

**Figure 1:** Lateral and anterior view of 17-segment anthropomorphic model. The shapes of the segments, as depicted here, accurately reflect the morphologies of the model segments. The local (segment-fixed) coordinate systems are also shown.

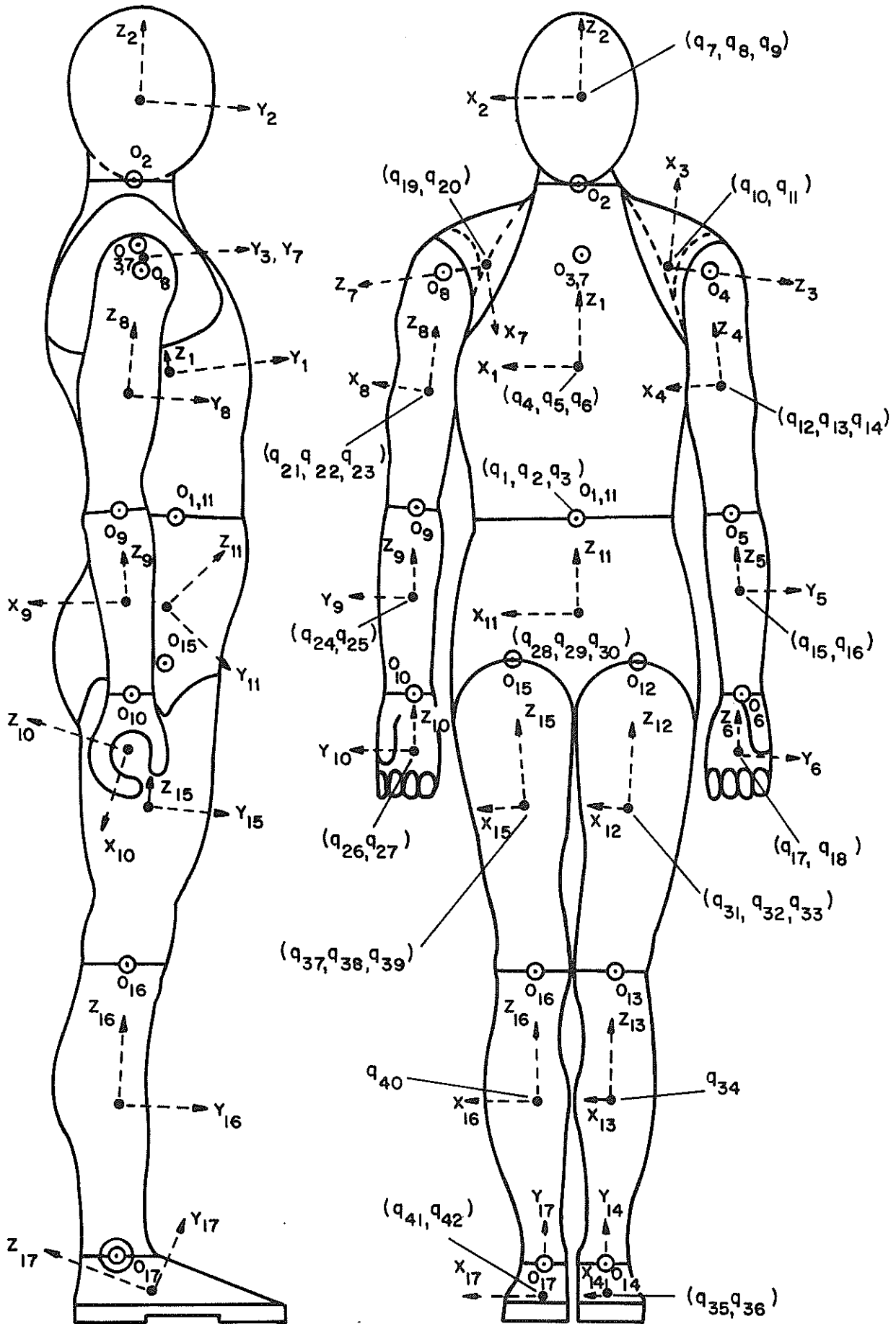
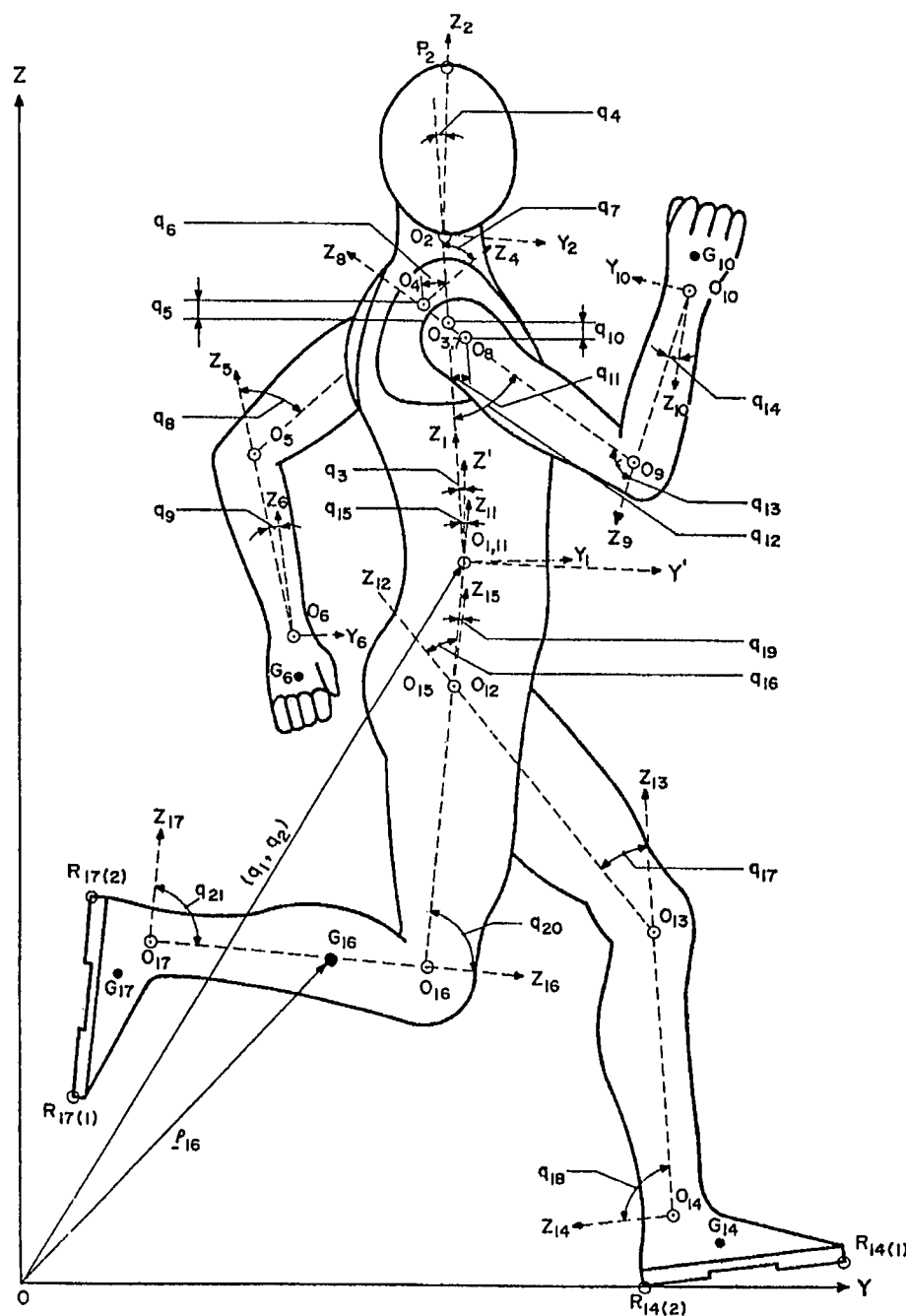


