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PEAK RATES OF OXYGEN FLOW FROM OXYGEN SUPPLY SYSTEMS.(U)
1944 J H WEATHERBY, A S BURT

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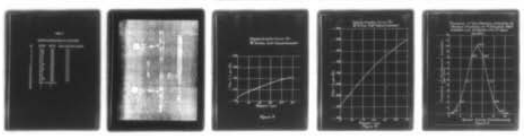

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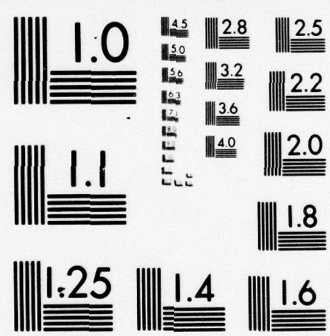

MICROCOPY RESOLUTION TEST CHART

U.S. NAVAL AIR TRAINING CENTER
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RESEARCH REPORT no. 1

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PROJECT NO: X-324(Av-185-f)

REPORT NO: One

TITLE: PEAK RATES OF OXYGEN FLOW FROM OXYGEN SUPPLY SYSTEMS.

NSAM-1

REPORT BY: Lieut. J.H. Weatherby, H-V(S) USNR
Ensign A.S. Burt, W-V(S) (H) USNR

APPROVED: Captain B. Groesbeck, Jr. (MC) USN
Medical Officer in Charge

J. H. Weatherby
Agnes S. Burt

SUMMARY AND CONCLUSIONS:

(1) Maximum rates of flow of oxygen required by a group of 10 men supplied from a single system were determined for conditions of rest and moderate exercise.

(2) Under the conditions indicated, maximum rates of flow were as follows:

(a) rest, random group breathing, 141 liters per minute.

(b) rest, rhythmic group breathing, 220 liters per minute.

(c) exercise, random group breathing, 415 liters per minute.

(d) exercise, rhythmic group breathing, 445 liters per minute.

(3) Respiratory minute volumes during exercise were determined on individual subjects receiving oxygen from systems capable of maximum rates of flow of 52 and 75 liters per minute respectively.

(4) With a mean minute volume of 19.2 liters per minute, the ratio, maximum rate of flow divided by minute volume (M.F./M.V.) was found to be 2.8 when determined on 19 subjects.

(5) With a mean minute volume of 29.6 liters per minute, M.F./M.V. was found to be 2.6 when determined on 11 subjects.

INTRODUCTION:

In accordance with BuMed directive of 18 February 1944 concerning Project No. X-324(Av-185-f), as modified by BuMed-X-EV-1f, A21/F49-1(112-38) of 8 June 1944, studies were made concerning maximum rates of flow of oxygen required by a group of 10 men at rest and during exercise. Included with these studies are observations dealing with respiratory minute volumes which may be attained by individual subjects from systems capable of supplying oxygen at specified maximum rates of flow.

EXPERIMENTAL METHODS:

GROUP EXPERIMENTS. Maximum rates of flow were ascertained for a group of 10 men under the following conditions: (1) rest, random group breathing; (2) rest, rhythmic group breathing; (3) exercise, random group breathing; (4) exercise, rhythmic group breathing. For this purpose oxygen was supplied through a 1/2" manifold (0.42" i.d.) under approximately atmospheric pressure. The manifold (Figure 1) consisted of two parallel lines each about 10 feet in length and 1 foot apart. These were joined together at the ends. The oxygen entered the system through an orifice flow meter (A) at one end. To the other end was attached a check valve (B) through which excess oxygen escaped to the outside.

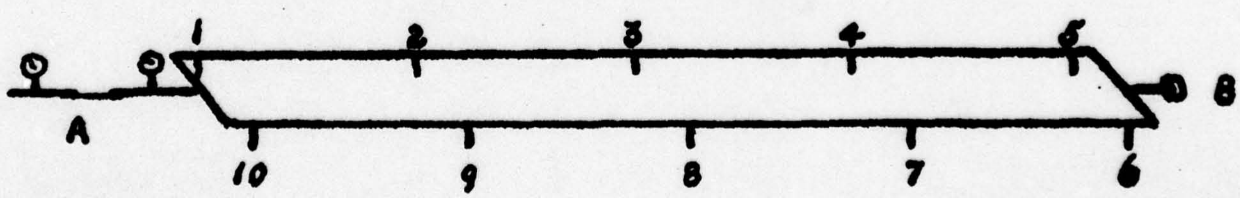

Figure 1.

