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APPLICATION OF BASIC PHYSIOLOGIC DATA IN THE DESIGN OF AAF OXYGEN EQUIPMENT

HEADQUARTERS

AIR TECHNICAL SERVICE COMMAND

Wright Field Dayton, Ohio

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ARMY AIR FORCES
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Application of Basic Physiologic Data in the Design of AAF Oxygen Equipment

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Object: To assemble in a general form for use in the design of respiratory equipment, the variety of data on respiratory physiology.

Summary: Data on respiratory physiology are assembled and unified into general statements which may be of use to engineers in the design of respiratory equipment. The varied and apparently independent data concerned with partial pressures of oxygen required for adequate arterial blood saturation; pulmonary ventilation; respiratory rate; human tolerable resistance to flow; and gas exchange in the lungs are collected and presented in a generalized framework.

Introduction

The design of continuous flow or diluter demand oxygen equipment requires the establishment and use of certain basic physiologic data. Design of more specialized equipment such as pressure demand or pressure suit equipment involves additional pertinent physiologic data. At present much of this basic physiologic and technical data has been accumulated at the Aero Medical Laboratory and under the auspices of the O.S.R.D. However, it has not been completely collated or organized. The use of these data in formulating equipment design has necessitated an organization of the data for the specific purpose. It is the purpose of this report to present and elaborate those data which are the bases for the design requirements of Army Air Forces oxygen equipment.

The factors which the engineer must carefully evaluate are few in number but the volume of data is large and, at times, complexly interrelated. Factors to be considered are:

1. The pressure of oxygen required to maintain adequate arterial oxygen.
2. Pulmonary ventilation:
    a. Effect of activity, cold, altitude, flight conditions.
    b. Inspiratory instantaneous rates of flow.
    c. Expiratory instantaneous rates of flow.
    d. Maximum instantaneous rate of flow.
    e. Mean instantaneous rate of flow.
    f. Per cent of total volume drawn in at various rates of flow.
3. Respiratory rate.
4. Human tolerable resistance to flow.
5. Gas exchange in lungs.

The data pertaining to these factors may have varying significance on the design of the various types of oxygen apparatus. Basically, all the data should be reviewed for any system.

Generally, data on any experimental subject are presented as an average with sufficient data being collected to insure significance. However, the average figure, if used in the design of respiratory equipment, can give an erroneous interpretation of equipment value. In no piece of equipment can the design be confined to the average, for by definition that development excludes 50% of the individual users from having adequate protection. A tenable thesis is proposed requiring that equipment should be so designed that 90 per cent of its users will be completely protected. Thus, in prediction of the duration of an oxygen supply, a value on the basis of average figures would give the flyer an even chance of having sufficient oxygen; on the basis of the thesis just stated the chances would be 9 to 1. If the average figure and the standard deviation are known, then the value to be used is determined as:

$$\text{Average} + (1.3 \times \text{Standard Deviation}) \tag{1}$$

In a few cases where necessary a minimum figure may be obtained by a corresponding subtraction.

The Partial Pressure of Oxygen Necessary to Maintain Adequate Aterial Saturation.

This question has been extensively discussed and adequate basic data are included in Reference 1. Calculations to determine the necessary fraction of oxygen may be determined by:

$$fO_2 = (pO_2 + pCO_2/R.Q.)/(Pa - 47 - pCO_2 - pCO_2/R.Q.) \tag{2}$$

or by a simpler formula

$$fO_2 = pO_2/Pa - 47 \tag{3}$$

(see glossary for definition of terms)

The desirability of using the latter formula in equipment design has been ably presented by Boothby and Ferguson (Reference 2 and 3).

The minimum pO_2 which is desirable has been indicated to be that simulating 5,000 ft. breathing air (References 1, 2, 3 and 4). This then is a minimum value for the equipment; the apparatus must deliver at least this quantity of oxygen at all conditions of flow and temperature. This is the minimum tolerance. Alveolar pO_2 at 5,000ft. is given at 81.6 mm. Hg. by Boothby (Reference 2). The standard deviation is 4.5 mm. Hg. To cover 90% of the cases in maintaining a pO_2 (alveolar) at 81.6 mm. Hg. the pO_2 for tracheal air in equation (3) will be fixed at 134 mm. Hg.

Pulmonary Ventilation.

Pulmonary ventilation or the amount of gas mixture breathed has significance in the design of respiratory equipment (mask and regulator) and also the amount of oxygen placed in the aircraft. The latter may be discussed briefly. The amount of oxygen to be carried in aircraft can certainly not be based on an average nor entirely on experimental results. Reports on experimental flights (Reference 5) indicate that the average ventilation in flight expressed at B.T.P.S. is constant up to 33,000 ft. The average value is 14.2 liters per minute B.T.P.S. for normal flying conditions. Statistical analysis places the 90% inclusive figure at 18.4 l/m. Data from actual combat flights (Reference 6) presents an average of 11.4 l/m B.T.P.S. and the 90% inclusive figure is 18.2 l/m.

An average ventilation has also been determined experimentally. No combat data are now available. The average active figure is presented in Reference 2 as 23.2 l/m B.T.P.S. Ninety per cent of the cases are covered by a value of 37.1 l/m B.T.P.S. From these data it is interesting to note that to cover adequately approximately 100% of the cases under consideration, the value becomes 66.0 l/m B.T.P.S. The maximum figure actually observed in these flights was approximately 60 l/m B.T.P.S.

In the design of equipment the average figure for ventilation has value for use in design of mechanical lungs for fatigue testing, average values for varying degrees of work and also is utilized for mechanical mask freezing tests, etc. The ventilation must be further dissected to determine maximum, minimum, average and instantaneous flow patterns (Figures 1 and 2). Data on these at present are taken from Reference 7 (that data which involves no inspiratory resistance) since a complete study is available for 27 subjects. General deductions from these data have been transferred to aircraft data. The minimum ventilation given is 6.1 l/m B.T.P.S., the maximum is 90 l/m B.T.P.S. (Compare with minimum of 6.8 l/m and maximum of 60 l/m in aircraft experiments, Reference 5). Average respiratory patterns in use for fatigue testing and mask freezing have been made as composites from the data in Reference 6 and Reference 7 (Figure 1).

Effect of Activity, Cold, Altitude and Flight Conditions.

The effect of activity on ventilation has been well shown (References 1, 7 and 8 for specific information). The effect of cold would seem to be negligible from data presented in Reference 5 although other data (Reference 10, unpublished, Ferguson RCAF) indicates an increase in ventilation when subjects were exposed to the cold. Flight conditions seem to effect an increase in the ventilation of fighter personnel with increasing altitude and of bomber personnel at altitudes above 33,000 ft. (Reference 11). Altitude introduces a factor above 33,000 ft. (Reference 8, Reference 11). The effect of clothing, tight fitting parachutes, and position in the airplane on respiratory patterns has not been clearly defined. Since it has been shown (Reference 7) that the inspiratory pattern changes with the type of exercise, further work is indicated.

Instantaneous Rates of Gas Flow.

Instantaneous rates of inspiratory gas flow are of interest from several points of view. The variation in flow during respiration must be used to duplicate respiratory patterns. Maximum instantaneous inspiratory flow indicates the maximum flow to be met by the respiratory equipment. The mean inspiratory flow has been used by Hart (Reference 11) in mask leakage considerations.

An analysis of the data in Reference 7 with the design of oxygen dispensing equipment specifically in mind discloses a number of generalities which may serve as a physiologic basis and form a framework which must be tested experimentally and upon which future data may be applied. These data furnish basic information about four important respiratory phenomena: minute volume, respiratory rate, maximum instantaneous flow, and portions of the respiratory cycle spent in inspiration and expiration. When the latter three are plotted against the minute volume certain regularities become apparent (see Figure 3). The relative time of inspiration is less than half at low ventilations and increases to one half with increasing ventilation. The maximum instantaneous flow may be determined from these data as given in Figure 3 as:

$$\underline{\text{M.I.F.}} = 2.6\ \text{V.} + 10 \qquad (4)$$

The 90% inclusive maximum instantaneous flow may be calculated from:

$$\underline{\text{M.I.F.(90)}} = 3.1\ \text{V.} + 16 \qquad (5)$$

The 90% inclusive minute volume as taken from Reference 5 may be determined by the equation:

$$\underline{\text{V.(90)}} = 1.4\ \text{V.} - 2 \qquad (6)$$

The mean inspiratory flow is 0.9 the maximum instantaneous flow and is:

$$\underline{\text{Mean I.F.}} = 2.3\ \text{V.} + 9 \qquad (7)$$

and

$$\underline{\text{Mean I.F. (90)}} = 2.8\ \text{V.} - 14 \qquad (8)$$

Figures 4, 5, 6 and 7 demonstrate that the actual inspiratory patterns can be generalized. The data from Figures 20, 21, 22, 23, 24 (Reference 7) are shown plotted as fraction of tidal volume inspired versus flow as a fraction of the maximum flow. The two figures supply information for determining representative curves at any minute volume.

