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# ANTHROPOMETRIC SIZING, FIT-TESTING AND EVALUATION OF THE MBU-12/P ORAL-NASAL OXYGEN MASK

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FOR THE COMMANDER

CHARLES BATES, JR.
Chief
Human Engineering Division
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This report describes the anthropometric sizing procedures used in the development of the MBU-12/P oral-nasal oxygen mask and documents results of subsequent fit-testing and evaluation of the mask. A successor to the MBU-5/P, the MBU-12/P is designed to withstand the G and Q forces in the newer high performance aircraft as well as to provide a better fit and improved visibility.

Sizing analysis and fit-testing revealed that four sizes of the MBU-12/P are sufficient to cover the USAF male flying population; the anthropometry and

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statistics upon which this decision was based are described in this report. Also documented here are the results of a number of ground and flight tests conducted over a period of four years which provide both objective and subjective evidence that the MBU-12/P is a well fitting mask which successfully achieves its design objectives. Subjects of all the tests were experienced aircrew whose head and face measurements were representative of a full range of the USAF flight crew population. Results of all the fit test/evaluations revealed a high degree of user acceptance and a decided preference for the MBU-12/P when compared to the older MBU-5/P.

## PREFACE

This report was prepared to fulfill requirements of contract F33615-79-C-0511 with the Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio. Contract monitor was Mr. Charles E. Clauser of Crew Station Integration Branch, Human Engineering Division.

A considerable number of agencies and individuals made significant contributions to the sizing, fit-testing and evaluation of the MBU-12/P oral-nasal oxygen mask from its initiation in 1974 to its standardization five years later. The authors are grateful for the cheerful and knowledgeable cooperation of the many test subjects and to a great number of unsung administrators and technicians who efficiently facilitated arrangements and smoothed our way at the various air bases where tests were conducted. We would particularly like to cite the help of Mr. Ned Ostendorf, Kettering, Ohio, for his accurate translation of the anthropometric sizing data into three-dimensional face forms. The authors would also like to thank Captain Robert L. Higgins, Mr. Ernest A. Horns, Mr. J. Donald Bowen and Mr. John James, of the 412A Life Support SPO, Wright-Patterson Air Force Base, for valuable efforts during all phases of the developmental program. Major Michael T. McGinness, former Life Support Officer, deserves special mention for his efficiency in handling the administrative details for the fit-testing of the 17th Bomb Wing subjects, Wright-Patterson Air Force Base. During the ground and flight tests at Nellis Air Force Base, Captain Philip Templin, M/Sgt Leslie Ray and T/Sgt Donald Wogoman efficiently performed numerous technical duties.

Mr. Ron Robinette executed the original drawings which appear in the Appendix and Ms. Jane Reese of the Anthropology Research Project prepared the manuscript for publication.

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## SECTION I

## INTRODUCTION

For some 20 years after its introduction in the late fifties, the MBU-5/P USAF oxygen mask proved to be a well-functioning, well-fitting and comfortable item of flight equipment which gained a high degree of user acceptance. However, the advent of a new generation of fighter aircraft in which pilots sustained higher G and Q forces made demands on the mask for which it was not designed and which it could not adequately meet. The need arose for a lighter weight oxygen mask that did not slide down the face in a sustained high-G environment, did not create pressure points or "hot spots" during normal flights, and provided better visibility and less bulk.

This report traces the development of the new mask, designated the MBU-12/P, from the original data analysis undertaken to determine its shape and size, through the ground and flight testing which determined the success of the new design in terms of fit, function and comfort.

The MBU-12/P pressure-demand oxygen mask manufactured by Sierra Engineering Company, Sierra Madre, California, has a low profile single-unit facepiece in which a deformable silicone rubber face form is bonded to a rigid polysulfone hard shell (see Figures 1 and 2). A soft corrugated hose connects the facepiece with the regulator; a nylon line inside the hose prevents over-stretching. Rigidly mounted over the inhalation/exhalation valve which couples the hose with the facepiece, is the microphone with its communications cord coiled around the outside of the hose. Individual harness adjustment straps anchored to the hard shell provide the base for attaching the standard straight or offset bayonets which are used with the HGU series helmets.

Figure 1. Front face MBU-12/P.

While the chief purpose of the mask is to provide oxygen to aircrews at high altitude, its secondary functions include acting as a carrier for the intercom and radio communications systems; protection from decompression, fire or fumes in the cockpit and from wind blast in the event of bailout; and provision of emergency oxygen during ditching or ejection.

Figure 2. Side view MBU-12/P.

The major differences between the old and new model lie between the two-part facepiece and hard shell of the MBU-5/P and the integrated hard shell and facepiece of the MBU-12/P. Additionally, the MBU-12/P facepiece has been reconfigured to provide better fit, increased visibility and greater stability under high G forces.

This report is divided into two major sections. The first outlines the procedures and data used in establishing the four sizes of the MBU-12/P mask and includes a presentation of the design limits and a suggested initial procurement tariff indicating the number of masks required in each size to accommodate the target population. Also described is the development of three-dimensional face forms which guided fabrication of the MBU-12/P prototypes.

The last section describes a series of fit tests which took place over a period of several years and which established that the MBU-12/P achieves a high degree of success in meeting its stated objectives.

## SECTION II

## SIZING AND DESIGN OF THE MBU-12/P

The first step in successful sizing of clothing or equipment is to select a sample population whose body size dimensions, when analyzed, will yield data directly applicable to the population for which a proposed new garment or piece of equipment is being designed. In 1967, an extensive body-size survey was conducted of USAF flight personnel (Churchill et al., 1977). The participants in the survey were members of each of the major USAF flight commands drawn from 17 air bases distributed throughout all sections of the continental United States. A total of 2420 rated male officers were measured for 187 body dimensions encompassing the head, face, torso, arms, legs, hands and feet. The anthropometric data of the head and face resulting from this survey serve as the basis for the new oral-nasal sizing program and face forms.

Some 48 measurements of the head and face were made on each subject in the survey. Of these measurements, 36 were directly or indirectly usable in the development of face forms for the sizing and design of oral-nasal oxygen masks. Prior to establishing a sizing program, the data were analyzed and a comparison made with the USAF 1950 anthropometric data from which the sizing dimensions of the MBU-5/P oxygen mask had been developed (Churchill & Daniels, 1953; Churchill & Truett, 1957; Hertzberg et al., 1954). This comparison indicated that the 1967 sample was, on the average, older (2.64 years), taller (1.78 cm), and heavier (4.61 kg). The dimensions of the head and face were, on the average, also somewhat larger; for example, head circumference 4.9 mm larger, face length 2.7 mm longer, and face breadth 1.4 mm wider. The differences in head and face dimensions, while small, are of sufficient magnitude to be significant in oxygen mask sizing.

While the developmental oxygen mask is designed primarily to be used by pilots of high-performance aircraft (Tactical Air Command, Air Defense Command), it must be assumed that it would be used by other commands as well (Strategic Air Command, Military Air Command). A comparison of the various command subgroup head and face measurement values (means and standard deviations) indicated that the differences in size among the subgroups were indeed small and were, in general, within 1 mm or less of the total sample values. The total 1967 sample was, therefore, used in the sizing analysis.

The relevant dimensions and the corresponding summary statistics (range, mean, standard deviation, and coefficient of variation) for the total sample are shown in Table 1. Definitions and illustrated measurement descriptions for each variable appear in the Appendix.

