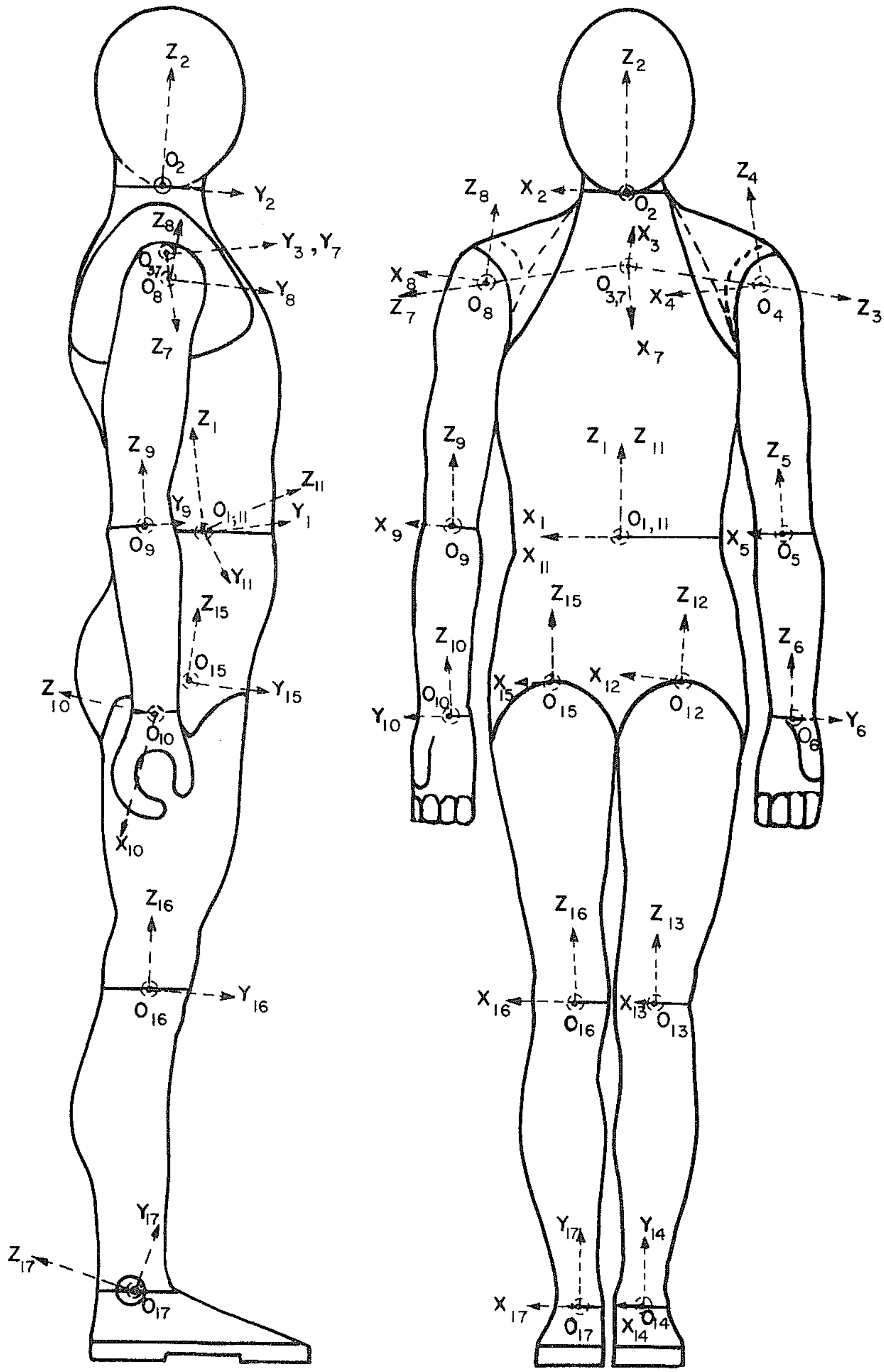


Figure 1: Lateral and anterior view of 17-segment anthropomorphic model. The shapes of the segments, as depicted here, accurately reflect the morphologies of the model segments. The local (segment-fixed) coordinate systems are also shown.

