AM 66-7

EVALUATION OF THE PHYSIOLOGICAL PROTECTIVE EFFICIENCY OF A NEW PROTOTYPE DISPOSABLE PASSENGER OXYGEN MASK

Ernest B. McFadden, M.S.

Approved by

J. Robert Dille

J. Robert Dille, M.D.
Chief, Civil Aeromedical Institute

Released by

PV Siegel MD

P. V. Siegel, M.D.
Federal Air Surgeon

April 1966

FEDERAL AVIATION AGENCY
Office of Aviation Medicine

ACKNOWLEDGMENTS

The author wishes to acknowledge the assistance provided by C. M. Brake, M.D.; H. F. Harrison; J. M. Simpson; J. W. Fitch, and F. F. Winters. In addition, acknowledgement is due B. Hansford, D. H. Grimm, and G. Gish of the Aerospace Division of the Puritan Equipment Company for their cooperation and assistance.

Qualified requestors may obtain Aviation Medical Reports from Defense Documentation Center. The general public may purchase from Clearinghouse for Federal Scientific and Technical Information, U.S. Dept. of Commerce, Springfield, Va. 22151

EVALUATION OF THE PHYSIOLOGICAL PROTECTIVE EFFICIENCY OF A NEW PROTOTYPE DISPOSABLE PASSENGER OXYGEN MASK

I. Introduction.

This report describes altitude chamber experiments conducted with human subjects using new Puritan protype disposable passenger oxygen masks applicable for emergency use to 40,000-foot altitudes.

The specific functional characteristics of continuous-flow oxygen masks in terms of human respiration are frequently not well understood. Although less costly to manufacture than a crew mask and deceptively simple in appearance, the continuous-flow passenger mask involves physiological performance characteristics that are relatively complex. Continuous-flow masks may be generally divided into the following categories.

A. Rebreathing Mask. A manual or automatic continuous flow of oxygen is delivered to the mask. A fraction of the expired gas from the dead spaces of the mouth and trachea that contain unused oxygen and air is collected and inspired as a part of the next inhalation. The remainder of gas required is obtained either from the oxygen supply or from dilution ports or valves. If the oxygen flow is excessively low or the respiratory pattern modified, the rebreathed gas may contain significant quantities of carbon dioxide from the lungs.

B. Continuous flow dilutor mask. As in the above mask, a continuous flow of oxygen is delivered manually or automatically. Dilution of oxygen by air occurs in the mask by use of orifices of a predetermined diameter or through a porous material. This mask, if not equipped with a reservoir bag, wastes oxygen since the flow must be sufficiently high to provide the volume required during the peak flow of inspiration. The flow that continues during the respiratory pause and exhalation phase is vented to the ambient atmosphere and wasted.

C. Continuous-flow reservoir mask. As in the previous masks, oxygen is delivered in a continuous flow; however, a reservoir is interposed between the delivery tube and the mask. The reservoir is separated from the mask by a sensitive check valve. The continuous flow of oxygen fills the reservoir bag during the respiratory pause and exhalation. The flow also continues at the same rate during inspiration. The mask wearer inspires and receives the 100% oxygen content of the reservoir until inspiration is complete or the bag emptied or both. If the reservoir is emptied, a spring-loaded valve in the mask opens, and ambient air is introduced in order to provide sufficient volume to meet the remainder of the inspiration. The flow of 100% oxygen is provided at the most advantageous point in the respiratory cycle; that is, at the beginning of inspiration. For example, if a human subject's tidal volume is 500 cc and the reservoir contains only 350 cc at the beginning of inspiration, the 350 cc of 100% oxygen will be inspired first and delivered to the active areas of the lungs. The ambient air valve will then open and deliver 150 cc of air, which will enter the mouth, trachea, and other "dead" or inactive spaces of the respiratory system. Upon expiration, this dead-space air is the first to exit through the exhalation valve. This is repeated with each respiratory cycle. In practice, the reservoir bags normally are capable of containing a maximum of 1,100 cc which, along with the volume introduced by the continuing flow, provide for increased tidal and minute volumes. It may be readily seen that this type of mask offers the following advantages:

1. Oxygen economy is afforded by use of a reservoir bag that fills and retains the oxygen flow during the respiratory pause and exhalation, allowing for the use of lower flow rates.

2. Reduced oxygen flow rates at lower altitudes may be utilized, providing air-dilution of oxygen in a more predictable and controlled manner.

3. Oxygen concentrations approaching 100%, which are required at 35,000 to 40,000 feet, may be obtained with moderate and reasonable flow rates.

One basic disadvantage of all continuous-flow oxygen systems is their inability to adjust automatically to the respiratory changes associated with changes in emotional and physical activity of the wearer.

A healthy young male breathing air at rest normally exhibits an approximate (volume/breath) tidal volume of 550 cc and a minute volume (volume/minute) of 7,700 cc, or 7.7 liters. Emotional or physical activity, or both, may cause values to increase greatly.