TABLE 1

SUMMARY STATISTICS FROM USAF 1967 SELECTED
HEAD AND FACE DATA (n=2420)*

| | Variable | Range | Mean | S.D. | V(%) |
|---|---|---|---|---|---|
| 1. | Minimum Frontal Curvature | 113-169 | 136.0 | 7.9 | 5.8 |
| 2. | Bitragion-Coronal Curv | 321-401 | 357.6 | 12.6 | 3.5 |
| 3. | Bitragion-Min Frontal Curv | 273-349 | 308.1 | 10.0 | 3.2 |
| 4. | Bitragion-Subnasale Curv | 259-327 | 293.1 | 10.2 | 3.5 |
| 5. | Bitragion-Menton Curv | 281-367 | 326.5 | 12.4 | 3.8 |
| 6. | Bitragion-Submandib Curv | 259-367 | 309.8 | 15.8 | 5.1 |
| 7. | Maximum Frontal Breadth | 96-131 | 116.0 | 4.6 | 3.9 |
| 8. | Bitragion Breadth | 124-161 | 142.5 | 5.6 | 3.9 |
| 9. | Bizygomatic Breadth | 124-159 | 142.3 | 5.2 | 3.7 |
| 10. | Bigonial Breadth | 95-142 | 117.3 | 6.9 | 5.9 |
| 11. | Biocular Breadth | 78-108 | 91.7 | 4.9 | 5.3 |
| 12. | Interpupillary Breadth | 51- 77 | 62.7 | 3.6 | 5.7 |
| 13. | Interocular Breadth | 23- 44 | 33.3 | 2.8 | 8.4 |
| 14. | Nose Breadth | 27- 51 | 35.4 | 2.9 | 8.2 |
| 15. | Lip Length | 39- 66 | 52.3 | 3.7 | 7.1 |
| 16. | Subnasale-Nasal Root Lgth | 39- 64 | 51.3 | 3.7 | 7.2 |
| 17. | Philtrum Length | 6- 25 | 15.5 | 2.8 | 18.1 |
| 18. | Lip to Lip Length | 3- 32 | 17.3 | 3.8 | 22.0 |
| 19. | Menton-Subnasale Length | 53- 89 | 69.0 | 5.3 | 7.6 |
| 20. | Menton-Nasal Root Length | 98-143 | 120.3 | 6.1 | 5.1 |
| 21. | Nasal Root Breadth** | 9- 23 | 15.5 | 2.1 | 13.5 |
| 22. | Glabella to Top of Head | 57-126 | 92.7 | 9.7 | 10.5 |
| 23. | Nasal Root to Top of Head | 69-141 | 107.5 | 9.4 | 8.7 |
| 24. | Ectocanthus to Top of Head | 91-148 | 119.5 | 7.7 | 6.4 |
| 25. | Pronasale to Top of Head | 110-186 | 147.4 | 11.0 | 7.5 |
| 26. | Subnasale to Top of Head | 125-196 | 160.9 | 10.2 | 6.3 |
| 27. | Stomion to Top of Head | 150-220 | 183.7 | 10.0 | 5.4 |
| 28. | Menton to Top of Head | 192-260 | 227.7 | 10.2 | 4.5 |
| 29. | Tragion to Top of Head | 115-155 | 134.5 | 6.1 | 4.5 |
| 30. | Glabella to Wall | 180-230 | 203.5 | 6.7 | 3.3 |
| 31. | Nasal Root to Wall | 180-228 | 201.7 | 6.6 | 3.3 |
| 32. | Ectocanthus to Wall | 156-204 | 177.9 | 6.6 | 3.7 |
| 33. | Pronasale to Wall | 196-252 | 226.8 | 7.5 | 3.3 |
| 34. | Subnasale to Wall | 180-236 | 209.9 | 7.9 | 3.8 |
| 35. | Lip Protrusion to Wall | 186-240 | 211.6 | 8.6 | 4.1 |
| 36. | Chin Prominence to Wall | 170-240 | 204.7 | 10.5 | 5.1 |
| 37. | Tragion to Wall | 81-125 | 103.3 | 6.5 | 6.3 |

* All values shown in millimeters; coefficient of variation shown in percent.

** U.S. Air Force 1950 survey data.

The first 20 dimensions listed in Table 1 are direct measurements of the face. The 21st variable, Nasal Root Breadth, was not measured in the USAF 1967 survey but is of value in sizing oral-nasal masks. It was, therefore, computed from regression equations based upon its relationship with the measured variables. The remaining 16 variables are measurements from a facial landmark to a plane tangential to the top or back of the head. These serve as Cartesian coordinates to locate the point in three-dimensional space.

An anthropometric sizing analysis consists of a series of discrete steps. The major steps, which are described in detail elsewhere (Alexander et al., 1971; Alexander et al., 1961; McConville et al., 1972; Ziegen et al., 1960), include:

(1) Selecting an appropriate body of anthropometric data for analysis.

(2) Selecting one or more key or basic sizing dimensions.

(3) Selecting the range of the key dimensions for the purpose of establishing a sizing category that will adequately accommodate all those individuals who fall within it.

(4) Developing for each sizing category all other dimensional data for use in the sizing of the item.

(5) Converting the summary data to the proper design value for the end item in terms of form or function.

(6) Establishing the sizing tariff.

The first step above has been completed. The second step is typically achieved by correlational analysis, with the key dimension selected on the basis of degree of relationship with all other dimensions involved in the sizing of the facepiece. In this instance, the dimensions of the face are known to have a relatively low correlation with each other and no single dimension, or pair of dimensions, could be specified as exerting significant control over all other measures of facial size. While ordinarily this sort of random body size variation makes sizing very difficult, the pliable nature of the mask material, capable of conforming to a variety of facial contours, made it possible to select one or two key dimensions on which to base the sizing. The present MBU-5/P (originally designated as the MC-1), for example, was designed for a six-size system with each of three face lengths having a narrow and wide size based upon lip length (Emanuel et al., 1959). In the fit-test and evaluation of the MBU-5/P, however, it was found that all the wide sizes were not necessary because the silicone facepieces were sufficiently deformable so that the narrow sizes spread apart to accommodate the wider faces and still provided a tight seal. The long-wide and the short-wide facepieces were, therefore, deleted from the sizing program. The regular-wide facepiece was retained because of the large number of subjects for whom this size was indicated.

As a result of these observations, it was decided to size the new oral-nasal masks on the basis of a single key dimension--face length (Menton-Nasal Root Length in Table 1). Selection of a single key dimension has the added advantage of facilitating measuring procedures in the field. Four face-length categories, each with a 9 mm range, encompassed some 99.6% of the sample population and were found to provide essentially the same degree of coverage of the population as did the six categories devised for the MBU-5/P. With the deformable rubber material taking care of the variations in facial width, the addition of a fourth face-length size, in fact, assured a somewhat better facepiece fit for the new mask. Sizing categories for the MBU-12/P are shown in Table 2.

