

FIT FACTORS OF AN ANTHROPOMETRICALLY DESIGNED 3 SIZE HALF MASK

Jones, J.A., Brissette, J.E. and Holm, J.M.

AMERICAN OPTICAL CORPORATION, SAFETY PRODUCTS BUSINESS
SOUTHBRIDGE, MA 01550

A series of Half Mask Respirators was designed with the goal providing superior fit for a variety of facial types and a wide range of fit for the middle (medium) size mask. To accomplish this goal, a team including a physical anthropologist, an industrial designer, a product designer and several engineers was assembled. The anthropologist provided data for facial measurements representing 95% of the U.S. population. These facial measurements denoted 3 different size ranges of facial dimensions, corresponding to a small, medium and large mask.

After the design was complete, the medium size mask in silicone (S5500) was tested for fit according to the criteria described in the paper "Selection of Respirator Test Panels Representative of U.S. Adult Facial Sizes." (A.L. Hack, Los Alamos Scientific Laboratory, Los Alamos, NM, March 1974).

Twenty-five subjects were selected on the basis of lip length and face length and quantitatively fit-tested using a corn oil challenge. The average protection factor for the 12 female panelists was 2,771 and for 13 male panelists was 2,790. The overall average protection factor was 2735.6.

The rubber medium (R5500) mask was also tested as above, and it was found that average protection factors were approximately 10x lower than those determined with the silicone medium (S5500) mask.

To determine the overlap of fit for small and large sizes, the male panel was employed. Since silicone had shown to give better fit, the silicone versions of the small and large masks were used. Experimental data illustrates that some subjects can obtain a satisfactory fit with two sizes of a respirator series.

The results of this study indicate that a superior fitting respirator can be designed using facial dimension data, silicone does give better fit factors than rubber, and that overlap of fit for different sizes is not unusual.

ABSTRACT

Background.

Prior to the enactment of the Williams and Steiger Occupational Safety and Health Act (OSHA) in 1970, there was a sparsity of published anthropometric facial data on the American industrial worker relating pertinent dimensions to the design of a respirator facepiece¹. However, there existed an abundance of such data that was developed for use by the military which was found to be representative of the general industrial population².

From this data, physical anthropologists and researchers derived statistical data for defining key measurements and percentages of the industrial work force that have faces which can be classified as small, medium and large.

Data from one source³ were used as a fundamental basis for the design of a new family of small, medium and large size half mask respirator facepieces. In addition to using this data as a design guide, a detailed study was made by the facepiece designer on measurements, comments and observations of people with varying facial shapes while wearing different brands of facepieces. The purpose was to gain objective value judgements and insights into various design

features that enhance sealing characteristics and contribute to wearer comfort.

Forty facial variables were analyzed and used in designing the three facepiece sizes.

Once the technical aspects of the designs were established, an industrial designer was consulted to assist in developing the aesthetic qualities of the facepiece for the purpose of having a positive influence on wearer acceptance.

After reviewing and processing the collective input from the mentioned sources, engineering drawings were developed and ultimately medium, small and large prototype facepieces were produced from single cavity molds. Initially, the medium size facepiece was produced and tested because a majority of the industrial population has facial dimensions compatible with its size. Experience gained in producing the medium size facepiece was used to facilitate producing the small and the large facepieces.

The motivation for designing a new family of facepieces was to stay in the vanguard of half-mask respirator technology and to meet the marketplace requests for better fitting, higher performing, and more comfortable respirators.

Respirator Fit Test Panel

Anthropometric specifications for subjects to qualify for fit testing of half mask and other respirators were developed by Los Alamos Scientific Laboratory at the request of NIOSH⁴. Data used in the development of these specifications were derived from the same sources as those used in the design of respirators reported in this paper. A matrix representation of such a 25 member fit test panel with facial sizes and distribution characteristics of ninety-five percent (95%) of the American industrial work force, both male and female, is shown in Figure 1.