Five outlets for the attachment of A14 masks were provided along each of the lines, thus allowing 10 men to be supplied simultaneously. Oxygen was metered into the system at various rates. With inadequate rates of flow the check valve closes, and those subjects who are inhaling at the moment are deprived of a supply of oxygen adequate for their inspiratory demands. As the rate of flow is increased the frequency with which one or more subjects complains of an inadequate oxygen supply becomes less and less. Ultimately a rate of flow can be obtained at which only an occasional subject will complain at relatively long intervals of time (several minutes). This is taken as the maximum rate of flow required under the conditions of the experiment.

The exercise used in some of these experiments consisted of stepping onto a box 6 inches high at a rate of 36 times per minute. This elevated respiratory minute volume to 20-30 liters per minute.

The orifice flow meter (Figure 2) consists of a short piece (3 to 4 inches in length) of small tubing (A,B) interposed between two portions of larger tubing (C,D). Pressure gauges (E,F) are attached to each of the larger portions of tubing. Rates of flow into a spirometer are measured under various heads of pressure, which may be regulated by valve G. Tables 1 and 2 show these data, and figures 3 and 4 the calibration curves obtained by plotting rate of flow against pressure. Unfortunately, the accuracy of these measurements at the highest rates of flow (above 350 liters per minute) was diminished because of the limited capacity of the spirometer.

EXPERIMENTS ON INDIVIDUAL SUBJECTS. For the purpose of investigating the extent to which maximum rates of flow may be reduced without harmful effects, a system having maximum flow characteristics within the desired range was prepared in the following manner. The oxygen inlet valve and orifice were removed from an A12 Pioneer Diluter Demand Oxygen Regulator. Rates of flow at 30 and 40 p.s.i. pressure and with various amounts of suction were measured by means of the National Bureau of Standards test stand designed for the purpose. The results of these measurements are shown in Table 3. A rapid increase in rate of flow results from a slight increase in suction until maximum rate is obtained. At maximum rate a large increase in suction produces no appreciable increase in flow. This large increase in suction is quite evident subjectively when a regulator is required to deliver maximum rate of flow; and when the increase is indicated by a manometer attached to the mask, it provides a convenient means of measuring maximum inspiratory rate of flow. If one is required to maintain this inspiratory rate during an appreciable portion of each inspiratory phase, then the resistance to respiration rapidly becomes very tiring.

Subjects were supplied with oxygen from such a system, including an A14 mask so modified that expired gas could be collected in a spirometer. A water manometer was connected to the mask primarily for the purpose of indicating when maximum rate of flow was being demanded rather than for providing an accurate indication of suction within the mask.

Respiration was stimulated by exercise. This exercise consisted of stepping onto a box 6 inches high at whatever rate found necessary to produce the desired degree of stimulation, or by pedalling a bicycle ergometer under an appropriate load. When stimulation had progressed to the point of causing maximum flow during an appreciable portion of each inspiration, as indicated by a great increase in suction shown by the manometer, the respiratory minute volume was measured by collecting the expired gas in a spirometer. All volumes were measured (over water) at ambient temperature and pressure.

RESULTS:

