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FINAL REPORT

STEREOMETRIC BODY VOLUME MEASUREMENT
NAS 9-11604, Mod 6S

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INTRODUCTION

This report covers the work performed under contract NAS 9-11604, Mod 6S during the period March 1, 1974 -- February 30, 1975, by the Biostereometrics Laboratory, Texas Institute for Rehabilitation and Research, in cooperation with the Food & Nutrition Branch, Biomedical Research Division, Directorate Life Sciences, L.B. Johnson Manned Space Center.

The report is divided into four main parts, as follows:

I. Effects of Extended Space Flight on Body Form of Skylab Astronauts Using Biostereometrics.

II. Comparison of Body Volume Determinations Using Hydrostatic Weighing and Biostereometrics.

III. First International Symposium on Biostereometrics, Washington, D.C., September 10-13, 1974.

IV. Training of Technology Inc. technician in Biostereometric principles and procedures.

I. Effects of Extended Space Flight on Body Form of Skylab Astronauts Using Biostereometrics.

The stereometric measurements of body form first made on the Apollo 16 crew have now been performed on all Skylab astronauts. The same biostereometric principles were used thoroughout the series, but, as with all the other missions, the final Skylab flight provided an opportunity to make further refinements. Specifically, some modifications in the data reduction procedures were explored and the results are outlined below. The balance of this section comprises a review of the data acquisition procedures and an evaluation of the findings for the three Skylab missions as a whole.

Method

Four stereometric cameras were used, for the data acquisition (Fig. I-1). The principal axes of the lenses of the two cameras were parallel, and separated horizontally by 50.8 cm (20 inches). The cameras were Hasselblad 'C' cameras with 38 mm f 4.5 lenses. The backs of the cameras had been modified to accept 6.3 cm (2 1/2 inch) square glass plates, and to put fiducial marks on the plates to facilitate alignment during the subsequent plotting process. The cameras were mounted on a tripod, and care was taken to insure that the two cameras were at the same height from the floor (90 cm, 35 inches), and that their axes were horizontal. The photographic plates were 1.83 m. (6 ft) from the plane of the 'control' stands to which distance the cameras were focused. The 2 control stands are portable structures consisting of a light telescopic stand supporting a steel tape measure with inch markings, and 4 pairs of discs which are

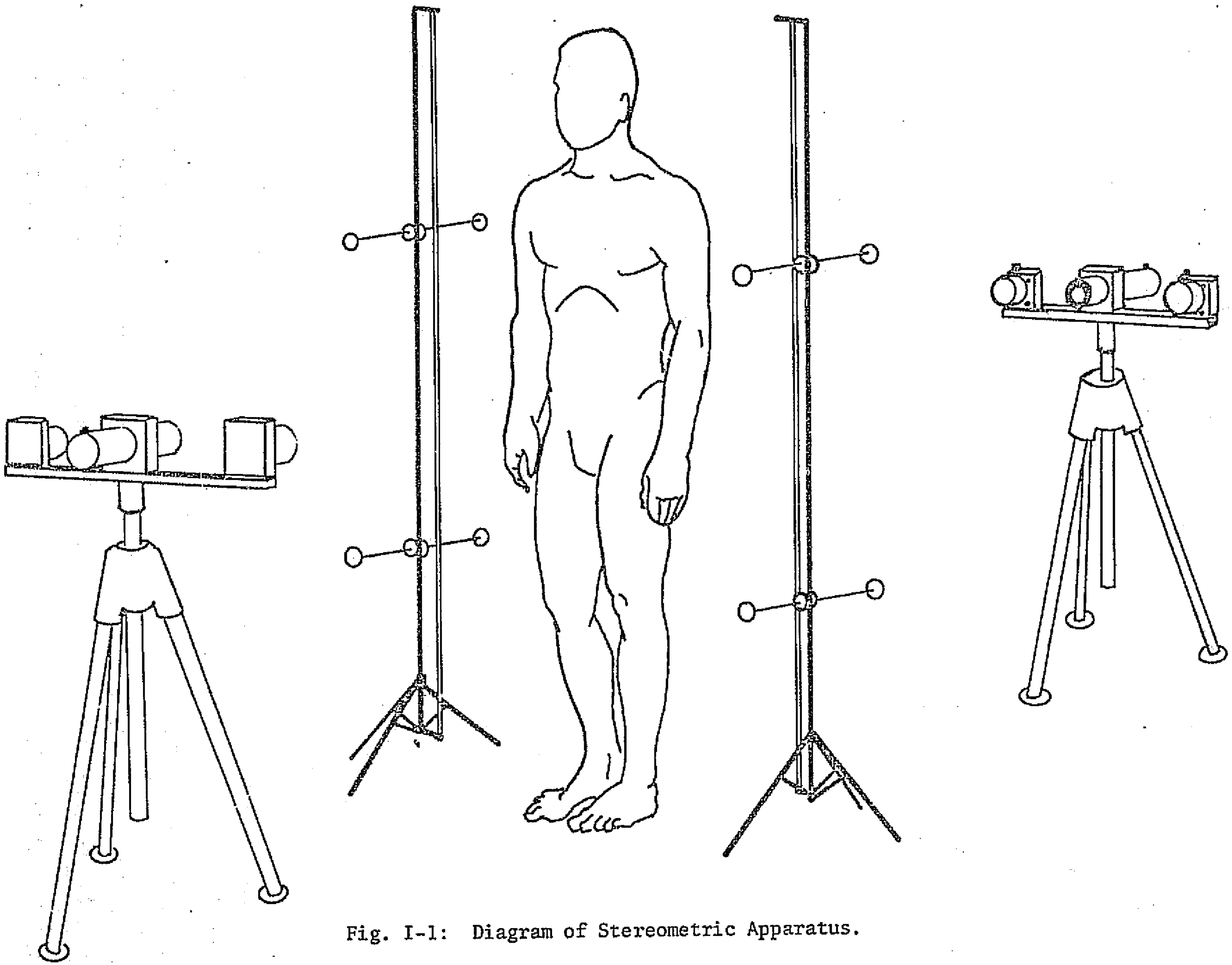

Fig. I-1: Diagram of Stereometric Apparatus.

separated by a fixed distance (15.555 cm; 6.124 ins) in the long axis of the system. The 2 stands are placed opposite each other with the steel tapes about 90 cm (35.4 in) apart, to define a plane in which the subject stands. The subject is nude except for an athletic supporter, and he wears an elastic skull cap to press his hair down. He stands on a pair of 'footprints' to give a reproducible location for the feet, and holds his arms straight and a little way away from the body, with the fingers and thumbs pressed together. Between each pair of cameras was a strobe-projector in which a 500 joule electronic flash tube projected a pattern of lines on the subject. The strobe-projector consisted of the flash tube, a condenser, a 35 mm transparency with a pattern of randomly arranged lines, and a projection lens (36 mm, f 3.0). The projector was focused at the plane of the control stands. The cameras were fired remotely by a solenoid, and the strobe projectors were each fired by one of the cameras. The cameras were used at full-aperture (f 4.5), and the shutter speed was adjusted, using exposure meter readings, to allow the room lighting to augment, but not to obliterate, the lighting from the strobes. This was necessary to visualize the top of the head and the shoulders, which were inadequately illuminated by the strobes.

The photographs were taken in black and white on Kokak 'M' plates (ASA 250) and developed for 8 min. in DK50 developer. The subject was photographed twice at each session, to allow for equipment malfunction or breakage of plates.

Plotting:

The plates were plotted and digitized in pairs on a Kern PG2 mechanical projection stereoplotter after enlargement to 25.4 cm using of a precision enlarger. The three-dimensional coordinates of a series of points were determined in arbitrary scale units and punched on IBM cards. The first card identified the subject and measurement; the next 3 cards were 'scale cards', followed by the coordinates of all the points on the body surface, for the front of the subject, then the scale cards and coordinate data for the back. The zero point of all 3 axes was taken as the center point of the measuring tape on the control stand to the subject's left. The 3 axes were named U(vertical), V(lateral) and W(front-to-back), using the sign convention shown in Fig. 2.

The scale cards were arranged as follows:

Cols:	1-6	7	8	9-14	15-20	21-26	27-44	45-62	63-80
	No.	Man	F/B	V_1	U_1	W_1	V,U,&W_2	V,U,&W_3	V,U,&W_4

The first 6 columns identify the card deck; column 7 gives the crewman, as follows:

1 = Kerwin	2 = Conrad	3 = Weitz
4 = Bean	5 = Lousma	6 = Garriott
7 = Carr	8 = Gibson	9 = Pogue

The 8th column (F/B) contains 1 for data from the front of the body, two (2) for the back. Then follow the V,U,&W coordinates of 4 points, as follows:

Card 1 = points above and below the center of each tape, separated by 48 or 60 inches in the W axis.

Cards 2 and 3 = points on the front and back disc of each pair of discs, giving the scale in the Z axis.

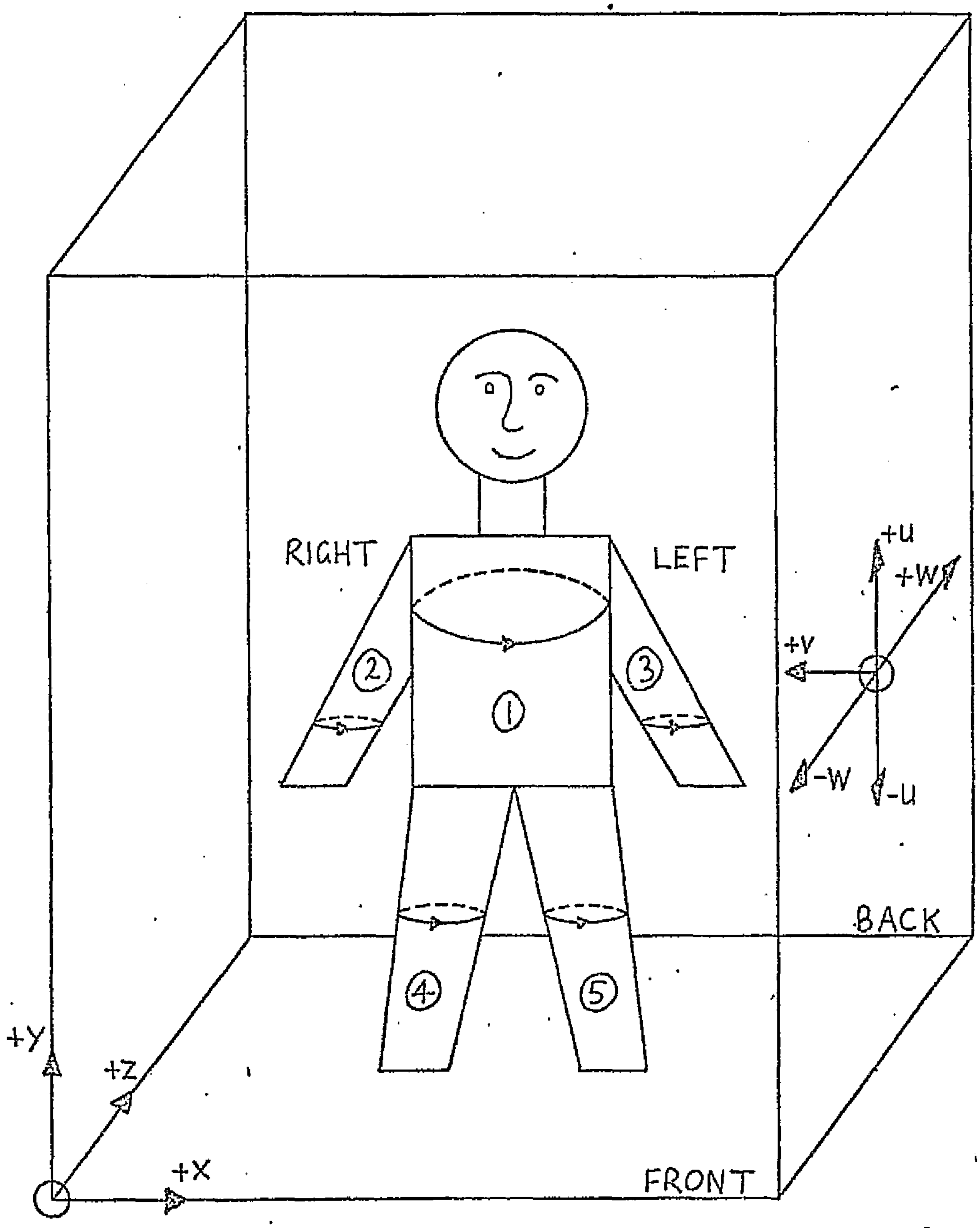

Fig. I-2: UVW and XYZ Coordinate Systems Body Part Numbering and Direction of Plotting.

The data cards were arranged as follows:

Cols:	1	2	3-8	9-14	15-20	21-32	33-44	45-56	57-68	69-80
	Man	F/B	U	V	W	$V\&W_2$	$V\&W_3$	$V\&W_4$	$V\&W_5$	$V\&W_6$

The format in which the coordinates are punched consists of the sign, followed by 5 digits with no decimal point; the first 2 digits are the whole number, and the last 3 are the decimal places, corresponding to a Fortran format of F 6.3. Each data card had a single U coordinate, and from 1 to 6 pairs of V&W; if less than 6 coordinates were punched, the remainder of the card was blank. The first coordinate plotted was a single point at the top of the head; then followed data for the front, level by level, working downwards, in the following order: 1) head and trunk, 2) right arm, 3) left arm, 4) right leg, 5) left leg. The spacing between successive levels was generally 2 inches, but 1 inch spacing was used in the following areas: chin and upper neck; wrist and hand; ankle and foot. The top of the head, and the feet at floor level, were plotted at their appropriate levels. After the final card for the left foot came a blank card, then the scale cards for the back, then the highest level of the back of the head. The data were then plotted level-by-level and part-by-part, as for the front, with 2 exceptions: 1) the back was plotted from the subject's left to his right; 2) a blank card followed each complete body part, except the last, which was followed by a card with either -1 or -9 in the first 2 columns.

Data Reduction

1. Production of Levels Data

The raw data are processed by the CUT program, which performs the following:

1) The scale in the U axis is calculated from the mean distance between the points plotted along the steel tapes, after deciding whether the distance between the points is 48 or 60 inches.

2) The scale in the W axis is calculated from the mean distance between the pairs of discs on the control stands.

3) The data for the front are multiplied by the two scale factors to give the coordinates in centimeters. The U scale is used for the V axis.

4) Sets of data cards in which the level in the U axis differs by less than 0.15 mm are regarded as a single level, and a mean value for U is calculated.

5) A number from 1-5 is assigned to the block of data to indicate the body part involved, as follwos: 1 = Head and trunk, 2 - Right arm, 3 = Left arm, 4 = Right leg, and 5 = Left Leg. The change in body part is detected by an increase in the U value by over 0.15 mm. On some sets of data, the U level does not increase between the left arm and the right leg - in these cases a 'dummy' card has to be inserted, with the coordinates of a single point below the left hand, in order to keep the body part detection correct.

6) The program constantly checks values to determine the maximum value in the V axis, and the minimum in the W axis.

7) The scale factors are calculated for the data from the back of the body, and the data are processed as in 3,4,5,and 6.

8) The U levels for both front and back are examined, and the lowest detected. Any value within 4.1 mm of this level is taken as the same level, and the mean of these values becomes the foot level.

9) The data are then scanned, level-by-level, and body part-by-body part, matching fronts and backs: levels within 4.1 mm are taken as the same, and the mean value taken.

10) The coordinate system is revised from UVW to XYZ as follows:

X - MAXIMUM V - V COORDINATE

Y = U COORDINATE - FOOT LEVEL

Z = W COORDINATE - Minimum W

This puts the origin of the X, Y, Z system at the level of the feet, as far to the right as the farthest point of the subject, and as far forward as the farthest point of the subject; in practice these points usually corresponded to the right little finger and the tip of the nose.

The program outputs a printout of the data, and also stores a copy on magnetic mass storage (file 7). These data are in the format used in all subsequent operations. The format is as follows:

First card: Format (3A6): Subject I.D. and measurement.

