*Stereophotogrammetry as an Anthropometric Tool**

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ABSTRACT: *This paper briefly reviews previous biological applications of stereophotogrammetry, and outlines with illustrations the present procedures used to draw human body contours at 1/2-inch intervals. It compares the dimensions derived from plotted profiles with those taken by hand on the subjects themselves. It discusses the utility of stereo data for special anthropometric purposes, and mentions further applications for other biological sciences.*

FOR centuries men have measured and drawn maps of the earth they live on, but only recently have they begun to seek precise delineation of their own bodies. This paper describes a method of accurately mapping the dimensions and curvatures of the body, and of establishing where and how much the surface of the body protrudes from a known plane of reference.

This work supports the Air Force effort to design form-fitting, protective garments that insure pilot survival at high altitudes. To design a protective garment that fits snugly to a man's skin, one must know the form of that skin. While conventional anthropometry is useful for the sizing of cockpits, personal equipment, loose clothing and the like, it is not efficient for sizing skin-fitting garments. For this special purpose, one is forced to use the techniques of stereophotogrammetry similar to those employed in the mapping of land-forms by aerial photography.

The basic principle of stereophotogrammetry is exactly that of binocular vision. The two eyes send slightly different images of an object to the brain, where they are interpreted in terms of depth as well as of length and breadth. Similarly, if two binocular or stereophotographs of an object are juxtaposed so that the left eye sees the left photograph and the right eye sees the right photograph in proper relation, the perception of depth can be as clear as if the object were seen directly. By suitable optical devices, stereophotographs of nearly any size can be made to give the effect of relief.

These stereoscopic facts have long been known and applied in cartography. Their usefulness in the medical and dental fields was pointed out in the early 1920's by Mannsbach and others. Zeller (1939) published actual contours of a man's face; Thalmann-Degen (1944) used contours to indicate the degree of swelling of a jaw; Lacmann (1950), apparently to emphasize the universal utility of stereo, presented contours not only of a man's face but also of the rear end of a cow; Berner (1954) made calculations of the surface area of a human body by stereophotogrammetry; Leydolph (1954) published contours of cows and sheep taken years previously, and discussed the uses of stereo in animal husbandry; and Björn, Lundquist and Hjelmström (1954) assessed the progress of facial swellings for dental purposes. After we had written our own paper, we learned that Miskin (1956) had applied stereo techniques to the study of new-born infants, including body volumes and surface areas, as well as the assessment of body builds and local deformations. The use of stereo-contouring methods in sculpture has been reported by Saralegui (1954) and Englemann (1956).

All these studies were made with stereo camera equipment manufactured especially for such applications. We have used only standard Air Force cameras modified for our purposes, and so far as we know, our subjects are the first to have been fully and accurately contoured over virtually their entire bodies.[1]

[1] This point is not easily determined because many articles are in European journals which are difficult to obtain (continued on next page)

* Presented at meeting of Ohio Region of the Society at Columbus, Ohio, October 11, 1947.

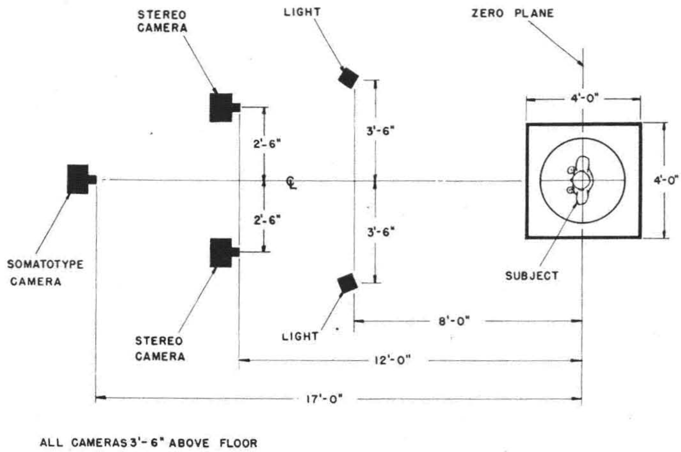

FIG. 1. Geometry of Experimental Stereo Equipment.

