOWER TORSO
      DO 52 I=2,3
      SIXX(I)=SM(I)*(3.*R(I)*R(I)+SL(I)*SL(I))/12.
      SIYY(I)=SM(I)*(3.*RR(I)*RR(I)+SL(I)*SL(I))/12.
   52 SIZZ(I)=SM(I)*(RR(I)*RR(I)+R(I)*R(I))/4.
C     HANDS
      I=4
      SIXX(I)=.4*SM(I)*R(I)*R(I)
      SIYY(I)=SIXX(I)
      SIZZ(I)=SIXX(I)
C     UPPER AND LOWER ARMS AND LEGS, AND FEET
      DO 53 I=6,14,2
      AA=9.*(1.+AMU(I)+AMUSQ(I)*(1.+AMU(I)+AMUSQ(I)))
```

```
     1      /SIGMA(I)/SIGMA(I)/20./PI
      BB=3.*(1.+4.*AMU(I)+AMUSQ(I)*(10.+4.*AMU(I)+AMUSQ(I)))
     1      /SIGMA(I)/SIGMA(I)/80.
      SIXX(I)=SM(I)*(AA*SM(I)/DELTA(I)/SL(I)+BB*SL(I)*SL(I))
      SIYY(I)=SIXX(I)
   53 SIZZ(I)=2.*SM(I)*SM(I)*AA/DELTA(I)/SL(I)
C     COMPLETE REMAINDER OF SEGMENTS
      DO 54 I=5,15,2
      SIXX(I)=SIXX(I-1)
      SIYY(I)=SIYY(I-1)
   54 SIZZ(I)=SIZZ(I-1)
C     CENTER OF GRAVITY OF HEAD,NECK AND TRUNK
      E(1,1)=SW(1)*Y(1)
      E(1,2)=SW(2)*(SL(1)+Y(2))
      E(1,3)=SW(3)*(SL(1)+SL(2)+Y(3))
      ETA123=(E(1,1)+E(1,2)+E(1,3))/(SW(1)+SW(2)+SW(3))
     1      /(STAT-TROCH)
C     CONVERT DENSITY TO SPECIFIC GRAVITY
      DO 55 I=1,15
   55 DELTA(I)=DELTA(I)*32.2/C2
C     DEFINE DISTANCES OF LOCAL CG FROM HINGE POINT
      DELSH=SITH-(STAT-TROCH)
      DO 60 I=1,15
   60 YY(I)=Y(I)
      YY(6)=Y(6)-R(6)
      YY(10)=Y(10)+DELSH
      YY(14)=0.
      DO 61 I=7,15,4
   61 YY(I)=YY(I-1)
C     DETERMINE FIXED HINGE POINTS
      DO 67 I=1,15
      DO 67 J=1,3
   67 H(I,J)=0.
      H(6,2)=CHESB/2.+R(6)
      H(6,3)=STAT-SHLDH+R(6)
      H(10,2)=HIPB/2.-R(10)
      H(10,3)=SL(1)+SL(2)+SL(3)-DELSH
      DO 68 I=7,11,4
      H(I,2)=-H(I-1,2)
   68 H(I,3)=H(I-1,3)
      RETURN
      END


      SUBROUTINE EULER
      COMMON N,W,CW,ETA123
      COMMON SW,SM,SL,R,RR,Y,DELTA,AMU,AMUSQ,SIGMA,ETA,YY
      COMMON STAT,CERV,SHLDH,SUPH,SUBH,TROCH,TIBH,UPARL
      COMMON FOARL,CHESD,WAISD,BUTTD,CHESB,WAISB,HIPB,AXILC
      COMMON ELBC,FOARC,WRISC,FISTC,THIHC,GKNEC,ANKC,SPHYH
      COMMON FOOTL,BIACD,HEADC,BISPB,SITH,DELSH
      COMMON XNAA,YNAA,ZNAA,XIXX,XIYY,XIZZ
      COMMON SIXX,SIYY,SIZZ
```

```
      COMMON THETA,SINT,COST,D,E,F,O,OT
      COMMON H,X,XCG,CI
      COMMON XMOD,YMOD,ZMOD
      COMMON XDIFR,YDIFR,ZDIFR,CIXX,CIYY,CIZZ,DIXX,DIYY,DIZZ
      COMMON PDIX,PDIY,PDIZ
      COMMON ALPHA,BETA,GAMMA,PMOM
      COMMON NERROR,MOSAIC,NI,NS,L1,L2,K
      DIMENSION SW(15),SM(15),SL(15),R(15),RR(15),Y(15)
      DIMENSION DELTA(15),AMU(15),AMUSC(15),SIGMA(15)
      DIMENSION ETA(15),YY(15)
      DIMENSION XNAA(7),YNAA(7),ZNAA(7)
      DIMENSION XIXX(7),XIYY(7),XIZZ(7)
      DIMENSION SIXX(15),SIYY(15),SIZZ(15)
      DIMENSION THETA(15,2),SINT(15,2),COST(15,2)
C               D(3,3),E(3,3),F(3,3) ARE DUMMY MATRICES
      DIMENSION D(3,3),E(3,3),F(3,3),O(3,3),OT(3,3)
      DIMENSION H(15,3),X(15,3),XCG(15,3,7),CI(3,3,7)
      DIMENSION XMOD(7),YMOD(7),ZMOD(7)
      DIMENSION XDIFR(7),YDIFR(7),ZDIFR(7)
      DIMENSION CIXX(7),CIYY(7),CIZZ(7)
      DIMENSION DIXX(7),DIYY(7),DIZZ(7)
      DIMENSION PDIX(7),PDIY(7),PDIZ(7)
      DIMENSION ALPHA(3,7),BETA(3,7),GAMMA(3,7),PMOM(3,7)
      DIMENSION NERROR(66,42),MOSAIC(43,43),NI(2,42),NS(66)
C     ESTABLISH EULER ANGLES
      PI=3.1415927
      C3=PI/180.
      K=K
      GO TO (1,4,6,9,12,14,17),K
C     STANDING
    1 K=1
      DO 2 I=10,12,2
      THETA(I,1)=-ATANF((H(10,2)-R(14))/
     1     (DELSH+SL(10)+SL(12)+R(14)))
    2 THETA(I+1,1)=-THETA(I,1)
      DO 3 I=14,15
      DO 3 J=1,2
    3 THETA(I,J)=90.*C3
      GO TO 21
C     STANDING, ARMS OVER HEAD
    4 K=2
      DO 5 I=4,9
    5 THETA(I,1)=180.*C3
      GO TO 21
C     SPREAD EAGLE
    6 K=3
      DO 7 I=4,8,2
      THETA(I,1)=135.*C3
      THETA(I+1,1)=-135.*C3
      THETA(I,2)=0.
    7 THETA(I+1,2)=0.
      DO 8 I=10,12,2
      THETA(I,1)=30.*C3
      THETA(I+1,1)=30.*C3
```

```
      THETA(I,2)=C.
    8 THETA(I+1,2)=180.*C3
      GO TO 21
C     SITTING
    9 K=4
      DO 10 I=8,11
      DO 10 J=1,2
      THETA(I-4,J)=90.*C3
   10 THETA(I,J)=90.*C3
      DO 11 I=6,12,6
      DO 11 J=1,2
      THETA(I,J)=C.
   11 THETA(I+1,J)=0.
      GO TO 21
C     SITTING, FOREARMS DOWN
   12 K=5
      DO 13 I=8,9
      DO 13 J=1,2
      THETA(I-4,J)=0.
   13 THETA(I,J)=C.
      GO TO 21
C     SITTING , THIGHS ELEVATED
   14 K=6
      DO 15 I=8,9
      DO 15 J=1,2
      THETA(I-4,J)=90.*C3
   15 THETA(I,J)=90.*C3
      DO 16 I=10,11
      THETA(I,1)=145.*C3
   16 THETA(I,2)=90.*C3
      GO TO 21
C     MERCURY POSITION
   17 K=7
      DO 18 I=4,5
      THETA(I,1)=80.*C3
   18 THETA(I,2)=90.*C3
      DO 19 I=8,11
      THETA(I,1)=80.*C3
   19 THETA(I,2)=90.*C3
      DO 20 I=12,13
      THETA(I,1)=12.*C3
   20 THETA(I,2)=90.*C3
C     CALCULATE SINE AND COS OF EULER ANGLES
   21 DO 22 I=1,15
      DO 22 J=1,2
      SINT(I,J)=SINF(THETA(I,J))
   22 COST(I,J)=COSF(THETA(I,J))
      RETURN
      END


      SUBROUTINE MCDMOM
      COMMON N,M,CK,CTA123
```

```
      COMMON SW,SM,SL,R,RR,Y,DELTA,AMU,AMUSQ,SIGMA,ETA,YY
      COMMON STAT,CERV,SHLDH,SUPH,SUBH,TROCH,TIBH,UPARL
      COMMON FOARL,CHESD,WAISD,BUTTD,CHESB,WAISB,HIPB,AXILC
      COMMON ELBC,FOARC,WRISC,FISTC,THIHC,GKNEC,ANKC,SPHYH
      COMMON FOOIL,BIACD,HEADC,BISPB,SITH,CELSH
      COMMON XNAA,YNAA,ZNAA,XIXX,XIYY,XIZZ
      COMMON SIXX,SIYY,SIZZ
      COMMON THETA,SINT,COST,D,E,F,O,OT
      COMMON H,X,XCG,CI
      COMMON XMOD,YMOD,ZMOD
      COMMON XDIFR,YDIFR,ZDIFR,CIXX,CIYY,CIZZ,DIXX,DIYY,DIZZ
      COMMON PDIX,PDIY,PDIZ
      COMMON ALPHA,BETA,GAMMA,PMOM
      COMMON NERROR,MOSAIC,NI,NS,L1,L2,K
      DIMENSION SW(15),SM(15),SL(15),R(15),RR(15),Y(15)
      DIMENSION DELTA(15),AMU(15),AMUSQ(15),SIGMA(15)
      DIMENSION ETA(15),YY(15)
      DIMENSION XNAA(7),YNAA(7),ZNAA(7)
      DIMENSION XIXX(7),XIYY(7),XIZZ(7)
      DIMENSION SIXX(15),SIYY(15),SIZZ(15)
      DIMENSION THETA(15,2),SINT(15,2),COST(15,2)
C                   D(3,3),E(3,3),F(3,3) ARE DUMMY MATRICES
      DIMENSION D(3,3),E(3,3),F(3,3),O(3,3),OT(3,3)
      DIMENSION H(15,3),X(15,3),XCG(15,3,7),CI(3,3,7)
      DIMENSION XMOD(7),YMOD(7),ZMOD(7)
      DIMENSION XDIFR(7),YDIFR(7),ZDIFR(7)
      DIMENSION CIXX(7),CIYY(7),CIZZ(7)
      DIMENSION DIXX(7),DIYY(7),DIZZ(7)
      DIMENSION PDIX(7),PDIY(7),PDIZ(7)
      DIMENSION ALPHA(3,7),BETA(3,7),GAMMA(3,7),PMOM(3,7)
      DIMENSION NERROR(66,42),MOSAIC(43,43),NI(2,42),NS(66)
      DIMENSION EV(3)
      K=K
      PI=3.1415927
      C3=PI/180.
C     ZERO DUMMY MATRICES D,E,F
      DO 1 II=1,3
      DO 1 JJ=1,3
      D(II,JJ)=0.
      E(II,JJ)=0.
    1 F(II,JJ)=0.
C     ZERO C.G. ARRAY
      DO 2 I=1,15
      DO 2 J=1,3
    2 X(I,J)=0.
C     ZERO THE INERTIA TENSOR ARRAY
      DO 3 II=1,3
      DO 3 JJ=1,3
    3 CI(II,JJ,K)=0.
C     CALCULATE HINGE POINTS OF MOVEABLE SEGMENTS
C     FOREARMS
      DO 9 I=8,9
      G=SL(I-2)-R(I-2)
      E(1,1)=SINT(I-2,1)*SINT(I-2,2)
```

```
      E(2,1)=SINT(I-2,1)*COST(I-2,2)
      E(3,1)=COST(I-2,1)
      DO 9 J=1,3
    9 H(I,J)=H(I-2,J)+E(J,1)*G
C     LOWER LEGS
      DO 10 I=12,13
      G=SL(I-2)+DELSH
      E(1,1)=SINT(I-2,1)*SINT(I-2,2)
      E(2,1)=SINT(I-2,1)*COST(I-2,2)
      E(3,1)=COST(I-2,1)
      DO 10 J=1,3
   10 H(I,J)=H(I-2,J)+E(J,1)*G
C     HANDS
      DO 11 I=4,5
      G=SL(I+4)
      E(1,1)=SINT(I+4,1)*SINT(I+4,2)
      E(2,1)=SINT(I+4,1)*COST(I+4,2)
      E(3,1)=COST(I+4,1)
      DO 11 J=1,3
   11 H(I,J)=H(I+4,J)+E(J,1)*G
C     FEET
      DO 12 I=14,15
      G=SL(I-2)+.5*SPHYH
      E(1,1)=SINT(I-2,1)*SINT(I-2,2)
      E(2,1)=SINT(I-2,1)*COST(I-2,2)
      E(3,1)=COST(I-2,1)
      DO 12 J=1,3
   12 H(I,J)=H(I-2,J)+E(J,1)*G
C     DETERMINE CCORD CF SEGMENT CG WRT TOP OF HEAC
      X(1,3)=Y(1)
      X(2,3)=SL(1)+Y(2)
      X(3,3)=SL(1)+SL(2)+Y(3)
      DO 13 I=4,15
      G=YY(I)
      F(1,1)=SINT(I,1)*SINT(I,2)
      F(2,1)=SINT(I,1)*COST(I,2)
      F(3,1)=COST(I,1)
      DO 13 J=1,3
   13 X(I,J)=H(I,J)+F(J,1)*G
      YNMA(K)=0.
      XMOD(K)=2.144323+0.152104*WAISD
      YMOD(K)=0.
      ZMOD(K)=0.
      DO 14 I=1,15
      XMOD(K)=XMOD(K)+SW(I)*X(I,1)/W
      YMOD(K)=YMOD(K)+SW(I)*X(I,2)/W
   14 ZMOD(K)=ZMOD(K)+SW(I)*X(I,3)/W
C     DETERMINE CCORD CF SEGMENT CG WRT CALC CG
      DO 15 I=1,15
      XCG(I,1,K)=X(I,1)-(XMOD(K)-XMOD(1))
      XCG(I,2,K)=X(I,2)-YMOD(K)
   15 XCG(I,3,K)=X(I,3)-ZMOD(K)
      DO 30 I=1,15
C     ARRANGE LOCAL MOMENTS INTO DUMMY MATRIX (3 X 3)
```

```
      DO 24 II=1,3
      DO 24 JJ=1,3
   24 D(II,JJ)=0.
      D(1,1)=SIXX(I)
      D(2,2)=SIYY(I)
      D(3,3)=SIZZ(I)
C     ARRANGE TRANSFORMATION MATRIX
   25 O(1,1)=COST(I,2)
      O(1,2)=SINT(I,2)*COST(I,1)
      O(1,3)=SINT(I,2)*SINT(I,1)
      O(2,1)=-SINT(I,2)
      O(2,2)=COST(I,2)*COST(I,1)
      O(2,3)=COST(I,2)*SINT(I,1)
      O(3,1)=0.
      O(3,2)=-SINT(I,1)
      O(3,3)=COST(I,1)
C     TRANSPOSE THE TRANSFORMATION MATRIX
   26 OT(1,1)=O(1,1)
      OT(1,2)=O(2,1)
      OT(1,3)=O(3,1)
      OT(2,1)=O(1,2)
      OT(2,2)=O(2,2)
      OT(2,3)=O(3,2)
      OT(3,1)=O(1,3)
      OT(3,2)=O(2,3)
      OT(3,3)=O(3,3)
      CALL HMMPY(D,OT,E,3,3,3,LM)
      CALL HMMPY(O,E,F,3,3,3,LM)
C     F(3,3) IS LOCAL MOMENT ROTATED PARALLEL TO BODY AXES
C     TRANSFER TO CALC CG BY PARALLEL AXIS THEOREM
      D(1,1)=XCG(I,2,K)*XCG(I,2,K)+XCG(I,3,K)*XCG(I,3,K)
      D(1,2)=-XCG(I,1,K)*XCG(I,2,K)
      D(1,3)=-XCG(I,1,K)*XCG(I,3,K)
      D(2,1)=D(1,2)
      D(2,2)=XCG(I,1,K)*XCG(I,1,K)+XCG(I,3,K)*XCG(I,3,K)
      D(2,3)=-XCG(I,2,K)*XCG(I,3,K)
      D(3,1)=D(1,3)
      D(3,2)=D(2,3)
      D(3,3)=XCG(I,1,K)*XCG(I,1,K)+XCG(I,2,K)*XCG(I,2,K)
      DO 30 II=1,3
      DO 30 JJ=1,3
      D(II,JJ)=SM(I)*D(II,JJ)/144.
      F(II,JJ)=F(II,JJ)/144.
   30 CI(II,JJ,K)=CI(II,JJ,K)+F(II,JJ)+D(II,JJ)
      DO 32 II=1,3
      DO 32 JJ=1,3
      IF(ABSF(CI(II,JJ,K))-1.E-07)31,31,32
   31 CI(II,JJ,K)=0.
   32 CONTINUE
C     CONVERT NAA MOMENTS TO SLUG-FT-FT
      XIXX(K)=XIXX(K)/12.
      XIYY(K)=XIYY(K)/12.
      XIZZ(K)=XIZZ(K)/12.
C     CALCULATE DIFFERENCE BETWEEN MODEL C.G. AND NAA C.G.
```

