Civil Aeromedical Research Institute, Federal Aviation Agency, Oklahoma City, Oklahoma. CARI Report 62-21, AN IMPROVED METHOD FOR DETERMINING THE EFFICIENCY OF CREW AND PASSENGER OXYGEN MASKS by E. B. McFadden, J. W. Raeke, and J. W. Young, November 1962.

1. Oxygen Equipment
2. Respiration
3. Hypoxia
4. Altitude
5. Decompression
6. Anthropometry

A method of determining oxygen mask leakage as developed under Contract FA-885 between the Federal Aviation Agency and the Pioneer-Central Division of the Bendix Corporation was evaluated. Measurement of nitrogen concentration within an oxygen mask following respiratory nitrogen washout appears to provide a valid index of inboard mask leakage. Further development of this technique and its application to a proposed mask design is described.

Civil Aeromedical Research Institute, Federal Aviation Agency, Oklahoma City, Oklahoma. CARI Report 62-21, AN IMPROVED METHOD FOR DETERMINING THE EFFICIENCY OF CREW AND PASSENGER OXYGEN MASKS by E. B. McFadden, J. W. Raeke, and J. W. Young, November 1962.

1. Oxygen Equipment
2. Respiration
3. Hypoxia
4. Altitude
5. Decompression
6. Anthropometry

A method of determining oxygen mask leakage as developed under Contract FA-885 between the Federal Aviation Agency and the Pioneer-Central Division of the Bendix Corporation was evaluated. Measurement of nitrogen concentration within an oxygen mask following respiratory nitrogen washout appears to provide a valid index of inboard mask leakage. Further development of this technique and its application to a proposed mask design is described.

Civil Aeromedical Research Institute, Federal Aviation Agency, Oklahoma City, Oklahoma. CARI Report 62-21, AN IMPROVED METHOD FOR DETERMINING THE EFFICIENCY OF CREW AND PASSENGER OXYGEN MASKS by E. B. McFadden, J. W. Raeke, and J. W. Young, November 1962.

1. Oxygen Equipment
2. Respiration
3. Hypoxia
4. Altitude
5. Decompression
6. Anthropometry

A method of determining oxygen mask leakage as developed under Contract FA-885 between the Federal Aviation Agency and the Pioneer-Central Division of the Bendix Corporation was evaluated. Measurement of nitrogen concentration within an oxygen mask following respiratory nitrogen washout appears to provide a valid index of inboard mask leakage. Further development of this technique and its application to a proposed mask design is described.

Civil Aeromedical Research Institute, Federal Aviation Agency, Oklahoma City, Oklahoma. CARI Report 62-21, AN IMPROVED METHOD FOR DETERMINING THE EFFICIENCY OF CREW AND PASSENGER OXYGEN MASKS by E. B. McFadden, J. W. Raeke, and J. W. Young, November 1962.

1. Oxygen Equipment
2. Respiration
3. Hypoxia
4. Altitude
5. Decompression
6. Anthropometry

A method of determining oxygen mask leakage as developed under Contract FA-885 between the Federal Aviation Agency and the Pioneer-Central Division of the Bendix Corporation was evaluated. Measurement of nitrogen concentration within an oxygen mask following respiratory nitrogen washout appears to provide a valid index of inboard mask leakage. Further development of this technique and its application to a proposed mask design is described.

AN IMPROVED METHOD FOR DETERMINING THE EFFICIENCY OF CREW AND PASSENGER OXYGEN MASKS

ERNEST B. McFADDEN, M.S.
Chief, Survival Equipment Section
JAMES W. RAEKE, M.S.
Survival Equipment Section
JOSEPH W. YOUNG, A.M.
Anthropology Section
Protection and Survival Branch

A PRELIMINARY REPORT

62-21

FEDERAL AVIATION AGENCY
AVIATION MEDICAL SERVICE
AEROMEDICAL RESEARCH DIVISION
CIVIL AEROMEDICAL RESEARCH INSTITUTE
OKLAHOMA CITY, OKLAHOMA

AN IMPROVED METHOD FOR DETERMINIING THE EFFICIENCY OF CREW AND PASSENGER OXYGEN MASKS

ERNEST B. McFADDEN, M.S.
JAMES W. RAEKE, M.S.
JOSEPH W. YOUNG, A.M.

ABSTRACT

A method of determining oxygen mask leakage as developed under contract FA-885 between the Federal Aviation Agency and the Pioneer-Central Division of the Bendix Corporation was evaluated. Measurement of nitrogen concentration within an oxygen mask following respiratory nitrogen washout appears to provide a valid index of inboard mask leakage. Further development of this technique and its application to a proposed mask design is described.

One of the most significant factors relating to the efficiency of an oxygen mask is the quantitative inboard leakage of nitrogen-rich ambient air which dilutes the oxygen supplied to the wearer. This factor is quite variable, depending upon the design of the mask and the facial structure of the wearer. In practice, inboard leakage may be minimized or even converted to outboard leakage by increasing the volume flow and/or hydrostatic pressure of oxygen supplied at the mask. However, compensation for excessive leakage in this manner results in poor oxygen economy.

The ultimate aim of an oxygen mask at altitude is the production of an adequate blood oxygen saturation. However, in order to evaluate the capability of a mask to maintain an adequate blood oxygen saturation in the subject, the performance of the mask and the resulting saturation must be predicted theoretically, or the subject must ascend to altitude and the blood oxygen saturation determined. The latter procedure tends to exclude some of the subject population and involves large and expensive facilities. In addition, techniques for the determination of blood oxygen saturation are quite tedious or limited in accuracy.

The primary purpose of this study was to extend the investigation and development of techniques of oxygen mask evaluation initiated by the Pioneer-Central Division of the Bendix Corporation under Contract FA-885.[2] Initial emphasis is being placed upon developing methods that may be utilized at ground level, on relatively large numbers of subjects, widely distributed in age and physical fitness. Ground level testing allows the study of subjects typical of the airline passenger population, many of which normally could not safely be exposed to hypoxia and environmental conditions in an altitude chamber. In addition, a greater number of subjects may be tested at ground level under controlled conditions, at a much lower cost than in an altitude chamber.