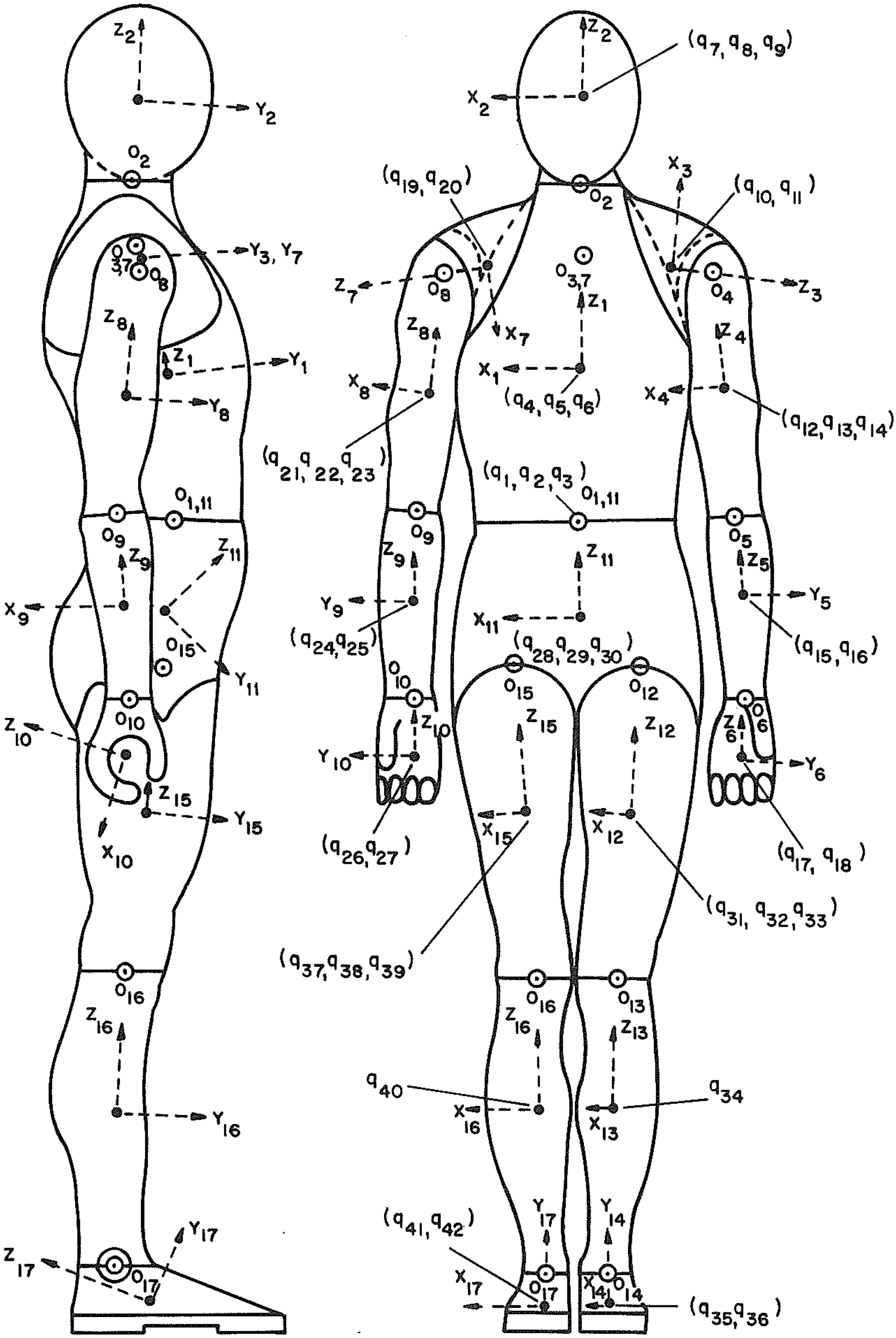


Fig. 1: Lateral and anterior view of 17-segment hominoid. The local (segment-fixed) coordinate systems and respective generalized coordinates, q_i, i=1,...,42, are also shown.