Fig. 1: Lateral and anterior view of 17-segment hominoid. The local (segment-fixed) coordinate systems and respective generalized coordinates,  $q_i$ ,  $i=1, \dots, 42$ , are also shown.

Figure 1—Lateral view of a 17-segment hominoid moving in the sagittal plane. The 21 configurational coordinates  $q_1, \dots, q_{21}$  are also shown (adapted from Hatze, H. Quantitative analysis, synthesis and optimization of human motion. *Hum. Mov. Sci.* 3:5–25, 1984).



shall merely give a brief summary here to the extent as is essential for the further discussion.

The visible motion,  $\Omega$ , during a time interval  $\tau$ , of a human body model (hominoid) comprising a certain number of segments is defined by the set of time functions of the configurational coordinates  $q_i$ ,  $i = 1, \dots, f$ , that is by

$$\Omega := \{q_i(t_k), \tau: t_k \in \tau; i = 1, \dots, f; k = 0, 1, \dots, N\}, \quad [1]$$

where the observed coordinate values  $q_i$  are assumed to be given at  $N + 1$  discrete points in time,  $t_k$ .

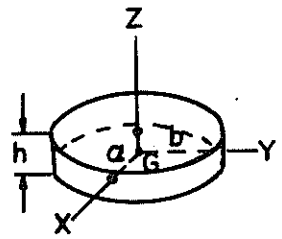
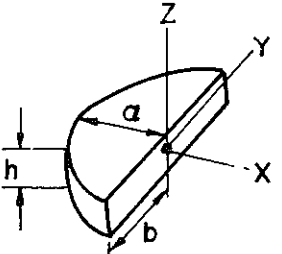
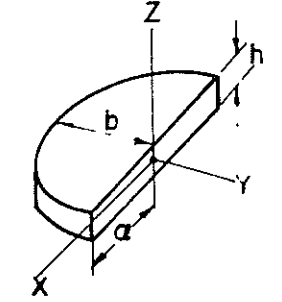
As an example, a 17-segment human body model is

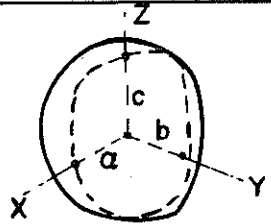
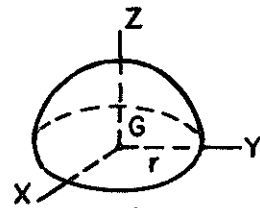
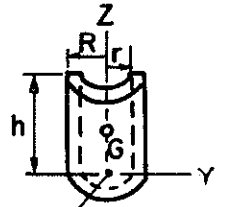
depicted in Figure 1. Its configuration for planar motions is described by  $f = 21$  generalized coordinates  $q_i$ ,  $i = 1, \dots, f$ .