Since the percentage composition of nitrogen in the ambient air at ground level and at altitude (up to 80,000 feet) is quite stable (78.09%), a reliable standard reference gas of relatively high concentration exists at all times in the surrounding ambient environment of the subject. When the subject is breathing 99.5% oxygen, any mask inboard leakage results in an inflow of nitrogen-containing air from the surrounding ambient environment. This produces

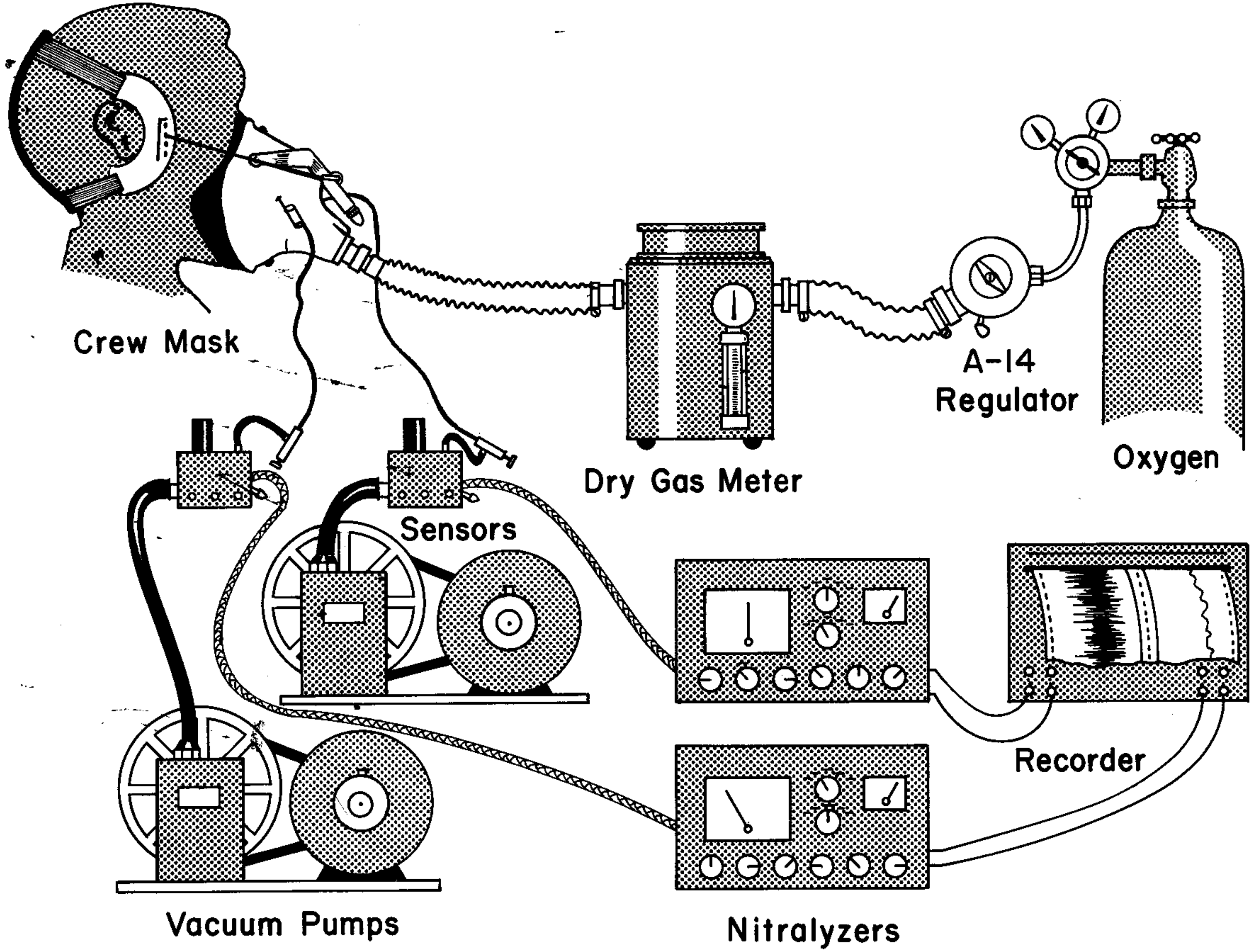

FIGURE 1. Schematic sketch of oxygen mask leakage testing system showing crew mask being utilized for pulmonary nitrogen washout. Demand System.

FIGURE 1. Schematic sketch of oxygen mask leakage testing system showing crew mask being utilized for pulmonary nitrogen washout. Demand System.

a dilution of the oxygen concentration in the mask and is immediately evident by continuous nitrogen analysis.

The use of nitrogen analysis to obtain mask leakage information appears to be the method of choice since the nitrogen analyzer provides accurate, rapid response unavailable in other gas analysis equipment.[1] In addition, unlike many other gas sampling devices, the nitrogen analyzer utilized in this study is unaffected by barometric pressure changes and operates as efficiently at altitude as at sea level.

A secondary, but integral, phase of this study is the evaluation of a proposed passenger oxygen mask design. All data presented were obtained utilizing a proposed mask design.

The use of specific minimum performance characteristics based upon tracheal partial pressures, as detailed in Part 4b of the Civil Air Regulations (CAR 4b), was in part adopted due to the difficulty involved in accurately measuring and determining alveolar partial pressures and blood oxygen saturation. Since alveolar partial pressure and blood oxygen saturation are directly related and determined by the inspired or tracheal partial pressure, the latter value was chosen as a basis for the regulation.

It is recognized that the alveolar partial pressure and blood oxygen saturation may exhibit a lower or higher value than theoretically calculated from tracheal oxygen partial pressure based upon nitrogen concentration in the mask. However, tracheal oxygen partial pressure was used in order to evaluate the proposed mask design in terms of performance requirements as specified by CAR 4b.

METHOD

The leakage testing technique is based upon a preliminary respiratory washout of pulmonary nitrogen utilizing aviators' oxygen (99.5%) as illustrated in Fig. 1. Following pulmonary nitrogen washout to an asymptotic level, nitrogen entering the system is primarily introduced by inboard leakage of ambient air. Tissue nitrogen elimination is an exception which normally occurs at such a low rate and constitues such a small percent of the continual gas composition

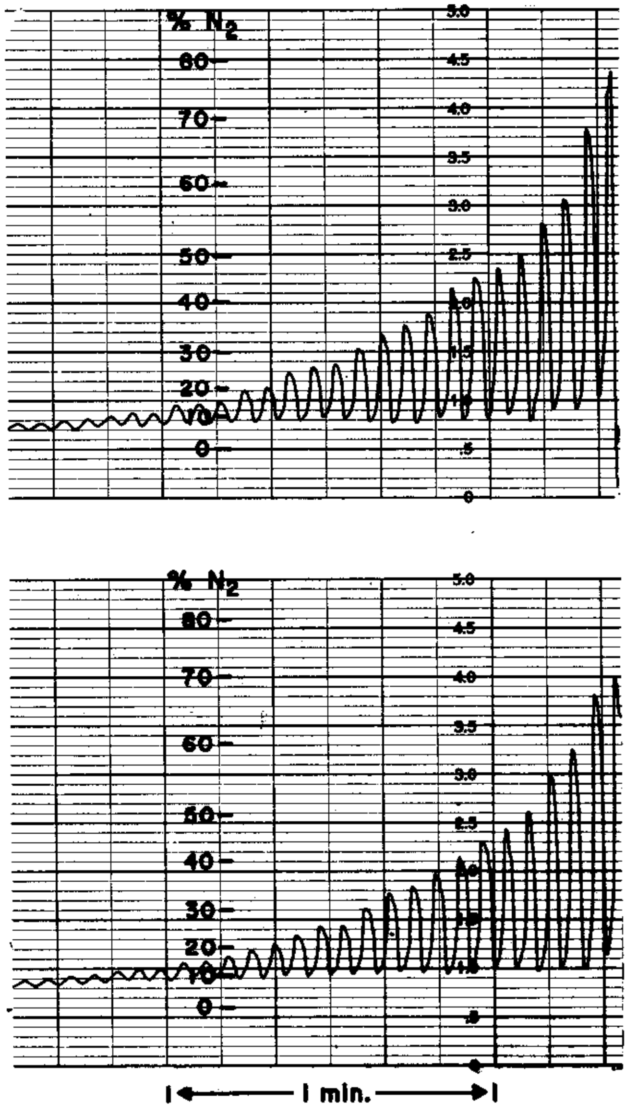

FIGURE 2. Nitrogen washout. Two separate matched and calibrated nitrogen analyzers connected symetrically to the left and right side of crew type oxygen mask. Demand System. Scale 0-100% N_2.

as to be negligible. Crew type oxygen masks and demand regulators were utilized for pulmonary nitrogen washout and the time-course of the recorded nitrogen observed.