The equipment for our experiments follows conventional photogrammetric practice by maintaining a carefully-aligned solid geometry based on fundamental stereoscopic principles.[2] A vertical plane is established by means of an aluminum arm affixed at right angles to a wall about seven feet above the floor. This datum plane is marked by 3×5-inch cards correctly positioned within five one-hundreths of an inch. In this plane is the center-line of the turn-table on which the subject stands. Two K-17 aerial cameras, using $9\frac{1}{2}$-inch by $9\frac{1}{2}$-inch film, are mounted $3\frac{1}{2}$ feet above the floor, five feet apart and twelve feet from the datum plane, their optical axes parallel. The camera shutters have been modified for synchronization with electronic flash lamps and their 90 degree metrogon lenses have been focussed on the datum plane.[3] For certain technical reasons a standard 4×5 view camera also is mounted 17 feet from the zero plane, shooting between the two K-17's. The over-all geometry is shown in Figure 1. The K-17 is shown in Figure 2.

Before deciding to standardize our work on the geometry and positioning of the cameras just described, two other alignments of the equipment were tried out in the initial stages of the research. In one of these orientations the cameras were placed five feet apart with their optical axes perpendicular to the datum plane, with each lens six feet from the datum plane. In the other alignment the cameras were also five feet apart, but were pointed directly at the subject standing in the center of rotation of the turntable and six feet from him. This orientation gave an angle of 40 degrees between camera axes. Both of these geometries were soon abandoned, however, as at this short shooting distance neither camera could pick up satisfactorily the control points on both sides of the turntable, thereby making it virtually impossible to achieve absolute orientation on the Kelsh Plotter. Furthermore, because of the large ratio of the object height (thickness of the subject's body) to the object distance, it was found that the vertical movement required of the floating dot far exceeded that provided by the standard Kelsh tracing table.

During the photographic procedure the subject stands on the turntable facing the cameras so that his lateral vertical plane lies as nearly as possible in the datum plane of the system. We have found that for our purposes his legs must be somewhat spread and his arms outstretched. To prevent movement during photography, the

in the United States. Actually much of our bibliography came in on inter-librarial loan after we had developed our techniques.

[2] We are indebted to Capt. L. E. Ross, formerly of WADC, now of Rome Air Development Center, who kindly worked out several geometries for us to try. The one described is the one we found most effective for our purposes.

[3] We are grateful for the skill and ingenuity of all personnel at Technical Photo Division, WADC, who processed our film and advised on photographic matters. Especial thanks are due to Mr. James E. Taylor and Mr. K. J. Jones of the Photo Instrumentation Branch, and their assistants, Mr. Elmer Fisher and A/2C Harold E. Geltmacher, who modified our cameras and made them work.

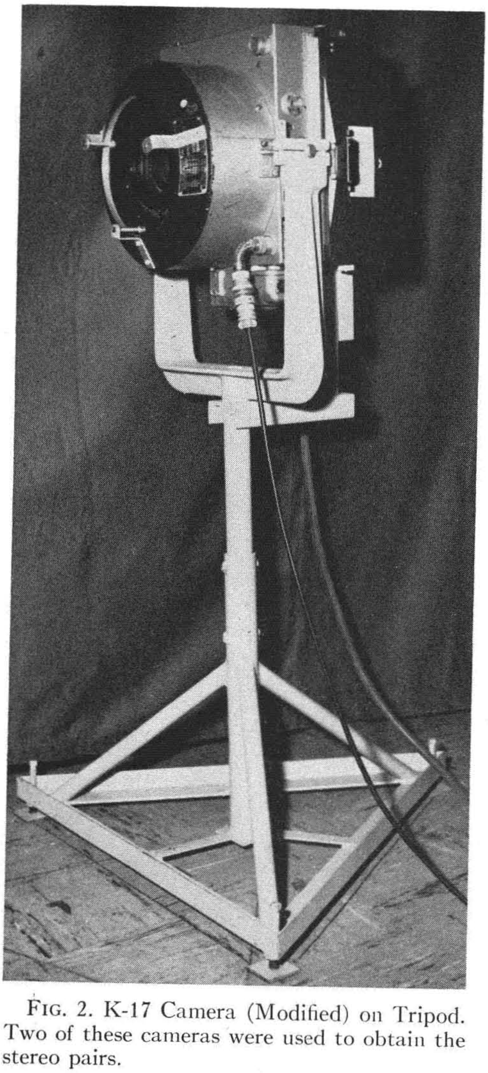

FIG. 2. K-17 Camera (Modified) on Tripod. Two of these cameras were used to obtain the stereo pairs.