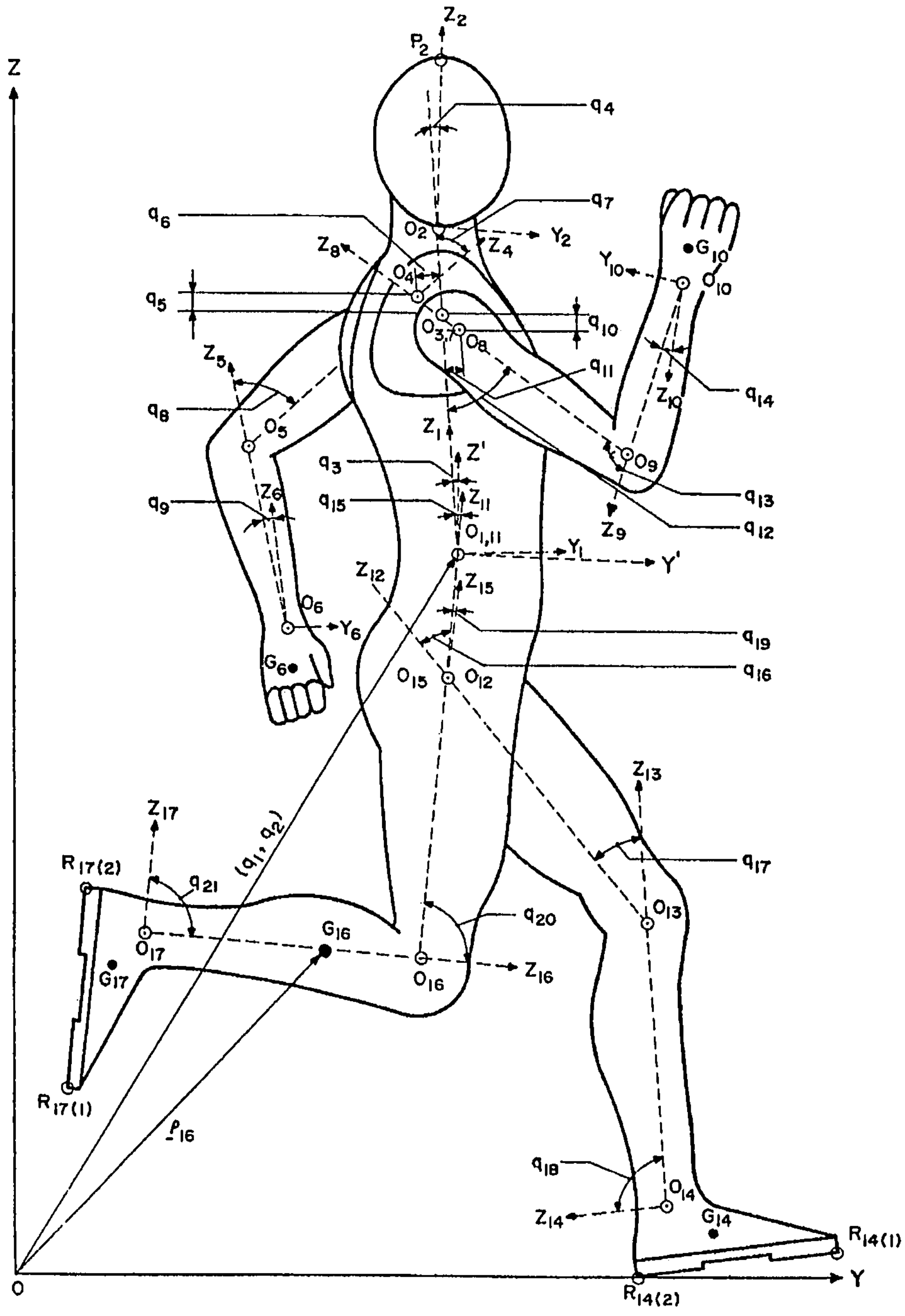


Figure 1—Lateral view of a 17-segment hominoid moving in the sagittal plane. The 21 configurational coordinates $q_1, \ldots, q_{21}$ are also shown (adapted from Hatze, H. Quantitative analysis, synthesis and optimization of human motion. *Hum. Mov. Sci.* 3:5–25, 1984).

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

The visible motion, Ω, during a time interval τ, 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, $i = 1, \ldots, f$, that is by

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

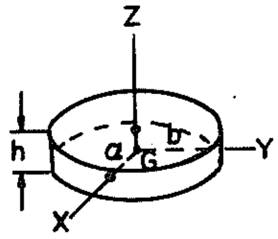
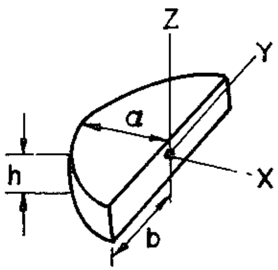
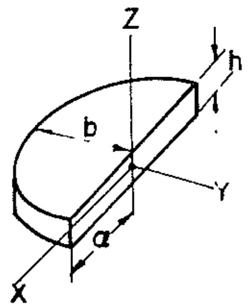
where the observed coordinate values q_i are assumed to be given at $N + 1$ discrete points in time, t_k.

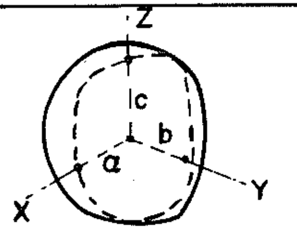
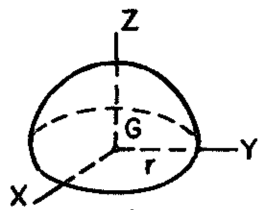
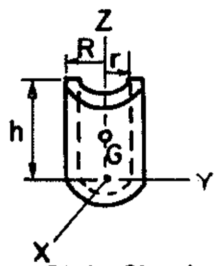
As an example, a 17-segment human body model is depicted in Figure 1. Its configuration for planar motions is described by $f = 21$ generalized coordinates q_i, $i = 1, \ldots, f$.

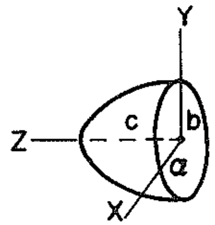
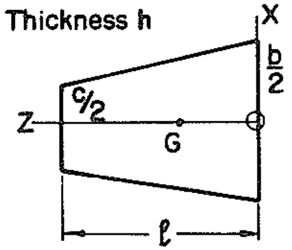
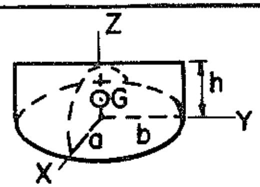
The complexity of the human body model chosen, and therefore the number of coordinates required to define its configuration, depends entirely on the purpose for which the model is to be used.