TABLE 2

SIZE CATEGORIES FOR MBU-12/P MASK

| Size Category | Face Length Range | Percent of USAF 1967 Sample |
|---|---|---|
| Size 1 (Short) | 102.5-111.5 mm | 7.40% |
| Size 2 (Regular) | 111.5-120.5 mm | 43.76% |
| Size 3 (Long) | 120.5-129.5 mm | 42.36% |
| Size 4 (Extra Long) | 129.5-138.5 mm | 6.12% |
| Outside design limits | | 0.36% |

The next step was the development of all other dimensional data relevant to the design of the mask in four sizes. To this end, individuals in each sizing category were treated as a subgroup and the mean for each of 35 facial dimensions was computed for each subgroup or size category. The standard deviation from the four categories for each measurement was averaged to reduce the effects of the variation in category sample size and these averaged standard deviations were used with the category means to establish the design ranges for each sizing category. While the range encompasses the measurements of all the persons who will be fitted by a particular size category, the mask itself must be manufactured in a single size for a given dimension. Thus, while the size range for the face length of the Short size was determined to be 102.5-111.5 mm (see Table 2 above), the actual face length and all other dimensions of the Size 1 mask are predicated on the basis of designated design values.

The design values were developed as a particular combination of the mean value with averaged standard deviation. The length of the face (menton-nasal root length), which was the key sizing dimension, was established at the midpoint of the category range. The proportions of upper and lower face length were then established by regression equations based upon the appropriate face length. The projection of the nose, nose breadth, lip length, and lip protrusion were established as the regression mean value plus 1.65 or two standard deviations (95th or 97.7th percentile value, respectively) as these must be cleared by the body or the internal sealing edge of the facepiece. The breadth of the facepiece was constructed by using design values for bizygomatic breadth and bigonial breadth equal to the mean minus one standard deviation. The assumption here is that the external sealing edge of the facepiece of the mask must not be so wide as to extend beyond the limits of the narrow faces. The majority of the other dimensions were based upon regression values using the appropriate face length for a particular size.

While dimensions of an end item are often established directly on the basis of statistical analysis of the anthropometric data, it was decided in this case to enhance the design process by using three dimensional face forms similar to those used in the development of the MBU-5/P. The design values for the MBU-12/P, shown in Table 3, were furnished to the sculptor to be incorporated into the face forms. For these purposes, only the face was of interest and the finished forms did not include the back of the head. Therefore, for variables 22-36 on Table 3, the zero point of the reference system was translated from "top-of-head" and "wall" to tragion and the facial points were located as a distance forward of and above or below it. The translation from one reference point to the other was accomplished by the simple subtraction of the tragion to-wall distance from all other to-wall measurements and the tragion to-top-of-head distance from all other to-top-of-head measurements.

The forms were sculpted in clay and achieved an accuracy of $\pm$ 1 mm for each of the 36 dimensions. After the final clay sculpture was accepted, a plaster of Paris-backed rubber mold was prepared from which plaster of Paris casts could be made. This technique preserved the detail and dimensional accuracy of the original sculpture in the final castings (see Figure 3). A

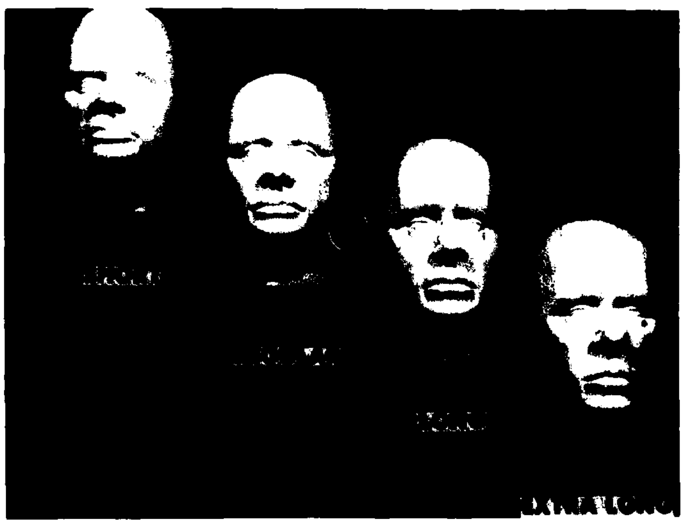


Figure 3. Oral-nasal four-size face forms.

## TABLE 3

## FOUR-SIZE FACE LENGTH DESIGN VALUES*

| | Variable | Size 1 | Size 2 | Size 3 | Size 4 | Design Criteria |
|---|---|---|---|---|---|---|
| 1. | Minimum Frontal Curvature | 133 | 135 | 137 | 139 | Regression Mean |
| 2. | Bitragion-Coronal Curv | 351 | 356 | 360 | 364 | Regression Mean |
| 3. | Bitragion-Min Frontal Curv | 302 | 306 | 310 | 315 | Regression Mean |
| 4. | Bitragion-Subnasale Curv | 289 | 292 | 295 | 297 | Regression Mean |
| 5. | Bitragion-Menton Curv | 318 | 324 | 330 | 336 | Regression Mean |
| 6. | Bitragion-Submandib Curv | 301 | 307 | 313 | 319 | Regression Mean |
| 7. | Maximum Frontal Breadth | 115 | 116 | 117 | 118 | Regression Mean |
| 8. | Bitragion Breadth | 140 | 142 | 143 | 145 | Regression Mean |
| 9. | Bizygomatic Breadth | 135 | 137 | 138 | 140 | Regr Mean minus 1 SD |
| 10. | Bigonial Breadth | 110 | 110 | 111 | 111 | Regr Mean minus 1 SD |
| 11. | Biocular Breadth | 86 | 86 | 87 | 88 | Regr Mean minus 1 SD |
| 12. | Interpupillary Breadth | 58 | 59 | 59 | 60 | Regr Mean minus 1 SD |
| 13. | Interocular Breadth | 27 | 28 | 28 | 29 | Regr Mean minus 2 SD |
| 14. | Nose Breadth | 41 | 41 | 41 | 42 | Regr Mean plus 2 SD |
| 15. | Lip Length | 60 | 60 | 60 | 60 | Regr Mean plus 2 SD |
| 16. | Subnasale-Nasal Root Lgth | 47 | 50 | 53 | 56 | Regression Mean |
| 17. | Philtrum Length | 14 | 15 | 16 | 18 | Regression Mean |
| 18. | Lip to Lip Length | 16 | 17 | 18 | 19 | Regression Mean |
| 19. | Menton-Subnasale Length | 60 | 66 | 72 | 78 | Regression Mean |
| 20. | Menton-Nasal Root Length | 107 | 116 | 125 | 134 | Category Midpoint |
| | (Above Tragion Level) | | | | | |
| 21. | Nasal Root Breadth** | 15 | 15 | 16 | 16 | Regression Mean |
| 22. | Glabella to Tragion | 39 | 41 | 43 | 45 | Regression Mean |
| 23. | Nasal Root to Tragion | 24 | 26 | 28 | 30 | Regression Mean |
| 24. | Ectocanthus to Tragion | 14 | 15 | 16 | 17 | Regression Mean |
| | (Below Tragion Level) | | | | | |
| 25. | Pronasale to Tragion | 12 | 13 | 13 | 14 | Regression Mean |
| 26. | Subnasale to Tragion | 25 | 26 | 27 | 28 | Regression Mean |
| 27. | Stomion to Tragion | 45 | 48 | 51 | 53 | Regression Mean |
| 28. | Menton to Tragion | 84 | 90 | 97 | 103 | Regression Mean |
| 29. | Tragion to Top of Head | 132 | 134 | 135 | 137 | Regression Mean |
| | (Forward of Tragion Level) | | | | | |
| 30. | Glabella to Tragion | 99 | 100 | 101 | 102 | Regression Mean |
| 31. | Nasal Root to Tragion | 94 | 95 | 96 | 97 | Regr Mean minus 0.5 SD |
| 32. | Ectocanthus to Tragion | 73 | 74 | 75 | 76 | Regression Mean |
| 33. | Pronasale to Tragion | 133 | 135 | 137 | 139 | Regr Mean plus 2 SD |
| 34. | Subnasale to Tragion | 105 | 106 | 107 | 108 | Regression Mean |
| 35. | Lip Protrusion to Tragion | 118 | 119 | 120 | 121 | Regr Mean plus 1.65 SD |
| 36. | Chin Prominence to Tragion | 102 | 102 | 101 | 101 | Regression Mean |

* All values shown in millimeters; U.S. Air Force 1967 survey data.

