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A HEAD CIRCUMFERENCE SIZING SYSTEM FOR HELMET DESIGN

Including Three-Dimensional Presentations of Anthropometric Data

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SECTION I

INTRODUCTION

The importance of a properly fitted rigid or semirigid helmet to protect flying personnel cannot be overly stressed. The high incidence of head injuries and the resultant fatalities in aircraft accidents have been referred to repeatedly in the literature (refs. 7, 17, 23). Measures to decrease this rate have led to improved devices for body restraint which aid in limiting head movement during impact. In spite of these efforts, modern jet-propelled aircraft increased the possibility of high-impact accidents with the concomitant probability of serious head injuries. The problems related to head injuries and the requirements for developing an adequate protective helmet were well summarized in a recent paper by J. S. P. Rawlins (ref. 21). He noted that some 40 percent of the injuries resulting from aircraft accidents are cranio-facial and "in the absence of head protection some 25 percent of fatalities can be attributed to head injury."

Proper sizing and design are of primary concern in developing a protective helmet, since the mere presence of a shell does not insure protection (ref. 21). A number of anthropometric sizing approaches already have been tried by the Air Force. This report presents the development and testing of several new approaches of presenting anthropometric data in three-dimensional forms for use in the design and sizing of helmets. For a comprehensive statement of overall objectives and concepts of sizing problems, the reader is referred to a recent paper (ref. 2).

The demand for new methods arose when earlier anthropometric sizing systems proved to be inadequate for existing helmet sizing and design problems. One such system, used during World War II, originally was developed only to check the sizes of the soft leather helmets in distribution at that time. Furthermore, the anthropometric statistics, which served as the basis for quality control gauges, were for an Air Force flying population which differs anthropometrically from the present one. A second system, developed in 1954, involved a rather complex arrangement, difficult to use in the field and designed primarily for the sizing of foam rubber and foam plastic liners and shells to fit over them.

It will be useful at this point to clarify certain concepts which will be referred to frequently in the remainder of the report. A sizing system will mean an approach in which key dimensions are selected as the basis for statistical analysis. Thus, there is the Height-Weight Sizing System for flight clothing, or as in the present instance, the Head Circumference Sizing System for helmet design. For a particular sizing system, sizing programs are established by dividing the range of key dimensions into appropriate intervals and obtaining the relevant statistical data for the men within each size subsample. In the present study, sizing programs (two six-size ones and a three-size one) were developed. For example, men with head circumference between 21.00 and 21.50 inches constitute one of the several size subsamples for a six-size program. The reader should be aware that there are two "levels" of sizing programs, - a general one in which consideration is made only of the intervals into which the key dimensions are divided, and specific ones which together with these size intervals consider the design ranges or values for all other required dimensions within each of the size subsamples. Lastly, based on the chosen sizing program, a series of items are fabricated to the dimensions of the various size subsamples. A series, therefore, may be considered as the concrete representation of a particular program. Following this reasoning, the

Six-Size Mean Headform Series is the concrete representation of the Six-Size Mean Head Circumference Program.

Developing a statistical method for more objective sizing of headgear is only one portion of the job of providing a comfortable, protective helmet. The end item must be a precise blend of sizing, materials, and design. No one combination works perfectly for all types of headgear. The function of the helmet, whether it is for ground wear, low-altitude buffeting protection, or high-altitude pressurization, dictates the sizing program, the types of materials to be used, and the methods of integrating the two. The end result, ideally, is a lightweight, nonbulky item in few sizes for procurement purposes, which offers sufficient crash protection and minimum discomfort and, at the same time, is based on a sizing system sufficiently uncomplicated that it can and will be used in the field by fitting personnel not trained in anthropometry. Neglect of this sizing-materials-design concept has and will continue to result in nonfunctional items (ref. 1).

To date, a statistical-anthropometric approach has been successful in adequately sizing many critical items of personal flying protective equipment, including pressure suits (ref. 10), oxygen masks (ref. 9), pressure gloves (ref. 3) and anti-g suits (ref. 8). In addition, it appears reasonably certain that such items as anti-exposure suits and flying coveralls can be sized adequately from existing data analysis. We hope that the most important remaining sizing problem, that relating to helmets, can largely be resolved by means of a sizing system based on the single dimension head circumference.

Unless otherwise indicated, the observations, recommendations, and data covered in this report are based on a reanalysis of the body size data of the 1950 Anthropometric Survey of Air Force Flying Personnel (ref. 12).

SECTION II

HISTORICAL DEVELOPMENT

General

Anthropometry, as is the case with any vital science, is a growing discipline, in which new and more sophisticated approaches are sought to handle old problems. The extreme complexity and variability of the head and face exaggerates the inherent limitations of any linear dimensions. In addition, there are the ever-changing requirements dictated by Air Force needs and by the limitations imposed by other scientific disciplines, such as physiology. To meet this nonstatic situation, we have always considered headforms as the most direct means of furnishing anthropometric data to helmet designers and manufucturers. The following brief survey of the development of headforms by the Air Force clearly demonstrates that helmet sizing is a complex matter which may require new insights as unique situations are encountered.

1942 Face Length System

The development of an adequately sized oxygen mask was the most pressing craniofacial personal equipment problem during the early days of World War II. The soft leather helmets in use then, while in no better state relative to sizing, did not present the comfort and physiological hazards inherent in improperly fitted oxygen masks. In attacking this problem, a facial dimension, face length (menton-nasal root depression), served as the key dimension of a sizing system developed in 1942. (See Appendix III for descriptions of all dimensions mentioned in this report.) A seven-size program was set up and a headform series sculptured to the 50 dimensions considered in the analysis of the data (ref. 19). The 1942 System used data obtained in a facial survey of 1454 Army Air Force Aviation Cadets plus 417 additional subjects (ref. 18). Desiring a maximum of 3 sizes of oxygen masks, face length was divided into 3 appropriate intervals. Various combinations of face length were used with the 49 additional dimensions sculptured into the seven headforms constructed as follows (fig. 1):

"Type I - Grand mean of all measurements derived from 1871 individuals.

Type II - Mean Nasion-Menton (123 mm.) combined with minimum values obtained on faces having Nasion-Menton of 122, 123, and 124 mm. 1453 individuals.

Type III - Mean Nasion-Menton (123 nm.) combined with maximum values obtained on faces having Nasion-Menton of 122, 123, and 124 mm. 1453 individuals.

Type IV - Average values of faces falling in lower 15 mm. of total range of Nasion-Menton dimensions.

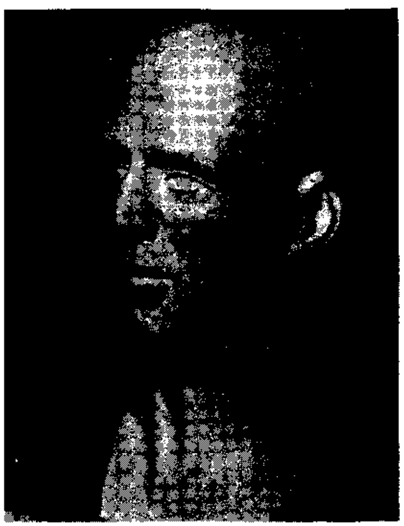
Type V - Average values of faces falling in upper 16 mm. of total range of Nasion-Menton dimensions.

A.M.R.L. TYPE I

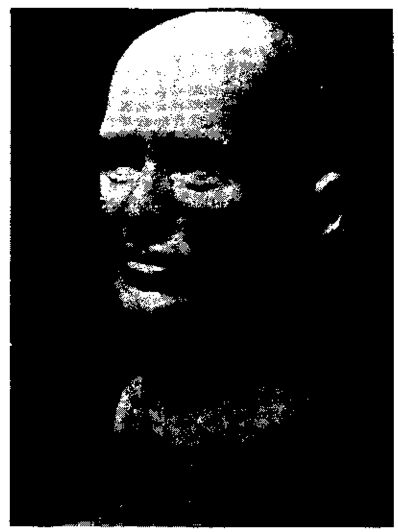
A.M.R.L. TYPE II

A.M.R.L. TYPE III

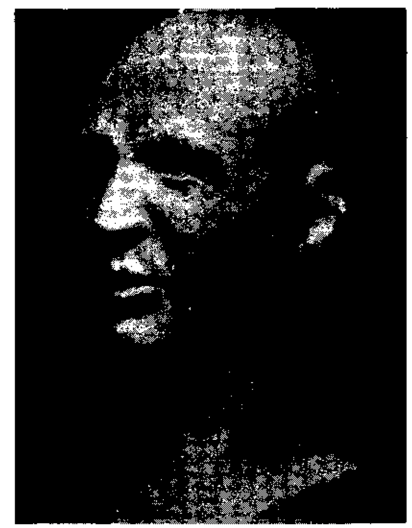
A.M.R.L. TYPE IV



A.M.R.L. TYPE V



A.M.R.L. TYPE VI



A.M.R.L. TYPE VII

Figure 1. 1942 Face Length Headform Series

Type VI - Average values of 16 faces falling in 102-108 mm. Nasion-Menton lengths. Approximately shortest 1 percent of population.

Type VII - Average values of 16 faces falling in 138-145 mm. Nasion-Menton lengths. Approximately longest 1 percent of population." (ref. 19)

Five faceform types (I, IV, V, VI, and VII) were described, in addition to two variations for persons having identical face lengths (II and III). Three of these headforms constituted the series used for sizing of oxygen masks.

When considering the potential value of the 1942 System for helmet design, thought must be given to the extreme variability of faces and heads and the resultant low correlations among linear dimensions on the head and face (ref. 5). Since face length is probably the most critical single dimension for oxygen masks, using this as the key dimension should have provided adequate sizing data for these articles. Face length, however, is not a particularly crucial dimension for helmet design. In addition, there are statistical reasons why the same headforms with faces are not applicable to helmet problems. Nevertheless, since the 1942 series was the only one available until 1944, it was of necessity used in the sizing of the steel, flak helmets developed during World War II.*

1944 Head Circumference System

Prior to World War II, the sizing and quality control of the soft leather helmets then in use remained largely a matter for separate resolution by the various interested manufacturers. The absence of fixed standards resulted in both inadequate sizing and procurement. The need for an objective sizing system was recognized during the early days of World War II. Initially, it was necessary to determine the range of head sizes of Army Air Force flying personnel and the distribution of sizes in the various groups; and secondly, it was essential to adjust helmet sizes to cover the range of head sizes and to control this adjustment in manufacture so as to insure proper fit (ref. 20). This was the first attempt by the Army Air Forces to objectively develop standard headgear. Using the cadet anthropometric series as the sample population and head circumference as the key dimension of the sizing system, a 4-size program was established: small, medium, large, and extra-large. Designs were drawn to the analyzed data, helmets were fabricated and were service tested for sizing adequacy. Once this was accomplished, sizing standards were required to facilitate inspection by check measurements and to provide references for future work in headgear sizing. With this in mind, four headforms were sculptured in 1944 to the Four Size Head Circumference Program (fig. 2). These headforms, used as quality control gauges, were fabricated to the mean values of 18 dimensions including a number of facial ones (ref. 16). The design criteria introduced into these headforms have been useful in the development of a sizing system for a new version of the M-1 Army helmet (ref. 6).

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*Verbal communication on 19 Aug 1959 from Dr. A. Damon, member of the Anthropometry Section during World War II. It is interesting to note that the New York City Metropolitan Museum of Art provided the skill and experience of its Curator of Arms and Armor and the facilities of its Armorers Workshop for the development of the flak helmets (ref. 11).

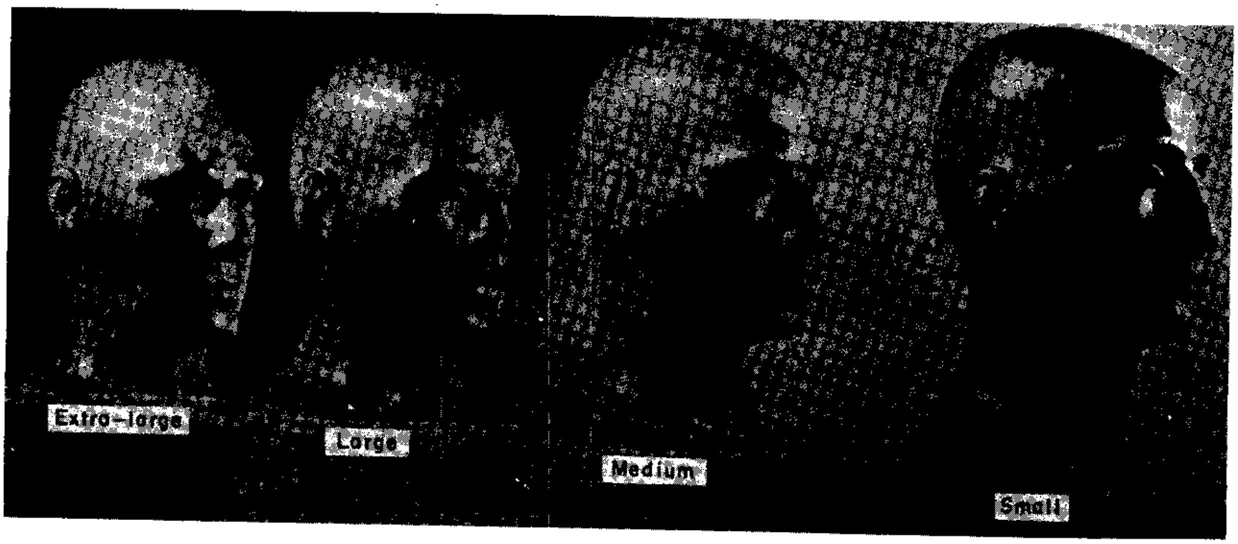

Figure 2. 1944 Head Circumference Headform Series

1954 Head Length-Head Breadth System

The 1944 Head Circumference Headform Series proved to be highly acceptable as quality gauges for the soft leather flying helmets. When rigid crash helmets became a necessity with the advent of high-speed aircraft, helmet designers resorted to the 1944 series as a guide for helmet sizing in the absence of any other approach. The degree of success in sizing helmets over these headforms was proportional to the amount of adjustability provided. Although from a sizing standpoint, the low altitude, hard-shell crash helmets designed over the 1944 headforms functioned adequately to some extent, many problems could not be satisfactorily resolved by means of these headforms.

Subsequently, the need arose for a helmet which would protect the flyer from "buffeting" and other impact injury, and which would provide oxygen and pressurization at extreme altitudes. The 1944 Headform Series was inadequate for at least two reasons: (1) it was based on measurements made on an Air Force population known to be significantly different from that measured in 1950; and (2) the problem related to rigid, nonclose fitting shells, requiring a joint consideration of the head and face, a matter not of prime concern in the 1944 Series. When pressure helmet development became crucial in 1954, a new sizing system was required.* Unlike the soft leather helmets, or rigid ones with sling-type suspensions (P-type helmets), it was not believed at the time that any appreciable adjustability could be incorporated into the proposed helmet design configuration of a close-fitting, plastic-foam liner which fit into a rigid shell. The requirement for a close-fitting liner was dictated by the physiological need to limit dead air space and to provide a comfortable support which could be worn for extended periods of time. The liners were to be manufactured of polyurethane having a high hysteresis, that is, slow rate of return from deformation. This is important from a comfort and protection standpoint. In evaluating the possible approaches to sizing such a support, the use of head breadth and head length as the key dimensions was considered together with the cephalic index or percentage relation between the former and latter dimensions. The 1950 survey data were re-analyzed in these terms. The end result was the 1954 Head Length, Head Breadth Shell-Liner Program.

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*This is reported in an unpublished manuscript prepared by F. P. Saul and B. Truett entitled "An Anthropometric Statistical Sizing System for Rigid Shell Helmets."

This analysis theoretically dictated 18 liner sizes on the basis of 6 head length intervals each combined with 3 cephalic index groups. The former had increments of 1/4 inch, while the latter were segregated into narrow, intermediate, and round head types. There was also a 1/4-inch increment between cephalic-index groups. The 2 extreme sizes were discarded immediately since few persons in the survey were included in these, and 16 liner sizes resulted. In an effort to minimize procurement problems, 6 shell sizes were established. These consisted of 3 shell sizes (small, medium, and large) each with a "short" and "long" faced version. Each shell was designed to cover 6 liners (5 each in the smallest and largest groupings). This approach was directed at minimizing the bulk of any one helmet, while maximizing comfort. At the same time, dead-air space would be restricted.

The statistical rationale for the various dimensions included in this sizing program was based on a number of special considerations. Since the liner was to be constructed of a temporarily deformable material, a modified "clearance" was desired. For this purpose, the mean plus one S.D. (standard deviation) was chosen for all dimensions except those concerned with head height. (Statistical terminology and concepts are discussed in Section III and in Appendix II). For head height, the mean plus two S.D. was used except when a dimension involved a horizontal dimension as well as head height in which case the mean plus one and one-half S.D. was included. For shell dimensions, the upper values of head length and breadth were selected with the mean plus two S.D. for each of the other dimensions except for those associated with face length. For face length, the mean plus two S. D. was used for the long faced shells and an appropriately smaller ratio for the short faced ones. It appeared feasible to eliminate the small faced shells and have three shell sizes if adjustable face pads could be provided. Forty-one dimensions were used in sculpturing the liner and shell headform series. For shells, complete faces were included for clearance (fig. 3), while the nose and mouth were omitted from the liners (fig. 4). Because of the poor correlation among head and face dimensions, certain of these were sculpturally incompatible, and the project engineer had to decide which dimension would be adhered to. This was not a unique situation, but has been true for all headforms sculptured.

A major drawback of the 1954 System was its complexity. Furthermore, due to the shortness of time, it was impossible to modify the resultant headforms as is done during a standard development program. In addition, certain modifications made in the final helmets designed over these headforms adversely affected sizing. These factors caused a somewhat bulky series of helmets which were not comfortable.

In addition these headforms were inadequate for use in designing other types of helmets, because they were developed for a limited application only.

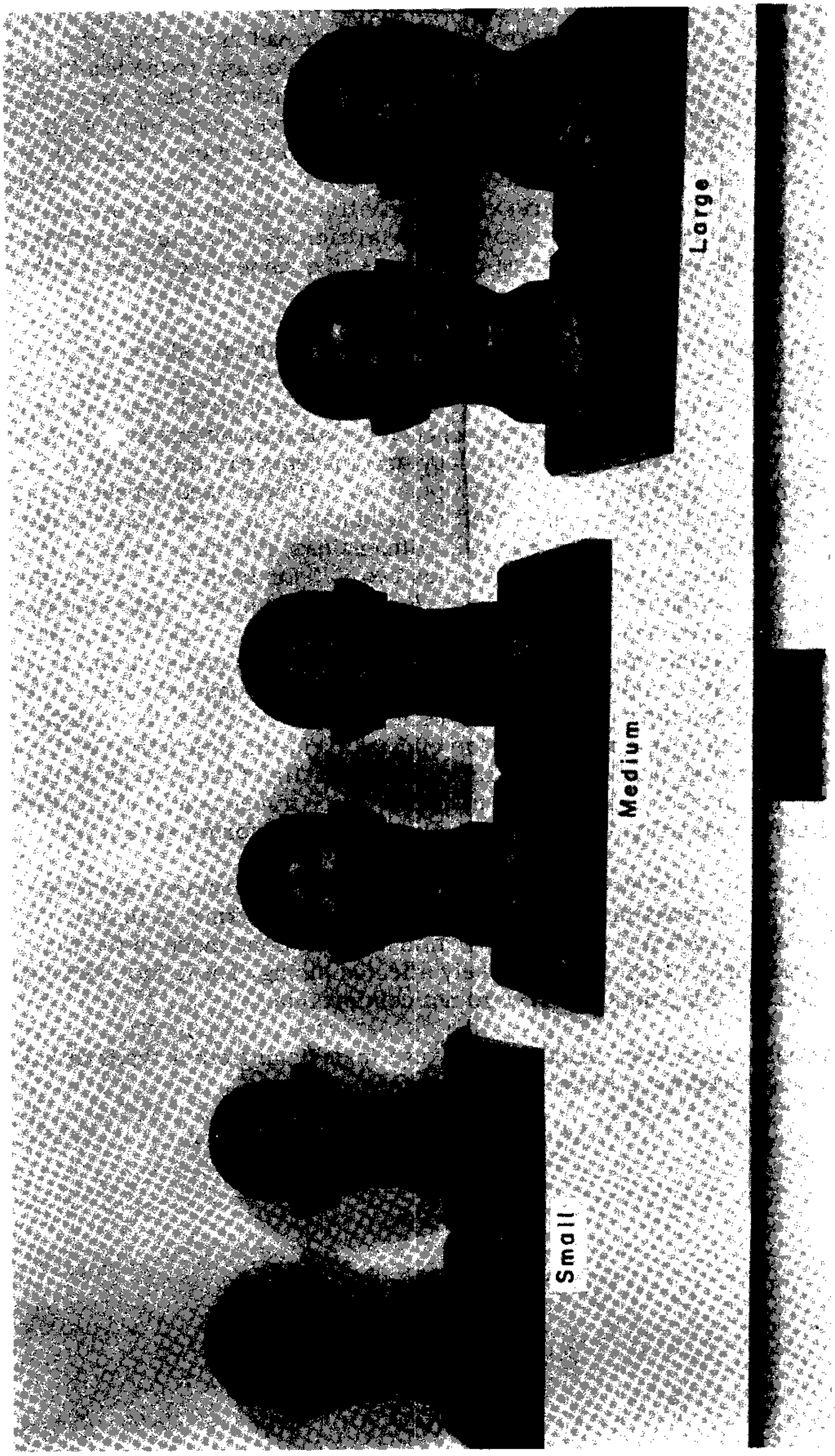

Figure 3. 1954 Head Length, Head Breadth Headform Series— Shell Headforms

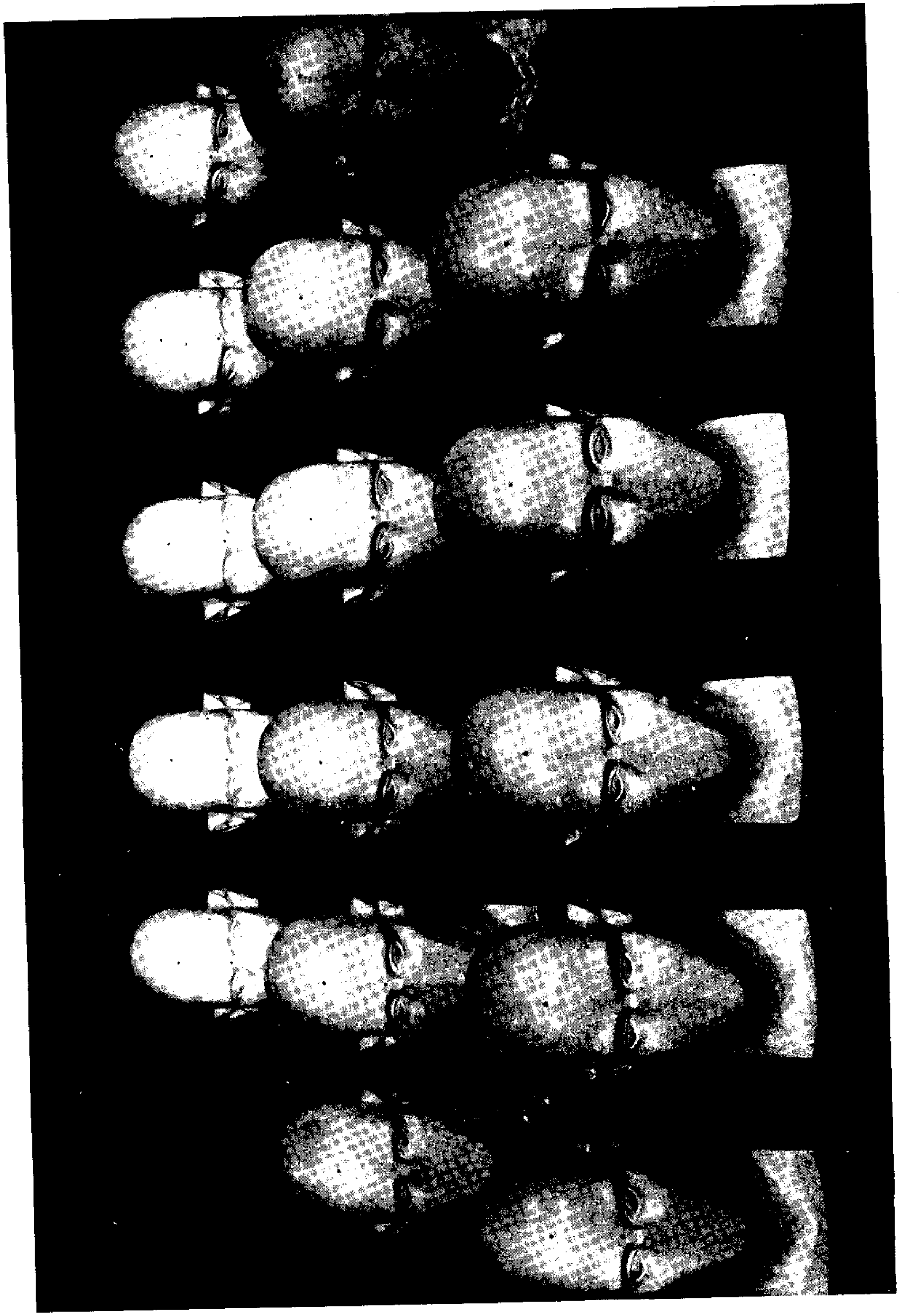

Figure 4. 1954 Head Length, Head Breadth Series— Liner Headforms

SECTION III

STATISTICAL METHODS

General

Sizing procedures for personal equipment involve a special type of statistical analysis. Whatever the item being designed may be, this analysis must usually contend with three broad problems:

1. the need to cope with a large number of body dimensions,

2. the requirement that a small number of sizes fit almost all potential users of this piece of equipment, and

3. the requirement that the sizing system be consistent with convenient field fitting procedures, easy tariffing, and simple procurement.

The statistical concepts involved in such analysis have been touched on in reports dealing with several types of personal equipment (refs. 9, 10). It seems worthwhile, nonetheless, to review these concepts here in full detail and to discuss them in terms of the development of sizing programs for helmet design.

Selection of Size Subgroups

The starting point of any statistical sizing procedure is the selection of one or more key dimensions which serve as the basis for further analysis. This constitutes the foundation for a sizing system. The proper selection of the key dimensions will generally be crucial to the success of the entire undertaking. Some of the factors which enter into the selection will be discussed later.

The individual sizes are next specified in terms of intervals within the range of the key dimension, or of "boxes" within the distribution of key dimensions or, in other words, sizing programs are constructed. Three principles must be considered in the selection of these intervals or boxes: the smaller the intervals or boxes, the easier the design problem and the less adjustability that must be built into the final product; the smaller the number of sizes the smaller the manufacturing costs and the simpler the problems of supply; and the larger the number of men included within the design ranges, the fewer the men who must be custom fitted or excluded from the use of the equipment under design.

These principles, unfortunately, are in mutual conflict. In practice, the specification of the sizes will of necessity represent a practical compromise among the demands of these principles.

The general procecure for choosing the size intervals is illustrated by the steps followed in the present study. Since head circumference had been selected as the key dimension and since our concern was with Air Force Flying personnel, the distribution of this dimension, as determined by the 1950 Anthropometric Survey (ref. 12) provided the basic data (see Appendix III). Head circumference ranged from 20.08 to 24.41 inches in the survey sample; both larger and smaller values undoubtably exist within the Air Force flying population.

Our first step was to truncate this distribution at both ends. It has long been considered neither necessary nor practical to attempt to design for the entire range of any one dimension (ref. 13). Few individuals occur in the "tails" of the distribution, and these extreme individuals can be included in the design plan only by increasing the number of sizes or by using large size-intervals or boxes. A decision was made in this case to cut the range to 21.00 to 24.00 inches. This cut reduced the range by 1.33 inches or 25 percent, with a loss of only about 3 percent of the sample. This reduced range was then divided into 6 equal half-inch intervals: 21.00 to 21.50 inches, and so forth. This division, as has been indicated, represents a practical compromise. Subsequent analysis of the data may indicate that half-inch intervals are too broad for satisfactory design purposes, in which case another, and narrower, set of intervals will have to be considered. On the other hand, it may prove possible to use wider intervals and fewer sizes for some articles. This latter possibility actually materialized in the present study; for some purposes, the 6 original half-inch intervals were combined into 3 full-inch ones.

Determination of Small, Average, and Large Values

Following the selection of the size-intervals, the sample of men for whom relevant data are available is segregated into the various size subsamples. The men in each size-subsample constitute, in effect, a separate "population." For each of these populations an individual item will be designed. Consequently, the next step is to gather--for each of these populations separately--all of the data needed and useful for the design problem at hand.