```
      XDIFR(K)=XMCD(K)-XNAA(K)
      YDIFR(K)=YMCD(K)-YNAA(K)
      ZDIFR(K)=ZMCD(K)-ZNAA(K)
C     CALCULATE DIFFERENCES AND PERCENTAGE DIFFERENCES
C     BETWEEN MODEL MOMENTS AND NAA MOMENTS
      CIXX(K)=CI(1,1,K)
      CIYY(K)=CI(2,2,K)
      CIZZ(K)=CI(3,3,K)
      DIXX(K)=CIXX(K)-XIXX(K)
      DIYY(K)=CIYY(K)-XIYY(K)
      DIZZ(K)=CIZZ(K)-XIZZ(K)
      PDIX(K)=DIXX(K)/XIXX(K)*100.
      PDIY(K)=DIYY(K)/XIYY(K)*100.
   33 PDIZ(K)=DIZZ(K)/XIZZ(K)*100.
C     CALCULATE PRINCIPAL MOMENTS AND AXES
      DO 34 II=1,3
      DO 34 JJ=1,3
   34 D(II,JJ)=CI(II,JJ,K)
      CALL EIGEN(D,E,EV,3,6)
      PMOM(1,K)=EV(1)
      PMOM(2,K)=EV(2)
      PMOM(3,K)=EV(3)
      DO 35 II=1,3
      ALPHA(II,K)=ACOS(E(II,1))/C3
      BETA(II,K)=ACOS(E(II,2))/C3
   35 GAMMA(II,K)=ACOS(E(II,3))/C3
C     ARRANGE ERROR TABLE
      NERROR(N,K)=XFIXF(10.*XDIFR(K)+SIGNF(.5,XDIFR(K)))
      NERROR(N,K+7)=XFIXF(10.*YDIFR(K)+SIGNF(.5,YDIFR(K)))
      NERROR(N,K+14)=XFIXF(10.*ZDIFR(K)+SIGNF(.5,ZDIFR(K)))
      NERROR(N,K+21)=XFIXF(PDIX(K)+SIGNF(.5,PDIX(K)))
      NERROR(N,K+28)=XFIXF(PDIY(K)+SIGNF(.5,PDIY(K)))
   37 NERROR(N,K+35)=XFIXF(PDIZ(K)+SIGNF(.5,PDIZ(K)))
      RETURN
      END


CHMMPY      MATRIX MULTIPLICATION, SINGLE PRECISION, FL. PT
C     CALLING SEQUENCE...
C     CALL HMMPY(A,B,C,M,K,N,L)
C        WHERE C(M,N)=A(M,K)*B(K,N)
C          (C MAY BE A, IN WHICH CASE A IS DESTROYED)
C        L=0 INDICATES OK
C        L=1 INDICATES FL. PT. OVERFLOW
      SUBROUTINE HMMPY(A,B,C,M,K,N,L)
      DIMENSION A(3,3),B(3,3),C(3,3),R(3)
      MM=M
      KK=K
      NN=N
      LL=0
      DO 120 I=1,MM
      DO 100 J=1,NN
      R(J)=0.
```

```
      DO 100 K1=1,KK
100   R(J)=A(I,K1)*B(K1,J)+R(J)
      DO 110 J=1,AN
110   C(I,J)=R(J)
      IF ACCUMULATOR OVERFLOW 130,120
120   CONTINUE
125   L=LL
      RETURN
130   LL=1
      GO TO 125
      END



      SUBROUTINE EIGEN(A,E,G,NA,L)
      DIMENSION A(3,3),E(3,3),G(3)
      N=NA
      DO 110 I=1,N
      DO 100 J=1,N
100   E(I,J)=0.0
110   E(I,I)=1.0
      FN=0.0
      FNO=0.0
      DO 130 I=1,N
      DO 120 J=1,N
      FN=FN+A(I,J)**2
120   FNO=FNO+A(I,J)**2
130   FNO=FNO-A(I,I)**2
      FN=FN*0.5*(10.**(-L))
      IF (FNO)-FN)240,240,135
135   DO 230 I=1,N
      DO 230 J=1,N
      IF (I-J) 140,230,140
140   IF (A(I,J)) 150,230,150
150   R=A(I,I)-A(J,J)
      S=SQRTF(A(I,J)**2+0.25*R*R)
      T=A(I,I)+A(J,J)
      COSSQ=0.5+0.25*R/S
      COSTH=SQRTF(COSSQ)
      SINTH=SQRTF(1.0-COSSQ)
      IF (A(I,J)) 160,230,170
160   SINTH=-SINTH
170   A(I,I)=0.5*T+S
      A(J,J)=0.5*T-S
      FNO=FNO-2.*(A(I,J)**2)
      A(I,J)=0.0
      DO 220 K=1,N
      IF(I-K)180,205,180
180   IF (J-K) 190,200,190
190   A(I,K)=A(I,K)*COSTH+A(J,K)*SINTH
      A(J,K)=A(J,K)*COSTH-A(K,I)*SINTH
      A(K,J)=A(J,K)
200   A(K,I)=A(I,K)
205   T=E(I,K)
```

```
210   E(I,K)=E(I,K)*COSTH+E(J,K)*SINTH
220   E(J,K)=-T*SINTH+E(J,K)*COSTH
      IF (FND-FN) 240,240,230
230   CONTINUE
      GO TO 135
240   DO 280 I=1,N
      J=I
      DO 260 K=I,N
      IF(A(J,J)-A(K,K))250,260,260
250   J=K
260   CONTINUE
      G(I)=A(J,J)
      A(J,J)=A(I,I)
      SUM=0.0
      DO 270 M=1,N
270   SUM=SUM+E(J,M)**2
      SUM=SQRTF(SUM)
      DO 280 M=1,N
      A(I,M)=E(J,M)/SUM
280   E(J,M)=E(I,M)
      DO 290 I=1,N
      DO 290 J=1,N
290   E(I,J)=A(I,J)
      RETURN
      END


      SUBROUTINE OUTPUT
      COMMON N,W,CW,ETA123
      COMMON SW,SM,SL,R,RR,Y,DELTA,AMU,AMUSC,SIGMA,ETA,YY
      COMMON STAT,CERV,SHLDH,SUPH,SUBH,TROCH,TIBH,UPARL
      COMMON FOARL,CHESD,WAISD,BUTTD,CHESB,WAISB,HIPB,AXILC
      COMMON ELBC,FOARC,WRISC,FISTC,THIHC,GKNEC,ANKC,SPHYH
      COMMON FOOTL,BIACD,HEADC,BISPB,SITH,DELSH
      COMMON XNAA,YNAA,ZNAA,XIXX,XIYY,XIZZ
      COMMON SIXX,SIYY,SIZZ
      COMMON THETA,SINT,COST,D,E,F,C,CT
      COMMON H,X,XCG,CI
      COMMON XMOD,YMOD,ZMOD
      COMMON XDIFR,YDIFR,ZDIFR,CIXX,CIYY,CIZZ,DIXX,DIYY,DIZZ
      COMMON PDIX,PDIY,PDIZ
      COMMON ALPHA,BETA,GAMMA,PMOM
      COMMON NERROR,MOSAIC,NI,NS,L1,L2,K
      DIMENSION SW(15),SM(15),SL(15),R(15),RR(15),Y(15)
      DIMENSION DELTA(15),AMU(15),AMUSC(15),SIGMA(15)
      DIMENSION ETA(15),YY(15)
      DIMENSION XNAA(7),YNAA(7),ZNAA(7)
      DIMENSION XIXX(7),XIYY(7),XIZZ(7)
      DIMENSION SIXX(15),SIYY(15),SIZZ(15)
      DIMENSION THETA(15,2),SINT(15,2),COST(15,2)
                D(3,3),E(3,3),F(3,3) ARE DUMMY MATRICES
      DIMENSION D(3,3),E(3,3),F(3,3),O(3,3),OT(3,3)
      DIMENSION H(15,3),X(15,3),XCG(15,3,7),CI(3,3,7)
```

```
      DIMENSION XMOD(7),YMOD(7),ZMOD(7)
      DIMENSION XDIFR(7),YDIFR(7),ZDIFR(7)
      DIMENSION CIXX(7),CIYY(7),CIZZ(7)
      DIMENSION DIXX(7),DIYY(7),DIZZ(7)
      DIMENSION PDIX(7),PDIY(7),PDIZ(7)
      DIMENSION ALPHA(3,7),BETA(3,7),GAMMA(3,7),PMOM(3,7)
      DIMENSION NERROR(66,42),MOSAIC(43,43),NI(2,42),NS(66)
C     OUTPUT
      IF (SENSE LIGHT 2)100,199
C     PREPARE MASTER TAPE WITH ANTHROPOMETRIC DATA,
C     NAA CG DATA AND MOMENTS OF INERTIA,
C     SEGMENT CHARACTERISTICS AND LOCAL MOMENTS
  100 WRITE OUTPUT TAPE 5,101,N,W,ETA123,DELSH
  101 FORMAT(3H1N=I3,3X,2HW=F6.1,5X,7HETA123=2PE10.2,5X,
     1      6HDELSH=1PE9.2)
      WRITE OUTPUT TAPE 5,102,STAT,CERV,SHLDH,SUPH,SUBH,
     1      TROCH,TIBH,UPARL,FOARL,CHESD,WAISD,BUTTD,CHESB,
     2      WAISB,HIPB,AXILC,ELBC,FOARC,WRISC,FISTC,THIHC,
     3      GKNEC,ANKC,SPHYH,FOOTL,BIACC,HEADC,BISPB,SITH
  102 FORMAT(15F5.1)
      WRITE OUTPUT TAPE 5,103,SW
  103 FORMAT(6H SW   ,3E18.8/6X,6E18.8/6X,6E18.8)
      WRITE OUTPUT TAPE 5,104,SM
  104 FORMAT(6H SM   ,3E18.8/6X,6E18.8/6X,6E18.8)
      WRITE OUTPUT TAPE 5,105,SL
  105 FORMAT(6H SL   ,3E18.8/6X,6E18.8/6X,6E18.8)
      WRITE OUTPUT TAPE 5,106,R
  106 FORMAT(6H R    ,3E18.8/6X,6E18.8/6X,6E18.8)
      WRITE OUTPUT TAPE 5,107,RR
  107 FORMAT(6H RR   ,3E18.8/6X,6E18.8/6X,6E18.8)
      WRITE OUTPUT TAPE 5,108,Y
  108 FORMAT(6H Y    ,3E18.8/6X,6E18.8/6X,6E18.8)
      WRITE OUTPUT TAPE 5,109,DELTA
  109 FORMAT(6H DELTA,3E18.8/6X,6E18.8/6X,6E18.8)
      WRITE OUTPUT TAPE 5,110,AMU
  110 FORMAT(6H AMU  ,3E18.8/6X,6E18.8/6X,6E18.8)
      WRITE OUTPUT TAPE 5,111,AMUSQ
  111 FORMAT(6H AMUSQ,3E18.8/6X,6E18.8/6X,6E18.8)
      WRITE OUTPUT TAPE 5,112,SIGMA
  112 FORMAT(6H SIGMA,3E18.8/6X,6E18.8/6X,6E18.8)
      WRITE OUTPUT TAPE 5,113,ETA
  113 FORMAT(6H ETA  ,3E18.8/6X,6E18.8/6X,6E18.8)
      WRITE OUTPUT TAPE 5,114,YY
  114 FORMAT(6H YY   ,3E18.8/6X,6E18.8/6X,6E18.8)
      WRITE OUTPUT TAPE 5,115,SIXX
  115 FORMAT(6H SIXX ,3E18.8/6X,6E18.8/6X,6E18.8)
      WRITE OUTPUT TAPE 5,116,SIYY
  116 FORMAT(6H SIYY ,3E18.8/6X,6E18.8/6X,6E18.8)
      WRITE OUTPUT TAPE 5,117,SIZZ
  117 FORMAT(6H SIZZ ,3E18.8/6X,6E18.8/6X,6E18.8)
  199 IF (SENSE LIGHT 1)200,300
  200 WRITE OUTPUT TAPE 3,201,N,W,CW,ETA123
  201 FORMAT(3H1N=I4,5X,3H W=F6.1,10X,3HCW=3PE10.1,5X,
     1      7HETA123=2PE9.1)
```

```
      WRITE OUTPUT TAPE 3,202
  202 FORMAT(1H0,13X,1H1,14X,1H2,14X,1H3,14X,1H4,14X,1H5,
     1       14X,1H6,14X,1H7)
      WRITE OUTPUT TAPE 3,203,XNAA
  203 FORMAT(6H XNAA ,4X,7(1PE10.2,5X))
      WRITE OUTPUT TAPE 3,204,XMOD
  204 FORMAT(6H XMOD ,4X,7(1PE10.2,5X))
      WRITE OUTPUT TAPE 3,205,XDIFR
  205 FORMAT(6H XDIFR,4X,7(E10.2,5X))
      WRITE OUTPUT TAPE 3,202
      WRITE OUTPUT TAPE 3,206,YNAA
  206 FORMAT(6H YNAA ,4X,7(1PE10.2,5X))
      WRITE OUTPUT TAPE 3,207,YMOD
  207 FORMAT(6H YMOD ,4X,7(1PE10.2,5X))
      WRITE OUTPUT TAPE 3,208,YDIFR
  208 FORMAT(6H YDIFR,4X,7(E10.2,5X))
      WRITE OUTPUT TAPE 3,202
      WRITE OUTPUT TAPE 3,209,ZNAA
  209 FORMAT(6H ZNAA ,4X,7(2PE10.1,5X))
      WRITE OUTPUT TAPE 3,210,ZMOD
  210 FORMAT(6H ZMOD ,4X,7(2PE10.1,5X))
      WRITE OUTPUT TAPE 3,211,ZDIFR
  211 FORMAT(6H ZDIFR,4X,7(E10.2,5X))
      WRITE OUTPUT TAPE 3,202
      WRITE OUTPUT TAPE 3,212,XIXX
  212 FORMAT(6H XIXX ,4X,7(1PE10.2,5X))
      WRITE OUTPUT TAPE 3,213,CIXX
  213 FORMAT(6H CIXX ,4X,7(1PE10.2,5X))
      WRITE OUTPUT TAPE 3,214,DIXX
  214 FORMAT(6H DIXX ,4X,7(1PE10.2,5X))
      WRITE OUTPUT TAPE 3,215,PDIX
  215 FORMAT(6H PDIX ,4X,7(E10.2,5X))
      WRITE OUTPUT TAPE 3,202
      WRITE OUTPUT TAPE 3,216,XIYY
  216 FORMAT(6H XIYY ,4X,7(1PE10.2,5X))
      WRITE OUTPUT TAPE 3,217,CIYY
  217 FORMAT(6H CIYY ,4X,7(1PE10.2,5X))
      WRITE OUTPUT TAPE 3,218,DIYY
  218 FORMAT(6H DIYY ,4X,7(1PE10.2,5X))
      WRITE OUTPUT TAPE 3,219,PDIY
  219 FORMAT(6H PDIY ,4X,7(E10.2,5X))
      WRITE OUTPUT TAPE 3,202
      WRITE OUTPUT TAPE 3,220,XIZZ
  220 FORMAT(6H XIZZ ,4X,7(1PE10.2,5X))
      WRITE OUTPUT TAPE 3,221,CIZZ
  221 FORMAT(6H CIZZ ,4X,7(1PE10.2,5X))
      WRITE OUTPUT TAPE 3,222,DIZZ
  222 FORMAT(6H DIZZ ,4X,7(1PE10.2,5X))
      WRITE OUTPUT TAPE 3,223,PDIZ
  223 FORMAT(6H PDIZ ,4X,7(E10.2,5X))
      WRITE OUTPUT TAPE 3,202
      WRITE OUTPUT TAPE 3,224,(PMOM(1,K),K=1,7)
  224 FORMAT(7H PMOM 1,4X,7(1PE10.2,5X))
      WRITE OUTPUT TAPE 3,225,(PMOM(2,K),K=1,7)
```

```
225 FORMAT(7H PMOM 2,4X,7(1PE10.2,5X))
    WRITE OUTPUT TAPE 3,226,(PMOM(3,K),K=1,7)
226 FORMAT(7H PMOM 3,4X,7(1PE10.2,5X))
    WRITE OUTPUT TAPE 3,202
    WRITE OUTPUT TAPE 3,228,(ALPHA(1,K),K=1,7)
228 FORMAT(8H ALPHA 1,2X,7(1PE10.2,5X))
    WRITE OUTPUT TAPE 3,229,(BETA(1,K),K=1,7)
229 FORMAT(8H  BETA 1,2X,7(1PE10.2,5X))
    WRITE OUTPUT TAPE 3,230,(GAMMA(1,K),K=1,7)
230 FORMAT(8H GAMMA 1,2X,7(1PE10.2,5X))
    WRITE OUTPUT TAPE 3,202
    WRITE OUTPUT TAPE 3,231,(ALPHA(2,K),K=1,7)
231 FORMAT(8H ALPHA 2,2X,7(1PE10.2,5X))
    WRITE OUTPUT TAPE 3,232,(BETA(2,K),K=1,7)
232 FORMAT(8H  BETA 2,2X,7(1PE10.2,5X))
    WRITE OUTPUT TAPE 3,233,(GAMMA(2,K),K=1,7)
233 FORMAT(8H GAMMA 2,2X,7(1PE10.2,5X))
    WRITE OUTPUT TAPE 3,202
    WRITE OUTPUT TAPE 3,234,(ALPHA(3,K),K=1,7)
234 FORMAT(8H ALPHA 3,2X,7(1PE10.2,5X))
    WRITE OUTPUT TAPE 3,235,(BETA(3,K),K=1,7)
235 FORMAT(8H  BETA 3,2X,7(1PE10.2,5X))
    WRITE OUTPUT TAPE 3,236,(GAMMA(3,K),K=1,7)
236 FORMAT(8H GAMMA 3,2X,7(1PE10.2,5X))
    WRITE OUTPUT TAPE 3,237
237 FORMAT(40HALENGTH IN INCHES, MOMENT OF INERTIA IN ,
   1      29HSLUG-FT-FT,ANGLES IN DEGREES.)
300 RETURN
    END