First card of a level: Format (14F5.2, F6.2, 13, I1), consisting of:

14F5.2:7 pairs of X&Z values

F6.2:Y value for level

13: Number of points in level

I1: Body part code (1-5).

Subsequent cards in a level: Format (145F5.2), consisting of 7 pairs of X&Z values.

The first point of a level is repeated at the end of that level, so that the section will always form a closed shape.

Because of the difference in spacing between the wrist and hand (1" between levels) and the body (2" between levels), the output of the 'CUT' program puts the wrists and hand levels in the wrong order. A program called 'SORT' is used to rewrite the 'levels' data to mass storage (file 7) with all the levels in the correct order.

Subject I.D. and measurement were coded as follows:

CN = Conrad	K = Kerwin	W = Weitz
B = Bean	GR = Garriott	L = Lousma
CR = Carr	GB = Gibson	P = Pogue

Photographs for the 3 missions were taken as follows:

SL-2			SL-3			SL-4		
1	16 Apr '73	(F-39)	1	27 Jun '73	(F-31)	1	12 Oct '73	(F-35)
2	11 May	(F-14)	2	14 Jul	(F-14)	2	26 Oct	(F-21)
3	23 May	(F-2)	3	23 Jul	(F-5)	3	6 Nov	(F-10)
4	22 Jun	(R+0)	4	26 Sept	(R+1)	4	10 Nov	(F-6)
5	11 Jul	(R+19)	5	26 Oct	(R±31)	5	8 Feb '74	(R+0)
						6	9 Feb	(R+1)
						7	12 Feb	(R+4)
						8	17 Apr	(R+68)

No photographs were taken of Lousma on 26 Oct '73, and the first set of photographs for the final mission (12 Oct. '73) have not been plotted.

2. Troubleshooting

A program called 'PLOT' is used to plot on microfilm the level-by-level coordinates. Any errors in the data are easily seen on the sections, and the raw data may be examined and the errors corrected. The transformation between the XYZ and UVW coordinates is given on the printout of the 'CUT' program. Most errors are in the order in which points are plotted. Occasionally, a card is obviously mispunched and the correct value can be deduced and used to correct the error. Any point which is obviously impossible is removed, although in practice very few such points have been found.

3. Location of Landmarks

A program called 'CF' is used to derive data describing the outline of the subject, viewed both from in front and from the side. The data at each Y level are taken and the point-by-point coordinates are smoothed into a curve (see section 4). The maximum and minimum values of the smoothed curve in the X&Z directions are detected, and stored in mass storage (file 7), along with the Y levels, in the same format as the 'levels' data. A program 'CC' takes these data and makes a tape for use on a 'Calcomp' plotter, which plots the frontal and lateral views on graph paper (Fig. 3). The 'CC' program is also able to plot a single cross-section on paper (Fig. 4).

Landmarks are determined from transparent prints made by a 'Thermofax' copier from the frontal and lateral views. For each subject, the distance between the inner sides of the arms is measured on the frontal view, at the highest level at which the arms were plotted separately. Whichever set of data shows the least separation becomes the model for establishing the arm "cut-off" plane. Vertical lines are drawn on the graph through these points, and each of the other graphs is, in turn, superimposed on the model. The best fit possible with the contour of shoulders, neck and upper chest is determined, and the overlying graph is then marked with the 'cut-off' lines. Subsequent processing regards any part of the upper trunk outside these lines as belonging to the appropriate arm.

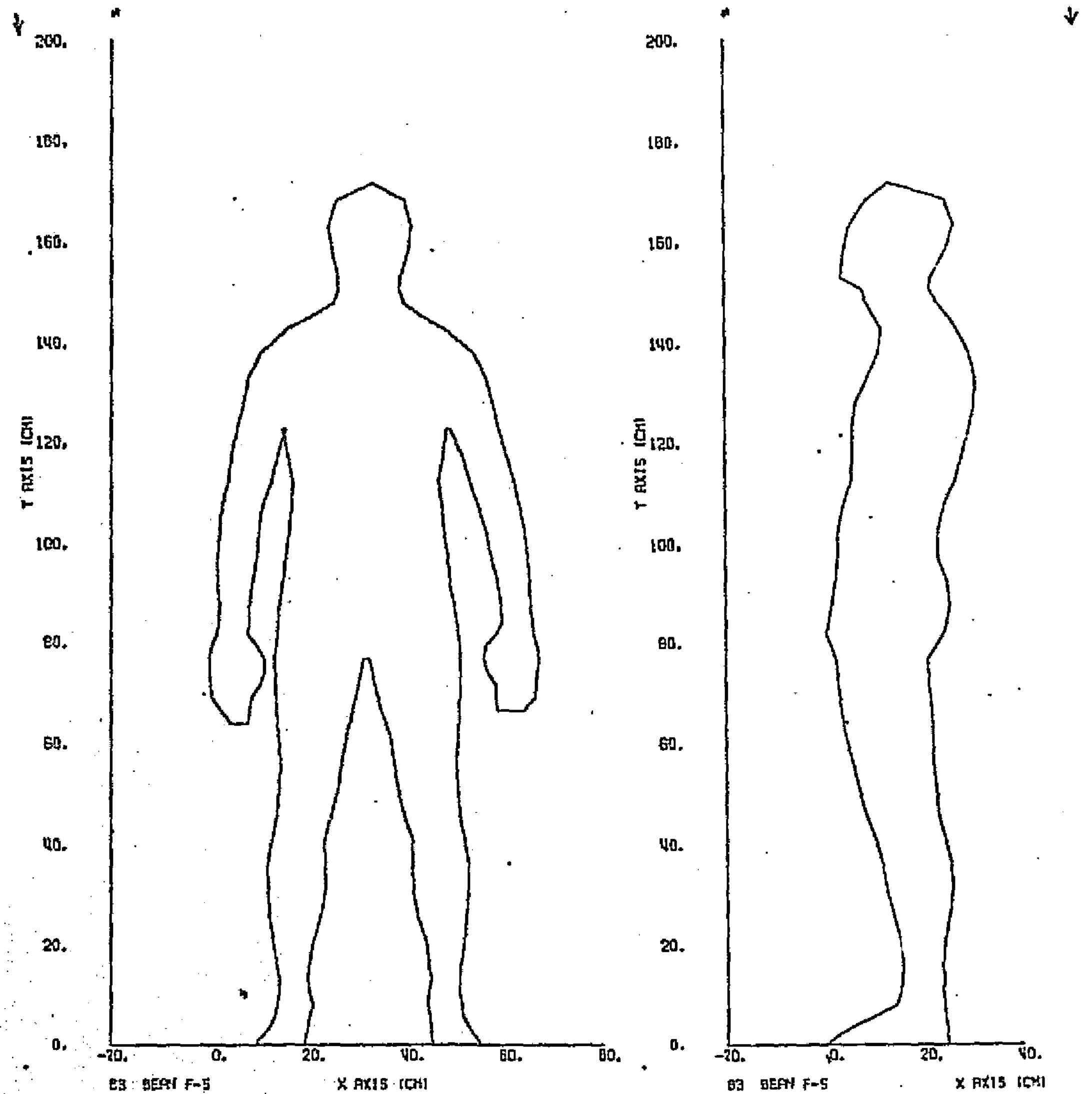

Fig. I-3: Frontal and Lateral Views Plotted by Computer

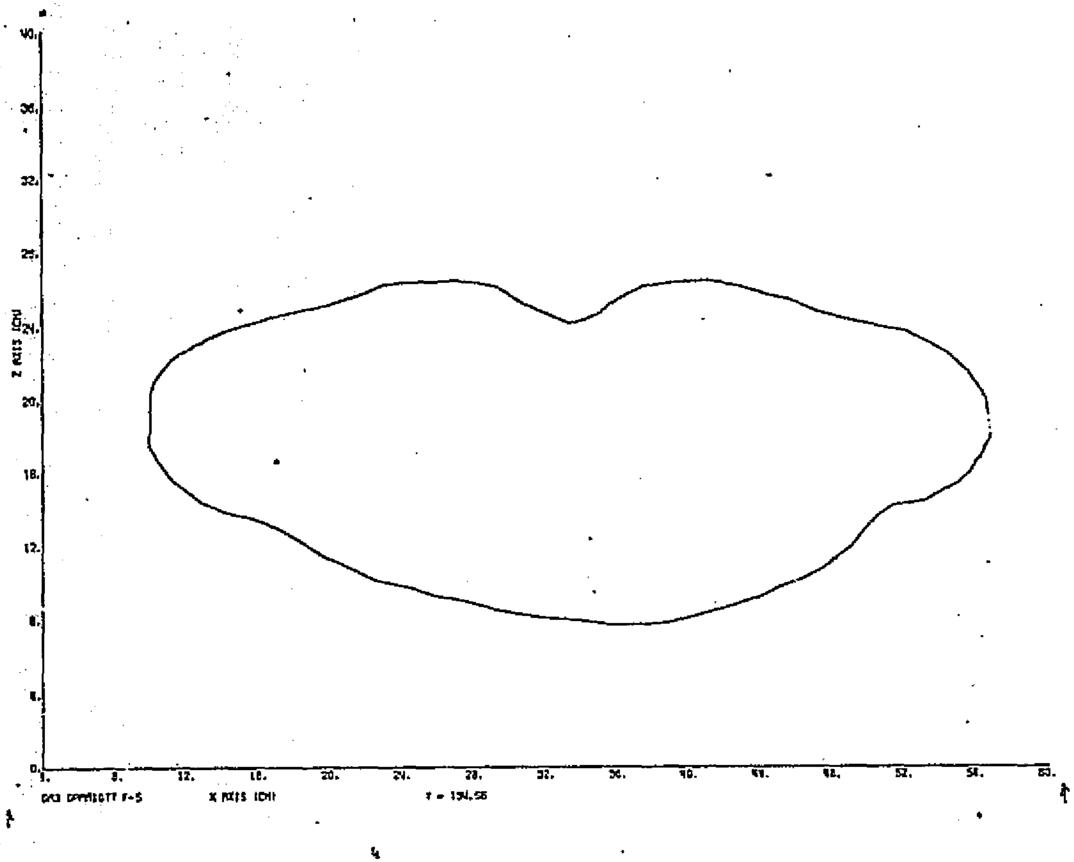

Fig. I-4: Cross-section Plotted by Computer

Five horizontal cut-off planes are determined, using the final preflight data as the model. The level of the ulnar styloid of each wrist is determined on the frontal view for the 'model', and the same position is located by superimposing each of the other graphs. As arm position varies, it is often necessary to rotate the overlying graph in order to match the wrists, and to take the value of the Y level in the center of the wrist. The error in volume introduced by this rotation is likely to be very small. On the lateral view, the position of the sternal notch, the gluteal fold and the ankle joint are estimated, and lines drawn across both the frontal and lateral views at these levels. The other graphs are then superimposed, in turn, and the positions of these 3 planes are determined independently on the frontal and lateral views. Rules have been established for acceptability of the resulting estimates of level:

1) If the distance from sternal notch to ankle joint in the graph under examination exceeds that in the model, neither sternal notch-gluteal fold nor gluteal fold-ankle distance is permitted ot be less than in the model.

2) Conversely if the sternal notch-ankle distance is less than in the model, neither of its 2 components may exceed the corresponding distance in the model.

3) If the estimates of the level of a given landmark from the lateral and frontal views differ by 1 cm or less, the mean of the two is taken.

4) If the estimates differ by more than 1 cm, both are reassessed in an attempt to move them closer together. This process may be repeated as many times as necessary until the estimates are within 1 cm, when a mean is taken. Although this process is entirely empirical, in practice there is usually no difficulty in determining the position of the landmarks, and in most cases the estimates from the 2 views are within 2 or 3 millimeters. When a discrepancy does arise, it is usually obvious that the estimate from one view is much more reliable than the other, and the latter can readily be changed.

4. Determination of Cross-Sectional Areas

The program 'CA' calculates the area of each cross-section. It first determines the center point of the section by averaging the X and Z values, then scans the section in sectors between the plotted coordinates. The radius to two adjacent points are determined, and the intermediate points at 0.02 radian angles are interpolated in such a way that the radius increments smoothly from one coordinate to the next along a spiral path. The area of each incremental arc is determined. Where the angle between points is less than 0.02 radians, or a residual angle is left after a whole number of 0.02 radian sectors, its area is calculated by the sine formula. In the region of the shoulders, the program calculates the area beyond the "arm cutoff' planes, and assigns this area to the appropriate arm. The output of the program to magnetic storage (file 9) is a level-by-level listing of format (F6.2, I2, F7.2), consisting of the Y level, the body part number (1-5) and the area in cm^2.

5. Calculation of Volumes

The program 'VOL' is a conversational program which calls for the body part number and the upper and lower Y levels between which the volume is required (format I1, 2F5.0). It then scans the body part required and fits a smooth curve to each successive cross-sectional area, generating values for intermediate cross-sectional areas at 1 mm intervals. The areas are integrated between the upper and lower Y levels to give the volume of the segment under examination. In order to eliminate discrepancies in the curve-fitting around the junction between the body and the legs, the body is taken as extending down through the first two levels of the legs (which are added together to give the new 'body' levels), and the legs are taken as extending up through the last two levels of the body (which is divided in the ratio of the areas of the top sections). Where the gluteal fold comes below the highest plotted section of the legs, an inaccurate volume determination for the buttocks would result, so that it is necessary to calculate the buttocks volume down to some intermediate level above the highest leg section, and add to it the volume of each leg from that level down to the gluteal fold (Fig. 5). The body segments examined on the Skylab study are as follows:

1) Upper third of sternal notch-gluteal fold segment (= 'chest').
2) Middle third of sternal notch-gluteal fold segment (= 'abdomen').
3) Lower third of sternal notch-gluteal fold segment (= 'buttocks').
4) Upper 40% of gluteal fold-ankle joint (= 'thigh').
5) Lower 60% of gluteal fold-ankle joint (= 'calf').
6) Arm from highest level to wrist (= 'arm').
7) Truncated total volume (total of 1-5 above plus both arms from sternal notch level to wrist).
8) Total volume (including head and shoulders, hands and feet).