Such data usually take the form of a variety of statistics for each of these size subgroups. What is ordinarily needed is to know, for each dimension, what constitutes small values (minimum values), average values (mean values), large values (maximum values), in terms, of course, of a particular size subsample. To provide these values, the mean (M) or average value and the standard deviation (S.D.) are calculated for each dimension for each size subsample. (See the Statistical Appendix II for the formula for the S.D. and for the definition of the within-a-size S.D.) The mean value, of course, provides the information as to what constitutes average values. The high and low values (or as they are referred to in the tables-maximum and minimum values) are obtained by combining the mean value and certain multiples of the S.D. The relationship between these statistical measures and high and low values is indicated by the following table and by figure 5 which demonstrates their approximate distribution according to the normal curve:

M + 2.33 S.D.:	99th percentile
M + 1.65 S.D.:	95th percentile
M + 1.50 S.D.:	93rd percentile
M + 1.28 S.D.:	90th percentile
M + 1.00 S.D.:	84th percentile
M − 1.00 S.D.:	16th percentile
M − 1.28 S.D.:	10th percentile
M − 1.50 S.D.:	7th percentile
M − 1.65 S.D.:	5th percentile
M − 2.33 S.D.:	1st percentile

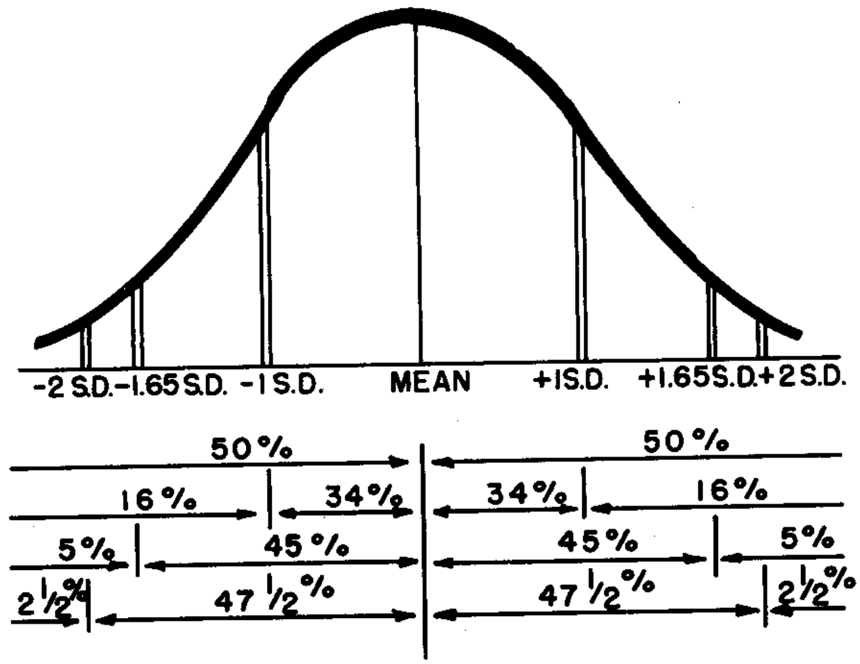

Figure 5. Normal Curve

To illustrate the use of this table, we may observe that the mean value of head length for the smallest size in the present study; i.e., for men with head circumferences in the 21.00 to 21.50 inch interval, was 7.48 inches. After obtaining these "raw" values, they were rounded to the nearest 0.05 inch, as reflected in all tables. The within-a-size S.D. was 0.194 inches. Adding 1.65 times 0.194 inches to the mean and performing a similar subtraction gives us 7.48 + 0.32 = 7.80 and 7.48 - 0.32 = 7.16 inches. These last values, plus the mean value, provide a reasonably clear picture of the head lengths of the men who fall into size one:

7.16 inches is a small (or minimum) head length, only 5 percent of the men of this size have shorter heads;

7.48 inches is the average (or mean) head length; and

7.80 inches is a large (or maximum) head length, only 5 percent of the men of this size have longer heads.

Thus, in designing and manufacturing an article of this "size," head lengths as short as 7.16 inches and as long as 7.80 inches will have to be accommodated.

By using other multiples of the within-a-size S.D., other "large" and "small" values can be obtained. It is worth observing the cost of substantially increasing the proportion of the men whose head lengths are to be designed for. Defining small and large in terms of the first and 99th percentiles (the mean minus or plus 2.33 S.D.) will increase the proportion of men whose head lengths fall between the small and large values from 90 to 98 percent--but the range of head lengths in the example just used will jump from 0.64 to 0.89 inches, an increase of 40 percent.

Once these low, average, and high values have been computed for each dimension for each size subgroup, the problem then consists of establishing design values or design ranges by making optimum choices among these values. For each dimension, the choice will depend on the article being designed and the role the individual dimension plays in the fit and function of this article.

Tables of size means and "minimum-maximum" intra-size design ranges, derived by the methods just discussed, appear in Section IV. A review of these tables will reveal that there are marked differences among the dimensions to the extent to which the mean values (and the minimum and maximum values) increase from size to size. In addition, a number of instances will be observed in which dimensions with large absolute values have narrower size design ranges than those of other dimensions of smaller absolute values.

The variations both in the pattern of increase from size to size and in the width of the design range are related to two statistical properties of the data: the inherent variability of the data as expressed, for example, by the S.D. for the total group, and the degree of relationship between a design dimension and the key dimension or dimensions, as expressed in terms of a correlation coefficient.

The correlation coefficient, usually represented by the letter "r," measures the degree of relationship between two variables on a scale running from zero,when the variables are totally unrelated,to unity, when the relationship is perfect, and the value of one dimension can be predicted with complete accuracy from a value of the other. (Correlation coefficients are given plus signs when an increase in the value of one dimension is associated with an increase in the value of the other and a negative sign when an increase in the value of one dimension is associated with a decrease in the value of the other.) No correlations of 1.00 are ever found between body dimensions, and we are never able to predict perfectly a man's value for one dimension from a knowledge of his value for any other dimension. Head and face dimensions generally have lower correlations than do dimensions of other parts of the body, and the ability to predict one head or face dimension from another is frequently rather poor (ref. 5).

These two statistics, the total group S.D. and the correlation coefficient, combine in rather different ways to influence the differences between successive sizes and the width of the design range. The differences between successive size values is directly proportional to both of these statistics: the larger the correlation of a dimension with head circumference and the larger the dimension's S.D., the larger the interval between sizes. On the other hand, the width of the design range is proportional to the S.D., but becomes progressively smaller the higher the correlation coefficient. The relationship between the correlation coefficient and the width of the design range is somewhat involved; a discussion of this relationship appears in Appendix II.

Selection of Key Dimensions

The primary purpose of dividing men into a series of size categories is to obtain groups of men who are more or less alike in a number of dimensions. The more alike the men are-the more they are of the same size-the more satisfactorily they will be fitted by a single size article, and the less the adjustability or tolerance the designer must provide. Differences in average values, from size to size while they must be known and taken into account, are of minor importance; it is the variation in a frequently large number of dimensions within the men who make up a single size group which is important. Control of this variation is the most important single factor in choosing the key dimension or dimensions and in setting up the size intervals.

Control of within-a-size variability can be accomplished both directly and indirectly. Direct control of the variability of a dimension can be achieved by selecting it as one of the key dimensions. Thus, in the Six-Size Head Circumference Program described in this report, the variability of head circumference is held to within plus or minus about a quarter of an inch from the size means. Indirect control over the variability of a dimension is accomplished by selecting key dimensions closely related to the dimension in question. Considerable control over the variability of head circumference, for example, can be obtained by using head length and head breadth as key dimensions, since head circumference has a statistically close relationship to this combination of dimensions. Indirect control will never be as effective as direct control when the number of sizes is kept constant, but a judicious choice of key dimensions will usually provide some control over the variability of a number of different dimensions.

In selecting key dimensions for a complex sizing program, i.e., for one in which the final product must conform to a large number of bodily dimensions, the final choice will, of necessity, be based on judgments as to the relative importance of controlling the variability of the different dimensions involved, balancing off the amount of indirect control provided by the choice of certain key dimensions against the tighter control of critical dimensions which their selection as key dimensions will achieve.

Before such judgments can be made properly, it is necessary to determine the degree of control which will be obtained by the use of various key dimensions or combinations of key dimensions. The most useful statistical measure for this purpose is the standard error of estimate. The precise formula for this statistic and the form in which it is dependent or the degree of relationship or correlation among the dimensions involved is discussed in Appendix II. For the present purposes, it will suffice to interpret the standard error of estimate, say, of head length based on head circumference, as the standard deviation of the head lengths of a group of men with identical head circumferences. This statistic thus is, in a sense, the within-a-size S.D. corresponding to a sizing system in which each size interval or size box consists of but a single point.

All sizing programs are, of course, based on finite ranges or subintervals of the key dimension or dimensions, not on single values. Nevertheless, the standard error of estimate is closely related to the within-a-size S.D. corresponding to any practical sizing program, and a study of the values of this statistic will provide considerable guidance in the selection of key dimensions. The following comments indicate the nature of the relationship:

1. For a given choice of key dimensions, the within-a-size S.D. deviation will never be smaller than the corresponding standard errors of estimate.

2. For as few sizes, based on a single key dimension, the standard errors of estimate will be virtually identical with the within-a-size S.D. With only 3 sizes, the differences between the 2 statistics will usually be rather small. For sizing systems based on more than one key dimension, agreement between the standard errors of estimate and the within-a-size S.D. will also be close, but the closeness of the agreement will tend to depend on the number of subintervals of each key dimension, rather than on the total number of sizes.

Thus, a table of standard errors of estimate, based on all likely choices of key dimensions, for all design dimensions, provides a fairly clear picture of the indirect control of the variability of the various dimensions which can be achieved. Such a table will show:

1. the choice of key dimension or dimensions which will result in the smallest within-a-size S.D. for any design dimension,

2. whether, for a particularly critical dimension, it is possible to reduce the variability sufficiently by any choice of key dimension other than itself, or whether it is necessary to select it as one of the key dimensions in order to control its variability directly,

3. the cost, in terms of added variability, of making a choice of key dimensions, other than the statistically "best" one.

Unfortunately, as we shall presently see, analysis of data in such a table, may often fall short of being clear cut. One choice of key dimensions will be best for certain design dimensions, another choice for others. Sometimes, a statistically optimum choice will call for key dimensions which are awkward to measure in the field, which present difficulties as the starting point for the manufacture of the article being designed, which are unsatisfactory as the basis for tariffs, or which have other practical drawbacks. The final choice should reflect a careful weighing of all the factors involved.

The standard errors of estimate for most of the head and face dimensions, based on head circumference and 21 other possible choices of key dimensions, have been assembled in table I. The way in which this table was prepared needs explanation. All the relevant standard errors were first computed. The minimum value for each design dimension was then found and listed in the first column of the table. For ease of making comparisons, rather than listing the other standard errors of estimate directly, the difference of the actual values and the minimum value were listed in the remaining columns. Zero differences indicating the combination or combinations of key dimensions which would provide the maximum control are indicated by three dashs. Blank spaces have been left whenever the same dimension was involved as both a design and a key dimension.

It will be useful to examine this table, both as a general exercise in using such a table and as an introduction to the specific problem with which this report is concerned.

The minimum value of the standard error of estimate listed for head circumference is 0.36 inches; this minimum value would be obtained if either the head length-head breadth or the head length-bizygomatic diameter combinations were used as key dimensions. To compare this measure of indirect control with the control achieved directly by using head circumference as the key dimension, we may recall that a working definition of the "small" man and the "large" man as the mean minus 1.65 within-a-size standard deviations and the mean plus an equal amount was introduced earlier in this section. Hence, twice 1.65 or 3.30 within-a-size S.D. can be taken as the effective width of the design range. Approximating the within-a-size S.D. for head circumference by its standard error of estimate, we get 3.30 x 0.36 or 1.19 inches as smallest effective design range for head circumference which can be achieved without using head circumference itself as a key dimension. Thus, the within-a-size variability for head circumference will be about the same using either:

1. head circumference as the key dimension with size intervals of 1.2 inches, or

2. head length and head breadth or head length and bizygomatic diameter as the key dimensions with a reasonably large number of sizes (a minimum of 9, to provide 3 intervals for each key dimension).

Nothing in the table will tell whether an effective range of 1.2 inches for head circumference can be tolerated or not; this, of course, is a question for the designer to answer. What the table does show is that indirect control cannot reduce the within-a-size variability of head circumference beyond this value. It is possible, of course, that some dimensions other than those presently available could provide tighter control; but it is doubtful that much improvement would result except by the use of a new dimension which would be anatomically almost identical to head circumference.

Similar comments can be made about the other dimensions: about 3.30 times the minimum standard error of estimate represents the smallest effective design range that can be achieved through indirect control.

Looking at the table as a whole, the combination of head length and bizygomatic diameter stands out. This combination shows minimum standard errors of estimate for half of the design dimensions. In the case of a few of these dimensions (nasal root breadth and lip-to-lip distance, for example), the minimum values have no significance: no choice of key dimensions provides much if any control and the minimum and maximum values are the same. The standard error of estimate for maximum frontal diameter is 0.14 inches, a good bit larger, relatively, than the minimum value. This difference is due to the inclusion in the list of possible key dimensions of minimum frontal diameter which, anatomically, is quite close to maximum frontal diameter. Similarly, the head length-bizygomatic value for philtrum length is well above the minimum value because the minimum value was given by a combination which included menton-subnasale length of which philtrum length is a part. Most of the other cases in which the head length-bizygomatic value is appreciably above the minimum value can also be traced to a special relationship between the particular design dimension and some one of the suggested key dimensions. Often, the nature of such a potential key dimension which makes it the best one for a single design dimension also would make it a poor choice for many of the other design dimensions.

Unfortunately, the head length-bizygomatic diameter combination suffers from a major weakness as a choice of key dimensions because of the difficulty of measuring bizygomatic diameter. The difficulties of measuring bizygomatic diameter should not rule out its use, but other possibilities should be evaluated in comparison with the head length-bizygomatic diameter results and a decision made which contrasts the poorer control with a greater ease of measurement.

The combination which, next to the one just discussed, gives the largest number of minimum values is head circumference and bitragion-subnasale arc. This combination presents little, if any, improvement as far as measurement difficulties over the one involving bizygomatic diameter, and little improvement in control except that it does control head circumference directly. Further, except for bitragion-menton arc, this combination is not much better than head circumference alone.

The two logical combinations from the point of view of measurement ease are head length and head breadth and head circumference alone. Examination of the table shows that both of these give standard errors of estimate usually only a couple of hundredths of an inch greater than those given by the head length-bizygomatic combination. A consideration of these two choices will be given in the next section of this report. A last statistical comment is worth making at this time: a six-size program based on head circumference alone can be expected to give within-a-size S.D. almost as small as the standard errors of estimate. A six-size program, based on head length and head breadth, will probably show within-a-size S.D. somewhat larger than the standard errors of estimate. In the former case, 6 sizes will mean a division of the head circumference

TABLE I

Comparison of Standard Errors of Estimate

Dimension*	Minimum Value	Head circumference	Head length and Head breadth	Head length and Min. Frontal diam.	Head length and Bizygomatic diameter	Head length and Bigonial diameter	Head length and Bitragion diameter	Head length and Biocular diameter	Head length and Menton-crinion length	Head length and Head height	Head length and Head circumference
Head circumference	.36**		--	.07	--	.08	.03	.08	.10	.10	
Head length	.17	.02									
Head breadth	.15	.02		.03	--	.04	.01	.05	.05	.05	.01
Min. frontal diameter	.15	.03	.02		--	.03	.02	.03	.04	.04	.03
Max. frontal diameter	.10	.08	.07	--	.04	.08	.07	.09	.10	.10	.08
Bizygomatic diameter	.14	.03	.02	.02		.03	--	.04	.05	.05	.03
Bigonial diameter	.19	.02	.02	.01	--		--	.02	.02	.03	.02
Bitragion diameter	.13	.05	.04	.06	--	.06		.07	.08	.08	.05
Biocular diameter	.16	--	--	--	--	.01	--		.01	.01	--
Interocular diameter	.09	.01	.01	--	--	.01	.01	--	.01	.01	.01
Interpupillary distance	.13	--	.01	--	--	.01	.01	.01	.01	.01	.01
Nose length	.13	--	.01	.01	--	.01	--	--	--	.01	.01
Nose breadth	.10	--	--	--	--	--	--	--	--	--	--
Nasal root breadth	.08	--	--	--	--	--	--	--	--	--	--
Nose protrusion	.10	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01
Philtrum length	.09	.04	.05	.05	.05	.05	.05	.04	.05	.05	.05
Menton-subnasale length	.25	.01	.02	.02	.01	.02	.02	.01	--	.01	.02
Menton-crinion length	.32	.02	.02	.02	.01	.02	.02	.02		.02	.01
Lip-to-lip distance	.12	--	--	--	--	--	--	--	--	--	--
Lip length	.13	.01	.01	.01	--	.01	.01	.01	.01	.01	.01
Ear length	.15	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01
Ear breadth	.10	.01	.01	.01	.01	.01	--	.01	.01	.01	--
Ear lth. above tragion	.10	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01
Ear protrusion	.14	--	--	--	--	--	--	--	--	--	--
Head height	.27	.02	.02	.02	.02	.02	.02	.02	.02		.02
Menton projection	.25	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01
External canthus to wall	.24	.05	.01	.01	--	.01	.01	.01	.01	.01	.01
Nasal root to wall	.24	.06	.01	.01	--	.01	.01	.01	.01	--	.01
Tragion to wall	.27	.02	--	--	--	--	--	--	--	--	--
Sagittal arc	.50	.02	.01	.01	--	.02	.02	.02	.02	.01	--
Bitragion-coronal arc	.40	.06	.03	.07	.06	.09	.08	.08	.09	.04	.06
Minimum frontal arc	.35	.04	.04	--	.03	.04	.04	.03	.04	.04	.03
Bitragion-min. frontal arc	.32	.03	.04	.04	.01	.06	.05	.05	.06	.07	.03
Bitragion-crinion arc	.44	.04	.02	--	.01	.05	.04	.05	.04	.04	.04
Bitragion-menton arc	.34	.10	.12	.12	.08	.11	.09	.12	.12	.14	.10
Bitr.-submandibular arc	.50	.05	.09	.09	.05	.07	.06	.09	.08	.10	.05
Bitr.-subnasale arc	.34	.04	.05	.04	--	.04	.03	.04	.06	.06	.04
Bitragion-posterior arc	.41	.01	.03	.04	.01	.03	--	.04	.05	.05	.01
Bitragion-inion arc	.50	--	.01	.02	.01	.01	--	.01	.02	.02	--

* Descriptions in Appendix III.

** All values in inches.

TABLE I (con't.)

Comparison of Standard Errors of Estimate

Dimension*	Head length and Bitragion-coronal arc	Head length and Bitragion-subnasale arc	Head breadth and Menton-crinion length	Head breadth and Head height	Head breadth and Head circumference	Head breadth and Bitragion-coronal arc	Head breadth and Bitragion-subnasale arc	Head circumference and Menton-crinion length	Head circumference and Head height	Head circumference and Bitragion-coronal arc	Head circumference and Bitragion-subnasale arc	Nose length and Menton-subnasale length
Head circumference	.07**	.07	.14	.16		.15	.12					.25
Head length			.07	.08	--	.07	.07	.02	.02	.02	.02	.08
Head breadth	.03	.05						.02	.02	.01	.02	.05
Min. frontal diameter	.02	.03	.02	.02	.02	.02	.02	.03	.03	.03	.02	.04
Max. frontal diameter	.09	.08	.08	.08	.07	.08	.07	.08	.08	.08	.08	.10
Bizygomatic diameter	.05	.03	.02	.02	.01	.02	--	.03	.03	.03	.02	.06
Bigonial diameter	.02	.02	.02	.02	.01	.02	.01	.02	.02	.02	.01	.03
Bitragion diameter	.07	.06	.04	.04	.03	.04	.03	.05	.05	.05	.05	.08
Biocular diameter	.01	--	.01	.01	--	.01	--	--	--	--	--	.01
Interocular diameter	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	--	.01
Interpupillary distance	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	--	--
Nose length	.01	--	--	.01	.01	.01	.01	--	.01	.01	--	
Nose breadth	--	--	--	--	--	--	--	--	--	--	--	
Nasal root breadth	--	--	--	--	--	--	--	--	--	--	--	--
Nose protrusion	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	--
Philtrum length	.05	.05	.05	.05	.05	.05	.05	.05	.05	.05	.05	--
Menton-subnasale length	.02	.02	--	.02	.02	.02	.02	--	.02	.02	.02	
Menton-crinion length	.02	.02		.03	.02	.03	.03		.02	.02	.02	--
Lip-to-lip distance	--	--	--	--	--	--	--	--	--	--	--	--
Lip length	.01	--	.01	.01	.01	.01	--	.01	.01	.01	--	.01
Ear length	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	--	--
Ear breadth	.01	--	.01	.01	--	.01	--	--	--	--	--	--
Ear lth. above tragion	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	--
Ear protrusion	--	--	--	--	--	--	--	--	--	--	--	--
Head height	--	.02	.02		.02	--	.02	.02		--	.02	.03
Menton projection	.01	--	.01	.01	.01	.01	--	.01	.01	.01	--	--
External canthus to wall	.01	.01	.07	.07	.04	.07	.07	.05	.05	.05	.05	.07
Nasal root to wall	.01	.01	.09	.07	.05	.09	.08	.06	.04	.06	.06	.10
Tragion to wall	--	--	.03	.02	.01	.03	.03	.02	.01	.02	.01	.03
Sagittal arc	--	.02	.10	.09	.02	.07	.10	.03	.02	.02	.03	.11
Bitragion-coronal arc		.09	.04	--	.03		.04	.06	.02		.06	.10
Minimum frontal arc	.04	.04	.04	.04	.03	.04	.03	.03	.03	.03	.03	.05
Bitragion-min. frontal arc	.05	.03	.07	.08	.03	.07	.03	.02	.03	.02	--	.11
Bitragion-crinion arc	.01	.04	.02	.04	.03	.01	.03	.03	.03	.01	.03	.08
Bitragion-menton arc	.13	.01	.12	.15	.10	.15	.01	.09	.10	.10	--	.15
Bitr.-submandibular arc	.10	.02	.09	.10	.05	.11	.02	.05	.05	.05	--	.11
Bitr.-subnasale arc	.06		.08	.08	.04	.08		.04	.04	.04		.09
Bitragion-posterior arc	.05	.04	.05	.05	.01	.05	.03	.01	.01	.01	.01	.07
Bitragion-inion arc	.01	.02	.03	.04	--	.03	.04	--	--	--	--	.05

* Descriptions in Appendix III.
** All values in inches.

range into 6 parts; in the latter case, 6 sizes will mean a division of the head length range into only 2 or 3 parts and a similar division for head breadth, giving an appreciably coarser breakdown.

The number of key dimensions that should be selected is worthy of brief discussion. Most sizing systems are based on one or two, although in theory any number of key dimensions could be used. The major deterent to multiple key dimension systems is the number of sizes which result even with fairly coarse subdivisions for each dimension. A small-medium-large type of subdivision for each of 3 dimensions would, theoretically, result in 27 sizes; for 4 dimensions, in 64 sizes. It is doubtful that the gains in lowered variability which would result from such a proliferation of sizes would compensate for the added cost and inconvenience which would be caused. Special requirements will sometimes dictate the use of three dimensions, e.g., the height-weight-VTC (vertical trunk circumference) system. This system, incidentally, is an interesting combination of indirect control for most dimensions (by the use of height and weight) and direct control for a critical measurement (VTC).

Factor Analysis

An interesting and statistically sophisticated approach to the selection of key dimensions is included in factor analysis. This approach "may be described as a statistical technique for reducing a large number of correlated variables to terms of a small number of uncorrelated variables" (ref 4). Factor analysis of the skull has been accomplished by Howells (ref. 14) and of the foot by Jeffrey and Thurstone (ref. 15). In certain ways, the factors arrived at by this type of analysis could serve as key dimensions. Unfortunately, the small number of variables of which Burt and Banks speak is far too large a number for this purpose; Howell's analysis extracted ten factors. In addition, no one is known to have ever translated these factors into individual (and easily measured) dimensions. A further drawback of this approach is that judgements as to the relative importance of various dimensions for design purposes cannot easily be introduced into the analysis and in most methods of factor analysis, a minor dimension like nasal root breadth, for example, will weigh as heavily as a major one, like head circumference.

SECTION IV

DESIGN RATIONALE

Advantages of Head Circumference as the Key Dimension

From comments in the previous Section and those appearing in an earlier report (ref. 5), it is quite clear that the designing of statistical sizing programs for the head is an extremely complex problem. Those dimensions of the head and face which describe the shape of the skull: head circumference, head length, head breadth and head height,appear to be most critical in terms of direct control. Head height need not be considered here since this dimension usually can be adequately designed for. Therefore, the problem appears to resolve itself into a consideration of a system using as its key dimensions head length and breadth, or one using the single key dimension, head circumference. As was demonstrated in Section III, there is no great advantage in selecting more than a single key dimension, head circumference, as the basis of a sizing system. This has been shown in statistical terms. In addition, a number of practical considerations for choosing this single key dimension were also suggested. These may be more fully defined as follows:

1. The probability that equipment personnel, untrained in anthropometric measuring techniques, will make a mistake is increased two-fold when both head length and breadth (or any other pair) must be taken for determining a size.

2. For those helmets in which a close fit is not critical, head circumference may be approximated from standard hat sizes. Furthermore, only an ordinary measuring tape is needed to determine head circumference, while a special instrument must be used to measure head length and breadth. Also in this connection, we know that personnel in the field frequently do not use the fitting instructions provided with an article of personal protective equipment, and the use of the simplest of procedures will enhance the probability of its being applied as directed.

3. Head length and breadth appear to be really critical only in entirely rigid helmets having no adjustability in the support; in liner, sling, or pad-type helmets, there is always some degree of adjustability, so that if head circumference is controlled, head breadth and length will also be readily accommodated as long as sufficient room is provided in the shell. Although head length and breadth may be thought to better represent head shape than head circumference, representative head shapes are still provided by headforms using the key dimension head circumference.

4. Another important consideration is that of the number of sizes needed. When using head length and breadth it is possible to establish a four- or six-size program, with the latter providing somewhat better coverage than the former. However, it is impossible to eliminate sizes without causing excessive bulk in the remaining helmets. On the other hand, as was noted in Section III, in those instances wherein a larger adjustability can be provided, it is possible to use every other size of a program based on head circumference, and there will be little added bulk since these are graded sizes. As part of the current analysis, theoretical Four- and Six-Size Head Length, Head Breadth Programs were set up using same type of analyses discussed in this report. Since these may be of interest for comparative purposes or conceivably may find application in the future, they are included as tables XVII - XXI in Appendix IV.

It is thus quite evident that at the present state-of-the-art a sizing system based on the single key dimension head circumference must be considered as offering the best possible approach for current helmet design problems.

Selection of Sizing Programs

Experience has shown that the sizing of any helmet, whether low altitude or pressure, requires individual consideration. The sizing of a helmet depends to a very large extent on the form and function of the helmet, as well as on the material of which it is made. The adjustability of a helmet or the compressibility of liner material must be considered before a sizing schedule can be decided. Nevertheless, there are sufficient criteria in common which permits the use of standardized sizing programs and their representative headforms. It was therefore possible to develop three sizing programs: a Six-Size Program based on mean values, a Three-Size Program based on mean values, and a Six-Size Liner Program. The statistics developed for the first named program serve also as the basis for the other two programs. Fundamentally, then, there is only one statistical analysis, with a number of modifications, for treating a variety of possible helmet sizing problems.

Initially, there was some question as to the design problems which might arise. In particular, the degree of adjustability feasible for different helmet designs was an unknown factor. From analysis of the 1950 survey data (ref. 12), it appeared that a six-size program offered a good basic compromise when a 0.5-inch adjustability in head circumference could be provided in a helmet (table II). Smaller size intervals were considered unwarranted, because they would probably approach the measurement error of the fitting personnel. The hope was to develop a generalized sizing program which could be adapted to a variety of problems.

It became increasingly evident that the need for a general Six-Size Head Circumference Program would probably not arise since virtually all adjustable helmets designed for the Air Force could accommodate a 1-inch interval of head circumference. The Three-Size Program listed in table III therefore was created through the elimination of sizes 1, 3, and 5. The resultant sizes were designated 1 - 2, 3 - 4, and 5 - 6, demonstrating their relationship to the Six-Size Program. If, in the future, these three headforms become standardized for general military specifications, they could be designated small (1-2), medium (3-4) and large (5-6).