To evaluate the efficacy of the new facepiece design, face fit testing was performed on a similar panel using our own employees. Male, female, Caucasians, orientals, hispanics and blacks were represented.

Investigated were the fit factors of the silicone and natural rubber medium size mask on the entire 25 member panel in addition to the cross-over fitting characteristics of the small and large silicone respirators. In addition to having the requisite facial dimensions to qualify for the panel, members were given a physical examination which included a pulmonary function test. Also, they were required to detect the odor of a minute concentration of isopentyl acetate vapor according to a modified federal standard and had to undergo training in the proper method of performing positive pressure respirator face fitting exercises.

Quantitative Fit Test Equipment

Many methods exist for performing quantitative facepiece fitting test on respirators, but it was important to use one that has reproducible physical parameters and with specifications accepted or under consideration by regulatory agencies⁵. In this regard, it was

decided to use the Dynatech Frontier Corporation's Model 260A Aerosol Generation and Test System with the Series 200 Booth for fit testing.

The aerosol test concentration is adjusted to contain approximately twenty-five (25) milligrams per cubic meter of corn oil with a mass medium aerodynamic diameter between .5 and .7 microns with a geometric standard deviation between 2 and 2.4. These aerosol criteria meet the test criteria in the proposed 42CFR84 draft. The particle size distribution analysis was conducted using a TSI Model 3030 electrical aerosol particle size analyzer.

Quantitative Face Fit Test Procedure

After passing the preliminary screening test, the subject dons a facepiece equipped with combination organic vapor-high efficiency cartridges which was modified to permit sampling of the facepiece cavity. The modified facepiece consists of a probe located between the nasal and mouth area of the

facepiece and connected to flexible tubing.

The subject enters the test chamber, connects the flexible tubing from the facepiece to the aerosol monitoring instrument by means of a feed-through connector with direct access to the aerosol monitor for making periodic chamber concentration measurements.

After the sampling connection is made, the aerosol concentration (C_i) is permitted to stabilize at twenty-five (25) milligrams per cubic meter and recorded. At this time the subject begins the following sequence of exercises which last for approximately one minute each:

1. Normal Breathing (nb)
2. Deep Breathing (db)
3. Side-to-side Head Motion (s/s)
4. Up and Down Head Motion (u/d)
5. Talking About (t)
6. Normal Breathing (nb)

During each exercise, continuous aerosol concentration measurements are performed within the facepiece cavity and the

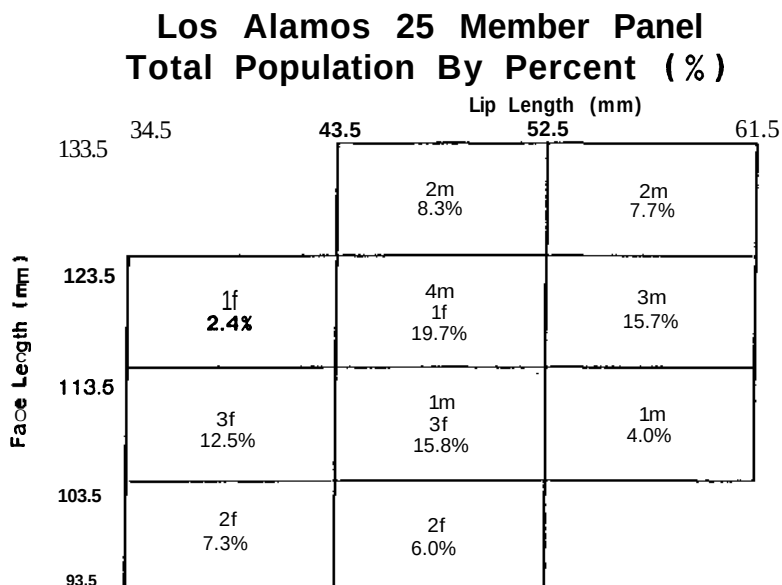


Figure 1

results are printed on a strip-chart recorder. After each exercise is completed, a straight line is drawn connecting the high and low points for the exercise. The concentration measured at the mid-point on the straight line is recorded as the average concentration for the exercise.