Concern with the problem is reflected in the Federal Aviation Regulation Part 25 (formerly Part 4b) 25.1443[1] which requires maintenance of a mean tracheal oxygen partial pressure of 83.8 mm Hg at a tidal volume of 1,100 cc, and a 30-liter body temperature pressure saturated, (BTPS) minute volume for altitudes of 18,500 to 40,000 feet.

With the introduction of jet-transport passenger aircraft certified to operate at high altitudes, new oxygen systems and masks were formulated and evaluated.[2,3]

Subsequently, standards for passenger oxygen masks were compiled and published. The National Aerospace Standard 1179[4] and Federal Aviation Agency Technical Standard Order C–64[5] set forth manufacturing, material, and testing standards for passenger oxygen masks.

An excellent description of the basic physiology of oxygen in aircraft as related to oxygen equipment design has been prepared by the SAE A–10, Aircraft Oxygen Equipment Committee.[6]

An additional report describes the basic criteria and design philosophy of jet transport passenger systems.[7]

II. Methods.

The altitude chamber flight profile is shown in Figure 1. (All figures and tables are in the appendix.) Six subjects were instrumented as shown in Figure 2, with the exception that the mask was not donned until air-breathing baselines were established at 10,000 and 14,000 feet. A chamber safety observer accompanied each subject.

After a preliminary test of the subject's capability to equalize ear pressures, the subject rested quietly at 10,000 feet until ear oximeter readings indicated a stabilization of blood saturation. The chamber then ascended to 14,000 feet to establish a similar baseline at this altitude.

When it appeared the blood saturation had stabilized at 14,000 feet, the subject donned a crew-type demand oxygen mask and commenced breathing 100% oxygen. Immediately following crew-mask donning, exercise on a bicycle ergometer was initiated. The exercise level in rpm (speed) and watts (load) was increased or decreased to stimulate and obtain the desired respiratory activity (approximately 25 to 30 liters/minute). This is regarded as a light to moderate work load approximately equivalent to walking at 3.0 to 3.5 mph.

Exercise was continued until the desired minute volume as indicated by a dry gas meter was obtained and stabilized. A mass flowmeter located in the mask hose also sensed and recorded the inspired tidal and minute volumes of the subject. The output of the mass flowmeter was fed into an integrator so that, when a predetermined volume was sensed, the unit would discharge and repeat. The subjects were denitrogenated during this period in an attempt to attenuate the increased bends potential due to exercise at the subsequent higher altitudes to be attained.

Continuing the exercise at the baseline level, the subject removed the crew mask and rapidly donned the Puritan prototype passenger mask (Part Number 11401902) as shown in Figure 3. The flow of oxygen to the mask was regulated by an altitude-sensitive regulator of the type used in multipassenger oxygen systems of transport aircraft. The flow from this regulator, instead of being transmitted directly to the subject, was first routed outside the chamber through a flowmeter and needle-valve arrangement in order to obtain precise measurement and control of the flow (Figure 3).

The subject continued to exercise at the predetermined level as the altitude was increased to 40,000 feet. The chamber was leveled off and readings were taken at 14,000, 21,500, 29,000, 35,000, and 40,000 feet.

Two Custom Engineering and Development Company Model 300AR nitralizers were used to continuously measure the mask nitrogen. These instruments exhibit an initial response time of 0.024 second, 90% response being obtained in 0.044 second. At the pressure setting used (0.6

mm Hg) the sampling rate was 3 cc per minute. The continuous sample was drawn through a needle valve and microcatheter tubing (PE 60) of 0.030 inch internal diameter. The small, extremely lightweight, microcatheter tubing connected to the mask did not require addition of significant weight or extensive modification of the mask, factors that might compromise the fit and operational characteristics of the mask. An integrator consisting of a small lucite reservoir and mixing chamber was interposed in the sampling tube near the mask as shown in Figures 2 and 3. In effect, this chamber integrates the area under the curve of the rapidly changing nitrogen concentration and provides a record of the mean mask nitrogen concentration.

The tracheal-oxygen partial pressure is calculated from the nitrogen data as follows:

$$P_{T_{O_2}} = (B\text{-}47)F_{I_{O_2}}$$

Where:

$P_{T_{O_2}}$ = Tracheal oxygen partial pressure
B = Ambient barometric pressure
47 = Vapor pressure of H_2O at body temperature (37°C) and 100% saturation

And:

$F_{I_{O_2}} = 1.0 - F_{I_{N_2}}$
$F_{I_{O_2}}$ = Fraction of inspired oxygen
1.0 = Unity
$F_{I_{N_2}}$ = Fraction of Nitrogen inspired

For a more detailed account of this technique consult references 8 and 9.

A Waters Conley ear oximeter Model XE–60A was affixed to the pinna of the subject's ear 10 to 15 minutes prior to the flight in order to allow warming and stabilization. The output of the earpiece was fed into an Electronics for Medicine oximeter amplifier and could be monitored on a panel meter and oscilloscope.