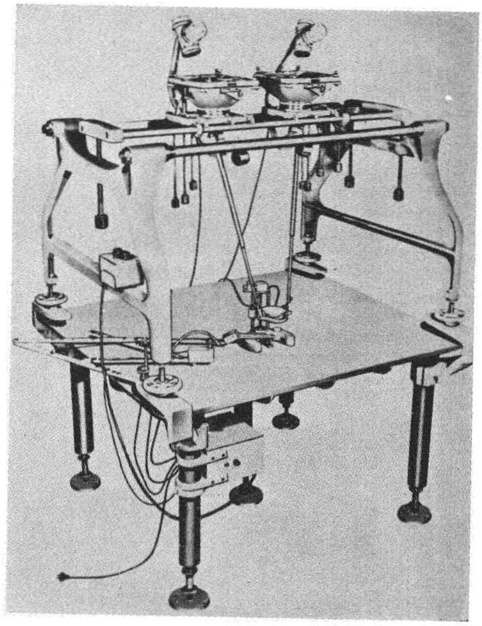

FIG. 3. The Kelsh Type Stereoscopic Plotter. Model 5010.

subject rests his arms on two arm supports on the turntable. Before photography the subject must be suitably marked. These marks are of two kinds: (1) marks for body measurement, to permit comparison of direct anthropometric data with the data derived from the photographs; and (2) stippling. The measurement marks are usually crosses ringed by a circle, located at certain points on the body. The stippling is necessary because the eye cannot easily discern depth when there is no contrast from one area to another.[4]

If unlimited space and equipment had been available it would have been ideal to arrange a ring of cameras and of light sources around the subject to photograph him in rapid sequence, thereby virtually eliminating his movement. We did not have ideal conditions, so were forced to the following technique. When properly posed the subject was photographed simultaneously by all three cameras and then was rotated 90 degrees and photographed again. This was repeated each 90 degrees. He made every effort not to move between photographs, as this would have introduced error by varying his protrusion from the zero plane.

When the negatives were developed, diapositives were prepared for use in the Kelsh plotter[5] (Figure 3). By means of this machine, contour maps of the human body were drawn for front, back, and side elevations.[5,6] After much experimentation it was

[4] We are indebted to Mr. L. J. Kosofsky, formerly of Wright-Patterson Air Force Base, for the suggestion to employ stippling. It has solved the problem perfectly. Mr. Kosofsky also calibrated the lenses for the 12-foot focus.

[5] We thank the U. S. Army Research and Development Laboratory, Corps of Engineers, for kindly making their Kelsh Plotter available.

Mr. E. D. Sewell, Chief, Aerial Photographic Branch, and Mr. C. E. Berndsen, Pantographic Consultant, were most helpful in teaching us the principles and practice of contour plotting. Mr. Robert Shearer, formerly of WADC, now of Rome Air Development Center, also assisted greatly to teach us the techniques of handling the Kelsh Plotter.

[6] All the contour maps shown in this report were produced by C. W. Dupertuis.