Expiratory rates of flow should be categorized similarly. Data used at present has been taken from Silverman (unpublished). Further data must be obtained. These data are important in design of expiratory valves. They cannot be transposed directly to intermittent or continuous pressure breathing equipment since the effects of the pressure alter the respiratory pattern, (Reference 13).

Volumes of Gas at Various Rates of Flow.

The per cent of tidal volume drawn in at various rates of flow has proved significant in certain aspects of continuous flow equipment, in the design of demand equipment and in the consideration of mask leakage. Hart (Reference 14) indicates that about 29% of the inspired volume of air is inhaled at rates below 75% of peak flow rates and about 60% of the inspired volume is inhaled at rates below 95% of the peak rate at rest and during exercise. This agrees with Figure 7. The individual variation is great and the report states that during quiet breathing 1 - 14% of the inspired volume is inhaled at rates below 10 l/m.

Respiratory Rate.

The general relationship of respiratory rate to ventilation is shown in Figure 3. At low ventilations, between 5 and 20 l/m, this curve may be sigmoid although a scatter diagram of the actual data indicates a straight line is more applicable. In this range the variation in respiratory rate is great. The data in Reference 7 indicate that where the average minute volume is 16.6 the range is from 8 to 24 breaths per minute. The extent of the range at any given average ventilation decreases with increasing ventilation.

Human Tolerable Resistance to Flow.

Tolerable inspiratory and expiratory resistance to flow has been indicated (Reference 1) and the effect of resistance on flow studied (Reference 7). Negative pressures less than one inch water column are unnoticed at 50 liters per minute flow (see Figure 8). At 100 liters per minute flow suctions as high as 1.5 inches water column are unnoticed. Maximum instantaneous rates of flow decrease and the relative time of inspiration increases with increased inspiratory resistance. Increasing inspiratory resistance decreases the minute volume and the maximum instantaneous rate of flow, and the relative time of inspiration increases. At high work loads a resistance of 50 mm. (measured at 80 l/m, 70°C. dry flow) causes a 7% decrease in ventilation and approximately 15% decrease in the maximum instantaneous flow. The greatest reduction of maximum instantaneous flow rates for all work loads occurs between 0 and 50 mm. resistance. Demand and continuous flow equipment require low resistance or positive pressure and are well below tolerable limits generally. Expiratory resistance is necessary in pressure demand equipment.

Gas Exchange in the Lungs.

For the design of closed respiratory systems it is necessary to consider the magnitudes of the gas exchanges which take place in the lungs (Figure 9). These changes are: (1) the removal of oxygen from inspired gas (oxygen consumption); (2) the addition of carbon dioxide to expiredgas (CO_2 elimination); and the addition of water vapor to expired gas (H_2O vapor elimination). Oxygen consumption and carbon dioxide production vary among individuals and the respective curves are experimentally determined and represent the 90% inclusive figures for oxygen consumption and carbon dioxide elimination. No significant data on water vapor elimination have been found and hence the curve represents the volume of vapor in expired air saturated at 37°C.

Examples of Applications of the Data.

Continuous Flow System.

The application of these data can be sampled by reference to the schematic types of continuous flow systems in Figure 10. In a straight continuous flow system (Figure 10-I) such as the Japanese use, the continuous supply of oxygen must be carefully related to the volumes inspired under given instantaneous flows. A use of the data for straight continuous flow may be given. Since only that part of the flow is used which is flowing during inspiration, the flow required will be equal to the flow at which a fraction of the inspired volume equals the fraction of oxygen required. Thus,

F = MIF x fraction of MIF under which fraction of tidal volume taken in is equal to the fraction of added oxygen required.

since:

$$MIF = 2.6 V + 10 \quad (9)$$

$$\text{Fraction added oxygen required} = 1.27 (fO_2 - 0.21) \quad (10)$$

Fraction of MIF under which fraction of tidal volume is taken in is equal to the fraction of added oxygen required taken from Figure 4, Curve 2 and between the fractions 0.1 and 0.9 is:

$$8/9 (1.27(fO_2 - 0.21)) \quad (11)$$

The flow required for a continuous flow system without economizer systems is:

$$F = (2.6 V + 10)(8/9(1.27(fO_2 - 0.21)))((\underline{Pa} - 47)/P)(T/\underline{Tb}) \quad (12)$$

This equation, due to the inadequacies of the fraction 8/9, is valid when fO_2 is greater than 0.10 and less than 0.90.

Substituting:

$fO_2 = pO_2/Pa - 47$ and solving for an equivalent altitude of 5000 ft. the equation is:

$$F = 1.44 - 0.0006 PaV - 0.0023 Pa + 0.37 V \quad (13)$$

Flows calculated from these data are in fair agreement with Reference 15. When a reservoir or rebreather reservoir (Figure 10, II and III) are used the relationship of the factors change. These systems are more complex to evaluate than the demand system. Making the assumption that the reservoir will save half the oxygen the above equation (9) can be utilized. Values here are analagous to those in Reference 16 and 17. Further refinements of the formula to evaluate the effect of a rebreather reservoir can be made from the graphic data. Limitations of the rebreather economizer due to its volume can be expressed by:

$$(V/n)/Ve \quad (14)$$

and the equation becomes:

$$2F = \frac{(2.6V + 10)(8/9(1.27(fO_2 - 0.21)))((\underline{Pa} - 47)/P(T/\underline{Tb}))}{((V/n)/Ve)} \quad (15)$$

This equation is in error by the amount of flow that occurs during the inspiratory cycle and can be further corrected with the use of:

$$((V/n/Ve) - 8/9(1.27(fO_2 - 0.21))/2 \qquad (16)$$

An economizer without a rebreather will require the modification of the basic formula whenever ((V/n)/Ve) is greater than one. With a 700 cc. economizer, (V/n)/Ve becomes 1.0 at 15 l/m ventilation which may lead to the statement that little difference exists in the two systems (Reference 17). Since these formulations incorporate the fraction of oxygen required they may be utilized to calculate flows necessary for oxygen therapy and such calculations show good agreement with Reference 18 and unpublished data from the Aero Medical Laboratory.

Demand System.

In the demand system requirements may be taken from the Figures 3, 5 and 7 when the value of pulmonary ventilation is set. Army Air Forces equipment is designed for an average inactive ventilation of 14 l/m B.T.P.S., and average active ventilation of 24 l/m B.T.P.S. and a maximal ventilation of 60 l/m B.T.P.S. Using equation (6) the 90% inclusive ventilations are 18 and 32 l/m B.T.P.S. respectively. Using equation (4) the 90% inclusive maximum instantaneous flows are 45, 93 and 166 l/m, respectively. Army Air Forces regulators must be designed to deliver these inclusive flows within the minimum suction requirements.

In the testing of respiratory equipment average data should be employed and corrected to the 90% inclusive value. At the present time Army Air Forces regulators are tested with a mechanical lung which duplicates the breathing pattern for 18 and 32 l/m ventilation, illustrated in Figure 1. These flow-time curves were reconstructed from the curves in Figures 3 and 5. In addition to testing with average (+1.3 Std. Dev.) data, extremes of the range encountered should also be used. Thus, in the inactive ventilation group (Reference 7) there is illustrated the flow-time pattern of the lowest ventilation (Figure 2), which should be duplicated on the mechanical lung. A ventilation pattern for 60 l/m(Figure 2) is used to test performance at maximum respiratory volumes.

The variables of respiratory phenomena discussed above have not been clearly defined for pressure breathing equipment (Reference 13). Interrelated physiologic factors as well as characteristics of equipment complicate the problem but do not obscure the solution. A similar approach can and will be made to reduce these factors to generalities for equipment design.

Discussion.