EQUIPMENT

Two Custom Engineering and Development Company, Model 300AR, nitralyzers were used in the study. These instruments exhibit an initial response time of 0.024 seconds, 90% response being obtained in 0.044 seconds. At the

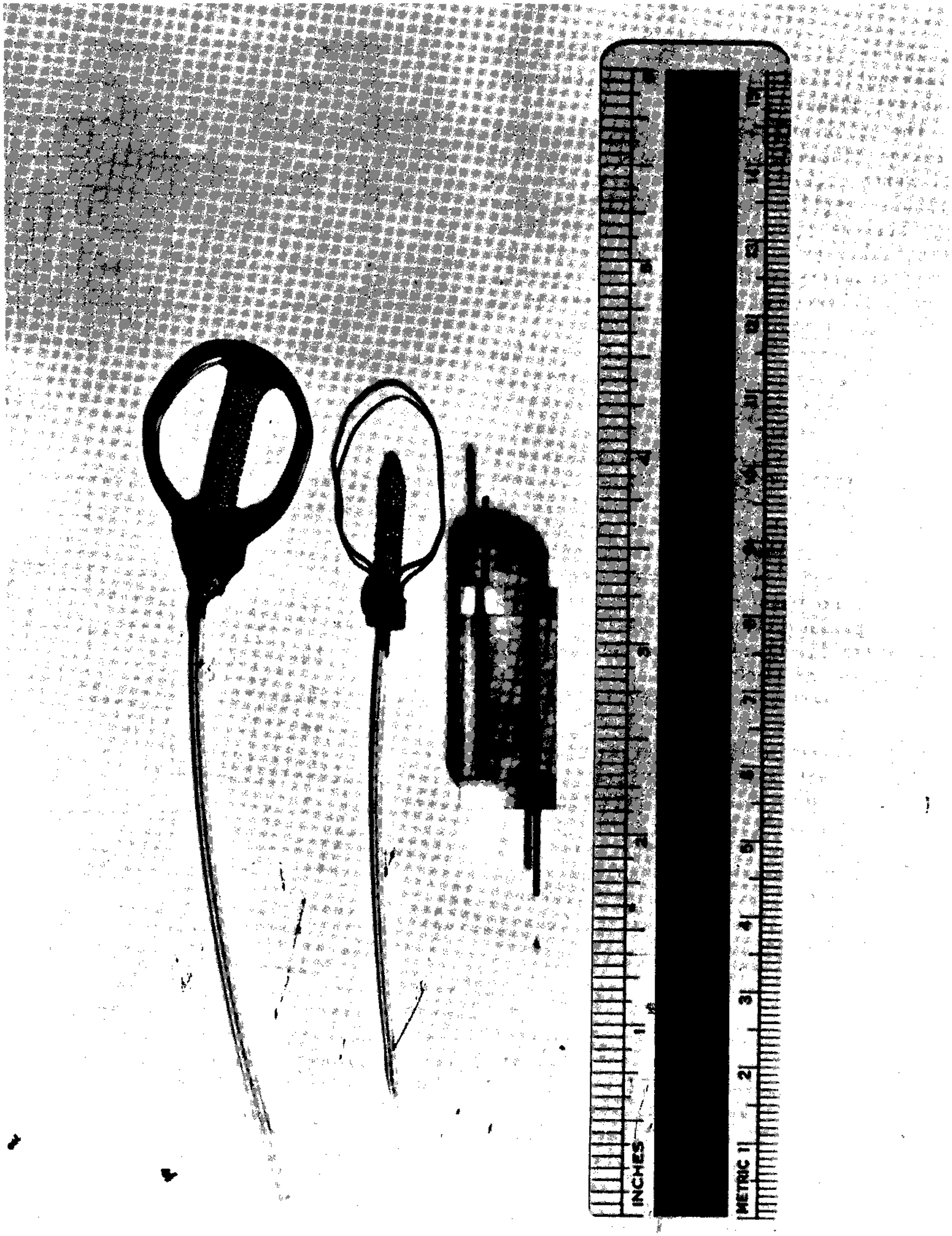

FIGURE 3. Two small nitrogen sampling devices designed for insertion in the nasal cavity and the lucite mixing chamber (integrator).

pressure setting used (0.6 mm. Hg) the sampling rate was 3 cubic centimeters per minute. The continuous sample was drawn through a needle valve and microcatheter tubing (PE 60) of 0.030 inches internal diameter. The small, extremely light-weight microcatheter tubing connected to the mask through the mask wall did not require the addition of signficant weight (thereby influencing the mask fit) or extensive modification of the mask (compromising the operational characteristics of the mask) as may be the case with other types of gas analysis equipment. A typical dual nitralyzer recording of pulmonary nitrogen washout in a subject wearing a crew mask is illustrated in Fig. 2

A small lucite reservoir and mixing chamber, shown in Fig. 3, was designed and added to one analyzer channel. In effect, the chamber integrates the area under the curve of the rapidly changing nitrogen concentration and provides a record of the mean mask nitrogen concentration. The effect on the nitrogen washout may be seen in Fig. 4. Two small sampling devices designed for insertion in the nasal cavities are also shown in Fig. 3 but were not utilized in this study. The microcatheter sampling tube openings were orientated directly over the exhalation valve.

TEST MASK

Known leakage characteristics are frequently incorporated in the design of oxygen masks. Control of tracheal oxygen partial pressure (pO_2) must then take into account oxygen flow rate as related to dilution port size and area, uncontrolled leakage as a result of mask fit, and respiratory activity of the mask wearer.