Table II

Intervals of Head Circumference for a Six-Size Program

Size	Head Circumference (in.)
1	21.0-21.5
2	21.5-22.0
3	22.0-22.5
4	22.5-23.0
5	23.0-23.5
6	23.5-24.0

Table III

Intervals of Head Circumference for a Three-Size Program

Size	Head Circumference (in.)
1-2	21.0-22.0
3-4	22.0-23.0
4-5	23.0-24.0

Design Ranges

After selection of the basic sizing programs, each size interval was then treated as a separate sample and means and within-a-size S.D. were determined for all dimensions which might be needed by the designer or by the sculptor of headforms. In considering the variability of the other dimensions which were to be accommodated, the approach taken in the recent design of other personal equipment has been followed. In previous attempts at helmet sizing, the mean or the mean plus and minus 2 S.D. design range was employed. In the first, instance, insufficient variability was provided, and in the second case, there was too much bulk. In recent Air Force studies for the sizing of personal equipment there has been a tendency to make the range of accommodation a compromise between these two approaches. To avoid bulk at the expense of a slightly reduced percentage fit, moderate design ranges were used in partial pressure gloves (ref. 3), flying clothing (ref. 10), and oxygen masks (ref. 9). Nevertheless, when the sizing rationale in these items were validated, percentage fit was always higher than would be expected theoretically on statistical grounds alone, and as a matter of fact, in general, was at least 95 percent. In the equipment sized to date in this manner, this greater than expected fitting percentage probably can be attributed mainly to the deformability of both the human body and the equipment being worn. On the basis of this recent experience, a range of accommodation or design range of the mean plus and minus 1.65 S.D. (5th to 95th percentiles) was selected. The reader will observe in the following paragraphs that this design range refers only to the clearance which should be provided in most helmet shells to accommodate the range of head sizes for the particular interval of head circumference.

Six-Size Program Based on Mean Values

Table IV represents the mean values and the within-a-size S.D. of 42 head and face dimensions for each interval of a six-size program. In using this program several important factors must be considered and dealt with.

1. Headforms sculptured to this program are designed for helmets which can accommodate a 0.5-inch interval of head circumference. If as much as a 1.0-inch interval can be accommodated, then the Three-Size Program can be used. As noted previously, this is the prevalent situation.

2. If helmets built over these forms allow no adjustability upward, then only those below the 50th percentile for head circumference of the Air Force flying population would be accommodated.

3. Since the mean-values for head circumference as represented in table IV are not exactly the mid-point of each size interval (due to a skewed distribution), the designer

TABLE IV

Six-Size Head Circumference Program Means and Within-a-Size Standard Deviations

Size:	1	2	3	4	5	6	Within-a-Size S.D.
Dimension *							
1. Head circumference	21.35**	21.80	22.30	22.75	23.20	23.65	.17
2. Head length	7.50	7.60	7.70	7.85	7.95	8.10	.19
3. Head breadth	5.85	5.95	6.05	6.10	6.20	6.30	.17
4. Minimum frontal diameter	4.20	4.30	4.35	4.40	4.45	4.50	.18
5. Maximum frontal diameter	4.60	4.65	4.70	4.75	4.80	4.85	.18
6. Bizygomatic diameter	5.35	5.45	5.50	5.60	5.70	5.75	.17
7. Bigonial diameter	4.15	4.20	4.25	4.30	4.35	4.40	.21
8. Bitragion diameter	5.40	5.50	5.55	5.65	5.70	5.80	.19
9. Biocular diameter	3.65	3.70	3.75	3.80	3.85	3.90	.13
10. Interocular diameter	1.20	1.20	1.25	1.25	1.30	1.30	.10
11. Interpupillary distance***	2.40	2.45	2.50	2.50	2.55	2.55	.14
12. Nose length***	2.00	2.00	2.00	2.00	2.05	2.05	.13
13. Nose breadth***	1.25	1.30	1.30	1.30	1.35	1.35	.10
14. Nasal root breadth	.60	.60	.60	.60	.65	.65	.08
15. Nose protrusion***	.90	.90	.90	.90	.90	.90	.11
16. Philtrum length***	.75	.75	.75	.80	.80	.80	.13
17. Menton-subnasale length***	2.55	2.60	2.65	2.65	2.70	2.70	.26
18. Face length	4.55	4.60	4.65	4.65	4.75	4.75	.33
19. Menton-crinion length	7.10	7.20	7.30	7.40	7.55	7.65	.34
20. Lip-to-lip distance***	.65	.65	.65	.65	.65	.65	.12
21. Lip length***	1.95	2.00	2.00	2.05	2.05	2.10	.14
22. Ear length	2.40	2.45	2.45	2.50	2.50	2.55	.16
23. Ear breadth	1.40	1.40	1.45	1.45	1.45	1.50	.11
24. Ear length above tragion	1.15	1.15	1.15	1.20	1.20	1.20	.11
25. Ear protrusion	.85	.85	.85	.85	.85	.85	.14
26. Head height	4.95	5.00	5.10	5.15	5.20	5.25	.29
27. Menton projection	1.75	1.80	1.85	1.90	1.95	2.00	.26
28. External canthus to wall	6.55	6.65	6.75	6.85	6.90	7.00	.29
29. Nasal root to wall	7.45	7.55	7.70	7.80	7.95	8.05	.30
30. Tragion to wall	3.90	3.95	4.00	4.05	4.15	4.20	.29
31. Pronasale to wall***	8.20	8.40	8.55	8.75	8.90	9.10	.30
32. Sagittal arc	14.55	14.75	14.95	15.20	15.40	15.65	.54
33. Bitragion-coronal arc	13.45	13.60	13.75	13.90	14.05	14.25	.47
34. Minimum frontal arc	5.30	5.35	5.40	5.50	5.55	5.60	.39
35. Bitragion-minimum frontal arc	11.60	11.80	12.00	12.20	12.40	12.60	.36
36. Bitragion-crinion arc	12.70	12.85	13.00	13.20	13.35	13.50	.49
37. Bitragion-menton arc	12.35	12.55	12.70	12.90	13.05	13.25	.45
38. Bitragion-submandibular arc	11.60	11.80	12.00	12.20	12.40	12.60	.56
39. Bitragion-subnasale arc***	11.10	11.25	11.40	11.55	11.70	11.85	.38
40. Bitragion-posterior arc	10.25	10.45	10.60	10.80	11.00	11.20	.42
41. Bitragion-inion arc	11.20	11.35	11.55	11.70	11.90	12.10	.50
42. Neck circumference	14.40	14.60	14.90	15.15	15.30	15.50	.68

* Descriptions in Appendix III.
** All values in inches.
*** Not sculptured in headforms.

must make appropriate corrections for any helmet with adjustment up and down from the headforms.

4. The mean values for all dimensions other than head circumference do represent the mid-point for each size.

The design ranges for the many dimensions in each size must be used to establish the necessary upward and downward adjustability from the mean headforms. Those ranges which must be accommodated are presented in table V and will allow coverage of about 90 to 95 percent of the Air Force flying population, depending on the particular helmet design. The percentiles covered by these ranges compared with the 1950 survey of Air Force flying personnel, are shown in table VI (ref. 12).

5. In most instances, the headforms sculptured to these programs cannot be used directly for shell design. A shell must be designed to cover the large or maximum values presented in table V for each size interval plus the bulk which results from the sling, pad, or spacer arrangement worn directly over the head. This bulk, of course, is unique for each helmet, so that no preconceived values can be established and must be determined empirically for each helmet. A helmet may be designed directly over the mean headforms providing it includes spacers which permit the shell to expand to the maximum values shown in table V, with allowances also being made for the bulk value.

6. Since head height correlates very poorly with horizontal head dimensions, some consideration must be given to providing vertical adjustability. This is particularly necessary in pressure helmets where the eyes should always be positioned at the point where optimum vision through the lens is provided. The variability of head height is about 1 inch for each of the 6 sizes. Therefore, a 1/2-inch adjustability up from the mean value and a similar amount downward, would be desirable. This also holds true for the Three-Size Program discussed below.

Three-Size Program Based on Mean Values

The Three-Size Program based on mean values can be used for design of helmets which are provided with adjustability through an arrangement of slings, pads, spacers or other devices capable of accommodating a 1.0-inch interval of head circumference within each of 3 sizes. As preciously noted, this is accomplished by selecting the alternate even sizes (2, 4, and 6) of the Six-Size Program.

In using sizes 2, 4, and 6 for the Three-Size Program it is apparent that some skewedness of the mean values will occur. Table VII represents the mean values for the data reanalyzed on the basis of the three, 1-inch intervals of head circumference (sizes 1 - 2, 3 - 4, and 5 - 6) and may be compared with sizes 2, 4 and 6 of table IV. In considering the desirability of introducing an additional series of headforms, a number of facts were given careful consideration. For one thing, such an additional series very probably would tend to confuse the designer in interpreting the data. Secondly, the reanalyzed sizes 1 - 2 and 3 - 4 are virtually identical in all dimensions with sizes 2 and 4. Our third point requires some appreciation as to the causes for the differences which do appear. Sizes 1 and 2 are heavily weighted to the men in size 2, whereas for sizes 5 and 6, 5 has the greater frequency. As a result, head circumference and a number of major arcs are larger in size 6 than in the reanalyzed size 5 - 6. However, by using size 6 we are able to maintain a uniform grading for head circumference. Furthermore, the mean programs permit some leeway as to shell size as will be subsequently discussed. Lastly, a number of developmental helmets designed over sizes 2, 4, and 6

TABLE V

Design Ranges for the Six-Size Mean and the Six-Size Liner Head Circumference Programs

Size: Dimension*	1 Min.	1 Max.	2 Min.	2 Max.	3 Min.	3 Max.
1. Head circumference	21.00**	22.00	22.00	23.00	22.00	22.50
2. Head length	7.15	7.80	7.25	7.90	7.40	8.05
3. Head breadth	5.60	6.15	5.65	6.25	5.75	6.30
4. Minimum frontal diameter	3.90	4.50	4.00	4.60	4.05	4.65
5. Maximum frontal diameter	4.30	4.90	4.35	4.95	4.40	5.00
6. Bizygomatic diameter	5.05	5.65	5.15	5.70	5.20	5.80
7. Bigonial diameter	3.80	4.50	3.85	4.55	3.90	4.60
8. Bitragion diameter	5.10	5.70	5.20	5.80	5.25	5.85
9. Biocular diameter	3.45	3.85	3.50	3.90	3.55	3.95
10. Interocular diameter	1.05	1.35	1.05	1.40	1.10	1.40
11. Interpupillary distance***	2.20	2.65	2.20	2.65	2.25	2.70
12. Nose length***	1.75	2.20	1.80	2.20	1.80	2.25
13. Nose breadth***	1.10	1.45	1.10	1.45	1.15	1.50
14. Nasal root breadth	.45	.70	.45	.75	.45	.75
15. Nose protrusion***	.70	1.05	.70	1.05	.70	1.10
16. Philtrum length***	.50	.95	.55	1.00	.55	1.00
17. Menton-subnasale length***	2.15	3.00	2.15	3.05	2.20	3.05
18. Face length	4.00	5.10	4.05	5.15	4.10	5.20
19. Menton-crinion length	6.55	7.65	6.65	7.80	6.75	7.90
20. Lip-to-lip distance***	.45	.85	.45	.85	.45	.85
21. Lip length***	1.75	2.20	1.75	2.25	1.80	2.25
22. Ear length	2.15	2.65	2.15	2.70	2.20	2.70
23. Ear breadth	1.25	1.55	1.25	1.60	1.25	1.60
24. Ear length above tragion	.95	1.35	1.00	1.35	1.00	1.35
25. Ear protrusion	.60	1.10	.60	1.10	.60	1.10
26. Head height	4.50	5.45	4.55	5.50	4.60	5.55
27. Menton projection	1.35	2.20	1.40	2.25	1.45	2.30
28. External canthus to wall	6.05	7.05	6.15	7.10	6.25	7.20
29. Nasal root to wall	6.95	7.95	7.05	8.05	7.20	8.20
30. Tragion to wall	3.40	4.40	3.50	4.45	3.55	4.50
31. Pronasale to wall***	7.70	8.70	7.90	8.90	8.05	9.05
32. Sagittal arc	13.65	15.45	13.85	15.65	14.10	15.85
33. Bitragion-coronal arc	12.70	14.20	12.85	14.35	13.00	14.55
34. Minimum frontal arc	4.65	5.95	4.70	6.00	4.80	6.05
35. Bitragion-minimum frontal arc	11.00	12.15	11.20	12.35	11.40	12.55
36. Bitragion-crinion arc	11.90	13.50	12.05	13.65	12.20	13.80
37. Bitragion-menton arc	11.60	13.10	11.80	13.25	11.95	13.45
38. Bitragion-submandibular arc	10.70	12.50	10.90	12.75	11.10	12.95
39. Bitragion-subnasale arc***	10.45	11.70	10.60	11.85	10.75	12.00
40. Bitragion-posterior arc	9.55	10.95	9.75	11.15	9.90	11.30
41. Bitragion-inion arc	10.35	12.05	10.55	12.20	10.70	12.40
42. Neck circumference	13.30	15.55	13.50	15.75	13.70	16.00

* Descriptions in Appendix III.
** All values in inches.
*** Not sculptured in headforms.

TABLE V (con't.)

Design Ranges for the Six-Size Mean and the Six-Size Liner Head Circumference Programs

Size: / Dimension*	4 Min.	4 Max.	5 Min.	5 Max.	6 Min.	6 Max.	1.65 Within-a-Size S. D.
1. Head circumference	22.50**	23.00	23.00	23.50	23.50	24.00	--
2. Head length	7.50	8.15	7.65	8.30	7.80	8.40	.32
3. Head breadth	5.85	6.40	5.95	6.50	6.00	6.60	.28
4. Minimum frontal diameter	4.10	4.70	4.15	4.75	4.20	4.80	.30
5. Maximum frontal diameter	4.45	5.05	4.50	5.10	4.55	5.15	.30
6. Bizygomatic diameter	5.30	5.85	5.40	5.95	5.45	6.05	.29
7. Bigonial diameter	3.95	4.65	4.00	4.70	4.10	4.75	.34
8. Bitragion diameter	5.35	5.95	5.40	6.00	5.50	6.10	.31
9. Biocular diameter	3.60	4.00	3.65	4.05	3.70	4.10	.21
10. Interocular diameter	1.10	1.45	1.15	1.45	1.15	1.45	.16
11. Interpupillary distance***	2.30	2.75	2.30	2.75	2.35	2.80	.22
12. Nose length***	1.80	2.25	1.80	2.25	1.80	2.25	.22
13. Nose breadth***	1.15	1.50	1.20	1.50	1.20	1.55	.17
14. Nasal root breadth	.50	.75	.50	.75	.50	.75	.14
15. Nose protrusion***	.70	1.10	.70	1.10	.70	1.10	.19
16. Philtrum length***	.55	1.00	.60	1.00	.60	1.05	.22
17. Menton-subnasale length***	2.25	3.10	2.25	3.10	2.30	3.15	.43
18. Face length	4.10	5.20	4.20	5.30	4.20	5.30	.54
19. Menton-crinion length	6.85	8.00	6.95	8.10	7.10	8.20	.56
20. Lip-to-lip distance***	.45	.85	.45	.85	.45	.85	.20
21. Lip length***	1.80	2.25	1.85	2.30	1.85	2.30	.23
22. Ear length	2.20	2.75	2.25	2.75	2.25	2.80	.26
23. Ear breadth	1.30	1.60	1.30	1.65	1.30	1.65	.17
24. Ear length above tragion	1.00	1.35	1.00	1.35	1.00	1.35	.18
25. Ear protrusion	.60	1.10	.60	1.10	.60	1.10	.24
26. Head height	4.65	5.60	4.70	5.70	4.80	5.75	.48
27. Menton projection	1.45	2.30	1.55	2.35	1.60	2.40	.42
28. External canthus to wall	6.35	7.30	6.45	7.40	6.55	7.50	.48
29. Nasal root to wall	7.30	8.30	7.45	8.45	7.55	8.55	.50
30. Tragion to wall	3.60	4.55	3.65	4.60	3.70	4.65	.48
31. Pronasale to wall***	8.25	9.25	8.40	9.40	8.60	9.60	.50
32. Sagittal arc	14.30	16.10	14.50	16.30	14.75	16.50	.89
33. Bitragion-coronal arc	13.15	14.70	13.30	14.85	13.45	15.00	.77
34. Minimum frontal arc	4.85	6.10	4.90	6.20	5.00	6.25	.64
35. Bitragion-minimum frontal arc	11.60	12.75	11.80	12.95	12.00	13.15	.59
36. Bitragion-crinion arc	12.40	14.00	12.55	14.15	12.70	14.30	.80
37. Bitragion-menton arc	12.15	13.65	12.30	13.80	12.50	14.00	.74
38. Bitragion-submandibular arc	11.30	13.10	11.50	13.30	11.65	13.50	.92
39. Bitragion-subnasale arc***	10.90	12.20	11.10	12.35	11.25	12.50	.63
40. Bitragion-posterior arc	10.10	11.50	10.30	11.70	10.50	11.90	.70
41. Bitragion-inion arc	10.90	12.55	11.10	12.75	11.25	12.90	.83
42. Neck circumference	13.95	16.20	14.15	16.40	14.35	16.65	1.13

* Descriptions in Appendix III.
** All values in inches.
*** Not sculptured in headforms.

TABLE VI

Percentile Coverage for Design Ranges of the Six-Size Mean and Liner Programs

Size:	1		2		3		4		5		6	
Dimension*	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
1. Head circumference	1	5	5	20	20	50	50	80	80	95	95	98
2. Head length	1	60	2	75	10	87	15	92	33	99	55	99
3. Head breadth	1	66	2	81	6	87	12	95	30	98	40	99
4. Min. frontal diameter	1	76	4	91	6	93	10	96	15	98	21	99
5. Max. frontal diameter	1	84	3	89	6	92	9	95	14	97	21	98
6. Bizygomatic diameter	1	71	3	80	5	90	11	92	24	99	31	99
7. Bigonial diameter	1	90	2	92	3	95	7	96	10	98	20	98
8. Bitragion diameter	1	75	2	85	4	87	12	96	15	98	25	99
9. Biocular diameter	3	65	6	75	11	85	16	91	24	94	32	97
10. Interocular diameter	2	85	2	92	6	92	6	97	18	97	18	97
11. Interpupillary dist.**	1	86	1	86	4	92	9	95	9	95	17	98
12. Nose length**	3	92	6	92	6	97	6	96	6	97	6	96
13. Nose breadth**	1	90	1	90	4	95	4	95	14	95	14	98
14. Nasal root breadth	2	87	2	95	2	95	9	95	9	95	9	95
15. Nose protrusion**	4	91	4	91	4	97	4	97	4	97	4	97
16. Philtrum length**	2	91	6	96	6	96	6	96	12	96	12	96
17. Menton-subnas. lth.**	3	91	3	93	6	93	8	96	8	96	12	97
18. Face length	3	92	4	94	5	95	5	95	12	97	12	97
19. Menton-crinion length	1	78	2	90	4	92	8	97	12	98	20	99
20. Lip-to-lip distance**	6	96	6	96	6	96	6	96	6	96	6	96
21. Lip length**	2	89	2	94	5	94	5	94	9	97	9	97
22. Ear length	2	87	2	92	5	92	5	96	9	96	9	98
23. Ear breadth	3	85	3	94	3	94	9	94	9	97	9	97
24. Ear lth. above tragion	2	95	6	95	6	95	6	95	6	95	6	95
25. Ear protrusion	3	95	3	95	3	95	3	95	3	95	3	95
26. Head height	2	87	4	90	5	92	7	95	10	98	15	98
27. Menton projection	1	90	2	92	4	95	4	95	12	96	15	98
28. Ext. canthus to wall	1	82	2	85	7	90	9	97	12	98	22	99
29. Nasal root to wall	1	72	1	82	5	90	10	95	17	98	27	99
30. Tragion to wall	1	90	3	92	7	95	10	96	12	97	15	97
32. Sagittal arc	1	72	2	82	5	88	10	96	15	98	27	99
33. Bitr.-coronal arc	1	80	2	87	5	92	8	95	15	97	22	99
34. Min. frontal arc	3	91	3	92	5	94	6	97	7	98	10	99
35. Bitr.-min. frontal arc	1	62	2	77	5	87	15	94	25	97	45	99
36. Bitr.-crinion arc	1	80	1	86	3	90	8	95	12	97	20	98
37. Bitr.-menton arc	1	75	2	82	4	92	12	96	17	98	30	99
38. Bitr.-submand. arc	1	75	2	84	5	91	10	97	15	97	22	98
39. Bitr.-subnasale arc**	1	75	2	82	7	90	10	95	20	98	32	99
40. Bitr.-posterior arc	1	72	2	82	3	90	10	95	20	98	30	99
41. Bitragion-inion arc	1	77	1	85	3	90	7	93	15	97	27	98
42. Neck circumference	1	84	1	89	3	92	6	96	9	97	17	99

* Descriptions in Appendix III.
** Not sculptured in headforms.

demonstrated a desirable fit in preliminary tests, and to this extent validated the decision to select the alternate sizes of the Six-Size Program.

Thus, the designer would turn to table IV to establish the mean values for the headforms he will be using. On the other hand, since our approach does not restrict the shell configuration to a specific pattern, table VIII represents the small and large values derived from table VII. By using the data in table VIII, the designer of a three-size series of helmets is able to slightly reduce the size and the bulk of the shell. Table IX, which portrays the percentiles of Air Force flying personnel (ref. 12) covered by the design ranges shown in table VII, may be compared with table V for evaluation of the slight decrease in percentage coverage provided through this approach.

All of the factors requiring consideration for the Six-Size Program are applicable to the Three-Size Program. Particular attention must be given by the designer to the amount of adjustability up and down from the mean values he must apply because of the skewedness already mentioned. Table IV shows that the mean values for head circumference are 21.80, 22.75, and 23.65 for sizes 2, 4, and 6, respectively. Table VIII (and table III also) shows, however, that the head circumference ranges for sizes 1 - 2, 3 - 4, and 5 - 6, respectively, are 21 to 22, 22 to 23, and 23 to 24 inches. Thus, the headform values are not the midpoints of the ranges which must be accommodated. This means that unequal adjustability on each side of the mean values will be required. Table VIII presents the ranges of all dimensions which must be accommodated in the Three-Size Program. A comparison between table IV and table VIII and simple subtraction will reveal exactly what upward and downward adjustability is needed. In this manner, size 3 - 4 has a value of head circumference of 22.75 and a range of accommodation of 22 to 23 inches. Thus for helmets built to size 3 - 4, 0.75 inches of downward adjustment and 0.25 inches of upward adjustment will be required.

In providing adjustabilities for all helmets the most important areas which must be dealt with are head circumference, the frontal area and head height, and these must be accommodated in all cases. All other dimensions are of secondary importance, but the designer should strive to insure their required adjustabilities nonetheless.

Six-Size Liner Program

The design of helmet liners presents a somewhat different problem to that of adjustable helmets. The major reason for this is that liners made of plastic or rubber foam are not as adjustable as other supports, and it is difficult to predict the degree of adjustability which will be provided. A certain amount of adjustability is inherent in foam liners, because of its compressibility and linear expansion. Furthermore, there are certain devices which may prove to be very effective in yielding additional adjustability such as spacers, pads, or accurately placed slits which allow expansion. To date, no tried and true method ofenhancingthe adjustability of foam helmet liners has been developed, but the desirability and theoretical feasibility of this makes experimentation in this area a very worthwhile pursuit.

The present concept is to consider foam helmet liners as slightly expandable bodies. It was decided that the following arrangement would probably yield acceptable items. Headforms are provided having dimensions which furnish about 84 percent coverage if the liner is completely noncompressible. This results from a basic design approach using the M+1 S.D. However, since all liners will be compressible, about another 10 percent coverage will result simply by allowing an increase of not more than 0.2-inches for any straight-line dimension. Thus, liners designed over these headforms should

TABLE VII

Three-Size Head Circumference Program Means and Within-a-Size Standard Deviations

Size:	1-2	3-4	5-6	Within-a-Size S.D.
Dimension*				
1. Head circumference	21.70**	22.50	23.30	--
2. Head length	7.55	7.75	8.00	.20
3. Head breadth	5.95	6.05	6.20	.18
4. Minimum frontal diameter	4.25	4.35	4.45	.18
5. Maximum frontal diameter	4.60	4.70	4.80	.19
6. Bizygomatic diameter	5.40	5.55	5.70	.18
7. Bigonial diameter	4.20	4.30	4.35	.21
8. Bitragion diameter	5.45	5.60	5.75	.19
9. Biocular diameter	3.70	3.75	3.90	.16
10. Interocular diameter	1.20	1.25	1.30	.10
11. Interpupillary distance***	2.45	2.50	2.55	.14
12. Nose length***	2.00	2.00	2.05	.14
13. Nose breadth***	1.30	1.30	1.35	.10
14. Nasal root breadth	.60	.60	.65	.08
15. Nose protrusion***	.90	.90	.90	.11
16. Philtrum length***	.75	.80	.80	.14
17. Menton-subnasale length***	2.55	2.65	2.70	.27
18. Face length	4.55	4.65	4.75	.33
19. Menton-crinion length	7.20	7.35	7.50	.34
20. Lip-to-lip distance***	.65	.65	.65	.12
21. Lip length***	2.00	2.05	2.10	.14
22. Ear length	2.45	2.45	2.50	.16
23. Ear breadth	1.40	1.45	1.45	.10
24. Ear length above tragion	1.15	1.15	1.20	.11
25. Ear protrusion	.85	.85	.85	.14
26. Head height	5.00	5.10	5.20	.29
27. Menton projection	1.85	1.90	1.95	.26
28. External canthus to wall	6.60	6.80	6.95	.29
29. Nasal root to wall	7.55	7.75	8.00	.30
30. Tragion to wall	3.95	4.00	4.15	.29
31. Pronasale to wall***	8.30	8.65	9.00	.33
32. Sagittal arc	14.65	15.10	15.50	.54
33. Bitragion-coronal arc	13.55	13.85	14.10	.47
34. Minimum frontal arc	5.30	5.45	5.60	.39
35. Bitragion-minimum frontal arc	11.70	12.10	12.40	.37
36. Bitragion-crinion arc	12.85	13.10	13.35	.49
37. Bitragion-menton arc	12.50	12.80	13.05	.46
38. Bitragion-submandibular arc	11.75	12.10	12.45	.57
39. Bitragion-subnasale arc	11.20	11.45	11.70	.39
40. Bitragion-posterior arc	10.45	10.70	11.00	.43
41. Bitragion-inion arc	11.35	11.60	11.95	.51
42. Neck circumference	14.55	14.95	15.40	.69

* Descriptions in Appendix III.
** All values in inches
*** Not sculptured in headforms.

TABLE VIII

Design Ranges for the Three-Size Mean Head Circumference Program

Size: / Dimension*	1-2 Min.	1-2 Max.	3-4 Min.	3-4 Max.	5-6 Min.	5-6 Max.	1.65 Within-a-Size S. D.
1. Head circumference	21.00**	22.00	22.00	23.00	23.00	24.00	--
2. Head length	7.20	7.90	7.45	8.10	7.65	8.30	.33
3. Head breadth	5.65	6.20	5.80	6.35	5.90	6.50	.29
4. Minimum frontal diameter	3.95	4.55	4.05	4.65	4.15	4.75	.30
5. Maximum frontal diameter	4.30	4.95	4.40	5.05	4.50	5.10	.31
6. Bizygomatic diameter	5.15	5.70	5.25	5.85	5.40	5.95	.29
7. Bigonial diameter	3.85	4.50	3.95	4.60	4.00	4.70	.34
8. Bitragion diameter	5.15	5.80	5.30	5.90	5.40	6.05	.31
9. Biocular diameter	3.40	3.95	3.50	4.05	3.60	4.15	.27
10. Interocular diameter	1.05	1.35	1.10	1.40	1.15	1.45	.16
11. Interpupillary distance***	2.20	2.65	2.25	2.75	2.30	2.75	.23
12. Nose length***	1.75	2.20	1.80	2.25	1.80	2.25	.22
13. Nose breadth***	1.10	1.45	1.15	1.50	1.15	1.50	.17
14. Nasal root breadth	.45	.75	.45	.75	.50	.80	.14
15. Nose protrusion***	.70	1.05	.70	1.10	.70	1.10	.19
16. Philtrum length***	.50	1.00	.55	1.00	.55	1.00	.23
17. Menton-subnasale length***	2.15	3.00	2.20	3.05	2.25	3.15	.44
18. Face length	4.00	5.10	4.10	5.20	4.20	5.25	.54
19. Menton-crinion length	6.65	7.80	6.80	7.95	6.95	8.05	.56
20. Lip-to-lip distance***	.45	.85	.45	.85	.45	.85	.20
21. Lip length***	1.75	2.20	1.80	2.25	1.85	2.30	.23
22. Ear length	2.15	2.70	2.20	2.75	2.25	2.75	.26
23. Ear breadth	1.25	1.60	1.25	1.60	1.30	1.65	.17
24. Ear length above tragion	1.00	1.35	1.00	1.35	1.00	1.35	.18
25. Ear protrusion	.60	1.05	.60	1.10	.60	1.10	.24
26. Head height	4.50	5.50	4.65	5.60	4.75	5.70	.48
27. Menton projection	1.40	2.25	1.45	2.30	1.50	2.35	.42
28. External canthus to wall	6.15	7.10	6.30	7.25	6.45	7.45	.49
29. Nasal root to wall	7.05	8.05	7.25	8.25	7.50	8.50	.50
30. Tragion to wall	3.45	4.40	3.55	4.50	3.65	4.60	.48
31. Pronasale to wall***	7.75	8.85	8.10	9.20	8.45	9.55	.54
32. Sagittal arc	13.75	15.55	14.20	16.00	14.60	16.40	.90
33. Bitragion-coronal arc	12.80	14.35	13.10	14.65	13.30	14.85	.78
34. Minimum frontal arc	4.65	5.95	4.80	6.10	4.95	6.25	.64
35. Bitragion-minimum frontal arc	11.10	12.30	11.45	12.70	11.75	13.00	.61
36. Bitragion-crinion arc	12.00	13.65	12.30	13.90	12.55	14.20	.81
37. Bitragion-menton arc	11.75	13.25	12.05	13.55	12.30	13.80	.75
38. Bitragion-submandibular arc	10.80	12.65	11.15	13.05	11.50	13.40	.94
39. Bitragion-subnasale arc***	10.55	11.80	10.85	12.10	11.10	12.35	.64
40. Bitragion-posterior arc	9.70	11.15	10.00	11.45	10.30	11.75	.71
41. Bitragion-inion arc	10.50	12.15	10.80	12.45	11.10	12.80	.84
42. Neck circumference	13.45	15.70	13.85	16.10	14.25	16.55	1.14

* Descriptions in Appendix III.
** All values in inches.
*** Not sculptured in headforms.