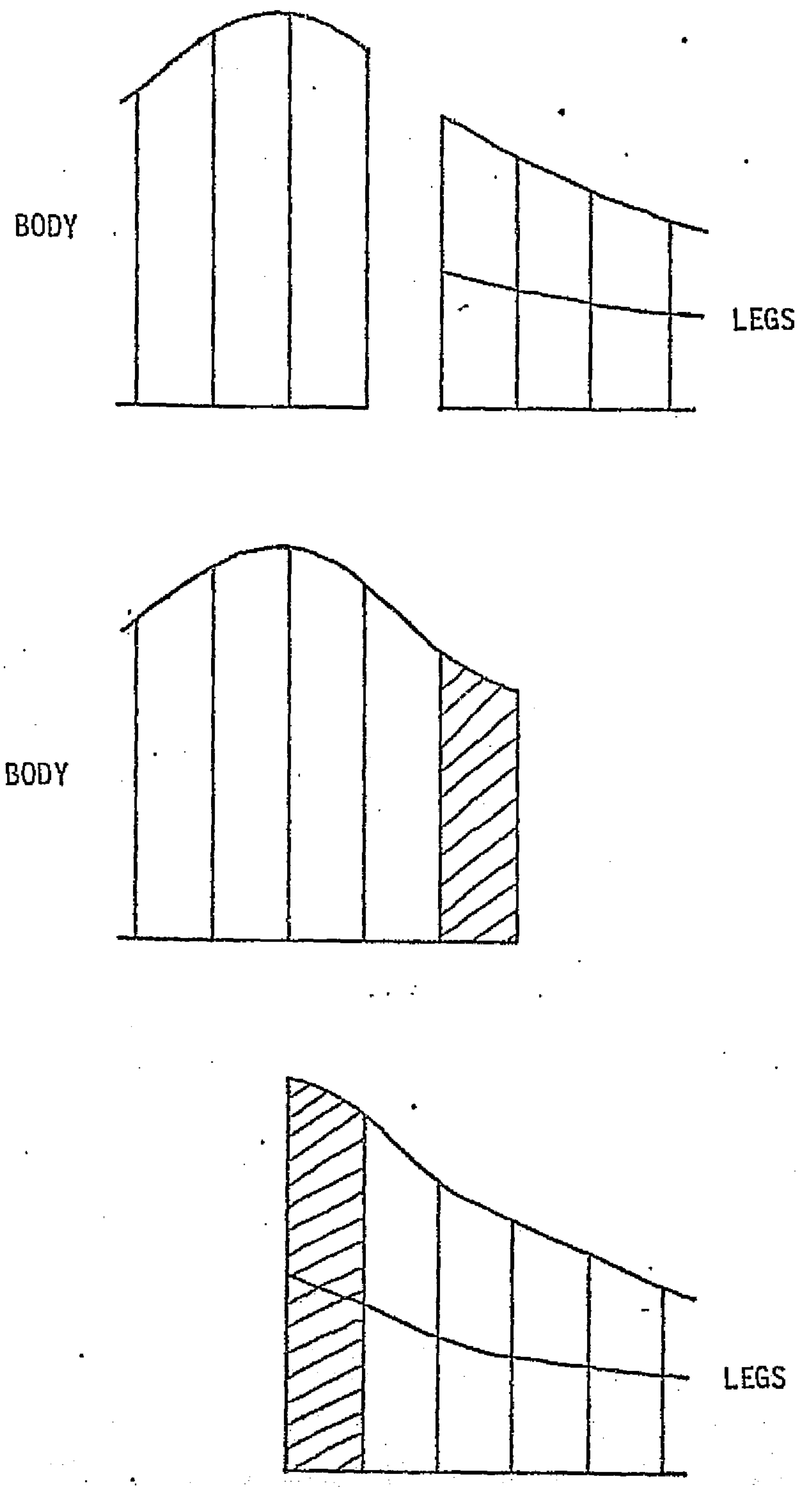

Fig. I-5: Extension of Body Levels into Upper Legs, and Upper Leg Levels into Body. The cross-hatched areas would give unreliable volume estimates and are not used except for curve fitting.

Evaluation of Findings For All Three Skylab Missions

Table 1 gives the preflight mean volume of the body and its segments for the 9 Skylab astronauts and the change observed at the first postflight measurement. Body weight is also given. Although all the body segments examined showed a postflight reduction in volume, the changes observed in the chest and arms were small, and not statistically significant. The greatest absolute losses of volume were seen in the abdomen and thigh, although the loss of volume from the calves was proportionally greater. The loss in weight exceeded the loss in total volume by 686 g, but this difference is not statistically significant, and probably results from the accumulation of inaccuracies when the volume of the whole body is calculated. It is hoped to eliminate these inaccuracies on future studies, and it may one day be possible to re-analyze the Skylab data, with an improvement in precision.

The rate of recovery of body volume was followed only on the final Skylab flight, in which 3 sets of photographs were obtained in the first 5 days postflight. Table II gives the difference in volume between various body segments and their mean preflight volume, for the 3 postflight measurements. The abdominal volume varies a great deal, as it is sensitive to food and drink intake - the recovery-plus-1 day measurements were made in the middle of the day, whereas the recovery-plus-4 days measurement was made before breakfast. Nonetheless, a marked increase in volume is seen between recovery day and the other 2 measurements. Buttock volume increased by 200 ml during the postflight period. Both the

	Preflight Mean	Postflight Difference	Proportional Difference	Significance†
	Liters	Liters	Percent	
Arms (Both)	6.927	-0.066	-1.0	N.S.
Chest	13.149	-0.150	-1.1	N.S.
Abdomen	11.305	-0.541	-4.8	P < 0.001
Buttocks	13.583	-0.393	-2.9	P < 0.005
Thighs (Both)	9.411	-0.559	-5.9	P < 0.001
Calves (Both)	6.349	-0.472	-7.4	P < 0.001
Total Body Volume	71.267	-2.342	-3.3	P < 0.001
	Kg	Kg		
Body Weight	71.988	-3.023	-4.2	P < 0.001

†Paired t-test

Table I. Regional and total body volume, and body weight: Difference between mean preflight and first postflight measurements (average for all Skylab crewmen: 9 subjects)

	Difference from Preflight Mean Volume (Liters)			
	Recovery Day	Recovery + 1 Day	Recovery + 4 Days	Recovery + 68 Days
Abdomen	-0.566	+0.186	-0.123	+0.411
Buttocks	-0.042	+0.034	+0.156	+0.845
Thighs (Both)	-0.425	-0.323	+0.009	+0.776
Calves (Both)	-0.450	-0.270	-0.120	+0.306

Table II. Postflight recovery of volume of body segments (average for final Skylab crew: 3 subjects) thighs and the calves show a rapid increase in volume, the rate of increase being initially greater in the calves, although by R + 4 the thighs had reached their preflight volume, whereas the calves were still 120 ml deficient.

Discussion

It is unfortunate that the pressures on the time of the astronauts prevented more photographic sessions being possible, particularly during the first few days following splashdown. However, the data collected does provide some interesting pointers to changes in body composition resulting from space flight. The rapid increase in volume in the first 5 days postflight clearly results from an increase in body fluid, the adaptation to zero gravity having caused a reduction in fluid volume, which is inappropriate for the 1-gravity environment. The recovery of volume proceeded faster in the calves than in the thighs, due to their more dependent position.

All the astronauts showed a rapid increase in weight in the first few days postflight, but the weight had generally leveled out by recovery plus 4 days, suggesting that rehydration was complete. The volume changes observed in the final crew at that time may be taken to represent the sum of the in-flight changes in fat and muscle, possibly modified by a little postflight recovery.

The postflight change in volume of the buttocks for the 9 Skylab astronauts correlates well with the postflight change in weight (correlation coefficient 0.92), suggesting, as might be expected, that the buttocks are a sensitive indicator of body fat. Using the regression equations from this correlation, and correcting for the effects of dehydration on the volume of the buttocks, it may be calculated that around 2.2 Kg of the postflight weight loss resulted from the combined loss of fluid and muscle, the remainder being due to changes in body fat.

The final Skylab crew relaxed their dietary and exercise regimes following the flight, and put on weight. The resulting change in volume of different body parts enables a correction to be made for subcutaneous fat in the postflight volume changes. With the small number of data points, such calculations must be taken as very approximate, but there appears to have been a mean loss for the final Skylab crew of about 90 g of muscle from each calf, and about 70 g from each thigh. Such losses are very modest, and are a tribute to the in-flight exercise program. With even less postflight data points, it is possible only to make very rough estimates for the first and second Skylab crews. The loss of muscle from the calf appears to be similar from one mission to another, whereas the loss of thigh muscle apparently decreased with succeeding missions. This observation fits in well with the use of the bicycle ergometer in-flight, which was increased on successive missions, but provides better exercise for the thigh muscles than for the calf.

A correlation coefficient of 0.92 has been established between the change in buttock volume over the course of the flight and the in-fligh caloric intake, expressed per Kg of lean body mass (LBM). A caloric intake of 49 Kcal/day/kg LBM appears optimal to preserve the fat depots at their preflight level. Only 1 Skylab crewman exceeded this intake, and he increased his fat reserves. The 2 crewmen losing the most fat in the course of their flight had intakes of 37 and 41 Kcal/day/kg LBM. The remaining crewmen had intakes in the 45-48 Kcal/day/kg LBM range, and all but 1 lost a little fat.

Conclusions

The 9 Skylab astronauts returned from their space flights with changes in the quantities of fluid, muscle and fat in their bodies. The change in fluid resulted from the adaptation of the cardiovascular system to the zero-g environment, and amounted to a deficit of almost 2 liters. It was replaced in the first 4 days postflight. The losses of muscle were fairly modest, amounting to about 160 g in each leg on the final mission. Losses were probably a little greater, particularly in the thigh, on the first 2 flights, and probably reflected the level of exercise undertaken. Techniques have not yet been devised to measure changes in muscle bulk in the upper part of the body, although no statistically significant changes in the volume of the arms or chest were observed. Changes in body fat were related to caloric intake, an in-flight intake of 49 Kcal/day/kg lean body mass appearing necessary to preserve the body fat at its preflight level, a value which was exceeded in practice by only 1 crewman.

Biostereometrics is a relatively new science, but it is emerging as a powerful tool in the medical and biological sciences. The stereoscopic photographs of the Skylab astronauts took no more than 5 minutes of the subject's time for each measurement, but provide a permanent detailed record of body form, which may, if necessary, be re-examined at any future date, either to answer new questions, or to take advantage of the increased accuracy resulting from improvements in the analytical technique.

II. COMPARISON OF BODY VOLUME DETERMINATIONS USING HYDROSTATIC WEIGHING AND BIOSTEREOMETRICS

Knowledge of total body volume is essential for estimating gross body composition in terms of fat content and fat-free weight from body density based on the simple equation:

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$

Water displacement or hydrostatic weighing has been the most widely used method for determining body volume for many years. In centers where the necessary equipment--water tank and weighing apparatus--is a relatively permanant fixture, the hydrostatic weighing procedure has proved effective for measuring total body volume in healthy subjects. However, the method is unsuitable for use with the very young, the very old, and seriously ill patients. It's relatively low portability and other practical limitations ruled it out for use in the Skylab biomedical examinations. This situation led to the use of biostereometrics, a more convenient but less well established procedure, in the present series of astronaut studies.

A coincidence led to the companion study described below. The Biostereometrics Laboratory was engaged in a collaborative study with the Lovelace Foundation involving stereometric measurements of children undergoing treatment at the Lovelace clinic. The attention of Dr. Ulrich Luft, a longtime member of the Lovelace staff and a NASA principal investigator associated with the Skylab Life Sciences program, was drawn to the biostereometric measurement activities. As a result, he suggested that a study of the two methods be undertaken while the biostereometric equipment was in use at Lovelace. We wholeheartedly approved of this suggestion and the necessary arrangements were made with Dr. Luft to take dual measurements on ten adult subjects.

The following description of the comparative study is largely derived from the preliminary report submitted by Dr. Luft. We have added further details about the biostereometric-data reduction procedures and some further comments aimed at helping to interpret the findings. In general, however, we consider Dr. Luft's conclusions to be fair and insightful, as we would expect from someone with his considerable experience in the realm of body composition studies.

Methodology

Measurements were made consecutively with both methods on ten healthy male volunteers, between 8 and 9 in the morning, in the fasting state. In two of the subjects the stereo and H_2O measurements were made two days apart, but their body weight had not changed more than 100g. The biostereometric photography of the subjects was performed with a four-camera system with strobe projector on loan for this study from Dr. R.E. Herron similar to that employed on the astronauts of the SKY-LAB program (8). The photographer had been trained in the procedure in the Biostereometrics Laboratory where the photographs were analyzed and processed.

For the hydrostatic weighing the subject is seated in a light metal chair suspended from a dynamometer balance (Chitillon 31154) of 15 kg capacity in a stainless steel tank filled with water that is maintained at 34^{o}C. The chair is lowered by block and tackle so that the subject is immersed up to his chin. Immediately before putting his head under water the subject is required to take five deep breaths fairly rapidly, followed by a maximal inspiration. Then a mouthpiece is offered to him by an attendant and he exhales approximately 2/3 of his vital capacity, previously marked on the recording drum, into a spirometer. At this point the operator calls "halt", the mouthpiece is withdrawn and the subject submerges his head without further loss or intake of air (nose clip) for 10-15 seconds until the reading is taken on the balance. The entire procedure is practiced before entering the tank and ths subject is directed not to press his lungs while submerged to minimize the reduction in lung volume. Three consecutive measurements are performed and the corresponding readings of submerged weight and exhaled gas volume is corrected to

BTPS conditions and subtracted from the subjects's total lung capacity previously measured in the pulmonary function laboratory by a N_2 washout method (4) to obtain the residual volume in the lungs on submerging.

Body volume and density are calculated by the following equations:

$$V_b = \frac{Ma - (Mw + RV \quad Dw)}{Dw} \qquad (2) \quad \text{and}$$

$$D_b = \frac{Ma \quad Dw}{Ma - (Mw + V \quad Dw)} \qquad (3),$$

where V_b = body volume, Ma = weight in air, Mw = weight under water, RV = residual lung volume, Dw = density of water at tank temperature and D = body density. The variation between three measurements of V_b taken in this manner is less than 0.20 liters (approximately 0.3% V_b). The average of three measurements was taken for each subject.

In order to insure that the gas volume in the subject's lungs during the stereophotography was as close as possible to the RV during the underwater weighing, the subject took a maximal inspiration and exhaled slowly to the same volume marked on the spirometer before holding his breath for the photograph.

Results

Table 1 shows the results for body density (column 2) and net body volume (column 3) by the H_2O method. Net body volume is the gross volume less the lung gas volume (column 4) and is used to estimate D by equation 3. Since the stereometric method gives gross body volume, the lung gas volume (column 4) must be added to the net volume (column 3) by the H_2O method in order to compare the two directly (columns 5 and 6).

Without exception the values with the stereometric method were higher than with the H_2O procedure. Using a paired comparison, in which the individual differences were analyzed, the mean difference (2.191 liters) was statistically highly significant ($p. < .0005$), but the standard error of the mean difference was relatively small (SEM: .273 liters).

The linear regression of the values obtained with the H_2O method (y) and the stereometric method (x) is plotted in Fig. I-6 with the identity line. The correlation coefficient was quite high:

$$r = .996$$

The regression equation was:

$$y = 1.008x - 2.791$$

$$SDy \text{ at } \bar{x} = 0.914 \text{ liter}$$

The individual points were all close to the regression line (Fig. I-6).

Discussion

The high correlation coefficient and the tight fit of the data around the regression line for the two methods implies that both procedures have a high degree of precision. However, the highly significant differences between the mean values raises the question: which of the two methods is more accurate in estimating the true body volume. A strong argument in favor of the H_2O method is that the values obtained for body density give results more compatible with those to be found in the literature from direct determinations on body tissue for animals (5) and man (3).

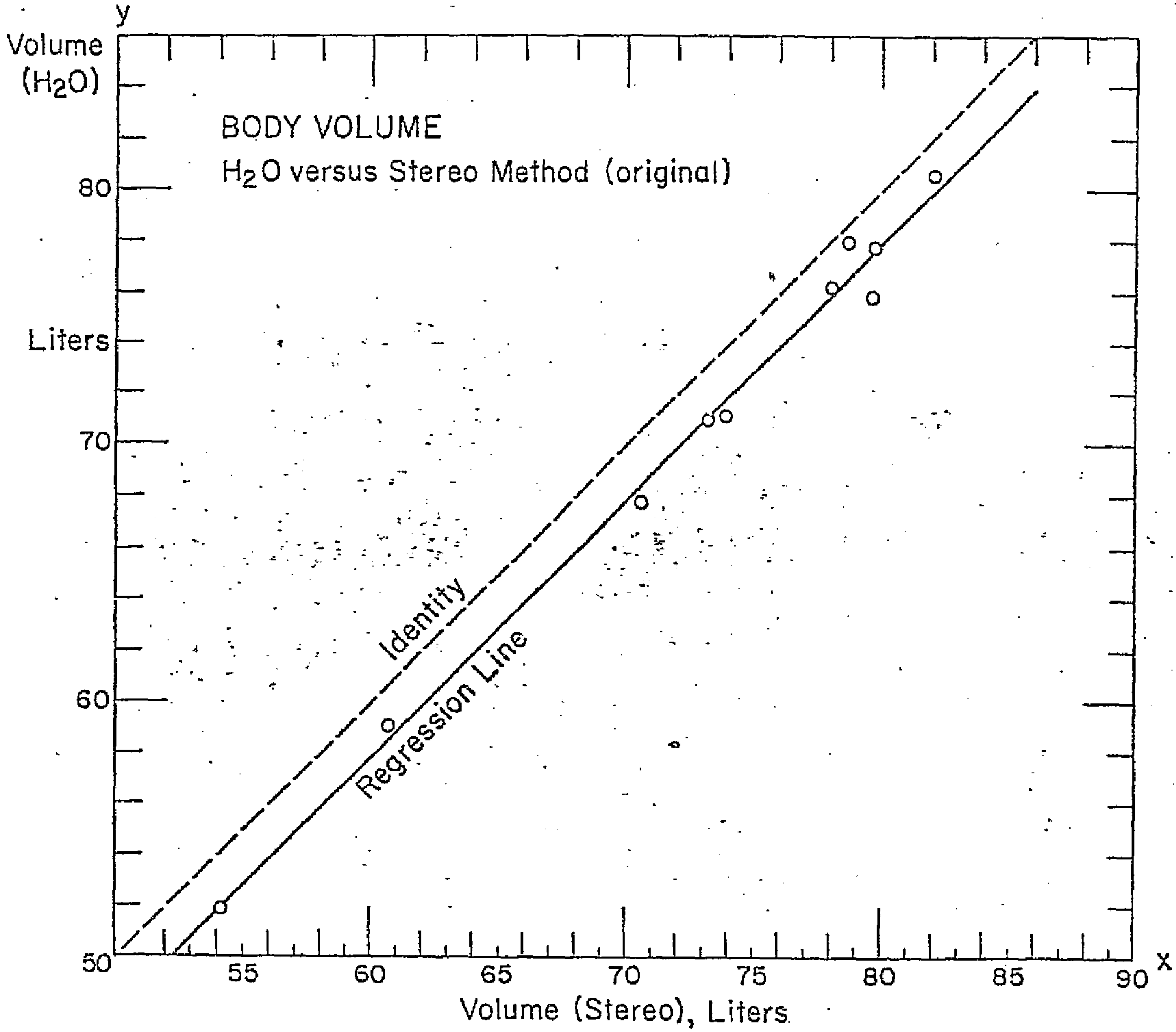

Figure I-6: Correlation Between H_2O and Stereometric Measurement of Body Volume.