Ear-oximeter results were recorded on a 14-channel Visicorder continuously throughout the chamber flight.

The signal from EKG electrodes was split and fed into an EKG monitor and cardiotachometer. Both of these signals were recorded on the Visicorder.

The output from the impedance pneumograph electrodes was fed into a Physiograph impedance pneumograph preamplifier and recorded on the Visicorder.

The impedance pneumograph was included in the experiment to attempt to determine if changes in the respiratory activity baseline occurred during subsequent ascent to altitude. At the present time, there is no satisfactory method of measuring respiratory volumes and activity while wearing a passenger mask without compromising the performance of the mask. A typical tracing is reproduced in Figure 4. The upper tracing shows the electrocardiograph (EKG), ear oximeter (S), altitude (A), impedance pneumograph (I), cardiotachometer (C), and mass flowmeter (V). The EKG in the lower tracing is erratic due to faulty electrode conductivity, and, therefore, the cardiotachometer is rendered inoperative. The calibrations along the left margin are approximate. For more accurate readings refer to the tables.

Motion pictures were taken of the subjects during the maximum altitude portion of the flights.

Closed-circuit television was also used as an aid to observe the activity and condition of the subjects at all times.

III. Results.

The oxygen flow of the passenger mask NTPD (normal temperature pressure dry 70° –760 mm – dry) and BTPS (body temperature pressure saturated, 37° – ambient – saturated) is shown in Table 1. The flow to the first two subjects (J. T. and B. R.) was established at higher rates than for subsequent subjects since this was the first use of the mask at altitude by human subjects. Subsequent flows to the remaining subjects were reduced to values approximately those provided by current jet transport systems. Minute and tidal inspired volumes during establishment of the exercise baseline at 14,000 feet are presented in Table 1. These volume measurements were obtained using both the mass flowmeter and dry gas meters. The dry gas meter readings are considered to be the more accurate of the two methods. Electronic problems associated with the mass-flowmeter integrator may have accounted for the discrepancy between these two determinations. Unfortunately the dry-gas meter readings of the first two subjects were not recorded, but the meter was monitored and the work load increased until a minute volume of approximately 25 liter minute was attained.

The first subject experienced Grade 1 bends in his right knee at 35,000 feet. This condition was not relieved by discontinuing the exercise. Reduction in altitude, however, relieved the condition. The remaining portion of this flight to 40,000 feet was cancelled.

The tidal volume of subject D. D. appeared abnormally high during exercise. This subject has previously demonstrated a very large vital capacity and was breathing very deeply at approximately one-half the normal resting respiratory rate.

The impedance pneumograph factor in Table 1 is the ratio by which the mean amplitude varies from unity, which was for the purpose of these tests established at 14,000 feet wearing the passenger mask. When attempting to assess this factor, one must keep in mind that the respiratory frequency, which increased with altitude, also affects minute or ventilation volume per unit of time, providing the tidal volume remains constant.

The electrocardiograph and cardiotachometer indicated an increast in heart rate at the maximum altitude attained. There was also a predictable increase of heart rate with exercise (Table 2).

The National Aerospace Standards (NAS) recognized gas analysis and blood-oxygen-saturation determination as the two principal alternate methods to be used in altitude-chamber evaluations of passenger masks.

In this study, the experiments were so designed that both of these parameters were measured simultaneously.

The tracheal oxygen partial pressures and ear oximetry data are summarized in Table 2.

A more detailed summary of the ear oximetry data is presented in Table 3.

Exercise time prior to ascending to altitude was held to a minimum in order to reduce the potential development of bends and reduce fatigue. Therefore the air-breathing baselines at 10,000 and 14,000 feet were carried out under resting conditions.

The NAS standard states that the baselines established at 10,000 and 14,000 feet should be conducted with the subject engaged at the same level of activity as during the altitude tests.

In order to investigate this factor, five air-breathing subjects were exposed to an altitude of 14,000 feet while resting and also exercising at the predetermined baseline level (Table 4).

These tests indicated that exercise reduced the air-breathing baseline ear oximeter reading by an average of 4.9%.

It would appear, therefore, that the resting, air-breathing baselines determined in conjunction with the altitude-exercise experiments may be approximately 5% too high and should be reduced by this factor for valid comparison.

Tracheal-oxygen partial pressure, blood-oxygen saturation and oxygen flow as related to the flight-altitude profile are plotted for each subject in Figures 5, 6, and 7.

IV. Discussion.

Previous passenger-mask, high-altitude evaluations have been carried out with the subjects in a resting or sedentary condition. In some previous evaluations, a brief episode of voluntary hyperventilation was carried out in order to elevate minute volume to 30 liters/minute. This procedure is recommended in NAS 1179, but it is practically impossible for a sedentary subject to maintain this level of respiration for more than 2 to 3 minutes without experiencing severe symptoms of hypocapnia (dizziness, paraesthesia, muscular cramps, etc.). In addition, the reduction of alveolar pCO_2 unrealistically provides for an increased alveolar pO_2. Drastic changes in blood chemistry and cerebral blood flow due to hyperventilation also detract from its usefulness in mask evaluations.