TABLE IX

Percentile Coverage for Design Ranges of the Three-Size Mean Program

Size: Dimension*	1-2 Min.	1-2 Max.	3-4 Min.	3-4 Max.	5-6 Min.	5-6 Max.
1. Head circumference	1	20	20	80	80	98
2. Head length	1	75	12	90	32	99
3. Head breadth	2	75	10	91	20	98
4. Minimum frontal diameter	2	85	5	93	15	98
5. Maximum frontal diameter	2	90	5	95	15	97
6. Bizygomatic diameter	3	80	8	93	25	98
7. Bigonial diameter	3	90	8	95	10	98
8. Bitragion diameter	2	85	5	95	15	98
9. Biocular diameter	1	85	6	95	16	98
10. Interocular diameter	2	85	6	92	17	97
11. Interpupillary distance**	1	86	3	95	10	95
12. Nose length**	3	92	6	97	6	97
13. Nose breadth	1	90	4	96	4	96
14. Nasal root breadth	2	95	2	95	9	99
15. Nose protrusion**	3	91	3	97	3	97
16. Philtrum length**	2	96	6	96	6	96
17. Menton-subnasale length**	3	91	5	94	8	97
18. Face length	3	90	5	95	12	96
19. Menton-crinion length	2	90	5	94	13	97
20. Lip-to-lip distance**	6	96	6	96	6	96
21. Lip length**	2	89	5	94	9	97
22. Ear length	2	92	5	96	9	96
23. Ear breadth	3	94	3	94	9	97
24. Ear length above tragion	6	95	6	95	6	95
25. Ear protrusion	3	91	3	95	3	95
26. Head height	2	90	8	95	12	98
27. Menton projection	2	92	4	95	5	96
28. External canthus to wall	2	85	8	92	12	98
29. Nasal root to wall	1	82	8	92	25	99
30. Tragion to wall	2	90	8	95	12	97
32. Sagittal arc	2	78	8	95	20	98
33. Bitragion-coronal arc	2	86	8	94	15	98
34. Minimum frontal arc	2	92	5	97	9	98
35. Bitragion-minimum frontal arc	1	75	8	92	22	98
36. Bitragion-crinion arc	1	86	5	92	12	98
37. Bitragion-menton arc	2	88	8	94	18	98
38. Bitragion-submandibular arc	1	81	6	94	15	98
39. Bitragion-subnasale arc**	1	80	9	92	20	98
40. Bitragion-posterior arc	1	82	5	94	20	98
41. Bitragion-inion arc	1	82	5	91	15	98
42. Neck circumference	2	88	6	92	16	98

* Descriptions in Appendix III.
** Not sculptured in headforms.

accommodate about 95 percent of the Air Force flying population.

Liners should be built directly over the Six-Size Liner Headform Series and shells then built over the liners. These liners and shells must accommodate the same people as the Six-Size Mean Program, and therefore the shells must cover the maximum values presented in table V. In determining shell dimensions it is essential to make the liners thick enough and the shells large enough so that even when the liner is compresssd by large heads in each size, the protective and comfort qualities of the helmet will not be compromised. It is also believed that it will be possible to have only 3 shells, designed over liner headforms 2, 4, and 6, for the 6 liners. Thus, liners 1 and 2 will both use the shell designed over headform and liner 2, liners 3 and 4 will both use the shell designed over headform and liner 4, and liners 5 and 6 will both use the shell designed over headform and liner 6. In order to accomplish this, the smaller liners in each duet, that is 1, 3, and 5, will have to be thicker than liners 2, 4, and 6 so that the outside dimensions of liners 1 and 2 will be equal, 3 and 4 will be equal, and 5 and 6 will be equal. This should not result in too much added bulk in the smaller liner for each of the 3 shells.

The design limits and values for the Six-Size Liner Program (table X) offer a compromise which is based on a studied consideration of the various problems concerned. While the M ± 1 S.D. served as the overall design criterion, a number of deviations from this were deemed necessary. These are discussed below:

1. The top of each size range for head circumference must be adhered to. Therefore, all dimensions which help to make up the shape and size of the head with head circumference must be considered in the same terms as the latter or incompatabilities will appear. The dimensions primarily concerned are head length and breadth together with those dimensions which are closely associated with these, namely: bitragion diameter, bizygomatic diameter and the wall-to-measurements of external canthus, nasal root, and tragion. In order to provide design values which insure adequate percentage coverage and which also integrate decently into the sculptured headforms, it was decided to use regression equation values of the above dimensions. These values were determined by using the upper limit of head circumference for each size interval. These regression equation values then represent the mean values of the various dimensions corresponding to the design values of head circumference.

2. A second problem concerns that of assuring adequate clearance in the frontal region. During the fit-test of the prototype MA-3 helmet, it was noted that more than 80 percent of the subjects had discomfort in the frontal region (ref. 1). Therefore, it is essential that as little pressure as possible be created in this region. Therefore, those dimensions concerned with this area are designed to the higher value of the M + 1.65 S.D. Those dimensions are the minimum frontal diameter and arc, the maximum frontal diameter, and the bitragion-minimum frontal arc.

3. Ears constitute a distinct problem. Maximum clearance must be assured. For this reason, the M + 1.65 S.D. is the chosen design factor. Since the ears are distinct entities from the rest of the head, no problem is created by making the ears maximum. For additional pertinent comments concerning ears, attention is invited to page 37 of this report.

4. The facial area poses another problem. This area is able to absorb considerable pressure without discomfort. The larger-faced man can therefore endure some compression in this region. On the other hand, the small-faced man suffers a penalty when the facial area is too large. Because the wearer of a pressurized helmet has extreme

TABLE X

Design Values for the Six-Size Liner Program

Size: Dimensions*	Design Limit	1	2	3	4	5	6
1. Head circumference	Upper Limit	21.50**	22.00	22.50	23.00	23.50	24.00
2. Head length	Regression	7.50	7.65	7.80	7.90	8.05	8.15
3. Head breadth	Regression	5.90	6.00	6.10	6.15	6.25	6.35
4. Minimum frontal diameter	M + 1.65 S.D.	4.50	4.60	4.65	4.70	4.75	4.80
5. Maximum frontal diameter	M + 1.65 S.D.	4.90	4.95	5.00	5.05	5.10	5.15
6. Bizygomatic diameter	Regression	5.40	5.45	5.55	5.65	5.70	5.80
7. Bigonial diameter	M	4.15	4.20	4.25	4.30	4.35	4.40
8. Bitragion diameter	Regression	5.45	5.50	5.60	5.70	5.75	5.85
9. Biocular diameter	M + 1 S.D.	3.80	3.85	3.90	3.95	4.00	4.05
10. Interocular diameter	M + 1 S.D.	1.30	1.30	1.35	1.35	1.40	1.40
14. Nasal root breadth	M + 1 S.D.	.65	.70	.70	.70	.70	.70
18. Face length	M + 1 S.D.	4.90	4.95	4.95	5.00	5.05	5.10
19. Menton-crinion length	M + 1 S.D.	7.45	7.55	7.65	7.75	7.85	8.00
22. Ear length	M + 1.65 S.D.	2.65	2.70	2.70	2.75	2.75	2.80
23. Ear breadth	M + 1.65 S.D.	1.55	1.60	1.60	1.60	1.65	1.65
24. Ear length above tragion	M + 1.65 S.D.	1.35	1.35	1.35	1.35	1.35	1.35
25. Ear protrusion	M + 1.65 S.D.	1.10	1.10	1.10	1.10	1.10	1.10
26. Head height	M + 1 S.D.	5.25	5.30	5.35	5.45	5.50	5.55
27. Menton projection	M + 1 S.D.	2.05	2.05	2.10	2.15	2.20	2.25
28. External canthus to wall	Regression	6.60	6.70	6.80	6.90	7.00	7.10
29. Nasal root to wall	Regression	7.50	7.65	7.75	7.90	8.00	8.15
30. Tragion to wall	Regression	3.90	3.95	4.05	4.10	4.15	4.25
32. Sagittal arc	M + 1 S.D.	15.10	15.30	15.50	15.75	15.95	16.15
33. Bitragion-coronal arc	M + 1 S.D.	13.90	14.05	14.25	14.40	14.55	14.70
34. Minimum frontal arc	M + 1.65 S.D.	5.95	6.00	6.05	6.10	6.20	6.25
35. Bitragion-min. frontal arc	M + 1.65 S.D.	12.15	12.35	12.55	12.75	12.95	13.15
36. Bitragion-crinion arc	M + 1 S.D.	13.20	13.35	13.50	13.65	13.85	14.00
37. Bitragion-menton arc	M	12.35	12.55	12.70	12.90	13.05	13.25
38. Bitr.-submandibular arc	M	11.60	11.80	12.00	12.20	12.40	12.60
40. Bitragion-posterior arc	M + 1 S.D.	10.65	10.85	11.05	11.20	11.40	11.60
41. Bitragion-inion arc	M + 1 S.D.	11.70	11.85	12.05	12.20	12.40	12.60
42. Neck circumference	M	14.40	14.65	14.85	15.05	15.30	15.50
-- Nasal root-tragion***	Mean Dif.	1.05	1.05	1.05	1.05	1.05	1.05
-- Internal canthus-tragion***	Mean Dif.	.75	.75	.75	.75	.75	.75

* Descriptions in Appendix III.
** All values in inches.
*** Descriptions appear in text, p. 35.

difficulty in turning his helmet unless his face is in contact with the liner, some compromise is needed. The best solution are adjustable cheek pads. For the designer, it probably would be convenient to have the adjustability up and down from the mean values of the several facial dimensions. These are the bitragion-menton and bitragion-submandibular arcs and the bigonial diameter. As will be noted in Section V, it was not possible to maintain all of these dimensions to the mean values.

5. The decision to make the neck circumference to the mean value was mainly for the sake of appearance, since it will not often be used in helmet design. However, data are provided should this need arise (see page 37).

6. All other design dimensions, as noted below, are the M+ 1 S.D.: sagittal arc, bitragion-coronal arc, bitragion-crinion arc, bitragion-posterior arc, bitragion-inion arc, biocular diameter, interocular diameter, nasal root breadth, menton-crinion length, menton projection, head height, and face length.

Of the above dimensions bitragion-posterior arc and bitragion-inion arc, and to a lesser extent, bigonial diameter, bitragion-crinion arc, menton-crinion length, and menton projection, are based on ill-defined points, and therefore were used as guides in sculpturing the headforms, rather than as absolute values. That is, these dimensions were adhered to whenever possible in sculpturing the headforms, but were not adhered to if it would have compromised other more important and more reliable dimensions.

7. General vertical relationships between the point tragion and various facial landmarks were established by subtracting mean values of the various measurements involved as determined from the 1950 Survey (ref. 12). Tragion height (from floor) was subtracted from dimensions similarly taken to the internal canthus and to the nasal root depression. The use of the mean differences is justifiable (a) in view of the very low correlations of these dimensions with other head and facial dimensions, (b) the fact that the three dimensions have almost equal variabilities and (c) because there is the possibility of magnifying small errors taken over large critical distances when these are subtracted from each other. These relationships, therefore, are identical for all sizes.

Table XI shows the percentiles of each value as compared with the 1950 Survey of Air Force flying personnel (ref. 12).

Because of the nature of the values which are included in the liner headforms, it is recommended that they be used only in the design of liner helmets and not be used as guides for making other types of helmets without prior consultation with the Aerospace Medical Division.

Special Dimensions

As previously noted, the dimensions considered for our current efforts were those taken in the 1950 Survey of Air Force flying personnel. There are, however, three dimensions, important in helmet design which are not described in that publication. Illustrations of the locations of the first two mentioned dimensions are included in Appendix III.

1. Face length. The vertical distance between the midpoint of the nasal root depression and menton.

TABLE XI

Percentile Coverage for the Six-Size Liner Program

Size:	1	2	3	4	5	6
Dimension*						
1. Head circumference	5	20	50	80	95	98
2. Head length	20	32	60	75	88	92
3. Head breadth	20	40	58	67	81	92
4. Minimum frontal diameter	77	91	93	96	98	99
5. Maximum frontal diameter	84	89	92	95	97	98
6. Bizygomatic diameter	24	31	52	71	80	90
7. Bigonial diameter	32	45	48	65	68	75
8. Bitragion diameter	22	40	60	75	78	88
9. Biocular diameter	55	65	75	85	90	95
10. Interocular diameter	70	70	85	85	92	92
14. Nasal root breadth	70	88	88	88	88	88
18. Face length	80	83	83	85	88	90
19. Menton-crinion length	62	72	78	88	91	97
22. Ear length	87	92	92	96	96	98
23. Ear breadth	85	94	94	94	97	97
24. Ear length above tragion	95	95	95	95	95	95
25. Ear protrusion	95	95	95	95	95	95
26. Head height	68	75	78	88	90	92
27. Menton projection	78	78	85	88	90	92
28. External canthus to wall	30	45	55	70	80	85
29. Nasal root to wall	25	38	48	70	80	88
30. Tragion to wall	40	42	52	65	68	78
32. Sagittal arc	50	65	75	87	92	97
33. Bitragion-coronal arc	60	68	82	88	91	95
34. Minimum frontal arc	91	92	94	97	98	98
35. Bitragion-minimum frontal arc	62	78	88	94	97	99
36. Bitragion-crinion arc	60	68	80	88	91	95
37. Bitragion-menton arc	19	32	45	60	72	82
38. Bitragion-submandibular arc	20	30	45	60	70	80
40. Bitragion-posterior arc	48	62	78	85	92	96
41. Bitragion-inion arc	55	68	78	85	90	95
42. Neck circumference	20	33	48	58	70	80

* Descriptions in Appendix III.

2. Pronasale to wall. The horizontal distance between the tip of the nose and a vertical plane tangent to the rearmost part of the head positioned in the Frankfort Plane (as defined in the Glossary--Appendix I).

3. Neck ring clearance. Based on a special survey of 47 subjects, it was found that an 8.5-inch minimum is required for the neck ring component of those pressure helmets using this method of integrating the helmet with a pressure suit (ref. 1). A ring of this size will work only if the back of the ring is lowered into the musculature of the neck just below the skull base, while the forward portion of the ring is held above the forehead; the forward portion is then swung downward over the face. This technique permits an appreciably smaller ring diameter than would be possible if the ring were lowered horizontally over the head since it avoids the nose and the usual protrusion at the back of the skull.

The values for face length were derived by the addition of nose length and menton-subnasale length. The S.D. for this dimension was statistically determined from those of the aforementioned two dimensions (ref. 5). Differences between the added values and actual values in a small sample proved to be trivial from a practical standpoint (ref. 9).

To obtain the values for pronasle to wall, measurements were taken from a selected series of slides, 20 for each of the 6 size intervals. These slides were obtained in 1957 during a Photometric survey of some 2,000 Air Force flying personnel (ref. 22).

Special Considerations

As has already been suggested, special consideration is required for the ears, neck circumference, and facial dimensions.

1. Ears. The ears must be to the maximum values recorded in tables V (Six-Size Program) and VIII (Three-Size Program). These values have been sculptured into the liner headforms; however, only mean values are included in the mean headforms. Therefore, in considering the ears for helmets designed over the mean headforms, the maximum values in tables V and VIII should be referred to.

There is another factor involving the ears which cannot easily be built into headforms. This factor is the variability of the horizontal and vertical location of the ears. The most convenient way to indicate this variability is to demonstrate how the point tragion moves around and to use the maximum values on tables V and VIII to represent the dimensional clearances required for the ear itself. The movement of tragion for both the mean and liner headforms is 0.5 inch forward and backward from tragion as located on each headform. For up and down movement of tragion, different values must be used for the mean headform series and for the liner headforms. For both the Three- and Six-Size Mean Headform Series, tragion may be expected to vary 0.5-inch up and down from the postion on the headforms. For the Six-Size Liner Headform Series, tragion moves up 0.8 inch and down 0.2 inch from the position on each headform.

2. Neck circumference. All headforms have mean neck circumference values sculptured into them. The mean was chosen arbitrarily for several reasons. Depending on the helmet problem, different design values will be applicable. For some helmets neck circumference does not even enter into the problem. Lastly, as already mentioned, mean values seem to integrate more adequately from a sculptural standpoint.

To construct neck seals, then, other information is needed. A minimum neck circumference is desired to insure a fit for the smallest neck. For larger necks, where the seal might be irritatingly tight, the seal can be trimmed to the proper fit; a maximum neck circumference will indicate to what values the seals must be trimmed. Tables V and VIII give the minimum and maximum values for the various programs.

3. Facial dimensions. The current programs and associated headform series have not been designed for use in the sizing of facial gear. Certain dimensions have been incorporated in the forehead-eye and vertical facial areas for helmet clearance problems only. It would be a grave mistake to fabricate goggles, oxygen masks, or gas masks over these forms. Attention is invited to special faceforms which have been developed for facial gear construction (ref. 9).

Fitting Table and Suggested Tariffs

Table XII represents a fitting chart and estimated procurement tariff (per 1000) for all Three- and Six-Size Head Circumference Programs discussed in this report (mean and liner). As also defined in Appendix III, the fitter need only take head circumference with a tape passing above (but not including) the brow ridges, measuring the maximum circumference of the head.

Table XII

Fitting Table and Suggested Tariffs for the Three- and Six-Size Head Circumference Programs

Program	Size	Interval of Head Circumference (in.)	Suggested Tariff* (per 1000)
Six-Size (mean and liner)	1	21.0 - 21.5	54
	2	21.5 - 22.0	171
	3	22.0 - 22.5	310
	4	22.5 - 23.0	269
	5	23.0 - 23.5	149
	6	23.5 - 24.0	47
Three-Size (mean)	1-2	21.0 - 22.0	225
	3-4	22.0 - 23.0	579
	5-6	23.0 - 24.0	196

*Proportion of 1950 survey sample theoretically included - 97%.

SECTION V

HEADFORM SERIES AND SCULPTURING TECHNIQUES

General

A series, as previously defined, is a concrete expression of a sizing program. Conventional linear and arc dimensions do not adequately indicate shape. Three-dimensional forms, therefore, serve to directly interpret these standard data for the designer. To provide such representations of anthropometric data for the 3 sizing programs discussed in Section IV, Mr. Seth Velsey, a professional sculptor, was retained, to provide his trained eye to supply the details of surface shape. Two distinct series of headforms were sculptured: the Six-Size Mean Headform Series to the data presented in table IV and the Six-Size Liner Headform Series to the data presented in table X. As noted later in this Section, the Three-Size Mean Headform Series consists of 3 of the forms of the Six-Size Mean Headform Series.

Techniques

Plaster of paris was selected as the medium in which to work because of the ease with which it can be handled. Hollow plaster blanks served as the foundations for the desired headforms. As an aid in building up this blank to dimensional values, copper nails were driven into it at various selected points including known landmarks. Taking tragion as the first point, nails could then be placed with accuracy at glabella, inion, and the point where the bitragion-coronal arc crosses the midsagittal plane. On the liner headforms, this last point was changed to that of the highest point on the head or vertex, whereas on the mean headform series, vertex is about 0.1-inches higher than this coronal nail point. Nails were also placed to simulate the maximum diameter of head breadth and of the zygomatic arches. Menton was marked by nails on the liner headforms, but not on the mean headforms. In each instance, the nails protruded from the blank to the desired design value. Plaster was then added to fill in the space between the nail and the blank. The arc measurements, as well as head circumference, were then tried and plaster either added or removed as required.

This technique met with few problems when used with the mean headform series; however, when used with the liner headform series, a number of anomolies developed because of the complexity of the design rationale and compromises had to be made. Thus it was found that in order to maintain the values of the maximum frontal diameter, somewhat larger browridges were needed than for the mean headforms. This was especially true for the largest of the liner headforms.

After each headform was sculptured, it was measured to insure there was no more than a plus or minus 0.1-inch difference between the statistical and the sculptured values (plus represents a sculptured value greater than the statistical one and minus, the reverse). Changes were made as needed. The final differences are noted in table XIII for the mean headform series and in table XIV for the liner headform series. As will be noted, the majority of the values fall within the 0.1-inch allowable sculpturing error. It is believed that none of those which exceed these limits will have any detrimental effect on sizing of helmets. In the main, the differences reflect the choice of the senior project engineer in cases of sculpturing incompatability between dimensions. This is true for the differences noted for bitragion-posterior arc, bitragion-inion arc, bitragion-minimum

TABLE XIII

Differences Between Statistical and Sculptured Values for the Mean Headform Series

Size:	1	2	3	4	5	6
Dimension*						
1. Head circumference	+.05**	.00	-.05	-.05	.00	-.04
2. Head length	+.05	.00	+.01	+.05	+.05	.00
3. Head breadth	.00	+.01	+.01	+.03	+.05	.00
4. Minimum frontal diameter	+.15	+.27	+.15	+.22	+.05	+.10
5. Maximum frontal diameter	+.10	-.02	+.07	.00	+.07	+.10
6. Bizygomatic diameter	+.01	+.01	+.01	+.05	+.02	.00
7. Bigonial diameter	-.20***	-.20***	-.15***	+.10***	+.10***	-.30***
8. Bitragion diameter	+.02	+.03	+.01	+.05	+.03	+.03
9. Biocular diameter	+.10	+.08	+.10	+.05	+.03	+.01
10. Interocular diameter	+.01	+.04	-.01	+.01	-.03	.00
14. Nasal root breadth	+.10	+.10	+.10	-.01	.00	+.04
18. Face length	+.12	+.12	+.24	+.27	+.20	+.17
19. Menton-crinion length	+.10	+.10	+.05	+.03	-.04	-.12
22. Ear length	+.02	+.05	+.05	+.01	+.05	+.05
23. Ear breadth	+.05	+.05	.00	.00	+.02	+.05
24. Ear length above tragion	.00	+.10	.00	+.04	+.05	+.02
25. Ear protrusion	.00	-.01	+.01	.00	.00	-.01
26. Head height	-.01	.00	+.10	+.03	+.05	+.05
27. Menton projection	+.10	+.10	+.03	+.10	+.03	+.10
28. External canthus to wall	+.05	+.05	+.01	+.05	-.05	-.05
29. Nasal root to wall	+.05	+.01	-.05	.00	-.09	-.04
30. Tragion to wall	.00	.00	-.01	-.05	.00	-.10
32. Sagittal arc	-.05	-.05	-.05	-.03	-.08	-.04
33. Bitragion-coronal arc	.00	.00	.00	-.02	-.05	+.03
34. Minimum frontal arc	+.10	+.05	.00	-.05	+.05	-.10
35. Bitragion-minimum frontal arc	-.20	-.10	-.06	-.10	+.05	-.03
36. Bitragion-crinion arc	-.20	-.15	-.20	-.22	-.15	-.30
37. Bitragion-menton arc	-.10	+.05	-.02	-.09	-.05	-.05
38. Bitragion-submandibular arc	-.08	-.02	.00	+.05	-.10	-.05
40. Bitragion-posterior arc	+.60	+.40	+.45	+.37	+.50	+.50
41. Bitragion-inion arc	.00	-.08	-.23	-.17	+.10	+.20
42. Neck circumference	.00	-.05	+.05	+.10	.00	+.05

* Descriptions in Appendix III.
** All values in inches.
*** Approximation.

TABLE XIV

Differences Between Statistical and Sculptured Values for the Liner Headform Series

Size:	1	2	3	4	5	6
Dimension*						
1. Head circumference	.00**	+.02	.00	-.05	.00	.00
2. Head length	.00	.00	.00	+.05	.00	+.01
3. Head breadth	.00	-.02	.00	+.02	.00	+.02
4. Minimum frontal diameter	-.04	+.05	.00	+.05	-.02	+.07
5. Maximum frontal diameter	+.05	+.05	-.02	+.05	+.03	+.01
6. Bizygomatic diameter	+.05	+.05	+.06	.00	+.05	.00
7. Bigonial diameter	+.05***	.00***	.00***	+.05***	.00***	+.10***
8. Bitragion diameter	.00	.00	.00	+.02	.00	+.02
9. Biocular diameter	+.05	+.03	.00	+.02	-.02	.00
10. Interocular diameter	-.05	-.03	-.05	+.03	-.03	.00
14. Nasal root breadth	+.02	.00	-.02	+.04	.00	.00
18. Face length	+.02	+.02	+.05	-.02	+.03	+.02
19. Menton-crinion length	+.04	-.03	.00	+.13	.00	-.25
22. Ear length	+.06	+.04	+.01	.00	+.01	.00
23. Ear breadth	-.04	.00	+.02	+.01	.00	+.05
24. Ear length above tragion	-.02	-.02	-.04	-.01	-.03	+.01
25. Ear protrusion	.00	-.02	.00	+.05	.00	-.08
26. Head height	-.04	.00	.00	-.05	-.02	+.03
27. Menton projection	-.03	.00	-.05	-.10	-.05	+.04
28. External canthus to wall	-.04	+.05	-.03	.00	-.05	+.08
29. Nasal root to wall	+.04	+.01	+.04	-.09	.00	.00
30. Tragion to wall	.00	.00	-.05	-.08	-.09	.00
32. Sagittal arc	-.02	.00	-.02	-.05	-.05	-.05
33. Bitragion-coronal arc	+.07	-.03	+.05	-.05	+.02	-.07
34. Minimum frontal arc	+.05	.00	+.05	+.10	.00	-.05
35. Bitragion-minimum frontal arc	+.05	-.05	+.03	-.05	+.05	-.05
36. Bitragion-crinion arc	+.05	.00	.00	-.03	+.05	-.30
37. Bitragion-menton arc	+.05	+.07	.00	+.30	-.05	+.05
38. Bitragion-submandibular arc	.00	+.01	.00	-.05	.00	-.05
40. Bitragion-posterior arc	+.45	+.85	+.60	+.85	+.60	+.40
41. Bitragion-inion arc	-.40	+.05	-.15	+1.00	+.30	-.30
42. Neck circumference	.00	.00	.00	.00	.00	.00
-- Tragion height-nasal root height	+.10	.00	.00	-.05	.00	+.10
-- Tragion height-inner canthus height	+.01	-.05	.00	-.05	-.14	.00

* Descriptions in Appendix III.
** All values in inches.
*** Approximation.

frontal arc, minimum frontal diameter, and bitragion-menton arc. Differences for the first two dimensions result from the fact that these were measured on live subjects with the ears depressed which is impossible to do on solid headforms. Since experience has demonstrated that a large frontal area is desirable (ref. 5), the one instance in which the bitragion-minimum frontal arc exceeds the sculpturing error should be of benefit as is also true for the larger minimum frontal diameters. On the liner headforms, it was not possible in all instances to sculpture the bitragion-menton arc to the desired mean values while attempting to maintain the design limit for face length. Therefore, the bitragion-menton arc represents the minimum possible for each liner headform consistent with the desired face length.

Differences between the sculptured and statistical values for bitragion-crinion arc and menton-crinion length must be considered in different terms than the above. After sculpturing the complete mean headform series and two of the liner headform series (sizes 4 and 6) and while the statistics incorporated into these headforms were being validated in developmental helmets, it was discovered that an error had been made in calculating the design values for these two dimensions (as a result of not eliminating subjects on whom these dimensions were not taken because of baldness or other reasons). At best, these dimensions are not well defined since the point crinion does not represent an anatomical landmark; however, they do aid in determining head proportions and shapes. Generally, the differences between the statistical values and the sculptured ones are not excessive from a practical standpoint. In this connection, it should be noted that the longer face lengths on the mean headforms (resulting from the attempt to maintain menton-crinion length) are of little or no significance since face gear should not be designed over these headforms. Liner headforms 1, 2, 3, and 5 reflect the corrected data for bitragion-crinion arc and menton-crinion length. Correct values for these dimensions are included in all tables.