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

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

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

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 $z\geqslant 0$, 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	$M=\gamma 2\pi r^3/3$ $\bar{x}=\bar{y}=0$ $\bar{z}=3r/8$	$\bar{I}_x=\bar{I}_y=Mr^2(2/5-9/64)$ $\bar{I}_z=2mr^2/5$	$\bar{I}_{xy}=\bar{I}_{yz}=\bar{I}_{zx}=0$
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	 Elliptic Paraboloid	$M = \gamma\pi abc/2$ $\bar{x} = \bar{y} = 0$ $\bar{z} = a/3$	$\bar{I}_x = M(3b^2+c^2)/18$ $\bar{I}_y = M(3a^2+c^2)/18$ $\bar{I}_z = M(a^2+b^2)/6$	$\bar{I}_{xy} = \bar{I}_{yz} = \bar{I}_{zx} = 0$
A1.8	Thickness h  Thin Trapezoidal Plate	$M = \gamma\ell h(b+c)/2$ $\bar{x} = 0$ $\bar{z} = \ell(b+2c)/3(b+c)$	$\bar{I}_x = M\ell^2(b^2+4bc+c^2)/18(b+c)^2$ $\bar{I}_z = M(b^2+c^2)/24$ $\bar{I}_y = \bar{I}_x + \bar{I}_z$	$\bar{I}_{xy} = \bar{I}_{yz} = \bar{I}_{zx} = 0$
A1.9	 Ellipto-parabolic Hoof	$M = \gamma 2\pi abh/3$ $\bar{x} = \bar{y} = 0$ $\bar{z} = 2h/5$	$\bar{I}_x = M(b^2/4+0.0686h^2)$ $\bar{I}_y = M(0.15a^2+0.0686h^2)$ $\bar{I}_z = M(0.15a^2+b^2/4)$	$\bar{I}_{xy} = \bar{I}_{yz} = \bar{I}_{zx} = 0$