** U.S. Air Force 1950 survey data.

female face form, based on data obtained from the 1968 survey of Air Force women (Clauser et al., 1972) was also developed at that time but this addition, having a face length of 102 mm and designed to supplement the male sizing program, has not yet been used to size a mask.

Just as design values do not constitute the actual dimensions of the finished garments for tailors, the face forms were not designed as positives from which facepieces were to be molded. Rather, they functioned as hands-on three-dimensional design guides to aid in the transposition of anthropometric data to well-fitting oral-nasal oxygen masks required to accommodate a range of facial variability in each of the 36 measured dimensions as well as in the unmeasured curves, protrusions and hollows in between. For nasal root breadth, for example, design values of 15 mm (Short and Regular) and 16 mm (Long and Extra Long) were used. As can be seen from Table 1, however, the USAF population, as a whole, ranges from 9 mm to 23 mm while the 5th to 95th percentiles for which one customarily designs spans 12 to 19 mm. A facepiece must provide a seal in the nasal bridge area for those individuals having a narrow nasal root but must not exert undue pressure on those individuals having a broad nasal root. The nature of the material used, the adjustability of the harness, location of the microphone, and integration with other gear all become factors in determining the design and dimensions of the finished items; the design values and contours of the face forms serve as frameworks around which these decisions are made.

The final step in the sizing analysis is the tariffing of the end item to establish the number of masks to be manufactured in each size. Sizing tariffs for the MBU-12/P are detailed in Section III, Table 8.

In January 1974, the face forms were furnished to the 412A Life Support Special Projects Office, Wright-Patterson Air Force Base, Ohio, which, in turn, contracted with Sierra Engineering Company, Sierra Madre, California for development of the experimental mask.

## SECTION III

## FIT-TESTING AND EVALUATION

The first of several fit-tests of the developmental MBU-12/P mask was conducted at Wright-Patterson Air Force Base in January 1975. Testing was done in a nonoperational laboratory environment using 66 crew members of the 17th Bombardment Wing, Strategic Air Command, as subjects.

Age, height and weight were recorded for each subject and six facial dimensions measured. Subjects were then fitted in their indicated mask sizes with the following results:

TABLE 4

INDICATED MASK SIZES

| Size | No. of Subjects |
|---|---|
| Short | 2 |
| Regular | 29 |
| Long | 30 |
| X-Long | 5 |

Tests for leakage at five different pressure settings were conducted using an A-14A oxygen regulator and flow meter. A criterion of one liter/minute of leakage was set by the expert oxygen mask technician assigned to the evaluation team as the point at which the mask would be considered to have failed to provide a functional seal. Further testing included objective and subjective evaluations of the fit and comfort of the masks by the investigators and the subjects.

To ascertain the representativeness of the test sample, their measurements were compared with comparable data obtained from the 1967 USAF flying population as shown in Table 5. The fit-test sample, though small, was judged to be a representative subset of the flying population in terms of the dimensions measured. The range in measurements of the subset was quite broad with subjects ranging from approximately the 1st to the 99th percentiles for most of the facial dimensions.

Table 6 depicts results of the leakage test in terms of the percentage of subjects achieving a seal at each pressure setting. All of the test subjects obtained a functional mask seal at the initial pressure setting of 30,000-40,000 feet of altitude (30-40 M or approximately 1.75 inches of water), a range which represents normal flight conditions. As can be seen,

TABLE 5

ANTHROPOMETRIC COMPARISON OF FIT-TEST SAMPLE WITH USAF POPULATION

| | FIT-TEST SERIES | | | 1967 USAF SURVEY | |
|---|---|---|---|---|---|
| Variable | Range | Mean | SD | Mean | SD |
| | (n=66) | | | (n=2420) | |
| Age | 19-45 | 29.40 | 5.33 | 29.53 | 6.31 |
| Height (Reported) | 60-76 | 70.16 | 2.97 | 69.58 | 2.37 |
| Weight (Reported) | 120-230 | 170.06 | 22.96 | 173.06 | 9.65 |
| Bizygomatic Br | 134-155 | 142.35 | 4.86 | 142.30 | 5.20 |
| Nasal Br | 28-44 | 34.78 | 2.73 | 35.40 | 2.90 |
| Lip Length | 47-62 | 54.79 | 3.71 | 52.30 | 3.70 |
| Nose Length | 44-60 | 51.64 | 3.42 | 51.30 | 3.70 |
| Lower Face Lgth | 61-84 | 72.68 | 4.73 | 69.00 | 5.30 |
| Total Face Lgth | 106-135 | 120.90 | 6.01 | 120.30 | 6.10 |

* Age in years, height in inches, weight in pounds and all other measurements in millimeters.

TABLE 6

QUANTITATIVE LEAK TEST RESULTS
(Seal = <1 ℓ/min leakage)

| | No. Tested | 30-40 M Seal % | 41 M Seal % | 43 M Seal % | 45 M Seal % | >45 M Seal % |
|---|---|---|---|---|---|---|
| Short | 2 | 2 (100) | 1 (50) | 1 (50) | 0 | 0 |
| Regular | 29 | 29 (100) | 26 (89.7) | 21 (72.4) | 15 (51.7) | 6 (20.7) |
| Long | 30 | 30 (100) | 30 (100) | 26 (86.7) | 20 (66.7) | 19 (63.3) |
| X-Long | 5 | 5 (100) | 4 (80) | 3 (60) | 2 (40) | 0 |
| | | 66 (100) | 61 (92.4) | 51 (77.3) | 37 (56.1) | 25 (37.9) |

increasingly higher altitude simulations resulted in decreasing seals although it should be emphasized that failure to achieve a seal as defined by the test criterion of more than one liter per minute leakage does not necessarily imply insufficient oxygenation. The regulator is designed to more than compensate for reasonable leakage.

Eight subjects were also tested in alternate sizes of masks. Seven of these subjects had face length measurements that fell at the extreme end of the size interval and they were, therefore, tested in the masks in the adjacent size category as well as in their indicated size masks. One subject with facial asymmetry was also tested in an alternate mask after a failure of the indicated size at the 41 M setting. The results of the tests of alternate size masks are given in Table 7.

TABLE 7

FIT-TEST RESULTS WITH ALTERNATE SIZE MASK

| Subject | Indicated Size | Functional Seal to | Alternate Size | Functional Seal to |
|---|---|---|---|---|
| 1 | Regular | Safe | Short | 43 M |
| 4 | Regular | 43 M | Short | >45 M |
| 14 | Regular | 43 M | Long | 45 M |
| 17 | Regular | 43 M | Short | 43 M |
| 22 | Regular | 43 M | Short | 45 M |
| 30 | Regular | 41 M | Short | 45 M |
| 32 | Regular | 41 M | Short | 43 M |
| 40 | Long | 45 M | X-Long | 41 M |

The alternate mask provided a better facial seal in six of the eight cases, a comparable seal in one case (Subject 17) and a poorer seal in one case (Subject 40). In the latter instance, the subject had always had difficulty obtaining a satisfactory oxygen mask and was then flying with a custom fit MBU-5/P.