A controlled and measured work load was used in these experiments in order to stimulate respiration to the 30 liters/minute standard without imposing severe changes in respiratory and blood-gas composition and chemistry.

It is admitted that the increased work load produces an increase in oxygen consumption. The level of work load used in these experiments should produce an increase in oxygen consumption of approximately 350 to 500 cc above the resting value.[10]

One disadvantage of using exercise in mask evaluations at altitude is the increased susceptibility to the development of bends. The degree of denitrogenation, altitude profile, and exposure time must be carefully considered in relation to the use of exercise.

The increased minute and tidal volumes developed during exercise impose mask-performance efficiency requirements in excess of similar evaluations conducted on the sedentary resting subject. In an altitude experiment of this type using jet transport flow rates, inboard mask leakage can only be determined at the 40,000-foot level. At altitudes below 40,000 feet, the reduced oxygen flow into the mask is diluted by introduction of air through the ambient air valve following depletion of oxygen in the reservoir bag.

At 40,000 feet, 3.6 liters/minute NTPD equals 30.6 liters/minute BTPS. A subject breathing 30.6 liters/minute or less will not empty the reservoir bag and draw in air through the ambient air valve, if the mask provides a good seal to the face.

If, however, there are significant and uncontrolled openings around the periphery of the mask, ambient air may be drawn into the mask during peak inspiration rather than through the check valve of the reservoir bag.

The percent of leakage may be calculated from the nitrogen data by applying appropriate corrections for the oxygen in the ambient air.[8,9]

The mean nitrogen concentration in the mask at 40,000 feet averaged 3.4% and never exceeded 5.0%. The mean tracheal-oxygen partial pressures of all subjects at 40,000 feet exceeded the air-breathing baselines established at 14,000 feet. In addition, mean tracheal-oxygen partial pressure of all subjects remained well above the 100 mm (10,000 to 18,500 feet) and 83.8 mm (18,500 to 40,000 feet) requirements of the Federal Aviation Regulations.[1]

The ear-oximeter determinations were more variable than the mean tracheal-oxygen partial pressures.

This wandering fluctuation of the ear oximeter was pronounced during resting and air breathing at 14,000 feet, become more stable with 100% oxygen and exercise at 14,000 feet, and was exhibited to a marked degree at 40,000 feet on oxygen (Figure 4).

In general, the ear-oximeter readings appeared to be more stable during exercise than at rest.

The ear-oximeter readings of subject E. Mc. in Table 2 were the minimum values recorded and may reflect the effect of a transient dip in saturation at 40,000 feet (Figure 4).

The ear-oximeter tracing of subject H. H. indicated a progressive drop of saturation at 40,000 feet that was not reversed by increased oxygen flows. The subject did not exhibit symptoms of hypoxia commensurate with the indicated blood-oxygen saturation. It appeared therefore that the ear oximeter was in error.

The nitralizer method of determining tracheal oxygen partial pressure appears to be a superior mask evaluation technique when compared to the ear-lobe oximeter blood-oxygenation method. It is admitted that the maintenance of an adequate blood-oxygen saturation is the desired end result. Instrumentation artifacts and variations in the physiological response of the mask wearer may result in considerable variation in the ear-oximetry indications of blood-oxygen saturation.

The function of the mask is to deliver sufficient oxygen to produce an adequate tracheal partial pressure. Since pressure breathing is not involved in passenger systems, the mask cannot provide partial pressures in excess of those provided by a 100% concentration of oxygen. A hypothetical leakfree mask providing 100% oxygen throughout inspiration has obtained maximum efficiency. The resulting oxygen partial pressure therefore becomes merely a function of the ambient barometric pressure.

It is suggested therefore that the evaluation of the mask should be primarily based upon the efficiency of the mask in providing an adequate partial pressure.

This does not mean that a determination of the blood-oxygen saturation is not important but, until the variability of individual wearer's physiological response can be reduced and techniques for indirect determination of blood oxygen saturation can be improved, mask evaluation should be primarily based on tracheal partial-pressure determinations. It is desirable that the measurements be supplemented by blood-oxygen saturation and other physiological determinations indicative of hypoxia.

The mask during various phases of the respiratory cycle contains oxygen introduced by continuous flow and the reservoir bag reserve. In addition, nitrogen from the ambient air due to leakage or dilution, or both, may be present as well as carbon dioxide in the expired air. It would appear that the carbon dioxide would have a significant effect on the calculated tracheal partial pressure; however, since the dead space of the mask is very small (100 cc) and the oxygen flow at critical altitudes through the mask very high (30,000 cc/minute) during expiration and the subsequent pause, the carbon dioxide of the expired gas is rapidly washed from the mask.