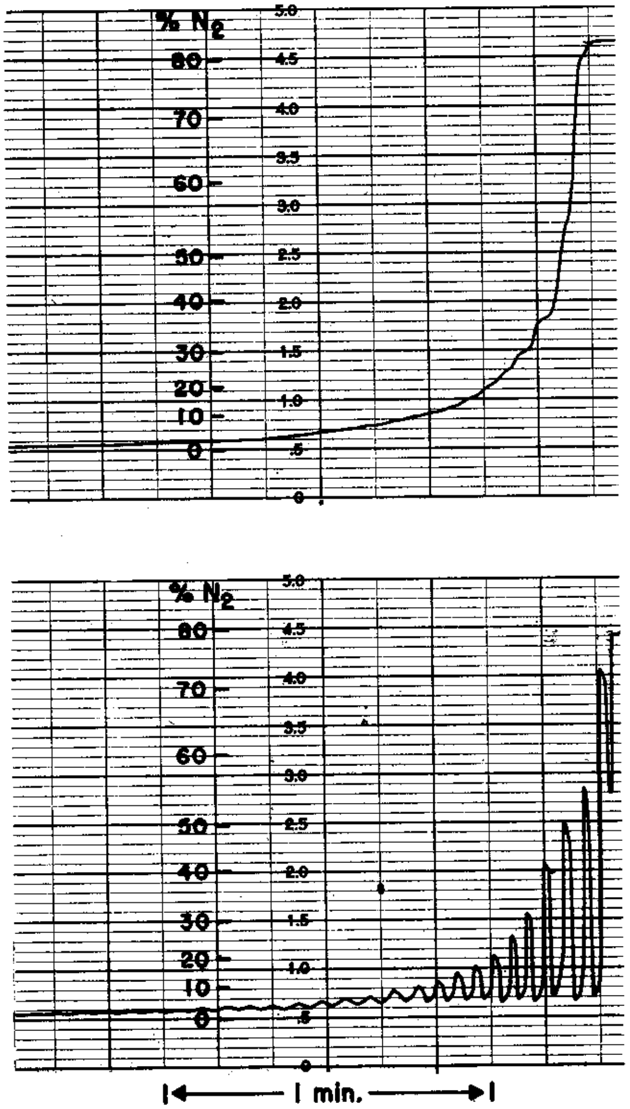

FIGURE 4. Nitrogen washout. Integrator added to system (upper channel). Demand System. Scale 0-100% N_2. Crew oxygen mask.

When nitrogen dilution is not desired and an inspired oxygen concentration of 99.5%+ is required, particular attention must be focused upon providing a sufficient quantity of oxygen to meet instantaneous requirements of the peak inspiratory flow rate. Volume flow during peak inspiration is normally in excess of three times that of the minute volume. To accommodate peak inspiratory flow, several current, constant-flow, oxygen masks utilize a reservoir bag. The function of the reservoir bag is to collect oxygen during the exhalation phase and thereby permit a greater non-diluted inspiratory flow of oxygen than would be possible with a purely constant flow system. A valve normally separates the mask from the reservoir so that the latter does not act as a rebreathing bag. If the mask does not provide a good fit to the face, thereby allowing relatively large areas of leakage to exist as illustrated in Figs. 5 and 6, ambient air will be drawn into the mask through these unobstructed leakage sites instead of from the valved reservoir bag. Under these conditions, the flow dynamics of the system approach those of a purely constant-flow system, since the action of the reservoir bag is functionally retarded by ambient inboard

FIGURE 5. Large leakage area due to incompatibility of mask and facial contours. Subject F-3. Details of the mask are blanked out to preclude compromising the manufacturer's proprietary rights.

Figure 5. Large leakage area due to incompatibility of mask and facial contours. Subject F-3. Details of the mask are blanked out to preclude compromising the manufacturer's proprietary rights.

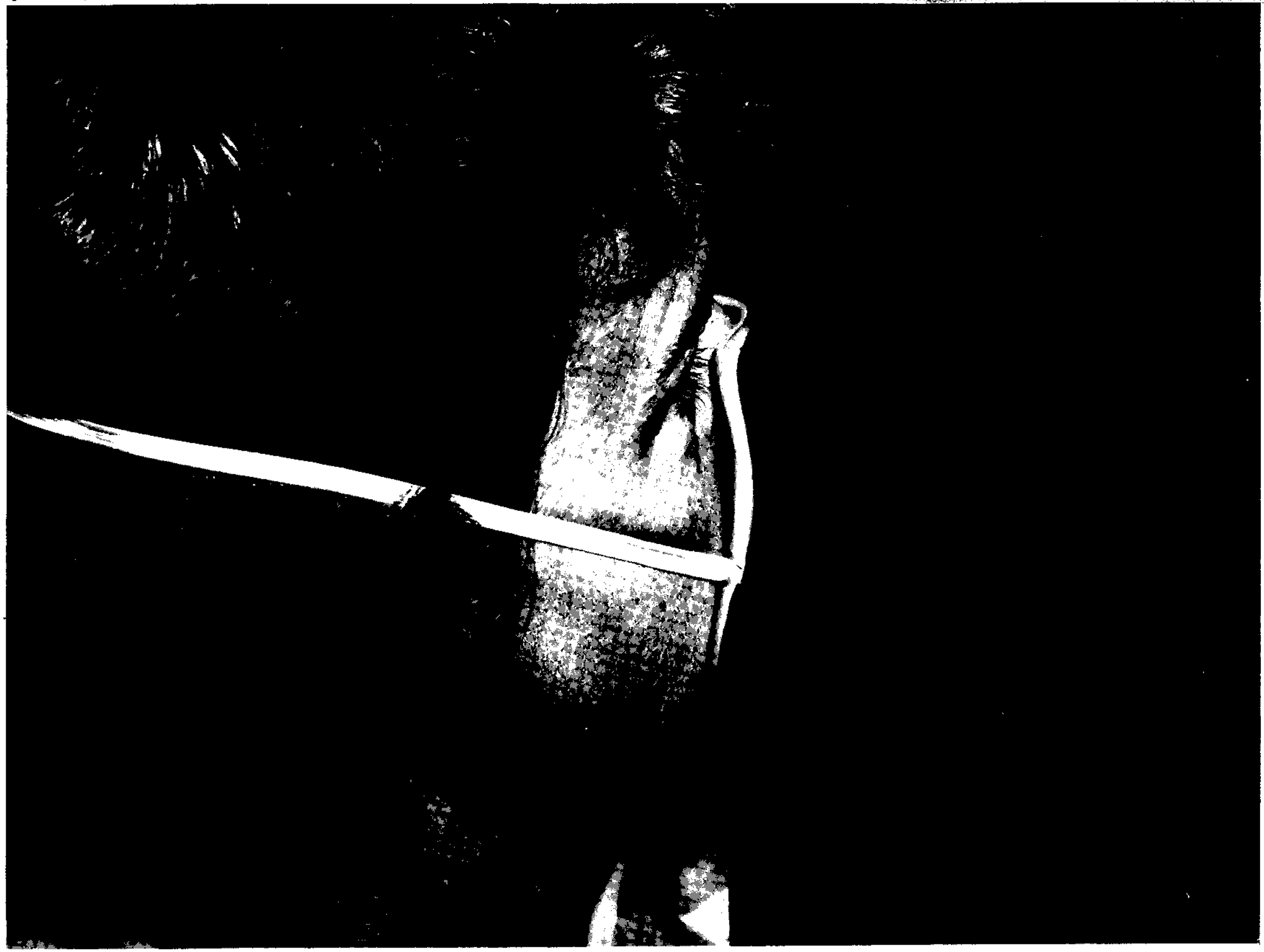

Figure 6. Large leakage area due to incompatibility of mask and facial contours. Subject F-1.