    SUBROUTINE ANALYZ
    COMMON N,W,CW,ETA123
    COMMON SW,SM,SL,R,RR,Y,DELTA,AMU,AMUSQ,SIGMA,ETA,YY
    COMMON STAT,CERV,SHLDH,SUPH,SUBH,TROCH,TIBH,UPARL
    COMMON FOARL,CHESD,WAISD,BUTTD,CHESB,WAISB,HIPB,AXILC
    COMMON ELBC,FOARC,WRISC,FISTC,THIHC,GKNEC,ANKC,SPHYH
    COMMON FOOTL,BIACD,HEADC,BISPB,SITH,CELSH
    COMMON XNAA,YNAA,ZNAA,XIXX,XIYY,XIZZ
    COMMON SIXX,SIYY,SIZZ
    COMMON THETA,SINT,COST,D,E,F,O,OT
    COMMON H,X,XCG,CI
    COMMON XMOD,YMOD,ZMOD
    COMMON XDIFR,YDIFR,ZDIFR,CIXX,CIYY,CIZZ,DIXX,DIYY,DIZZ
    COMMON PDIX,PDIY,PDIZ
    COMMON ALPHA,BETA,GAMMA,PMOM
    COMMON NERROR,MOSAIC,NI,NS,L1,L2,K
    DIMENSION SW(15),SM(15),SL(15),R(15),RR(15),Y(15)
    DIMENSION DELTA(15),AMU(15),AMUSQ(15),SIGMA(15)
    DIMENSION ETA(15),YY(15)
    DIMENSION XNAA(7),YNAA(7),ZNAA(7)
    DIMENSION XIXX(7),XIYY(7),XIZZ(7)
    DIMENSION SIXX(15),SIYY(15),SIZZ(15)
```

```
      DIMENSION THETA(15,2),SINT(15,2),COST(15,2)
C                 D(3,3),E(3,3),F(3,3) ARE DUMMY MATRICES
      DIMENSION D(3,3),E(3,3),F(3,3),O(3,3),OT(3,3)
      DIMENSION H(15,3),X(15,3),XCG(15,3,7),CI(3,3,7)
      DIMENSION XMOD(7),YMOD(7),ZMOD(7)
      DIMENSION XDIFR(7),YDIFR(7),ZDIFR(7)
      DIMENSION CIXX(7),CIYY(7),CIZZ(7)
      DIMENSION DIXX(7),DIYY(7),DIZZ(7)
      DIMENSION PDIX(7),PDIY(7),PDIZ(7)
      DIMENSION ALPHA(3,7),BETA(3,7),GAMMA(3,7),PMOM(3,7)
      DIMENSION NERROR(66,42),MOSAIC(43,43),NI(2,42),NS(66)
      WRITE OUTPUT TAPE 3,100
  100 FORMAT(1H1,54X,16HDIFFERENCE TABLE)
      WRITE OUTPUT TAPE 3,101
  101 FORMAT(1HB,14X,1HX,20X,1HY,20X,1HZ,19X,3HIXX,18X,
     1      3HIYY,18X,3HIZZ)
      WRITE OUTPUT TAPE 3,102
  102 FORMAT( 4HA NO,
     1      42H  1  2  3  4  5  6  7  1  2  3  4  5  6  7,
     2      42H  1  2  3  4  5  6  7  1  2  3  4  5  6  7,
     3      42H  1  2  3  4  5  6  7  1  2  3  4  5  6  7)
      WRITE OUTPUT TAPE 3,103
  103 FORMAT(1H0)
      DO 1 II=1,2
      DO 1 JJ=1,42
    1 NI(II,JJ)=0
      DO 5 IL=1,66
      II=NS(IL)
    5 WRITE OUTPUT TAPE 3,104,II,(NERROR(II,KK),KK=1,42)
  104 FORMAT(1H ,43I3)
C     CALCULATE AVERAGE ERROR
      DO 6 JJ=1,42
      DO 6 II=1,66
    6 NI(2,JJ)=NI(2,JJ)+NERROR(II,JJ)
      DO 7 JJ=1,42
    7 NI(2,JJ)=NI(2,JJ)/66
C     ARRANGE ERROR ANALYSIS ARRAY AND LOCATE MEDIAN
      DO 8 II=1,43
      DO 8 JJ=1,43
    8 MOSAIC(II,JJ)=0
      DO 10 JJ=1,1
      MOSAIC(1,JJ)=30
      MOSAIC(2,JJ)=20
      DO 9 II=3,42
    9 MOSAIC(II,JJ)=MOSAIC(II-1,JJ)-1
   10 MOSAIC(43,JJ)=-30
      DO 15 K=2,43
      DO 15 N=1,66
      MADD=NERROR(N,K-1)
      IF(XABSF(MADD)-20)14,14,11
   11 IF(MADD)13,14,12
   12 MOSAIC(1,K)=MOSAIC(1,K)+1
      GO TO 15
   13 MOSAIC(43,K)=MOSAIC(43,K)+1
```

```
      GO TO 15
   14 MADD=-MADD
      MOSAIC(MADD+22,K)=MOSAIC(MADD+22,K)+1
   15 CONTINUE
      WRITE OUTPUT TAPE 3,105
  105 FORMAT(1H1,55X,14HERROR ANALYSIS)
      WRITE OUTPUT TAPE 3,101
      WRITE OUTPUT TAPE 3,102
      WRITE OUTPUT TAPE 3,103
   20 WRITE OUTPUT TAPE 3,107,((MOSAIC(II,JJ),JJ=1,43),
     1      II=1,43)
  107 FORMAT(1H ,43I3)
      DO 24 JJ=2,43
      MD=0
      NO=1
   22 MD=MOSAIC(NO,JJ)+MD
      IF(MD-33)23,24,24
   23 NO=NO+1
      GO TO 22
   24 NI(1,JJ-1)=22-NO
      WRITE OUTPUT TAPE 3,108,(NI(1,JJ),JJ=1,42)
  108 FORMAT(4HMED,42I3)
      WRITE OUTPUT TAPE 3,109,(NI(2,JJ),JJ=1,42)
  109 FORMAT(4H AVE,42I3)
      WRITE OUTPUT TAPE 3,110
  110 FORMAT(33HAC.G. ERRORS ARE IN TENTHS OF INC,
     1      33HHES,MOMENT ERRORS ARE IN PER CENT)
      RETURN
      END
```

APPENDIX F

COMPUTER PROGRAM APMOD (FORTRAN II)

```
      COMMON N,W,CW,ETA123
      COMMON STAT,SHLDH,SUBH,TROCH,TIBH,UPARL,FOARL,CHESD,
     1       WAISD,BUTTD,CHESB,WAISB,HIPB,AXILC,ELBC,WRISC,
     2       FISTC,THIHC,GKNEC,ANKC,SPHYH,FOOTL,SITH,HEADC
      COMMON SW,SM,SL,R,RR,Y,DELTA,AMU,AMUSQ,SIGMA,ETA,YY
      COMMON SIXX,SIYY,SIZZ
      COMMON THETA,SINT,COST,D,E,F,O,OT
      COMMON H,X,XCG,CI
      COMMON XMOD,YMOD,ZMOD,DELSH
      COMMON ALPHA,BETA,GAMMA,PMCM
      COMMON L1,L2,K
      DIMENSION SW(15),SM(15),SL(15),R(15),RR(15),Y(15)
      DIMENSION DELTA(15),AMU(15),AMUSQ(15),SIGMA(15)
      DIMENSION ETA(15),YY(15)
      DIMENSION SIXX(15),SIYY(15),SIZZ(15)
      DIMENSION THETA(15,2),SINT(15,2),COST(15,2)
C                D(3,3),E(3,3),F(3,3) ARE DUMMY MATRICES
      DIMENSION D(3,3),E(3,3),F(3,3),O(3,3),OT(3,3)
      DIMENSION H(15,3),X(15,3),XCG(15,3,7),CI(3,3,7)
      DIMENSION XMOD(7),YMOD(7),ZMOD(7)
      DIMENSION ALPHA(3,7),BETA(3,7),GAMMA(3,7),PMCM(3,7)
      READ INPUT TAPE 2,100,L1,L2
  100 FORMAT(2I5)
C     OUTPUT DESIRED
C     NORMAL    MASTER      CARD PUNCHED
C       NO        NO          0     0
C       NO        YES         0     1
C       YES       NO          1     0
C       YES       YES         1     1
    1 SENSE LIGHT 0
      IF(L1-1)3,2,3
    2 SENSE LIGHT 1
    3 IF(L2-1)5,4,4
    4 SENSE LIGHT 2
    5 READ INPUT TAPE 2,101,N,W
  101 FORMAT(I5,4X,F6.1)
      READ INPUT TAPE 2,102,STAT,SHLDH,SUBH,TROCH,TIBH,
     1     UPARL,FOARL,CHESD,WAISD,BUTTD,CHESB,WAISB,HIPB,
     2     AXILC,ELBC,WRISC,FISTC,THIHC,GKNEC,ANKC,
     3     SPHYH,FOOTL,HEADC,SITH
  102 FORMAT(12F5.1)
      CALL DESIGN
      DO 6 I=1,15
      DO 6 J=1,2
```

```
    6 THETA(I,J)=0.
      K=1
    7 CALL EULER
      CALL MODMOM
      K=K+1
      IF(K-8)7,8,7
    8 CALL OUTPUT
      GO TO 1
       END


      SUBROUTINE DESIGN
      COMMON N,W,CW,ETA123
      COMMON STAT,SHLDH,SUBH,TROCH,TIBH,UPARL,FOARL,CHESD,
     1       WAISD,BUTTD,CHESB,WAISB,HIPB,AXILC,ELBC,WRISC,
     2       FISTC,THIHC,GKNEC,ANKC,SPHYH,FOOTL,SITH,HEADC
      COMMON SW,SM,SL,R,RR,Y,DELTA,AMU,AMUSQ,SIGMA,ETA,YY
      COMMON SIXX,SIYY,SIZZ
      COMMON THETA,SINT,COST,D,E,F,O,OT
      COMMON H,X,XCG,CI
      COMMON XMOD,YMOD,ZMOD,DELSH
      COMMON ALPHA,BETA,GAMMA,PMOM
      COMMON L1,L2,K
      DIMENSION SW(15),SM(15),SL(15),R(15),RR(15),Y(15)
      DIMENSION DELTA(15),AMU(15),AMUSQ(15),SIGMA(15)
      DIMENSION ETA(15),YY(15)
      DIMENSION SIXX(15),SIYY(15),SIZZ(15)
      DIMENSION THETA(15,2),SINT(15,2),COST(15,2)
C               D(3,3),E(3,3),F(3,3) ARE DUMMY MATRICES
      DIMENSION D(3,3),E(3,3),F(3,3),O(3,3),OT(3,3)
      DIMENSION H(15,3),X(15,3),XCG(15,3,7),CI(3,3,7)
      DIMENSION XMOD(7),YMOD(7),ZMOD(7)
      DIMENSION ALPHA(3,7),BETA(3,7),GAMMA(3,7),PMOM(3,7)
      PI=3.1415927
      TWOPI=2.*PI
      C1=PI/3.
      C2=62.427/1728.
C     DESIGN MODEL MAN BY USING ANTHROPOMETRIC DIMENSIONS
C     APPLY BARTER REGRESSION EQUATION TO SUBJECT WEIGHT
    1 HNT=(.47*W)+12.
      BUA=(.08*W)-2.9
      BFO=(.04*W)-.5
      BH=(.01*W)+.7
      BUL=(.18*W)+3.2
      BLL=(.11*W)-1.9
      BF=(.02*W)+1.5
      WDIFF=W-(HNT+BUA+BFO+BH+BUL+BLL+BF)
      WR=WDIFF/(HNT+BUA+BFO+BH+BUL+BLL+BF)
      WR1=1.+WR
C     DISTRIBUTE WDIFF PROPORTIONALLY OVER ALL SEGMENTS
    2 SW(1)=.079*W
      SW23=HNT*WR1-SW(1)
      SW(4)=BH*WR1/2.
```

```
      SW(6)=BUA*WR1/2.
      SW(8)=BFO*WR1/2.
      SW(10)=BUL*WR1/2.
      SW(12)=BLL*WR1/2.
      SW(14)=BF*WR1/2.
C     DEVELOPMENT OF HEAD
    3 I=1
      R(I)=(STAT-SHLDH)/2.
      RR(I)=HEADC/TWOPI
      DELTA(I)=SW(I)/RR(I)/RR(I)/R(I)/C1/4.
      SL(I)=2.*R(I)
      ETA(I)=.5
      Y(I)=R(I)
C     DEVELOPMENT OF TRUNK
      SL(2)=SHLDH-SUBH
      SL(3)=SITH-(STAT-SUBH)
      R(2)=CHESB/2.
      R(3)=HIPB/2.
      RR(2)=(CHESD+WAISD)/4.
      RR(3)=(WAISD+BUTTD)/4.
      ETA(2)=.5
      ETA(3)=.5
      Y(2)=ETA(2)*SL(2)
      Y(3)=ETA(3)*SL(3)
      DELTA(2)=SW23/PI/(R(2)*RR(2)*SL(2)
     1     +1.01/.92*R(3)*RR(3)*SL(3))
      DELTA(3)=1.01/.92*DELTA(2)
      SW(2)=DELTA(2)*R(2)*RR(2)*SL(2)*PI
      SW(3)=DELTA(3)*R(3)*RR(3)*SL(3)*PI
C     DEVELOPMENT OF HANDS
      I=4
    5 R(I)=FISTC/TWOPI
      RR(I)=R(I)
      SL(I)=2.*RR(I)
      ETA(I)=.5
      Y(I)=ETA(I)*SL(I)
      SW(I)=SW(4)
      DELTA(I)=SW(I)/R(I)/R(I)/R(I)/C1/4.
      IJ=I-3
      I=5
      GO TO (5,6),IJ
C     DEVELOPMENT OF UPPER ARMS
    6 IJ=1
      I=6
      R(I)=AXILC/TWOPI
      RR(I)=ELBC/TWOPI
      SL(I)=UPARL
      GO TO 20
C     DEVELOPMENT OF FOREARMS
    8 IJ=2
      I=8
      R(I)=ELBC/TWOPI
      RR(I)=WRISC/TWOPI
      SL(I)=FOARL
```

```
      GO TO 20
C     DEVELOPMENT OF UPPER LEGS
   10 IJ=3
      I=10
      R(I)=THIHC/TWOPI
      RR(I)=GKNEC/TWOPI
      SL(I)=STAT-SITH-TIBH
      GO TO 20
C     DEVELOPMENT OF LOWER LEGS
   12 IJ=4
      I=12
      R(I)=GKNEC/TWOPI
      RR(I)=ANKC/TWOPI
      SL(I)=TIBH-SPHYH
   20 G=R(I)*R(I)+R(I)*RR(I)+RR(I)*RR(I)
      DELTA(I)=SW(I)/SL(I)/G/C1
      AMU(I)=RR(I)/R(I)
      AMUSQ(I)=AMU(I)*AMU(I)
      SIGMA(I)=1.+AMU(I)+AMUSQ(I)
      ETA(I)=(1.+2.*AMU(I)+3.*AMUSQ(I))/SIGMA(I)/4.
      Y(I)=ETA(I)*SL(I)
      GO TO (8,10,12,14),IJ
C     DEVELOPMENT OF FEET
   14 I=14
      SL(I)=FOOTL
      ETA(I)=.429
      Y(I)=ETA(I)*SL(I)
      G=1.-2.*ETA(I)+SQRTF(ETA(I)*ETA(I)
     1     *(-12.)+12.*ETA(I)-2.)
      AMU(I)=(4.*ETA(I)-1.)/G
      AMUSQ(I)=AMU(I)*AMU(I)
      SIGMA(I)=1.+AMU(I)+AMUSQ(I)
      R(I)=SPHYH/2.
      RR(I)=AMU(I)*R(I)
      G=R(I)*R(I)+R(I)*RR(I)+RR(I)*RR(I)
      DELTA(I)=SW(I)/SL(I)/G/C1
   30 DO 31 I=7,15,2
      SW(I)=SW(I-1)
      DELTA(I)=DELTA(I-1)
      R(I)=R(I-1)
      RR(I)=RR(I-1)
      SL(I)=SL(I-1)
      AMU(I)=AMU(I-1)
      AMUSQ(I)=AMUSQ(I-1)
      SIGMA(I)=SIGMA(I-1)
      ETA(I)=ETA(I-1)
   31 Y(I)=Y(I-1)
   40 DO 41 I=1,5
      AMU(I)=0.
      AMUSQ(I)=0.
   41 SIGMA(I)=0.
C     CALCULATE SEGMENT MASS AND MASS DENSITY
C     CHECK SUM OF SEGMENT WEIGHTS EQUAL TO BODY WEIGHT
      CW=0.
```

```
   50 DO 51 I=1,15
      SM(I)=SW(I)/32.2
      DELTA(I)=DELTA(I)/32.2
   51 CW=CW+SW(I)
C     DETERMINATION OF LOCAL MOMENTS OF INERTIA OF SEGMENTS
C     HEAD
      I=1
      SIXX(I)=.2*SM(I)*(R(I)*R(I)+RR(I)*RR(I))
      SIYY(I)=SIXX(I)
      SIZZ(I)=.4*SM(I)*RR(I)*RR(I)
C     UPPER TORSO AND LOWER TORSO
      DO 52 I=2,3
      SIXX(I)=SM(I)*(3.*R(I)*R(I)+SL(I)*SL(I))/12.
      SIYY(I)=SM(I)*(3.*RR(I)*RR(I)+SL(I)*SL(I))/12.
   52 SIZZ(I)=SM(I)*(RR(I)*RR(I)+R(I)*R(I))/4.
C     HANDS
      I=4
      SIXX(I)=.4*SM(I)*R(I)*R(I)
      SIYY(I)=SIXX(I)
      SIZZ(I)=SIXX(I)
C     UPPER AND LOWER ARMS AND LEGS, AND FEET
      DO 53 I=6,14,2
      AA=9.*(1.+AMU(I)+AMUSQ(I)*(1.+AMU(I)+AMUSQ(I)))
     1     /SIGMA(I)/SIGMA(I)/20./PI
      BB=3.*(1.+4.*AMU(I)+AMUSQ(I)*(10.+4.*AMU(I)+AMUSQ(I)))
     1     /SIGMA(I)/SIGMA(I)/80.
      SIXX(I)=SM(I)*(AA*SM(I)/DELTA(I)/SL(I)+BB*SL(I)*SL(I))
      SIYY(I)=SIXX(I)
   53 SIZZ(I)=2.*SM(I)*SM(I)*AA/DELTA(I)/SL(I)
C     COMPLETE REMAINDER OF SEGMENTS
      DO 54 I=5,15,2
      SIXX(I)=SIXX(I-1)
      SIYY(I)=SIYY(I-1)
   54 SIZZ(I)=SIZZ(I-1)
C     CENTER OF GRAVITY OF HEAD,NECK AND TRUNK
      E(1,1)=SW(1)*Y(1)
      E(1,2)=SW(2)*(SL(1)+Y(2))
      E(1,3)=SW(3)*(SL(1)+SL(2)+Y(3))
      ETA123=(E(1,1)+E(1,2)+E(1,3))/(SW(1)+SW(2)+SW(3))
     1     /(STAT-TROCH)
C     CONVERT DENSITY TO SPECIFIC GRAVITY
      DO 55 I=1,15
   55 DELTA(I)=DELTA(I)*32.2/C2
C     DEFINE DISTANCES OF LOCAL CG FROM HINGE POINT
      DELSH=SITH-(STAT-TROCH)
      DO 60 I=1,15
   60 YY(I)=Y(I)
      YY(6)=Y(6)-R(6)
      YY(10)=Y(10)+DELSH
      YY(14)=0.
      DO 61 I=7,15,4
   61 YY(I)=YY(I-1)
C     DETERMINE FIXED HINGE POINTS
      DO 67 I=1,15
```