GROUP EXPERIMENTS. As shown in Table 4, a maximum rate of flow of 141 liters per minute was found necessary to satisfy 10 subjects, sedentary, and breathing at random. With rhythmic group breathing these same subjects required 220 liters per minute (Table 5). With exercise and random group breathing, the rate was 415 liters per minute (Table 6), while with rhythmic group breathing, it was 445 liters per minute (Table 7). In this connection it should be remembered that with a group of subjects, each member of which is breathing at his own individual rate with no conscious relationship to the rates of others, there will be occasions when no one will be in the inspiratory phase, as well as other occasions when all will be inhaling simultaneously. All gradations between these extremes will occur from time to time, the frequency depending largely on the laws of chance. For example, in Table 4 only one subject was obtaining an inadequate supply of oxygen at a rate of flow of 115 liters per minute; whereas shortly thereafter five subjects complained with a flow of 119 liters per minute. Likewise, in Table 7 all were satisfied for a short period with 438 liters per minute, but one subject complained occasionally with a rate of 445 liters per minute. Figure 5 shows the probabilities that various members of a group of 10 subjects will be in the inspiratory phase at any given instant when inspiratory and expiratory phases are of equal duration. While it was not possible to measure the minute volume of each subject individually during the course of these experiments, other observations indicate that a minute volume of 20-30 liters per minute is attained by such exercise. On the basis of an average weight of 148 pounds for the members of the group, a minimum of 2664 foot pounds of work per minute was performed.

EXPERIMENTS ON INDIVIDUAL SUBJECTS. In Table 8 are shown pertinent data obtained from individuals under various loads of work while obtaining oxygen from the A12 regulator as described above. Pressures of 30 and 40 p.s.i. were supplied to the regulator, which provided maximum rates of flow of 52 and 75 liters per minute respectively. It will be noted that the ratios for maximum flow divided by minute volume (M.F./M.V.) of 2.8 and 2.6 (standard deviations are 0.5 and 0.4 respectively) are practically identical with those obtained by Silverman, et al., (OSRD Report No. 1222, Tables 16 and 17) under similar though not quite identical conditions.

Table 9 shows height, weight, and vital capacity for most of the subjects participating in these experiments. All but No. 18 were males. In Tables 4,5,6, and 7 references are made to these subjects by numbers in the columns listing complaints.

DISCUSSION:

Data concerning maximum flow for the group of 10 men under various conditions requires little comment. The rate of 141 liters per minute for resting conditions (Table 4) appears unexpectedly low. This may have been caused by "dead space" in the oxygen lines, or by a greater or less amount of rebreathing of the gases in the line. Rebreathing, as indicated by the sensation of inhaling vitiated air, was definitely noted when rates of flow were inadequate, but not at the several highest rates. Lines with less "dead space" were not practicable because of the added resistance to flow these would have imposed. The volume of "dead space", exclusive of mask hoses, was approximately 350 cc. The rate of 220 liters per minute at rest and 445 liters per minute with exercise, (Tables 5 and 7) both obtained with rhythmic group breathing, are believed to be valid. However, in this connection it must be recalled that maximum rate of flow during inspiration persists for only a fraction of a second. For this reason it cannot be stated with certainty that all members of the group were attaining maximum rate of flow simultaneously, even though a deliberate effort was being made to accomplish this. It is doubtful if the maximum rate of flow required by a group of individuals in which all reach the maximum inspiratory rate simultaneously can be other than the sum of their individual maximum rates.

In the experiments on individual subjects, it is significant that hardly anyone was conscious of the gradually increasing inspiratory resistance during exercise until the system was being required to deliver maximum rate of flow. During periods of physical activity and rapid ventilation, presumably the inspiratory resistance normally encountered in the respiratory passages is sufficiently high that the external resistance is masked until the appearance of the sudden and marked increase in suction which occurs when maximum rate of flow is attained. Essentially the same observation was made on subjects at rest. With the modified A12 regulator operating at line pressures barely sufficient to meet the respiratory demands of the subject, inspiratory resistance was not objectionable until maximum rate of flow of the regulator was attained. When this occurred, the sudden increase in suction necessary to satisfy the inspiratory demand was quite objectionable and poorly tolerated by the subject.

TABLE 1.

CALIBRATION OF 3/16"ORIFICE (0.12" i.d.).

PRESSURE	FLOW - L./min.
5	65
7.5	84
10	91
12.5	101
15	110
20	137
25	143
30	156
40	207

TABLE 2.

CALIBRATION OF 1/4" ORIFICE (0.18" i.d.).

PRESSURE	FLOW - L./min.
5	160
7.5	198
10	216
12.5	248
15	272
17.5	306
20	340
25	368
30	394
35	474

TABLE 3.