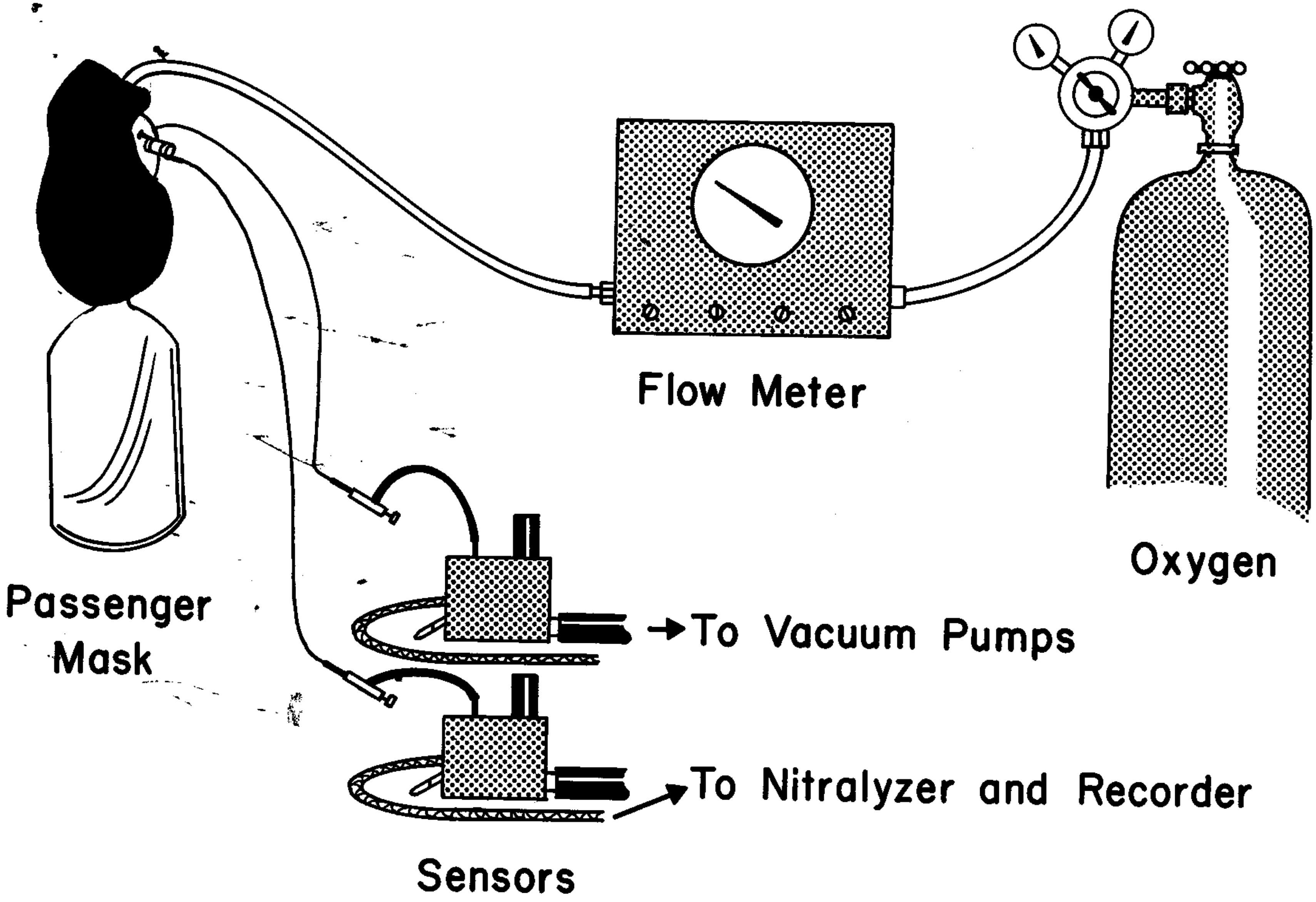

FIGURE 7. Schematic sketch of passenger oxygen mask testing system. Continuous Flow System.

FIGURE 7. Schematic sketch of passenger oxygen mask testing system. Continuous Flow System.

leakage to the extent that the reservoir may act merely as an extension of the supply line. As a consequence, the system may then be unable to furnish the required volume of oxygen demanded at peak inspiratory flow, except at prohibitively large oxygen-supply flow rates.

The test mask used in this study utilized a reservoir bag of light weight plastic film and a mask facepiece constructed of semi-rigid polyethylene.

TECHNIQUE

The preliminary nitrogen washout and subsequent testing is carried out with the subject walking on a treadmill at a slow rate (1.8-2.2 mph). Preliminary nitrogen washout is continued until the curve becomes essentially asymptotic. The curve in a normal, healthy individual becomes flat (slope less than .6) in approximately 5 - 6 minutes or less. Tidal and minute volumes are recorded and the treadmill speed adjusted until the desired respiratory response is obtained as specified for passenger oxygen equipment utilized at altitudes of 18,500 to 40,000 feet (tidal volume of 1100cc, per CAR 4b).

After pulmonary nitrogen washout is accomplished, the subject is instructed to hold his breath following inspiration. During breath-holding, the crew mask is removed, the test mask is donned with oxygen flowing at 30 l/min. BTPS and the test continued as illustrated in Fig. 7 at the activity level previously established. Since in all cases the nitrogen washout equilibrium is at a lower level with the crew masks than with the test masks, the nitrogen concentration recording is observed to climb to a new and greater level. Short sections of nitrogen analysis recordings, during which the subject was wearing the proposed passenger mask, are shown in Fig. 8 and 9.

The oxygen supply flow rate of 30 l/min. BTPS is continued for 5 - 6 minutes and the leakage level determined at equilibration. The oxygen flow is then reduced to 15 l/min. BTPS (per CAR 4b for altitudes of 10,000-18,500 ft.) and the nitrogen recording is again observed to climb and equilibrate at a new and higher level.