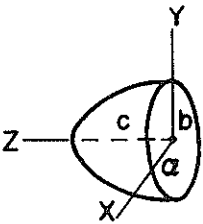
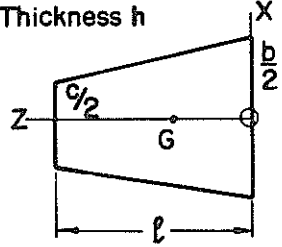
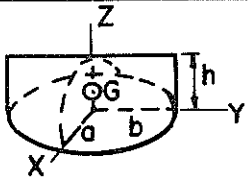
The complexity of the human body model chosen, and therefore the number of coordinates required to define its configuration, depends entirely on the purpose for which the model is to be used.

Having defined the concept of motion of a human body model, the state vector function including also the configurational velocities  $\dot{q}_i$  is given by

$$x(t) := (q_1(t), \dots, q_f(t), \dot{q}_1(t), \dots, \dot{q}_f(t))^T, \quad t \in \tau. \quad [2]$$

Body No.	Body	Mass and Centroid	Moments of Inertia	Products of Inertia
A1.1	 <p>Elliptic Cylinder</p>	$M = \gamma \pi a b h$ $\bar{x} = \bar{y} = \bar{z} = 0$	$\bar{I}_x = M(3b^2 + h^2)/12$ $\bar{I}_y = M(3a^2 + h^2)/12$ $\bar{I}_z = M(a^2 + b^2)/4$	$\bar{I}_{xy} = \bar{I}_{yz} = \bar{I}_{zx} = 0$
A1.2	 <p>Parabolic Plate</p>	$M = 4\gamma a b h/3$ $\bar{x} = -0.4a$ $\bar{y} = \bar{z} = 0$	$\bar{I}_x = M(b^2/5 + h^2/12)$ $\bar{I}_y = M(12a^2/175 + h^2/12)$ $\bar{I}_z = M(12a^2/175 + b^2/5)$	$\bar{I}_{xy} = \bar{I}_{yz} = \bar{I}_{zx} = 0$
A1.3	 <p>Semi-elliptic Plate</p>	$M = \gamma a b h \pi/2$ $\bar{x} = 0$ $\bar{y} = -4b/3\pi$ $\bar{z} = 0$	$\bar{I}_x = M(0.07b^2 + h^2/12)$ $\bar{I}_y = M(a^2/4 + h^2/12)$ $\bar{I}_z = M(a^2/4 + 0.07b^2)$	$\bar{I}_{xy} = \bar{I}_{yz} = \bar{I}_{zx} = 0$

Body No.	Body	Mass and Centroid	Moments of Inertia	Products of Inertia
A1.4	 Elliptic Octoparaboloid	Defining equation for body shape in xz-plane along y-axis: $z = \pm ck(1 - (x/ak)^8)$ , for $z \geq 0$ , where $k = (1 - (y/b)^2)^{\frac{1}{2}}$ . $M = \gamma 4.66493abc$ $\bar{x} = \bar{y} = \bar{z} = 0$	$\bar{I}_x = M(0.19473b^2 + 0.23511c^2)$ $\bar{I}_y = M(0.211a^2 + 0.23511c^2)$ $\bar{I}_z = M(0.211a^2 + 0.19473b^2)$	$\bar{I}_{xy} = \bar{I}_{yz} = \bar{I}_{zx} = 0$
A1.5	 Hemisphere	$M = \gamma 2\pi r^3/3$ $\bar{x} = \bar{y} = 0$ $\bar{z} = 3r/8$	$\bar{I}_x = \bar{I}_y = Mr^2(2/5 - 9/64)$ $\bar{I}_z = 2\pi r^2/5$	$\bar{I}_{xy} = \bar{I}_{yz} = \bar{I}_{zx} = 0$
A1.6	 Hollow Right Circular Half-Cylinder	$M = \gamma \pi h(R^2 - r^2)/2$ $\bar{x} = 4(R^3 - r^3)/3\pi(R^2 - r^2)$ $\bar{y} = 0$ $\bar{z} = h/2$	$\bar{I}_x = M(R^2 + r^2 + h^2/3)/4$ $\bar{I}_y = \bar{I}_x - M\bar{x}^2$ $\bar{I}_z = M((R^2 + r^2)/2 - \bar{x}^2)$	$\bar{I}_{xy} = \bar{I}_{yz} = \bar{I}_{zx} = 0$

Body No.	Body	Mass and Centroid	Moments of Inertia	Products of Inertia
A1.7	 <p>Elliptic Paraboloid</p>	$M = \gamma \pi a b c / 2$ $\bar{x} = \bar{y} = 0$ $\bar{z} = a / 3$	$\bar{I}_x = M(3b^2 + c^2) / 18$ $\bar{I}_y = M(3a^2 + c^2) / 18$ $\bar{I}_z = M(a^2 + b^2) / 6$	$\bar{I}_{xy} = \bar{I}_{yz} = \bar{I}_{zx} = 0$
A1.8	<p>Thickness <math>h</math></p>  <p>Thin Trapezoidal Plate</p>	$M = \gamma l h (b + c) / 2$ $\bar{x} = 0$ $\bar{z} = l(b + 2c) / 3(b + c)$	$\bar{I}_x = M l^2 (b^2 + 4bc + c^2) / 18(b + c)^2$ $\bar{I}_z = M(b^2 + c^2) / 24$ $\bar{I}_y = \bar{I}_x + \bar{I}_z$	$\bar{I}_{xy} = \bar{I}_{yz} = \bar{I}_{zx} = 0$
A1.9	 <p>Ellipto-parabolic Hoof</p>	$M = \gamma 2 \pi a b h / 3$ $\bar{x} = \bar{y} = 0$ $\bar{z} = 2h / 5$	$\bar{I}_x = M(b^2 / 4 + 0.0686h^2)$ $\bar{I}_y = M(0.15a^2 + 0.0686h^2)$ $\bar{I}_z = M(0.15a^2 + b^2 / 4)$	$\bar{I}_{xy} = \bar{I}_{yz} = \bar{I}_{zx} = 0$