The mean density (D) for the 10 subjects by the H_2O method was 1.064 (Table 1 column 2) and with the stereo method 1.030. According to the equation proposed by Keys and Brozek (3) for the fat fraction of the body (Ff)

$$Ff = \frac{4.201}{D_b} - 3.813$$

the mean D from the H_2O method gives a fat fraction of 13.5%, which is in good agreement with the mean value of 13.9% reported by the same authors for a larger number of subjects in the same age category. Making the same calculation with the mean D from the stereometric method results in a fat fraction of 26.6% indicating considerable obesity. Not one of our subjects was grossly overweight. Therefore it appears justified to assume that the results of the H_2O method are closer to the true value.

In view of the consistency and precision of the stereometric method and the fact that the discrepancy with the H_2O method is apparently not due to a random error but to a strictly systematic one, it might be feasible to utilize the regression established from H O method data to adjust stereometric values obtained in future studies to correspond with values that would be found by the H_2O method. With this in mind we have transformed the stereometric data from Table 1, column 6 to the adjusted body volume by equation 4. The individual results are shown in Table 1, column 9 and are plotted in Fig. I-7. All points are now closely clustered around the identity line and the mean values differ by only 0.016 liters and the average for body density is identical (Table 1, columns 2 and 11). Obviously the validity of this type of manipulation of the stereo data will have to be tested on a much larger number of paired measurements on subjects of different body types before it can be accepted with confidence.

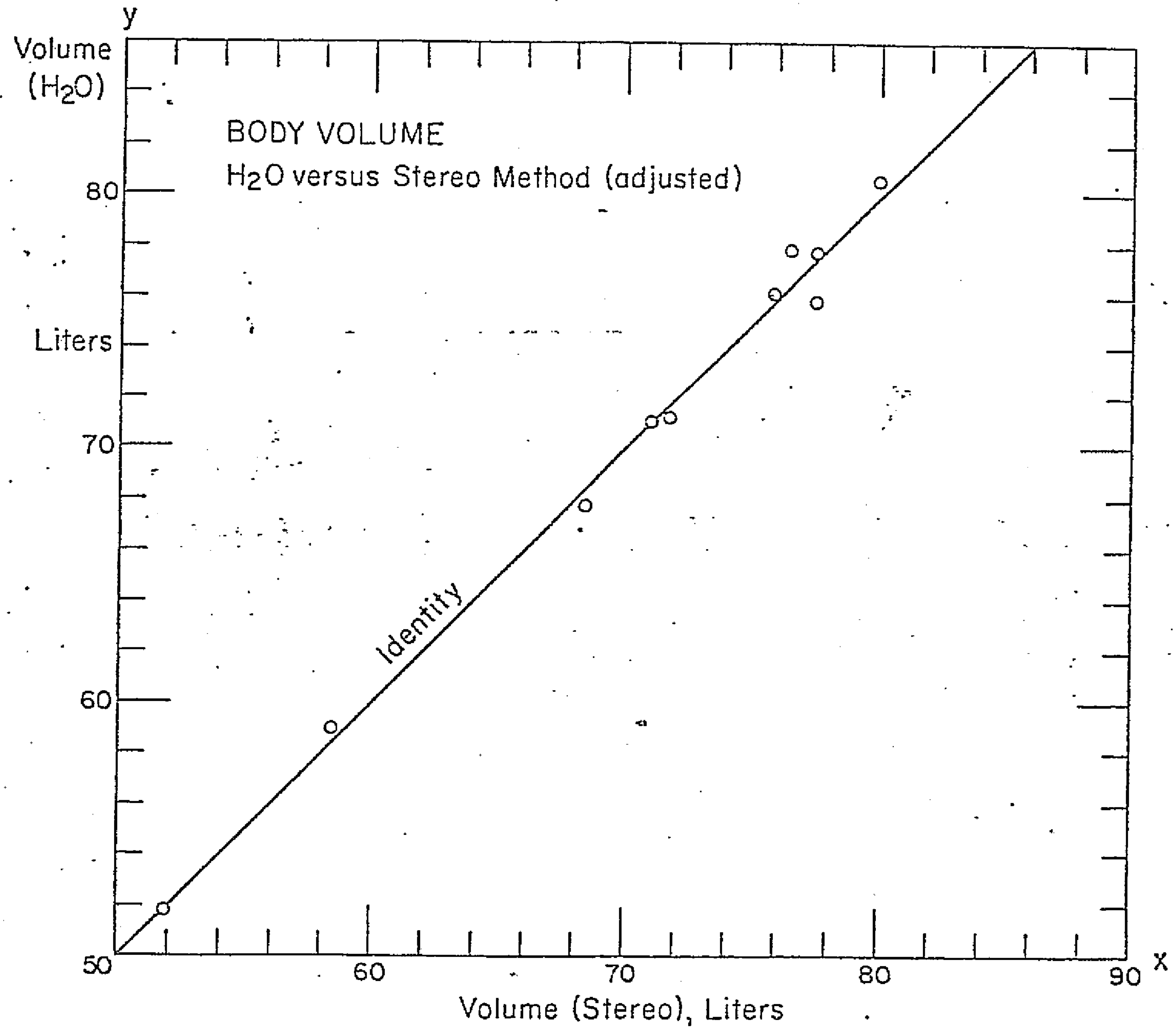

Figure I-7: Adjusted correlation Between H_2O and Stereometric Measurement of Body Volume.

	Hydrostatic Weighing					Stereometric Measurement					
						Original			Adjusted		
	1	2	3	4	5	6	7	8	9	10	11
Subj. Nr.	Mass kg.	D	Vol. net	Vol. Lung	Vol. gross	Vol. gross	Vol. net	D	Vol. gross	Vol. net	D
1	60.40	1.087	55.566	3.458	59.024	60.728	57.270	1.055	58.423	54.962	1.099
2	77.35	1.042	74.232	3.716	77.948	78.729	75.013	1.031	76.568	72.854	1.062
3	77.05	1.054	73.102	3.137	76.239	78.073	74.936	1.028	75.907	72.773	1.059
4	71.70	1.069	67.072	4.172	71.199	73.953	69.826	1.027	71.954	67.623	1.060
5	78.65	1.042	75.480	5.233	80.713	82.085	76.852	1.023	79.951	74.717	1.053
6	79.65	1.068	74.579	3.169	77.748	79.776	76.607	1.040	77.623	74.451	1.070
7	71.55	1.034	69.197	1.798	70.995	73.296	71.498	1.001	71.091	69.292	1.033
8	68.40	1.085	63.041	4.721	67.762	70.590	65.869	1.038	68.364	63.639	1.075
9	53.55	1.068	50.140	1.665	51.802	54.221	52.556	1.019	51.864	50.195	1.067
10	78.10	1.090	71.651	4.238	75.889	79.783	75.545	1.034	77.630	73.392	1.064
Mean	71.64	1.064	67.406	3.526	70.932	73.123	69.597	1.030	70.916	67.390	1.064

Net Volume is gross volume less lung volume. $D = \frac{\text{Mass}}{\text{Net Volume}}$

All volumes are in Liters.

Table III Comparative numerical data for Hydrostatic and stereometric body volume measurement.

The systematic overestimation of body volume by the stereometric method used here may be due to the lack of coverage of hidden body concavities, for example, in such areas as the armpits, the groin and the buttocks. However, if it can be shown that this source of error is sufficiently consistent to be amenable to a correction, as proposed here, the stereometric method would be acceptable as a rapid, convenient and accurate method for estimating body volume.

Additional cameras or other procedural modifications could be used to achieve more detailed coverage, but, if further research shows that the discrepancy between stereometric and hydrostatic is consistent, then a simple adjustment can be made.

Finally, it is important to recognize that stereometric records can be analyzed and displayed in various ways to yield body form and volumetric information not readily available heretofore. The following series of records for two of the Albuquerque subjects illustrate this potential.

Stereometric Records - Extent and Variety of Coverage

Figures II,1-13 illustrate the type of data produced by stereometric analysis on the Albuquerque subjects (two cases are shown). These examples demonstrate the extent and variety of body form and volume data contained in the stereometric records.

Subject A

Figure II-1. Cross-sectional plots based on polynomial computati n.

Figure II-2. Volume distribution curve (VDC)--cross sectional are plotted against length (distance along verti. al axis from head to foot).

Figure II-3. Composite cross sectional (polynomial based) and VDC display--any point on the curve gives the cross sectional area at the corresponding level on the body.

Figure II-4. Perimeter (girth) distribution curve--the girth at any horizontal level of the body can be obtained by reading the perimeter value at the appropriate level.

Figure II-5. Cross sectional plots based on raw coordinate data.

Figure II-6. Volume distribution curve derived from raw coordinate data.

Figure II-7. Perimeter distribution curve derived from raw coordinate data.

Subject B

Figure II-8. As for II-1.

Figure II-9. As for II-2.

Figure II-10. As for II-4.

Figure II-11. As for II-5

Figure II-12. As for II-6.

Figure II-13. As for II-7.

The difference between the volume computed using the polynomial and the volume computed using the raw coordinate data was 0.3%. The corresponding figure for Subject B was 0.2%.

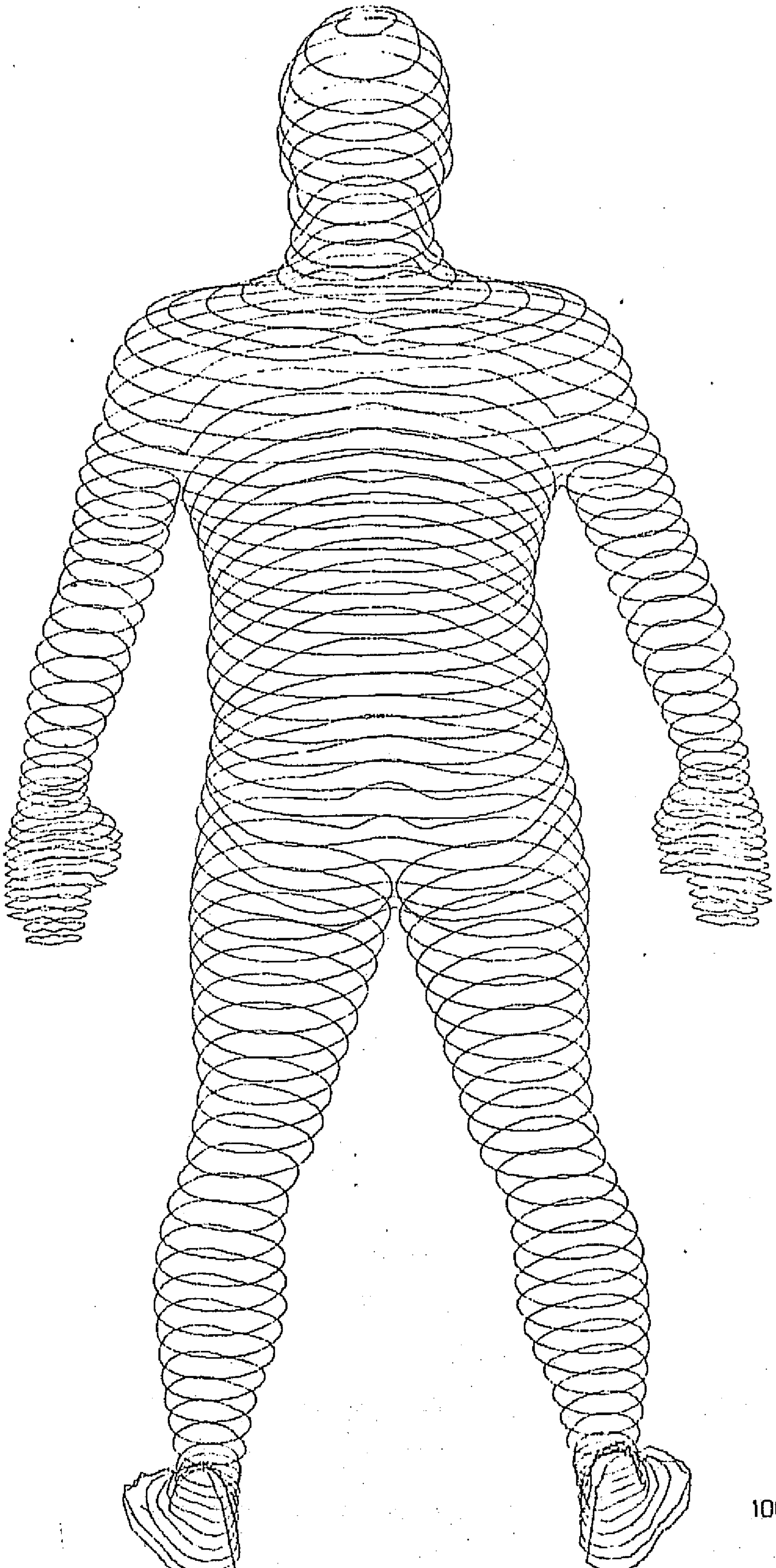

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Fig. II-1: Cross-sectional plots based on polynomial computation.