```
      DO 67 J=1,3
   67 H(I,J)=0.
      H(6,2)=CHESB/2.+R(6)
      H(6,3)=STAT-SHLDH+R(6)
      H(10,2)=HIPB/2.-R(10)
      H(10,3)=SL(1)+SL(2)+SL(3)-DELSH
      DO 68 I=7,11,4
      H(I,2)=-H(I-1,2)
   68 H(I,3)=H(I-1,3)
      RETURN
      END


      SUBROUTINE MODMOM
      COMMON N,W,CW,ETA123
      COMMON STAT,SHLDH,SUBH,TROCH,TIBH,UPARL,FOARL,CHESD,
     1       WAISD,BUTTD,CHESB,WAISB,HIPB,AXILC,ELBC,WRISC,
     2       FISTC,THIHC,GKNEC,ANKC,SPHYH,FOOTL,SITH,HEADC
      COMMON SW,SM,SL,R,RR,Y,DELTA,AMU,AMUSQ,SIGMA,ETA,YY
      COMMON SIXX,SIYY,SIZZ
      COMMON THETA,SINT,COST,D,E,F,O,OT
      COMMON H,X,XCG,CI
      COMMON XMOD,YMOD,ZMOD,DELSH
      COMMON ALPHA,BETA,GAMMA,PMOM
      COMMON L1,L2,K
      DIMENSION SW(15),SM(15),SL(15),R(15),RR(15),Y(15)
      DIMENSION DELTA(15),AMU(15),AMUSQ(15),SIGMA(15)
      DIMENSION ETA(15),YY(15)
      DIMENSION SIXX(15),SIYY(15),SIZZ(15)
      DIMENSION THETA(15,2),SINT(15,2),COST(15,2)
C            D(3,3),E(3,3),F(3,3) ARE DUMMY MATRICES
      DIMENSION D(3,3),E(3,3),F(3,3),O(3,3),OT(3,3)
      DIMENSION H(15,3),X(15,3),XCG(15,3,7),CI(3,3,7)
      DIMENSION XMOD(7),YMOD(7),ZMOD(7)
      DIMENSION ALPHA(3,7),BETA(3,7),GAMMA(3,7),PMOM(3,7)
      DIMENSION EV(3)
      K=K
      PI=3.1415927
      C3=PI/180.
C     ZERO DUMMY MATRICES D,E,F
      DO 1 II=1,3
      DO 1 JJ=1,3
      D(II,JJ)=0.
      E(II,JJ)=0.
    1 F(II,JJ)=0.
C     ZERO C.G. ARRAY
      DO 2 I=1,15
      DO 2 J=1,3
    2 X(I,J)=0.
C     ZERO THE INERTIA TENSOR ARRAY
      DO 3 II=1,3
      DO 3 JJ=1,3
    3 CI(II,JJ,K)=0.
```

```
C     CALCULATE HINGE POINTS OF MOVEABLE SEGMENTS
C     FOREARMS
      DO 9 I=8,9
      G=SL(I-2)-R(I-2)
      E(1,1)=SINT(I-2,1)*SINT(I-2,2)
      E(2,1)=SINT(I-2,1)*COST(I-2,2)
      E(3,1)=COST(I-2,1)
      DO 9 J=1,3
    9 H(I,J)=H(I-2,J)+E(J,1)*G
C     LOWER LEGS
      DO 10 I=12,13
      G=SL(I-2)+DELSH
      E(1,1)=SINT(I-2,1)*SINT(I-2,2)
      E(2,1)=SINT(I-2,1)*COST(I-2,2)
      E(3,1)=COST(I-2,1)
      DO 10 J=1,3
   10 H(I,J)=H(I-2,J)+E(J,1)*G
C     HANDS
      DO 11 I=4,5
      G=SL(I+4)
      E(1,1)=SINT(I+4,1)*SINT(I+4,2)
      E(2,1)=SINT(I+4,1)*COST(I+4,2)
      E(3,1)=COST(I+4,1)
      DO 11 J=1,3
   11 H(I,J)=H(I+4,J)+E(J,1)*G
C     FEET
      DO 12 I=14,15
      G=SL(I-2)+.5*SPHYH
      E(1,1)=SINT(I-2,1)*SINT(I-2,2)
      E(2,1)=SINT(I-2,1)*COST(I-2,2)
      E(3,1)=COST(I-2,1)
      DO 12 J=1,3
   12 H(I,J)=H(I-2,J)+E(J,1)*G
C     DETERMINE COORD OF SEGMENT CG WRT TOP OF HEAD
      X(1,3)=Y(1)
      X(2,3)=SL(1)+Y(2)
      X(3,3)=SL(1)+SL(2)+Y(3)
      DO 13 I=4,15
      G=YY(I)
      F(1,1)=SINT(I,1)*SINT(I,2)
      F(2,1)=SINT(I,1)*COST(I,2)
      F(3,1)=COST(I,1)
      DO 13 J=1,3
   13 X(I,J)=H(I,J)+F(J,1)*G
      XMOD(K)=2.144323+0.1521804*WAISD
      YMOD(K)=0.
      ZMOD(K)=0.
      DO 14 I=1,15
      XMOD(K)=XMOD(K)+SW(I)*X(I,1)/W
      YMOD(K)=YMOD(K)+SW(I)*X(I,2)/W
   14 ZMOD(K)=ZMOD(K)+SW(I)*X(I,3)/W
C     DETERMINE COORD OF SEGMENT CG WRT CALC CG
      DO 15 I=1,15
      XCG(I,1,K)=X(I,1)-(XMOD(K)-XMOD(1))
```

```
      XCG(I,2,K)=X(I,2)-YMOD(K)
   15 XCG(I,3,K)=X(I,3)-ZMOD(K)
      DO 30 I=1,15
C     ARRANGE LOCAL MOMENTS INTO DUMMY MATRIX (3 X 3)
      DO 24 II=1,3
      DO 24 JJ=1,3
   24 D(II,JJ)=0.
      D(1,1)=SIXX(I)
      D(2,2)=SIYY(I)
      D(3,3)=SIZZ(I)
C     ARRANGE TRANSFORMATION MATRIX
   25 O(1,1)=COST(I,2)
      O(1,2)=SINT(I,2)*COST(I,1)
      O(1,3)=SINT(I,2)*SINT(I,1)
      O(2,1)=-SINT(I,2)
      O(2,2)=COST(I,2)*COST(I,1)
      O(2,3)=COST(I,2)*SINT(I,1)
      O(3,1)=0.
      O(3,2)=-SINT(I,1)
      O(3,3)=COST(I,1)
C     TRANSPOSE THE TRANSFORMATION MATRIX
   26 OT(1,1)=O(1,1)
      OT(1,2)=O(2,1)
      OT(1,3)=O(3,1)
      OT(2,1)=O(1,2)
      OT(2,2)=O(2,2)
      OT(2,3)=O(3,2)
      OT(3,1)=O(1,3)
      OT(3,2)=O(2,3)
      OT(3,3)=O(3,3)
      CALL HMMPY(D,OT,E,3,3,3,LM)
      CALL HMMPY(O,E,F,3,3,3,LM)
C     F(3,3) IS LOCAL MOMENT ROTATED PARALLEL TO BODY AXES
C     TRANSFER TO CALC CG BY PARALLEL AXIS THEOREM
      D(1,1)=XCG(I,2,K)*XCG(I,2,K)+XCG(I,3,K)*XCG(I,3,K)
      D(1,2)=-XCG(I,1,K)*XCG(I,2,K)
      D(1,3)=-XCG(I,1,K)*XCG(I,3,K)
      D(2,1)=D(1,2)
      D(2,2)=XCG(I,1,K)*XCG(I,1,K)+XCG(I,3,K)*XCG(I,3,K)
      D(2,3)=-XCG(I,2,K)*XCG(I,3,K)
      D(3,1)=D(1,3)
      D(3,2)=D(2,3)
      D(3,3)=XCG(I,1,K)*XCG(I,1,K)+XCG(I,2,K)*XCG(I,2,K)
      DO 30 II=1,3
      DO 30 JJ=1,3
      D(II,JJ)=SM(I)*D(II,JJ)/144.
      F(II,JJ)=F(II,JJ)/144.
   30 CI(II,JJ,K)=CI(II,JJ,K)+F(II,JJ)+D(II,JJ)
      DO 32 II=1,3
      DO 32 JJ=1,3
      IF(ABSF(CI(II,JJ,K))-1.E-07)31,31,32
   31 CI(II,JJ,K)=0.
   32 CONTINUE
C     CALCULATE PRINCIPAL MOMENTS AND AXES
```

```
      DO 34 II=1,3
      DO 34 JJ=1,3
   34 D(II,JJ)=CI(II,JJ,K)
      CALL EIGEN(D,E,EV,3,6)
      PMOM(1,K)=EV(1)
      PMOM(2,K)=EV(2)
      PMOM(3,K)=EV(3)
      DO 35 II=1,3
      ALPHA(II,K)=ACOS(E(II,1))/C3
      BETA(II,K)=ACOS(E(II,2))/C3
   35 GAMMA(II,K)=ACOS(E(II,3))/C3
      RETURN
      END
```

```
CHMMPY      MATRIX MULTIPLICATION, SINGLE PRECISION, FL. PT.
C     CALLING SEQUENCE...
C     CALL HMMPY(A,B,C,M,K,N,L)
C        WHERE C(M,N)=A(M,K)*B(K,N)
C          (C MAY BE A, IN WHICH CASE A IS DESTROYED)
C        L=0 INDICATES OK
C        L=1 INDICATES FL. PT. OVERFLOW
      SUBROUTINE HMMPY(A,B,C,M,K,N,L)
      DIMENSION A(3,3),B(3,3),C(3,3),R(3)
      MM=M
      KK=K
      NN=N
      LL=0
      DO 120 I=1,MM
      DO 100 J=1,NN
      R(J)=0.
      DO 100 K1=1,KK
  100 R(J)=A(I,K1)*B(K1,J)+R(J)
      DO 110 J=1,NN
  110 C(I,J)=R(J)
      IF ACCUMULATOR OVERFLOW 130,120
  120 CONTINUE
  125 L=LL
      RETURN
  130 LL=1
      GO TO 125
      END
```

```
      SUBROUTINE EIGEN(A,E,G,NA,L)
      DIMENSION A(3,3),E(3,3),G(3)
      N=NA
      DO 110 I=1,N
      DO 100 J=1,N
  100 E(I,J)=0.0
  110 E(I,I)=1.0
      FN=0.0
```

```
      FNO=0.0
      DO 130 I=1,N
      DO 120 J=1,N
      FN=FN+A(I,J)**2
120   FNO=FNO+A(I,J)**2
130   FNO=FNO-A(I,I)**2
      FN=FN*0.5*(10.**(-L))
      IF (FNO-FN)240,240,135
135   DO 230 I=1,N
      DO 230 J=1,N
      IF (I-J) 140,230,140
140   IF (A(I,J)) 150,230,150
150   R=A(I,I)-A(J,J)
      S=SQRTF(A(I,J)**2+0.25*R*R)
      T=A(I,I)+A(J,J)
      COSSQ=0.5+0.25*R/S
      COSTH=SQRTF(COSSQ)
      SINTH=SQRTF(1.0-COSSQ)
      IF (A(I,J)) 160,230,170
160   SINTH=-SINTH
170   A(I,I)=0.5*T+S
      A(J,J)=0.5*T-S
      FNO=FNO-2.*(A(I,J)**2)
      A(I,J)=0.0
      DO 220 K=1,N
      IF(I-K)180,205,180
180   IF (J-K) 190,200,190
190   A(I,K)=A(I,K)*COSTH+A(J,K)*SINTH
      A(J,K)=A(J,K)*COSTH-A(K,I)*SINTH
      A(K,J)=A(J,K)
200   A(K,I)=A(I,K)
205   T=E(I,K)
210   E(I,K)=E(I,K)*COSTH+E(J,K)*SINTH
220   E(J,K)=-T*SINTH+E(J,K)*COSTH
      IF (FNO-FN) 240,240,230
230   CONTINUE
      GO TO 135
240   DO 280 I=1,N
      J=I
      DO 260 K=I,N
      IF(A(J,J)-A(K,K))250,260,260
250   J=K
260   CONTINUE
      G(I)=A(J,J)
      A(J,J)=A(I,I)
      SUM=0.0
      DO 270 M=1,N
270   SUM=SUM+E(J,M)**2
      SUM=SQRTF(SUM)
      DO 280 M=1,N
      A(I,M)=E(J,M)/SUM
280   E(J,M)=E(I,M)
      DO 290 I=1,N
      DO 290 J=1,N
```

```
290   C(I,J)=A(I,J)
      RETURN
      END


      SUBROUTINE OUTPUT
      COMMON N,W,CW,ETA123
      COMMON STAT,SHLDH,SUBH,TROCH,TIBH,UPARL,FOARL,CHESD,
     1       WAISD,BUTTD,CHESB,WAISB,HIPB,AXILC,ELBC,WRISC,
     2       FISTC,THIHC,GKNEC,ANKC,SPHYH,FOOTL,SITH,HEADC
      COMMON SW,SM,SL,R,RR,Y,DELTA,AMU,AMUSQ,SIGMA,ETA,YY
      COMMON SIXX,SIYY,SIZZ
      COMMON THETA,SINT,COST,D,E,F,O,OT
      COMMON H,X,XCG,CI
      COMMON XMOD,YMOD,ZMOD,DELSH
      COMMON ALPHA,BETA,GAMMA,PMOM
      COMMON L1,L2,K
      DIMENSION SW(15),SM(15),SL(15),R(15),RR(15),Y(15)
      DIMENSION DELTA(15),AMU(15),AMUSQ(15),SIGMA(15)
      DIMENSION ETA(15),YY(15)
      DIMENSION SIXX(15),SIYY(15),SIZZ(15)
      DIMENSION THETA(15,2),SINT(15,2),COST(15,2)
C               D(3,3),E(3,3),F(3,3) ARE DUMMY MATRICES
      DIMENSION D(3,3),E(3,3),F(3,3),O(3,3),OT(3,3)
      DIMENSION H(15,3),X(15,3),XCG(15,3,7),CI(3,3,7)
      DIMENSION XMOD(7),YMOD(7),ZMOD(7)
      DIMENSION ALPHA(3,7),BETA(3,7),GAMMA(3,7),PMOM(3,7)
C     OUTPUT
      IF (SENSE LIGHT 2)100,199
C     PREPARE MASTER TAPE WITH ANTHROPOMETRIC DATA,
C     SEGMENT CHARACTERISTICS AND LOCAL MOMENTS
  100 WRITE OUTPUT TAPE 5,101,N,W,ETA123,DELSH
  101 FORMAT(3H1N=I3,3X,2HW=F6.1,5X,7HETA123=2PE10.2,5X,
     1   6HDELSH=1PE9.2)
      WRITE OUTPUT TAPE 5,102,STAT,SHLDH,SUBH,TROCH,TIBH,
     1     UPARL,FOARL,CHESD,WAISD,BUTTD,CHESB,WAISB,HIPB,
     2     AXILC,ELBC,WRISC,FISTC,THIHC,GKNEC,ANKC,
     3     SPHYH,FOOTL,HEADC,SITH
  102 FORMAT(12F5.1)
      WRITE OUTPUT TAPE 5,103,SW
  103 FORMAT(6H SW   ,3E18.8/6X,6E18.8/6X,6E18.8)
      WRITE OUTPUT TAPE 5,104,SM
  104 FORMAT(6H SM   ,3E18.8/6X,6E18.8/6X,6E18.8)
      WRITE OUTPUT TAPE 5,105,SL
  105 FORMAT(6H SL   ,3E18.8/6X,6E18.8/6X,6E18.8)
      WRITE OUTPUT TAPE 5,106,R
  106 FORMAT(6H R    ,3E18.8/6X,6E18.8/6X,6E18.8)
      WRITE OUTPUT TAPE 5,107,RR
  107 FORMAT(6H RR   ,3E18.8/6X,6E18.8/6X,6E18.8)
      WRITE OUTPUT TAPE 5,108,Y
  108 FORMAT(6H Y    ,3E18.8/6X,6E18.8/6X,6E18.8)
      WRITE OUTPUT TAPE 5,109,DELTA
  109 FORMAT(6H DELTA,3E18.8/6X,6E18.8/6X,6E18.8)
```