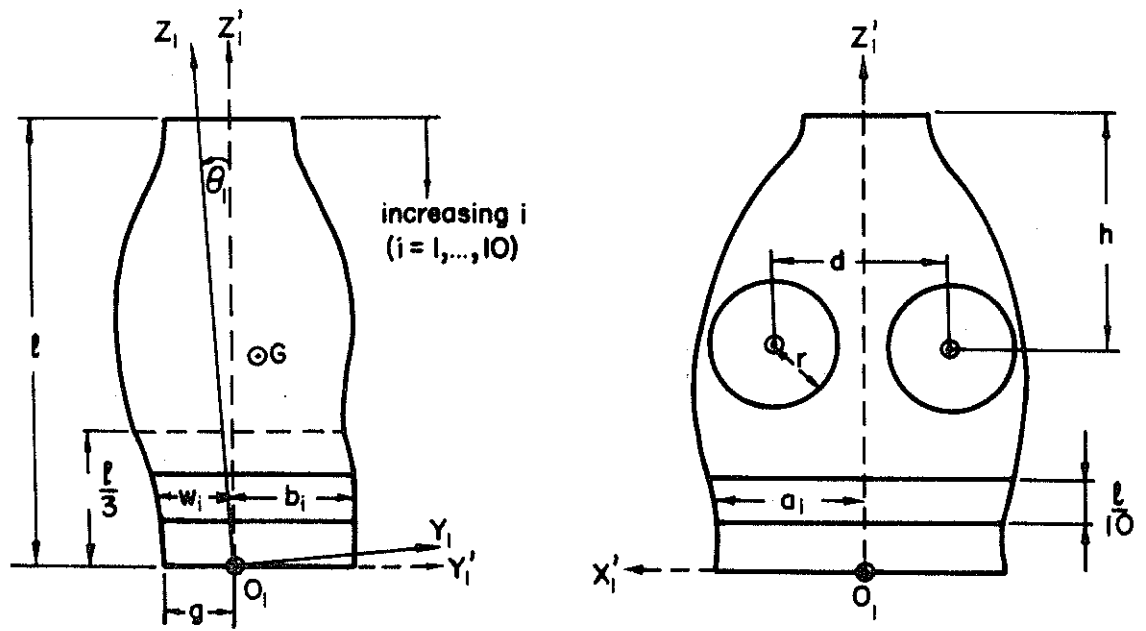


Fig. F2.1

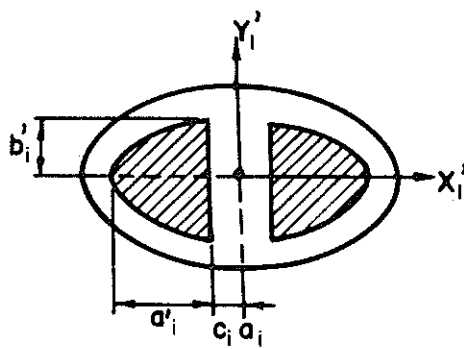


Fig. F2.2

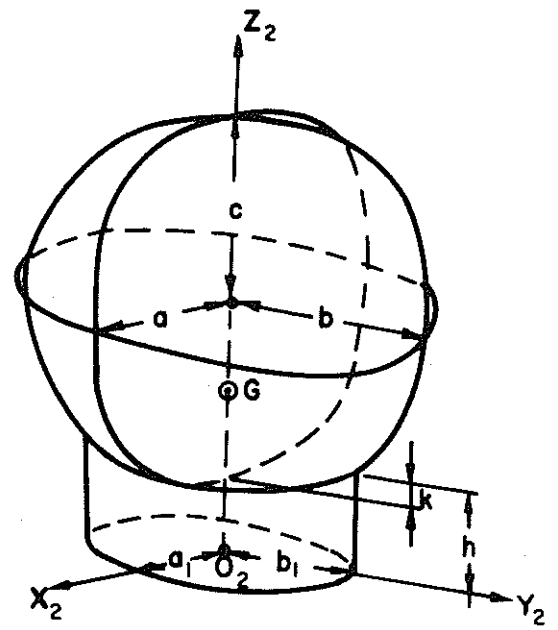


Fig. F2.3

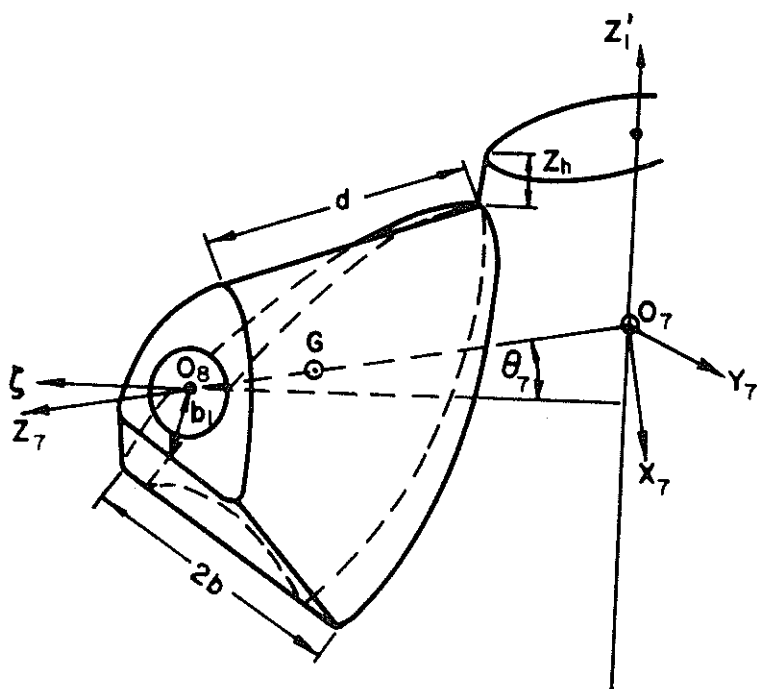
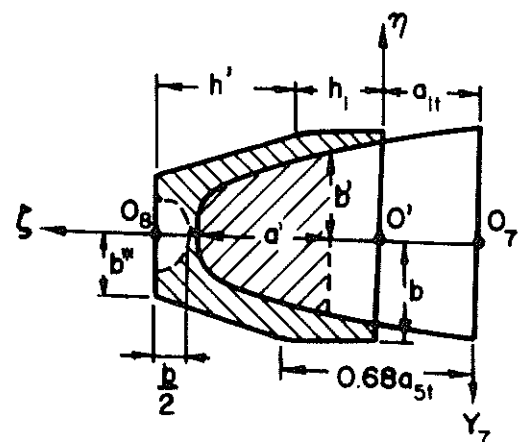