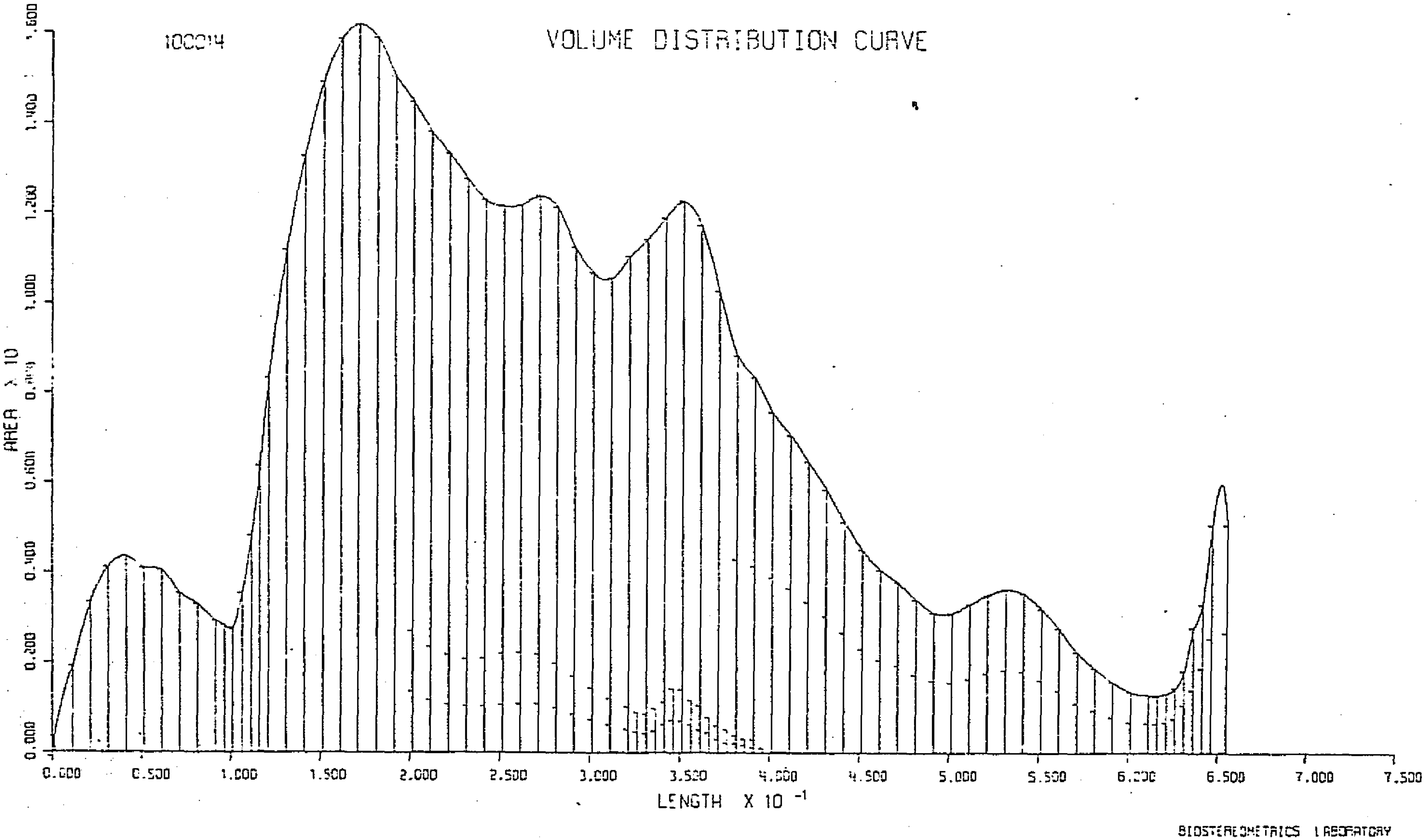

Fig. II- 2: Volume distribution curve (VDC)--cross sectional are plotted against length (distance along vertical axis from head to foot).

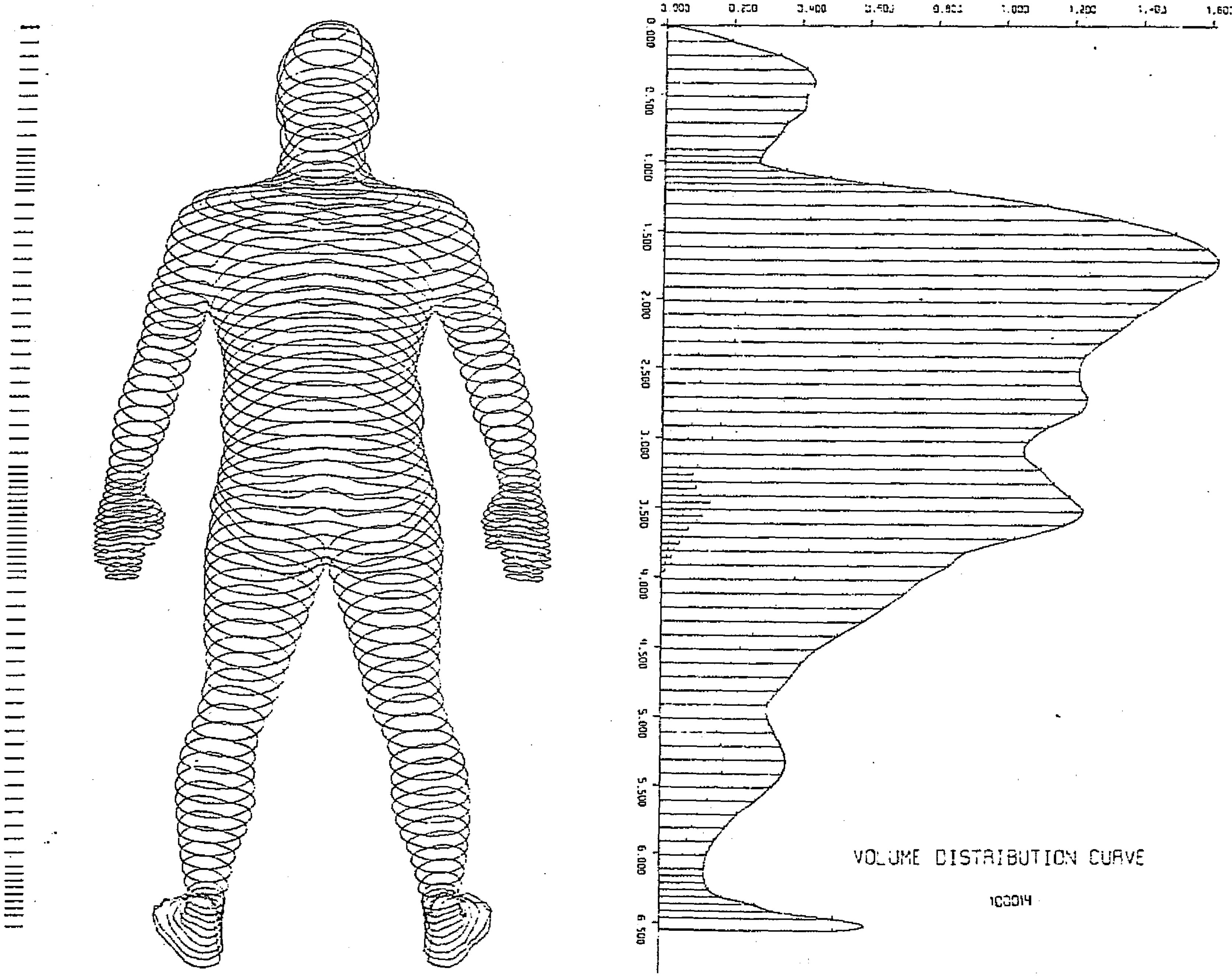

Fig. II-3: Composite cross sectional (polynomial based) and VDC display-- any point on the curve gives the cross sectional area at the corresponding level on the body.

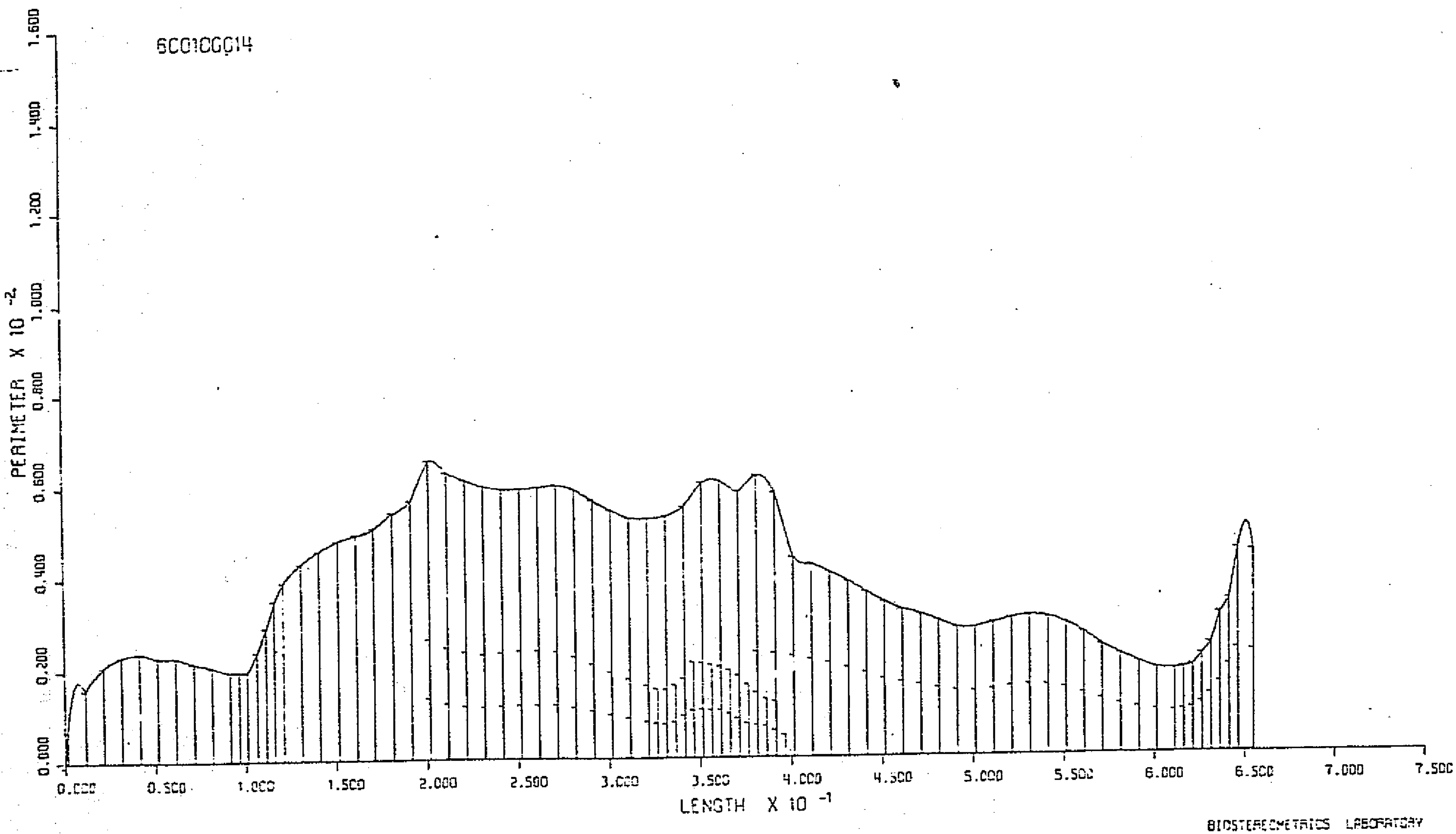

Fig. II-4: Perimeter (girth) distribution curve-- the girth at any horizontal level of the body can be obtained by reading the perimeter value at the appropriate level.

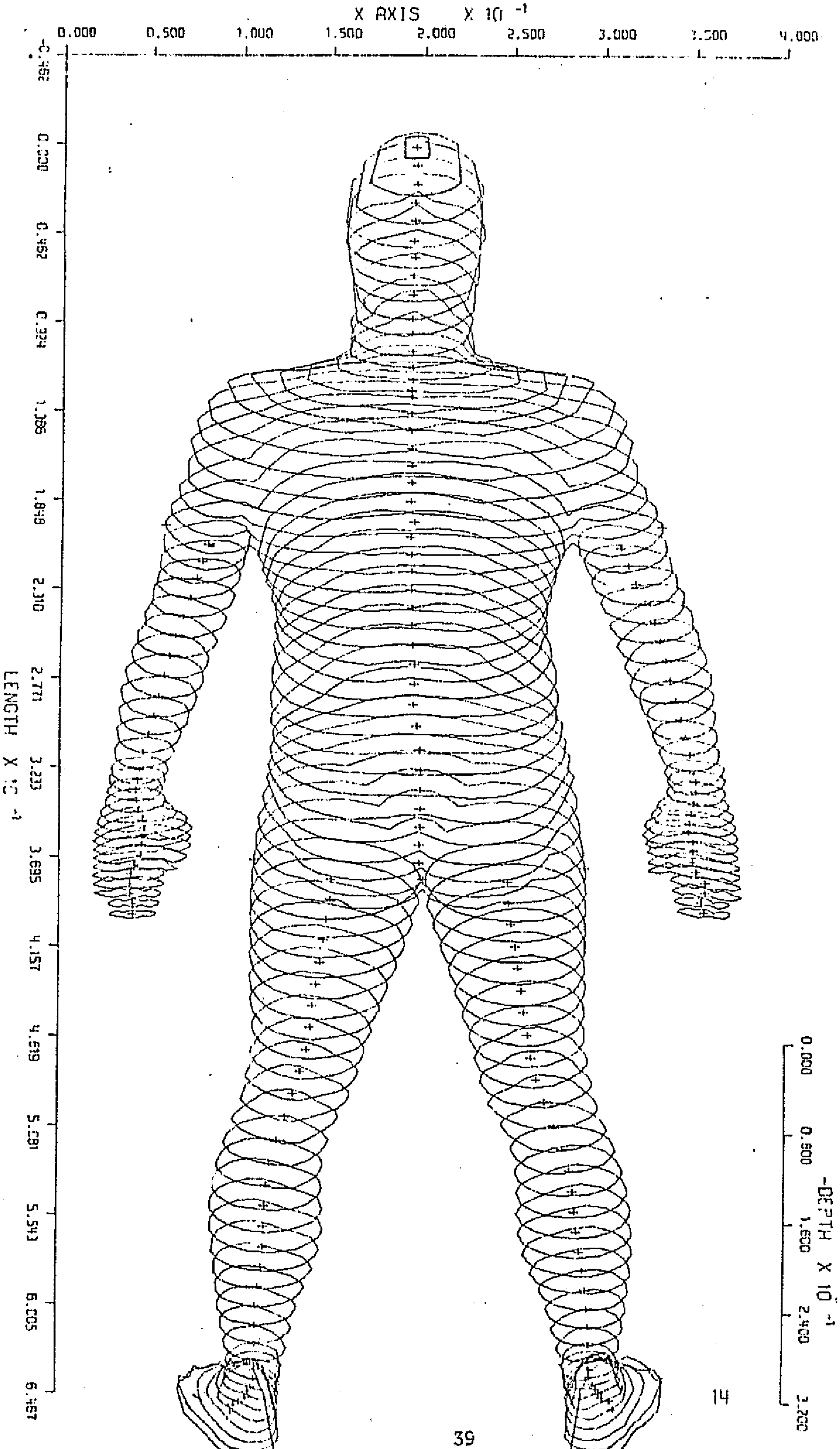

Fig: II-5: Cross sectional plots based on raw coordinate data.