```
      WRITE OUTPUT TAPE 5,110,AMU
  110 FORMAT(6H AMU  ,3E18.8/6X,6E18.8/6X,6E18.8)
      WRITE OUTPUT TAPE 5,111,AMUSQ
  111 FORMAT(6H AMUSQ,3E18.8/6X,6E18.8/6X,6E18.8)
      WRITE OUTPUT TAPE 5,112,SIGMA
  112 FORMAT(6H SIGMA,3E18.8/6X,6E18.8/6X,6E18.8)
      WRITE OUTPUT TAPE 5,113,ETA
  113 FORMAT(6H ETA  ,3E18.8/6X,6E18.8/6X,6E18.8)
      WRITE OUTPUT TAPE 5,114,YY
  114 FORMAT(6H YY   ,3E18.8/6X,6E18.8/6X,6E18.8)
      WRITE OUTPUT TAPE 5,115,SIXX
  115 FORMAT(6H SIXX ,3E18.8/6X,6E18.8/6X,6E18.8)
      WRITE OUTPUT TAPE 5,116,SIYY
  116 FORMAT(6H SIYY ,3E18.8/6X,6E18.8/6X,6E18.8)
      WRITE OUTPUT TAPE 5,117,SIZZ
  117 FORMAT(6H SIZZ ,3E18.8/6X,6E18.8/6X,6E18.8)
  199 IF (SENSE LIGHT 1)200,300
  200 WRITE OUTPUT TAPE 3,201,N,W,CW,ETA123
  201 FORMAT(3H1N=I4,5X,3H W=F6.1,10X,3HCW=3PE10.1,5X,
     1      7HETA123=2PE9.1)
      WRITE OUTPUT TAPE 3,202
  202 FORMAT(1H0,13X,1H1,14X,1H2,14X,1H3,14X,1H4,14X,1H5,
     1      14X,1H6,14X,1H7)
      WRITE OUTPUT TAPE 3,203,XMOD
  203 FORMAT(6H XMOD ,4X,7(1PE10.2,5X))
      WRITE OUTPUT TAPE 3,204,YMOD
  204 FORMAT(6H YMOD ,4X,7(1PE10.2,5X))
      WRITE OUTPUT TAPE 3,205,ZMOD
  205 FORMAT(6H ZMOD ,4X,7(2PE10.1,5X))
      WRITE OUTPUT TAPE 3,202
      WRITE OUTPUT TAPE 3,206,(CI(1,1,K),K=1,7)
  206 FORMAT(6H  IXX ,4X,7(1PE10.2,5X))
      WRITE OUTPUT TAPE 3,207,(CI(2,2,K),K=1,7)
  207 FORMAT(6H  IYY ,4X,7(1PE10.2,5X))
      WRITE OUTPUT TAPE 3,208,(CI(3,3,K),K=1,7)
  208 FORMAT(6H  IZZ ,4X,7(1PE10.2,5X))
      WRITE OUTPUT TAPE 3,202
      WRITE OUTPUT TAPE 3,209,(CI(1,2,K),K=1,7)
  209 FORMAT(6H  IXY ,4X,7(1PE10.2,5X))
      WRITE OUTPUT TAPE 3,210,(CI(1,3,K),K=1,7)
  210 FORMAT(6H  IXZ ,4X,7(1PE10.2,5X))
      WRITE OUTPUT TAPE 3,211,(CI(2,3,K),K=1,7)
  211 FORMAT(6H  IYZ ,4X,7(1PE10.2,5X))
      WRITE OUTPUT TAPE 3,202
      WRITE OUTPUT TAPE 3,212,(PMOM(1,K),K=1,7)
  212 FORMAT(7H PMOM 1,4X,7(1PE10.2,5X))
      WRITE OUTPUT TAPE 3,213,(PMOM(2,K),K=1,7)
  213 FORMAT(7H PMOM 2,4X,7(1PE10.2,5X))
      WRITE OUTPUT TAPE 3,214,(PMOM(3,K),K=1,7)
  214 FORMAT(7H PMOM 3,4X,7(1PE10.2,5X))
      WRITE OUTPUT TAPE 3,202
      WRITE OUTPUT TAPE 3,215,(ALPHA(1,K),K=1,7)
  215 FORMAT(8H ALPHA 1,2X,7(1PE10.2,5X))
      WRITE OUTPUT TAPE 3,216,(BETA(1,K),K=1,7)
```

```
216 FORMAT(8H  BETA 1,2X,7(1PE10.2,5X))
    WRITE OUTPUT TAPE 3,217,(GAMMA(1,K),K=1,7)
217 FORMAT(8H GAMMA 1,2X,7(1PE10.2,5X))
    WRITE OUTPUT TAPE 3,202
    WRITE OUTPUT TAPE 3,218,(ALPHA(2,K),K=1,7)
218 FORMAT(8H ALPHA 2,2X,7(1PE10.2,5X))
    WRITE OUTPUT TAPE 3,219,(BETA(2,K),K=1,7)
219 FORMAT(8H  BETA 2,2X,7(1PE10.2,5X))
    WRITE OUTPUT TAPE 3,220,(GAMMA(2,K),K=1,7)
220 FORMAT(8H GAMMA 2,2X,7(1PE10.2,5X))
    WRITE OUTPUT TAPE 3,202
    WRITE OUTPUT TAPE 3,221,(ALPHA(3,K),K=1,7)
221 FORMAT(8H ALPHA 3,2X,7(1PE10.2,5X))
    WRITE OUTPUT TAPE 3,222,(BETA(3,K),K=1,7)
222 FORMAT(8H  BETA 3,2X,7(1PE10.2,5X))
    WRITE OUTPUT TAPE 3,223,(GAMMA(3,K),K=1,7)
223 FORMAT(8H GAMMA 3,2X,7(1PE10.2,5X))
    WRITE OUTPUT TAPE 3,224
224 FORMAT(40HALENGTH IN INCHES, MOMENT OF INERTIA IN ,
   1      29HSLUG-FT-FT,ANGLES IN DEGREES.)
300 RETURN
    END
```

APPENDIX G

COMPUTER PROGRAM APMOD (FORTRAN IV)

```
C APMOD     ANY POSITION MATHEMATICAL MODEL OF HUMAN BODY
      COMMON /B1/N,W,CH,ETA123,DELSH,
     1       SW(15),SM(15),SL(15),R(15),RR(15),Y(15),
     2       DELTA(15),AMU(15),AMUSQ(15),SIGMA(15),ETA(15),
     3       YY(15),SIXX(15),SIYY(15),SIZZ(15)
     4       XMOD(7),YMOD(7),ZMOD(7)
      COMMON /B2/STAT,SHLDH,SUBH,TROCH,TIBH,UPARL,FOARL,
     1       CHESD,WAISD,BUTTD,CHESB,WAISB,HIPB,AXILC,ELBC,
     2       WRISC,FISTC,THIHC,GKNEC,ANKC,SPHYH,FOOTL,
     3       SITH,HEADC
      COMMON /B3/D(3,3),E(3,3),F(3,3)
      COMMON /B4/THETA(15,2),SINT(15,2),COST(15,2),
     1       O(3,3),OT(3,3),H(15,3),X(15,3),XCG(15,3,7),
     2       CI(3,3,7)
      COMMON /B5/ALPHA(3,7),BETA(3,7),GAMMA(3,7),PMOM(3,7)
      COMMON /B6/K,L1,L2
      READ  (5,100)L1,L2
  100 FORMAT(2I5)
C     OUTPUT DESIRED
C     NORMAL   MASTER      CARD PUNCHED
C       NO       NO          0    0
C       NO       YES         0    1
C       YES      NO          1    0
C       YES      YES         1    1
    1 CALL SLITE (0)
      IF(L1-1)3,2,3
    2 CALL SLITE (1)
    3 IF(L2-1)5,4,4
    4 CALL SLITE (2)
    5 READ  (5,101)N,W
  101 FORMAT(I5,4X,F6.1)
      READ  (5,102)STAT,SHLDH,SUBH,TROCH,TIBH,UPARL,FOARL,
     1     CHESD,WAISD,BUTTD,CHESB,WAISB,HIPB,AXILC,ELBC,
     2     WRISC,FISTC,THIHC,GKNEC,ANKC,SPHYH,FOOTL,
     3     HEADC,SITH
  102 FORMAT(12F5.1)
      CALL DESIGN
      DO 6 I=1,15
      DO 6 J=1,2
    6 THETA(I,J)=0.
      K=1
    7 CALL EULER
      CALL MODMOM
      K=K+1
```

```
      IF(K-8)7,8,7
    8 CALL OUTPUT
C     NUMBER ASSIGNED TO LAST SUBJECT SHOULD BE 99
      IF(N-99)9,10,9
    9 GO TO 1
   10 IF (L2-1)12,11,11
   11 END FILE 18
      REWIND 18
   12 STOP
      END


      SUBROUTINE DESIGN
      COMMON /B1/N,W,CW,ETA123,DELSH,
     1       SW(15),SM(15),SL(15),R(15),RR(15),Y(15),
     2       DELTA(15),AMU(15),AMUSQ(15),SIGMA(15),ETA(15),
     3       YY(15),SIXX(15),SIYY(15),SIZZ(15)
     4       XMOD(7),YMOD(7),ZMOD(7)
      COMMON /B2/STAT,SHLDH,SUBH,TROCH,TIBH,UPARL,FOARL,
     1       CHESD,WAISD,BUTTD,CHESB,WAISB,HIPB,AXILC,FLBC,
     2       WRISC,FISTC,THIHC,GKNEC,ANKC,SPHYH,FOOTL,
     3       SITH,HEADC
      COMMON /B3/D(3,3),E(3,3),F(3,3)
      COMMON /B4/THETA(15,2),SINT(15,2),COST(15,2),
     1       O(3,3),OT(3,3),H(15,3),X(15,3),XCG(15,3,7),
     2       CI(3,3,7)
      COMMON /B5/ALPHA(3,7),BETA(3,7),GAMMA(3,7),PMOM(3,7)
      COMMON /B6/K,L1,L2
      PI=3.1415927
      TWOPI=2.*PI
      C1=PI/3.
      C2=62.427/1728.
C     DESIGN MODEL MAN BY USING ANTHROPOMETRIC DIMENSIONS
C     APPLY BARTER REGRESSION EQUATION TO SUBJECT WEIGHT
    1 HNT=(.47*W)+12.
      BUA=(.08*W)-2.9
      BFO=(.04*W)-.5
      BH=(.01*W)+.7
      BUL=(.18*W)+3.2
      BLL=(.11*W)-1.9
      BF=(.02*W)+1.5
      WDIFF=W-(HNT+BUA+BFO+BH+BUL+BLL+BF)
      WR=WDIFF/(HNT+BUA+BFO+BH+BUL+BLL+BF)
      WR1=1.+WR
C     DISTRIBUTE WDIFF PROPORTIONALLY OVER ALL SEGMENTS
    2 SW(1)=.079*W
      SW23=HNT*WR1-SW(1)
      SW(4)=BH*WR1/2.
      SW(6)=BUA*WR1/2.
      SW(8)=BFO*WR1/2.
      SW(10)=BUL*WR1/2.
      SW(12)=BLL*WR1/2.
      SW(14)=BF*WR1/2.
```

```
C     DEVELOPMENT OF HEAD
    3 I=1
      R(I)=(STAT-SHLDH)/2.
      RR(I)=HEADC/TWOPI
      DELTA(I)=SW(I)/RR(I)/RR(I)/R(I)/C1/4.
      SL(I)=2.*R(I)
      ETA(I)=.5
      Y(I)=R(I)
C     DEVELOPMENT OF TRUNK
    4 SL(2)=SHLDH-SUBH
      SL(3)=SITH-(STAT-SUBH)
      R(2)=CHESB/2.
      R(3)=HIPB/2.
      RR(2)=(CHESD+WAISD)/4.
      RR(3)=(WAISD+BUTTD)/4.
      ETA(2)=.5
      ETA(3)=.5
      Y(2)=ETA(2)*SL(2)
      Y(3)=ETA(3)*SL(3)
      DELTA(2)=SW23/PI/(R(2)*RR(2)*SL(2)
     1     +1.01/.92*R(3)*RR(3)*SL(3))
      DELTA(3)=1.01/.92*DELTA(2)
      SW(2)=DELTA(2)*R(2)*RR(2)*SL(2)*PI
      SW(3)=DELTA(3)*R(3)*RR(3)*SL(3)*PI
C     DEVELOPMENT OF HANDS
      I=4
    5 R(I)=FISTC/TWOPI
      RR(I)=R(I)
      SL(I)=2.*RR(I)
      ETA(I)=.5
      Y(I)=ETA(I)*SL(I)
      SW(I)=SW(4)
      DELTA(I)=SW(I)/R(I)/R(I)/R(I)/C1/4.
      IJ=I-3
      I=5
      GO TO (5,6),IJ
C     DEVELOPMENT OF UPPER ARMS.
    6 IJ=1
      I=6
      R(I)=AXILC/TWOPI
      RR(I)=ELBC/TWOPI
      SL(I)=UPARL
      GO TO 13
C     DEVELOPMENT OF FOREARMS
    8 IJ=2
      I=8
      R(I)=ELBC/TWOPI
      RR(I)=WRISC/TWOPI
      SL(I)=FOARL
      GO TO 13
C     DEVELOPMENT OF UPPER LEGS
   10 IJ=3
      I=10
      R(I)=THIHC/TWOPI
```

```
      RR(I)=GKNEC/TWOPI
      SL(I)=STAT-SITH-TIBH
      GO TO 13
C     DEVELOPMENT OF LOWER LEGS
   12 IJ=4
      I=12
      R(I)=GKNEC/TWOPI
      RR(I)=ANKC/TWOPI
      SL(I)=TIBH-SPHYH
   13 G=R(I)*R(I)+R(I)*RR(I)+RR(I)*RR(I)
      DELTA(I)=SW(I)/SL(I)/G/C1
      AMU(I)=RR(I)/R(I)
      AMUSQ(I)=AMU(I)*AMU(I)
      SIGMA(I)=1.+AMU(I)+AMUSQ(I)
      ETA(I)=(1.+2.*AMU(I)+3.*AMUSQ(I))/SIGMA(I)/4.
      Y(I)=ETA(I)*SL(I)
      GO TO (8,10,12,14),IJ
C     DEVELOPMENT OF FEET
   14 I=14
      SL(I)=FOOTL
      ETA(I)=.429
      Y(I)=ETA(I)*SL(I)
      G=1.-2.*ETA(I)+SQRT(ETA(I)*ETA(I)
     1      *(-12.)+12.*ETA(I)-2.)
      AMU(I)=(4.*ETA(I)-1.)/G
      AMUSQ(I)=AMU(I)*AMU(I)
      SIGMA(I)=1.0+AMU(I)+AMUSQ(I)
      R(I)=SPHYH/2.
      RR(I)=AMU(I)*R(I)
      G=R(I)*R(I)+R(I)*RR(I)+RR(I)*RR(I)
      DELTA(I)=SW(I)/SL(I)/G/C1
   15 DO 16 I=7,15,2
      SW(I)=SW(I-1)
      DELTA(I)=DELTA(I-1)
      R(I)=R(I-1)
      RR(I)=RR(I-1)
      SL(I)=SL(I-1)
      AMU(I)=AMU(I-1)
      AMUSQ(I)=AMUSQ(I-1)
      SIGMA(I)=SIGMA(I-1)
      ETA(I)=ETA(I-1)
   16 Y(I)=Y(I-1)
   17 DO 18 I=1,5
      AMU(I)=0.
      AMUSQ(I)=0.
   18 SIGMA(I)=0.
C     CALCULATE SEGMENT MASS AND MASS DENSITY
C     CHECK SUM OF SW(I)
      CW=0.
   19 DO 20 I=1,15
      SM(I)=SW(I)/32.2
      DELTA(I)=DELTA(I)/32.2
   20 CW=CW+SW(I)
C     DETERMINATION OF LOCAL MOMENTS OF INERTIA OF SEGMENTS
```

```
C       HEAD
   31   I=1
        SIXX(I)=.2*SM(I)*(R(I)*R(I)+RR(I)*RR(I))
        SIYY(I)=SIXX(I)
        SIZZ(I)=.4*SM(I)*RR(I)*RR(I)
C       UPPER TORSO AND LOWER TORSO
   32   DO 33 I=2,3
        SIXX(I)=SM(I)*(3.*R(I)*R(I)+SL(I)*SL(I))/12.
        SIYY(I)=SM(I)*(3.*RR(I)*RR(I)+SL(I)*SL(I))/12.
   33   SIZZ(I)=SM(I)*(RR(I)*RR(I)+R(I)*R(I))/4.
C       HANDS
   34   I=4
        SIXX(I)=.4*SM(I)*R(I)*R(I)
        SIYY(I)=SIXX(I)
        SIZZ(I)=SIXX(I)
C       UPPER AND LOWER ARMS AND LEGS, AND FEET
   36   DO 42 I=6,14,2
        AA=9.0*(1.0+AMU(I)+AMUSQ(I)*(1.0+AMU(I)+AMUSQ(I)))
      1      /SIGMA(I)/SIGMA(I)/20./PI
        BB=3.0*(1.0+4.0*AMU(I)+AMUSQ(I)*(10.0+4.0*AMU(I)+AMUSQ
      1      /SIGMA(I)/SIGMA(I)/80.
        SIXX(I)=SM(I)*(AA*SM(I)/DELTA(I)/SL(I)+BB*SL(I)*SL(I))
        SIYY(I)=SIXX(I)
   42   SIZZ(I)=2.*SM(I)*SM(I)*AA/DELTA(I)/SL(I)
C       COMPLETE REMAINDER OF SEGMENTS
        DO 43 I=5,15,2
        SIXX(I)=SIXX(I-1)
        SIYY(I)=SIYY(I-1)
   43   SIZZ(I)=SIZZ(I-1)
C       CENTER OF GRAVITY OF HEAD,NECK AND TRUNK
        E(1,1)=SW(1)*Y(1)
        E(1,2)=SW(2)*(SL(1)+Y(2))
        E(1,3)=SW(3)*(SL(1)+SL(2)+Y(3))
        ETA123=(E(1,1)+E(1,2)+E(1,3))/(SW(1)+SW(2)+SW(3))
      1      /(STAT-TROCH)
C       CONVERT DENSITY TO SPECIFIC GRAVITY
        DO 44 I=1,15
   44   DELTA(I)=DELTA(I)*32.2/C2
C       DEFINE DISTANCES OF LOCAL CG FROM HINGE POINT
        DELSH=SITH-(STAT-TROCH)
        DO 51 I=1,15
   51   YY(I)=Y(I)
        YY(6)=Y(6)-R(6)
        YY(10)=Y(10)+DELSH
        YY(14)=0.
        DO 52 I=7,15,4
   52   YY(I)=YY(I-1)
C       DETERMINE FIXED HINGE POINTS
        DO 53 I=1,15
        DO 53 J=1,3
   53   H(I,J)=0.
        H(6,2)=CHESB/2.+R(6)
        H(6,3)=STAT-SHLDH+R(6)
        H(10,2)=HIPP/2.-R(10)
```