Fig. F2.4



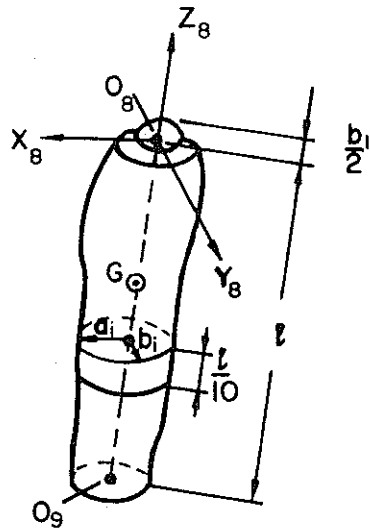


Fig. F2.5

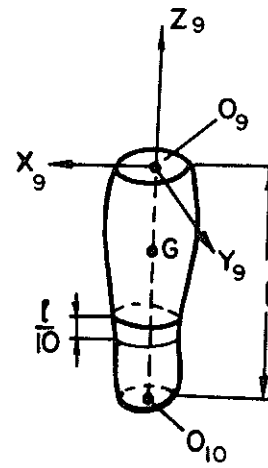


Fig. F2.6

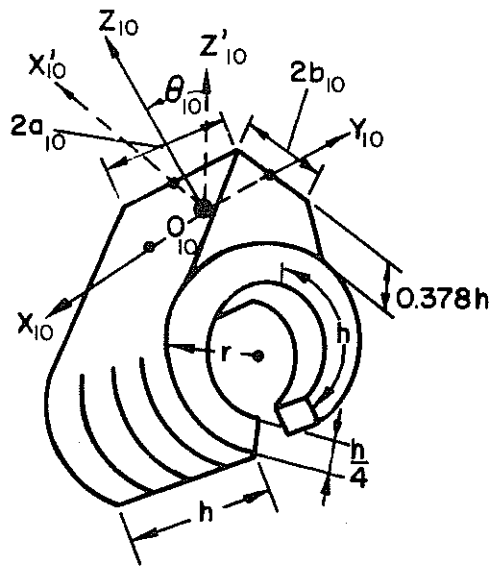


Fig. F2.7

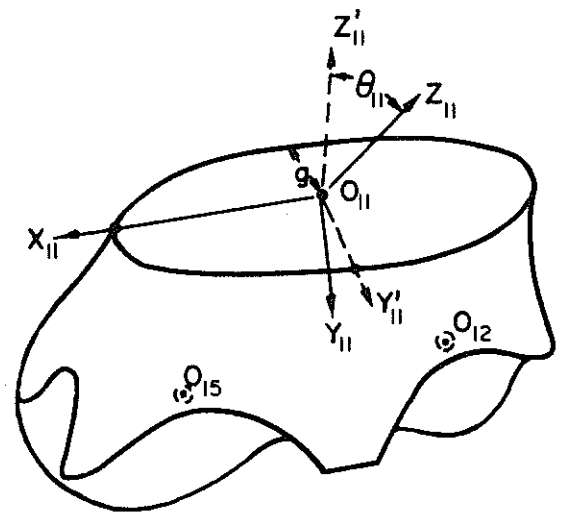


Fig. F2.8

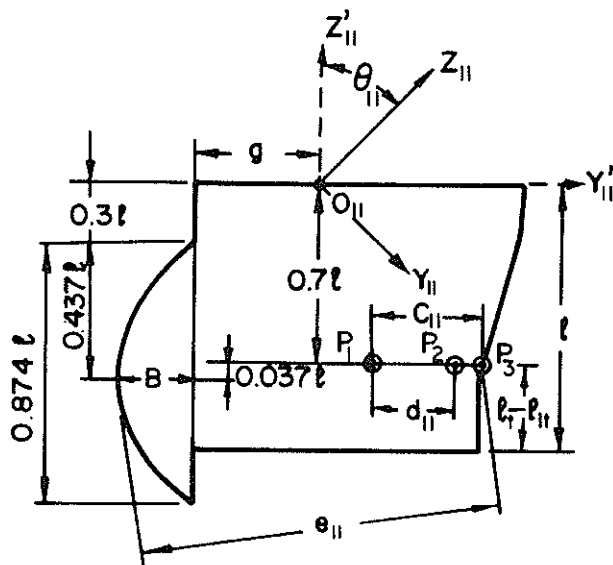


Fig. F2.9

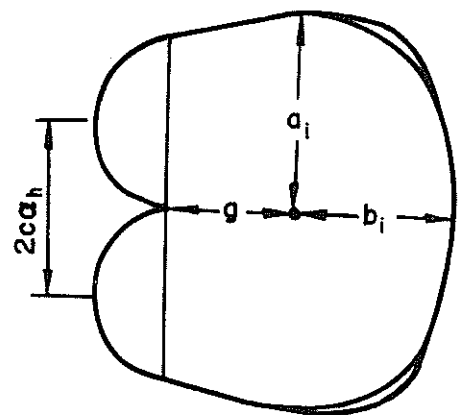


Fig. F2.10



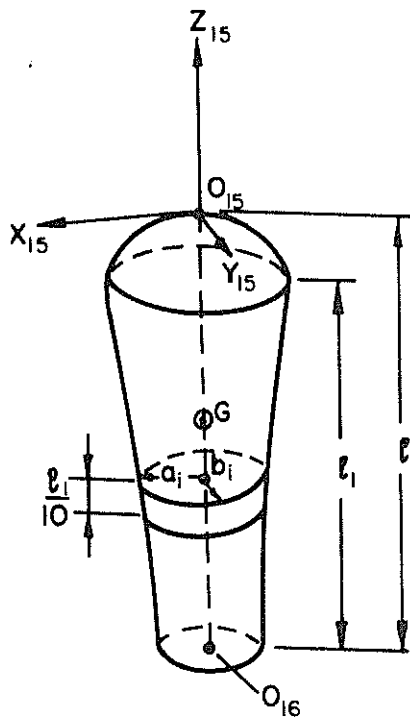


Fig. F2.11

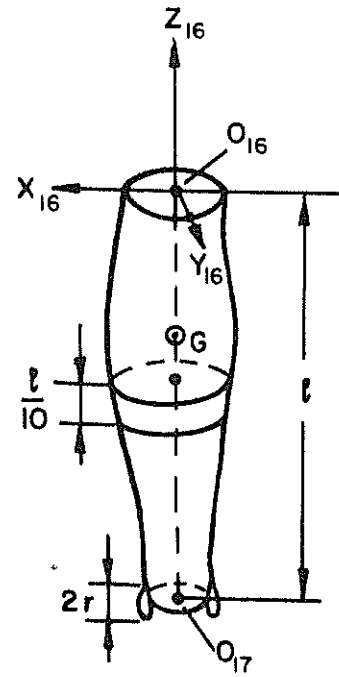


Fig. F2.12