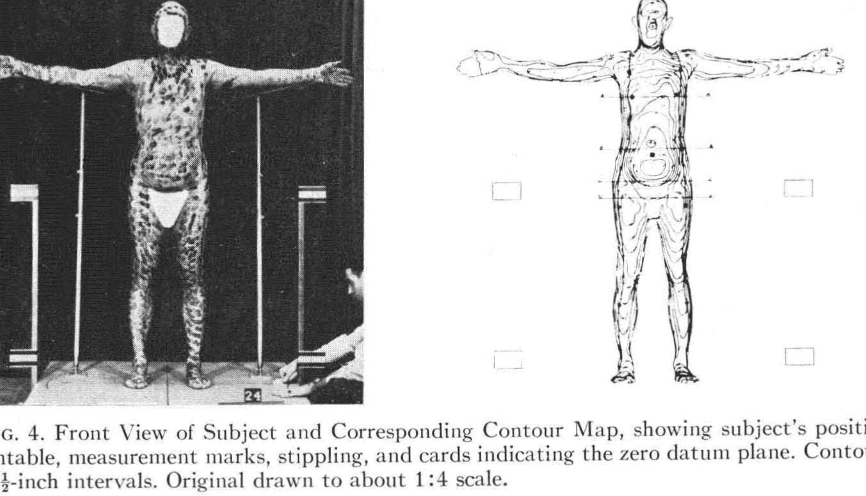

FIG. 4. Front View of Subject and Corresponding Contour Map, showing subject's position on turntable, measurement marks, stippling, and cards indicating the zero datum plane. Contours are at ½-inch intervals. Original drawn to about 1:4 scale.

found that a scale of 1:4 and contour intervals of one-half inch were suitable for our purposes.

Once the contour maps are drawn it is possible to plot profiles or cross sections between any two known points on the map, as is done daily in geological science. One of our immediate purposes, of course, is the extraction of body dimensions; our long-range purpose is a more precise description of body types in statistical terms. Figure 4 shows the subject's position on the turntable, the marks and stippling, and the front and back views contoured at one-half inch intervals. The several 3×5 cards visible on both sides of the subject and over his head indicate the zero reference plane. The circled crosses on the subject's skin are the points used for measurement; the lines from the shoulders to the feet delineate four experimental surfaces—front, each side and back.[7] These lines need not be precisely drawn, as they would vary with each person.

Although the contour maps constitute the basic data of this study, by themselves

[7] We are indebted to A/2C James T. Barter, formerly of the Anthropology Section, for this suggestion. Airman Barter also assisted in the design of the turntable.

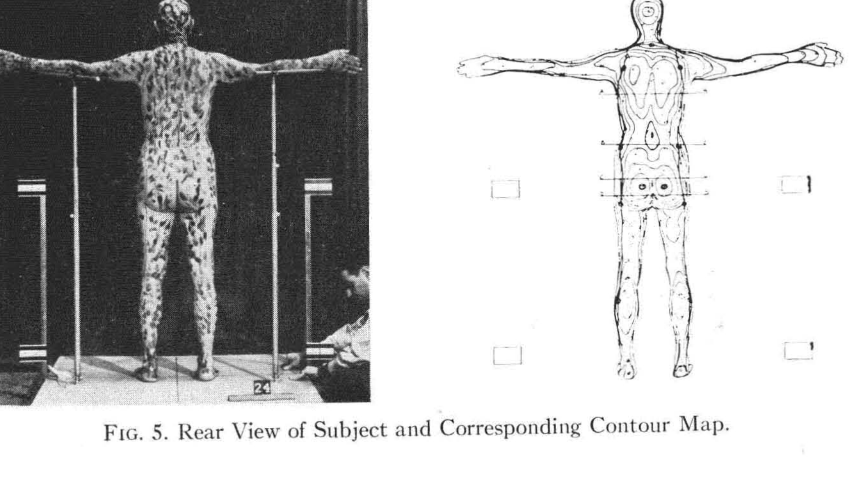

FIG. 5. Rear View of Subject and Corresponding Contour Map.

TABLE I

COMPARISON OF ANTHROPOMETRIC AND PHOTOGRAMMETRIC MEASUREMENTS

Dimension	From Actual Body	From Contour Map
Upper Chest Arc	9.65 Inches	9.58 Inches
Intra-Nipple Arc	8.30 Inches	8.24 Inches
Lower Abdomen Arc	12.50 Inches	12.40 Inches
Upper Shoulder Arc	10.50 Inches	10.35 Inches
Trunk-Shoulder Arc	39.50 Inches	39.51 Inches
Circumference at Nipples	37.7 Inches	37.3 Inches
Circumference at Waist	37.7 Inches	37.2 Inches
Suprasternale Height	57.1 Inches	57.0 Inches

they are not enough. The next step is the plotting of profiles. These can be surface arcs, as between the nipples, or complete circumferences at any elevation. To plot them one must first establish a line between two known points on the contour map, then measure the distances from one contour to the next as they intersect that line. After each distance is brought to full size by applying the known scale of the contour map, it is plotted on cross section paper with due regard for the difference in elevation between contours. Figure 5 shows four circumferential profiles plotted isometrically for the planes A, B, C and D, that are shown as horizontal lines on the contour maps. These planes, however, need not always be horizontal. They may be drawn in any direction across the contours, permitting the plotting of the surface trace along that plane.