CALIBRATION OF A12 PIONEER DILUTER DEMAND REGULATOR FOR OXYGEN OUTPUT AT VARIOUS AMOUNTS OF SUCTION AND AT 30 AND 40 P.S.I. LINE PRESSURES

O_2 Flow: L./min.	Suction - inches water 30 psi	40 psi
10	0.2	0.2
15	0.2	0.2
20	0.2	0.2
25	0.25	0.25
30	0.3	0.25
35	0.4	0.3
40	0.6	0.4
45	0.7	0.5
50	1.0	0.6
52	-2.6	- -
55		0.7
60		0.8
65		1.0
70		1.2
75		2.4

TABLE 4.

MAXIMUM FLOW, 10 MEN, REST, RANDOM GROUP BREATHING.

3/16" ORIFICE (0.12" i.d.)

PRESSURE	L./Min.	COMPLAINTS
7	78	4,5,9,10
9	88	4,5,8,9,10
11	98	all
14	111	3,4,5,8,9,10
15	115	5
16	119	2,3,4,5,10
17	123	4,5
18	127	3,4,5
20	134	3,4,10 occasionally
22.5	141	none

TABLE 5.

MAXIMUM FLOW, 10 MEN, REST, RHYTHMIC GROUP BREATHING.

1/4" ORIFICE (0.18" i.d.).

PRESSURE	L./Min.	COMPLAINTS
5	160	all
6	172	3,4,5,6,7
7	185	4,5,9
8	198	4,9
10	220	4, occasionally

TABLE 6.

MAXIMUM FLOW, 10 MEN, EXERCISE, RANDOM GROUP BREATHING

1/4" ORIFICE (0.18" i.d.)

PRESSURE	L./min.	COMPLAINTS
10	220	1,2,3,4,5,8,10
13	255	3,4,5,6,8,9,10
14	267	all, occasionally
15	278	3,4,5,6,8,10
20	330	3,4,8, occasionally
25	378	3,4,5,9
30	415	3,4, rarely

TABLE 7.

MAXIMUM FLOW, 10 MEN, EXERCISE, RHYTHMIC GROUP BREATHING.

1/4" ORIFICE (0.18" i.d.)

PRESSURE	L./min.	COMPLAINTS
25	378	all
26	385	all
30	415	all
32	430	none
33	438	none
34	445	4, occasionally

TABLE 8.

DETERMINATION OF MINUTE VOLUME AT FIXED MAXIMUM FLOW.

SUBJECT NO.	30 psi Gauge Setting (M.F. = 52 L./min.)			40 psi Gauge Setting (M.F. = 75 L./min.)		
	Mask Suction (in.H_2O)	M.V.	M.F./M.V.	Mask Suction (in.H_2O)	M.V.	M.F./M.V.
17	2.5	14.1	3.7			
18	2.0	14.9	3.5	3	24.8	3.0
"	4.0	15.1	3.4			
"	1.5	20.5	2.6			
15	1.5	15.1	3.4	2.0-3.0	30.4	2.5
11	2.5	16.9	3.1	2.5	25.9	2.9
10	2.5	17.6	3.0	2.5	22.7	3.3
"	2.5	17.8	2.9	2.0-3.0	24.5	3.1
"	2.5	18.4	2.8			
19	2.5	17.8	2.9			
14	2.5	19.8	2.6	2.5	24.7	3.0
9	2.5	19.6	2.6			
13	1.5	20.9	2.5	3.0-4.0	34.7	2.2
20	1.3	21.3	2.4			
5	2.5	22.1	2.4	6.0-8.0	34.8	2.2
22				3.0-4.0	31.9	2.4
4	2.5	22.8	2.3	1.5	28.5	2.6
16	3.0	22.2	2.3	4.0-6.0	32.6	2.3
21	2.5	23.7	2.2			
12	3.0	24.8	2.1	8.0-10.0	39.9	1.9
Mean		19.2	2.8		29.6	2.6
Standard Deviation		3.1	0.5		5.1	0.4

TABLE 9.

SUBJECTS PARTICIPATING IN EXPERIMENTS.