If one assumes, for example, that the mask wearer is receiving an oxygen flow rate of 30 liters/minute, the oxygen flow through the mask during exhalation would approximate 500 cc/second, rapidly washing the carbon dioxide from the mask dead space.

A control experiment at 14,000 feet breathing air and exercising indicated that the baseline resting blood-oxygen saturations at an altitude of 14,000 feet in Tables 2 and 3 and Figures 5, 6 and 7 were approximately 5% too high for valid comparison and should be corrected accordingly.

The discrepancy between constant-altitude experiments as presented in this report and the dynamic physiological changes that occur during a rapid decompression as related to protective efficiency of passenger masks have never been completely resolved. Experiments have been conducted in this area by Bryan and Donaldson[11,12] in an effort to bridge this gap in knowledge.

V. Conclusions.

1. The prototype passenger mask demonstrated an adequate capability to maintain human subjects in a satisfactory physiological condition at 40,000 feet for the duration of dwell at this altitude. The increased minute and tidal volumes developed during exercise impose mask-performance efficiency requirements in excess of previous evaluations carried out with sedentary subjects.

2. The mask demonstrated the low leakage characteristics desirable at the maximum altitude of 40,000 feet.

3. The mean tracheal partial pressure exceeded the requirements of FAR-25, TSO-C64, and NAS 1179 in all tests.

4. Control subjects breathing air at 14,000 feet and exercising indicated an average of 5% reduction in blood-oxygen saturation when compared to similar tests conducted on resting subjects.

5. Blood-oxygen saturation as determined by ear oximetry was subject to considerable variation. Three of the five subjects ascending to 40,000 feet maintained a blood saturation in excess of the 14,000-foot air-breathing baseline corrected for the effects of exercise.

6. In order to stimulate respiration to the level required by applicable regulations and standards, measured and controlled exercise should be the method of choice during ground level testing. The use of exercise at altitude is subject to certain limitations and its use should be considered with respect to the experimental design.

REFERENCES

1. Federal Regulations, Part 25. Airworthiness Standards, Transport Category Airplanes.
2. Evaluation of Prototype Passenger Oxygen Mask Assemblies. Boeing Airplane Company Report D6-1954, Transport Division, Renton, Washington, D.C., Feb. 9, 1959.
3. Qualification Test Report, Passenger Oxygen Mask, QTR-59-6. Aro Equipment Company of California, Los Angeles, Calif., Jun. 24, 1959.
4. National Aerospace Standard, 1179. Revised. Aerospace Industries Association of America, Washington, D.C., Mar. 31, 1961.
5. Federal Aviation Agency, Technical Standard Order C-64, Aug. 23, 1961.
6. Oxygen Equipment for Aircraft. Aerospace Information Report 825. Society of Automotive Engineers, New York, N.Y., Feb. 25, 1965.
7. A Design Analysis of a Jet Transport Passenger-Oxygen System. Douglas Report SM-42564. Missile and Space Systems Division, Douglas Aircraft Company, Santa Monica, California, Mar. 1963.
8. Final Report on the Investigation of Mask Leakage in Passenger Oxygen Masks. Pioneer-Central Division, The Bendix Corporation. Federal Aviation Agency Contract FA-885, Feb. 1962.
9. McFadden, E. B., Raeke, J. W., Young, J. W.; An Improved Method for Determining the Efficiency of Crew and Passenger Oxygen Masks. Report 62-21, Federal Aviation Agency, Civil Aeromedical Research Institute, Oklahoma City, Oklahome, Nov. 1962.
10. NASA Life Sciences Data Book, First Edition. Jun. 1962.
11. Bryan and Leach: Physiological Effects of Cabin Failure in High Altitude Passenger Aircraft. *Aerospace Med.* 31 (4): 267-275. Apr. 1960.
12. Donaldson, R. T.: A Study of Areterial Oxygen Saturation During Rapidly Changed Barometric Pressure. Ohio State University. M. S. Thesis.