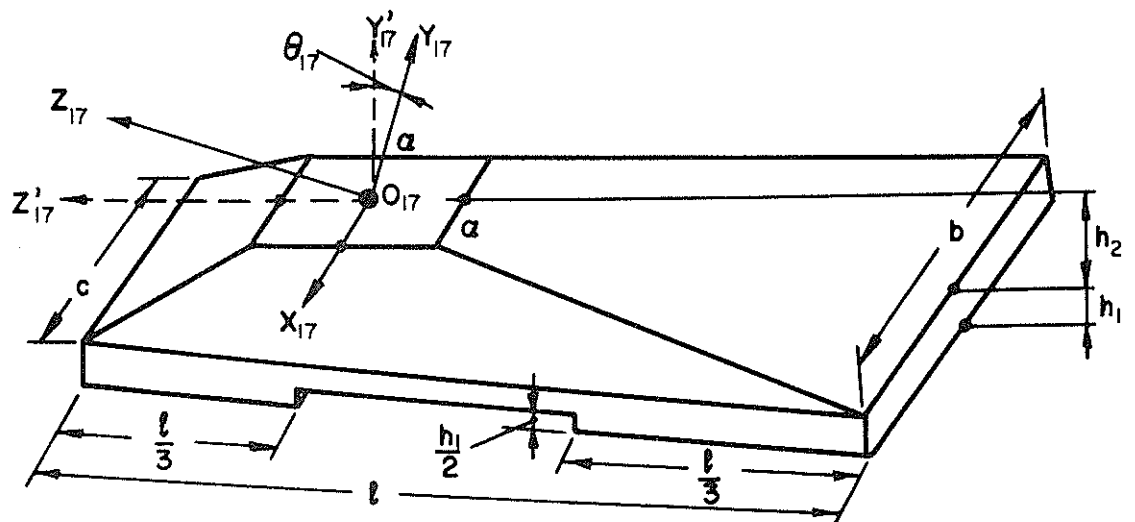


Fig. F2.13

APPENDIX 4 : SAMPLE PRINT-OUT

## ANTHROPOMETRIC DATA RECORD (DATA SEQUENCE AS ON EXPERIMENTAL RECORDING SHEET)

SUBJECT'S NAME: R. MARGA                      SEX: F      AGE (YEARS): 31      MEASURED MASS (KG): 64.7

IMALE                      AGE  
0                      31.41

ABDOMINO-THORACIC SEGMENT  
.101 .273 .275 .264 .251 .245 .262 .178 .084 .695 .117 .149 .168 .192 .190 .184 .174 .174 .170 .452 .213