When the series of exercises is completed, a final chamber concentration (cf) measurement is recorded and a respirator protection factor (PF) is calculated by means of the following formula.

Protection Factor Calculation

$$PF = \frac{3(C_i + C_f)}{C_{nb} + C_{db} + C_{ss} + C_t + C_{ud} + C_{nb}}$$

The C subscript values in the denominator are - Average facepiece aerosol concentration measurements for the indicated exercises.

Results And Discussion

Figure 2 shows the protection factors obtained for the entire 25 member panel with the medium size silicone AO 5 Star Half Mask Respirator. The maximum protection factor obtained was 18,750 while the minimum protection factor was 174. The average protection factor of the 25 subjects was 2,735, over 270 times the designated protection factor of 10.

Fit factors obtained with the rubber medium size AO 5 Star Half Mask were approximately 10 times lower than those determined for the silicone medium mask, as illustrated in Figure 3. Here the maximum protection factor was 838 and the minimum was 20. The overall average protection factor for 25 subjects was 214 compared to 2,735 for the silicone.

Because of silicone's lower coefficient of friction, the material seals/conforms better to facial surfaces resulting in better face fit.

Average Protection Factors AO 5 Star

S5500 Medium Silicone Half Mask

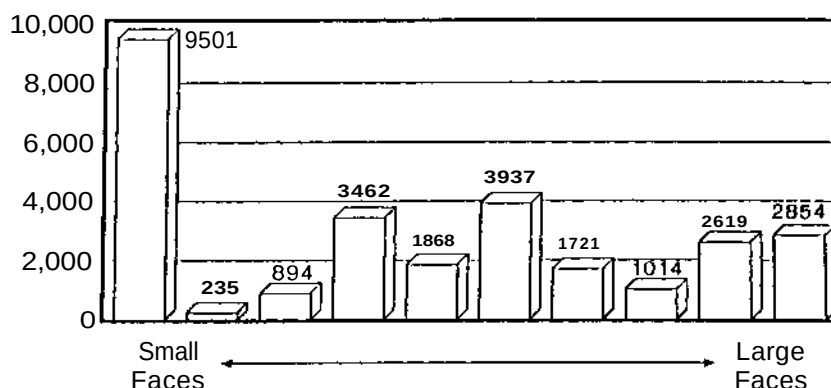


Figure 2

Average Protection Factors AO 5 Star

R5500 Medium Rubber Half Mask

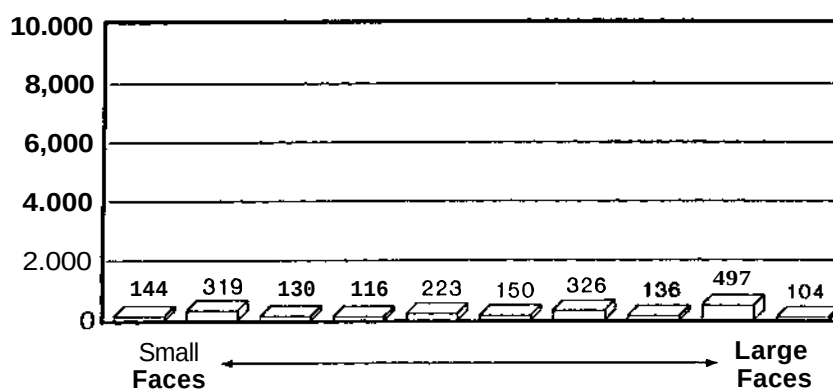


Figure 3

- 1 J.T. McConville, E. Churchill and L.L. Laubach, "Anthropometry For Respirator Sizing," Final Report, Contract No. HSM099-71-11 (April 30, 1972)
- 2 AL. Hack, J.T. McConville, "Respirator Protection Factors: Part 1 - Development of an Anthropometric Test Panel," American Industrial Hygiene Association Journal, Vol. 39, No. 12.