Figure 6a, b, and c depict the mean headforms. Headforms 2, 4, and 6 comprise the Three-Size Mean Headform Series, whereas all of the headforms constitute the Six-Size Mean Headform Series.

Figures 7a, b, c, and d demonstrate the differences between the mean headforms and liner headforms as illustrated by size 4 of each series; the former is distinguished by the letters HC and the latter by HCL carved into the base of each headform.

A plaster-of-paris mold was made for each headform. To prevent expansion of the poured headform on hardening, special four-way clamps were used. This approach was most effective.

It is again noted that the headforms have not been fabricated for use in sizing facial gear. It would be a mistake to design goggles, oxygen masks, or gas masks over these forms. Attention is invited to the special faceforms which are available through the Aerospace Medical Division (ref. 9).

One last aspect of this program should be referred to, namely, the feasibility of translating the data in tables V and VIII (design ranges) into headforms so that designers could construct shells directly over such headforms. The headforms reflected in figures 8a, b, c, and d clearly demonstrate that this is not feasible when attempting to maintain head circumference to the upper limit for each size. Furthermore, anyone who has worked with designing rigid or semi-rigid helmets appreciates the uniqueness of each helmet, and it therefore seemed desirable not to restrict the helmet designer to specific shell shapes through maximum headforms. That there may be a variety of shell shapes designed over the same headforms has been demonstrated by those helmets which have been sized over the current forms. This leeway is provided even though the maximum design values are virtually the same for all helmets designed to these headforms. Lastly, there is the very simple fact that the fewer the headforms on hand the less chance there is for a designer to mis-apply them.

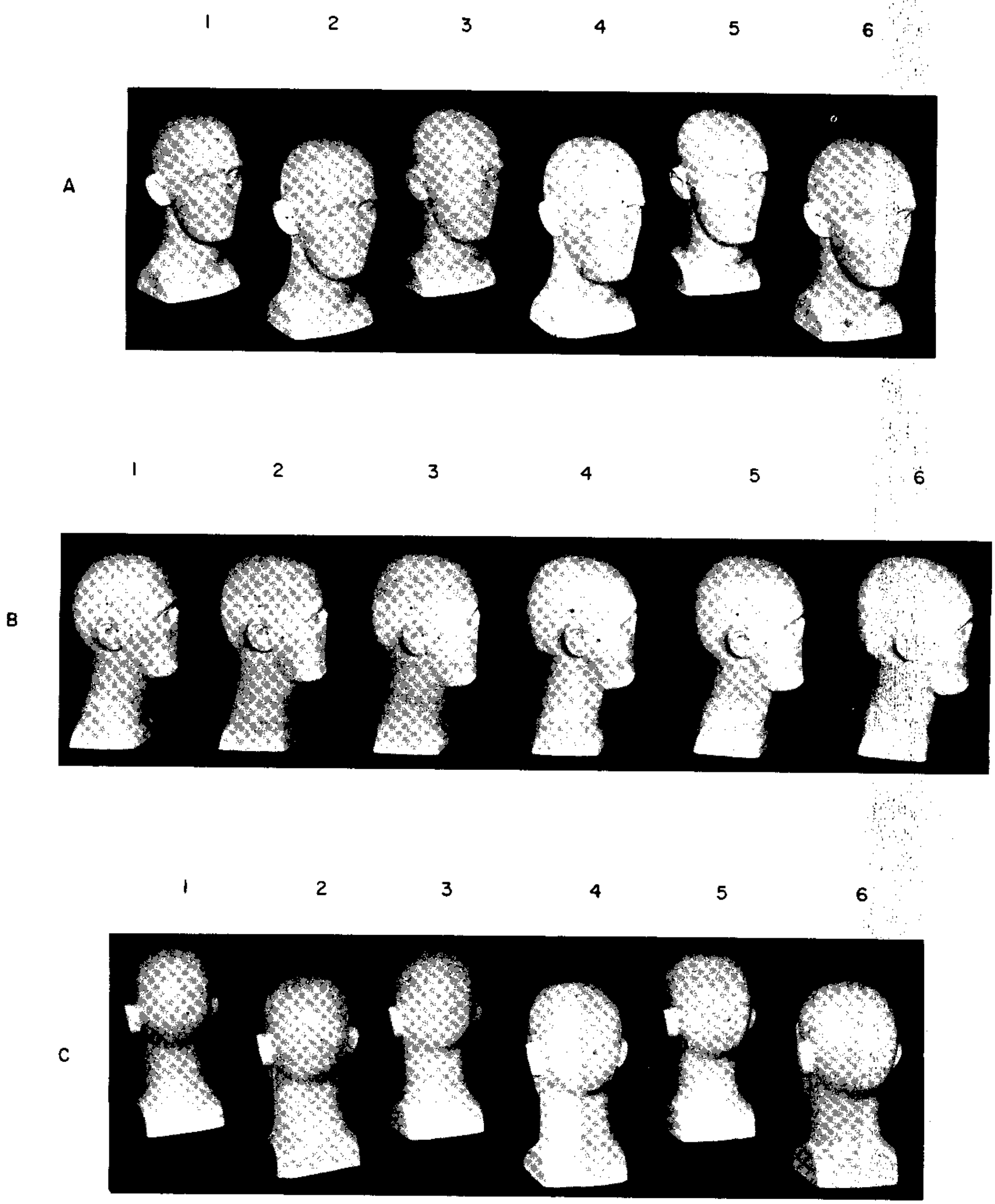

Figure 6. Three- and Six-Size Mean Headform Series

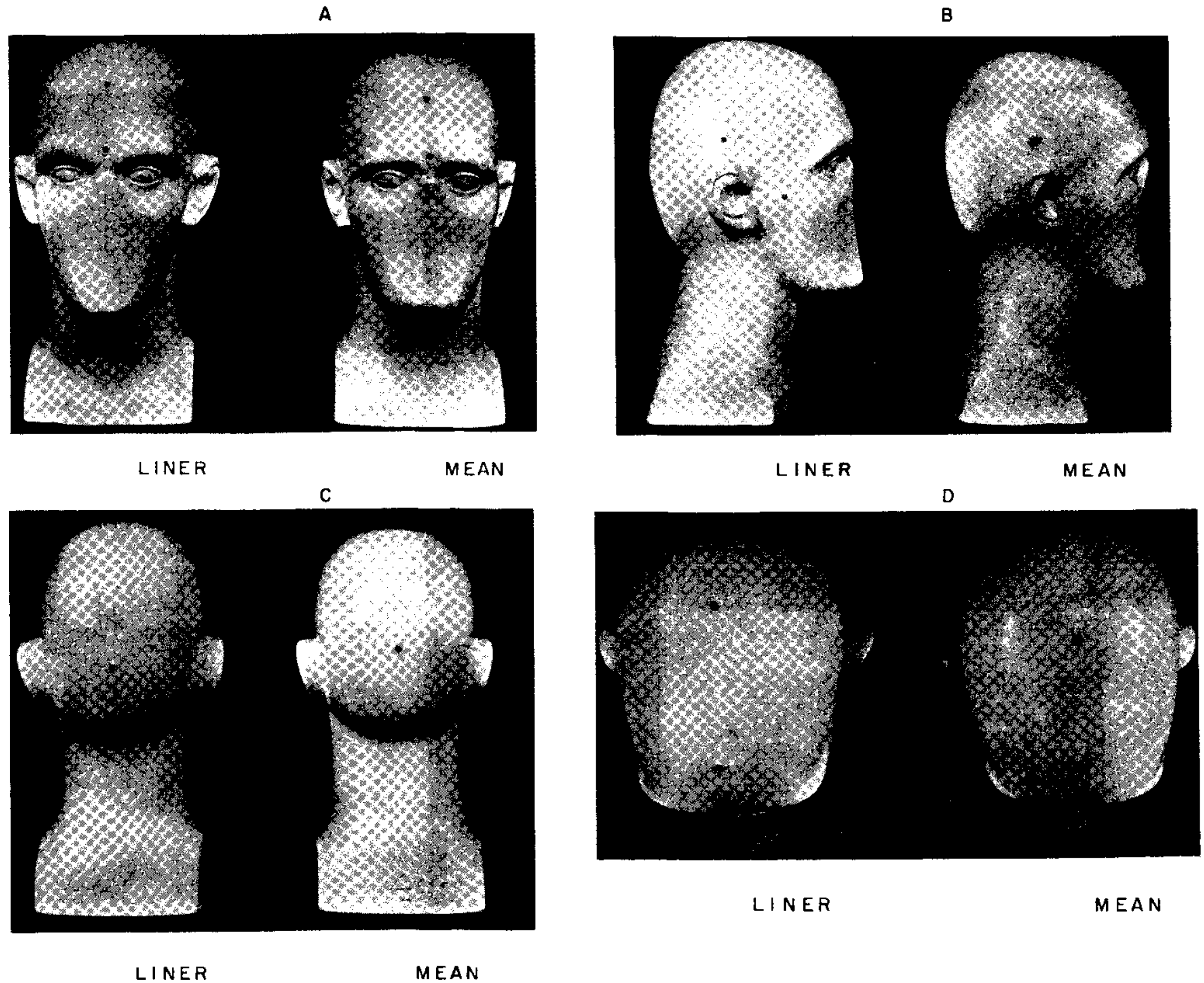

Figure 7. Mean and Liner Headforms, Size 4

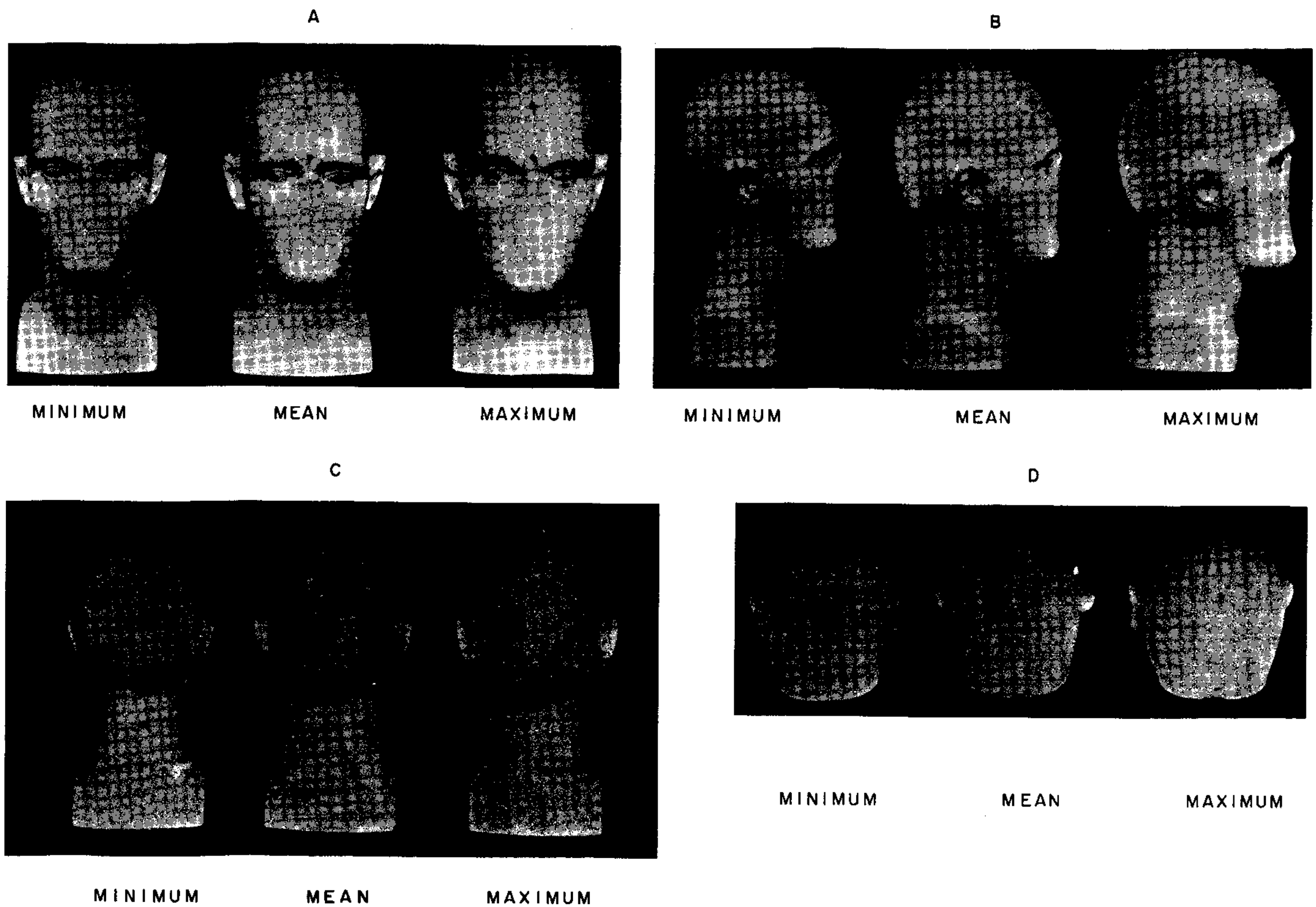

Figure 8. Minimum, Mean, and Maximum Headforms, Size 4

Instruments

Standard anthropometric measuring instruments (tape, anthropometer, sliding and spreading calipers) as shown in Figure 9, were used both by the sculptor and the project engineer.

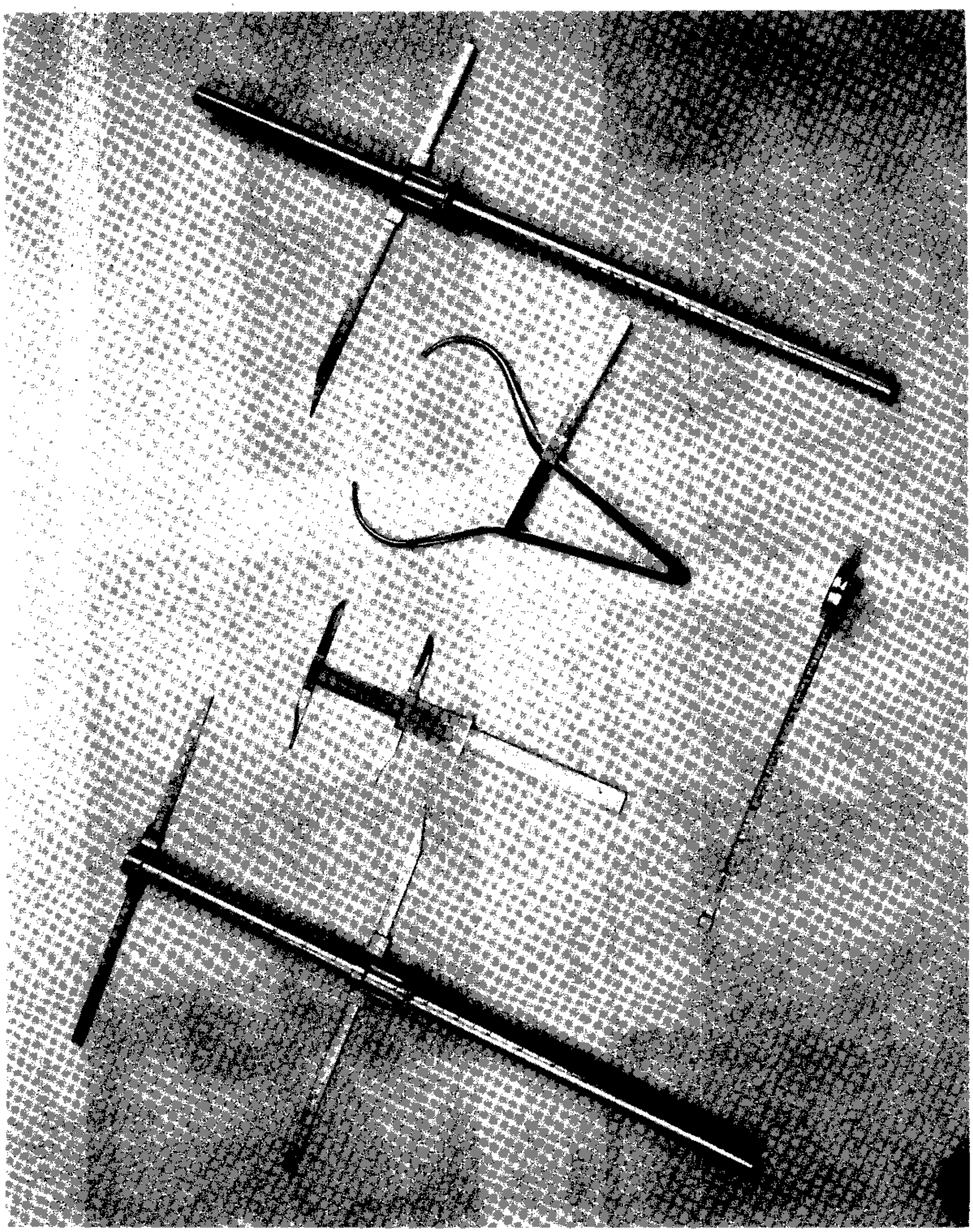

Figure 9. Anthropometric Instruments

SECTION VI

VALIDATION TESTS

General Concepts

The previous Sections of this report have dealt with the basic considerations for development of a sizing system, its component sizing programs and resultant headform series. The final test to which this "theorizing" must be put is application of the sizing data into appropriate developmental items. The Anthropology Section must test such prototype items for fit and comfort. This validation or "fit" test, as it is more commonly called, is the final step before the sizing and design data can be released for general usage. As such, the validation test may be regarded as the final phase of the presentation of sizing data for the designers of personal protective equipment. The procedures followed in the validation phase are common to all such items. An exposition of these procedures is included below as they have not been fully defined in past publications.

The validation test is conducted on a prototype series of a specific item. It serves to verify the accuracy of the raw data gathered during the survey, the statistical methods and analysis employed in transforming the raw data into the working sizing program, and the effectiveness of the integration of the sizing data with the materials of which the item is composed. The entire developmental program is put to a final test during the validation phase to determine how the item fits and protects the wearer.

Sizing data alone are not the sole determinants of item fit. Indeed, a sizing program alone is merely a presentation of the nude dimensions of a using population, statistically treated. Each piece of equipment must be treated individually, especially in terms of its function which is the overall governing factor. Function determines the way the item or garment is to fit the wearer and, to some extent, dictates the materials from which it will be made. The individual decisions to be made for integration of the sizing program, materials and design must of necessity be a series of compromises. A number of these have been suggested in previous Sections of this report.

The validation test generally proceeds along the following steps:

1. Selection of the subjects to insure a representative sample of the Air Force flying population.

2. Measurement of key dimensions and of other critical dimensions.

3. Determination of the indicated size.

4. Fit and comfort evaluation.

Selection of the sample is of primary importance in conducting a test of this nature. The sample must be composed of a legitimate cross-section of the potential using population. The general criteria of age, sex, and status (military or civilian, rated or non-rated) are complied with from the outset. From that point, body dimensions become the main criteria for selection.

As previously noted in this report, the key dimensions serve as the basis for selecting the indicated size, that is the size the person should wear. In the validation test, these dimensions are measured as precisely as possible, adhering strictly to the techniques used in taking the same dimensions during the basic anthropometric survey. Effort is made to have the measuring done by one investigator thus minimizing intra-measurer variability. Selected critical dimensions which are included in the sizing program are also measured according to the same careful standards. This is done to insure that the minimum-maximum (small-large) coverage for each of these dimensions within each size interval is included in the validation test, if possible. Examples of such coverage may be seen in tables V and VIII. It will be observed in table V, for example, that for persons with head circumferences between 21.0 and 21.5 inches, there may be those with head lengths as large as 7.80 inches and as small as 7.15 inches and comparable head breadth values of 6.15 and 5.60 inches. Of course for the indicated head circumference interval you could not have maximums or minimums of the two linear head dimensions, but you must expect to cover each of these values independently. This factor again clearly indicates why the helmet shells must accommodate the maximum values shown in tables V and VIII.

It is quite obvious that the validation test should include coverage of the extremes of the intervals of the key dimensions i.e., - - 21.0 to 21.5 in the example referred to in the previous paragraph. Normally if this is done on a large enough sample, minimum-maximum coverage will also be provided for the critical dimensions which have been measured.

A fitting chart presents the key dimensions divided into the size intervals used in formulating the sizing program. At times these dimensions may overlap or be borderline from one size to the next. When the key dimensions fall in this "grey" area, a choice must be made as to which size is considered the indicated one. A policy must be formulated before the validation test starts, based on desired fit and the amount of adjustability, as to which size should be chosen. Once this decision is made it must be adhered to throughout the test. It goes without saying that the fitting chart should be simple with a minimum of confusing guides. Also, measurement instruments should be, if possible, of a conventional nature and be easy to procure. We previously observed that the fitting personnel in the field are not trained anthropologists and do not have ready access to anthropometric instruments.

Evaluation is the final step in the validation test. If the test is to be effective at all the criteria for fitting must be established before the test commences.

In cases where the item to be tested has a protective function it is essential that fit is evaluated commensurate with that function. Comfort, which is implied in fit, is important but secondarily so, in the case of equipment which must exert pressure on the body in order to protect it; e.g. anti-g suit or partial pressure suit. However, there is a point beyond which comfort can no longer be sacrificed. That point is reached when the item affords so much discomfort to the wearer, that he must remove and discard it. At this point the entire developmental program is a failure. Therefore, when sizing and designing any item of personal equipment, comfort must be a prime factor in choice of sizing and materials. The relationship of fit and comfort on the one hand and protection on the other must be established between the physiologists and anthropologists.

There is one aspect of validation tests that sometimes tends to obscure the results in terms of sizing data input; that is, the specific design features of an item which cause discomfort such as pressure on the skin, binding of cloth, scratching of zippers, etc. For example, in a form-fitting helmet the presence of sewn seams on the inside portion tend to bow out and cause excessive ridging thereby exerting pressure points on the head. The sizing program could be quite adequate, yet the pressure resulting from such a seam could invalidate it. It becomes important then to recognize those discomfort features of the item, to distinguish between them, and to determine whether they are a function of sizing or a function of design. At times these discomfort features are so numerous that a sizing program cannot be objectively evaluated (ref. 1).

Validation of the Three-Size Mean Head Circumference Program

It should be quite clear that validating a sizing program is a continuing matter due largely to the variation in the functions of the items being sized. Nonetheless, each successful test goes further to demonstrate the basic validity of the data and statistical rationale and analysis used. The exceptions that might arise could be attributed to peculiarities of function, and some modification of the original approach must be made to accommodate this situation.

Our main concern in the present instance is to test the validity (1) of the shapes introduced into the head circumference headform series and (2) of the associated minimum and maximum coverage values or design ranges as reflected in tables V and VIII. Several prototype developmental low-altitude and high-altitude or pressure helmets were designed over the various headform series discussed in previous Sections of this report. One of these, designed to the Three-Size Mean Head Circumference Program illustrates the extent of coverage provided. It may be recalled that ideally for the sizing program in question, the helmet support should provide approximately a 1/2-inch adjustability above and below the mean value for head circumference for each size. The helmet which we will consider is less than ideal in this sense because it is built directly over the headform without any provisions for downward adjustability. Therefore, if the coverage provided by this helmet is acceptable it can be assumed that it will also be sufficient for the more adaptable sling- or pad-type support helmet.

The helmet in question may be described as a close-fitting, semi-rigid protective helmet with a 4-segmented fiber-glass protective shell, having upward adjustability provided by rivets located in slots. This adjustability must accommodate the values shown in table VIII. The entire helmet assembly is covered with a soft-leather shell, and the inner polyurethane energy-absorbing support is lined with a moderately rigid suede material. In the final model, this last feature will be replaced with a cooler more flexible rayon material, less subject to discomforting ridges. The final helmet will also have earcups and attachments for an oxygen mask. The absence of these last two items on the prototype model is not expected to prejudice the results.

The validation test procedures followed those mentioned in the first part of this Section. One person took all measurements and the approaches used are those described in Appendix III. The sample consisted of 90 subjects, 43 military and 47 civilians. Differences on the head and face in dimensional values between these groups are insignificant in absolute terms. Table XV reflects the means, ranges, and S.D. of age and of 12 selected dimensions measured on the sample. The data are compared with the 1950 survey of flying personnel (ref. 12). For more accurate determination of sample compatibility with the theoretical statistical values, the entire group was divided into appropriate sizes, means, and average within-a-size S.D., and a minimum-maximum design range table (table XVI) prepared. The appropriate values from table VIII are shown in parentheses for ready reference. Values for the test results have been rounded to the nearest 1/20th inch in this table to conform with table VIII. All values except for head height are substantially the same. The differences in head height may relate to a slight variation in measuring techniques; however, because all new developmental helmets incorporate earcups with horizontal and vertical adjustability, such differences are not negative factors.

It may be seen from tables XV and XVI that the validation sample is comparable to the 1950 survey group used as the basis of the statistical analysis followed in this report. All subjects could wear their indicated size and any points of discomfort were explained in terms of design features, primarily stiff seams in the suede lining and failure of the rivets to spread in their slots. Both of these factors are to be corrected.

The number of subjects in each size were 13 in size 1 to 2, 53 in size 3 to 4, and 24 in size 5 to 6. These proportions are somewhat overweighted toward the largest size when compared with the procurement tariff suggested in table XII. Normally, small heads can be accommodated in helmets by adding padding where needed; however, the shell perimeter and the requirement for some space between the shell and the head (provided by sling or pad) restricts larger heads, frequently leading to points of discomfort. A review of table XV will show that for such critical head dimensions as head length and breadth the sample range exceeds the 99th percentile of these dimensions as obtained in 1950. It has already been noted that the helmet studied fit all subjects adequately. The variety of shapes so covered serves as an excellent indicator of this helmet's sizing and also gives us an objective evaluation of the Three-Size Mean Head Circumference Program and associated headform series.

Table XV

Validation Test Results, Total Sample

	Range		Mean		S.D.	
Dimension*	1 - 99% 1950**	Sample	1950	Sample	1950	Sample
1. Head circumference	21.00 - 24.30***	21.20 - 24.10	22.47	22.62	.62	.58
2. Head length	7.20 - 8.30	6.95 - 8.60	7.76	7.83	.25	.32
3. Head breadth	5.61 - 6.56	5.67 - 6.95	6.07	6.12	.20	.23
6. Bizygomatic diameter	5.07 - 6.02	5.20 - 6.20	5.55	5.66	.20	.23
8. Bitragion diameter	5.10 - 6.10	5.26 - 6.25	5.60	5.72	.21	.21
9. Biocular diameter	3.38 - 4.19	3.05 - 4.20	3.78	3.87	.17	.19
18. Face length	3.90 - 5.40 f	4.02 - 5.31	4.63	4.74	.33	.27
22. Ear length	2.08 - 2.84	2.22 - 3.02	2.47	2.60	.16	.16
26. Head height	4.40 - 5.80	4.45 - 5.63	5.11	4.96	.30	.26
33. Bitr.- coronal arc	12.70 - 15.10	12.70 - 15.30	13.83	14.01	.51	.55
35. Bitr.-min. frontal arc	11.10 - 13.10	11.10 - 13.20	12.05	12.11	.44	.45
37. Bitr.-menton arc	11.60 - 14.00	11.60 - 14.10	12.78	12.78	.50	.53
-- Age	20.40 - 37.70	19 - 54	27.87	32.1	4.22	8.09

* Descriptions in Appendix III.

** Anthropometric survey of flying personnel (12).

*** All values in inches.

f Estimated values (5).