```
      H(10,3)=SL(1)+SL(2)+SL(3)-DELSH
      DO 54 I=7,11,4
      H(I,2)=-H(I-1,2)
   54 H(I,3)=H(I-1,3)
C     PREPARE MASTER INPUT TAPE WITH ANTHROPOMETRIC DATA,
C     AND CALCULATED SEGMENT MOMENTS OF INERTIA (LOCAL)
      CALL SLITET(2,KOOOFX)
      GO TO (59,60),KOOOFX
   59 WRITE(18,101)N,W,ETA123,DELSH
  101 FORMAT(3H1N=I3,3X,2HW=F6.1,5X,7HETA123=2PE10.2,5X,
     1       6HDELSH=1PE9.2)
      WRITE(18,102)STAT,SHLDH,SUBH,TROCH,TIBH,UPARL,FOARL,
     1       CHESD,WAISD,BUTTD,CHESB,WAISB,HIPB,AXILC,ELBC,
     2       WRISC,FISTC,THIHC,GKNEC,ANKC,SPHYH,FOOTL,
     3       HEADC,SITH
  102 FORMAT(12F5.1)
      WRITE(18,103)SW
  103 FORMAT(6H SW    ,3E18.8/6X,6E18.3/6X,6E18.8)
      WRITE(18,104)SM
  104 FORMAT(6H SM    ,3E18.8/6X,6E18.8/6X,6E18.8)
      WRITE(18,105)SL
  105 FORMAT(6H SL    ,3E18.8/6X,6E18.8/6X,6E18.8)
      WRITE(18,106)R
  106 FORMAT(6H R     ,3E18.8/6X,6E18.8/6X,6E18.8)
      WRITE(18,107)RR
  107 FORMAT(6H RR    ,3E18.8/6X,6E18.8/6X,6E18.8)
      WRITE(18,108)Y
  108 FORMAT(6H Y     ,3E18.8/6X,6E18.8/6X,6E18.8)
      WRITE(18,109)DELTA
  109 FORMAT(6H DELTA,3E18.8/6X,6E18.8/6X,6E18.8)
      WRITE(18,110)AMU
  110 FORMAT(6H AMU   ,3E18.8/6X,6E18.8/6X,6E18.8)
      WRITE(18,111)AMUSQ
  111 FORMAT(6H AMUSQ,3E18.8/6X,6E18.8/6X,6E18.8)
      WRITE(18,112)SIGMA
  112 FORMAT(6H SIGMA,3E18.8/6X,6E18.8/6X,6E18.8)
      WRITE(18,113)ETA
  113 FORMAT(6H ETA   ,3E18.8/6X,6E18.8/6X,6E18.8)
      WRITE(18,114)YY
  114 FORMAT(6H YY    ,3E18.8/6X,6E18.8/6X,6E18.8)
      WRITE(18,115)SIXX
  115 FORMAT(6H SIXX ,3E18.8/6X,6E18.8/6X,6E18.8)
      WRITE(18,116)SIYY
  116 FORMAT(6H SIYY ,3E18.8/6X,6E18.8/6X,6E18.8)
      WRITE(18,117)SIZZ
  117 FORMAT(6H SIZZ ,3E18.8/6X,6E18.8/6X,6E18.8)
   60 RETURN
      END


      SUBROUTINE MCDMCM
      COMMON /B1/N,W,CW,ETA123,DELSH,
     1       SW(15),SM(15),SL(15),R(15),RR(15),Y(15),
```

```
      2         DELTA(15),AMU(15),AMUSQ(15),SIGMA(15),ETA(15),
      3         YY(15),SIXX(15),SIYY(15),SIZZ(15)
      4         XMOD(7),YMOD(7),ZMOD(7)
       COMMON /B2/STAT,SHLDH,SUBH,TROCH,TIBH,UPARL,FOARL,
      1         CHESD,WAISD,BUTTD,CHESB,WAISB,HIPB,AXILC,ELBC,
      2         WRISC,FISTC,THIHC,GKNEC,ANKC,SPHYH,FOOTL,
      3         SITH,HEADC
       COMMON /B3/D(3,3),E(3,3),F(3,3)
       COMMON /B4/THETA(15,2),SINT(15,2),COST(15,2),
      1         U(3,3),UT(3,3),H(15,3),X(15,3),XCG(15,3,7),
      2         CI(3,3,7)
       COMMON /B5/ALPHA(3,7),BETA(3,7),GAMMA(3,7),PMOM(3,7)
       COMMON /B6/K,L1,L2
       DIMENSION EV(3)
       K=K
       PI=3.1415927
       C3=PI/180.
C      ZERO DUMMY MATRICES D,E,F
       DO 1 II=1,3
       DO 1 JJ=1,3
       D(II,JJ)=0.
       E(II,JJ)=0.
     1 F(II,JJ)=0.
C      ZERO C.G. ARRAY
       DO 2 I=1,15
       DO 2 J=1,3
     2 X(I,J)=0.
C      ZERO THE INERTIA TENSOR ARRAY
       DO 3 II=1,3
       DO 3 JJ=1,3
     3 CI(II,JJ,K)=C.
C      CALCULATE HINGE POINTS OF MOVEABLE SEGMENTS
C      FOREARMS
       DO 9 I=8,9
       G=SL(I-2)-R(I-2)
       E(1,1)=SINT(I-2,1)*SINT(I-2,2)
       E(2,1)=SINT(I-2,1)*COST(I-2,2)
       E(3,1)=COST(I-2,1)
       DO 9 J=1,3
     9 H(I,J)=H(I-2,J)+E(J,1)*G
C      LOWER LEGS
       DO 10 I=12,13
       G=SL(I-2)+DELSH
       E(1,1)=SINT(I-2,1)*SINT(I-2,2)
       E(2,1)=SINT(I-2,1)*COST(I-2,2)
       E(3,1)=COST(I-2,1)
       DO 10 J=1,3
    10 H(I,J)=H(I-2,J)+E(J,1)*G
C      HANDS
       DO 11 I=4,5
       G=SL(I+4)
       E(1,1)=SINT(I+4,1)*SINT(I+4,2)
       E(2,1)=SINT(I+4,1)*COST(I+4,2)
       E(3,1)=COST(I+4,1)
```

```
      DO 11  J=1,3
   11 H(I,J)=H(I+4,J)+F(J,1)*G
C     FEET
      DO 12 I=14,15
      G=SL(I-2)+.5*SPHYH
      E(1,1)=SINT(I-2,1)*SINT(I-2,2)
      E(2,1)=SINT(I-2,1)*COST(I-2,2)
      E(3,1)=COST(I-2,1)
      DO 12 J=1,3
   12 H(I,J)=H(I-2,J)+E(J,1)*G
C     DETERMINE CCORD OF LOCAL CG WRT TOP OF HEAD
      X(1,3)=Y(1)
      X(2,3)=SL(1)+Y(2)
      X(3,3)=SL(1)+SL(2)+Y(3)
      DO 13 I=4,15
      G=YY(I)
      F(1,1)=SINT(I,1)*SINT(I,2)
      F(2,1)=SINT(I,1)*COST(I,2)
      F(3,1)=COST(I,1)
      DO 13 J=1,3
   13 X(I,J)=H(I,J)+F(J,1)*G
      XMCD(K)=2.144323+0.1521804*WAISD
      YMCD(K)=0.
      ZMOD(K)=0.
      DO 14 I=1,15
      XMCD(K)=XMOL(K)+SW(I)*X(I,1)/W
      YMOD(K)=YMOD(K)+SW(I)*X(I,2)/W
   14 ZMCD(K)=ZMOD(K)+SW(I)*X(I,3)/W
C     DETERMINE CCORD OF SEGMENT CG WRT CALC CG
      DO 15 I=1,15
      XCG(I,1,K)=X(I,1)-(XMOD(K)-XMOD(1))
      XCG(I,2,K)=X(I,2)-YMCD(K)
   15 XCG(I,3,K)=X(I,3)-ZMCD(K)
      DO 30 I=1,15
C     ARRANGE LOCAL MOMENTS INTO DUMMY MATRIX (3 X 3)
      DO 24 II=1,3
      DO 24 JJ=1,3
   24 D(II,JJ)=0.
      D(1,1)=SIXX(I)
      D(2,2)=SIYY(I)
      D(3,3)=SIZZ(I)
C     ARRANGE TRANSFORMATION MATRIX
   25 O(1,1)=COST(I,2)
      O(1,2)=SINT(I,2)*COST(I,1)
      O(1,3)=SINT(I,2)*SINT(I,1)
      O(2,1)=-SINT(I,2)
      O(2,2)=COST(I,2)*COST(I,1)
      O(2,3)=COST(I,2)*SINT(I,1)
      O(3,1)=0.
      O(3,2)=-SINT(I,1)
      O(3,3)=COST(I,1)
C     TRANSPOSE THE TRANSFORMATION MATRIX
   26 OT(1,1)=O(1,1)
      OT(1,2)=O(2,1)
```

```
      OT(1,3)=O(3,1)
      OT(2,1)=O(1,2)
      OT(2,2)=O(2,2)
      OT(2,3)=O(3,2)
      OT(3,1)=O(1,3)
      OT(3,2)=O(2,3)
      OT(3,3)=O(3,3)
      CALL HMMPY(D,OT,E,3,3,3,LM)
      CALL HMMPY(C,E,F,3,3,3,LM)
C     F(3,3) IS LOCAL MOMENT ROTATED PARALLEL TO BODY AXES
C     TRANSFER TO CALC CG BY PARALLEL AXIS THEOREM
      D(1,1)=XCG(I,2,K)*XCG(I,2,K)+XCG(I,3,K)*XCG(I,3,K)
      D(1,2)=-XCG(I,1,K)*XCG(I,2,K)
      D(1,3)=-XCG(I,1,K)*XCG(I,3,K)
      D(2,1)=D(1,2)
      D(2,2)=XCG(I,1,K)*XCG(I,1,K)+XCG(I,3,K)*XCG(I,3,K)
      D(2,3)=-XCG(I,2,K)*XCG(I,3,K)
      D(3,1)=D(1,3)
      D(3,2)=D(2,3)
      D(3,3)=XCG(I,1,K)*XCG(I,1,K)+XCG(I,2,K)*XCG(I,2,K)
      DO 30 II=1,3
      DO 30 JJ=1,3
      D(II,JJ)=SM(I)*D(II,JJ)/144.
      F(II,JJ)=F(II,JJ)/144.
   30 CI(II,JJ,K)=CI(II,JJ,K)+F(II,JJ)+D(II,JJ)
      DO 32 II=1,3
      DO 32 JJ=1,3
      IF(ABS(CI(II,JJ,K))-1.E-07)31,31,32
   31 CI(II,JJ,K)=0.
   32 CONTINUE
C     CALCULATE PRINCIPAL MOMENTS AND AXES
      DO 34 II=1,3
      DO 34 JJ=1,3
   34 D(II,JJ)=CI(II,JJ,K)
      CALL EIGEN(D,E,EV,3,6)
      PMOM(1,K)=EV(1)
      PMOM(2,K)=EV(2)
      PMOM(3,K)=EV(3)
      DO 35 II=1,3
      ALPHA(II,K)=ACOS(E(II,1))/C3
      BETA(II,K)=ACOS(E(II,2))/C3
   35 GAMMA(II,K)=ACOS(E(II,3))/C3
      RETURN
      END


CHMMPY     MATRIX MULTIPLICATION, SINGLE PRECISION, FL. PT.
C     CALLING SEQUENCE...
C     CALL HMMPY(A,B,C,M,K,N,L)
C        WHERE C(M,N)=A(M,K)*B(K,N)
C          (C MAY BE A, IN WHICH CASE A IS DESTROYED)
C        L=0 INDICATES OK
C        L=1 INDICATES FL. PT. OVERFLOW
```

```
      SUBROUTINE MMMPY(A,B,C,M,K,N,L)
      DIMENSION A(3,3),B(3,3),C(3,3),R(3)
      MM=M
      KK=K
      NN=N
      LL=0
      DO 120 I=1,MM
      DO 100 J=1,NN
      R(J)=0.
      DO 100 K1=1,KK
  100 R(J)=A(I,K1)*B(K1,J)+R(J)
      DO 110 J=1,NN
  110 C(I,J)=R(J)
      CALL OVERFL (LO)
      GO TO (130,120),LO
  120 CONTINUE
  125 L=LL
      RETURN
  130 LL=1
      GO TO 125
      END


      SUBROUTINE EIGEN (A,E,G,NA,L)
      DIMENSION A(3,3),E(3,3),G(3)
      N=NA
      DO 110 I=1,N
      DO 100 J=1,N
  100 E(I,J)=0.0
  110 E(I,I)=1.0
      FN=0.0
      FNO=0.0
      DO 130 I=1,N
      DO 120 J=1,N
      FN=FN+A(I,J)**2
  120 FNO=FNO+A(I,J)**2
  130 FNO=FNO-A(I,I)**2
      FN=FN*0.5*(10.**(-L))
      IF (FNO-FN)240,240,135
  135 DO 230 I=1,N
      DO 230 J=1,N
      IF (I-J) 140,230,140
  140 IF (A(I,J)) 150,230,150
  150 R=A(I,I)-A(J,J)
      S=SQRT(A(I,J)**2+0.25*R*R)
      T=A(I,I)+A(J,J)
      COSSQ=0.5+0.25*R/S
      COSTH=SQRT(COSSQ)
      SINTH=SQRT(1.0-COSSQ)
      IF (A(I,J)) 160,230,170
  160 SINTH=-SINTH
  170 A(I,I)=0.5*T+S
      A(J,J)=0.5*T-S
```

```
      FNO=FN)-2.*(A(I,J)**2)
      A(I,J)=0.0
      DO 220 K=1,N
      IF(I-K)180,205,180
180   IF (J-K) 190,200,190
190   A(I,K)=A(I,K)*COSTH+A(J,K)*SINTH
      A(J,K)=A(J,K)*COSTH-A(K,I)*SINTH
      A(K,J)=A(J,K)
200   A(K,I)=A(I,K)
205   T=E(I,K)
210   E(I,K)=E(I,K)*COSTH+E(J,K)*SINTH
220   E(J,K)=-T*SINTH+E(J,K)*COSTH
      IF (FNO-FN) 240,240,230
230   CONTINUE
      GO TO 135
240   DO 280 I=1,N
      J=I
      DO 260 K=I,N
      IF(A(J,J)-A(K,K))250,260,260
250   J=K
260   CONTINUE
      G(I)=A(J,J)
      A(J,J)=A(I,I)
      SUM=0.0
      DO 270 M=1,N
270   SUM=SUM+E(J,M)**2
      SUM=SQRT(SUM)
      DO 280 M=1,N
      A(I,M)=E(J,M)/SUM
280   E(J,M)=E(I,M)
      DO 290 I=1,N
      DO 290 J=1,N
290   E(I,J)=A(I,J)
      RETURN
      END


      SUBROUTINE OUTPUT
      COMMON /B1/N,W,CW,ETA123,DELSH,
     1        SW(15),SM(15),SL(15),R(15),RR(15),Y(15),
     2        DELTA(15),AMU(15),AMUSQ(15),SIGMA(15),ETA(15),
     3        YY(15),SIXX(15),SIYY(15),SIZZ(15)
     4        XMOD(7),YMOD(7),ZMOD(7)
      COMMON /B2/STAT,SHLDH,SUBH,TROCH,TIBH,UPARL,FOARL,
     1        CHESD,WAISD,BUTTD,CHESB,WAISB,HIPB,AXILC,ELBC,
     2        WRISC,FISTC,THIHC,GKNEC,ANKC,SPHYH,FOOTL,
     3        SITH,HEADC
      COMMON /B3/D(3,3),E(3,3),F(3,3)
      COMMON /B4/THETA(15,2),SINT(15,2),COST(15,2),
     1        O(3,3),OT(3,3),H(15,3),X(15,3),XCG(15,3,7),
     2        CI(3,3,7)
      COMMON /B5/ALPHA(3,7),BETA(3,7),GAMMA(3,7),PMOM(3,7)
      COMMON /B6/K,L1,L2
```

```
C      OUTPUT
       CALL SLITET(1,KOOOFX)
        GO TO(200,300),KOOOFX
  200 WRITE (6,201)N,W,CW,ETA123
  201 FORMAT(3H1N=I4,5X,3H W=F6.1,10X,3HCW=3PE10.1,5X,
     1      7HETA123=2PE9.1)
      WRITE (6,202)
  202 FORMAT(1H0,13X,1H1,14X,1H2,14X,1H3,14X,1H4,14X,1H5,
     1      14X,1H6,14X,1H7)
      WRITE (6,203)XMOD
  203 FORMAT(6H XMOD ,4X,7(1PE10.2,5X))
      WRITE (6,204)YMOD
  204 FORMAT(6H YMOD ,4X,7(1PE10.2,5X))
      WRITE (6,205)ZMOD
  205 FORMAT(6H ZMOD ,4X,7(2PE10.1,5X))
      WRITE (6,202)
      WRITE (6,206)(CI(1,1,K),K=1,7)
  206 FORMAT(6H  IXX ,4X,7(1PE10.2,5X))
      WRITE (6,207)(CI(2,2,K),K=1,7)
  207 FORMAT(6H  IYY ,4X,7(1PE10.2,5X))
      WRITE (6,208)(CI(3,3,K),K=1,7)
  208 FORMAT(6H  IZZ ,4X,7(1PE10.2,5X))
      WRITE (6,202)
      WRITE (6,209)(CI(1,2,K),K=1,7)
  209 FORMAT(6H  IXY ,4X,7(1PE10.2,5X))
      WRITE (6,210)(CI(1,3,K),K=1,7)
  210 FORMAT(6H  IXZ ,4X,7(1PE10.2,5X))
      WRITE (6,211)(CI(2,3,K),K=1,7)
  211 FORMAT(6H  IYZ ,4X,7(1PE10.2,5X))
      WRITE (6,202)
      WRITE (6,212)(PMOM(1,K),K=1,7)
  212 FORMAT(7H PMOM 1,4X,7(1PE10.2,5X))
      WRITE (6,213)(PMOM(2,K),K=1,7)
  213 FORMAT(7H PMOM 2,4X,7(1PE10.2,5X))
      WRITE (6,214)(PMOM(3,K),K=1,7)
  214 FORMAT(7H PMOM 3,4X,7(1PE10.2,5X))
      WRITE (6,202)
      WRITE (6,215)(ALPHA(1,K),K=1,7)
  215 FORMAT(8H ALPHA 1,2X,7(1PE10.2,5X))
      WRITE (6,216)(BETA(1,K),K=1,7)
  216 FORMAT(8H  BETA 1,2X,7(1PE10.2,5X))
      WRITE (6,217)(GAMMA(1,K),K=1,7)
  217 FORMAT(8H GAMMA 1,2X,7(1PE10.2,5X))
      WRITE (6,202)
      WRITE (6,218)(ALPHA(2,K),K=1,7)
  218 FORMAT(8H ALPHA 2,2X,7(1PE10.2,5X))
      WRITE (6,219)(BETA(2,K),K=1,7)
  219 FORMAT(8H  BETA 2,2X,7(1PE10.2,5X))
      WRITE (6,220)(GAMMA(2,K),K=1,7)
  220 FORMAT(8H GAMMA 2,2X,7(1PE10.2,5X))
      WRITE (6,202)
      WRITE (6,221)(ALPHA(3,K),K=1,7)
  221 FORMAT(8H ALPHA 3,2X,7(1PE10.2,5X))
      WRITE (6,222)(BETA(3,K),K=1,7)
```