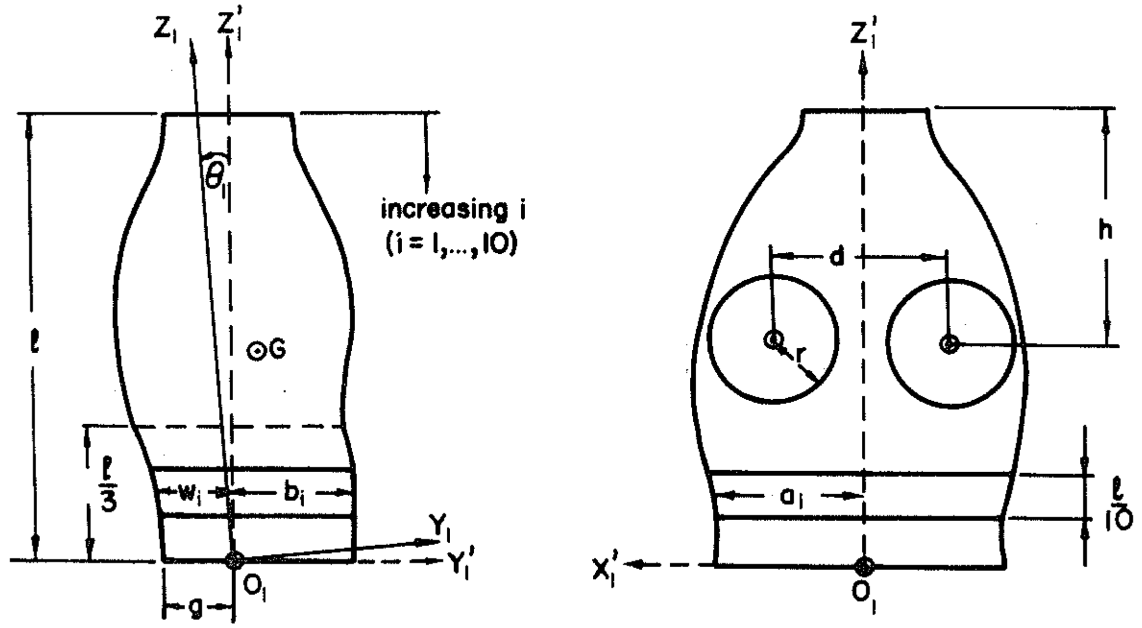


Fig. F2.1

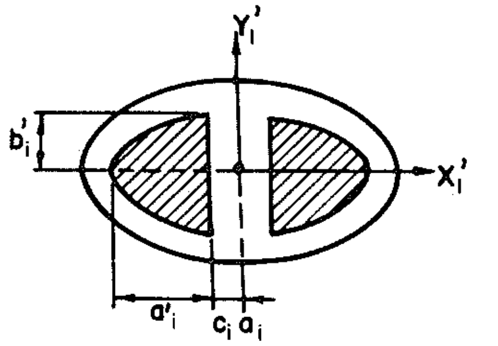


Fig. F2.2

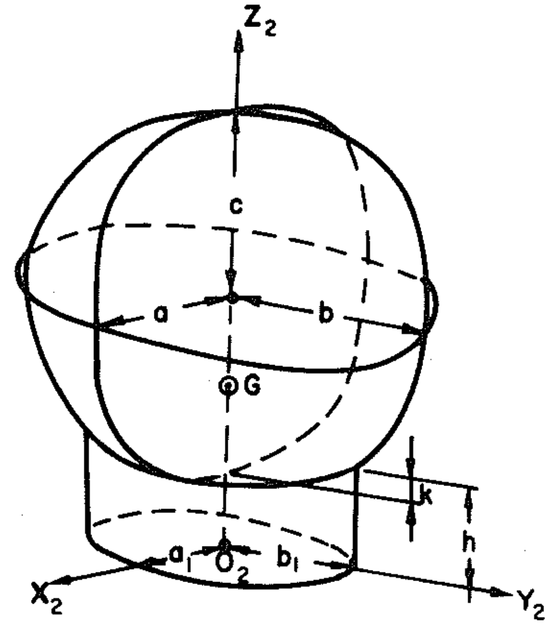


Fig. F2.3

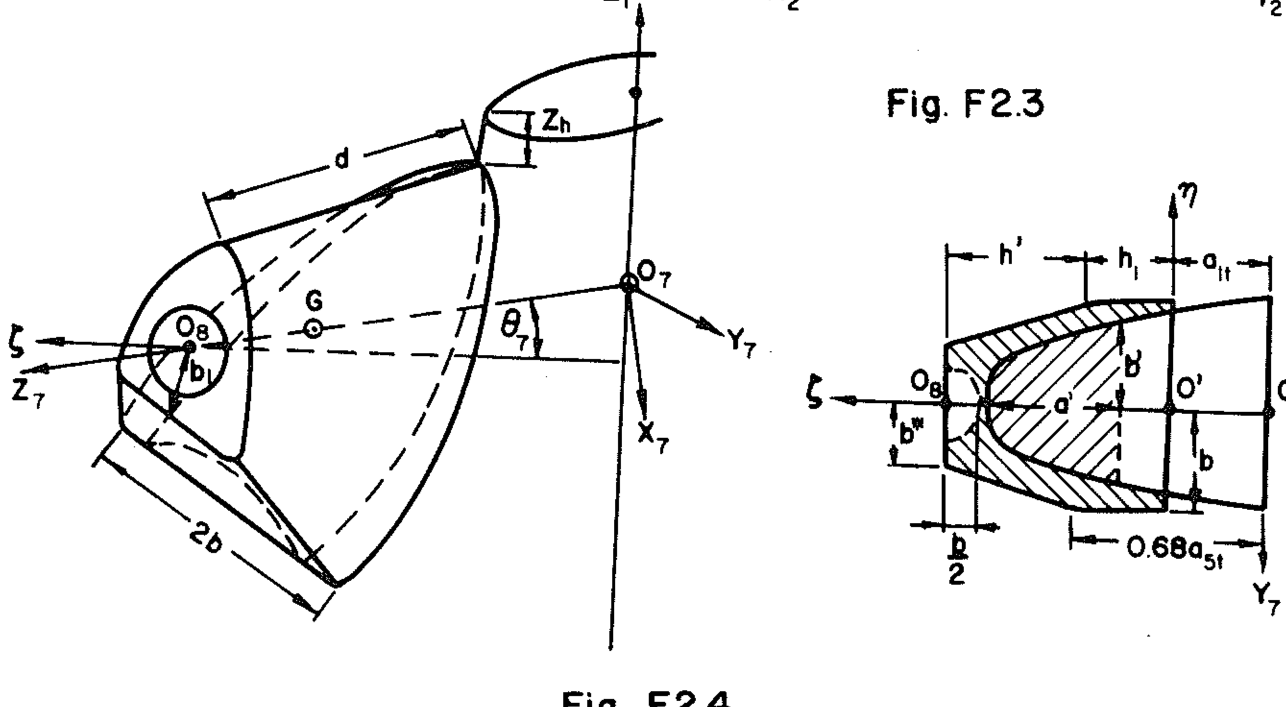


Fig. F2.4

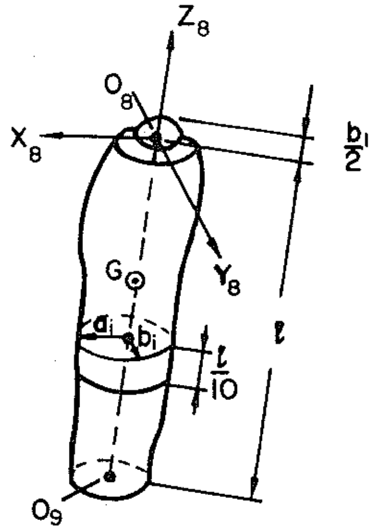


Fig. F2.5

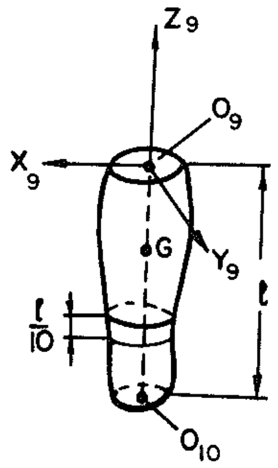


Fig. F2.6

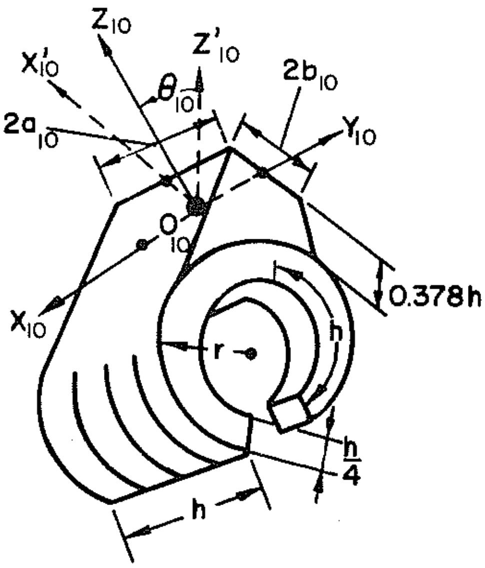


Fig. F2.7

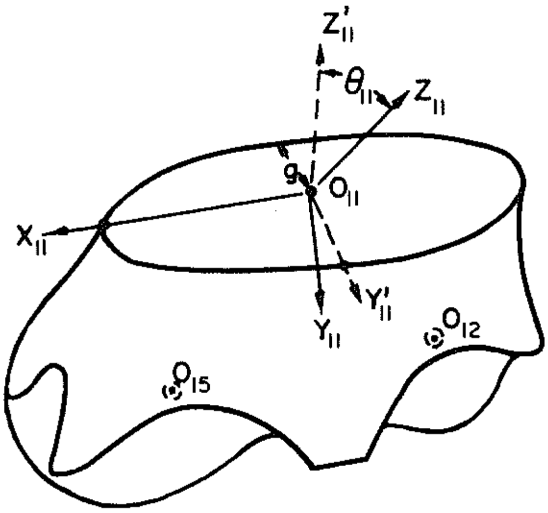


Fig. F2.8

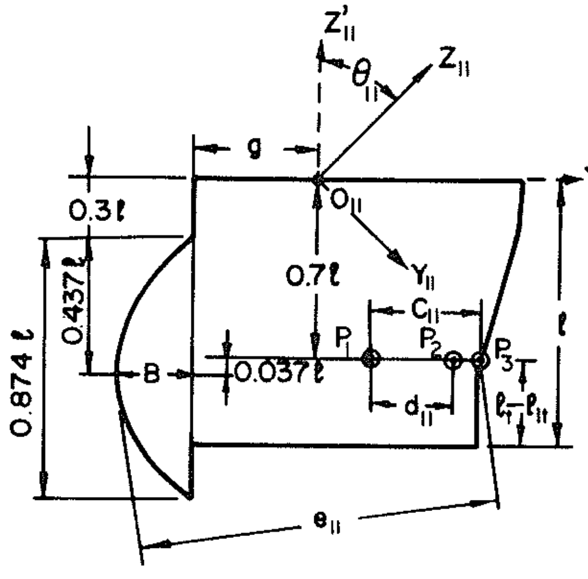


Fig. F2.9

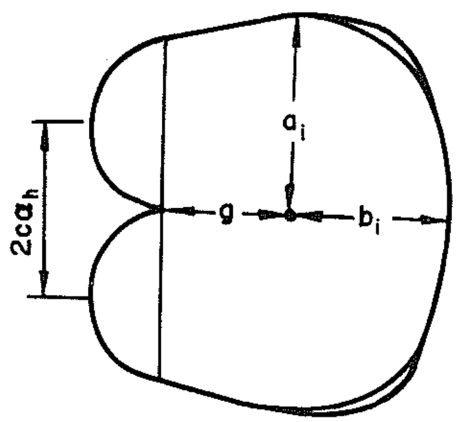


Fig. F 2.10

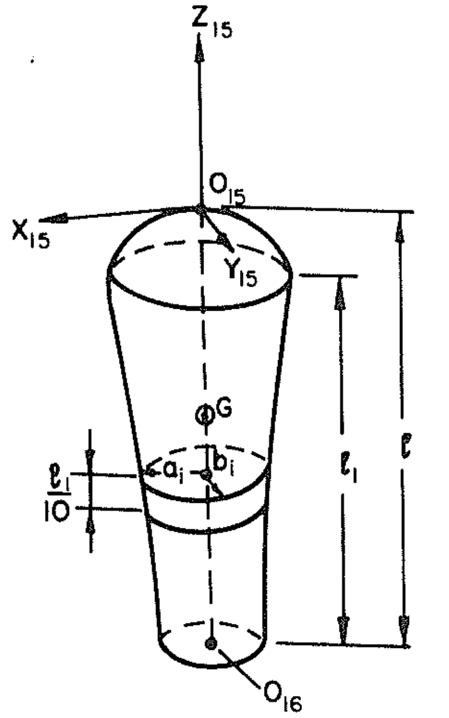


Fig. F2.11

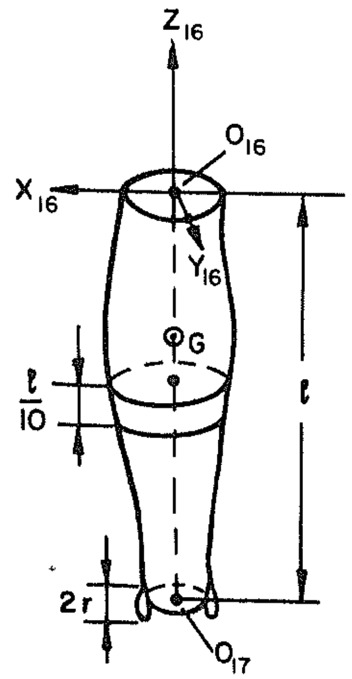


Fig. F2.12

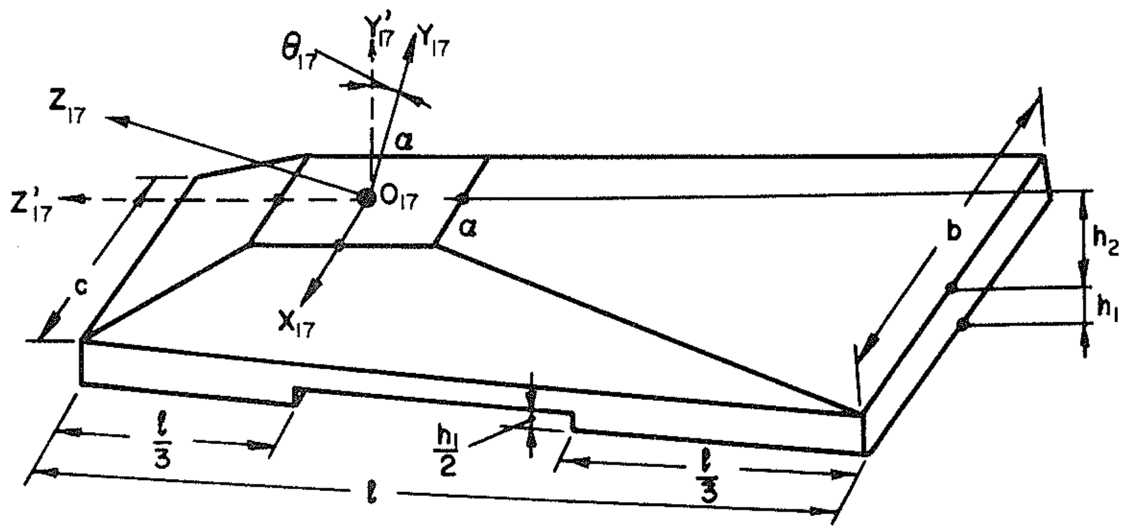


Fig. F 2.13

APPENDIX 4 : SAMPLE PRINT-OUT

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               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-THURACIC 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 KG*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 SEGM. RELATIVE TO LOCAL COORD.-SYSTEM OF PROXIMAL SEGM.
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
                           0.000       0.000       0.000