The anticipated sizing tariff shown in Table 8, is based on the frequency of the four face-length ranges as found in the USAF population as a whole and, as is customary, was determined before the fit-testing began.

TABLE 8

SIZING TARIFFS

| Size | Face Length Range (mm) | Anticipated Frequency | Fit-Test Sample Frequency |
|---|---|---|---|
| 1 (Short) | 102.5-111.5 | 7.40% | 3.0% |
| 2 (Regular) | 111.5-120.5 | 43.76% | 43.9% |
| 3 (Long) | 120.5-129.5 | 42.36% | 45.5% |
| 4 (Extra Long) | 129.5-138.5 | 6.12% | 7.5% |
| Outside design limits | | 0.36% | 0% |

As can be seen, these frequencies are slightly at variance with those found in the fit-test sample for the Short and Long sizes. It was judged by the investigators that the short face lengths were under-represented in the sample while the long ones were slightly over-represented. The sample size and frequency deviations were too small to warrant a reevaluation of the tariff, especially in light of the number of subjects downgraded with the Short category as an alternate size.

Comments were solicited from each subject at the end of the individual fit-tests regarding the fit, comfort, and suitability of the mask for flight operations. The responses indicated a very high level of user acceptance of the mask. In general, the test subjects indicated the mask provided a better fit and was more comfortable than their present mask. The single most common complaint related to the placement of the internally mounted microphone which tended to touch the lips even when fully recessed. Only one subject felt he did not obtain as good a fit with this mask as with his then-current MBU-5/P. Three subjects noted excessive pressure on the cheek and/or bridge of the nose when the mask was tightened for the higher pressure setting but stated the mask was quite comfortable and fit well for the lower pressure settings.

Investigators concluded that results of the laboratory fit-test proved the validity of the four-size program devised for the MBU-12/P mask.

Over the next several years, the MBU-12/P mask was the subject of several more thorough evaluations. In 1977-78, the U.S. Navy conducted an operational evaluation in which a total of 90 masks were provided to eight U.S. Navy squadrons and a unit of the First Marine Air Wing. Men in these groups logged over 4,000 flight hours while wearing the mask. Sixty-five valid questionnaires, representing a total of 7,569 hours of flight and ground testing were completed by the subjects.

The MBU-12/P was found to be an effective and suitable oxygen mask for use in high-G environments and was recommended by the Operational Test and Evaluation Force for service use and production. Asked to compare the qualities of the MBU-12/P with those exhibited by the older MBU-5/P, subjects rated the test mask as high or higher in virtually all measured categories. On a scale of 1 (Poor) to 5 (Excellent), over 95% of the test sample rated the fit of the MBU-12/P "good" or "excellent" and close to 90% gave the mask a "good" or "excellent" rating for comfort. Improved stability under high G's and better visibility were also clearly documented by the respondents. Only minor problems were noted in the report (Anon., 1978); these included some difficulties associated with the procedure used to obtain the indicated mask size for a given individual, a problem also noted in testing conducted by the Tactical Air Command (TAC).

Over an 18-month period between 1976 and 1978, an initial operational test and evaluation (IOT&E) of the MBU-12/P was carried out under the auspices of the USAF Tactical Air Warfare Center. While results of the flight testing at several bases in the continental U.S. further confirmed the effectiveness of the MBU-12/P, the IOT&E report cited apparent problems associated with determining the proper size of mask indicated for each subject. "During initial fitting of the masks," the report stated, "it was noted that a sizeable number of individuals needed a mask one size larger than that indicated by the mask sizing categories."

For this reason, it was decided to conduct another sizing and fit-test at Nellis Air Force Base, Nevada in August 1978.

A total of 52 pilots and navigators were used as subjects in the combined ground and flight test. Of these, 28 subjects participated in the flight test. The sample was composed of highly experienced flight personnel who normally flew a variety of aircraft, including aircraft capable of very high G performance.

Using essentially the same approach we employed in the original fit-test, the age of each subject was recorded and 10 head and facial dimensions measured (Table 9). Included in the recorded measurements were also reported height and weight. The summary statistics for each sample are given and contrasted with comparable values from the 1967 anthropometric survey of the USAF flying population. These data indicate that the total fit-test sample is, on the average, somewhat older (3.3 years), taller (1.3 inches), and heavier (2.0 pounds).

TABLE 9

ANTHROPOMETRIC PROFILE OF FIT-TEST SAMPLE*

| | Total Sample (n=52) | | Flight Sample (n=31) | | USAF 1967 (n=2420) | | |
|---|---|---|---|---|---|---|---|
| | $\bar{X}$ | SD | $\bar{X}$ | SD | $\bar{X}$ | SD | |
| Age | 32.8 | (3.4) | 33.4 | 3.2 | 29.5 | 6.3 | |
| Height (reported) | 70.9 | (2.2) | 70.7 | 2.4 | 69.6 | 2.4 | |
| Weight (reported) | 175.1 | (18.3) | 174.1 | 19.7 | 173.1 | 19.7 | |
| Face Length | 121.6 | (5.9) | 121.8 | 6.4 | 120.3 | 6.1 | |
| Upper Face Length | 52.4 | (3.5) | 52.6 | 3.8 | 51.3 | 3.7 | |
| Lower Face Length | 72.8 | (5.4) | 73.3 | 4.6 | 69.0 | 5.3 | |
| Nasal Root Br | 18.4 | (1.9) | 18.4 | 2.0 | 18.3 | 2.6 | (1965 survey) |
| Lip Length | 55.2 | (3.0) | 55.2 | 2.9 | 52.3 | 3.7 | |
| Face Breadth | 140.8 | (4.8) | 141.4 | 5.0 | 142.3 | 5.2 | |
| Bigonial Breadth | 113.4 | (6.6) | 113.0 | 6.6 | 117.3 | 6.9 | |
| Head Length | 198.9 | (6.5) | 199.0 | 7.0 | 198.7 | 6.7 | |
| Head Breadth | 154.4 | (4.7) | 155.1 | 4.7 | 156.0 | 5.4 | |
| Nose Breadth | 34.1 | (3.0) | 34.0 | 3.0 | 35.4 | 2.9 | |

* Age in years, weight in pounds, height in inches; all other dimensions in millimeters.

The percentile equivalents of facial and head size coverage of the fit-test sample are shown in Table 10.

TABLE 10

PERCENTILE EQUIVALENTS OF FIT-TEST SAMPLE

| | Minimum | Maximum |
|---|---|---|
| Face Length | 4 | 99 |
| Upper Face Length | 8 | 98 |
| Lower Face Length | 2 | >99 |
| Nasal Root Breadth | 10 | 99 |
| Lip Length | 13 | >99 |
| Face Breadth | 1 | 95 |
| Bigonial Breadth | <1 | 83 |
| Head Length | 4 | 97 |
| Head Breadth | 3 | 93 |
| Nose Breadth | <1 | >99 |

From this coverage it is apparent that the range in facial size variability in the sample was adequate for purposes of the fit-test.