Table XVI

Validation Test Results, Size Breakdown

Size:	1-2		3-4		5-6		1.65 Within-a-Size S.D.
Dimensions*	Min.	Max.	Min.	Max.	Min.	Max.	
	**						
1. Head circumference	21.00	21.95	22.10	22.95	23.00	24.10	--
(Design ranges)***	(21.00	22.00)	(22.00	23.00)	(23.00	24.00)	
2. Head length	7.05	7.85	7.40	8.20	7.70	8.50	.40
(Design ranges)	(7.20	7.90)	(7.45	8.10)	(7.65	8.30)	(.33)
3. Head breadth	5.60	6.30	5.75	6.45	5.85	6.55	.35
(Design ranges)	(5.65	6.20)	(5.80	6.35)	(5.90	6.50)	(.29)
6. Bizygomatic diameter	5.15	5.85	5.30	6.00	5.40	6.10	.35
(Design ranges)	(5.15	5.70)	(5.25	5.85)	(5.40	5.95)	(.29)
8. Bitragion diameter	5.30	5.95	5.35	6.05	5.45	6.15	.33
(Design ranges)	(5.15	5.80)	(5.30	5.90)	(5.40	6.05)	(.31)
9. Biocular diameter	3.45	4.05	3.55	4.20	3.60	4.25	.31
(Design ranges)	(3.40	3.95)	(3.50	4.05)	(3.60	4.15)	(.27)
18. Face length	4.15	5.05	4.30	5.17	4.40	5.25	.43
(Design ranges)	(4.00	5.10)	(4.10	5.20)	(4.20	5.25)	(.54)
22. Ear length	2.30	2.80	2.35	2.85	2.40	2.90	.26
(Design ranges)	(2.15	2.70)	(2.20	2.75)	(2.25	2.75)	(.26)
26. Head height	4.45	5.25	4.50	5.30	4.70	5.50	.40
(Design ranges)	(4.50	5.50)	(4.65	5.60)	(4.75	5.70)	(.48)
33. Bitr.-coronal arc	12.70	14.20	13.20	14.75	13.60	15.15	.76
(Design Ranges)	(12.80	14.35)	(13.10	14.65)	(13.30	14.85)	(.78)
35. Bitr.-min. frontal arc	11.00	12.15	11.50	12.65	11.90	13.10	.58
(Design ranges)	(11.10	12.30)	(11.45	12.70)	(11.75	13.00)	(.61)
37. Bitr.-menton arc	11.60	13.20	11.95	13.55	12.20	13.85	.81
(Design ranges)	(11.75	13.25)	(12.05	13.55)	(12.30	13.80)	(.75)
Number	13		53		24		

* Descriptions in Appendix III.

** All values in inches.

*** Values in parentheses extracted from table VIII (Design Ranges).

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APPENDIX I

APPENDIX I

GLOSSARY

Anterior - the front part, or pertaining to the front part, of the body.

Brow ridge - the bony protrusion above the eye sockets.

Bi - indicating, usually, the distance from a point on the right side to the same point on the left side, e. g., bitragion = tragion to tragion.

Canthus - a corner or angle formed by the meeting of the eyelids; hence, external canthus, the outer corner of the eye and internal canthus, the inner corner.

Cephalic index - the ratio of head breadth to head length, expressed as a percent.

Correlation - See appendix II.

Coefficient of correlation - See appendix II.

Crinion - the point in the midsagittal plane where the hairline meets the forehead.

Frankfort plane - the standard plane of orientation of the head, determined by locating the lower edges of the eye sockets and a single tragion in the same horizontal plane. The head usually is in this position when the subject looks forward.

Glabella - the most forward point in the midline between the brow ridges.

Gonion - the most lateral point at the angle (gonial angle) formed by the intersection of the back edge of the vertical portion of the jaw with the bottom edge of the jaw.

Headform - a three-dimensional presentation of anthropometric data of the head.

Hysteresis - retardation effect of a material as it returns to original form after deformation.

Inion - a small bony bump often found at the rearmost part of the head.

Key dimension (s) - the dimension or dimensions used to establish size intervals and serve also as fitting criteria in determining indicated size.

Lateral - lying to the right or left side of the midsagittal plane of the body; opposed to medial.

Mandible - the lower jaw.

Mean - See appendix II.

Medial - lying near the midsagittal plane of the body; opposed to lateral.

Menton - the point at the lower surface of the tip of the chin in the midsagittal plane.

Midsagittal plane - the plane dividing the body into equal right and left sections.

Nasal root - the area of greatest indentation where the nose meets the forehead.

Nasal septum - the cartilaginous wall separating the right nostril from the left.

Occipital region - the back of the head.

Philtrum - the groove running from the membranous lip to the base of the nasal septum.

Posterior - the back part of the body, or pertaining to the back part of the body.

Program - See sizing program.

Pronasale - the tip of the nose.

Regression equation - See apendix II.

Sagittal - See midsagittal.

Series - a concrete expression of a sizing program.

Sizing program - the result of the division of key dimensions into appropriate size intervals and the determination of the relevant statistical values for all other important dimensions for the men who fall into each interval.

Standard deviation - See appendix II.

Standard error of estimate - See appendix II.

Statistical sizing system - a statistical approach to the problem of developing sizing programs.

Submandibular - under the mandible or lower jaw.

Subnasale - the point where the base of the nasal septum meets the philtrum in the midsagittal plane.

System - See statistical sizing system.

Temporal crest - a narrow, bony ridge running along the side of the head, curving up from the upper lateral margin of the eye socket, above and past the ear, and downward, ending behind the ear. This serves as the area of attachment for the temporal muscles.

Tragion - a point located, approximately, at the upper edge of the ear hole. More precisely, the point at the notch just above the tragus.

Tragus - the small cartilaginous flap in front of the ear hole.

Vertex - the highest point on the head.

"Wall to" - measurements containing this phrase in their titles were made from a vertical plane tangent to the back of the head, the head being in the standard, erect position (Frankfort plane).

Within-a-size standard deviation - See appendix II.

Zygomatic arch - the bony arch running along the side of the cheek almost to the ear.

APPENDIX II

APPENDIX II
STATISTICAL DEFINITIONS AND CALCULATIONS

Definitions

This appendix consists of two parts: a set of brief definitions of the statistical terms used in this report, and some examples of the calculation of these statistical measures. These examples are intended only to illustrate the formulae involved; we trust that no one will assume that statistics computed on a sample of five individuals will support the detailed intepretation we have given these statistics. In addition, the computational methods are not the most practical ones for use with large samples, but this matter need not concern us here: the more efficient methods provide the same answers.

The four major questions that can be asked about a set of statistical data are (a) what is typical or average of the entire set of data? (b) to what extent do the data cluster around the typical or average value and to what extent do the values spread out above and below the average value? (c) where does an individual datum stand in relationship to the entire group of data? and (d) to what extent and in what manner are the values of one variable related to those of another?

Arithmetic Mean. The commonest measure of central tendency, i. e., of what is typical or average of a group of data, is the arithmetic mean. This statistic is obtained by adding the individual data values, and dividing the sum by the number of individuals. Because the arithmetic mean is so common, it is frequently referred to simply as the mean or, even more informally, as the average value.

In tables the mean value is usually designated either by M (as in this report) or by $\overline{X}$. If several means are given together, they may be indicated by Mx, My, . . ., or $\overline{X}$, $\overline{Y}$, . . .

Standard Deviation. The usual measure of dispersion, the extent to which the data spread out above and below the mean value, is the standard deviation. The procedure for calculating the standard deviation, briefly, is this: from each individual datum, subtract the mean value, square the resulting differences, add these squared values, divide the sum thus obtained by the number of data involved, and, finally, take the square root of this quotient. More important than the details of this computational procedure is the basic significance of the statistic: the larger the standard deviation, the more variable the data, the greater the differences between the smallest and the largest values, etc. For most body dimensional data, we can state with a fair degree of accuracy that two-thirds of the data fall within one standard deviation of the mean (about one man in six will be more than a standard deviation below the mean and one in six more than a standard deviation above the mean), about 95 percent of the data will be within two standard deviations of the mean, and virtually all data will be within three standard deviations of the mean. The list on page 12 may provide further help in interpreting this statistic.

In this report, the standard deviation is listed in tables as S. D.. Often, however, the lower case Greek sigma (σ) is used, and, sometimes, the abbreviation Std Dev.

Within-a-Size Standard Deviation. This is defined as the standard deviation of a dimension for the group of men who fall, on the basis of their values of the key dimensions, within a single size-interval or size-box. The within-a-size standard deviations reported here and in connection with other Air Force sizing systems are averages of the values computed for the several sizes (technically, they are the square root of the weighted mean of the squares of the within-a-size standard deviations). The average values thus obtained have added accuracy and stability because they are based on a large sample. Using the average values also provides design ranges of equal width for all the sizes of a single dimension.

Percentiles. The position of a particular datum relative to the entire set of data is conveniently stated by specifying what proportion of the data are smaller than the one in question. If, say, 95 percent of a group of heads are shorter than 8.2 inches, we can designate 8.2 inches as the 95th percentile for head length. Similarly, a complete set of percentiles, from the first to the 99th, can be derived; and, using these percentiles, each individual value can be specified as being equal to the appropriate percentile.

The percentiles can be used to designate any partial range to set design limits. The range from the 5th to the 95th percentile, for example, is one which will include the central 90 percent (= 95% - 5%) of the entire set of data.

Clearly, the greater the standard deviation, the further apart any particular pair of percentiles will be. Thus, there must be some relationship between the standard deviation and the percentiles. The list on page 12 provides a basis for estimating certain percentiles in terms of the mean and standard deviation; more extensive tables can be found in most statistics texts. For most body size dimensions, these estimates are quite accurate.

Coefficient of Correlation - Regression Equations - Standard Errors of Estimate. These several statistical measures all, in somewhat different ways, relate to the question of how two variables, i.e., two sets of data, relate to each other.

Logically, it is best to start a consideration of these statistics with the regression equation or regression line. Given a set of data consisting of the head length and head breadth measurements of a group of men, we can seek a formula or straight-line equation which tells us as accurately as possible a man's head breadth when we put his head length value into the formula or equation. Such an equation or formula is called the regression equation for head breadth in terms of head length. ("As accurately as possible" requires some explanation, for accuracy can be defined in a variety of ways. Almost without exception the definition used in deriving regression lines is that, on the average, the squares of the differences between the actual values of, in this case, head breadth and the values given by the equation be as small as possible.)

This regression equation provides two primary (and identical) pieces of information: the most accurate estimate of an individual's head breadth that we can make when the information available to us is the value of his head length, and, the average head breadth value for a group of men all of whom have heads of a particular length.

If the two variables are closely related, the estimates will be quite accurate, a plot of the pairs of values will show most of the points lying close to the line, and the line will have an appreciable slope with a noticable increase in the size of the predicted or estimated values as the size of the "known" values increase.

On the contrary, if the degree of relationship is low, the estimates will be relatively inaccurate, the points will not, in general, fall close to the line, and the line will be comparatively flat with only small increments in the estimated values for large changes in the "known" values.

The two extreme cases are those of perfect relationships, in which the estimates are exact and all points lie on the line, and those of non-existant relationships in which there is a general scatter of the points, the regression line is perfectly flat, and our knowledge of the value of the "known" variable contributes nothing to our ability to estimate the other variable. (In this latter case, our estimated values will all equal the mean value of the estimated variable.)

It is possible to define the degree of relationship or <u>coefficient of correlation</u> (r) in terms of the accuracy of the estimates obtained from such a regression line. The coefficient of correlation is a relative measure. It is based, not on the actual accuracy of the regression line estimates, but on a comparison of this accuracy with the accuracy we would obtain if we did not have such an equation. (In this latter case, our estimates would be the mean value and the measure of accuracy would be the standard deviation.) In the two extreme cases discussed in the previous paragraph, the correlation coefficient would be 1.00 in the first case (perfect relationship) and 0.00 in the second (no relationship). Exact nuances between different values of the correlation coefficient are difficult to interpret, but this much is surely clear: predictions of one variable in terms of each of several others will be in the same order of accuracy as the order of the corresponding correlation coefficients, the higher the correlation, the greater the accuracy.

In those instances, rare in body dimension studies, in which one set of values decreases as the other set increases, a negative sign precedes the correlation coefficient. Negative correlations result in precisely the same degree of accuracy in estimating as do positive ones of the same magnitude.

While the equation for predicting, say, head breadth in terms of head length is quite different from the equation for predicting head length from head breadth, the correlation coefficients are identical in both cases.

Just as the correlation coefficient is a relative measure of the accuracy of estimates obtained by the use of a regression equation, the standard error of estimate is an absolute measure of this accuracy. In making estimates of a particular variable from a knowledge of another, the accuracy of the results will depend both on the degree of relationship involved and the inherent variability (or standard deviation) of the estimated variable. In terms of statistics already discussed, the standard error of estimate is given by the formula

$$SEy = S.D.(y)\sqrt{1 - r^2}$$

Like the values given by the regression equation (best estimate for an individual, mean value for all men with a common value of the "known" variable) the standard error of estimate has two logically different but numerically identical interpretations. It is a measure of the likely error of our estimates when we estimate an individual's value (within 1 standard error of estimate 2 times out of 3, within 2 standard errors 19 times out of 20, etc.), and is also the standard deviation of, for example, head breadth of the group of men who have a particular value of head length. It is this latter interpretation of this statistic which connects it to the within-a-size standard deviation.

While there is a clear relationship between the standard error of estimate and the correlation coefficient, the two are in no sense proportional.

Multiple Correlation. More than one variable can be used to predict a given variable. When more than one is used, we obtain a multiple regression equation. The accuracy of the estimates made using a multiple regression equation is measured, in a relative sense, by the multiple correlation coefficient, and, absolutely, by the multiple standard error of estimate. All of these statistics can be interpreted in the same way as the simple correlational measures.

Sample Calculations of Statistics Discussed in this Appendix

The Means, Standard Deviations, and Correlation Coefficients.

	X	Y	$X-\bar{X}$	$Y-\bar{Y}$	$(X-\bar{X})^2$	$(Y-\bar{Y})^2$	$(X-\bar{X})(Y-\bar{Y})$
	5	12	0	2	0	4	0
	8	16	3	6	9	36	18
	2	8	-3	-2	9	4	6
	4	10	-1	0	1	0	0
	6	4	+1	-6	1	36	-6
Total	25	50	0	0	20	80	18
Mean	5.0	10.0					

$$\text{Standard Deviation of } X = \sqrt{\frac{\text{Sum } (X-\bar{X})^2}{N}} = \sqrt{\frac{20}{5}} = 2.0$$

$$\text{Standard Deviation of } Y = \sqrt{\frac{\text{Sum } (Y-\bar{Y})^2}{N}} = \sqrt{\frac{80}{5}} = 4.0$$

$$\text{Correlation of X and Y} = \frac{[\text{Sum } (X-\bar{X}) \cdot (Y-\bar{Y})] / N}{\text{S. D. } (x) \cdot \text{S. D. } (y)} = \frac{18/5}{2.0 \cdot 4.0}$$

$$= \frac{3.6}{8.0} = 0.45 = r$$

The Regression Equations.

Regression equation, to predict Y, knowing X:

$$Y - \text{Avg } Y = r \bullet \frac{\text{S. D. } (y)}{\text{S. D. } (x)} \bullet (X - \text{Avg } X)$$

$$Y - 10.0 = 0.45 \bullet \frac{4.0}{2.0} \quad (X - 5.0)$$

$$Y - 10.0 = 0.90\ (X - 5.0)$$

$$Y - 10.0 = 0.90\ X - 4.5$$

$$Y = 0.90X - 4.5 + 10.0 = 0.90X + 5.5$$

Thus, if X is known to be 3.0, we can estimate that Y equals 0.90 • 3.0 + 5.5 or 2.7 + 5.5 = 8.2. Similarly, for a group of men all of whom have X values of 3.0, the average Y value will be 8.2.

Regression equation to predict X, knowing Y:

$$X - \text{Avg } X = r \bullet \frac{S.D.\ (x)}{S.D.\ (y)} \bullet (Y - \text{Avg } Y)$$

$$X - 5.0 = 0.45 \bullet \frac{2.0}{4.0} (Y - 10.0)$$

$$X - 5.0 = 0.225 \ (Y - 10.0)$$

$$X - 5.0 = 0.225 \ Y - 2.25$$

$$X = 0.225 \ Y + 2.75$$

Thus, if Y is known to be 12.0, we can estimate that X equals 0.225 • 12.0 + 2.75 = 2.70 + 2.75 = 5.45. Similarly, for a group of men all of whom have Y values of 12.0, the average X value will be 5.45.

The Standard Errors of Estimate.

When estimating Y from X:

$$S.D.\ (y) \bullet \sqrt{1 - r^2} = 4.0\sqrt{1 - (.45)^2} = 4.0\sqrt{1 - 0.2025} = 4.0\sqrt{.7975}$$

$$= 4.0 \bullet 0.893 = 3.57$$

This statistic (a) measures the accuracy with which we can estimate a value of y, using the regression equation derived above:

about 2 times out of 3, our error will be 3.57 or less,

about once in 20 times, our error will exceed twice 3.57 or 7.14 units

almost never will our error exceed 3 times 3.57 or 10.71 units

(b) represents the standard deviation of y values for a group of men all of whom have the same x value

(c) approximates the within-a-size standard deviation of y for a sizing system based on x as the key dimension. When the ranges of x has been divided into six or more sizing intervals, the approximation is quite close.

When estimating X from Y:

$$S.D.\ (x) \bullet \sqrt{1 - r^2} = 2.0\sqrt{1 - (.45)^2} = 2.0 \bullet 0.893 = 1.79$$

This value is to be interpreted in a manner parallel to that immediately above.

Multiple Correlation Coefficient.

The multiple correlation coefficient, measuring the degree of relationship between one variable (e.g., z) and two or more others (e.g., x and y), is ordinarily calculated from the simple correlation coefficients, i.e., the r for x and z, the r for y and z, and the r for x and y. Rarely, if ever, is it calculated directly from the raw data. The formula is:

$$R = \sqrt{\frac{r^2(x,z) + r^2(y,z) - 2\,r(x,z)\;r(y,z)\;r(x,y)}{1 - r^2(x,y)}}$$

Thus, if the correlation between x and z = 0.60
between y and z = 0.70
between x and y = 0.45

we get

$$R = \sqrt{\frac{(0.60)^2 + (0.70)^2 - 2\,(0.60)\;(0.70)\;(0.45)}{1 - (0.45)^2}}$$

$$= \sqrt{\frac{0.36 + 0.49 - .378}{1 - .2025}}$$

$$= \sqrt{\frac{.472}{.7975}} \qquad = \sqrt{.592} \qquad = 0.769$$

The standard error of estimate, for estimating z from known values of both x and y, is given by virtually the same formula as in the case of simple correlations:

$$S.D.\ (z) \bullet \sqrt{1 - R^2}$$

If the standard deviation of z is 3.0 inches in this case, the standard error of measurement will be:

$$3.0\sqrt{1 - (.769)^2} = 3.0\sqrt{1 - .592} = 3.0\sqrt{.408}$$

$$3.0 \bullet 0.639 = 1.92 \text{ inches}$$

This 1.92 inches measures the accuracy with which we can estimate z knowing both x and y; it also represents the standard deviation of z for a group of men all of whom have the same values of x and the same values of y. It approximates the within-a-size standard deviation of z when x and y are the key dimensions of a sizing system, but the approximation may not be very good unless there are enough sizes so that the dimensions of a size "box" are no more than one-sixth the total range as far as both x and y are concerned.

The formula for the multiple regression equation:

$$z = Ax + By + C$$

is as follows:

$$A = \left(\frac{r(xz) - r(xy) \cdot r(yz)}{1 - r^2(xy)}\right) \frac{S.D.(z)}{S.D.(x)}$$

$$B = \left(\frac{r(yz) - r(xy) \cdot r(xz)}{1 - r^2(xy)}\right) \frac{S.D.(z)}{S.D.(y)}$$

$$C = \text{Avg}(z) - A \cdot \text{Avg}(x) - B \cdot \text{Avg}(y)$$

For the values already introduced, and taking the average (mean) value for z to be 20.0, we get:

$$A = \frac{0.60 - (0.45)(0.70)}{1 - (0.45)^2} - \frac{3.0}{2.0} = \frac{0.60 - 0.315}{1 - 0.2025} \cdot 1.5$$

$$= \frac{0.285}{0.7975} \cdot 1.5 = 0.536$$

$$B = \frac{(0.70) - (0.45)(0.60)}{1 - (0.45)^2} \cdot \frac{3.0}{4.0}$$

$$\frac{0.70 - 0.270}{1 - 0.2025} \cdot 0.75 = \frac{0.430}{0.7975} \cdot .75 = 0.404$$

$$C = 20 - 0.536 \cdot 5.0 - 0.404 \cdot 10.0 = 13.28$$

and

$$Z = 0.536\,x + 0.404y + 13.28$$

Within-a-Size Standard Deviation.

For direct calculation, there is no difference in the formula between the within-a-size standard deviation and the usual standard deviation. The difference is in the groups of data used in the calculations. The standard deviation for sagittal arc is calculated using the data for all the men involved; the within-a-size standard deviation for sagittal arc for a particular size of a particular sizing program is calculated using only the data for the men who, presumably, will be fitted by a garment of the size in question.

The "average" within-a-size standard deviations used in this report can be obtained from the values for the several sizes as illustrated below:

Size	N	Within-a-Size S. D.	$(S.D.)^2$	$N \bullet (S.D.)^2$
1	370	2.46	6.0516	2,239.0920
2	1040	2.51	6.3001	6,552.1040
3	625	2.39	5.7121	3,570.0625
Total	2035			12,361.2585

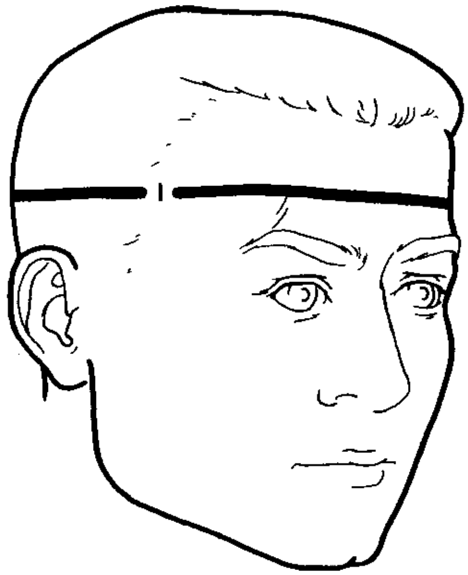
$$\text{Avg Within-a-Size S.D.} = \sqrt{\frac{\text{Total } [N \bullet (S.D.)^2]}{\text{Total } N}} = \sqrt{\frac{12,361.2585}{2,035}}$$

$$= \sqrt{6.0743} = 2.46.$$

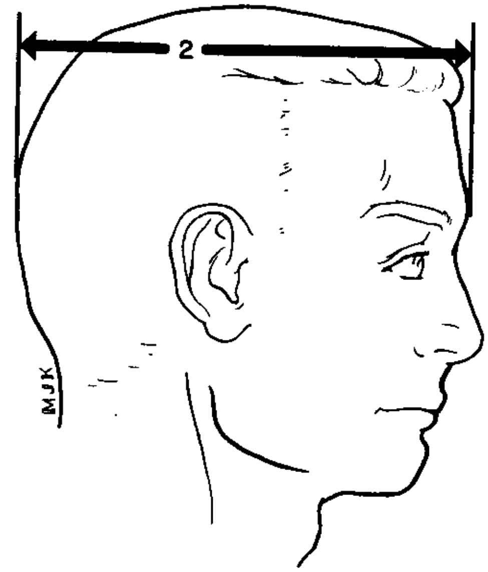
APPENDIX III

DESCRIPTIONS AND ILLUSTRATIONS OF DIMENSIONS*

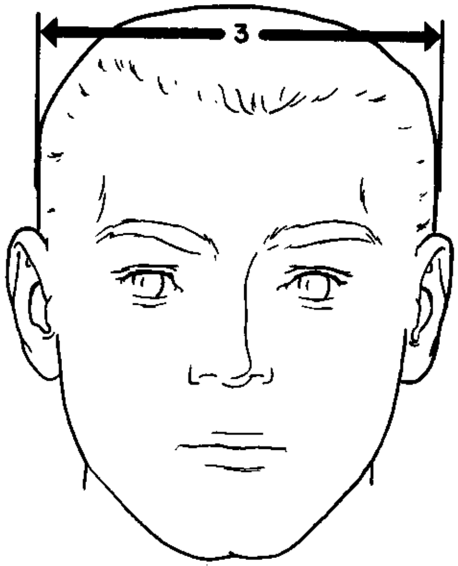
* See appendix I, Glossary, for terms not otherwise defined in the descriptions which follow.



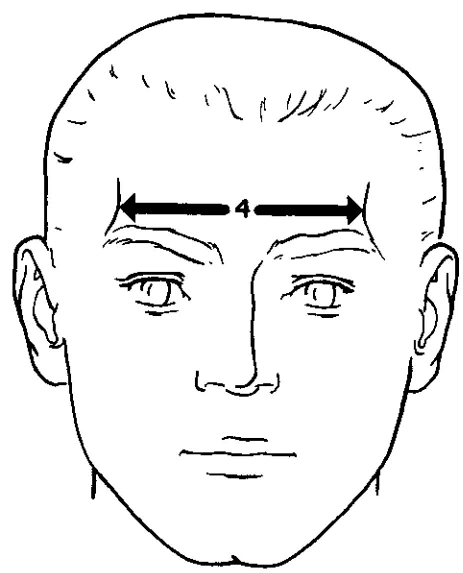
HEAD CIRCUMFERENCE



HEAD LENGTH



HEAD BREADTH



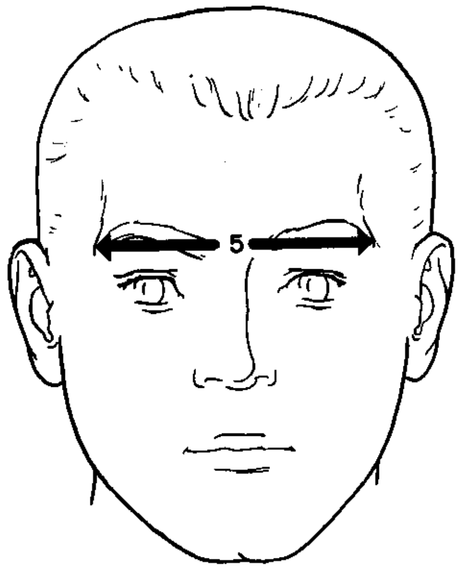
MINIMUM FRONTAL DIAMETER

1. Head Circumference - The maximum circumference of the head measured above, but not including the brow ridges.

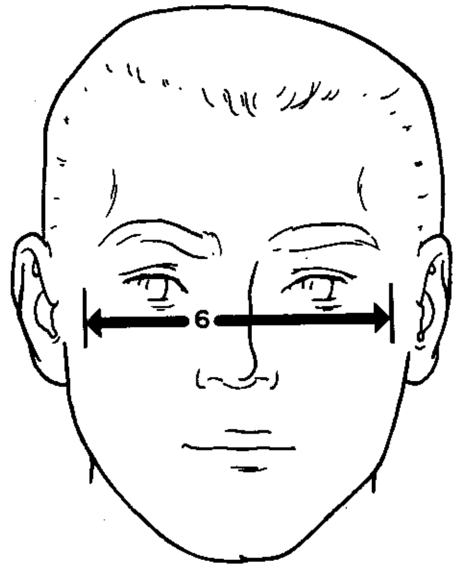
2. Head Length - The maximum length of the head from glabella to the occipital region.

3. Head Breadth - The maximum breadth of the head in a plane perpendicular to the midsagittal plane.

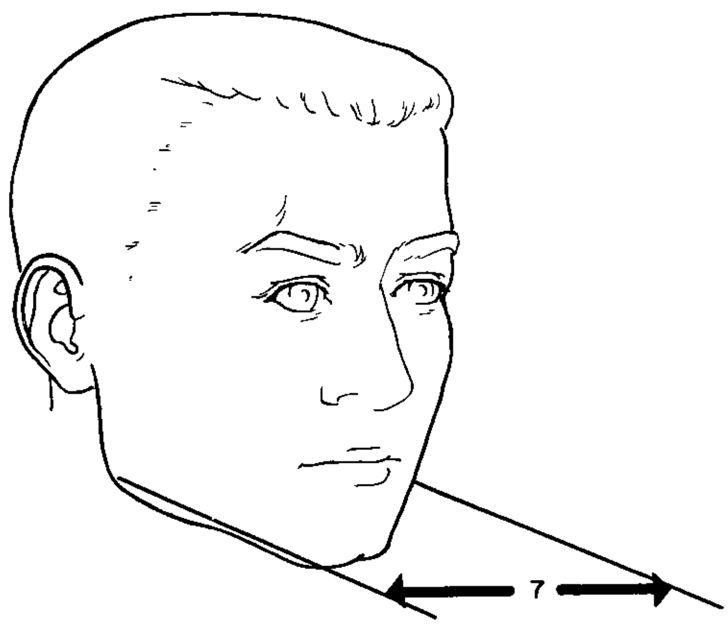
4. Minimum Frontal Diameter - The minimum horizontal diameter across the temporal crests at their points of greatest indentation.