The synthesis of varied and apparently independent data into a unified and generalized relation is desirable when large and diverse groups of data exist and this data is to be transferred from the field of physiologic investigation to serve as a basic requirement for an engineering development. In addition, such a synthesis has the advantage of establishing a measure for evaluation of data already existent, permits rapid comprehension of the significance of such data, readily directs research into channels where sufficient data are lacking and permits rapid and sufficiently accurate (i.e. 10%) extraction of average data for practical application. The presentation of the general relations of respiratory data in the above report embodies the characteristics of such a synthesis.

The construction of such a generalized framework is based upon experimental data. The value of such a framework depends upon the accuracy and validity of the data used. As an example, the average curve for respiratory rate in Figure 3 embodies a large range among individual determinations which is not apparent upon inspection of the curve but is apparent when compared with other experimental data. Similarly, the curve for water vapor elimination in Figure 9 is not based on experimental data but calculated on the basis of certain assumptions (refer to text). Comparison of this curve with experimental data, as these become available, may show a discrepancy, since the values in Figure 9 are probably too high.

In spite of the faults of the framework presented in this report, it is believed to be a worthwhile approach to a synthesis of respiratory data which should not be considered a definitive attempt but rather a directional attempt to be modified and corrected by subsequent experimental data. The value of such an attempt is certainly indicated generally for all fields of investigation.

Glossary of Abbreviations

F = flow of oxygen liters per minute S.T.P.D.

S.T.P.D. = 760 mm. Hg., 0°C, dry.

B.T.P.S. = Body temperature and pressure saturated with water vapor at 37°C.

MIF = Maximum instantaneous rate of flow, liters per minute B.T.P.S.

V = Ventilation or minute volume in liters per minute B.T.P.S.

fO_2 = fraction of oxygen required.

P = 760 mm. Hg.

Pa = ambient pressure, mm. Hg.

T = 273°K.

Tb = body temperature, 310°K.

n = number of breaths per minute.

Ve = Volume economizer or rebreather in liters.

pO_2 = partial pressure of oxygen in mm. Hg.

pCO_2 = partial pressure of carbon dioxide in mm. Hg.

R.Q. = respiratory quotient.

I.F. = instantaneous rate of flow, liters per minute B.T.P.S.

References

1. Office of Scientific Research and Development, Committee on Medical Research, Committee on Aviation Medicine: Handbook of Respiratory Data in Aviation, 1944.

2. Office of Scientific Research and Development, Committee on Medical Research: Development of Oxygen Equipment: Physiologic Criteria to be Considered by Engineers by Walter M. Boothby, checked by E. J. Baldes, Ph.D., Mayo Aero Medical Unit, Special Report No. 3, 20 August 1942.

3. R.C.A.F. No. 1 Clinical Investigation Unit: The Problem of Equipment Altitudes, by J. K. W. Ferguson. Report No. B-114, January, 1944.

4. AAF Air Technical Service Command, Engineering Division, Aero Medical Laboratory: Requirements and Design Characteristics of Regulators, by Verner J. Wulff. Memorandum Report ENG-49-660-17-F-2, 19 November 1943.

5. AAF Air Technical Service Command, Engineering Division, Aero Medical Laboratory: Pulmonary Ventilation of Flyers, by W. Randolph Lovelace, II, L. D. Carlson and V. J. Wulff. Memorandum Report ENG-49-660-50-H, 11 March 1944.

6. AAF Air Technical Service Command, Engineering Division, Aero Medical Laboratory: Oxygen Consumption of Aircrew in Combat by Mary Bennett and V. J. Wulff. Memorandum Report ENG-49-660-48-F, 20 September 1944.

7. Office of Scientific Research and Development, National Defense Research Council, Division 11, Section 11.2, Fundamental Factors in the Design of Respiratory Equipment: Inspiratory Air Flow Measurements on Human Subjects With and Without Resistance by Leslie Silverman, Robert C. Lee, George Lee, Dr. Katherine R. Drinker and Dr. Thorne M. Carpenter. Report No. 1222, January, 1943.

8. AAF Air Technical Service Command, Engineering Division, Aero Medical Laboratory: Oxygen Requirements as Affected by Physical Activity and Altitude, by John W. Wilson, John T. Bonner and Asher J. Finkel, Memorandum Report ENG-49-696-7C, 11 November 1943.

9. Associate Committee on Aviation Medical Research, N.R.C., Ottawa. The Demand for Oxygen in the Air by A. C. Burton, G. R. Macdongall and H. C. Bazett, April, 1942

10. AAF Air Technical Service Command, Engineering Division, Aero Medical Laboratory: Pulmonary Ventilation of Flyers at High Altitude by Loren D. Carlson and V. J. Wulff. Memorandum Report ENG-49-660-48-G, 9 October 1944.

11. R.C.A.F. No. 1 Clinical Investigation Unit: Theory of Inspiratory Mask Leakage, by J. S. Hart. Report No. B.150, 21 August 1944.

12 Office of Scientific Research and Development, Committee on Medical Research: The Physiology of Pressure Breathing: A Brief Review of Its Present Status by A. L. Barach, W. O. Fenn, E. B. Ferris, C. F. Schmidt, December, 1944.

13. R.C.A.F. No. 1 Clinical Investigation Unit: Instantaneous Rates at Which Various Fractions of Inspired Air Are Inhaled by J. S. Hart. Report No. B-67, January, 1944.

14. AAF Air Technical Service Command, Engineering Division, Aero Medical Laboratory: Oxygen Requirments While Using the A-8B Mask Without the Rebreather Bag, by Howard G. Swann. Memorandum Report No. TSEAL3-696-42I, 20 February 1945.

15. AAF Air Technical Service Command, Engineering Division, Aero Medical Laboratory: Oxygen Requirements with Constant Flow Equipment by Howard S. Swann. Memorandum Report No. TSEAL3-696-42H, 30 December 1944.

16. R.C.A.F. No. 1 Clinical Investigation Unit: Adequacy of Reservoir Delivery Oxygen Systems by J. K. W. Ferguson. Report No. B.117, 8 February 1944.

17. Boothby, W. M., The B.L.B. Oxygen Inhalation Apparatus: Improvement in Design and Efficiency by Studies on Oxygen Percentages in Alveolar Air. Proc. Staff Meet., Mayo Clinic, 15:194, 1940.

18. Schneider, E. C., Physiology of Muscular Activity, p. 105, ed. 2 revised, W. B. Saunders and Company, Philadelphia.

Figure 1

Standard Inspiratory Flow-time Curves for 18 and 32 l/m Ventilation
Reconstructed from Data Presented in this Report.

Inspiratory flow curves reconstructed from the generalized average data presented in Figures 3 and 5. These inspiratory curves will result in minute volumes of approximately 18 and 32 liters per minute. Such curves may be used as a basis for design of cams for driving mechanical pumps. In order to obtain the data required for the construction of these curves, the minute volume must be predetermined.