The evaluation was conducted in two phases using flight personnel from the training wing. A special caliper (see Figure 4),

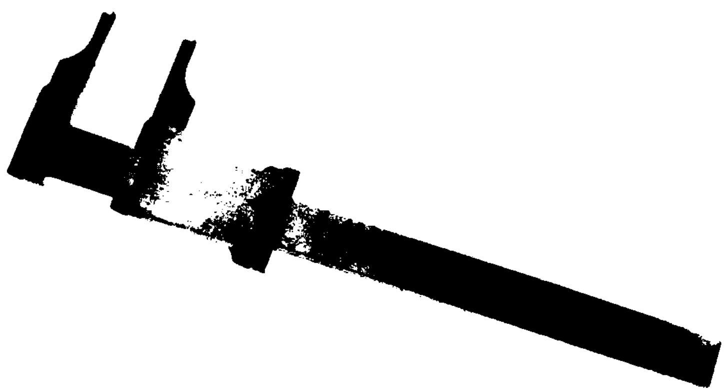


Figure 4. MBU-12/P mask-sizing calipers.

to ascertain the proper mask size, was used to measure the subjects who were then fitted in their indicated sizes. The MBU-12/P is designed to fit on the face somewhat differently from the old MBU-5/P whose upper edge is seated on the nasal root depression between the eyes. The MBU-12/P, designed to afford improved visibility, is anchored under the chin with its upper edge falling somewhat lower on the bridge of the nose (see Figure 5).

In the first phase of the evaluation, 31 pilots and Electronic Warfare Officers (EWO's) were fitted in their indicated sizes while wearing their actual flight helmets. Oxygen mask receivers

were adjusted for each aircrewman to provide for optimum attachment of the offset or straight bayonets and then tested for seal using the A-14 regulator or the MQ1 tester. A face mask seal was judged satisfactory if no leakage occurred at the A-14A regulator pressure setting of 43,000 feet. The mask was adjusted on each man to afford the optimum trade-off between seal and comfort. When the aircrewman and the investigators were satisfied that the proper size mask had the optimum adjustment, the oxygen mask was then given to the aircrewman.

Figure 5. Properly fitted MBU-12/P lower on the nose to permit improved visibility.

In the second phase of the test, 21 additional crew members were measured, fitted and tested in the same fashion as the first phase except that the bayonet receivers on the helmet were not adjusted for the MBU-12/P mask. The fitting in this phase was limited to ground testing only because of an insufficient supply of test masks.

The results of the two fit-tests are as follows:

| | PHASE I | PHASE II | TOTAL |
|---|---|---|---|
| Number of Subjects | 31 | 21 | 52 |
| Seal Accomplished | 30 | 15 | 45 |

One subject (#7) in phase one could not obtain a seal with strap adjustment but could obtain a seal by holding the mask lightly on the face. It appeared that the receiver could not be rotated sufficiently to provide a proper facial seal and that a remounting of the bayonet receivers on the helmet would be necessary to achieve an effective seal. This remounting was not possible during the test. One other test subject (#28) who achieved a seal objected to the facial pressure of the mask. Again this could possibly have been alleviated by remounting of the bayonet receivers on the helmet. However, this subject normally flies with a custom-fit MBU-5/P mask and appeared hypersensitive to any pressure on the face.

In the second phase, 15 of the 21 subjects attained a good seal. Six aircrewmen could not be tested properly since the bayonet receivers on the helmet were not adjusted for the MBU-12/P mask. The aircrews were in an operation flight status continually, and we hesitated to adjust the receivers to accept the MBU-12/P mask since we could not give them one to fly. However, when these subjects held the mask to the face with moderate pressure a good seal was attained.

After termination of the ground test, a flight test questionnaire was left for completion by those 31 aircrewmen who were issued test oxygen masks. The questionnaires were to be completed after a minimum of five flight hours had been accomplished. Of the 31 subjects who had MBU-12/P masks, 28 provided completed evaluation forms. Results are summarized on Table 11.

Investigators noted that the test sample was numerically smaller than was desired and that, once again, subjects in the "small" face-length category were under-represented. They noted, in addition, that the results of the ground test are not entirely clear-cut since the second-phase subjects' bayonet receivers could not be adjusted for optimum fitting of the test mask. Test results from subjects who could hold the mask on the face and obtain a seal must be considered as inconclusive due to the difficulties of transferring such fits to the mask suspension system.

They concluded nonetheless that the MBU-12/P mask is, on the whole, well designed and well sized to achieve its stated purposes. The large majority of the subjects tested attained a good fit and, except for some minor discomfort, found the mask comfortable and functionally sound. Most subjects preferred the MBU-12/P mask to oral-nasal masks previously worn and a number of subjects commented in superlative terms on the merits of the test mask.

Some recommendations for minor modifications were made and steps have been taken to address these problems, particularly those associated with the placement and operation of the communications system.

The quality of fitting and comfort of the MBU-12/P for USAF aircrew women is unknown. If this mask is to be used by female aircrews, a fitting and comfort evaluation similar to the one reported here should be undertaken. Data for an X-short oral-nasal face size based on female anthropometry and a completed face form are available at the Human Engineering Division, 6570th Aerospace Medical Research Laboratory.