```
222 FORMAT(8H  BETA 3,2X,7(1PE10.2,5X))
    WRITE (6,223)(GAMMA(3,K),K=1,7)
223 FORMAT(8H GAMMA 3,2X,7(1PE10.2,5X))
    WRITE (6,224)
224 FORMAT(40HALENGTH IN INCHES, MOMENT OF INERTIA IN ,
   1      29HSLUG-FT-FT,ANGLES IN DEGREES.)
300 RETURN
    END
```

APPENDIX H

COMPUTER PROGRAM GUIDE (FORTRAN II)

```
C GUIDE    DESIGN GUIDE OF DYNAMIC CHARACTERISTICS OF MAN
      COMMON W,STAT,SHLDH,SUBH,TROCH,TIBH,UPARL,FOARL,CHESD,
     1      WAISD,BUTTD,CHESB,WAISB,HIPB,AXILC,ELBC,WRISC,
     2      FISTC,THIHC,GKNEC,ANKC,SPHYH,FOOTL,SITH,HEADC
      COMMON SW,SM,SL,R,RR,Y,DELTA,AMU,AMUSQ,SIGMA,ETA,YY
      COMMON SIXX,SIYY,SIZZ
      COMMON THETA,SINT,COST,D,E,F,O,OT
      COMMON H,X,XCG,CI
      COMMON XMOD,ZMOD,DELSH
      COMMON PSI,PIXX,PIYY,PIZZ
      COMMON IJ,K,KK,IP,NP
      DIMENSION SW(15),SM(15),SL(15),R(15),RR(15),Y(15),
     1      DELTA(15),AMU(15),AMUSQ(15),SIGMA(15),ETA(15),
     2      YY(15)
      DIMENSION SIXX(15),SIYY(15),SIZZ(15)
      DIMENSION THETA(15,2),SINT(15,2),COST(15,2)
C             D(3,3),E(3,3),F(3,3) ARE DUMMY MATRICES
      DIMENSION D(3,3),E(3,3),F(3,3),O(3,3),OT(3,3)
      DIMENSION H(15,3),X(15,3),XCG(15,3),CI(3,3)
      DIMENSION PERMAN(25,6),TABLE(10,5,31),NP(5)
      READ INPUT TAPE 2,99,NP
   99 FORMAT (5I5)
      DO 1 II=1,25
    1 READ INPUT TAPE 2,100,(PERMAN(II,JJ),JJ=1,6)
  100 FORMAT(A6,F6.1,18X,F6.1,24X,F6.1/30X,F6.1,18X,F6.1)
      WRITE OUTPUT TAPE 3,101
  101 FORMAT(1H1)
      WRITE OUTPUT TAPE 3,102
  102 FORMAT(2H .,15X,15HGA/PHYSICS/64-3,55X,1H.)
      WRITE OUTPUT TAPE 3,103
  103 FORMAT(1HB/2HO.,40X,8HTABLE IV/2HB.,31X,
     1      29HANTHROPOMETRIC DATA OF MODELS)
      WRITE OUTPUT TAPE 3,104
  104 FORMAT(2HB.,15X,30X,10HPERCENTILE,30X,1H.)
      WRITE OUTPUT TAPE 3,105,NP
  105 FORMAT(2H .,25X,I6,4I10)
      WRITE OUTPUT TAPE 3,106
  106 FORMAT(1HO)
      DO 2 II=1,25
    2 WRITE OUTPUT TAPE 3,107,(PERMAN(II,JJ),JJ=1,6)
  107 FORMAT(2H .,17X,A6,4X,F5.1,4F10.1,13X,1H.)
      WRITE OUTPUT TAPE 3,108
  108 FORMAT(2HB.,17X,14HWEIGHT IN LB.,
     1      22H DIMENSIONS IN INCHES./1H1)
```

```
      DO 10 IJ=2,6
      IP=0
      W=PERMAN(1,IJ)
      STAT=PERMAN(2,IJ)
      SHLDH=PERMAN(3,IJ)
      SUBH=PERMAN(4,IJ)
      TROCH=PERMAN(5,IJ)
      TIBH=PERMAN(6,IJ)
      UPARL=PERMAN(7,IJ)
      FOARL=PERMAN(8,IJ)
      CHESD=PERMAN(9,IJ)
      WAISD=PERMAN(10,IJ)
      BUTTD=PERMAN(11,IJ)
      CHESB=PERMAN(12,IJ)
      WAISB=PERMAN(13,IJ)
      HIPB=PERMAN(14,IJ)
      AXILC=PERMAN(15,IJ)
      ELBC=PERMAN(16,IJ)
      WRISC=PERMAN(17,IJ)
      FISTC=PERMAN(18,IJ)
      THIHC=PERMAN(19,IJ)
      GKNEC=PERMAN(20,IJ)
      ANKC=PERMAN(21,IJ)
      SPHYH=PERMAN(22,IJ)
      FOOTL=PERMAN(23,IJ)
      SITH=PERMAN(24,IJ)
      HEADC=PERMAN(25,IJ)
      CALL DESIGN
      DO 10 K=1,7
      IF (K-7)7,6,6
    6 IP=IP+1
      K=K
      CALL EULER
      CALL MODMOM
      TABLE(1,IJ-1,IP)=XMOD
      TABLE(2,IJ-1,IP)=ZMOD
      TABLE(3,IJ-1,IP)=CI(1,1)
      TABLE(4,IJ-1,IP)=CI(2,2)
      TABLE(5,IJ-1,IP)=CI(3,3)
      TABLE(6,IJ-1,IP)=CI(1,3)
      TABLE(7,IJ-1,IP)=PSI
      TABLE(8,IJ-1,IP)=PIXX
      TABLE(9,IJ-1,IP)=PIYY
      TABLE(10,IJ-1,IP)=PIZZ
      GO TO 10
    7 DO 9 KK=1,5
    8 IP=IP+1
      K=K
      KK=KK
      CALL EULER
      CALL MODMOM
      TABLE(1,IJ-1,IP)=XMOD
      TABLE(2,IJ-1,IP)=ZMOD
      TABLE(3,IJ-1,IP)=CI(1,1)
```

```
      TABLE(4,IJ-1,IP)=CI(2,2)
      TABLE(5,IJ-1,IP)=CI(3,3)
      TABLE(6,IJ-1,IP)=CI(1,3)
      TABLE(7,IJ-1,IP)=PSI
      TABLE(8,IJ-1,IP)=PIXX
      TABLE(9,IJ-1,IP)=PIYY
      TABLE(10,IJ-1,IP)=PIZZ
    9 CONTINUE
   10 CONTINUE
      DO 20 JP=1,11
      WRITE OUTPUT TAPE 3,102
      DO 15 IMP=1,3
      IP=3*(JP-1)+IMP
      WRITE OUTPUT TAPE 3,109,IP
  109 FORMAT(2HA.,15X,8HPOSITION,I3)
      WRITE OUTPUT TAPE 3,110
  110 FORMAT(2HB./1H /2HB.,22X,4HC.G.,8X,14HINERTIA TENSOR,
     1       11X,17HPRINCIPAL MOMENTS,9X,1H.)
      WRITE OUTPUT TAPE 3,111
  111 FORMAT(2H .,15X,3HD/0,2X,1HX,5X,1HZ,3X,3HIXX,3X,3HIYY,
     1       3X,3HIZZ,3X,3HIXZ,2X,5HTHETA,2X,3HIXX,3X,3HIYY,
     2       3X,3HIZZ,10X,1H.)
      DO 12 JJ=1,5
   12 WRITE OUTPUT TAPE 3,112,NP(JJ),
     1       (TABLE(II,JJ,IP),II=1,10)
  112 FORMAT(2H .,15X,I2,F6.2,F5.1,4F6.2,F6.1,3F6.2,9X,1H.)
      IF(JP-11)15,13,13
   13 WRITE OUTPUT TAPE 3,113
  113 FORMAT(2H0.,15X,27HALL POSITIONS ARE SYMMETRIC
     1       20H (IXY,IYZ ARE ZERO),23X,1H./
     2       17X,30HX,Z IN INCHES, IXX,IYY,IZZ,IXZ
     3       29H IN SLUG-FT-FT, THETA IN DEG.,11X,1H.)
      GO TO 20
   15 CONTINUE
      WRITE OUTPUT TAPE 3,113
   20 WRITE OUTPUT TAPE 3,101
      CALL EXIT
       END
```

```
      SUBROUTINE DESIGN
      COMMON W,STAT,SHLDH,SUBH,TROCH,TIBH,UPARL,FOARL,CHESD,
     1       WAISD,BUTTD,CHESB,WAISB,HIPB,AXILC,ELBC,WRISC,
     2       FISTC,THIHC,GKNEC,ANKC,SPHYH,FOOTL,SITH,HEADC
      COMMON SW,SM,SL,R,RR,Y,DELTA,AMU,AMUSQ,SIGMA,ETA,YY
      COMMON SIXX,SIYY,SIZZ
      COMMON THETA,SINT,COST,D,E,F,O,OT
      COMMON H,X,XCG,CI
      COMMON XMOD,ZMOD,DELSH
      COMMON PSI,PIXX,PIYY,PIZZ
      COMMON ZZ,K,KK,IP,NP
      DIMENSION SW(15),SM(15),SL(15),R(15),RR(15),Y(15),
     1       DELTA(15),AMU(15),AMUSQ(15),SIGMA(15),ETA(15),
```

```
     2      YY(15)
      DIMENSION SIXX(15),SIYY(15),SIZZ(15)
      DIMENSION THETA(15,2),SINT(15,2),COST(15,2)
C               D(3,3),E(3,3),F(3,3) ARE DUMMY MATRICES
      DIMENSION D(3,3),E(3,3),F(3,3),O(3,3),OT(3,3)
      DIMENSION H(15,3),X(15,3),XCG(15,3),CI(3,3)
      PI=3.1415927
      TWOPI=2.*PI
      C1=PI/3.
      C2=62.427/1728.
C     DESIGN MODEL MAN BY USING ANTHROPOMETRIC DIMENSIONS
C     APPLY BARTER REGRESSION EQUATICN TO SUBJECT WEIGHT
    1 HNT=(.47*W)+12.
      BUA=(.08*W)-2.9
      BFO=(.04*W)-.5
      BH=(.01*W)+.7
      BUL=(.18*W)+3.2
      BLL=(.11*W)-1.9
      BF=(.02*W)+1.5
      WDIFF=W-(HNT+BUA+BFO+BH+BUL+BLL+BF)
      WR=WDIFF/(HNT+BUA+BFO+BH+BUL+BLL+BF)
      WR1=1.+WR
C     DISTRIBUTE WDIFF PROPORTIONALLY OVER ALL SEGMENTS
    2 SW(1)=.079*W
      SW23=HNT*WR1-SW(1)
      SW(4)=BH*WR1/2.
      SW(6)=BUA*WR1/2.
      SW(8)=BFO*WR1/2.
      SW(10)=BUL*WR1/2.
      SW(12)=BLL*WR1/2.
      SW(14)=BF*WR1/2.
C     DEVELOPMENT OF HEAD
    3 I=1
      R(I)=(STAT-SHLDH)/2.
      RR(I)=HEADC/TWOPI
      DELTA(I)=SW(I)/RR(I)/RR(I)/C1/4./R(I)
      SL(I)=2.*R(I)
      ETA(I)=.5
      Y(I)=R(I)
C     DEVELOPMENT OF TRUNK
    4 SL(2)=SHLDH-SUBH
      SL(3)=SITH-(STAT-SUBH)
      R(2)=CHESB/2.
      R(3)=HIPB/2.
      RR(2)=(CHESD+WAISD)/4.
      RR(3)=(WAISD+BUTTD)/4.
      ETA(2)=.5
      ETA(3)=ETA(2)
      Y(2)=.5*SL(2)
      Y(3)=.5*SL(3)
      DELTA(2)=SW23/PI/(R(2)*RR(2)*SL(2)
     1     +1.01/.92*R(3)*RR(3)*SL(3))
      DELTA(3)=1.01/.92*DELTA(2)
      SW(2)=DELTA(2)*R(2)*RR(2)*SL(2)*PI
```

```
      SW(3)=DELTA(3)*R(3)*RR(3)*SL(3)*PI
C     DEVELOPMENT OF HANDS
      I=4
    5 R(I)=FISTC/TWOPI
      RR(I)=R(I)
      SL(I)=2.*RR(I)
      ETA(I)=.5
      Y(I)=ETA(I)*SL(I)
      SW(I)=SW(4)
      DELTA(I)=SW(I)/C1/R(I)/R(I)/R(I)/4.
      IJ=I-3
      I=5
      GO TO (5,6),IJ
C     DEVELOPMENT OF UPPER ARM
    6 IJ=1
      I=6
      R(I)=AXILC/TWOPI
      RR(I)=ELBC/TWOPI
      SL(I)=UPARL
      GO TO 20
C     DEVELOPMENT OF FOREARM
    8 IJ=2
      I=8
      R(I)=ELBC/TWOPI
      RR(I)=WRISC/TWOPI
      SL(I)=FOARL
      GO TO 20
C     DEVELOPMENT OF UPPER LEG
   10 IJ=3
      I=10
      R(I)=THIHC/TWOPI
      RR(I)=GKNEC/TWOPI
      SL(I)=STAT-SITH-TIBH
      GO TO 20
C     DEVELOPMENT OF LOWER LEG
   12 IJ=4
      I=12
      R(I)=GKNEC/TWOPI
      RR(I)=ANKC/TWOPI
      SL(I)=TIBH-SPHYH
   20 G=R(I)*R(I)+R(I)*RR(I)+RR(I)*RR(I)
      DELTA(I)=SW(I)/C1/SL(I)/G
      AMU(I)=RR(I)/R(I)
      AMUSQ(I)=AMU(I)*AMU(I)
      SIGMA(I)=1.+AMU(I)+AMUSQ(I)
      ETA(I)=(1.+2.*AMU(I)+3.*AMUSQ(I))/SIGMA(I)/4.
      Y(I)=ETA(I)*SL(I)
      GO TO (8,10,12,14),IJ
C     DEVELOPMENT OF FEET
   14 I=14
      SL(I)=FOOTL
      ETA(I)=.429
      Y(I)=ETA(I)*SL(I)
      G=1.-2.*ETA(I)+SQRTF(ETA(I)*ETA(I)
```

```
     1      *(-12.)+12.*ETA(I)-2.)
      AMU(I)=(4.*ETA(I)-1.)/G
      AMUSQ(I)=AMU(I)*AMU(I)
      SIGMA(I)=1.+AMU(I)+AMUSQ(I)
      R(I)=SPHYH/2.
      RR(I)=AMU(I)*R(I)
      G=R(I)*R(I)+R(I)*RR(I)+RR(I)*RR(I)
      DELTA(I)=SW(I)/C1/SL(I)/G
   30 DO 31 I=7,15,2
      SW(I)=SW(I-1)
      DELTA(I)=DELTA(I-1)
      R(I)=R(I-1)
      RR(I)=RR(I-1)
      SL(I)=SL(I-1)
      AMU(I)=AMU(I-1)
      AMUSQ(I)=AMUSQ(I-1)
      SIGMA(I)=SIGMA(I-1)
      ETA(I)=ETA(I-1)
   31 Y(I)=Y(I-1)
   40 DO 41 I=1,5
      AMU(I)=0.
      AMUSQ(I)=0.
   41 SIGMA(I)=0.
C     CALCULATE SEGMENT MASS, MASS DENSITY, AND SUM OF SW(I)
   50 DO 51 I=1,15
      SM(I)=SW(I)/32.2
   51 DELTA(I)=DELTA(I)/32.2
C     DEFINE DISTANCES OF LOCAL CG FROM HINGE POINT
      DELSH=SITH-(STAT-TROCH)
      DO 60 I=1,15
   60 YY(I)=Y(I)
      YY(6)=Y(6)-R(6)
      YY(10)=Y(10)+DELSH
      YY(14)=0.
      DO 61 I=7,15,4
   61 YY(I)=YY(I-1)
C     DETERMINE FIXED HINGE POINTS
      DO 67 I=1,15
      DO 67 J=1,3
   67 H(I,J)=0.
      H(6,2)=CHESB/2.+R(6)
      H(6,3)=STAT-SHLDH+R(6)
      H(10,2)=HIPB/2.-R(10)
      H(10,3)=SL(1)+SL(2)+SL(3)-DELSH
      DO 68 I=7,11,4
      H(I,2)=-H(I-1,2)
   68 H(I,3)=H(I-1,3)
C     DETERMINATION OF LOCAL MOMENTS OF INERTIA OF SEGMENTS
C     HEAD
   71 I=1
      SIXX(I)=.2*SM(I)*(R(I)*R(I)+RR(I)*RR(I))
      SIYY(I)=SIXX(I)
      SIZZ(I)=.4*SM(I)*RR(I)*RR(I)
C     UPPER TORSO AND LOWER TORSO
```