HEAD-NECK SEGMENT  
.139 .184 .214 .055

LEFT SHOULDER  
.140 .176 .090 .025

RIGHT SHOULDER  
.145 .182 .086 .025

LEFT ARM  
.085 .085 .080 .077 .073 .072 .072 .072 .072 .083 .303 .292 .280 .267 .260 .256 .250 .243 .235 .237 .294

RIGHT ARM  
.093 .091 .085 .087 .085 .078 .074 .070 .070 .076 .290 .279 .268 .260 .257 .251 .246 .236 .223 .217 .291

LEFT FOREARM  
.085 .084 .083 .082 .075 .070 .065 .062 .058 .055 .235 .239 .239 .233 .219 .201 .185 .171 .162 .160 .252

RIGHT FOREARM  
.079 .083 .078 .076 .069 .066 .066 .061 .061 .056 .231 .229 .225 .221 .211 .195 .184 .174 .164 .161 .257

LEFT HAND  
.043 .077

RIGHT HAND  
.045 .076

ABDOMINO-PELVIC SEGMENT  
.287 .301 .318 .331 .341 .344 .359 .382 .326 .240 .767 .797 .844 .887 .940 .954 .975 .097 .081 .228 .053

LEFT THIGH  
.191 .191 .190 .180 .162 .146 .132 .126 .119 .119 .629 .604 .590 .565 .536 .500 .453 .418 .386 .373 .439 .364

RIGHT THIGH  
.186 .187 .189 .182 .171 .176 .143 .136 .130 .126 .620 .602 .592 .563 .528 .495 .461 .417 .388 .377 .445 .353

LEFT LEG  
.110 .103 .109 .116 .117 .105 .091 .079 .065 .064 .353 .335 .362 .375 .370 .338 .293 .264 .238 .238 .406 .032

RIGHT LEG  
.109 .103 .109 .116 .117 .106 .095 .079 .066 .062 .351 .332 .353 .375 .374 .351 .309 .279 .245 .239 .419 .034

LEFT FOOT  
.099 .053 .035 .072 .216 .158

RIGHT FOOT  
.098 .058 .035 .077 .212 .147

## COMPUTED SEGMENT PARAMETER VALUES

(UNITS: VOLUME IN LITRE, MASS IN KG, COORDINATES IN M, MOMENTS OF INERTIA IN  $\text{KG}\cdot\text{M}^2$ )

## FORMAT AND SEQUENCE OF DATA PRESENTATION:

## SEGMENT NAME

VOLUME, MASS, COORDINATES OF CENTROID (X,Y,Z)

PRINC. MOMENTS OF INERTIA W.R.T. CENTROID (IX,IY,IZ) AND LOCAL SYSTEMS ORIGIN (IOX,IOY,IOZ)

COORDINATES (OX,OY,OZ) OF ORIGIN OF DISTAL SEG. RELATIVE TO LOCAL COORD.-SYSTEM OF PROXIMAL SEG.

## SPECIAL SEGMENT PARAMETERS

NOTE THAT COORDINATES OF CENTROIDS ARE GIVEN W.R.T. LOCAL (SEGMENT-FIXED) COORD. SYSTEMS, WHICH EMANATE FROM THE SEGMENT ORIGIN, AND WHICH ARE PARALLEL TO THE SEGMENT PRINCIPAL AXES. WHERE PRINCIPAL AXES DIFFER FROM ORIGINAL SEGMENT AXES (SEE MANUAL), THE CENTROID COORDINATES W.R.T. THESE AXES ARE ALSO GIVEN AS \*SPECIAL SEGMENT PARAMETERS\*.

## ABDOMINO-THORACIC SEGMENT

14.537    12.950    0.000    .003    .194  
.206372    .231513    .082898    .693646    .718701    .082984

ANGLE (RADIAN) BETWEEN PRINCIPAL Z-AXIS AND ORIGINAL Z-AXIS OF THE SEGMENT:

0.000    0.000    0.000  
-0.001  
COORDINATES (X,Y,Z) OF CENTROID REL. TO ORIGINAL (NON-PRINCIPAL) SEGMENT AXES:  
0.000    .003    .194

## HEAD-NECK SEGMENT

3.595    3.993    0.000    0.000    .132  
.020953    .017553    .012160    .090123    .086722    .012160

0.000    -0.001    .452  
COORDINATES (VX,VY,VZ) OF VERTEX OF HEAD REL. HEAD-NECK COORD.-SYSTEM:  
0.000    0.000    .244

## LEFT SHOULDER SEGMENT

NOTE THAT NO VALUES ARE COMPUTED FOR IZ AND IOZ FOR THE SHOULDER SEGMENTS SINCE NO ROTATION OCCURS ABOUT THEIR Z-AXES.