## TABLE 11

## MBU-12/P FLIGHT TEST RESULTS

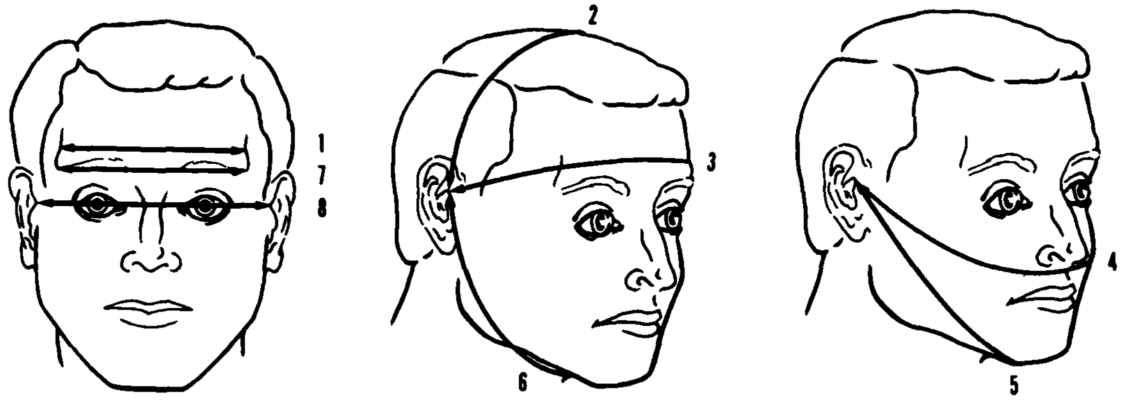
| Subj No. | Rank | Age | Aero† | Flight Hrs | Air-craft | MBU-12/P Size | Mis-sions | Hrs | Seal | Leak | Perform-ance | Vision Loss | Accept-able Fit | Com-fort | Pres-sure | Pref-erence |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Capt | 32 | P | 1500 | F-4 | R | 4 | 3.2 | Yes | No | Yes | No | Yes | Yes | No | 12/P |
| 2 | Maj | 40 | N | 3600 | F-4 | R | 8 | 5.6 | Yes | No | Yes | No | Yes | Yes | No | 12/P |
| 3 | Capt | 33 | N | 2400 | F-4 | R | 6 | 5.4 | Yes | No | Yes | No | Yes | Yes | No | 12/P |
| 4 | Capt | 32 | P | 1500 | A-10 | L | 10 | 20.2 | Yes | No | Yes | Yes | No | Yes | Yes | 12/P |
| 5 | Maj | 39 | P | 3200 | F-15 | R | 12 | 11 | Yes | No | Yes | No | Yes | Yes | No | 12/P |
| 6 | Col | 37 | P | 2500 | F-15 | L | 6 | 5 | Yes | No | Yes | No | Yes | Yes | No | 12/P |
| 7 | Maj | 35 | P | 3000 | F-4 | NO RESPONSE | | | | | | | | | | |
| 8 | Capt | 35 | N | 2500 | F-4 | XL | 4 | 2.8 | Yes | Yes | Yes | Yes | Yes | Yes | Yes | 5/P |
| 9 | Capt | 31 | P | 1800 | F-15 | NO RESPONSE | | | | | | | | | | |
| 10 | Capt | 33 | P | 2600 | F-4 | L | 11 | ~8 | Yes | No | Yes | No | No | No | Yes | * |
| 11 | Capt | 28 | P | 1500 | F-5 | R | 40 | 21 | Yes | No | Yes | No | Yes | Yes | No | 12/P |
| 12 | Capt | 30 | P | 2000 | F-4 | L | 15 | 13 | Yes | No | Yes | No | Yes | Yes | No | 12/P |
| 13 | Maj | 37 | P | 4000 | F-15 | L | 16 | 13 | Yes | No | Yes | Yes | Yes | Yes | No | * |
| 14 | Capt | 27 | P | 1100 | F-4 | L | 9 | 10 | Yes | No | Yes | No | Yes | Yes | No | * |
| 15 | Capt | 33 | P | 2300 | F-4 | L | 22 | 17 | Yes | No | Yes | No | Yes | Yes | No | 12/P |
| 16 | LCol | 39 | P | 3600 | F-4 | R | 5 | 5 | Yes | No | Yes | No | Yes | Yes | No | 12/P |
| 17 | Capt | 33 | P | 2000 | F-4 | L | 5 | 6 | Yes | No | Yes | No | No | No | Yes | Custom |
| 18 | Capt | 34 | N | 1700 | F-4 | XL | 5 | 2.5 | Yes | No | Yes | No | Yes | Yes | No | 12/P |
| 19 | Maj | 33 | P | 1950 | F-4 | L | 6 | 8.3 | Yes | Yes | Yes | No | Yes | Marg | No | 12/P |
| 20 | Maj | 35 | P | 2500 | F-4 | L | 5 | 6.0 | Yes | No | Yes | No | Yes | No | Yes | 12/P |
| 21 | Capt | 30 | N | 1400 | F-4 | L | 14 | ? | Yes | No | Yes | No | Yes | No | Yes | * |
| 22 | Capt | 28 | P | 1100 | F-5 | R | 25 | 20 | Yes | No | Yes | No | Yes | Yes | No | 12/P |
| 23 | Capt | 32 | P | 2400 | F-4 | R | 6 | 8 | Yes | No | ? | No | No | No | No | 5/P |
| 24 | Capt | 33 | P | 2600 | F-15 | R | 21 | 16.6 | Yes | No | Yes | No | No | ? | Yes | 12/P |
| 25 | Maj | 37 | P | 2500 | F-15 | NO RESPONSE | | | | | | | | | | |
| 26 | Maj | 34 | P | 3100 | F-15 | R | 10 | 15 | Yes | No | Yes | No | Yes | Yes | No | 12/P |
| 27 | Capt | 30 | P | 1500 | F-15 | XL | 190 | 200 | Yes | No | Yes | No | Yes | Yes | No | 12/P |
| 28 | Capt | 32 | P | 2000 | F-15 | L | 10 | 8 | Yes | Yes | Yes | Yes | Yes | No | No | 5/P |
| 31 | Capt | 33 | P | 3200 | F-15 | L | 50 | 28 | Yes | No | Yes | No | Yes | Yes | No | 12/P |
| 36 | Maj | 35 | P | 2900 | F-15 | L | 25-30 | 17-20 | Yes | No | Yes | No | No | No | Yes | 5/P |
| 51 | Capt | 35 | N | 1700 | F-4 | R | 20 | 25 | Yes | No | Yes | Yes | Yes | Yes | No | 12/P |

* Subject's preference was divided between the MBU-12/P and the MBU-5/P masks.
† P=Pilot; N=Navigator.

## APPENDIX

### *MEASUREMENT DEFINITIONS*

This appendix contains illustrated descriptions of all the measurements taken during the various stages of the sizing and fit-testing of the MBU-12/P oral-nasal oxygen mask. The first 21 measurements were taken with a tape and with spreading and sliding calipers customarily used in anthropometric surveys. Variables 22-37, the "top-of-head" and "wall" measurements, were obtained by using a headboard and special gauge. The subject is instructed to stand or sit under the headboard which is then adjusted so that its vertical and horizontal planes are in firm contact with the back and top of the head. With the subject looking straight ahead, the measurement is then taken from the vertical plane ("wall") or the horizontal plane ("top-of-the-head") to the indicated landmark on the face.




1. Minimum Frontal Curvature: the distance across the forehead between the points of greatest indentation of the temporal crests just above the eyebrows.

2. Bitragion-Coronal Curvature: the distance across the top of the head from right tragion (the cartilaginous notch just in front of the upper edge of the right ear hole) to the corresponding tragion of the left ear.

3. Bitragion-Minimum Frontal Curvature: the distance across the forehead measured just superior to the brow ridges, from right tragion (the cartilaginous notch just in front of the upper edge of the right ear hole) to the corresponding tragion of the left ear.

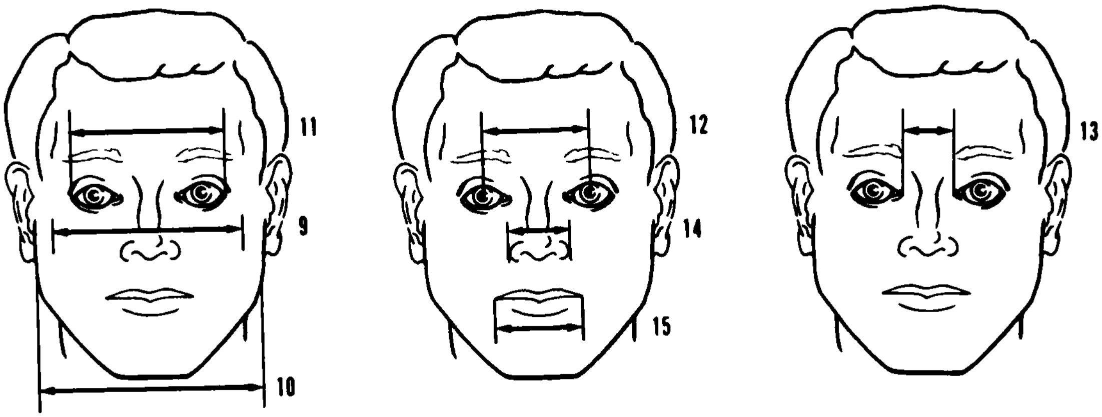
4. Bitragion-Subnasale Curvature: the distance across the face just below the nose from right tragion (the cartilaginous notch just in front of the upper edge of the right ear hole) to the corresponding tragion on the left ear.

5. Bitragion-Menton Curvature: the distance from right tragion (the cartilaginous notch just in front of the upper edge of the right ear hole) to the corresponding tragion on the left ear as measured across the tip of the chin.

6. Bitragion-Submandibular Curvature: the distance from right tragion (the cartilaginous notch just in front of the upper edge of the right ear hole) to the corresponding tragion on the left ear as measured along the juncture of the jaw with the neck.