NO.	HEIGHT	WEIGHT	VITAL CAPACITY (Liters)
1	5-8	140	4.6
2	5-6½	140	3.9
3	5-10	135	5.1
4	5-8	155	4.2
5	5-11	175	5.3
6	5-8	155	4.6
7	6-0	150	4.7
8	6-0	150	4.3
9	5-10½	160	4.4
10	5-8	120	4.1
11	5-10	175	4.5
12	5-8½	135	5.7
13	6-0	150	5.0
14	6-2	190	5.1
15	5-8	160	4.2
16	5-11	165	4.0
17	5-10½	150	4.3
18	5-9	130	3.6
19	Data Unavailable		
20	"	"	
21	"	"	
22	"	"	

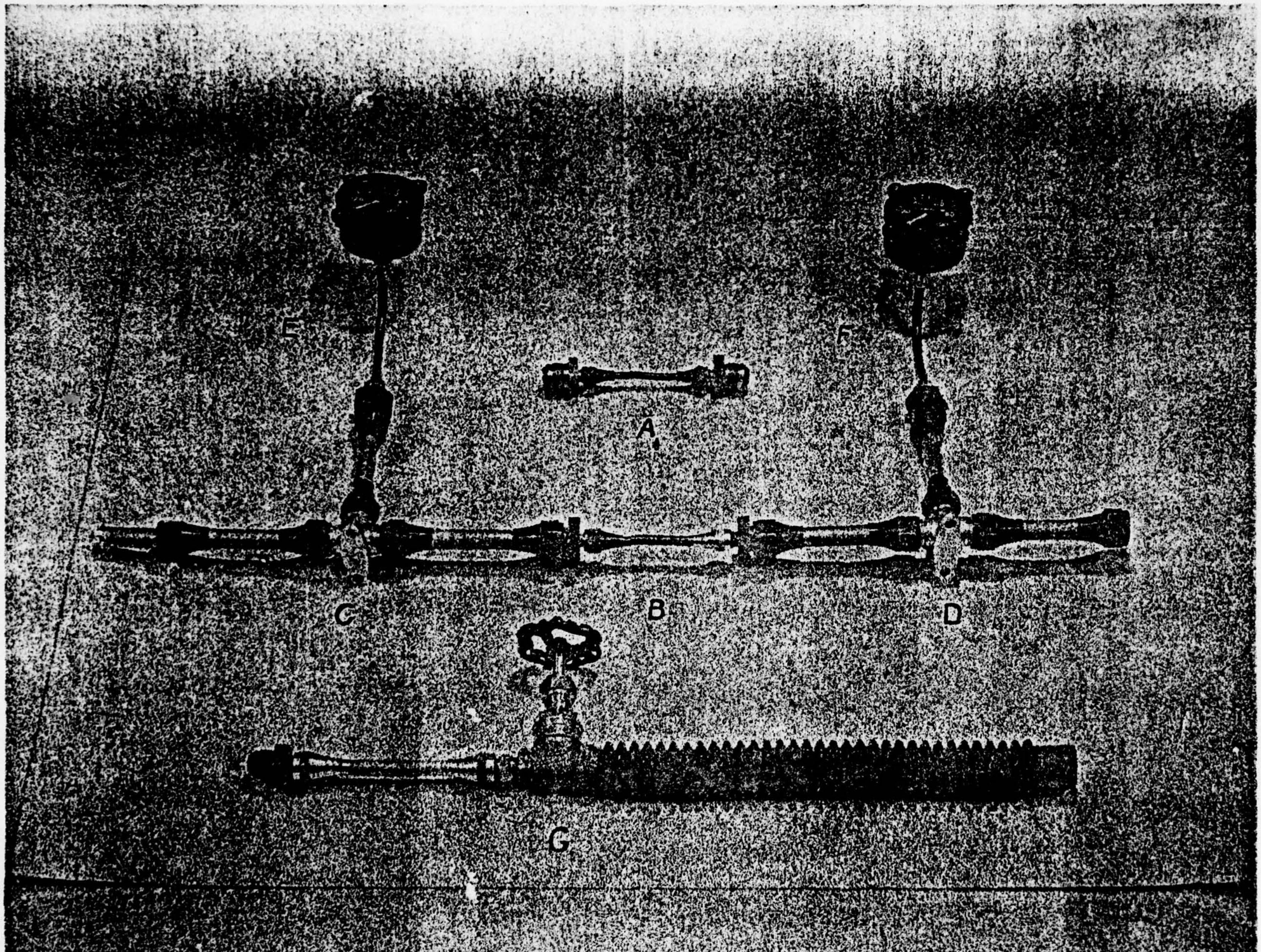

Figure 2.