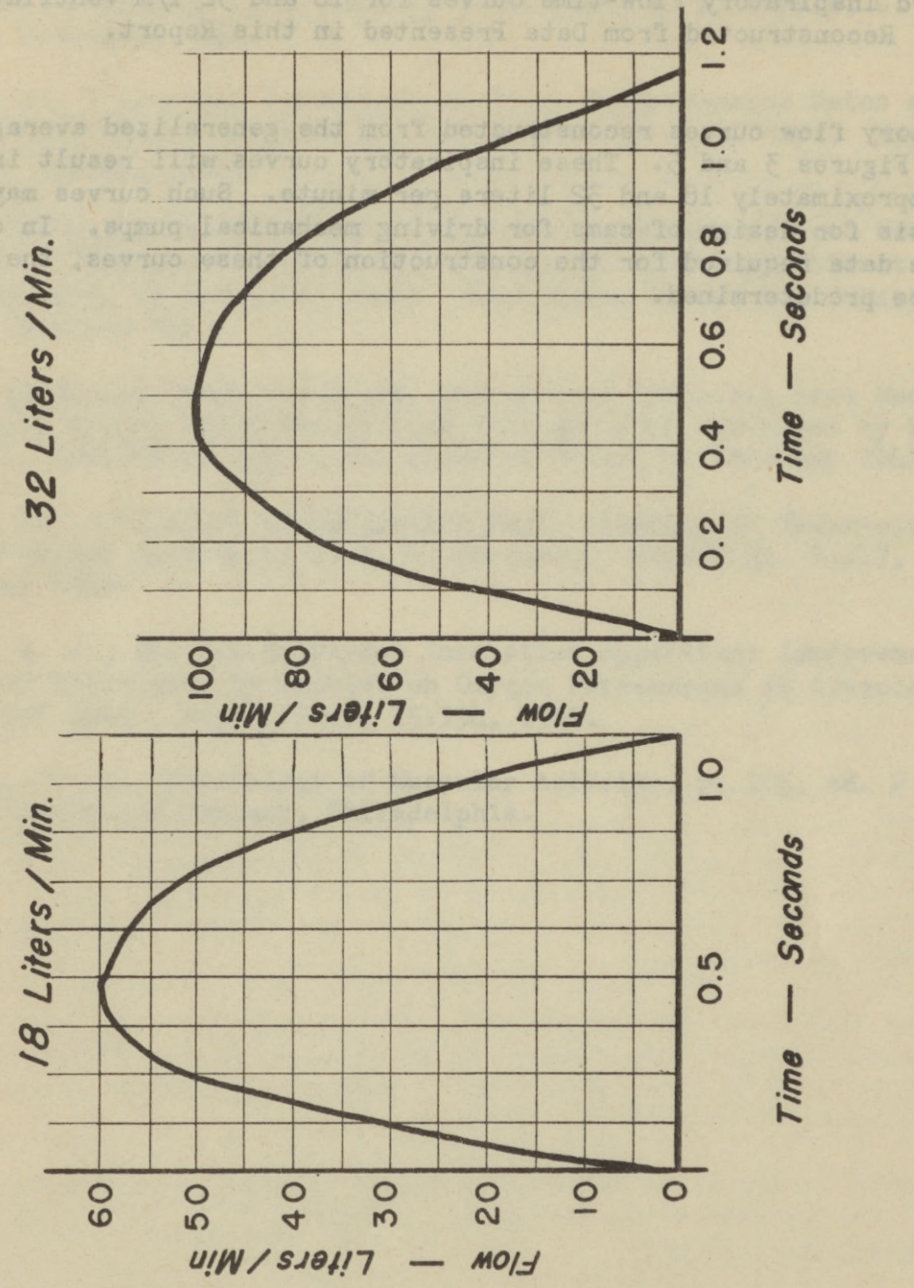
32 Liters / Min.
Flow — Liters / Min
100
80
60
40
20
0.2
0.4
0.6
0.8
1.0
1.2
Time — Seconds
18 Liters / Min.
Flow — Liters / Min
60
50
40
30
20
10
0
0.5
1.0
Time — Seconds

Fig. 1

Figure 2

Maximum and Minimum Inspiratory Flow-time Curves Obtained by Tracing of Original Records.

Inspiratory flow curves, obtained by tracing from an original record, representing minimum and maximum inspiratory flow-time curves. The minimum flow time curve pertains to a subject with the lowest ventilation and the lowest respiratory rate in a group of 27 sedentary subjects. These respiratory curves may also be used for the design of test equipment for respiratory apparatus.

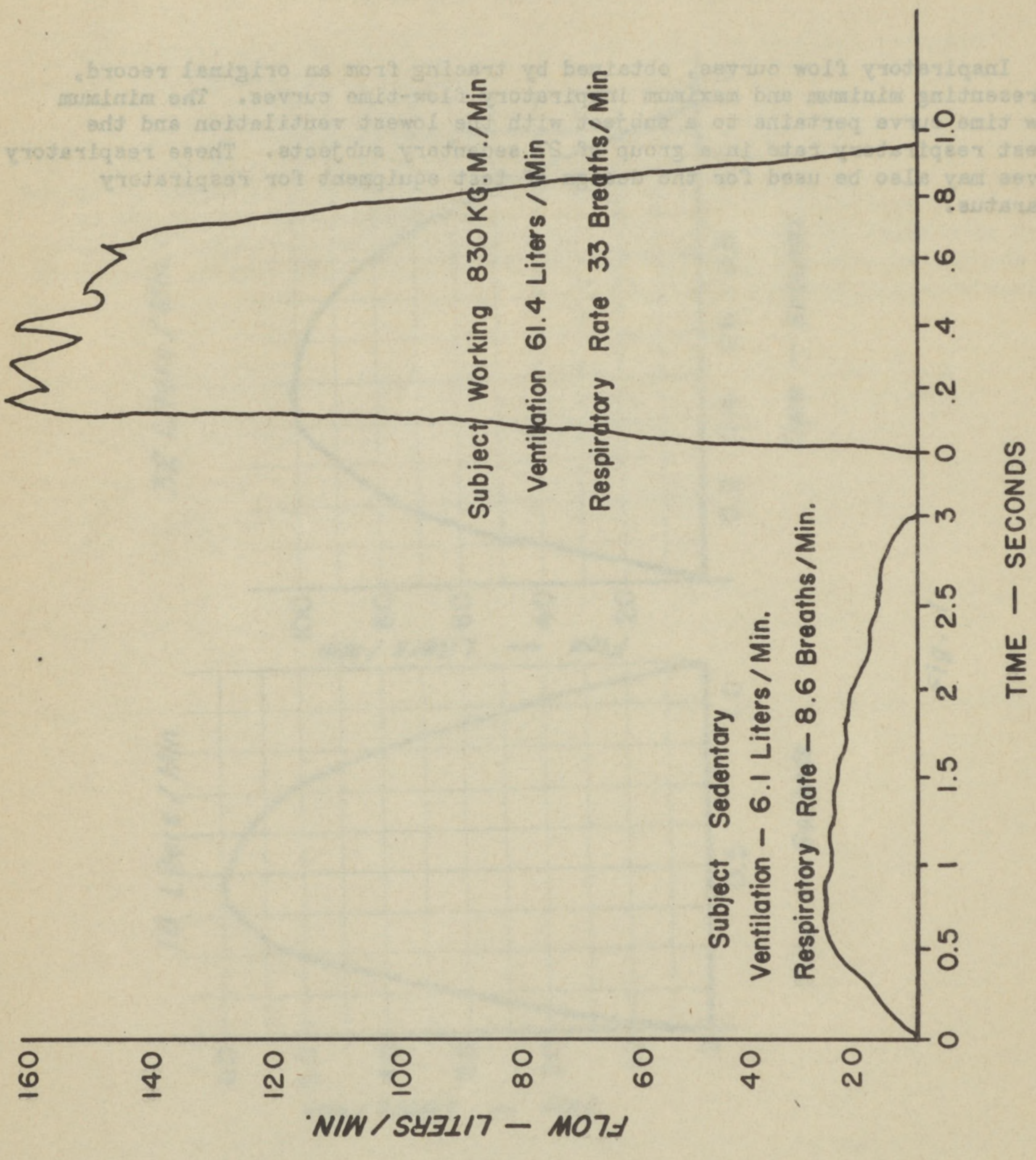
Subject Working 830 KG M./Min
Ventilation 61.4 Liters / Min
Respiratory Rate 33 Breaths/ Min
Subject Sedentary
Ventilation – 6.1 Liters / Min.
Respiratory Rate – 8.6 Breaths/Min.
FLOW — LITERS / MIN.
160
140
120
100
80
60
40
20
0
0.5
1
1.5
2
2.5
3
0
.2
.4
.6
.8
1.0
TIME — SECONDS

FIG. 2

Figure 3

Presentation of Average Respiratory Data.

This graph represents several factors in respiration plotted against the minute volume. The data used for all curves except the 90% inclusive MIF curve are average data obtained from Reference 7.

The 90% inclusive MIF curve was calculated from the average minute volume data of reference 7. The standard error of the MIF 90% data, computed for the data series having the largest standard deviation, is ± 0.63 l/m, indicating that out of any number of future groups of data, 90% of the MIF 90% figures will fall within ± 2 l/m of the indicated values.