MAXIMUM FRONTAL DIAMETER



BIZYGOMATIC DIAMETER

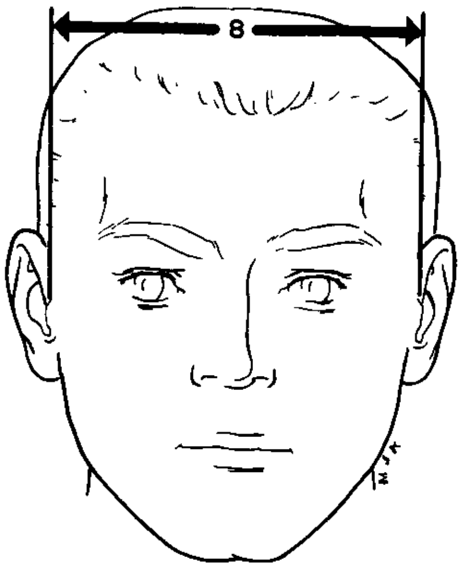


BIGONIAL DIAMETER

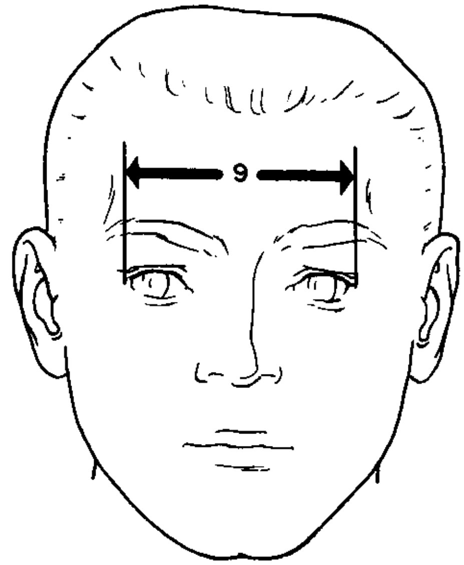
5. Maximum Frontal Diameter - The horizontal distance between the maximum bulges of the brow ridges, just below the minimum frontal region, at about the ends of the eye brows.

6. Bizygomatic Diameter - The maximum horizontal breadth across the most laterally projecting bones of the cheek (zygomatic arches).

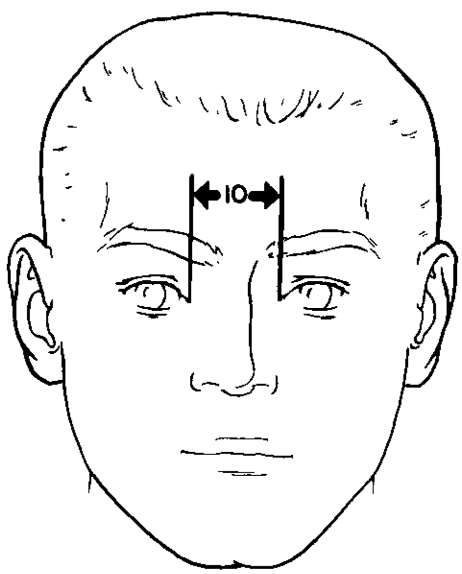
7. Bigonial Diameter - The maximum horizontal width of the jaw across the gonial angles.



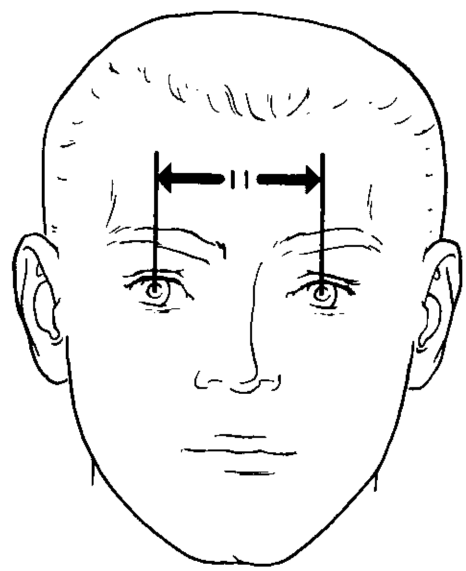
BITRAGION DIAMETER



BIOCULAR DIAMETER



INTEROCULAR DIAMETER



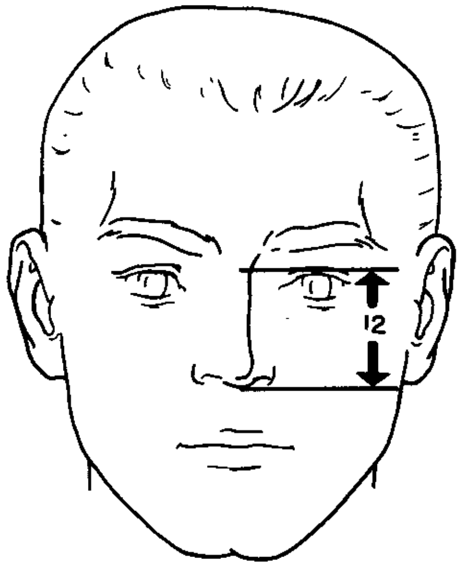
INTERPUPILLARY DISTANCE

8. <u>Bitragion Diameter</u> - The diameter between the right and left tragion.

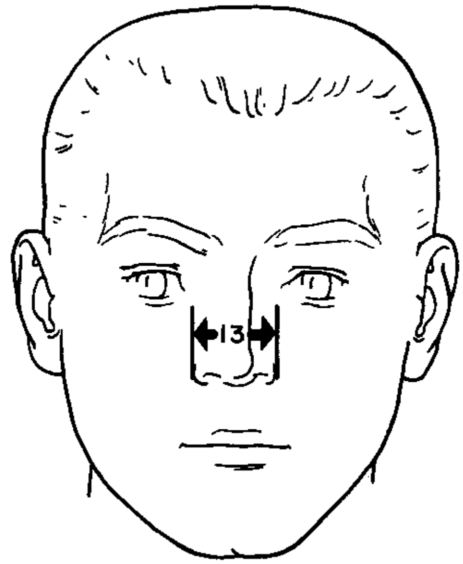
9. <u>Biocular Diameter</u> - The distance between the outer corners of the eyes.

10. <u>Interocular Diameter</u> - The distance between the inner corners of the eyes.

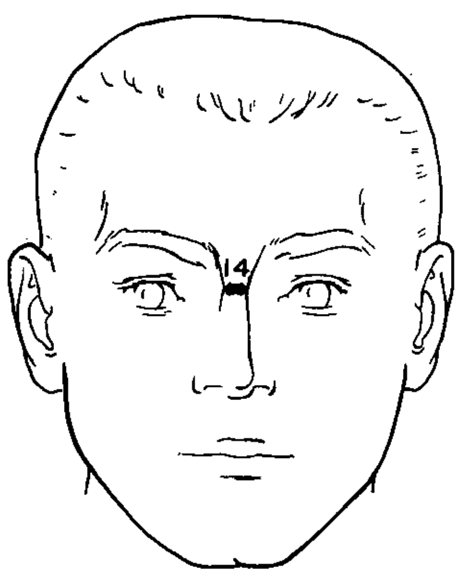
11. <u>Interpupillary Distance</u> - The distance between the centers of the pupils of the eyes.



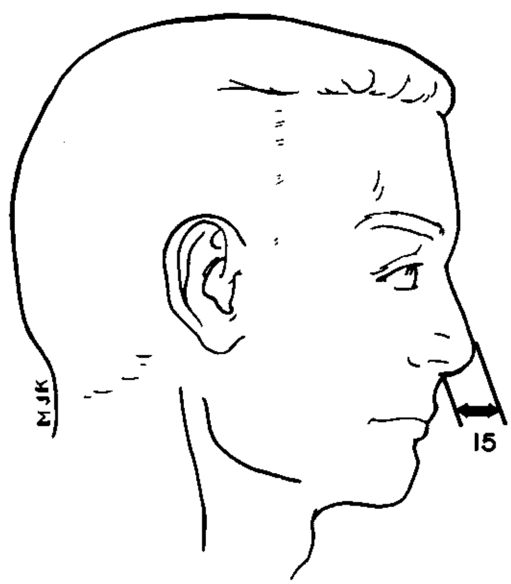
NOSE LENGTH



NOSE BREADTH



NASAL ROOT BREADTH



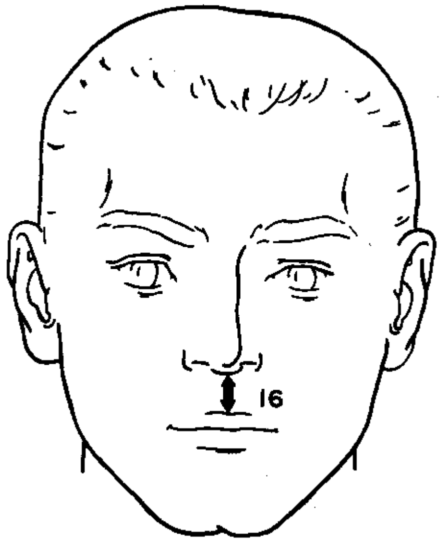
NOSE PROTRUSION

12. Nose Length - The distance between the base of the nose and the center of the nasal root depression.

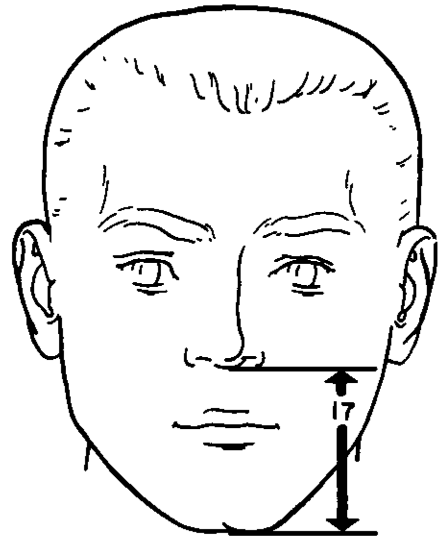
13. Nose Breadth - The distance across the nostrils at their widest point.

14. Nasal Root Breadth - The distance across the nasal bridge at its greatest indentation between the eyes.

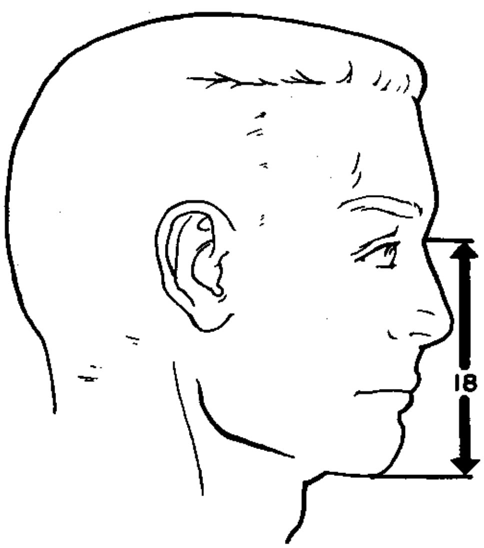
15. Nose Protrusion - The distance between the base of the nasal septum and the maximum forward protrusion of the nose.



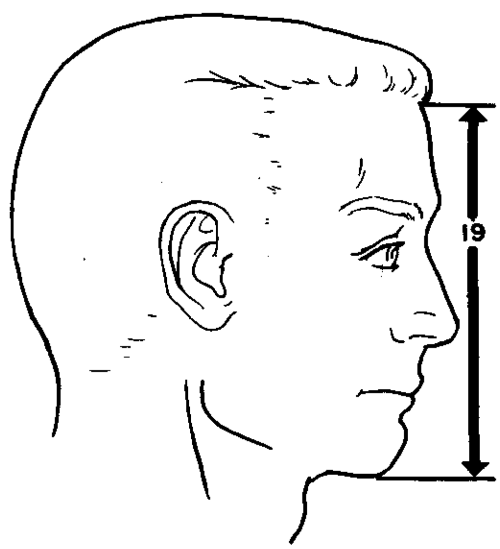
PHILTRUM LENGTH



MENTON-SUBNASALE LENGTH



FACE LENGTH



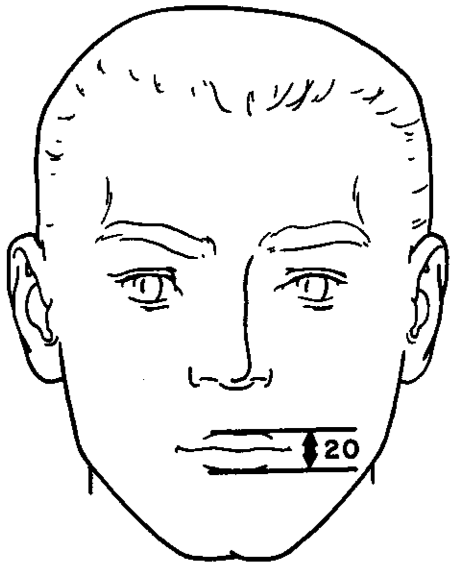
MENTON-CRINION LENGTH

16. Philtrum Length - The length of the vertical groove that runs from the edge of the upper lip to the bottom of the nose.

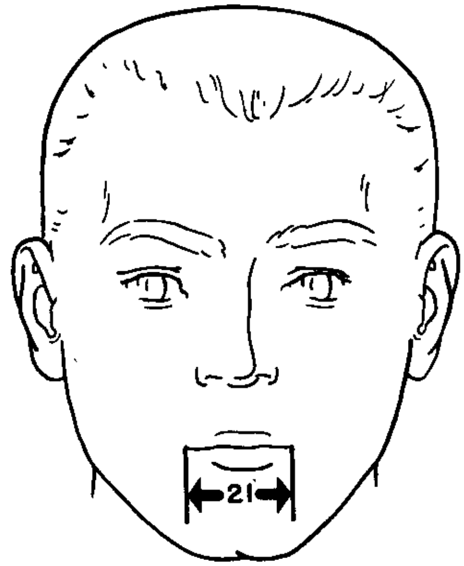
17. Menton-Subnasale Length - The vertical distance between menton and the bottom of the nose.

18. Face Length - The vertical distance between the mid-point of the nasal root depression and menton.

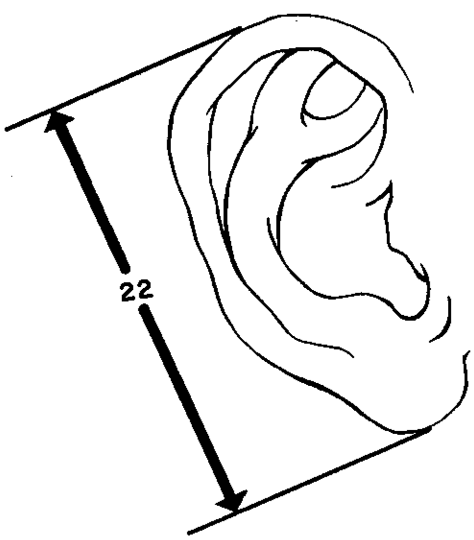
19. Menton-Crinion Length - The vertical distance between the mid-point of the hair line and menton.



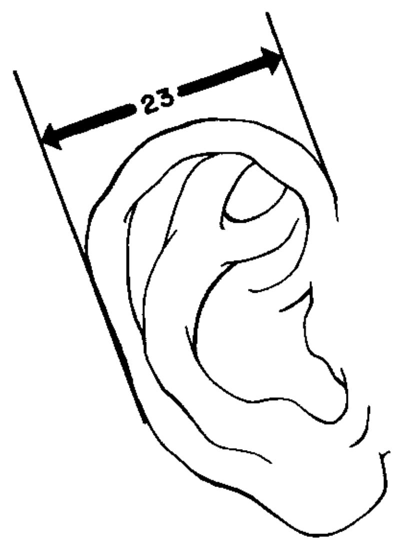
LIP-TO-LIP DISTANCE



LIP LENGTH



EAR LENGTH



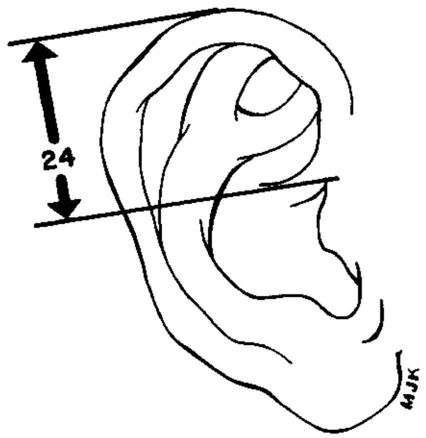
EAR BREADTH

20. Lip-To-Lip Distance - The vertical distance between the center of the upper lip and the bottom of the lower one, when the jaws are lightly closed.

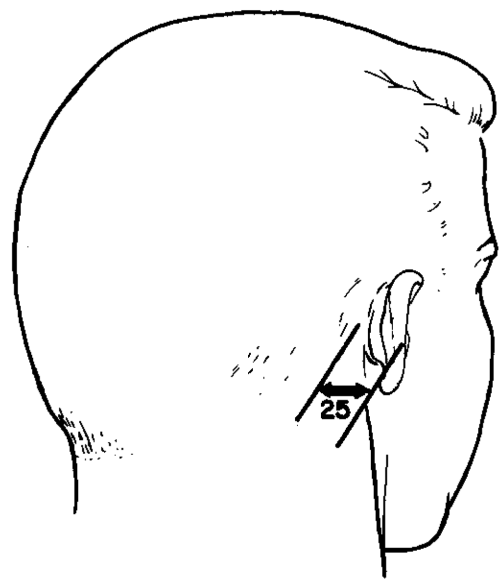
21. Lip Length - The maximum horizontal distance between the corners of the mouth in a normal or relaxed position.

22. Ear Length - The maximum length of the ear along its long axis.

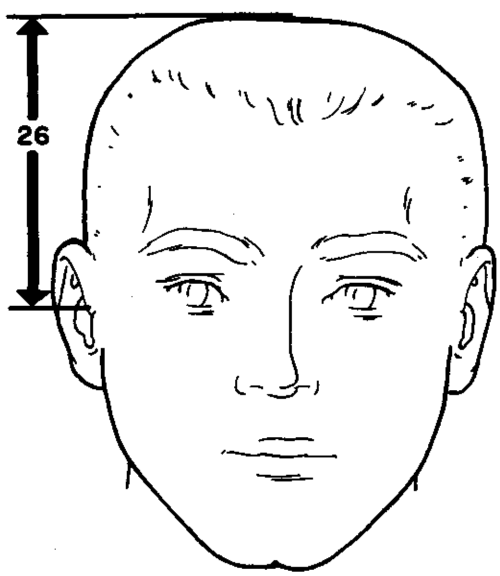
23. Ear Breadth - The maximum breadth of the ear parallel to its long axis.



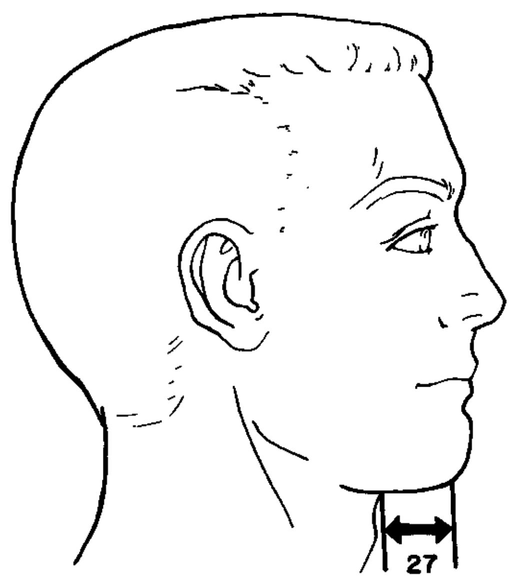
EAR LENGTH ABOVE TRAGION



EAR PROTRUSION



HEAD HEIGHT



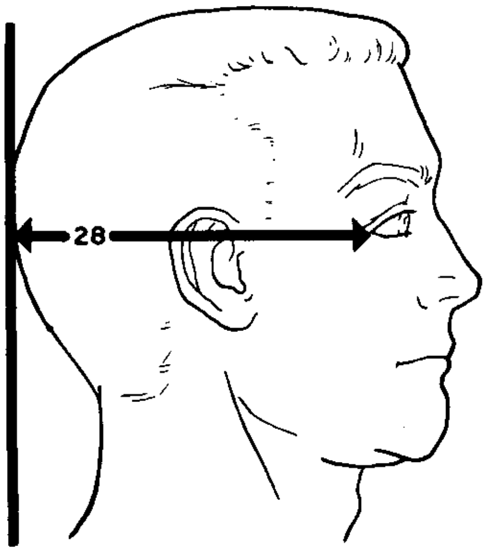
MENTON PROJECTION

24. Ear Length Above Tragion - The distance between tragion and the top of the ear along its long axis.

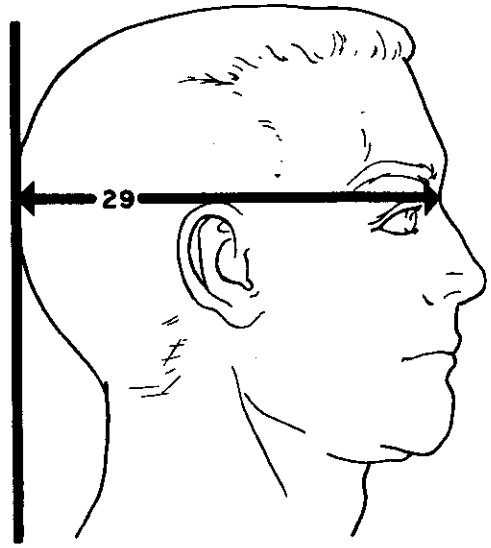
25. Ear Protrusion - The horizontal distance between the mastoid process (the bony eminence directly behind the ear) and the most lateral protrusion of the ear.

26. Head Height - The vertical distance between tragion and the highest point of the head.

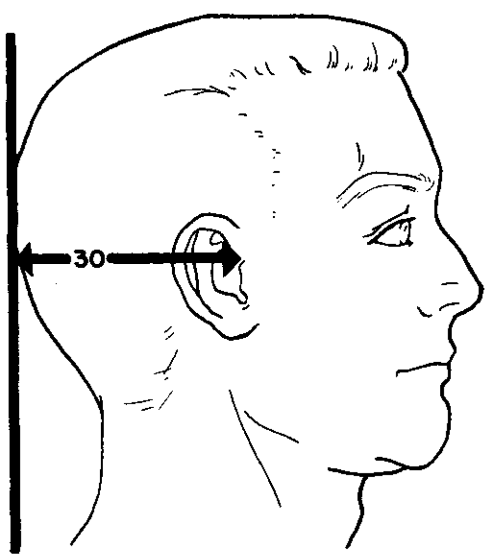
27. Menton Projection - The distance between menton and the juncture of the neck with the jaw.



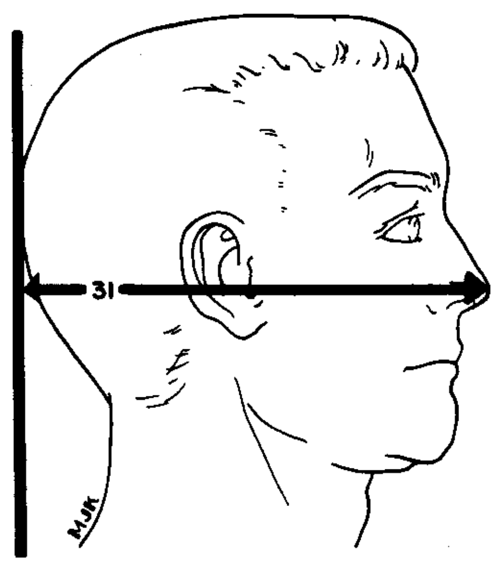
EXTERNAL CANTHUS TO WALL



NASAL ROOT TO WALL



TRAGION TO WALL



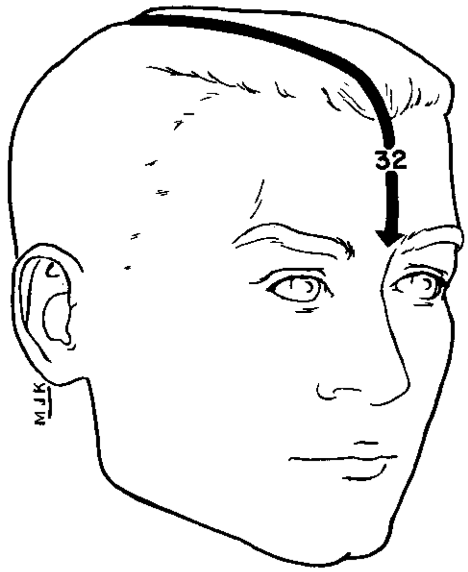
PRONASALE TO WALL

28. External Canthus to Wall - The horizontal distance between the outer corner of the eye and a vertical plane tangent to the rearmost part of the head positioned in the Frankfort plane.

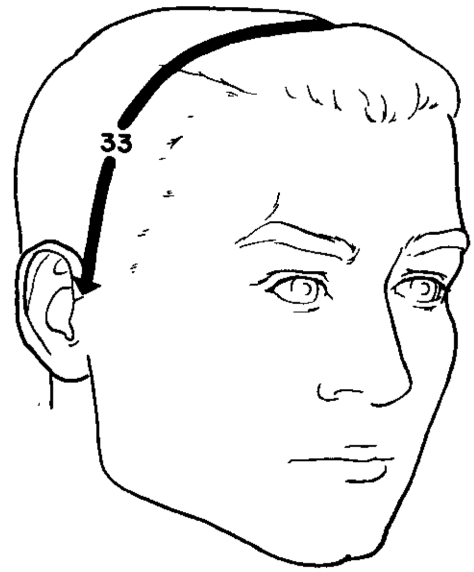
29. Nasal Root to Wall - The horizontal distance between the maximum indentation of the nasal root and a vertical plane tangent to the rearmost part of the head positioned in the Frankfort plane.

30. Tragion to Wall - The horizontal distance between tragion and a vertical plane tangent to the rearmost part of the head positioned in the Frankfort plane.

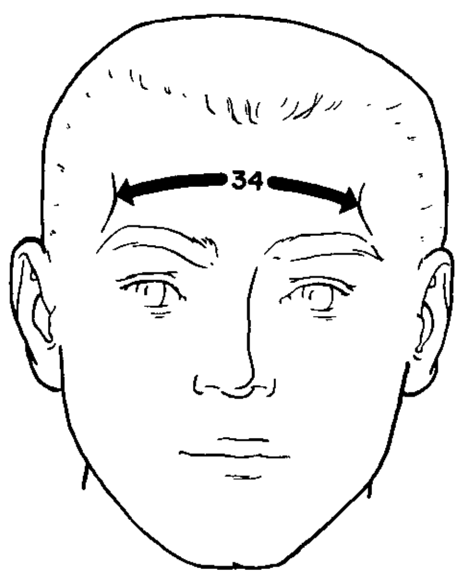
31. Pronasale to Wall - The horizontal distance between the tip of the nose and a vertical plane tangent to the rearmost part of the head positioned in the Frankfort plane.



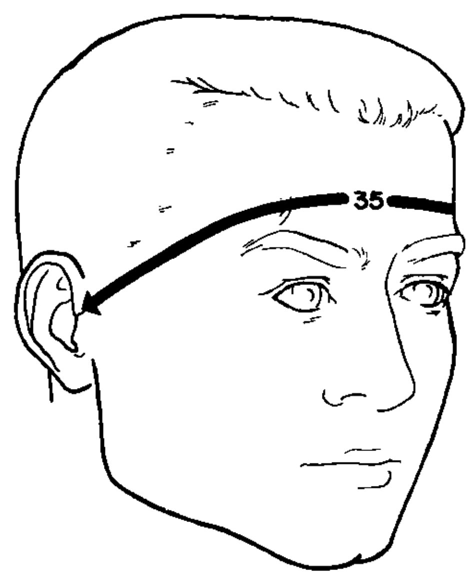
SAGITTAL ARC



BITRAGION-CORONAL ARC



MINIMUM FRONTAL ARC



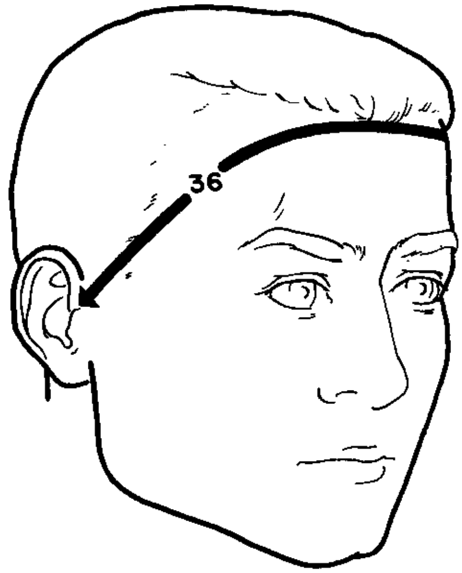
BITRAGION-MINIMUM FRONTAL ARC

32. Sagittal Arc - The arc between glabella on the forehead and the lowest point of the skull.

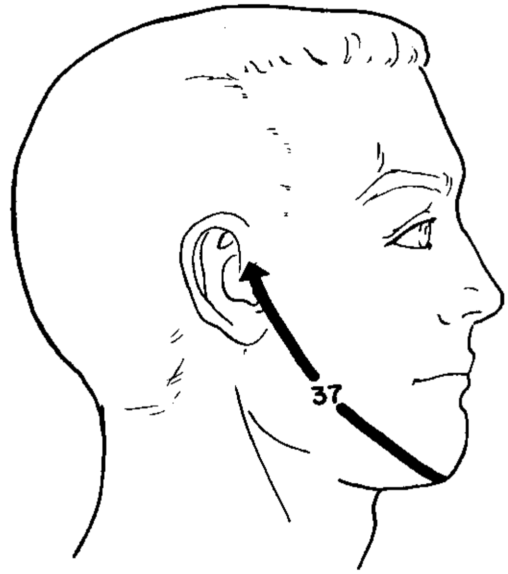
33. Bitragion-Coronal Arc - The arc between the right and left tragion as measured over the top of the head in a plane perpendicular to the midsagittal plane.