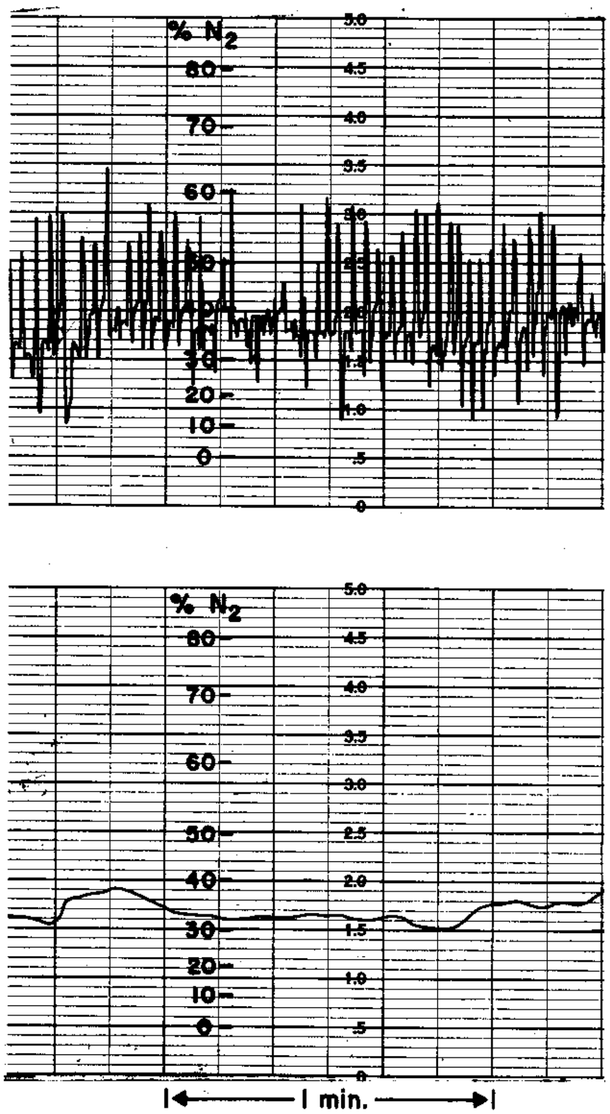

FIGURE 8. Nitrogen analysis recording of subject F-2 wearing the passenger mask. This subject demonstrated the highest mean nitrogen level. Integrator in the lower channel. Oxygen continuous flow 30 l/min. Scale 0-100% N$_2$.

The flow of oxygen is then decreased to the point at which the reservoir bag can be maintained at a volume equilibrium. Oxygen flow is adjusted and equilibrium obtained when the reservoir bag is neither allowed to distend or collapse. If the leakage about the face is low, then the required volume flow of oxygen approaches the minute volume. If, in contrast, the leakage is high about the face with ambient air being drawn into the mask in preference to oxygen from the reservoir bag, then the

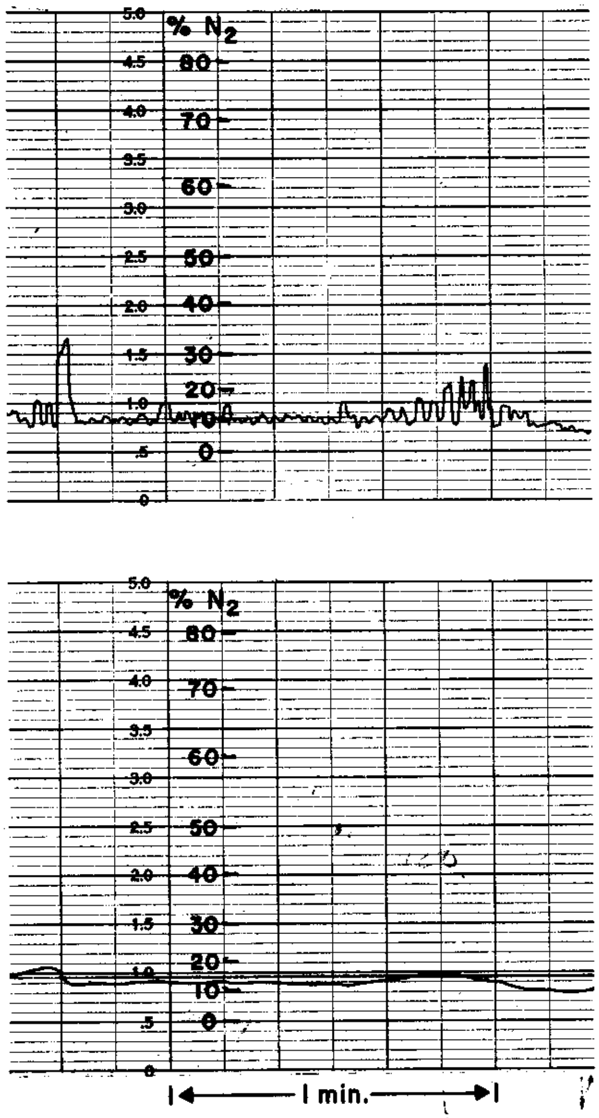

FIGURE 9. Nitrogen analysis recording of subject F-9 wearing the passenger mask. This subject demonstrated one of the lowest mean nitrogen levels. Integrator in the lower channel. Oxygen continuous flow 30 l/min., tidal volume 1100cc, minute volume 14 l/min. Scale 0-100% N_2.

volume flow of oxygen to produce reservoir bag equilibrium may represent only a fraction of the total minute volume. Dual channel recording of the nitrogen concentration was continued throughout the testing procedure.

In order to evaluate the procedure, ten female and ten male subjects wearing the proposed mask design were tested.

In addition, a survey of facial anthropometry was performed on all test subjects by standardized and new measuring techniques. This survey was conducted to obtain reliable and realistic dimensional data to aid in evaluating mask efficiency by establishing significant correlations of facial structure with level of efficiency attained.

A formal statistical treatment of these data was not performed due to the small number of subjects involved.

RESULTS

Adjustment of the tidal volume in female subjects to 1100cc was readily accomplished. Tidal volumes of 1100cc were not readily obtained with male subjects, even when the treadmill speed was reduced to its lowest level (1.8 mph). Apparently, in males (who normally exhibit a larger basal tidal volume than females), even the lowest level of exercise is sufficient to elevate their tidal volumes to values in excess of 1100cc. However, it may be noted in Table 1 that the mean nitrogen concentration of female and male subjects appears to be in close agreement. Total leakage as calculated from the nitrogen composition utilizing the curve developed by Bendix under Contract FA-885[2] is presented in Table 2. Nitrogen concentration and the calculated tracheal pO_2 as related to CAR 4b is presented in Table 3. Nitrogen percentage obtained by analysis, as compared to the nitrogen percentage calculated from the relationship of the oxygen flow required to maintain reservoir equilibrium to the minute volume, is shown in Table 4. Nitrogen concentrations calculated from flow data are less precise and overestimate the values obtained by actual continuous nitrogen analysis.

With the treadmill adjusted to the slowest speed, the tidal volume could not be reduced to the 700cc specified in CAR 4b (for altitudes of 10,000-18,500 ft.). It may be noted in Table 3 that the specified tracheal pO_2 is readily obtained and exceeded (even when a tidal volume of 1100cc is maintained and the oxygen flow reduced to 15 l/min.). Therefore, reduction of the tital volume from the 1100cc to 700cc was not deemed necessary. With the flow rates and tidal volumes specified for the altitude range of 10,000-18,500 feet, the mask provides adequate protection.

It is at the higher altitude range of 18,500-40,000 feet that the principal and critical problem area exists. Comparison in Table 3 of the tracheal pO_2 for an altitude of 40,000 feet to the values specified in CAR 4b indicate that the mask does not provide the minimum tracheal pO_2 as specified, and may not provide adequate protection at this altitude.