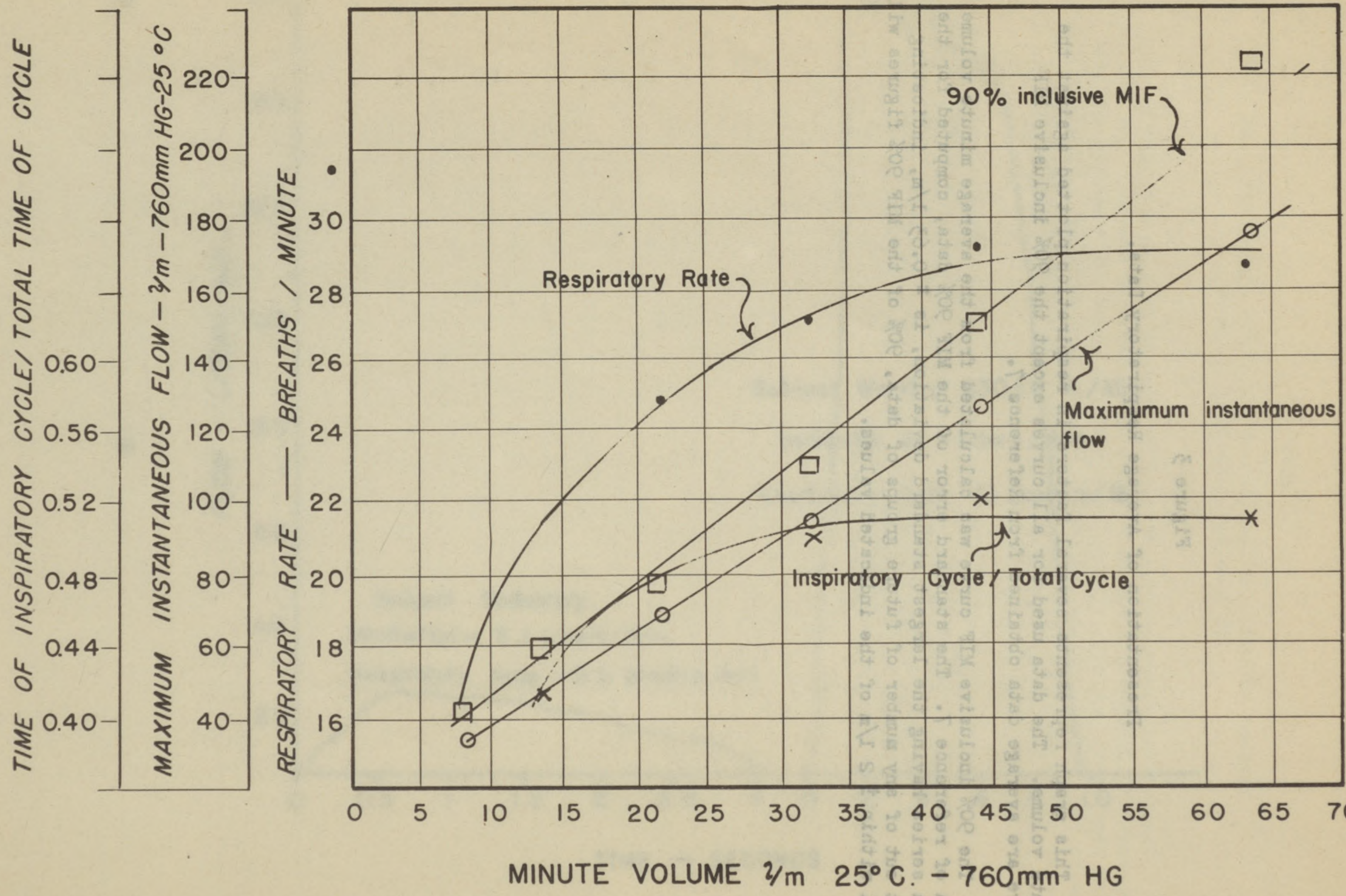
TIME OF INSPIRATORY CYCLE/ TOTAL TIME OF CYCLE
0.40
0.44
0.48
0.52
0.56
0.60
MAXIMUM INSTANTANEOUS FLOW — ℓ/m — 760mm HG-25 °C
40
60
80
100
120
140
160
180
200
220
RESPIRATORY RATE — BREATHS / MINUTE
16
18
20
22
24
26
28
30
Respiratory Rate
90% inclusive MIF
Maximumum instantaneous flow
Inspiratory Cycle / Total Cycle
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70
MINUTE VOLUME ℓ/m 25° C. – 760mm HG

FIG. 3

Figure 4

Inspiratory Flow-time Pattern Marked to Obtain Data for Construction of Curves on Figure 5.

An average inspiratory flow curve for a work load of 620 Kg. meter/min. obtained from Reference 7. This curve is divided into 7 parts by vertical lines which intersect the flow curve at 40, 80 and 120 liters per minute. Relative flow is obtained from the ratio of fractional flow to maximum flow; relative volume from the ratio fractional time to total time. A plot of the latter two against relative flow is illustrated in Figure 5.

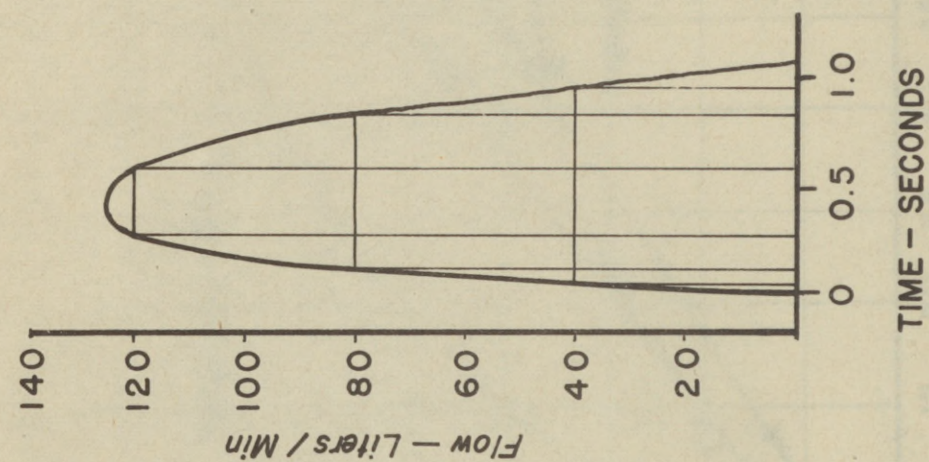

FIG. 4

Figure 5

Generalized Relative Volume - Relative Flow and Relative Time - Relative Flow Curves.

Generalized relative volume - relative flow and relative time - relative flow curves obtained in the manner described in explanation for Figure 4. From these curves average data may be extracted for construction of inspiratory flow curves and for construction of curves in Figure 7.

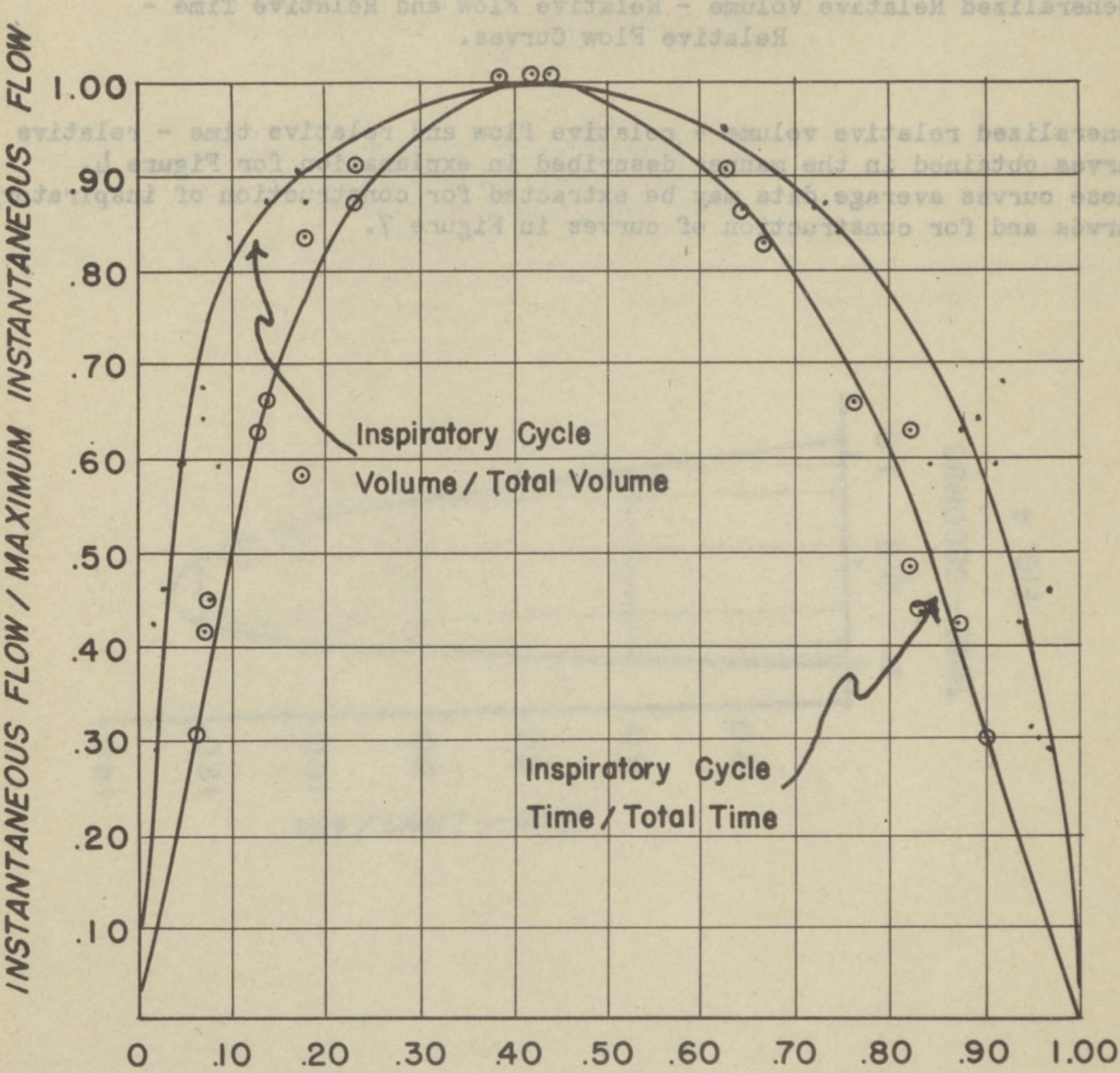
INSTANTANEOUS FLOW / MAXIMUM INSTANTANEOUS FLOW
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
0
.10
.20
.30
.40
.50
.60
.70
.80
.90
1.00
Inspiratory Cycle
Volume / Total Volume
Inspiratory Cycle
Time / Total Time