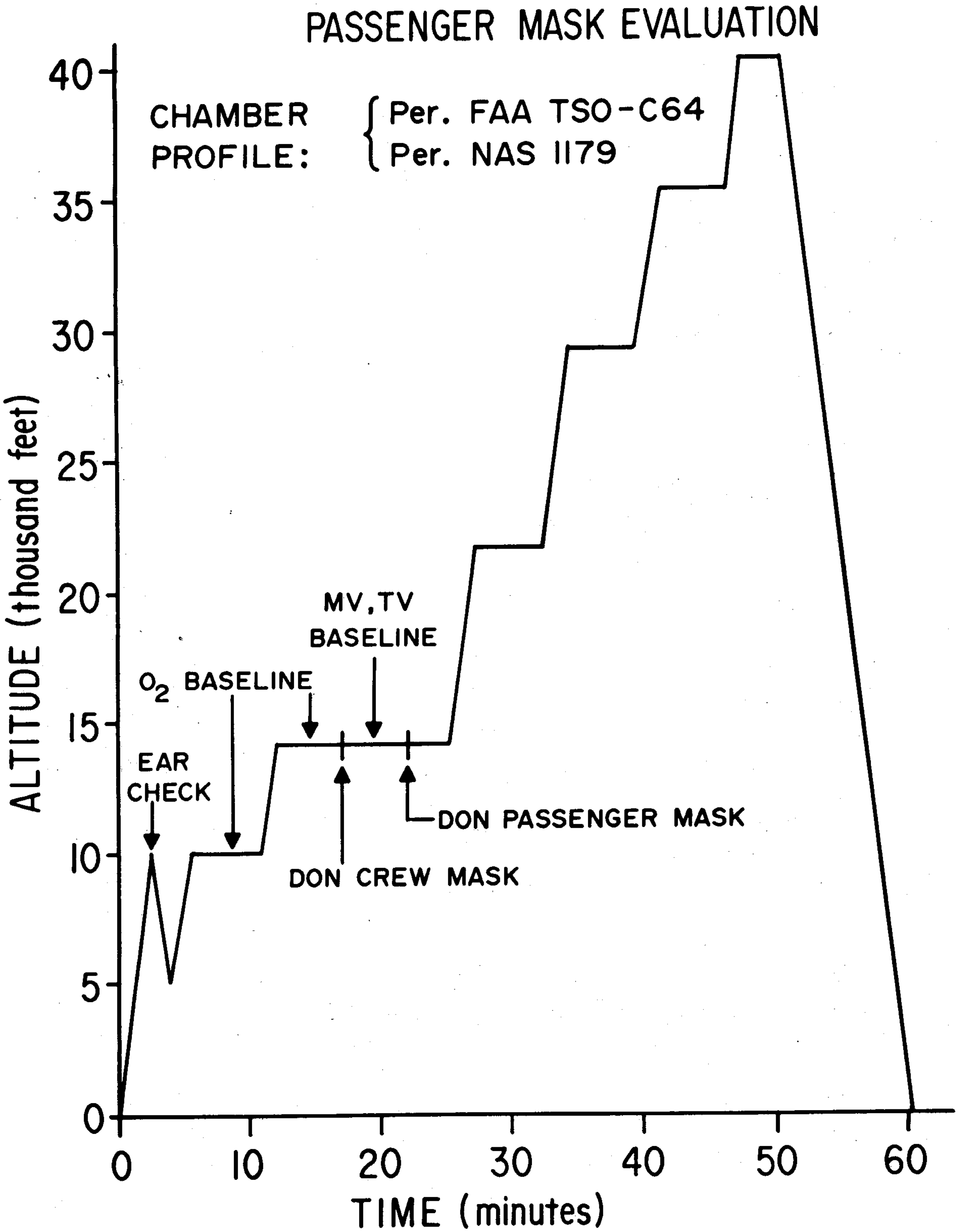


FIGURE 1. Altitude-chamber profile used in evaluation of the Puritan prototype disposable passenger mask. Subjects were resting until the crew mask was donned and exercising the remainder of the flight until descent from 40,000 feet was initiated.