```
      DO 72 I=2,3
      SIXX(I)=SM(I)*(3.*R(I)*R(I)+SL(I)*SL(I))/12.
      SIYY(I)=SM(I)*(3.*RR(I)*RR(I)+SL(I)*SL(I))/12.
   72 SIZZ(I)=SM(I)*(RR(I)*RR(I)+R(I)*R(I))/4.
C     HANDS
   74 I=4
      SIXX(I)=.4*SM(I)*R(I)*R(I)
      SIYY(I)=SIXX(I)
      SIZZ(I)=SIXX(I)
C     UPPER AND LOWER ARMS AND LEGS, AND FEET
   76 DO 82 I=6,14,2
      AA=9.*(1.+AMU(I)+AMUSQ(I)*(1.+AMU(I)+AMUSQ(I)))
     1     /SIGMA(I)/SIGMA(I)/20./PI
      BB=3.*(1.+4.*AMU(I)+AMUSQ(I)*(10.+4.*AMU(I)+AMUSQ(I)))
     1     /SIGMA(I)/SIGMA(I)/80.
      SIXX(I)=SM(I)*(AA*SM(I)/DELTA(I)/SL(I)+BB*SL(I)*SL(I))
      SIYY(I)=SIXX(I)
   82 SIZZ(I)=2.*SM(I)*SM(I)*AA/DELTA(I)/SL(I)
C     COMPLETE REMAINDER OF SEGMENTS
      DO 120 I=5,15,2
      SIXX(I)=SIXX(I-1)
      SIYY(I)=SIYY(I-1)
  120 SIZZ(I)=SIZZ(I-1)
      RETURN
      END



      SUBROUTINE EULER
      COMMON W,STAT,SHLDH,SUBH,TROCH,TIBH,UPARL,FOARL,CHESD,
     1     WAISD,BUTTD,CHESB,WAISB,HIPB,AXILC,ELBC,WRISC,
     2     FISTC,THIHC,GKNEC,ANKC,SPHYH,FOOTL,SITH,HEADC
      COMMON SW,SM,SL,R,RR,Y,DELTA,AMU,AMUSQ,SIGMA,ETA,YY
      COMMON SIXX,SIYY,SIZZ
      COMMON THETA,SINT,COST,D,E,F,O,OT
      COMMON H,X,XCG,CI
      COMMON XMOD,ZMOD,DELSH
      COMMON PSI,PIXX,PIYY,PIZZ
      COMMON IJ,K,KK,IP,NP
      DIMENSION SW(15),SM(15),SL(15),R(15),RR(15),Y(15),
     1     DELTA(15),AMU(15),AMUSQ(15),SIGMA(15),ETA(15),
     2     YY(15)
      DIMENSION SIXX(15),SIYY(15),SIZZ(15)
      DIMENSION THETA(15,2),SINT(15,2),COST(15,2)
      DIMENSION D(3,3),E(3,3),F(3,3),O(3,3),OT(3,3)
      DIMENSION H(15,3),X(15,3),XCG(15,3),CI(3,3)
      PI=3.1415927
      C3=PI/180.
      DO 1 I=1,15
      DO 1 J=1,2
      THETA(I,J)=0.
      SINT(I,J)=0.
    1 COST(I,J)=0.
      K=K
```

```
      GO TO (2,3,5,7,9,11,13),K
C     ARMS AT ATTENTION
C     K=1
    2 GO TO 18
C     ARMS DIRECTLY CVER HEAD
C     K=2
    3 DO 4 I=4,9
    4 THETA(I,1)=180.*C3
      GO TO 18
C     ARMS SPREAD IN CRUCIFORM POSITION
C     K=3
    5 DO 6 I=5,9,2
      THETA(I,1)=-90.*C3
    6 THETA(I-1,1)=-THETA(I,1)
      GO TO 18
C     ARMS EXTENDED IN FRONT OF BODY
C     K=4
    7 DO 8 I=4,9
      DO 8 J=1,2
    8 THETA(I,J)=90.*C3
      GO TO 18
C     ARMS BENT 9C AT ELBOW, FOREARMS IN FRONT OF BODY
C     K=5
    9 DO 10 I=5,9,4
      DO 10 J=1,2
      THETA(I,J)=90.*C3
   10 THETA(I-1,J)=THETA(I,J)
      GO TO 18
C     UPPER ARMS AT SHOULDER LEVEL, FOREARMS EXTENDED IN FRO
C     K=6
   11 DO 12 I=5,9,4
      DO 12 J=1,2
      THETA(I,J)=90.*C3
   12 THETA(I-1,J)=THETA(I,J)
      THETA(6,1)=90.*C3
      THETA(7,1)=-THETA(6,1)
      GO TO 18
C     SPECIAL POSITION
C     K=7
   13 DO 14 I=4,5
      THETA(I,1)=60.*C3
   14 THETA(I,2)=90.*C3
      DO 15 I=8,11
      THETA(I,1)=60.*C3
   15 THETA(I,2)=90.*C3
      DO 16 I=12,13
      THETA(I,1)=12.*C3
   16 THETA(I,2)=90.*C3
      DO 17 I=14,15
      DO 17 J=1,2
   17 THETA(I,J)=90.*C3
      GO TO 31
   18 KK=KK
      GO TO (19,21,23,25,28),KK
```

```
C     STANDING
C     KK=1
   19 DO 20 I=14,15
      DO 20 J=1,2
   20 THETA(I,J)=90.*C3
      GO TO 31
C     KNELLING
C     KK=2
   21 DO 22 I=12,13
      THETA(I,1)=90.*C3
   22 THETA(I,2)=-90.*C3
      GO TO 31
C     SITTING
C     KK=3
   23 DO 24 I=11,15,4
      DO 24 J=1,2
      THETA(I,J)=90.*C3
   24 THETA(I-1,J)=THETA(I,J)
      GO TO 31
C     SITTING, LEGS EXTENDED FORWARD
C     KK=4
   25 DO 26 I=10,13
      DO 26 J=1,2
   26 THETA(I,J)=90.*C3
      DO 27 I=14,15
   27 THETA(I,1)=180.*C3
      GO TO 31
C     STANDING, LEGS AT 30 DEGREES
C     KK=5
   28 DO 29 I=11,13,2
      THETA(I,1)=-30.*C3
   29 THETA(I-1,1)=-THETA(I,1)
      DO 30 I=14,15
      DO 30 J=1,2
   30 THETA(I,J)=90.*C3
   31 DO 32 II=1,15
      DO 32 JJ=1,2
      SINT(II,JJ)=SINF(THETA(II,JJ))
   32 COST(II,JJ)=COSF(THETA(II,JJ))
      RETURN
      END


      SUBROUTINE MCOMCM
      COMMON W,STAT,SHLDH,SUBH,TROCH,TIBH,UPARL,FOARL,CHESD,
     1       WAISD,BUTTD,CHESB,WAISB,HIPB,AXILC,ELBC,WRISC,
     2       FISTC,THIRC,GKNEC,ANKC,SPHYH,FOOTL,SITH,HEADC
      COMMON SW,SM,SL,R,RR,Y,DELTA,AMU,AMUSQ,SIGMA,ETA,YY
      COMMON SIXX,SIYY,SIZZ
      COMMON THETA,SINT,COST,D,E,F,O,OT
      COMMON H,X,XCG,CI
      COMMON XMOD,ZMOD,DELSH
      COMMON PSI,PIXX,PIYY,PIZZ
```

```
      COMMON IJ,K,KK,IP,NP
      DIMENSION SW(15),SM(15),SL(15),R(15),RR(15),Y(15),
     1     DELTA(15),AMU(15),AMUSQ(15),SIGMA(15),ETA(15),
     2     YY(15)
      DIMENSION SIXX(15),SIYY(15),SIZZ(15)
      DIMENSION THETA(15,2),SINT(15,2),COST(15,2)
C              D(3,3),E(3,3),F(3,3) ARE DUMMY MATRICES
      DIMENSION D(3,3),E(3,3),F(3,3),O(3,3),OT(3,3)
      DIMENSION H(15,3),X(15,3),XCG(15,3),CI(3,3)
      PI=3.1415927
      C3=PI/180.
C     ZERO DUMMY MATRICES D,E,F
      DO 1 II=1,3
      DO 1 JJ=1,3
      D(II,JJ)=0.
      E(II,JJ)=0.
    1 F(II,JJ)=0.
C     ZERO C.G. ARRAY
      DO 2 I=1,15
      DO 2 J=1,3
    2 X(I,J)=0.
C     ZERO THE INERTIA TENSOR ARRAY
      DO 3 II=1,3
      DO 3 JJ=1,3
    3 CI(II,JJ)=0.
C     CALCULATE HINGE POINTS OF MOVEABLE SEGMENTS
C     FOREARMS
      DO 9 I=8,9
      G=SL(I-2)-R(I-2)
      E(1,1)=SINT(I-2,1)*SINT(I-2,2)
      E(2,1)=SINT(I-2,1)*COST(I-2,2)
      E(3,1)=COST(I-2,1)
      DO 9 J=1,3
    9 H(I,J)=H(I-2,J)+E(J,1)*G
C     LOWER LEGS
      DO 10 I=12,13
      G=SL(I-2)+DELSH
      E(1,1)=SINT(I-2,1)*SINT(I-2,2)
      E(2,1)=SINT(I-2,1)*COST(I-2,2)
      E(3,1)=COST(I-2,1)
      DO 10 J=1,3
   10 H(I,J)=H(I-2,J)+E(J,1)*G
C     HANDS
      DO 11 I=4,5
      G=SL(I+4)
      E(1,1)=SINT(I+4,1)*SINT(I+4,2)
      E(2,1)=SINT(I+4,1)*COST(I+4,2)
      E(3,1)=COST(I+4,1)
      DO 11 J=1,3
   11 H(I,J)=H(I+4,J)+E(J,1)*G
C     FEET
      DO 12 I=14,15
      G=SL(I-2)+.5*SPHYH
      E(1,1)=SINT(I-2,1)*SINT(I-2,2)
```

```
      E(2,1)=SINT(I-2,1)*COST(I-2,2)
      E(3,1)=COST(I-2,1)
      DO 12 J=1,3
   12 H(I,J)=H(I-2,J)+E(J,1)*G
C     DETERMINE COORD OF LOCAL CG WRT TOP OF HEAD
      X(1,3)=Y(1)
      X(2,3)=SL(1)+Y(2)
      X(3,3)=SL(1)+SL(2)+Y(3)
      DO 13 I=4,15
      G=YY(I)
      F(1,1)=SINT(I,1)*SINT(I,2)
      F(2,1)=SINT(I,1)*COST(I,2)
      F(3,1)=COST(I,1)
      DO 13 J=1,3
   13 X(I,J)=H(I,J)+F(J,1)*G
      XMOD=2.144323+0.1521604*WAISD
      XREF=XMOD
      ZMOD=0.
      DO 14 I=1,15
      XMOD=XMOD+SW(I)*X(I,1)/W
   14 ZMOD=ZMOD+SW(I)*X(I,3)/W
C     DETERMINE COORD OF SEGMENT CG WRT CALC CG
      DO 15 I=1,15
      XCG(I,1)=X(I,1)-(XMOD-XREF)
      XCG(I,2)=X(I,2)
   15 XCG(I,3)=X(I,3)-ZMOD
      DO 30 I=1,15
C     ARRANGE LOCAL MOMENTS INTO DUMMY MATRIX (3 X 3)
      DO 24 II=1,3
      DO 24 JJ=1,3
   24 D(II,JJ)=0.
      D(1,1)=SIXX(I)
      D(2,2)=SIYY(I)
      D(3,3)=SIZZ(I)
C     ARRANGE TRANSFORMATION MATRIX
   25 O(1,1)=COST(I,2)
      O(1,2)=SINT(I,2)*COST(I,1)
      O(1,3)=SINT(I,2)*SINT(I,1)
      O(2,1)=-SINT(I,2)
      O(2,2)=COST(I,2)*COST(I,1)
      O(2,3)=COST(I,2)*SINT(I,1)
      O(3,1)=0.
      O(3,2)=-SINT(I,1)
      O(3,3)=COST(I,1)
C     TRANSPOSE THE TRANSFORMATION MATRIX
   26 OT(1,1)=O(1,1)
      OT(1,2)=O(2,1)
      OT(1,3)=O(3,1)
      OT(2,1)=O(1,2)
      OT(2,2)=O(2,2)
      OT(2,3)=O(3,2)
      OT(3,1)=O(1,3)
      OT(3,2)=O(2,3)
      OT(3,3)=O(3,3)
```

```
      CALL HMMPY(D,QT,E,3,3,3,LM)
      CALL HMMPY(C,E,F,3,3,3,LM)
C     F(3,3) IS LOCAL MOMENT ROTATED PARALLEL TO BODY AXES
C     TRANSFER TO CALC CG BY PARALLEL AXIS THEOREM
      D(1,1)=XCG(I,2)*XCG(I,2)+XCG(I,3)*XCG(I,3)
      D(1,2)=-XCG(I,1)*XCG(I,2)
      D(1,3)=-XCG(I,1)*XCG(I,3)
      D(2,1)=D(1,2)
      D(2,2)=XCG(I,1)*XCG(I,1)+XCG(I,3)*XCG(I,3)
      D(2,3)=-XCG(I,2)*XCG(I 3)
      D(3,1)=D(1,3)
      D(3,2)=D(2,3)
      D(3,3)=XCG(I,1)*XCG(I,1)+XCG(I,2)*XCG(I,2)
      DO 30 II=1,3
      DO 30 JJ=1,3
      D(II,JJ)=SM(I)*D(II,JJ)/144.
      F(II,JJ)=F(II,JJ)/144.
   30 CI(II,JJ)=CI(II,JJ)+D(II,JJ)+F(II,JJ)
C     CALCULATE PRINCIPAL AXES AND PRINCIPAL MOMENTS
      PSI=.5*ATANF(-2.*CI(1,3)/(CI(1,1)-CI(3,3)))
      PIXX=CI(1,1)*COSF(PSI)*COSF(PSI)+CI(3,3)*SINF(PSI)
     1     *SINF(PSI)-2.*CI(1,3)*SINF(PSI)*COSF(PSI)
      PIYY=CI(2,2)
      PIZZ=CI(1,1)*SINF(PSI)*SINF(PSI)+CI(3,3)*COSF(PSI)
     1     *COSF(PSI)+2.*CI(1,3)*SINF(PSI)*COSF(PSI)
      PSI=PSI/C3
      IF(PIXX-PIZZ)31,32,32
   31 G=PIXX
      PIXX=PIZZ
      PIZZ=G
      PSI=90.+PSI
   32 RETURN
      END


CHMMPY     MATRIX MULTIPLICATION, SINGLE PRECISION, FL. PT.
C     CALLING SEQUENCE...
C     CALL HMMPY(A,B,C,M,K,N,L)
C        WHERE C(M,N)=A(M,K)*B(K,N)
C          (C MAY BE A, IN WHICH CASE A IS DESTROYED)
C        L=0 INDICATES OK
C        L=1 INDICATES FL. PT. OVERFLOW
      SUBROUTINE HMMPY(A,B,C,M,K,N,L)
      DIMENSION A(3,3),B(3,3),C(3,3),R(3)
      MM=M
      KK=K
      NN=N
      LL=0
      DO 120 I=1,MM
      DO 100 J=1,NN
      R(J)=0.
      DO 100 K1=1,KK
  100 R(J)=A(I,K1)*B(K1,J)+R(J)
```

```
      DO 110 J=1,NN
110   C(I,J)=R(J)
      IF ACCUMULATOR OVERFLOW 130,120
120   CONTINUE
125   L=LL
      RETURN
130   LL=1
      GO TO 125
      END
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13 ABSTRACT

A mathematical model for predicting the inertial properties of a human body in various positions has been developed. Twenty-five standard anthropometric dimensions are used in the model to predict an individual's center of gravity, moments and products of inertia, principal moments, and principal axes. The validity of the model was tested by comparing its predictions with experimental data from 66 subjects. The center of gravity was generally predicted within 0.7 inches and moments of inertia within 10 percent. The principal vertical axis was found to deviate from the longitudinal axis of the body by as much as 50 degrees, depending on the body position assumed. A generalized computer program to calculate the inertial properties of a subject in any body position is presented. The inertial properties of five composite subjects in each of 31 body positions is offered as a design guide. IBM 7094 digital computer programs are appended.

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AMRL-TR-64-102 October 1964

ERRATA - January 1965

The following corrections apply to Technical Report No. AMRL-TR-64-102, A Mathematical Model of the Human Body.

Page	Line	
14	2	Eq (2g) should read: $DELTA = \frac{3\ SW}{4\ R\ (RR)^2\ PI}$
15	13	Eq (3j) should read: $SIXX = \frac{SM\ (3\ (R)^2 + (SL)^2)}{12}$
15	14	Eq (3k) should read: $SIYY = \frac{SM\ (3\ (RR)^2 + (SL)^2)}{12}$
15	15	Eq (3l) should read: $SIZZ = \frac{SM\ ((R)^2 + (RR)^2)}{4}$
16	8	Eq (4i) should read: SIXX = [same as Eq (3j) above]
16	9	Eq (4j) should read: SIYY = [same as Eq (3k) above]
16	10	Eq (4k) should read: SIZZ = [same as Eq (3l) above]
19	10	Eq (7a) should read: $R = \frac{ELBC}{2\ PI}$
29	19	Delete "The Y location of the center of gravity, YNAA, is" and insert "The Z location of the center of gravity, ZNAA, is"
56	—	TABLE IV, entry for WAISB under 75%, delete "10.2" and insert "11.2"
A-2	34	Delete "(Ref 27:35)" and insert "(Ref 27:58)"
B-1	35	Units for DELTA(I), delete "SLUG/IN-IN-IN" and insert "LB/IN-IN-IN"

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