FIG. 5

Figure 6

Generalized Relative Volume - Relative Flow Curve to Explain Construction of Curves in Figure 7.

Generalized relative volume - relative flow curve marked to illustrate extraction of data used to construct curves of Figure 7. The flow ratio is arbitrarily selected, i.e. 0.50, and a horizontal line intersecting the relative volume curve is drawn. The ratio of the area below this horizontal line and bounded by the relative volume curve (hatched and cross hatched region) and the total area is plotted against relative flow to obtain data for the construction of curve 2, Figure 7, labelled Total Volume at Fraction. Where the horizontal line, i.e. 0.50, intersects the relative volume curve, perpendicular lines are dropped to the abcissa. The ratio of the sum of the areas between these perpendicular lines and the relative volume curve (cross hatched area) and the total area beneath the relative volume curve is plotted against relative flow to obtain curve 1 of Figure 7, labelled Total Volume at Fraction or Less.

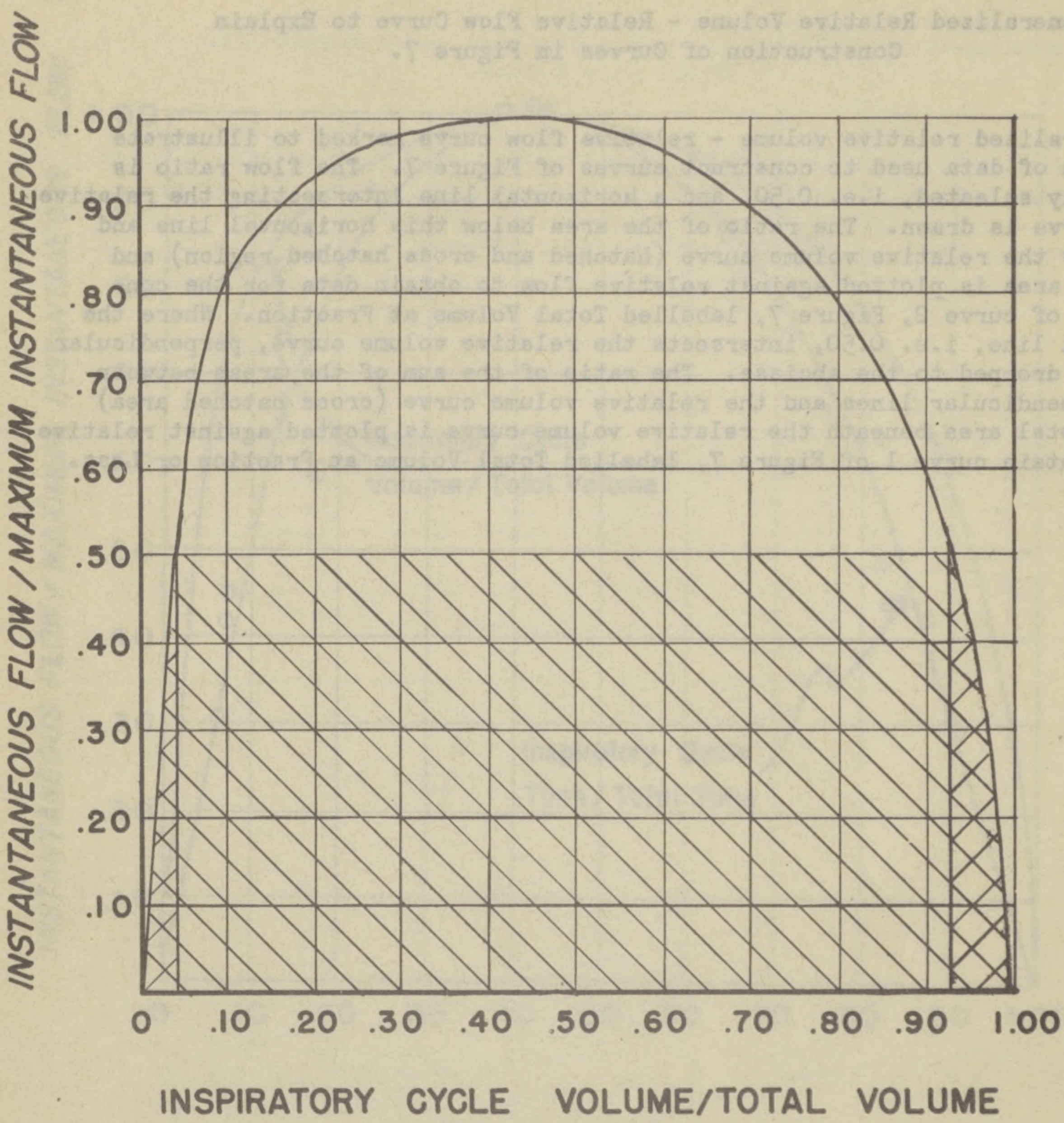
INSTANTANEOUS FLOW / MAXIMUM INSTANTANEOUS FLOW
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
0
.10
.20
.30
.40
.50
.60
.70
.80
.90
1.00
INSPIRATORY CYCLE VOLUME/TOTAL VOLUME

FIG. 6

Figure 7

Generalized Fractional Volume - Relative Flow Curves

The curves in Figure 7 present generalized inspiratory flow data obtained from curves in Figure 6 as follows:

(a) Curve 1 is a plot of the ratio of flow (instantaneous flow and maximum instantaneous flow) against the fraction of volume inspired at a given instantaneous rate of flow.

(b) Curve 2 is a plot of the ratio of flow against total volume inspired at a given instantaneous rate of flow. These data are obtained from Figure 6 in the manner described in that figure.