Average Protection Factors AO 5 Star

S4500 Small Silicone Half Mask

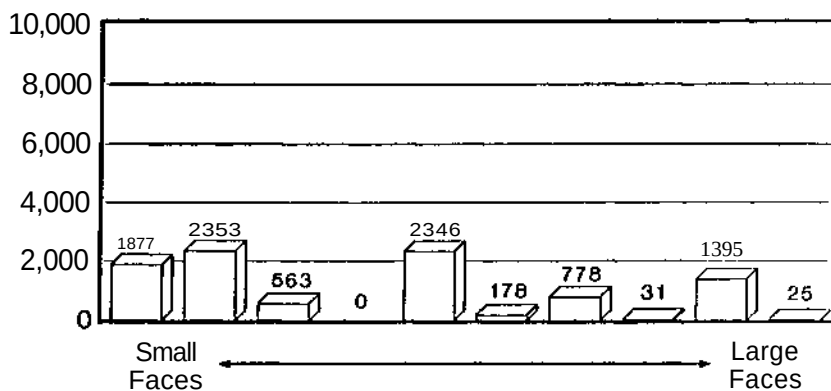


Figure 4

Average Protection Factors AO 5 Star

S6500 Large Silicone Half Mask

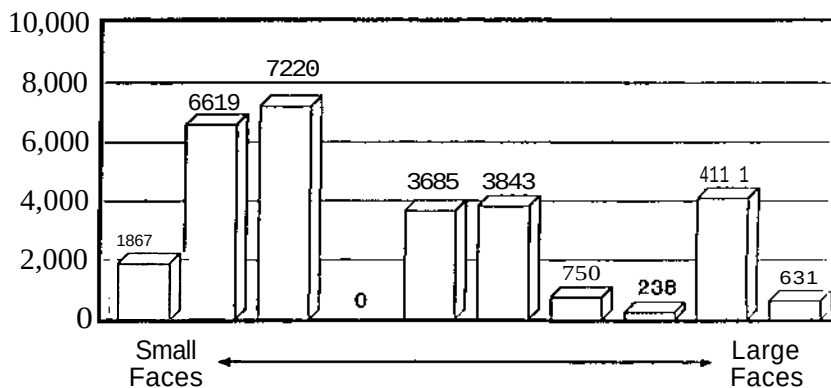


Figure 5

Another aspect of our study involved cross-over fitting characteristics of small and large silicone AO 5 Star Half Masks compared to the medium silicone mask, again using the entire 25 member panel.

Figure 4 shows the protection factors obtained with the small mask. Twelve percent of the subjects failed to obtain an acceptable preliminary fit and the remaining 88% attained protection factors in excess of 20.

Figure 5 shows the protection factors obtained with the large silicone AO 5 Star Half Mask. Only 4% of the entire panel (2 out of 25) failed to achieve a satisfactory preliminary fit with the large mask. The remaining 96% achieved protection factors in excess of 196.

The data suggests that the order for increasing fit in the general population is small, large, then medium. Also, the data suggests that excellent cross-over fitting characteristics are achieved within the three sizes for the general population.

Conclusions

On the basis of the data developed in this paper, the following conclusions are made:

1. The use of facial anthropometric data, from a nonindustrial source, is supported in the design of half-mask facepieces as evidenced by the protection factor data.
2. The creative integration of anthropometric facial size data with contemporary technology and materials resulted in the design of a respirator facepiece series with excellent face sealing and comfort characteristics for 95% of the general industrial population.
3. A family of half mask facepieces has been designed that far exceeds the present assigned protection factor rating of 10.

3 J. T. McConville, "Sizing Data For Three-Size Face Mask,"
Personal Communication
4 Hack and McConville, *Respirator Protection Factors: Part 1 -
Development of An Anthropometric Test Panel*, p. 970
5 NIOSH Pre-Proposal Draft Revision of 42CRF84