DISCUSSION

Observation of the nitrogen recordings made during early stages of this study indicated that excursions of the nitrogen recorder did not necessarily follow the respiratory cycle when a constant flow mask was being tested. In fact, when respiration was experimentally slowed to an abnormally slow rate, two separate peaks were observed; one during inspiration and one during expiration. Consideration of the design characteristics of a constant flow mask provides an explanation of this phenomenon. During inspiration, ambient air containing nitrogen may be drawn into the mask, upper respiratory spaces and lungs through leakage apertures, thus eliciting a spike on the nitrogen recorder. During the subsequent respiratory pause, oxygen flowing through the mask at 30 l/min. (500cc/second) rapidly washes out the relatively small mask dead space and the nitrogen concentration falls. The second, or expiratory peak, occurs as a result of nitrogen previously inspired, since it is not probable that inboard leakage will have occurred during the previous respiratory pause due to the continuous flow of oxygen delivered to the mask. During expiration, the same flow of oxygen is delivered in addition to the expiratory volume thereby eliminating any tendency for a negative pressure to develop within the mask which would permit inboard leakage.

Frequently, very large, isolated nitrogen concentration spikes were observed and were usually associated with some action on the part of the subject, (e.g. talking, moving the head, smiling or coughing). If the nitrogen concentration immediately returned to the previous level following the respiratory pause, then the spike was considered to be insignificant as it was presumed that the nitrogen dilution occurred only in the mask dead space. However, if the spike was followed by a series of slowly descending peaks before the former nitrogen level was reached, it was obvious that a relatively large quantity of nitrogen had reached the lungs and was in the process of being washed out.

Use of the minimum nitrogen concentration for calculation of tracheal pO_2 is not justified since the minimum concentration occurs during the respiratory pause as a result of the constant flow of oxygen washing out the mask dead space. In contrast, utilization of the peak nitrogen concentration is just as unrealistic since maximum nitrogen dilution may occur in the mask dead space. The level of penetration of this nitrogen into the respiratory dead space and lungs may vary.

An integrated mean nitrogen concentration provides a more realistic value although it is consistently lower than the concentration of nitrogen calculated from oxygen flow requirements. A comparison of these two values is shown in Table 4. However, nitrogen analysis remains the more precise method, the oxygen flow data providing only a crude estimate of the nitrogen concentration.

Although the technique investigated provides a valid index of mask leakage per se, additional data must be acquired at altitude. This technique will be applied to a few trained subjects at various simulated altitudes in an altitude chamber. Correlation of nitrogen concentration, mask leakage, and blood oxygen saturation during various levels of respiratory activity will be studied. Information so gained should assist in increasing the accuracy and interpretation of this relatively simple and inexpensive ground level testing technique.

TABLE 1

Nitrogen concentration in passenger masks as measured by continuous analysis at three oxygen flow rates.

	%N_2 at 30 l/m 0_2			*%N_2 at 15 l/m 0_2*			*%N at bag equil.*					
Subject No.	*Mean*	*Peak Min.*	*Peak Max.*	*Mean*	*Peak Min.*	*Peak Max.*	*Mean*	*Peak Min.*	*Peak Max.*	*Flow of O_2 to maintain res. equil.*	*Min. vol. (BTPS) l/m*	*Tidal vol. (BTPS) cc.*
F-1	10	8	20	20	12	43	36	26	43	5.3 l/m	16.4	1100
F-2	30	10	63	49	22	66	64	56	71	1.8 l/m	21.0	1100
F-3	11	5	51	38	11	60	57	41	69	5.6 l/m	18.7	1100
F-4	22	10	62	38	22	54	46	32	68	5.6 l/m	21.0	1100
F-5	11.5	1	16.5	17.5	5.5	28	20	10	56	10.0 l/m	19.9	1100
F-6	22	8	60	45	18	70	56	35	73	5.6 l/m	21.0	1100
F-7	14	11	37	21	17	30	28	20	32	8.5 l/m	12.8	1100
F-8	12	8	23	36	8	70	26	7	57	11.1 l/m	19.9	1100
F-9	9	8	33	30	17	40	34	20	53	7.0 l/m	16.4	1000
F-10	16	5	27	29	6	60	49	31	55	7.0 l/m	17.5	1000
Mean Female Subjects	**15.7**			**32.3**			**41.6**			**6.7**	**18.5**	
M-11	8	5	56	18	7	64	22	11	54	9.8 l/m	17.5	1500
M-12	9	8	23	27	15	38	45	26	65	5.6 l/m	14.0	1500
M-13	24	8	38	43	10	65	51	34	68	5.6 l/m	23.4	1500
M-14	13	8	33	26	12	58	52	32	66	3.7 l/m	19.9	1400
M-15	22	9	63	33	16	55	53	23	73	3.7 l/m	19.9	1500
M-16	12	5	56	22	9	45	32	12	46	6.7 l/m	21.0	1400
M-17	10	1	19	25	13	46	42	22	58	5.6 l/m	25.7	1200
M-18	18	7	43	38	10	40	48	30	57	3.7 l/m	25.7	1100
M-19	6	5	34	20	10	48	42	19	70	3.7 l/m	16.4	1500
M-20	22	3	44	26	4	63	27	8	53	12.3 l/m	23.4	1700
Mean Male Subjects	**14.4**			**27.8**			**41.4**			**6.0**	**20.7**	
Mean All Subjects	**15.0**			**30.0**			**41.5**			**6.4**	**19.6**	

Subjects 15.0 30.0 41.5 6.4 19.6

TABLE 2

Total leakage in passenger masks as calculated from continuous nitrogen analysis data in Table 1.