ANGLE (RADIANS) BETWEEN PRINCIPAL Z-AXIS AND ORIGINAL Z-AXIS OF THE SEGMENT:
                      -.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       -.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      -.001        .400
Y AND Z COORD. OF SYSTEM ORIGIN(REL. ABD.-THOR. SEGM.) FOR 2-DIM. MODEL MOVING IN SAGITTAL PLANE:
                                       -.001        .362
RESTING INCLINATION ANGLE (RADIANS) OF SEGMENT  Z-AXIS TO HORIZONTAL:
                      .199
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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 (RADIANS) 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 (RADIANS) 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 (RADIANS) 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       .183782
                           0.000      0.000      0.000
ANGLE (RADIANS) 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
      .050537       .050114       .005438       .177607       .177184       .005438
                           0.000      0.000     -.445



LEFT FOOT
      .842       .961      0.000     -.034     -.040
      .003610       .003781       .000763       .006273       .005343       .001863
                           0.000      0.000     -.406
ANGLE (RADIANS) 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 (RADIANS) 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      .040      0.000     -.065     -.145


TOTAL VOLUME AND MASS
      [illegible]    [illegible]


*** END OF RECORD ***
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superior surface of the greater trochanter of the femur to the floor.

14. *Right Tibiale Height* (Anthropometer). From the superior surface of the medial condyle of the tibia to the floor.

15. *Right Sphyrion Height* (Anthropometer). From the inferior surface of the medial malleolus to the floor.

Transverse and Antero-Posterior Dimensions

16. *Span* (Anthropometer). The distance between the tips of the middle fingers of each hand when the arms are outstretched sidewards horizontally from the body. Measured from behind.

17. *Bi-Acromial Breadth* (Anthropometer used as sliding compass). The distance between the most lateral margins of the acromion processes of the scapula, the subject standing as he does normally.