34. Minimum Frontal Arc - The arc across the forehead between the points of greatest indentation of the crests just above the eyebrows.

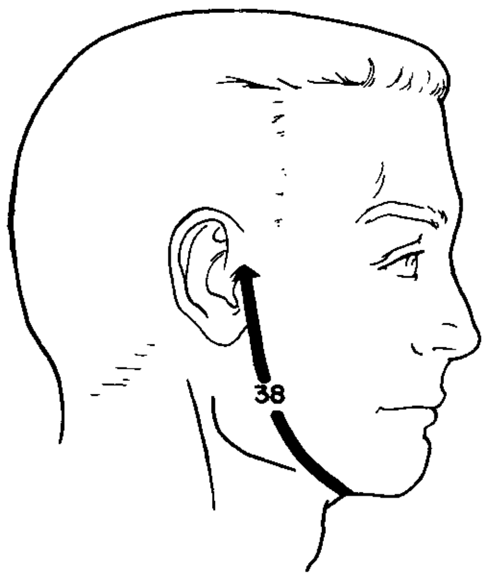
35. Bitragion-Minimum Frontal Arc - The arc between the right and left tragion as measured above the brow ridge.



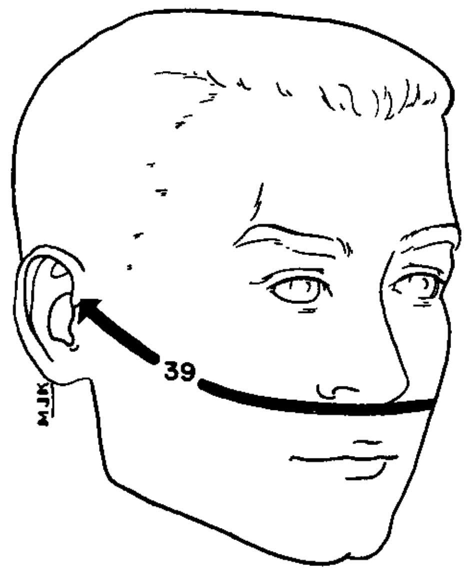
BITRAGION-CRINION ARC



BITRAGION-MENTON ARC



BITRAGION-SUBMANDIBULAR ARC



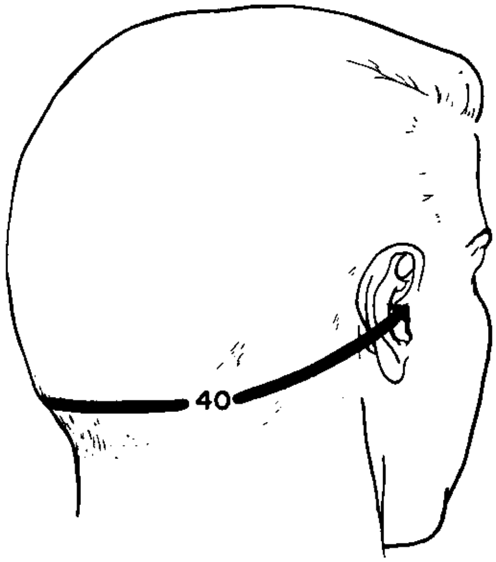
BITRAGION-SUBNASALE ARC

36. Bitragion-Crinion Arc - The arc between the right and left tragion as measured over the midpoint of the hairline.

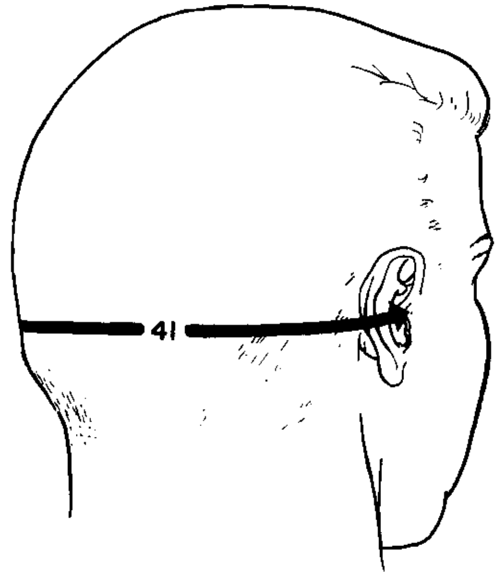
37. Bitragion-Menton Arc - The arc between the right and left tragion as measured over menton.

38. Bitragion-Submandibular Arc - The arc between the right and left tragion as measured along the juncture of the jaw and the neck.

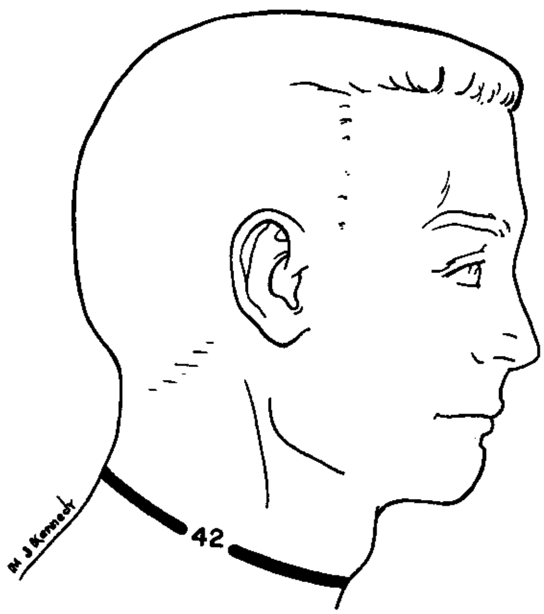
39. Bitragion-Subnasale Arc - The arc between the right and left tragion as measured across the face and the base of nose.



BITRAGION-POSTERIOR ARC



BITRAGION-INION ARC



NECK CIRCUMFERENCE

40. Bitragion-Posterior Arc - The arc between tragion as measured over the lowest point of the skull.

41. Bitragion-Inion Arc - The arc between tragion as measured over inion.

42. Neck Circumference - The distance around the neck in a plane perpendicular to its axis and passing just below the "Adam's Apple".

APPENDIX IV

THEORETICAL FOUR- AND SIX-SIZE HEAD LENGTH, HEAD BREADTH TABLES

TABLE XVII

Fitting Table and Suggested Tariffs for Four- and Six-Size Head Length, Head Breadth Programs

Program	Size	Head Length	Head Breadth	Suggested Tariff (per 1000)
Four-Size	1	7.3 - 7.8*	5.6 - 6.1	380
	2	7.8 - 8.3	5.6 - 6.1	239
	3	7.3 - 7.8	6.1 - 6.6	207
	4	7.8 - 8.3	6.1 - 6.6	174
Proportion of Survey Sample Theoretically Included = 91.8%				
Six-Size	1	7.2 - 7.6	5.6 - 6.1	145
	2	7.6 - 8.0	5.6 - 6.1	406
	3	8.0 - 8.4	5.6 - 6.1	69
	4	7.2 - 7.6	6.1 - 6.6	75
	5	7.6 - 8.0	6.1 - 6.6	239
	6	8.0 - 8.4	6.1 - 6.6	66
Proportion of Survey Sample Theoretically Included = 96.7%				

* All values in inches

TABLE XVIII

Four-Size Head Length, Head Breadth Program Means and Within-a-Size Standard Deviations

Size: / Dimension*	1	2	3	4	Within-a-Size S.D.
1. Head circumference	22.10**	22.65	22.55	23.10	.45
2. Head length***	7.65	8.00	7.65	8.00	.19
3. Head breadth***	5.95	5.95	6.25	6.25	.17
4. Minimum frontal diameter	4.30	4.35	4.40	4.45	.18
5. Maximum frontal diameter	4.65	4.70	4.80	4.85	.18
6. Bizygomatic diameter	5.45	5.50	5.65	5.70	.17
7. Bigonial diameter	4.20	4.25	4.30	4.35	.21
8. Bitragion diameter	5.50	5.55	5.70	5.75	.18
9. Biocular diameter	3.75	3.80	3.80	3.85	.17
10. Interocular diameter	1.25	1.25	1.25	1.30	.10
11. Interpupillary distance	2.45	2.50	2.50	2.55	.14
12. Nose length	2.00	2.00	2.00	2.05	.13
13. Nose breadth	1.30	1.30	1.30	1.35	.10
14. Nasal root breadth	.60	.60	.60	.65	.08
15. Nose protrusion	.90	.90	.90	.90	.11
16. Philtrum length	.75	.80	.75	.80	.14
17. Menton-subnasale length	2.60	2.65	2.60	2.70	.27
18. Face length	4.60	4.70	4.60	4.70	.33
19. Menton-crinion length	7.30	7.45	7.35	7.50	.34
20. Lip-to-lip distance	.65	.65	.65	.65	.12
21. Lip length	2.00	2.05	2.05	2.05	.14
22. Ear length	2.45	2.50	2.45	2.50	.16
23. Ear breadth	1.45	1.45	1.45	1.45	.11
24. Ear length above tragion	1.15	1.15	1.15	1.20	.11
25. Ear protrusion	.85	.85	.85	.85	.14
26. Head height	5.05	5.10	5.10	5.20	.29
27. Menton projection	1.85	1.90	1.85	1.95	.26
28. External canthus to wall	6.70	6.95	6.70	6.95	.27
29. Nasal root to wall	7.65	7.95	7.65	8.00	.26
30. Tragion to wall	3.95	4.15	3.95	4.15	.28
31. Pronasale to wall	8.50	8.85	8.55	8.90	.34
32. Sagittal arc	14.85	15.35	15.00	15.45	.54
33. Bitragion-coronal arc	13.60	13.80	14.00	14.20	.45
34. Minimum frontal arc	5.35	5.45	5.50	5.60	.39
35. Bitragion-minimum frontal arc	11.85	12.15	12.10	12.35	.38
36. Bitragion-crinion arc	12.90	13.15	13.20	13.45	.47
37. Bitragion-menton arc	12.60	12.85	12.80	13.00	.47
38. Bitragion-submandibular arc	11.95	12.10	12.15	12.35	.60
39. Bitragion-subnasale arc	11.30	11.55	11.45	11.70	.40
40. Bitragion-posterior arc	10.55	10.75	10.75	10.95	.45
41. Bitragion-inion arc	11.45	11.70	11.60	11.90	.52
42. Neck circumference	14.75	14.95	15.05	15.35	.71

* Descriptions in Appendix III.
** All values in inches.
*** Key dimensions.

TABLE XIX

Design Ranges for a Four-Size Head Length, Head Breadth Program

Size: Dimension*	1 Min.	1 Max.	2 Min.	2 Max.
1. Head circumference	21.35**	22.85	21.90	23.40
2. Head length***	7.30	7.80	7.80	8.30
3. Head breadth***	5.60	6.10	5.60	6.10
4. Minimum frontal diameter	4.00	4.60	4.05	4.65
5. Maximum frontal diameter	4.35	4.95	4.40	5.00
6. Bizygomatic diameter	5.15	5.75	5.25	5.80
7. Bigonial diameter	3.85	4.55	3.90	4.60
8. Bitragion diameter	5.20	5.80	5.25	5.85
9. Biocular diameter	3.45	4.00	3.50	4.05
10. Interocular diameter	1.05	1.40	1.10	1.40
11. Interpupillary distance	2.25	2.70	2.25	2.75
12. Nose length	1.75	2.20	1.80	2.25
13. Nose breadth	1.15	1.45	1.15	1.50
14. Nasal root breadth	.45	.75	.50	.75
15. Nose protrusion	.70	1.05	.70	1.10
16. Philtrum length	.55	1.00	.55	1.00
17. Menton-subnasale length	2.15	3.05	2.25	3.10
18. Face length	4.05	5.15	4.15	5.25
19. Menton-crinion length	6.70	7.85	6.85	8.00
20. Lip-to-lip distance	.45	.85	.45	.85
21. Lip length	1.75	2.25	1.80	2.25
22. Ear length	2.20	2.70	2.25	2.75
23. Ear breadth	1.25	1.60	1.30	1.60
24. Ear length above tragion	1.00	1.35	1.00	1.35
25. Ear protrusion	.60	1.05	.60	1.10
26. Head height	4.55	5.50	4.65	5.60
27. Menton projection	1.40	2.25	1.45	2.35
28. External canthus to wall	6.25	7.15	6.50	7.40
29. Nasal root to wall	7.20	8.05	7.50	8.40
30. Tragion to wall	3.50	4.45	3.65	4.60
31. Pronasale to wall	7.95	9.05	8.30	9.40
32. Sagittal arc	13.95	15.75	14.45	16.20
33. Bitragion-coronal arc	12.90	14.35	13.05	14.55
34. Minimum frontal arc	4.70	6.00	4.80	6.10
35. Bitragion-minimum frontal arc	11.25	12.50	11.50	12.75
36. Bitragion-crinion arc	12.10	13.65	12.35	13.90
37. Bitragion-menton arc	11.85	13.40	12.10	13.65
38. Bitragion-submandibular arc	10.95	12.95	11.15	13.10
39. Bitragion-subnasale arc	10.65	11.95	10.90	12.20
40. Bitragion-posterior arc	9.80	11.30	10.00	11.50
41. Bitragion-inion arc	10.60	12.30	10.85	12.55
42. Neck circumference	13.60	15.95	13.75	16.10

* Descriptions in Appendix III.
** All values in inches.
*** Key dimensions.

TABLE XIX (con't.)

Design Ranges for a Four-Size Head Length, Head Breadth Program

Size: / Dimension*	3 Min.	3 Max.	4 Min.	4 Max.	1.65 Within-a-Size S. D.
1. Head circumference	21.80**	23.25	22.35	23.85	.74
2. Head length***	7.30	7.80	7.80	8.30	--
3. Head breadth***	6.10	6.60	6.10	6.60	--
4. Minimum frontal diameter	4.10	4.70	4.15	4.75	.30
5. Maximum frontal diameter	4.50	5.10	4.55	5.15	.30
6. Bizygomatic diameter	5.35	5.90	5.40	5.95	.28
7. Bigonial diameter	4.00	4.65	4.00	4.70	.35
8. Bitragion diameter	5.40	6.00	5.45	6.05	.30
9. Biocular diameter	3.50	4.10	3.55	4.10	.28
10. Interocular diameter	1.10	1.40	1.15	1.45	.16
11. Interpupillary distance	2.25	2.75	2.30	2.80	.23
12. Nose length	1.80	2.20	1.80	2.25	.22
13. Nose breadth	1.15	1.50	1.15	1.50	.17
14. Nasal root breadth	.50	.75	.50	.75	.14
15. Nose protrusion	.70	1.10	.70	1.10	.19
16. Philtrum length	.55	.95	.55	1.00	.22
17. Menton-subnasale length	2.15	3.00	2.25	3.10	.44
18. Face length	4.05	5.10	4.15	5.25	.54
19. Menton-crinion length	6.80	7.90	6.95	8.05	.56
20. Lip-to-lip distance	.45	.85	.45	.85	.20
21. Lip length	1.80	2.25	1.85	2.30	.23
22. Ear length	2.20	2.70	2.25	2.75	.26
23. Ear breadth	1.25	1.60	1.30	1.65	.18
24. Ear length above tragion	1.00	1.35	1.00	1.35	.18
25. Ear protrusion	.60	1.10	.65	1.10	.24
26. Head height	4.65	5.60	4.75	5.70	.48
27. Menton projection	1.45	2.30	1.50	2.35	.43
28. External canthus to wall	6.25	7.15	6.50	7.40	.45
29. Nasal root to wall	7.20	8.05	7.55	8.40	.43
30. Tragion to wall	3.50	4.45	3.65	4.60	.46
31. Pronasale to wall	7.95	9.10	8.35	9.45	.56
32. Sagittal arc	14.10	15.85	14.55	16.35	.89
33. Bitragion-coronal arc	13.25	14.75	13.45	14.95	.74
34. Minimum frontal arc	4.85	6.15	4.95	6.20	.64
35. Bitragion-minimum frontal arc	11.50	12.75	11.75	13.00	.63
36. Bitragion-crinion arc	12.40	14.00	12.65	14.20	.78
37. Bitragion-menton arc	12.05	13.60	12.25	13.80	.78
38. Bitragion-submandibular arc	11.15	13.10	11.35	13.30	1.00
39. Bitragion-subnasale arc	10.80	12.10	11.05	12.35	.66
40. Bitragion-posterior arc	10.00	11.50	10.20	11.70	.75
41. Bitragion-inion arc	10.75	12.45	11.05	12.75	.85
42. Neck circumference	13.90	16.25	14.15	16.50	1.18

* Descriptions in Appendix III.
** All values in inches.
*** Kev dimensions.

TABLE XX

Six-Size Head Length, Head Breadth Program Means and Within-a-Size Standard Deviations

Size: Dimension*	1	2	3	4	5	6	Within-a-Size S.D.
1. Head circumference	21.80**	22.35	22.95	22.25	22.80	23.35	.44
2. Head length***	7.45	7.80	8.15	7.45	7.80	8.15	.17
3. Head breadth***	5.95	5.95	5.95	6.25	6.25	6.25	.19
4. Minimum frontal diameter	4.25	4.30	4.35	4.40	4.45	4.50	.18
5. Maximum frontal diameter	4.65	4.65	4.70	4.75	4.80	4.85	.18
6. Bizygomatic diameter	5.45	5.45	5.55	5.60	5.65	5.70	.17
7. Bigonial diameter	4.20	4.25	4.30	4.30	4.35	4.40	.21
8. Bitragion diameter	5.50	5.50	5.60	5.70	5.70	5.75	.19
9. Biocular diameter	3.70	3.75	3.85	3.75	3.80	3.85	.17
10. Interocular diameter	1.20	1.25	1.25	1.25	1.25	1.30	.10
11. Interpupillary distance	2.45	2.45	2.55	2.50	2.50	2.55	.14
12. Nose length	2.00	2.00	2.00	2.00	2.00	2.05	.14
13. Nose breadth	1.30	1.30	1.35	1.30	1.35	1.35	.10
14. Nasal root breadth	.60	.60	.65	.60	.60	.65	.08
15. Nose protrusion	.85	.90	.90	.90	.90	.90	.11
16. Philtrum length	.75	.75	.80	.75	.75	.80	.14
17. Menton-subnasale length	2.60	2.60	2.75	2.55	2.65	2.75	.27
18. Face length	4.55	4.65	4.75	4.55	4.65	4.75	.33
19. Menton-crinion length	7.20	7.35	7.50	7.25	7.45	7.55	.34
20. Lip-to-lip distance	.65	.65	.65	.60	.60	.65	.12
21. Lip length	2.00	2.00	2.05	2.00	2.05	2.05	.14
22. Ear length	2.45	2.45	2.50	2.45	2.50	2.50	.16
23. Ear breadth	1.40	1.45	1.45	1.45	1.45	1.45	.11
24. Ear length above tragion	1.15	1.15	1.20	1.15	1.15	1.20	.11
25. Ear protrusion	.85	.85	.85	.85	.85	.85	.14
26. Head height	5.00	5.05	5.20	5.10	5.15	5.25	.29
27. Menton projection	1.85	1.85	1.95	1.85	1.90	1.95	.26
28. External canthus to wall	6.55	6.80	7.10	6.55	6.80	7.05	.27
29. Nasal root to wall	7.45	7.80	8.10	7.45	7.80	8.10	.26
30. Tragion to wall	3.90	4.05	4.20	3.90	4.05	4.20	.28
31. Pronasale to wall	8.35	8.65	9.05	8.35	8.70	9.00	.32
32. Sagittal arc	14.60	15.05	15.55	14.75	15.20	15.65	.54
33. Bitragion-coronal arc	13.50	13.70	13.90	13.95	14.10	14.20	.45
34. Minimum frontal arc	5.35	5.40	5.50	5.45	5.55	5.60	.39
35. Bitragion-minimum frontal arc	11.70	12.00	12.25	11.95	12.25	12.45	.38
36. Bitragion-crinion arc	12.75	13.00	13.20	13.05	13.35	13.55	.47
37. Bitragion-menton arc	12.55	12.70	13.00	12.65	12.90	13.15	.47
38. Bitragion-submandibular arc	11.85	12.00	12.25	11.95	12.25	12.40	.60
39. Bitragion-subnasale arc	11.20	11.40	11.65	11.35	11.55	11.80	.40
40. Bitragion-posterior arc	10.50	10.65	10.85	10.65	10.85	11.05	.45
41. Bitragion-inion arc	11.35	11.55	11.90	11.45	11.75	12.00	.51
42. Neck circumference	14.65	14.85	15.15	14.90	15.20	15.40	.71

* Descriptions in Appendix III.
** All values in inches.
*** Key dimensions.

TABLE XXI

Design Ranges for a Six-Size Head Length, Head Breadth Program

Size: Dimension*	1 Min.	1 Max.	2 Min.	2 Max.	3 Min.	3 Max.
1. Head circumference	21.10**	22.55	21.65	23.05	22.20	23.65
2. Head length***	7.20	7.60	7.60	8.00	8.00	8.40
3. Head breadth***	5.60	6.10	5.60	6.10	5.60	6.10
4. Minimum frontal diameter	3.95	4.55	4.00	4.60	4.05	4.65
5. Maximum frontal diameter	4.35	4.95	4.35	4.95	4.40	5.00
6. Bizygomatic diameter	5.15	5.70	5.20	5.75	5.25	5.80
7. Bigonial diameter	3.85	4.55	3.90	4.55	3.95	4.65
8. Bitragion diameter	5.20	5.80	5.20	5.80	5.30	5.90
9. Biocular diameter	3.45	4.00	3.50	4.05	3.55	4.10
10. Interocular diameter	1.05	1.40	1.10	1.40	1.10	1.45
11. Interpupillary distance	2.20	2.65	2.25	2.70	2.30	2.75
12. Nose length	1.75	2.20	1.80	2.25	1.80	2.25
13. Nose breadth	1.10	1.45	1.15	1.50	1.15	1.50
14. Nasal root breadth	.45	.75	.45	.75	.50	.75
15. Nose protrusion	.70	1.05	.70	1.10	.75	1.10
16. Philtrum length	.55	1.00	.55	1.00	.60	1.00
17. Menton-subnasale length	2.15	3.00	2.20	3.05	2.30	3.15
18. Face length	4.05	5.10	4.10	5.15	4.20	5.30
19. Menton-crinion length	6.65	7.75	6.80	7.90	6.95	8.05
20. Lip-to-lip distance	.45	.85	.45	.85	.45	.85
21. Lip length	1.75	2.20	1.80	2.25	1.80	2.30
22. Ear length	2.15	2.70	2.20	2.70	2.25	2.80
23. Ear breadth	1.25	1.60	1.25	1.60	1.30	1.65
24. Ear length above tragion	1.00	1.35	1.00	1.35	1.00	1.35
25. Ear protrusion	.60	1.05	.60	1.05	.60	1.05
26. Head height	4.50	5.45	4.60	5.55	4.70	5.65
27. Menton projection	1.40	2.25	1.45	2.30	1.50	2.35
28. External canthus to wall	6.10	7.00	6.35	7.25	6.65	7.50
29. Nasal root to wall	7.00	7.90	7.35	8.20	7.65	8.55
30. Tragion to wall	3.40	4.35	3.60	4.50	3.75	4.70
31. Pronasale to wall	7.80	8.85	8.15	9.20	8.50	9.55
32. Sagittal arc	13.70	15.50	14.20	15.95	14.65	16.45
33. Bitragion-coronal arc	12.80	14.25	12.95	14.45	13.15	14.65
34. Minimum frontal arc	4.70	5.95	4.75	6.05	4.85	6.15
35. Bitragion-minimum frontal arc	11.10	12.35	11.35	12.60	11.65	12.90
36. Bitragion-crinion arc	11.95	13.55	12.20	13.80	12.45	14.00
37. Bitragion-menton arc	11.75	13.30	11.95	13.50	12.20	13.80
38. Bitragion-submandibular arc	10.85	12.85	11.00	13.00	11.25	13.20
39. Bitragion-subnasale arc	10.55	11.85	10.75	12.05	11.00	12.30
40. Bitragion-posterior arc	9.75	11.25	9.90	11.35	10.10	11.60
41. Bitragion-inion arc	10.50	12.20	10.70	12.40	11.05	12.75
42. Neck circumference	13.50	15.85	13.65	16.00	13.95	16.30

* Descriptions in Appendix III.
** All values in inches.
*** Key dimensions.

TABLE XXI (con't.)

Design Ranges for a Six-Size Head Length, Head Breadth Program

Size: / Dimension*	4 Min.	4 Max.	5 Min.	5 Max.	6 Min.	6 Max.	1.65 Within-a-Size S. D.
1. Head circumference	21.55**	23.00	22.05	23.50	22.60	24.05	.72
2. Head length***	7.20	7.60	7.60	8.00	8.00	8.40	--
3. Head breadth***	6.10	6.60	6.10	6.60	6.10	6.60	--
4. Minimum frontal diameter	4.10	4.70	4.15	4.75	4.20	4.80	.30
5. Maximum frontal diameter	4.45	5.05	4.50	5.10	4.55	5.15	.30
6. Bizygomatic diameter	5.35	5.90	5.40	5.95	5.40	6.00	.28
7. Bigonial diameter	3.95	4.65	4.00	4.70	4.05	4.75	.35
8. Bitragion diameter	5.40	6.00	5.40	6.00	5.45	6.05	.30
9. Biocular diameter	3.50	4.05	3.55	4.10	3.60	4.15	.27
10. Interocular diameter	1.10	1.40	1.10	1.45	1.15	1.45	.16
11. Interpupillary distance	2.25	2.70	2.30	2.75	2.35	2.80	.23
12. Nose length	1.80	2.20	1.80	2.25	1.80	2.25	.22
13. Nose breadth	1.15	1.45	1.15	1.50	1.20	1.50	.17
14. Nasal root breadth	.50	.75	.50	.75	.50	.75	.14
15. Nose protrusion	.70	1.10	.70	1.10	.75	1.10	.19
16. Philtrum length	.50	.95	.55	1.00	.55	1.00	.22
17. Menton-subnasale length	2.10	3.00	2.20	3.05	2.30	3.20	.44
18. Face length	4.00	5.10	4.10	5.20	4.25	5.30	.54
19. Menton-crinion length	6.70	7.80	6.85	8.00	7.00	8.10	.56
20. Lip-to-lip distance	.40	.80	.40	.85	.45	.85	.20
21. Lip length	1.80	2.25	1.85	2.30	1.85	2.30	.23
22. Ear length	2.15	2.70	2.20	2.75	2.25	2.80	.26
23. Ear breadth	1.25	1.60	1.30	1.60	1.30	1.65	.18
24. Ear length above tragion	.95	1.35	1.00	1.35	1.00	1.35	.18
25. Ear protrusion	.60	1.10	.60	1.10	.65	1.10	.24
26. Head height	4.65	5.60	4.70	5.65	4.75	5.70	.48
27. Menton projection	1.40	2.25	1.45	2.30	1.55	2.40	.43
28. External canthus to wall	6.10	7.00	6.35	7.25	6.60	7.50	.44
29. Nasal root to wall	7.05	7.90	7.35	8.25	7.70	8.55	.45
30. Tragion to wall	3.45	4.35	3.55	4.50	3.75	4.70	.46
31. Pronasale to wall	7.85	8.90	8.15	9.20	8.50	9.55	.53
32. Sagittal arc	13.85	15.60	14.30	16.10	14.75	16.55	.89
33. Bitragion-coronal arc	13.20	14.70	13.35	14.85	13.50	14.95	.74
34. Minimum frontal arc	4.80	6.10	4.90	6.20	5.00	6.25	.64
35. Bitragion-minimum frontal arc	11.35	12.60	11.60	12.85	11.85	13.10	.63
36. Bitragion-crinion arc	12.25	13.80	12.55	14.10	12.75	14.30	.78
37. Bitragion-menton arc	11.90	13.45	12.10	13.70	12.35	13.95	.78
38. Bitragion-submandibular arc	11.00	12.95	11.25	13.20	11.40	13.40	1.00
39. Bitragion-subnasale arc	10.70	12.00	10.90	12.20	11.15	12.45	.66
40. Bitragion-posterior arc	9.95	11.40	10.10	11.60	10.30	11.80	.74
41. Bitragion-inion arc	10.60	12.30	10.90	12.60	11.15	12.85	.85
42. Neck circumference	13.75	16.10	14.00	16.35	14.20	16.55	1.17

* Descriptions in Appendix III.
** All values in inches.
*** Key dimensions.