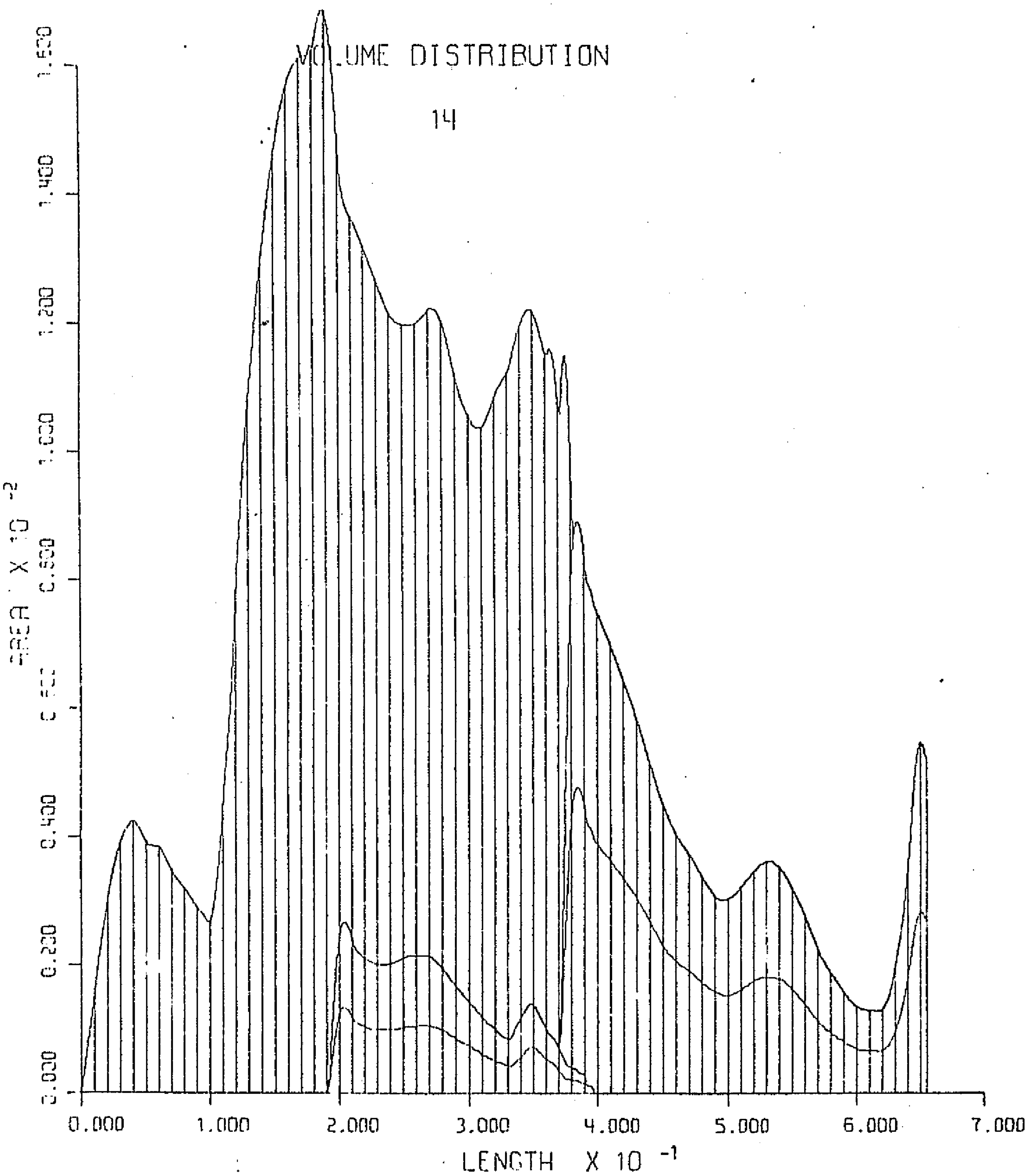

Fig. II-6: Volume distribution curve derived from raw coordinate data.

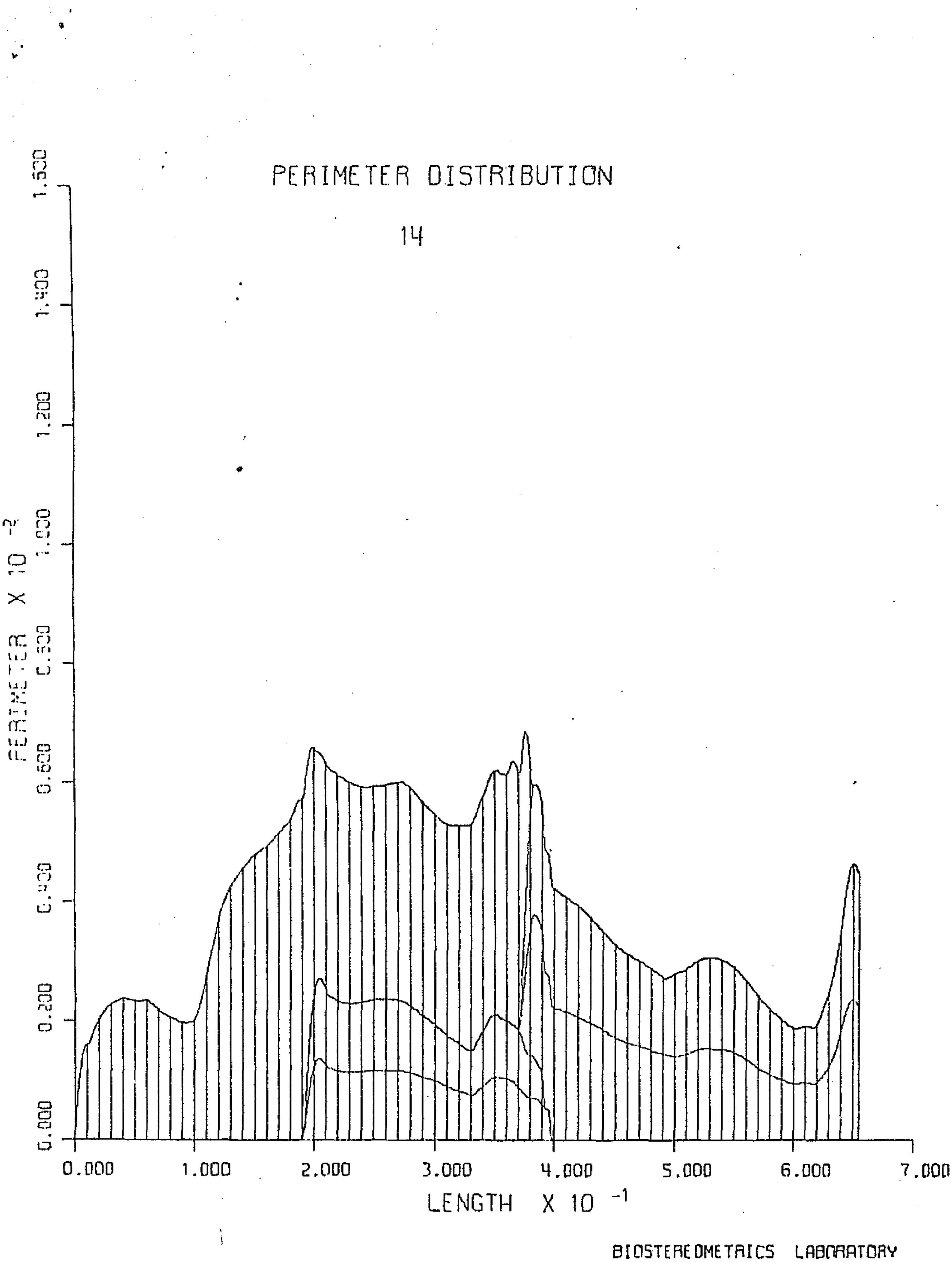

Fig. II-7: Perimeter distribution curve derived from raw coordinate data.

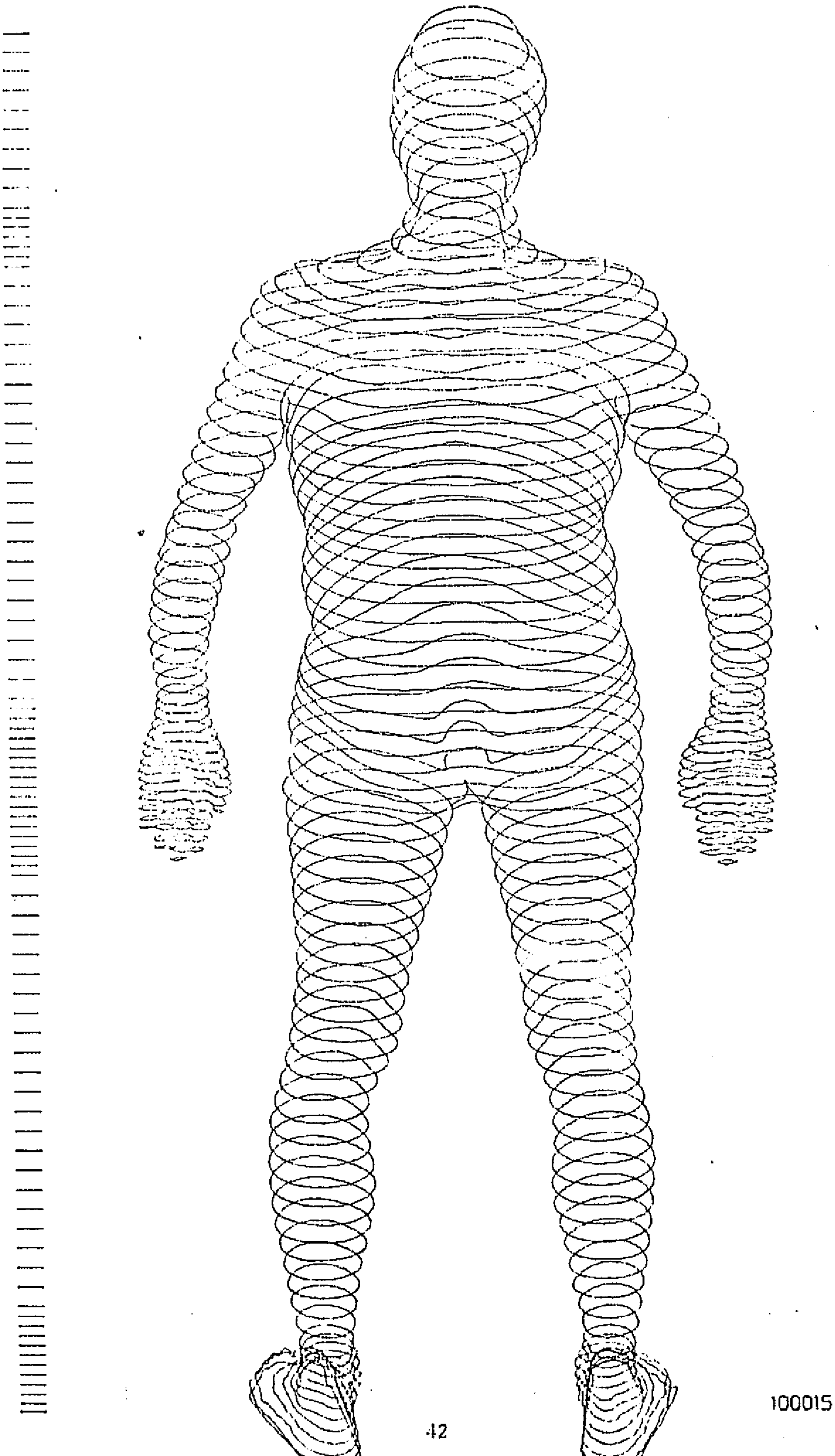

Fig. II-8: As for II-1.

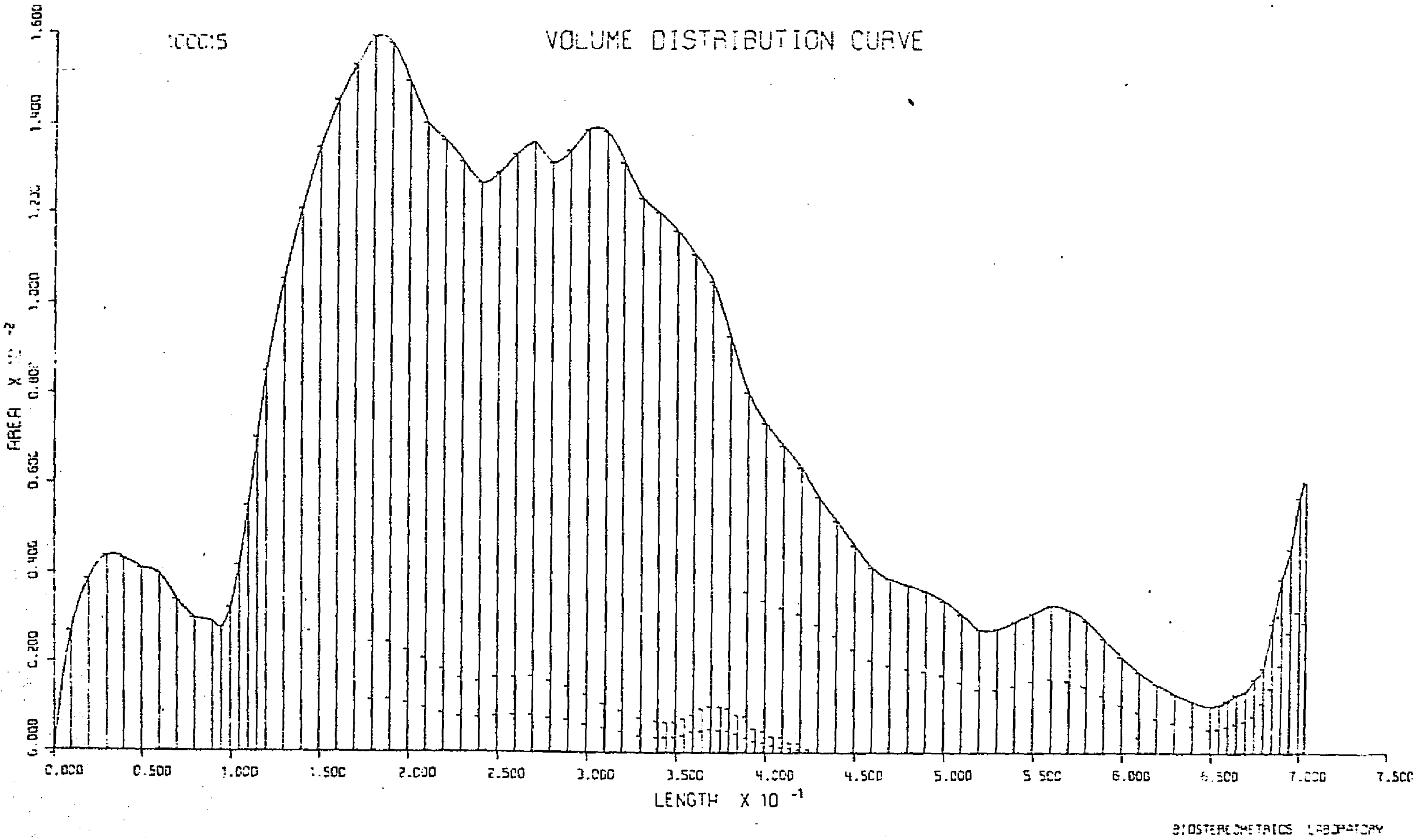

Fig. II-9: As for II-2.

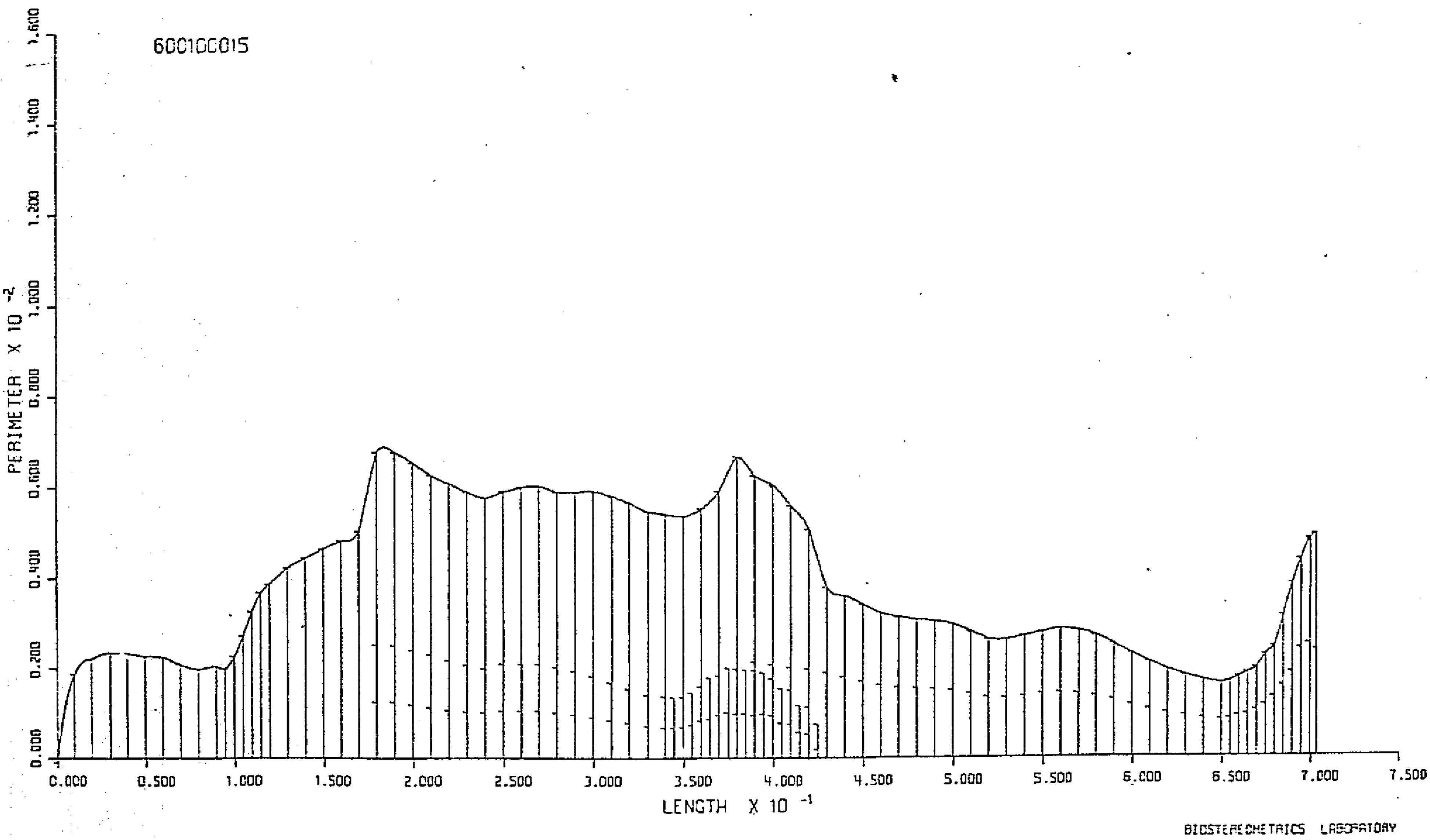

Fig. II-10: As for II-4.