18. *Chest Breadth or Transverse Diameter of the Thorax* (Anthropometer used as sliding compass). The transverse distance between the most lateral points on the chest. The mean of the measurements made at expiration and inspiration while the subject is breathing normally.

19. *Chest Depth or Antero-Posterior Diameter of the Thorax* (Large Spreading Caliper). At the level of the inferior angles of the scapulae. The mean of the measurements made at expiration and inspiration while the subject is breathing normally.

20. *Bi-Iliac or Pelvic Breadth* (Anthropometer used as a sliding

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FIG. 147 Landmarks of the body (after Martin).

FIG. 147A. Landmarks on the frontal view. 1, vertex; 2, trichion; 3, nasion; 4, prosthion; 5, gnathion; 6, suprasternale; 7, akromion; 8, mesosternale; 9, thelion; 10, radiale; 11, omphalion; 12, iliocristale; 13, iliospinale anterior; 14, symphysion; 15, trochanterion; 16, stylion; 17, phalangion; 18, daktylion; 19, tibiale; 20, sphyrion.

FIG. 147B. Landmarks in the lateral view. 1, vertex; 2, nasion; 3, stomion; 4, gnathion; 5, cervicale; 6, akromion; 7, suprasternale; 8, mesosternale; 9, thelion; 10, radiale; 11, omphalion; 12, iliospinale anterior; 13, symphysion; 14, trochanterion; 15, stylion; 16, phalangion; 17, daktylion; 18, pternion; 19, akropodion.

FIG. 147C. Landmarks in the posterior view. 1, vertex; 2, cervicale; 3, akromion; 4, radiale; 5, lumbale; 6, iliocristale; 7, iliospinale posterior; 8, trochanterion; 9, phalangion; 10, daktylion; 11, tibiale; 12, sphyrion.

compass). From iliocristale, the most lateral point on the crest of the ilium to iliocristale.

21. *Bi-Trochanteric or Hip Breadth* (Anthropometer used as a sliding compass). From trochanterion, the most lateral point on the great trochanter, to trochanterion.

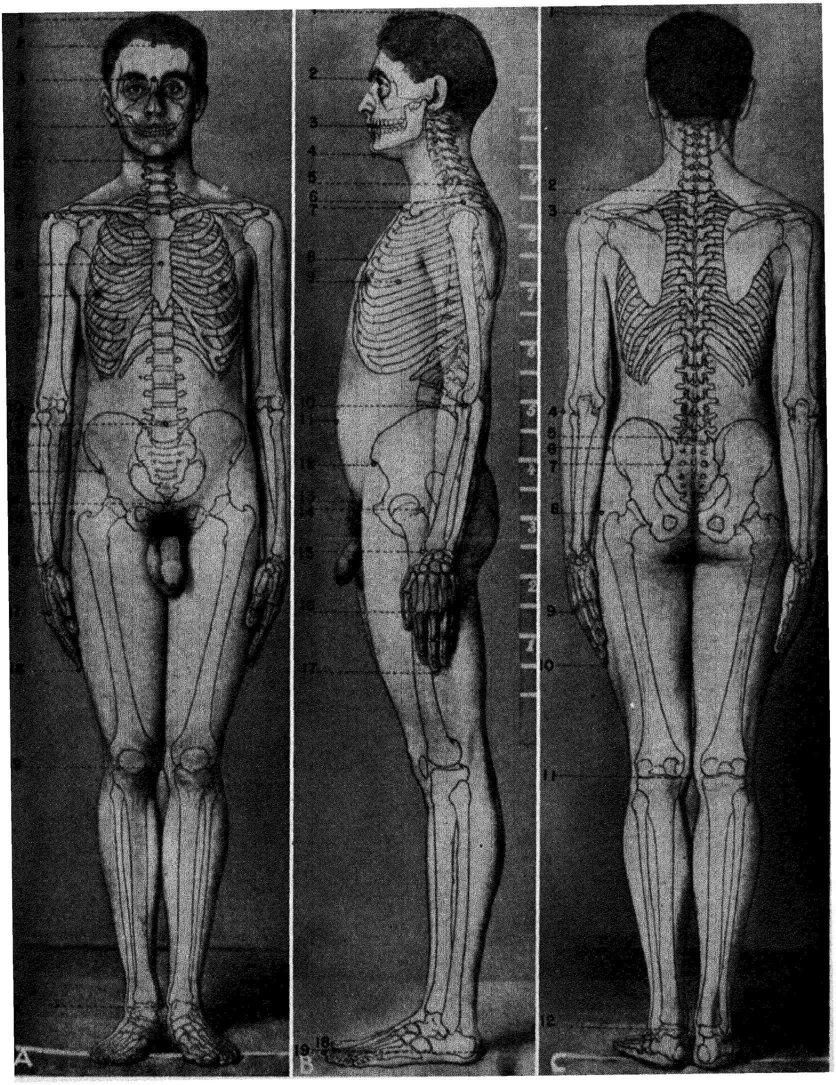

FIG. 147. See legend opposite page.