Standardization Curve For
3/16" Orifice (0.12" internal diameter)

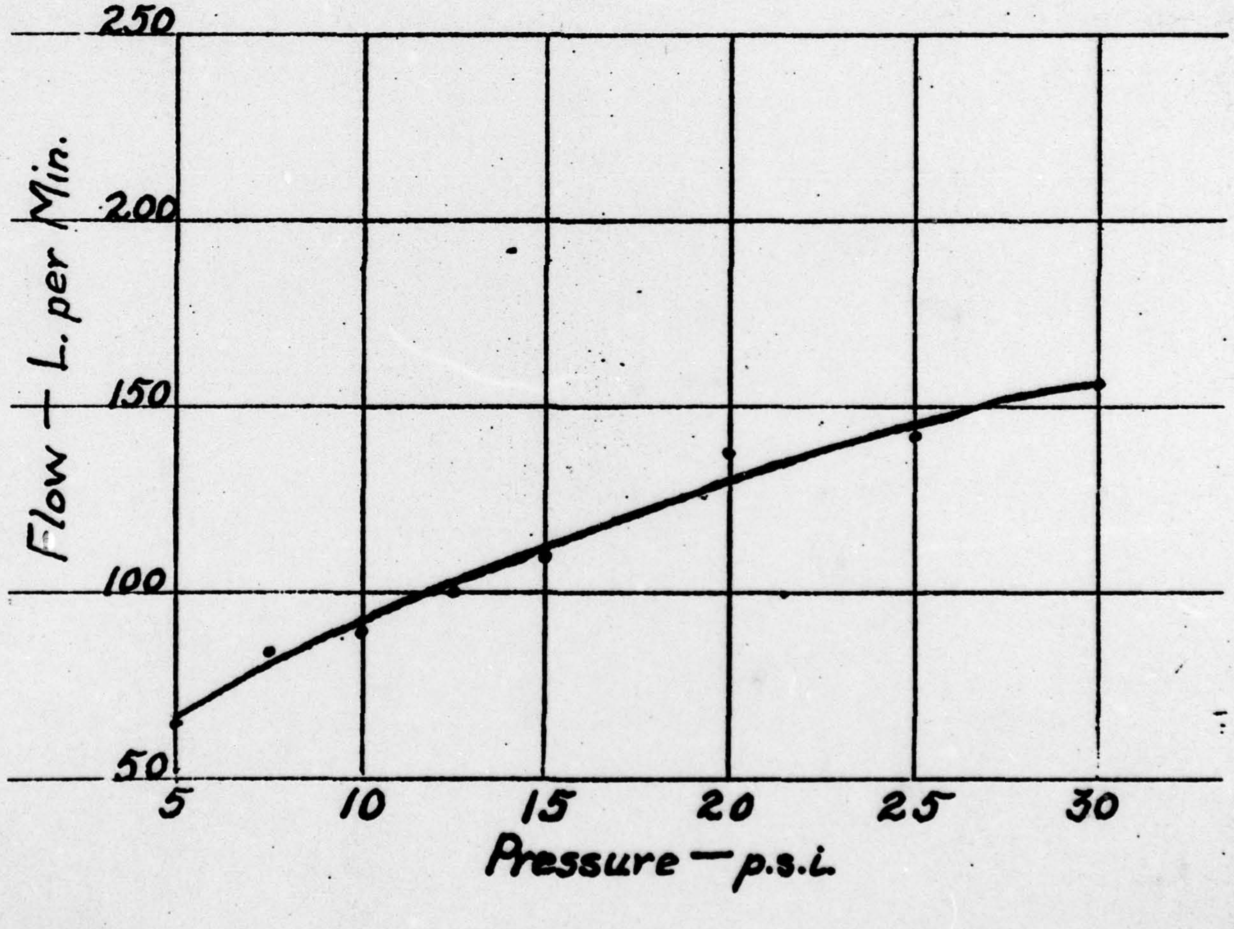

Figure 3.