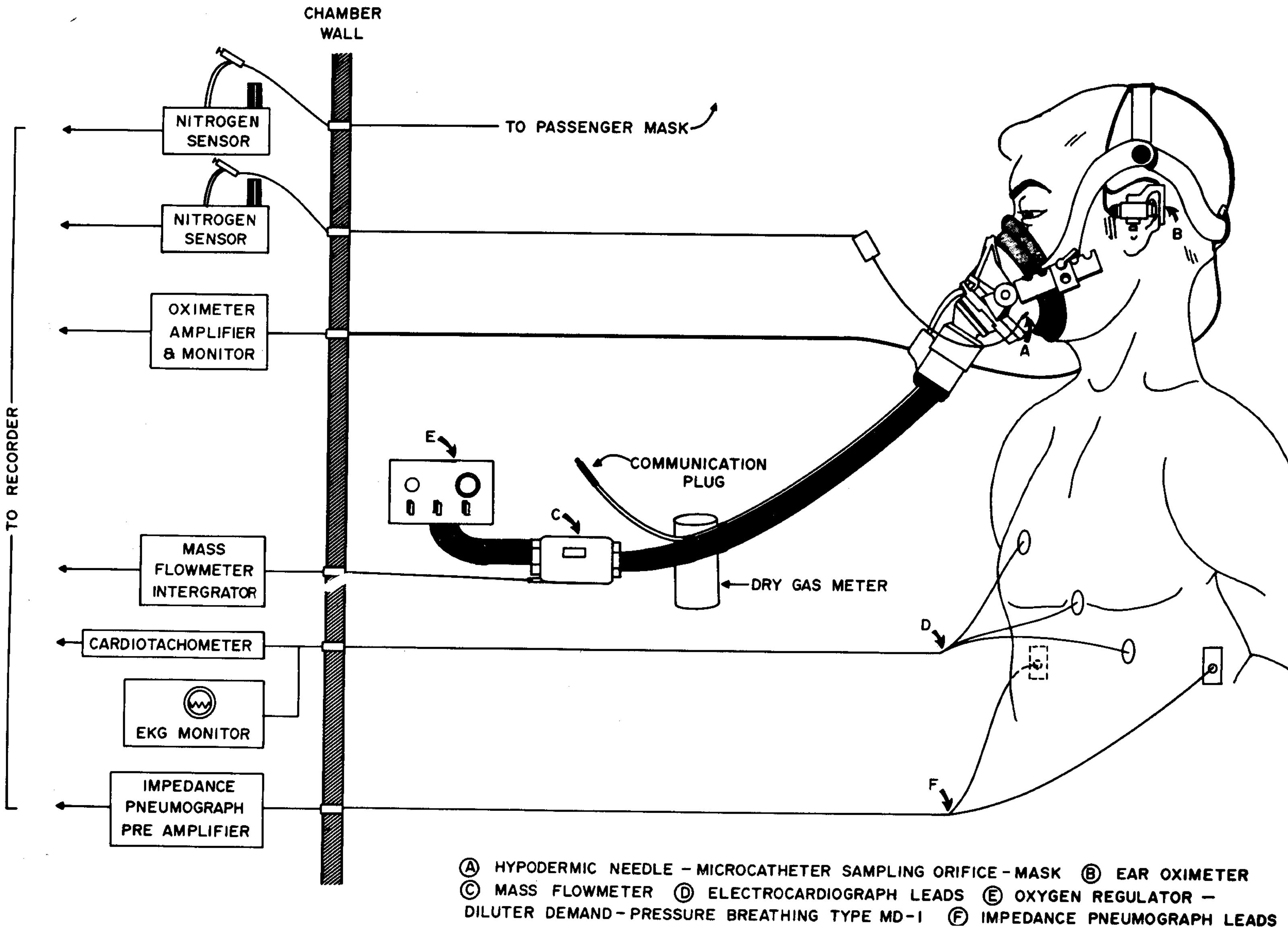


FIGURE 2. Instrumentation of exercising subject during nitrogen washout and establishment of minute and tidal volumes prior to donning passenger mask.