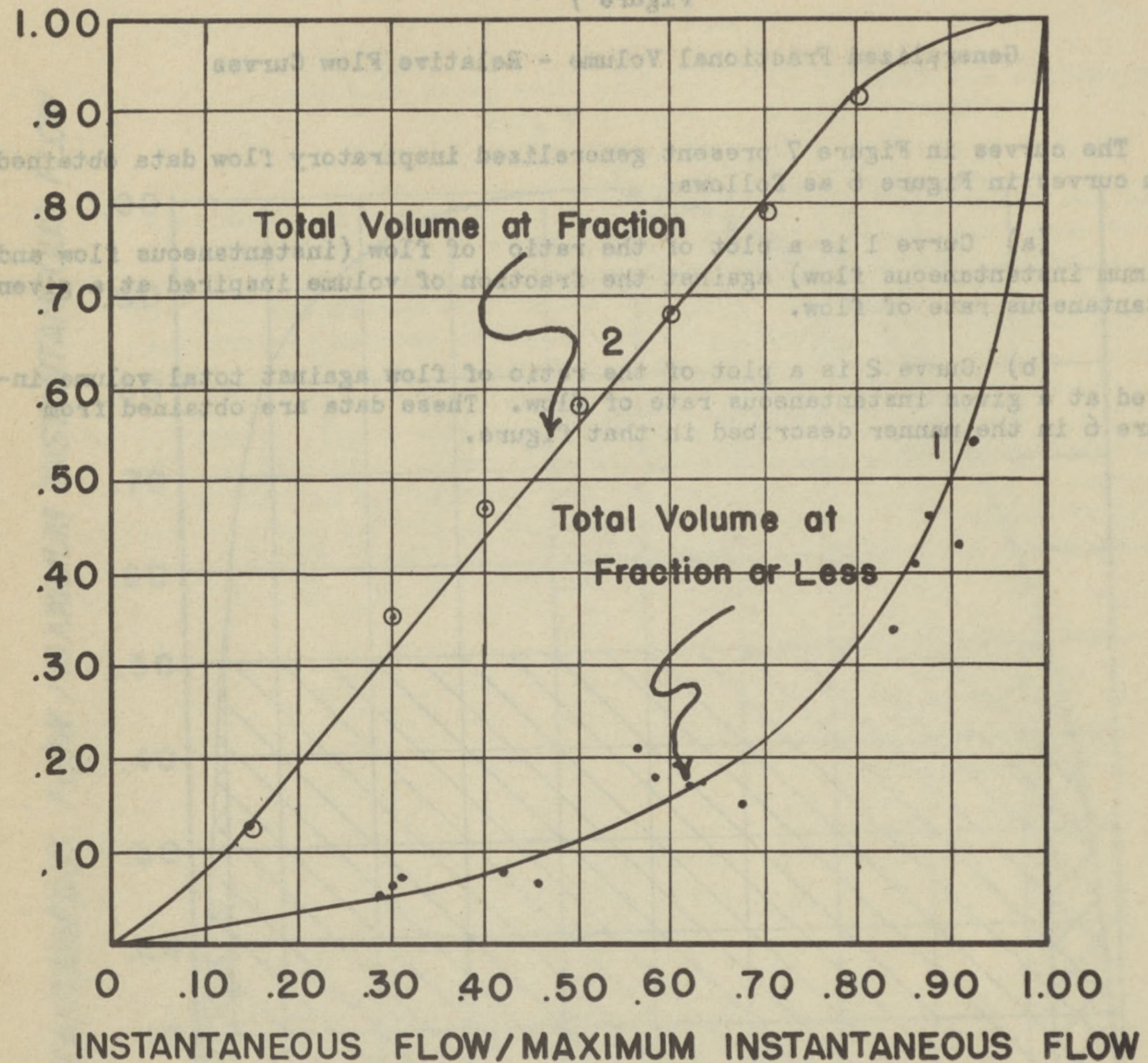
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
Total Volume at Fraction
2
1
Total Volume at
Fraction or Less
0
.10
.20
.30
.40
.50
.60
.70
.80
.90
1.00
INSTANTANEOUS FLOW/MAXIMUM INSTANTANEOUS FLOW

FIG. 7

Figure 8

Resistance to Breathing

Data illustrating negative mask pressure in relation to maximum instantaneous rates of flow. The data were obtained by the instantaneous measurement and recording of pressure in a mask fitted with orifices of varying diameter. The open circles denote resistances which were not noticed by subjects. The closed circles denote resistances noticed by the subjects; the closed triangles denote resistance uncomfortable for short periods.

Curve A represents the maximum allowable inspiratory resistance which is unnoticed by subjects; curve B represents the maximum allowable resistance which is noticed but not classified as uncomfortable by subjects.

Data from Reference 1.

RESISTANCE TO BREATHING

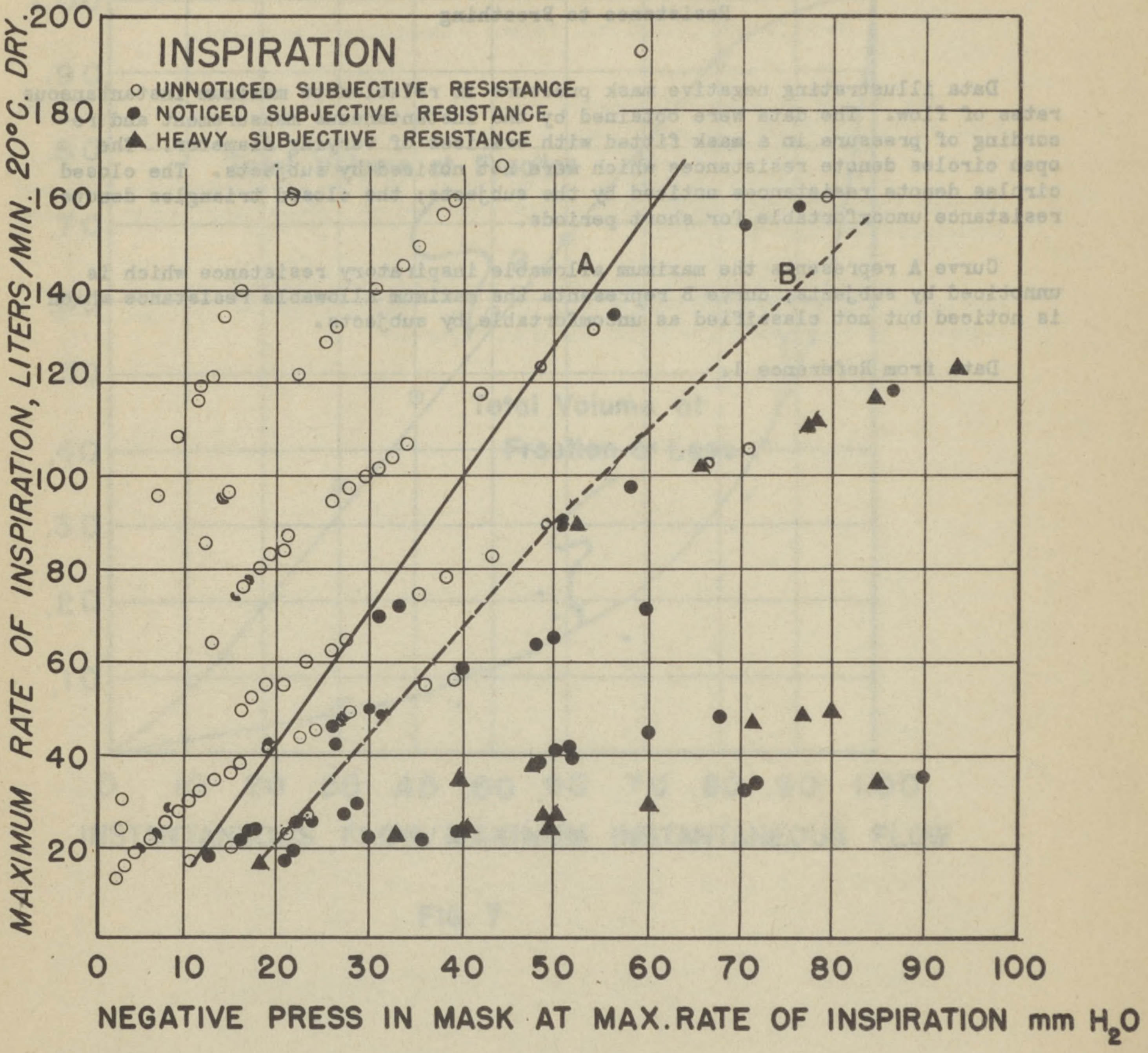

FIG. 8

Data from Ref. 1.

Figure 9

Curves Relating Oxygen Consumption, Carbon Dioxide Elimination and Water Vapor Elimination to Pulmonary Ventilation.

Curves illustrating the relation of oxygen consumption, carbon dioxide elimination and water vapor elimination to minute volume. The oxygen consumption and carbon dioxide elimination curves are based on the 90% inclusive figure calculated from average data obtained from Silverman, unpublished data. The reliability of these curves was checked by plotting data from reference 18; open squares represent carbon dioxide elimination and closed squares represent oxygen consumption. Notice that these values from reference 18 fall on or below the 90% inclusive curves.

The standard error of the oxygen consumption and carbon dicxide elimination 90% inclusive values, computed for the data series having the largest standard deviation, is ± 0.0047 l/m, indicating that out of any number of future groups of data, 90% of the oxygen consumption and carbon dioxide 90% inclusive values will fall within ± 0.014 l/m of indicated values.