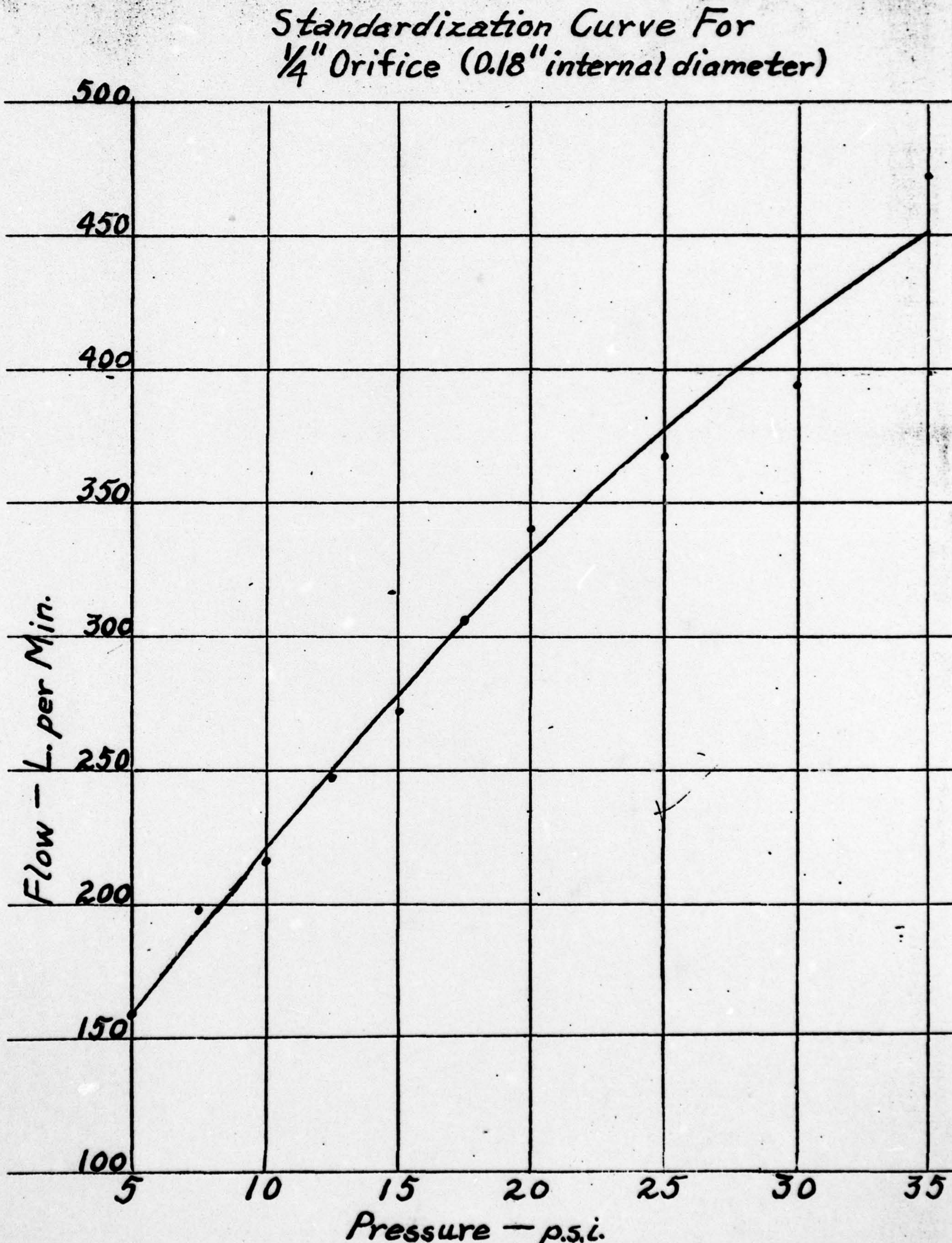
Standardization Curve For
1/4" Orifice (0.18" internal diameter)
500
450
400
350
300
250
200
150
100
Flow — L. per Min.
5
10
15
20
25
30
35
Pressure — p.s.i.