1.110    1.144    0.000    0.000    .140  
.002725    .002172    .024991    .024437  
0.000    -0.001    .400

Y AND Z COORD. OF SYSTEM ORIGIN (REL. ABD.-THOR. SEG.) FOR 2-DIM. MODEL MOVING IN SAGITTAL PLANE:

-0.001    .362  
RESTING INCLINATION ANGLE (RADIAN) OF SEGMENT Z-AXIS TO HORIZONTAL:  
.199

RIGHT SHOULDER SEGMENT  
 1.146 1.180 0.000 0.000 .141  
 .002922 .002289 .026218 .025584  
 0.000 -.001 .398  
 Y AND Z COORD. OF SYSTEM ORIGIN(REL. ABD.-THOR. SEGM.) FOR 2-DIM. MODEL MOVING IN SAGITTAL PLANE:  
 -.001 .362  
 RESTING INCLINATION ANGLE (RADIAN) OF SEGMENT Z-AXIS TO HORIZONTAL:  
 -.182

LEFT ARM  
 1.616 1.713 0.000 0.000 -.131  
 .013677 .013435 .001528 .043258 .043017 .001528  
 0.000 0.000 .194

RIGHT ARM  
 1.505 1.595 0.000 0.000 -.129  
 .011917 .011937 .001325 .038495 .038514 .001325  
 0.000 0.000 .199  
 NOTE: FOR 2-DIM. MODEL ORIGINS OF ARM SEGMENTS COINCIDE WITH ORIGINS OF SHOULDER SEGM.

## LEFT FOREARM

.835 .896 0.000 0.000 -.108  
 .004596 .004712 .000523 .014956 .015071 .000523  
 0.000 0.000 -.294

RIGHT FOREARM  
 .809 .869 0.000 0.000 -.112  
 .004765 .004855 .000472 .015595 .015685 .000472  
 0.000 0.000 -.291

LEFT HAND  
 .285 .317 -.049 .003 -.010  
 .000231 .000448 .000521 .000263 .001246 .001291  
 0.000 0.000 -.252

ANGLE (RADIAN) BETWEEN PRINCIPAL Z-AXIS AND ORIGINAL Z-AXIS OF THE SEGMENT:  
 -1.185  
 COORDINATES (X,Y,Z) OF CENTROID REL. TO ORIGINAL (NON-PRINCIPAL) SEGMENT AXES:  
 -.010 .003 -.049

RIGHT HAND  
 .288 .319 .051 .003 -.009  
 .000240 .000491 .000551 .000267 .001352 .001389  
 0.000 0.000 -.257

ANGLE (RADIAN) BETWEEN PRINCIPAL Z-AXIS AND ORIGINAL Z-AXIS OF THE SEGMENT:  
 1.195  
 COORDINATES (X,Y,Z) OF CENTROID REL. TO ORIGINAL (NON-PRINCIPAL) SEGMENT AXES:  
 .010 .003 -.051

ABDOMINO-PELVIC SEGMENT  
 11.208 11.304 0.000 .092 -.050  
 .068933 .123422 .087840 .193037 .151584 .163782  
 0.000 0.000 0.000

ANGLE (RADIAN) BETWEEN PRINCIPAL Z-AXIS AND ORIGINAL Z-AXIS OF THE SEGMENT:  
 -1.100  
 COORDINATES (X,Y,Z) OF CENTROID REL. TO ORIGINAL (NON-PRINCIPAL) SEGMENT AXES:  
 0.000 -.003 -.165

LEFT THIGH  
 9.166 9.593 0.000 0.000 -.194  
 .156305 .152523 .035853 .516023 .512241 .035853  
 -.096 .146 -.078

RIGHT THIGH  
 8.955 9.375 0.000 0.000 -.194  
 .149153 .146883 .034605 .500603 .498333 .034605  
 .098 .140 -.075

LEFT LEG  
 3.310 3.602 0.000 0.000 -.174  
 .045315 .044973 .005106 .154274 .153933 .005106  
 0.000 0.000 -.439

RIGHT LEG  
 3.487 3.794 0.000 0.000 -.183  
 .050937 .050114 .005438 .177607 .177184 .005438  
 0.000 0.000 -.445

LEFT FOOT  
 .842 .961 0.000 -.034 -.040  
 .003610 .003781 .000765 .006273 .005343 .001863  
 0.000 0.000 -.406

ANGLE (RADIAN) BETWEEN PRINCIPAL Z-AXIS AND ORIGINAL Z-AXIS OF THE SEGMENT:  
 -.080  
 COORDINATES (X,Y,Z) OF CENTROID REL. TO ORIGINAL (NON-PRINCIPAL) SEGMENT AXES:  
 0.000 -.037 -.037  
 COORD. OF HEEL(XH,YH,ZH) AND TOE(XT,YT,ZT) GROUND CONTACT POINTS (REL. TO FOOT COORD. SYST.):  
 0.000 -.076 .047 0.000 -.060 -.155

RIGHT FOOT  
 .887 1.020 0.000 -.037 -.038  
 .003706 .003847 .000859 .006607 .005351 .002256  
 0.000 0.000 -.419

ANGLE (RADIAN) BETWEEN PRINCIPAL Z-AXIS AND ORIGINAL Z-AXIS OF THE SEGMENT:  
 -.086  
 COORDINATES (X,Y,Z) OF CENTROID REL. TO ORIGINAL (NON-PRINCIPAL) SEGMENT AXES:  
 0.000 -.040 -.035  
 COORD. OF HEEL(XH,YH,ZH) AND TOE(XT,YT,ZT) GROUND CONTACT POINTS (REL. TO FOOT COORD. SYST.):  
 0.000 -.081 .046 0.000 -.065 -.145

TOTAL VOLUME AND MASS  
 88.888 44.444

\*\*\* END OF RECORD \*\*\*