7. Maximum Frontal Breadth: the distance across the face between the lateral bony ends of the brow ridges.

8. Bitragion Breadth: the distance across the face from right tragion (the cartilaginous notch just in front of the upper edge of the right ear hole) to the corresponding tragion of the left ear.




9. Bizygomatic Breadth: the maximum horizontal breadth of the face between the most laterally projecting bones of the cheeks.

10. Bigonial Breadth: the maximum horizontal width of the jaw.

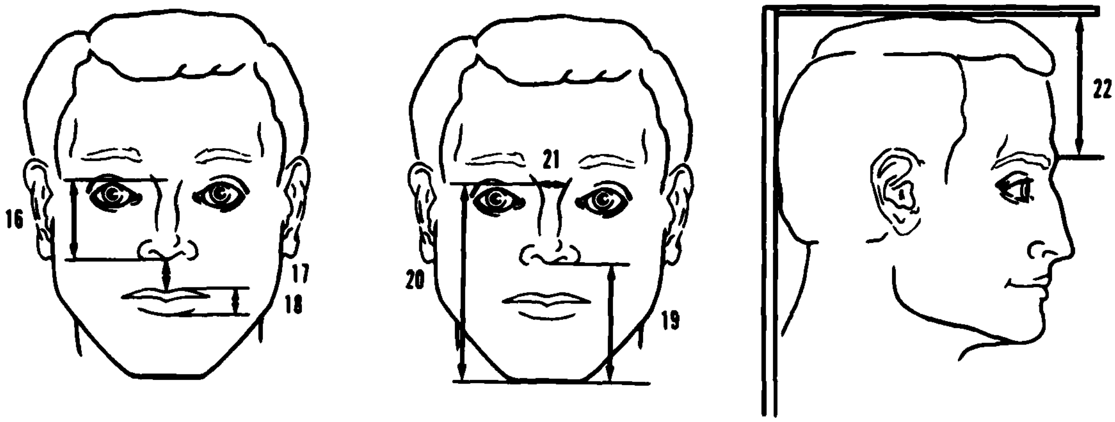
11. Biocular Breadth: the distance between the outer corners of the eyes.

12. Interpupillary Breadth: the distance between the centers of the pupils with the subject looking straight ahead.

13. Interocular Breadth: the distance between the inner corners of the eyes.

14. Nose Breadth: the maximum horizontal breadth of the nose.

15. Lip Length: the maximum distance between the corners of the mouth.




16. Subnasale-Nasal Root Length: the distance from the base of the nose to the center of the nasal root (the greatest indentation between the eyes).

17. Philtrum Length: the length of the vertical groove that runs from the upper lip to the base of the nose.

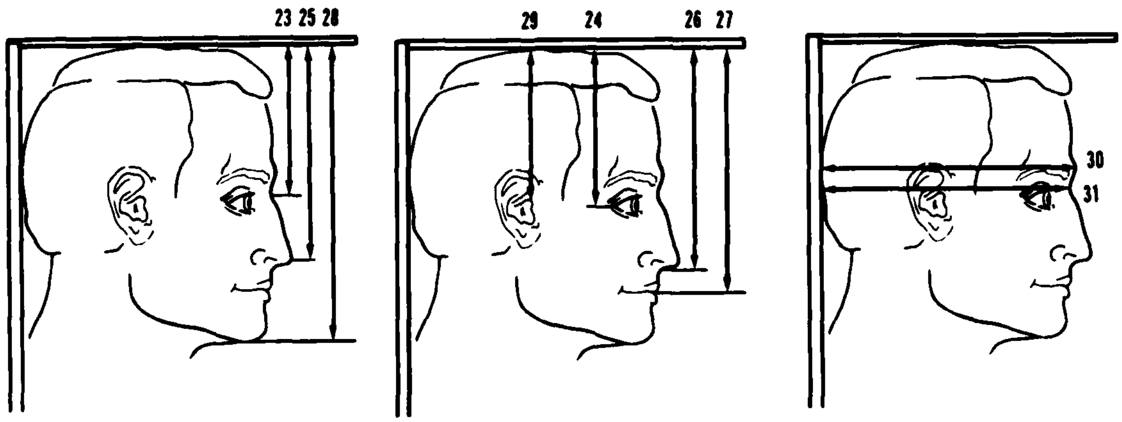
18. Lip-to-Lip Length: the maximum distance between the lower margin of the lower lip and the upper margin of the upper lip.

19. Menton-Subnasale Length: the vertical distance from the tip of the chin to the base of the nose.

20. Menton-Nasal Root Length: the distance between the tip of the chin and the deepest point of the nasal root depression.

21. Nasal Root Breadth: the distance across the nasal bridge at its greatest indentation between the eyes.

22. Glabella to Top of Head: the vertical distance between the top of the head and glabella (the most protruding point of the forehead between the eyebrows).




23. Nasal Root to Top of Head: the vertical distance between the top of the head and the nasal root (the greatest indentation between the eyes).

24. Ectocanthus to Top of Head: the vertical distance between the top of the head and the outside corner of the eye.

25. Pronasale to Top of Head: the vertical distance between the top of the head and the tip of the nose.

26. Subnasale to Top of Head: the vertical distance from the top of the head to the base of the nose.

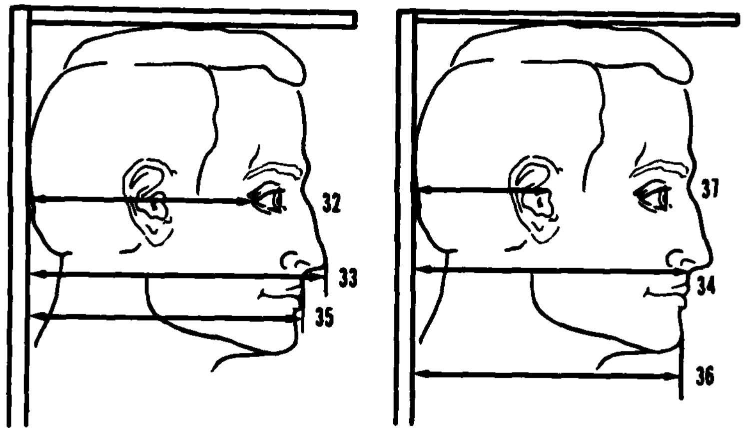
27. Stomion to Top of Head: the vertical distance between the top of the head and stomion (the point of contact in the center of the upper and lower lips).

28. Menton to Top of Head: the vertical distance between the top of the head and the tip of the chin.

29. Tragion to Top of Head: the vertical distance between the top of the head and tragion (the cartilaginous notch just in front of the upper edge of the ear hole).

30. Glabella to Wall: the horizontal distance between the wall and glabella (the most protruding point of the forehead between the eyebrows).

31. Nasal Root to Wall: the horizontal distance between the wall and nasal root (the greatest indentation between the eyes).




32. Ectocanthus to Wall: the horizontal distance between the wall and the outside corner of the eye.

33. Pronasale to Wall: the horizontal distance between the wall and the tip of the nose.

34. Subnasale to Wall: the horizontal distance between the wall and the base of the nose.

35. Lip Protrusion to Wall: the horizontal distance between the wall and the maximum protrusion of the lips.

36. Chin Prominence to Wall: the horizontal distance between the wall and the maximum protrusion of the chin.

37. Tragion to Wall: the horizontal distance between the wall and tragion (the cartilaginous notch just in front of the upper edge of the ear hole).

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