Figure 4.

Frequency of Simultaneous Inhalation by Members of a Group of 10 Subjects When Inhalation and Exhalation Are of Equal Duration

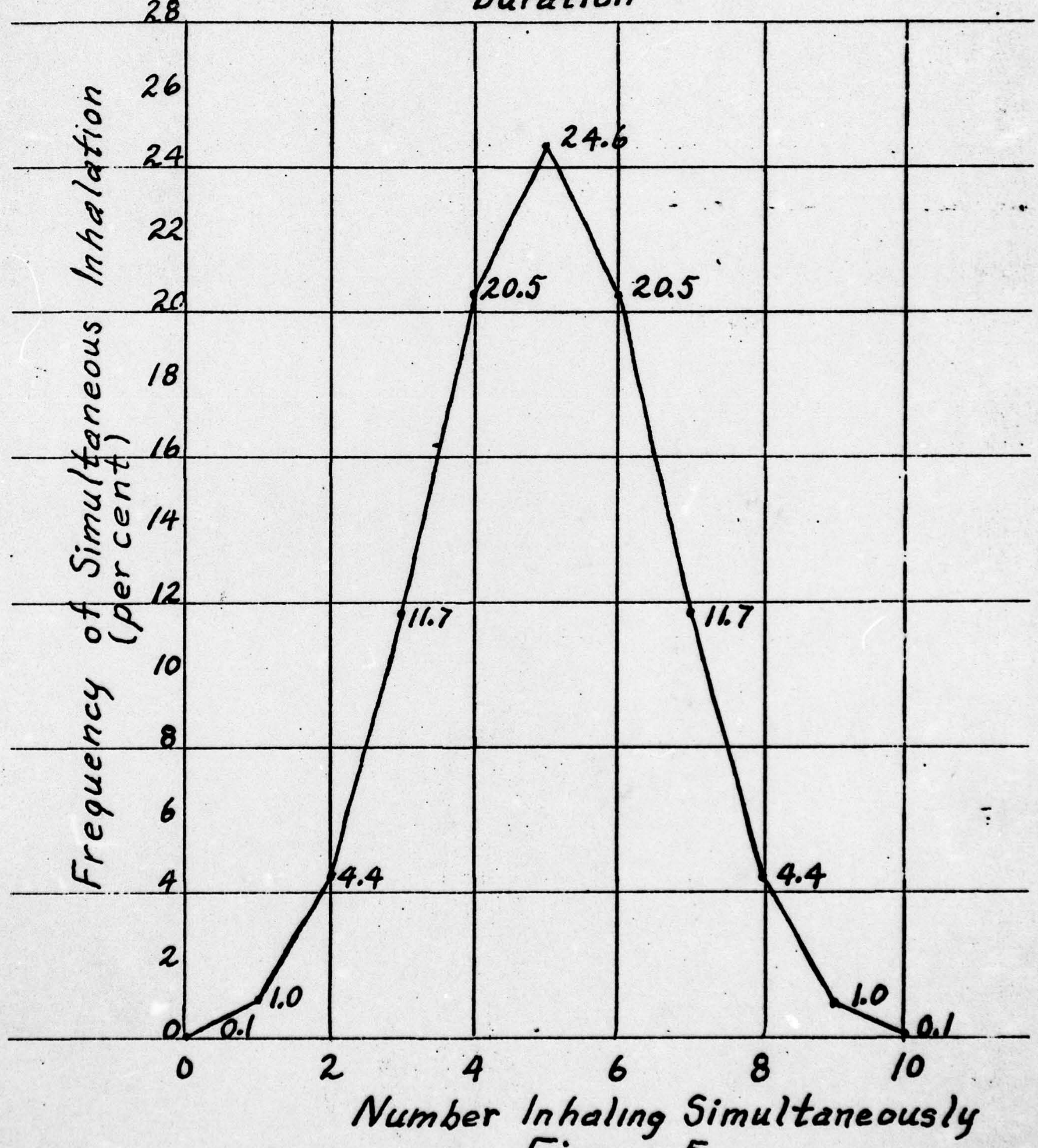

Figure 5.