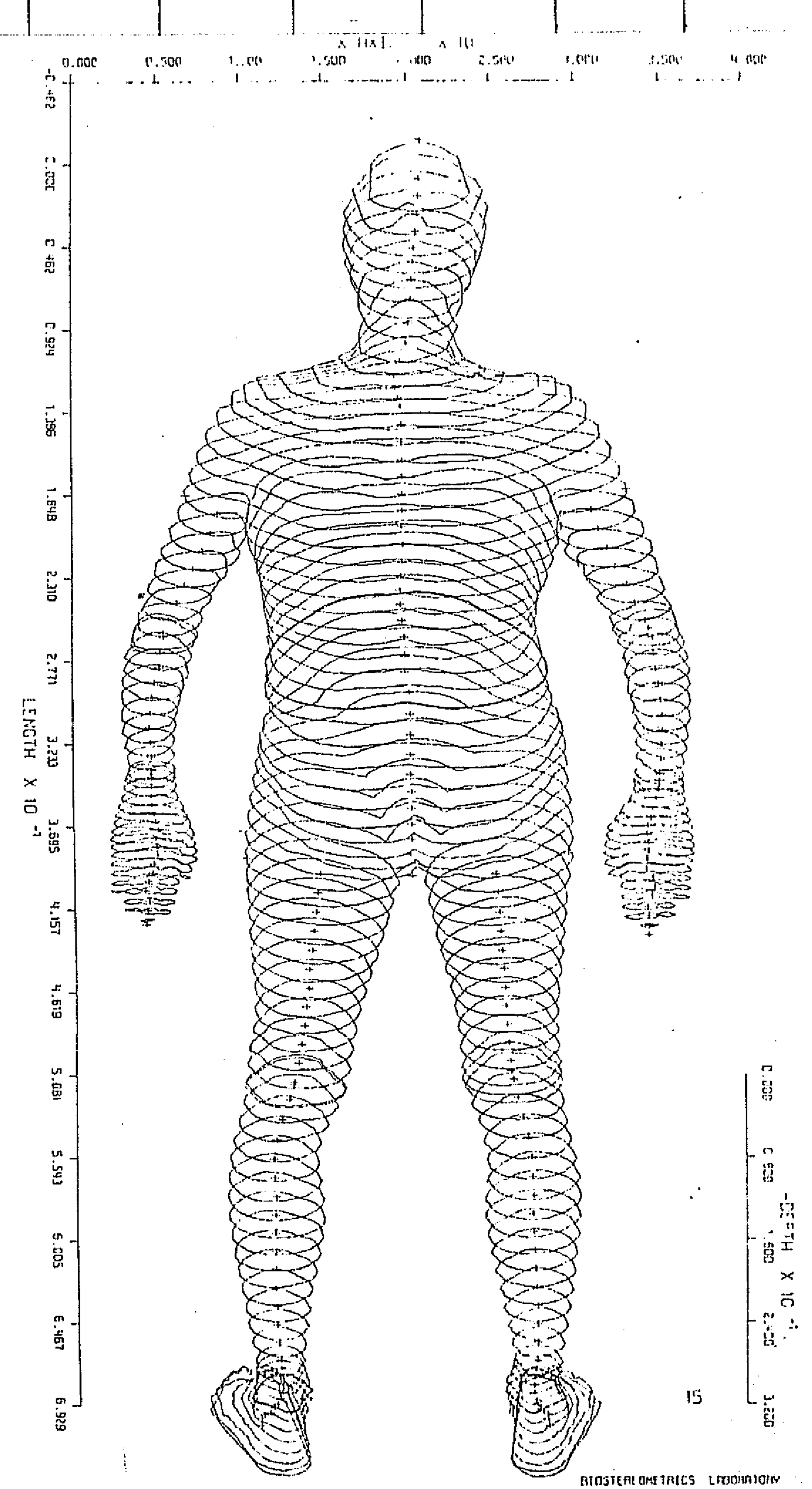

Fig. II-11: As for II-5.

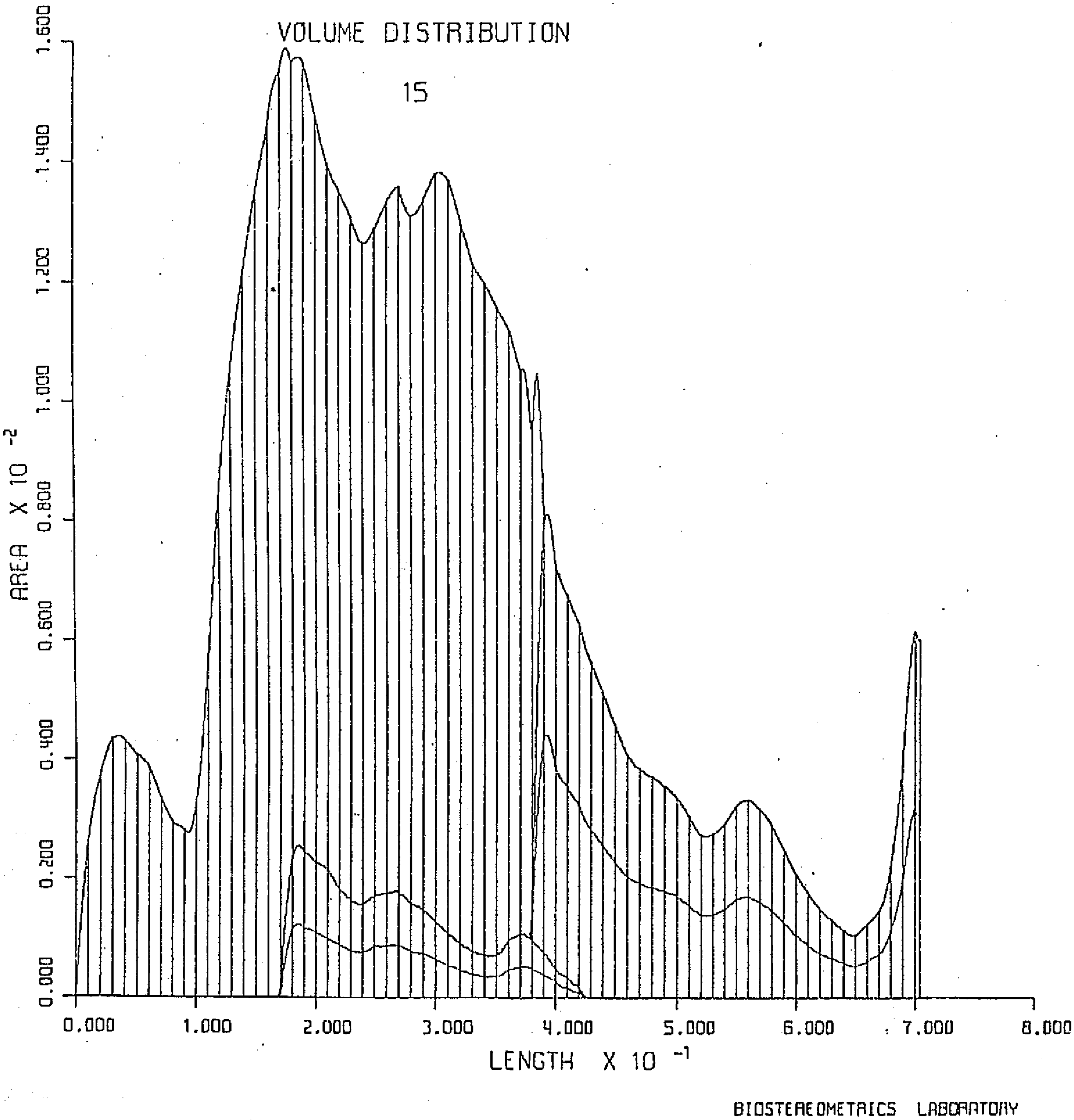

Fig. II-12: As for II-6.

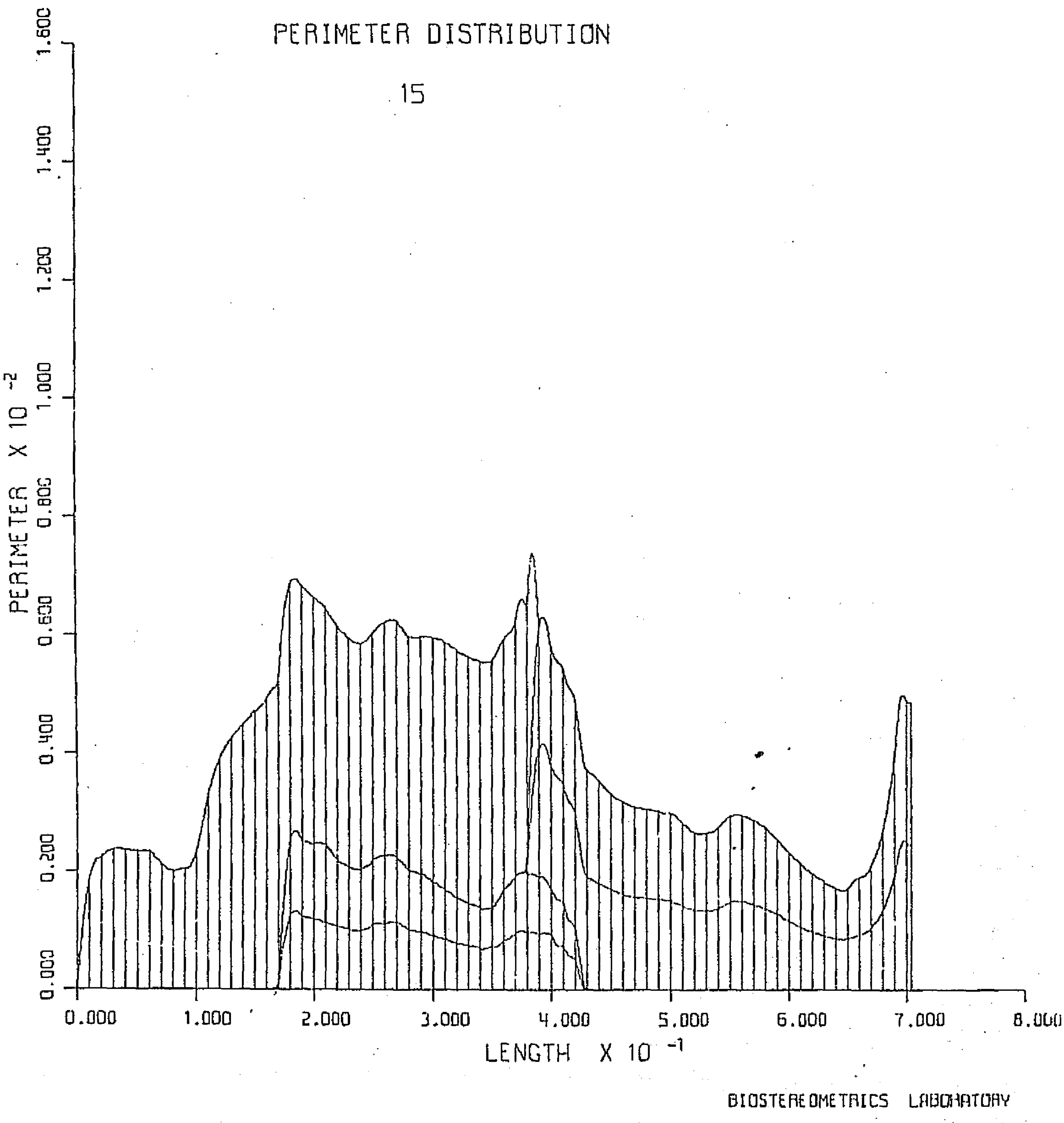

Fig. II-13: As for II-7.

III. First International Symposium on Biostereometrics, Washington, D.C., September 10-13, 1974

XIII Congress of the
International Society for Photogrammetry
Helsinki, 1976

Commission V
Invited Paper

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Houston, TX 77025, USA

Biostereometrics '74—A Report

A review of the presented papers.

The International Society of Photogrammetry Commission V Symposium: "Biostereometrics '74" held in Washington, D.C., September 10-13, 1974, was hosted by the American Society of Photogrammetry in conjunction with the XIV International Congress of Surveyors. The Proceedings published by the ASP contain complete manuscripts of all papers presented at the symposium, except for a few which missed the printer's deadline.* In this report I will summarize the presentations, mention some of the highlights, and make a few personal comments.

For the benefit of readers who are unfamiliar with the term "biostereometrics," perhaps a definition would be helpful. Biostereometrics is *the spatial and spatio-temporal analysis of biological form and function based on principles of analytic geometry*. The primary tools of biostereometrics are stereophotography, holography, interferometry and other three-dimensional form sensing techniques which yield signals, imagery, or other data which can be readily handled by modern stereoplotters, comparators, computers, and related data processing and display devices.

The major components of the symposium were seven technical sessions, an informal forum, and a speaker's luncheon.

Session I on "Biostereometric Systems" opened with a series of welcomes from ISP President, Dr. S.G. Gamble, Commission V President, Dr. H.M. Karara, and the Program Chairman, Dr. R.E. Herron.

In the first paper, Dr. Karara, University of Illinois, reviewed recent developments in the design of photogrammetric systems for use in biostereometrics. He stressed the need for close cooperation between photogrammetric engineers and biomedical specialists in order to ensure future expansion of the field.

L.F.H. Beard of Addenbrooke's Hospital, Cambridge, England, in a paper co-authored by P.F. Dale, K.B. Atkinson, H.J. Law, and A.R. Elkington, described the design and use of a hand-held stereometric camera which promises to make stereometric analysis more widely accessible for hospital and other clinical use.

Professor J.R. Cuzzi, Baylor College of Medicine, Houston, USA, outlined an automatic system for stereometric analysis based on the possibility of controlling the object, the photographic conditions and the necessary elements of orientation.

Dr. W. Faig, University of New Brunswick, Canada, described an analytical plotter system and derivation of the pertinent equations for precision mapping of a close-range object.

W.J. Iams of Memorial University of Newfoundland, St. Johns, Canada, in a paper co-authored by Dr. John W. Evans, described how a photogrammetric system has been used to monitor interactions of organisms and rock substrate over a three-year period along the Barbados coastline.

Col. M. Kurtz, U.S. Army, read a paper authored by Dr. E.M. Mikhail, Purdue University, USA, concerning the growing potentials of hologrammetry in biostereometrics. Examples involving the use of holograms and holographic stereomodels were described and compared.

G. Voss, Jenoptik, Jena G.m.b.H., German

* Copies are available from ASP Headquarters, 105 North Virginia Avenue, Falls Church, Virginia 22046, USA. The price for ASP members is $7.50 and for non-members $12.50.