Subject No.	%Lkg at 30 *l/m* O_2 Mean	%Lkg at 30 *l/m* O_2 Peak Min.	%Lkg at 30 *l/m* O_2 Peak Max.	%Lkg at 15 *l/m* O_2 Mean	%Lkg at 15 *l/m* O_2 Peak Min.	%Lkg at 15 *l/m* O_2 Peak Max.	%Lkg at bag equil. Mean	%Lkg at bag equil. Peak Min.	%Lkg at bag equil. Peak Max.	Flow of O_2 to maintain res. equil.	Min. vol. (BTPS) *l/m*	Tidal vol. (BTPS) *cc.*
F-1	12.9	10.3	25.8	26	15	55	46	34	55	5.3 l/m	16.4	1100
F-2	39	12.9	81	63	28	85	83	72	92	1.8 l/m	21.0	1100
F-3	14	6	66	49	14	77	74	53	89	5.6 l/m	18.7	1100
F-4	28	12.9	80	49	28	70	59	41	88	5.6 l/m	21.0	1100
F-5	15	1	21	23	7	36	26	13	72	10.0 l/m	19.9	1100
F-6	28	10	77	58	23	90	72	45	94	5.6 l/m	21.0	1100
F-7	18	14	48	27	22	39	36	26	41	8.5 l/m	12.8	1100
F-8	15	10	30	46	10	90	34	9	74	11.1 l/m	19.9	1100
F-9	12	10	43	39	22	52	44	26	68	7.0 l/m	16.4	1000
F-10	21	6	35	37	8	77	63	40	71	7.0 l/m	17.5	1000
Mean Female Subjects	**20.2**			**41.7**			**53.7**			**6.7**	**18.46**	
M-11	9	6	72	23	9	83	28	14	70	9.8 l/m	17.5	1500
M-12	12	9	30	35	19	49	58	34	84	5.6 l/m	14.0	1500
M-13	31	9	49	55	13	84	66	44	88	5.6 l/m	23.4	1500
M-14	17	9	43	34	15	75	67	41	85	3.7 l/m	19.9	1400
M-15	28	12	81	43	21	71	68	30	94	3.7 l/m	19.9	1500
M-16	15	6	72	29	12	58	41	15	59	6.7 l/m	21.0	1400
M-17	13	1	25	32	17	59	54	28	75	5.6 l/m	25.7	1200
M-18	23	9	55	49	13	52	62	40	74	3.7 l/m	25.7	1100
M-19	8	6	44	26	13	62	54	25	90	3.7 l/m	16.4	1500
M-20	28	4	57	34	5	81	35	10	68	12.3 l/m	23.4	1700
Mean Male Subjects	**18.4**			**36.0**			**53.3**			**6.0**	**20.7**	
Mean All Subjects	**19.3**			**38.8**			**53.5**			**6.4**	**19.6**	

TABLE 3

Mean mask nitrogen concentrations obtained by continuous analysis and the tracheal P_{O_2} derived by $P_{T_{O_2}} = (B - 47)\ F_{I_{O_2}}$

	30 l/m Flow O_2		*±83.3 mm/Hg*	*15 l/m Flow O_2*		*±100/Hg*	
Subject No.	*% N_2 (Mean)*	*Calc. $P_{T_{O_2}}$ 40,000 ft.*	*$P_{T_{O_2}}$ CAR 4b*	*% N_2 (Mean)*	*Calc. $P_{T_{O_2}}$ 18,500 ft.*	*$P_{T_{O_2}}$ CAR 4b*	*Tidal vol. (BTPS) cc.*
F-1	10	84.8	+ 1.5	20	260	+160	1100
F-2	30	65.9	−17.4	49	166	+ 66	1100
F-3	11	83.8	+ 0.5	38	201	+101	1100
F-4	22	73.5	− 9.8	38	201	+101	1100
F-5	11.5	83.3	± 0	17.5	267	+167	1100
F-6	22	73.5	− 9.8	45	179	+ 79	1100
F-7	14	81.0	− 2.3	21	257	+157	1100
F-8	12	83.0	− 0.3	36	208	+108	1100
F-9	9	86.0	+ 2.7	30	227	+127	1000
F-10	16	79.0	− 4.3	29	231	+131	1000
Mean Female Subjects	**15.7**	**79.4**		**32.3**	**219**		
M-11	8	86.6	+ 3.3	18	266	+166	1500
M-12	9	85.7	+ 2.4	27	237	+137	1500
M-13	24	71.6	−11.7	43	185	+ 85	1500
M-14	13	81.9	− 1.4	26	240	+140	1400
M-15	22	73.5	− 9.8	33	218	+118	1500
M-16	12	83.0	− 0.3	22	253	+153	1400
M-17	10	84.8	+ 1.5	25	244	+144	1200
M-18	18	77.2	− 6.1	38	235	+135	1100
M-19	6	88.5	+ 5.2	20	260	+160	1500
M-20	22	73.5	− 9.8	26	240	+140	1700
Mean Male Subjects	**14.4**	**80.6**		**27.8**	**237**		
Mean All Subjects	**15.0%**	**80.0**		**30.0%**	**224**		

TABLE 4

Comparison of nitrogen and leakage values calculated from oxygen flow data to nitrogen analyzer data

Subject No.	O_2 flow to maintain bag equil.	Min. vol. (BTPS) l/m	% Nitrogen Calculated*	% Nitrogen From N_2 Analyzer	% Leakage Calculated**	% Leakage From N_2 Analyzer
F-1	5.3 l/m	16.4	54	36	67.7	83
F-2	1.8 l/m	21.0	73	64	91.4	74
F-3	5.6 l/m	18.7	56	57	70.0	59
F-4	5.6 l/m	21.0	59	46	73.3	46
F-5	10.0 l/m	19.9	40	20	49.7	26
F-6	5.6 l/m	21.0	59	56	73.3	72
F-7	8.5 l/m	12.8	27	28	19.5	36
F-8	11.1 l/m	19.9	35	26	44.2	34
F-9	7.0 l/m	16.4	46	34	57.3	44
F-10	7.0 l/m	17.5	48	49	50.0	63
Mean Female Subjects	**6.7**	**18.46**	**49.7**	**41.6**	**60.6**	**53.7**
M-1	9.8 l/m	17.5	35	22	44.0	28
M-2	5.6 l/m	14.0	48	45	60.0	58
M-3	5.6 l/m	23.4	61	51	76.0	66
M-4	3.7 l/m	19.9	65	52	81.4	67
M-5	3.7 l/m	19.9	65	53	81.4	68
M-6	6.7 l/m	21.0	54	32	68.0	41
M-7	5.6 l/m	25.7	62	42	78.2	54
M-8	3.7 l/m	25.7	68	48	85.6	62
M-9	3.7 l/m	16.4	62	42	77.4	54
M-10	12.3 l/m	23.4	38	27	47.4	35
Mean Male Subjects	**6.0**	**20.7**	**55.8**	**41.4**	**69.9**	**53.3**
Mean All Subjects	**6.4**	**19.6**	**52.7**	**41.5**	**65.3**	**53.5**

$*V_{N2} = MV - V_{EQ} \times .8 \quad N_2 = \frac{V_{N2}}{MV}$

Volume of N_2 (V_{N2}) = volume of ambient air × 80%

Volume of ambient introduced to mask = minute volume (MV) — volume of oxygen suplied to maintain reservoir bag equilibrium (V_{EQ})

$$\%N_2 = \frac{\text{Volume of } N_2\ (V_{N2})}{\text{Minute Volume (MV)}}$$

$**V_L = MV - V_{EQ}$

Volume of ambient leakage (V_L) = minute volume (MV) — the volume of oxygen supplied to maintain reservoir bag equilibrium (V_{EQ})

$$\text{Per cent leakage } (\%L) = \frac{\text{volume of ambient leakage } (V_L)}{\text{minute volume (MV)}}$$

REFERENCES

1. White, C. S., Lovelace, W. R., Clark, J., and Hirsch, F. G., "Recent Advances of Instrumentation of Interest in Aviation Medicine" *in Collected Papers on Aviation Medicine,* Butterworth's Scientific Publications, p. 96, 1955.

2. *Final Report on The Investigation of Mask Leakage in Passenger Oxygen Masks,* Pioneer-Central Div., The Bendix Corporation, FAA Contract Number FA-885, 8 Feb. 1962.