The curve for water vapor elimination is calculated, assuming the expired air is saturated with water vapor at 37°C.

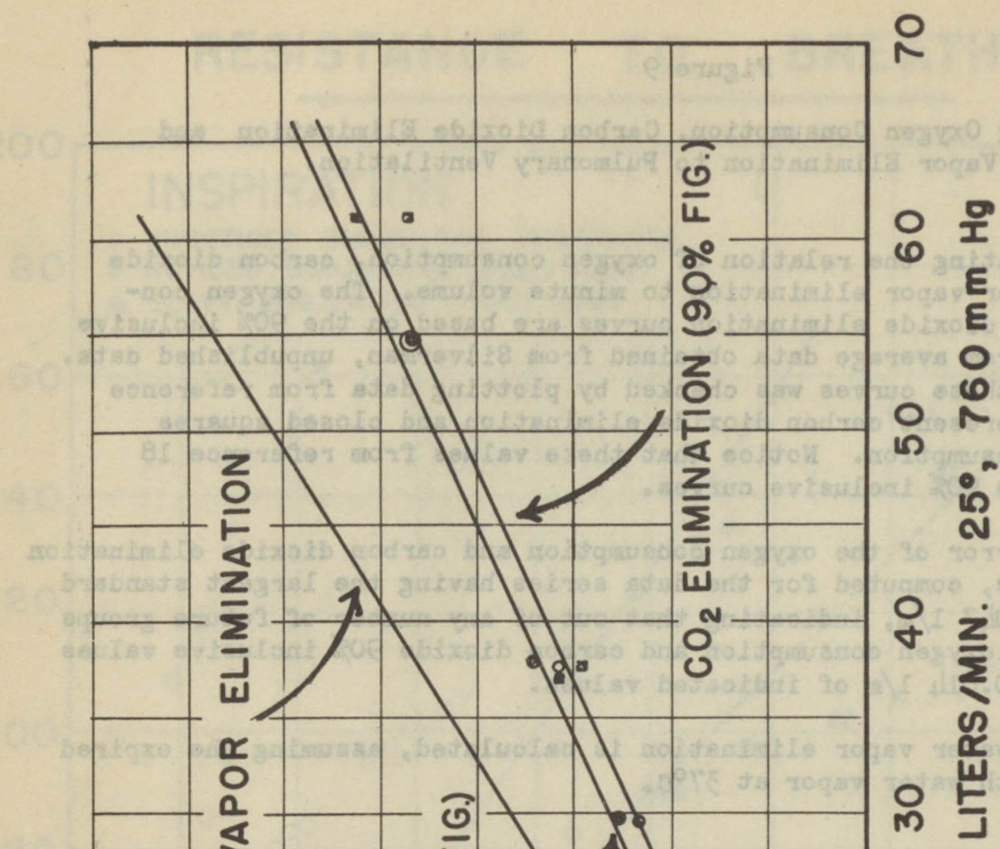
H2O VAPOR ELIMINATION
CO2 ELIMINATION (90% FIG.)
O2 CONSUMPTION (90% FIG.)
MINUTE VOLUME LITERS/MIN. 25°, 760 mm Hg
VOLUME LITERS/MIN. 25°C, 760mm. Hg
0
10
20
30
40
50
60
70
1
2
3
4

FIG. 9

Figure 10

Sketches of Oxygen Supply Systems.

Schematic sketches of oxygen supply systems are illustrated. Sketch 1 represents a constant flow system consisting only of regulator and mask. Sketch 2 represents a constant flow system consisting of regulator, mask and a reservoir volume. Sketch 3 represents a constant flow system consisting of regulator, mask and a rebreather bag. Sketch 4 represents a demand system consisting of regulator and mask. Refer to text for further detail.

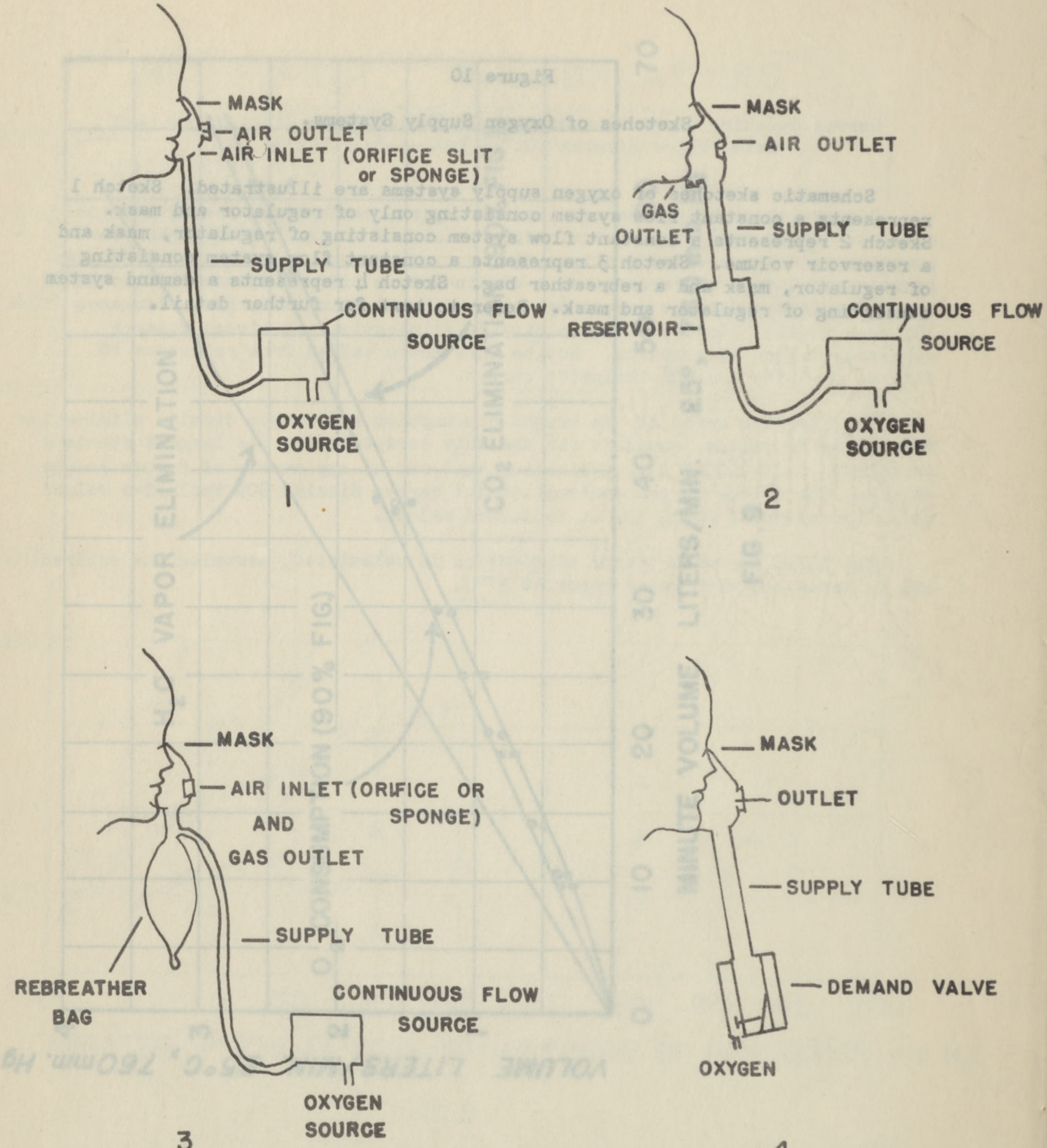
MASK
AIR OUTLET
AIR INLET (ORIFICE SLIT or SPONGE)
SUPPLY TUBE
CONTINUOUS FLOW SOURCE
OXYGEN SOURCE
1
MASK
AIR OUTLET
GAS OUTLET
SUPPLY TUBE
RESERVOIR
CONTINUOUS FLOW SOURCE
OXYGEN SOURCE
2
MASK
AIR INLET (ORIFICE OR SPONGE)
AND
GAS OUTLET
SUPPLY TUBE
REBREATHER BAG
CONTINUOUS FLOW SOURCE
OXYGEN SOURCE
3
MASK
OUTLET
SUPPLY TUBE
DEMAND VALVE
OXYGEN
4

FIG. 10