Democratic Republic, reviewed recent developments in the Jena Instrument System for biostereometrics. Emphasis was placed on the cameras, e.g., the UMK 10/1318, and suggestions for new applications were given.

Session II, presided over by Prof. A.K. Tolegård, Royal Institute of Technology, Stockholm, Sweden, including two further papers on biosteterometrics systems and six papers on cranio-facial morphology.

Dr. J. Höhle, Wild Heerbrugg Instruments, N.Y., described how the Wild P31, P32 and C40 cameras and widely available aerial mapping instruments can be used for biostereometric purposes.

J.E. Hugg, Baylor College of Medicine, Houston, USA, outlined a procedure for simultaneous recording of front and rear stereopairs of a standing human subject and the associated use of conventional plotting techniques.

I. Newton, University of Newcastle upon Tyne, England, described an investigation of several different techniques of posing the head for studies of facial change. The accuracies of the various systems were reviewed and compared.

Dr. E.J. Lovesey, Royal Air Force, Farnborough, England, described the development of a projected grid (light-slit) system of photogrammetry for use in anthropometric studies such as the measurement of facial form.

A.M. Wright, Hospital for Sick Children, Toronto, Canada, in a paper co-authored by H.U. Lichtenberg and R. Moore, described various uses of stereometric data (including the production of physical models) for planning surgical reconstruction of congenital facial deformities.

K.B. Atkinson, University College, London, in a paper co-authored by I. Newton and B.D.G. Morgan, examined the relationships between prosthesis content and volume determination in a case of breast reconstructive surgery.

I.J. Dowman, University College London, in a paper co-authored by A.R. Elkington, reported on a feasibility study involving the use of photogrammetry to measure glaucoma development in the human retina.

Prof. K. Torlegård, Royal Institute of Technology, Stockholm, in a paper co-authored by C.E.T. Krakau, compared the use of a light-slit method with stereophotogrammetry for measuring volume of a normal optic disc.

Session III, with Dr. V.R. Kratky, National Research Council, Ottawa, Canada, presiding, comprised seven further papers on cranio-facial morphology.

Dr. Bernard Schwartz, Tufts University School of Medicine, Boston, USA, in a paper co-authored by Dr. R.E. Herron and Prof. J.R. Cuzzi, described some of the advantages of using stereometric parameters other than contour maps for quantifying the geometry of the eye and its component structures.

Dr. V.R. Kratky presented a review paper on problems associated with the choice of instrumentation and analytic methods for ophthalmologic applications of photogrammetry.

Dr. G.L. Portney, University of California, Davis, USA, described the use of photogrammetry for measuring three-dimensional changes in the optic nerve head cup in normal and glaucomatous eyes.

Dr. B.E. Cohan, University of Michigan, Ann Arbor, USA, described preliminary results achieved with a system of instrumentation for stereometric analysis in ophthalmology.

Dr. W.W. Bowley, University of Connecticut, Stowe, USA, in a paper co-authored by rs. C. Burstone, H.A. Koenig and R. Siatkowski, described the use of a laser holographic system and a finite element technique for predicting tooth displacement based on a ten-times-sized model.

Dr. J.E. Bergström, Royal Institute of Technology, Stockholm, in a paper co-authored by Carl-Olaf Jonason, reported on the accuracy of a stereophotogrammetric method involving a stereomicroscope for quantifying gingival topography *in vivo*.

Dr. R.J. Forstrom, University of Minnesota, Minneapolis, USA, in a paper co-authored by F.F. Ahlgren, F.D. Dorman, R.J. Isaacson, T.M. Speidel, and A. Erdman, described a stereo movie system for stereometric measurement of human jaw motion.

Session IV was devoted to spatio-temporal-four-dimensional studies in biostereometrics. Dr. H.M. Kara, University of Illinois, USA, presided.

V.D. Brandow, University of Illinois, read the paper of Dr. M.I. Bullock, University of Queensland, St. Lucia, Australia, on the use of stereophotogrammetry in a comparative study of three-dimensional spinal and leg movements in foot pedal operations.

Dr. F.C. Lippert, University of Washington, Seattle, USA, in a paper co-authored by Drs. M. Hussain and S.A. Veress, evaluated two photogrammetric approaches, one semi-analytical, the other analytical, for three or four-dimensional measurement of musculoskeletal motions. Both medical and engineering aspects were considered.

Prof. J.R. Cuzzi, Baylor College of Medicine, Houston, presented a paper, co-authored by D.V. Goulet and R.E. Herron, describing how a set of stereometric body form and function parameters can be derived from a digital three-dimensional description of human body geometry.

Dr. R. Stowe, Argonne National Laboratories, Chicago, USA, in a paper co-authored by N.A. Frigerio and J.W. Howe, described the use of a stereometric x-ray system for measuring *in vivo* skeletal motions.

B.C. Trenholm, Shriners Hospital for Crippled Children, Winnepeg, Canada, in a paper co-authored by Dr. D.A. Winter and G.D. Reimer, presented the results of using a TV-computer approach to the solution of two spatio-temporal problems in clinical medicine, one relating to left ventricular geometry and the other to human gait kinematics.

Dr. R.E. Herron, Baylor College of Medicine, Houston, in a paper co-authored by Dr. Y.I. Abdel-Aziz, described the development of a simple stereometric sensor, the "contour-graph," for clinical measurement of stump-socket geometry for improving the fit of artificial limbs.

On September 12, the President of ISP's Commission V, Dr. H.M. Karara, and the Chairman of ASP's Close-Range Photogrammetry Committee, Mr. R.F. McGivern, hosted a luncheon at the International Club of Washington in honor of the symposium speakers. The luncheon was co-sponsored by the following companies: H. Dell Foster Company, Galileo Corporation of America, The Kelsh Instrument Division of Danko Arlington, Inc., Kern Instruments, Inc., and Zena Company. The generous contributions of these companies are gratefully acknowledged. We are also indebted to Mr. S. Jack Friedman, Executive Vice President, O.M.I. Corporation of America, who was instrumental in having the club's excellent staff and facilities put at our disposal for this memorable occasion.

Session V, with Professor Hans Greuel, University of Düsseldorf, Federal Republic of Germany, presiding, was devoted to stereometric x-rays. Prof. Greuel, in the opening paper, reviewed some of the theoretical and practical problems associated with stereometric x-ray analysis of the relationship between the child's skull and the mother's pelvic dimensions shortly before delivery. The localization of tumors was also discussed.

Dr. B. Altschuler, Brooks AFB, San Antonio, Texas, in a paper co-authored by R.M. Perry and Dr. M.D. Altschuler, reported on an improved mathematical technique (multiangular laminagraphy) for deriving axial sections, serial cross-sections, serial sagittal sections, and serial frontal sections of anatomical structures.

Prof. T. Oshima, Tokyo University, Japan, presented an overview of recent developments in biostereometrics in Japan, including a wide range of clinical, biological, and industrial applications.

E. Seeger, Stuttgart University, Federal Republic of Germany, in a paper co-authored by M. Arnu, described the Zeiss ST R 1-3 stereocomparator for stereometric x-ray analysis. The historical background of stereometric x-ray analysis was also briefly reviewed.

C-O Jonason, Royal Institue of Technology, Stockholm, in a paper co-authored by K.O. Frykholm and A. Frykholm described the application of a stereometric method for three-dimensional measurement of tooth impressions in criminological investigations.

Prof. J. Kobelin, Miami-Dade Community College, USA, outlined a course for the training of photogrammetric technicians in biostereometrics, architecture, transportation, and other fields.

An informal forum was held on the evening of September 12, with Dr. R.E. Herron presiding (Figure 1). This very informal happening consisted of brief presentations by those with equipment, films, and slide-tape shows to display, promote, or otherwise take advantage of a willingly captive audience. Spokesmen and exhibitors included those named in the composite photograph which accompanies this report and others who escaped the attentions of roving photographer John Hugg. As well as having an opportunity to sample brain-washing in all its international variety, the forum participants generally "let their hair down" and had a forthright, informative, and stimulating exchange, which lasted until the hotel staff demanded that the room be cleared so that they could set up the chairs for next morning's session.

Session VI, with K.B. Atkinson, University College London, presiding, was devoted to studies of body geometry/form.

J. Defer, National Geographical Institute, St. Mande, France, in a paper co-authored by F. Borel, described an analog photogrammetric method for determining human body surface geometry as an aid to radiation dose planning.

K.B. Atkinson, University College, London, read a paper submitted by A. Boyde, University College London, and H.F. Ross and W.R. Bucknall, Cartographic Engineering Ltd., Salisbury, England. Two new stereometric plotting instruments designed especially for use with scanning electron microscopic records were described.

Dr. S. Ghosh, The Ohio State University, Columbus, USA, outlined a new procedure for analytical calibration of the scanning electron microscope and reported the results of a sample test at three different magnifications.

Professor P.H. Burke, University of Sheffield, England, described the use of a modified dual-"Multiplex" stereometric camera in a study of normal and abnormal facial morphology and growth of children.

Dr. J.P. Duncan, University of British Columbia, in a paper co-authored by J. Foort and S.G. Mair, outlined a new approach to the physical modeling of human body parts based on an automatic process called "Polyhedral Machining." A silhouette technique, using optical or video recording, was also described.

Prof. Homorodi, Geodetic Institute, Budapest, Hungary, read a paper submitted by Drs. M. Domokos and B. Kismartoni, Technical University, Budapest, Hungary. The paper dealt with the use of a simple stereometric method of recording facial morphology, particularly ear form, in a health survey of mentally handicapped children.

Dr. V. Kratky, National Research Council, Ottawa, Canada, read a paper authored by Dr. G.W.D. Armstrong, Dr. T.J. Blachut, and M.C. van Wijk. The paper described an application of analytical photogrammetry to evaluate the performance of a transverse loading system in surgical correction of scoliosis.

Session VII, with Dr. R.E. Herron, Baylor College of Medicine presiding, included seven further papers on body geometry/form.

Prof. J. Anderson, Kings College, London, in a paper co-authored by A. Short, M. Mutch, and R.D. Grover, described the development and use of a new approach to stereometric measurement of body form based on a pulse-modulated ultra-sonic camera which houses the transmitter, receiver, and associated circuitry.

Dr. M.J. Whittle, NASA, Houston, in a paper co-authored by Dr. R.E. Herron, J.R. Cuzzi, and J.E. Hugg, described recent uses of the Baylor Biostereometric System to monitor the effects of extended space flight on the body forms of Skylab astronauts.

Dr. H. Takasaki, Shizuoka University, Japan, described his work in moire interferometry as related to biostereometric studies. Theoretical and practical aspects of the method were reviewed.

Dr. J. der Hovanesian, Oakland University, Rochester, Michigan, in a paper co-authored by M. Tafralian described the use of moiré interferometry in corneal, podiatric, biomechanical and other human morphological studies.

R.V. Free, Birmingham, Alabama, outlined further uses of a moiré interferometric method in biostereometrics, with special reference to studies of external spinal geometry.

Dr. R.E. Herron, Baylor College of Medicine, Houston, presented an epilogue which focused on helping the beginner to understand the proceedings of the Biostereometrics 74 Symposium and thanking the speakers, exhibitors, and attendees.

Dr. H.M. Karara, in a brief closing session, thanked everyone for their fine support. The first International Symposium on Biostereometrics was then adjourned.

It is difficult to summarize in a few lines the overall impact of a meeting which ranged so widely as this one. The expressed goal of the symposium was to stimulate improved communications among those already interested in biostereometrics such as researchers, clinicians, designers, instrument manufacturers, and others. In addition, it was hoped that newcomers to biostereometrics would find the presentations and proceedings useful as an introduction to the "state-of-the-art."

Many participants formally and informally expressed satisfaction that the symposium had indeed provided a valuable and altogether too rare opportunity to make friends and discuss mutual interests with far-flung colleagues. Hopefully, many of these contacts will be sustained through the medium of correspondence and exchange of reprints until the next symposium comes around.

The scope and variety of the presentations must have been somewhat overwhelming for newcomers and even for some of the more experienced participants. Yet, the fact that the symposium did not represent a very coherent whole is not surprising, considering that we are dealing with a new field (although the roots of stereometric analysis go back at least five centuries). New sciences develop in which theory and technology intersect and, in this instance, new understandings about the mathematical analysis of organic form are "intersecting" with advances in photo-optics, electronics, and other modern technologies. The fusion of hardware, software, and theoretical insights from what have traditionally been rather disparate disciplines will take time, but the future course seems almost assured (perhaps inevitable).

More specifically, the symposium demonstrated that:

(1) The mathematical strategy of biostereometrics is sound, but the methods must be further refined to make solutions more efficient and cost-effective.

(2) There is no universal "best" method of stereometric sensing. The range of potential applications is so broad and the measurement conditions are so varied that we can expect to see many different techniques and instrumentation systems play important roles in the future.

(3) More objective evaluation of the various approaches to stereometric sensing is needed.

(4) Research which is aimed at better understanding and definition of a problem must be clearly distinguished from the development of clinical tools (aimed at improving hardware or software design). It is generally inappropriate to evaluate one type of study by the standards one would apply to the other.

(5) Communications between exponents of biostereometrics, photogrammetric engineers, physical scientists and manufacturers must be greatly improved. There is still too much "reinventing of the wheel." Instrument manufacturers could benefit from using a wider knowledge base than in-house and local experts can provide.

(6) Most of us yield too often to an unfortunate ethno-centricity in attributing the sources of relevant literature and ideas, which belies the potential of modern information retrieval systems such as are available in libraries around the world. American writers tend to quote other Americans, the British other British, the Canadians other Canadians, the French other French, the Germans other Germans, Swedes other Swedes, and so on. In the biomedical sciences there should be no national knowledge boundaries.

This writer will continue to do everything possible to remove such boundaries (inadvertent or otherwise). By the time of the Helsinki meeting, I hope to complete a supplement to the bibliography on biostereometrics compiled for the 1972 ISP meeting in Ottawa. Anyone interested can obtain a copy of the supplement after the Helsinki meeting by writing to the Biostereometrics Laboratory, Baylor College of Medicine, 1333 Moursund Avenue, Houston, Texas 77025, USA. Contributions of reprints and other pertinent information would be greatly appreciated and included in future supplements.

Before concluding this report, I want to express my personal thanks to Dr. H.M. Karara, for his indefatigable and always timely contributions as symposium coordinator; Dr. K. Wong, U.S. correspondent for ISP Commission V, for yeoman service on the program committee; to V.D. Brandow and J.B. Ihenacho, both from the University of Illinois, for supervising the registration procedures and helping the participants in myriad ways with consistent good humor, and to Jaime R. Cuzzi, John E. Hugg, Sherry Gilleland, Marjorie Gordon, and other staff members of the Biostereometrics Laboratory, Baylor College of Medicine, for assistance too wide-ranging to recount in detail here.

I have not been able to do justice to all the planners, speakers, exhibitors, program assistants, and other participants whose contributions made the symposium what it was. One experienced observer commented that "It was as perfect a symposium as I have ever experienced." This remark reflects the unusual spirit of cooperation and enthusiasm which prevailed among those involved at all stages of the undertaking. It also might help to explain why the program chairman and the planning committee regard their association with this stimulating event as a rare privilege.

IV. Training of Technician, Technology Inc., in Biostereometric Principles and Techniques.

Between mid October and the end of the report period Mr. Cris Keys from Technology Inc. was given insturction in the areas indicated below. The total time devoted to this effort was 118 man hours. Time spent by Mr. Keys using the facilities of the Biostereometrics Laboratory under direct and indirect supervision was 115 hours.

		Hours
A.	General Principles of Biostereometrics.	6
B.	Photography. 1. Setting up equipment. 2. Picture taking. 3. Handling & process plates. 4. Printing	42
C.	Plotting. 1. Principles involved. 2. Preparation of plotter. 3. Use of digitizer and keypunch. 4. Plotting front and neck of whole body. 5. Sorting and arranging punched IBM cards.	42
D.	Computer Analysis. 1. Matrix algebra. 2. Curve fitting principles.	20
E.	Consultation. 1. Design ideas for spacelab biostereometric equipment. 2. Stereometric techniques for analysis of underwater subjects.	8

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