A comparison of certain anthropometric measurements taken on the subject and photogrammetric measurements derived from the contour maps are presented in Table I.

It can be seen from Table I that there is very little disagreement between the two only three being over 1/10 of an inch and amounting generally to less than one per cent of difference between dimensions. Even the largest, Circumference at Waist, amounts to only 1.25 per cent.

In our opinion, stereoanthropometry is much more precise than hand anthropometry, and the question is no longer, how accurate is the system, but how accurate is the man! For this surface changes every time he moves, by breathing or otherwise, and it becomes very difficult to replace him-and to remeasure him!—exactly in the same position. It appears probable that the major discrepancies in Table I are due to postural changes by the subject.

Having described an exacting and somewhat expensive system, we think it is only fair to assess its benefits in terms of what can be done by conventional anthropometry. Table II compares the capabilities of the two systems in providing ten categories of data.

From Table II it can be seen that conventional anthropometry can give body

TABLE II

COMPARISON OF SYSTEM VALUES

Values	Anthropometry	Stereophotogrammetry
1. Diameters	Yes	Yes
2. Surface Arcs	Yes	Yes
3. Circumferences	Yes	Yes
4. Circumference Shapes	No	Yes
5. Body Proportions	No	Yes
6. Body Surface Area	No	Yes
7. Body Volume	No	Yes
8. Record of the White Man	No	Yes
9. Expense	No	Yes
10. Simplicity	Yes	No

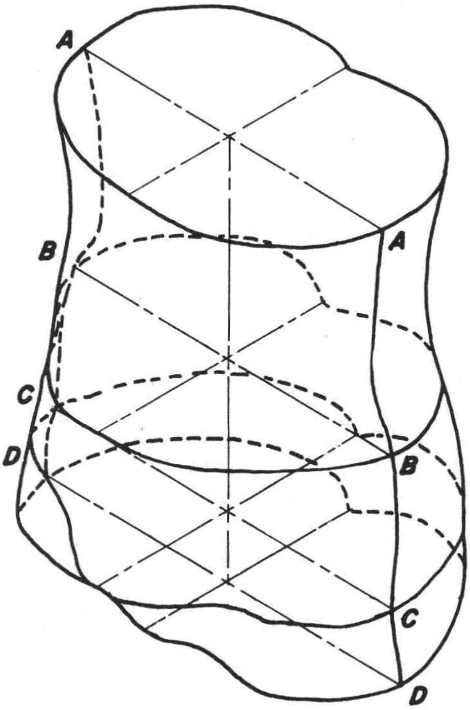

FIG. 6. Isometric Plot of Profiles at 4 Levels on the Torso.

diameters and surface dimensions which are adequate for the sizing of loosely-fitting clothing and of work places. Stereophotogrammetry, on the other hand, is capable of providing not only these data, but also body proportions and the form of the surface. In short, stereophotogrammetry is so far the only means of providing simultaneously the record, the dimension, and the form of all the features of the body. Furthermore, from subsequent work we have found that the measurements of total body volume and the volumes of individual body segments very closely approximate those calculated by the Dubois formula (Dubois and Dubois, 1916). In addition, we have been able recently to determine the surface area of various body parts with a high degree of accuracy.

We believe that through use of the stereophotogrammetric method we eventually will be able to give close approximations to the total body surface area. Certainly the method should find increasing application for the medical and dental purposes to which other workers have already put it; and it should become very useful among biological sciences for the measurement of growth and age changes of any animal, including man. It also shares the exceedingly valuable feature possessed in common by all photographic methods, namely, that a large sample can be stored in a small space to be restudied for new dimensions or purposes at any time.

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