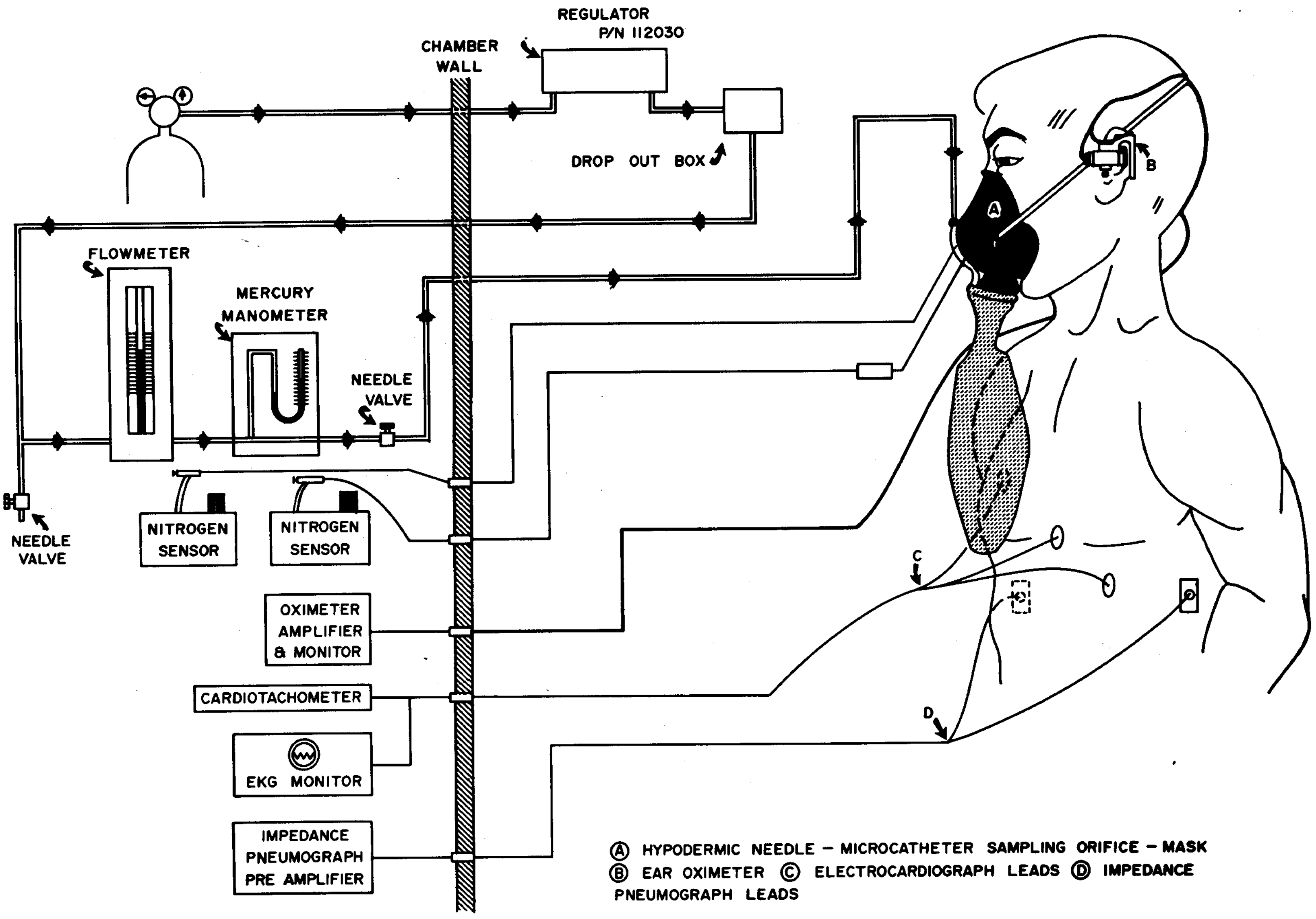
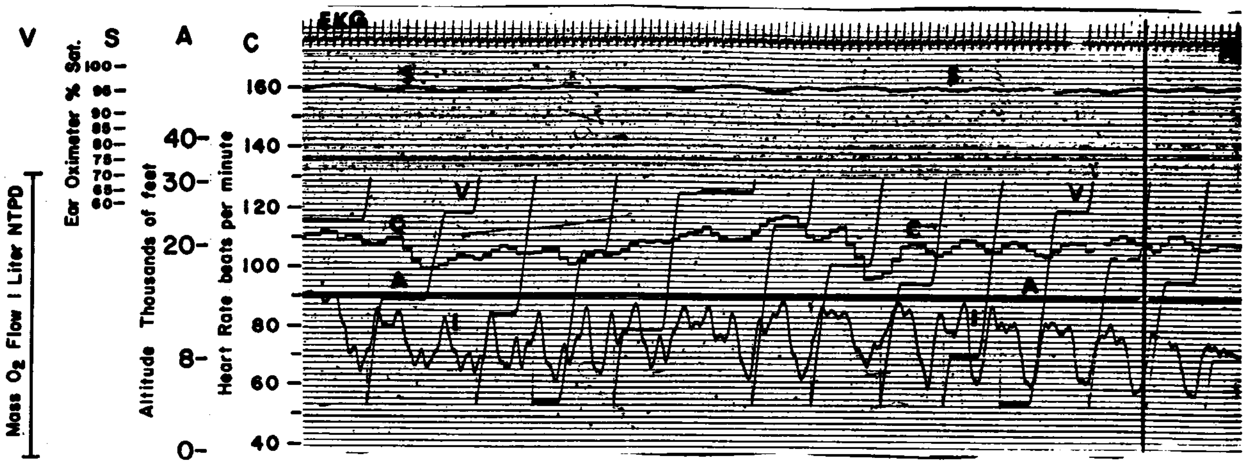
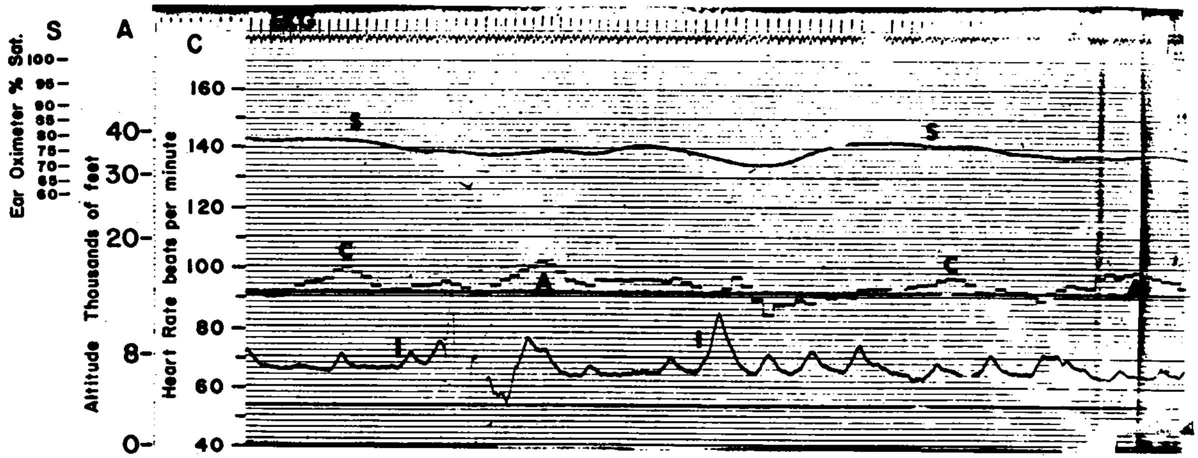


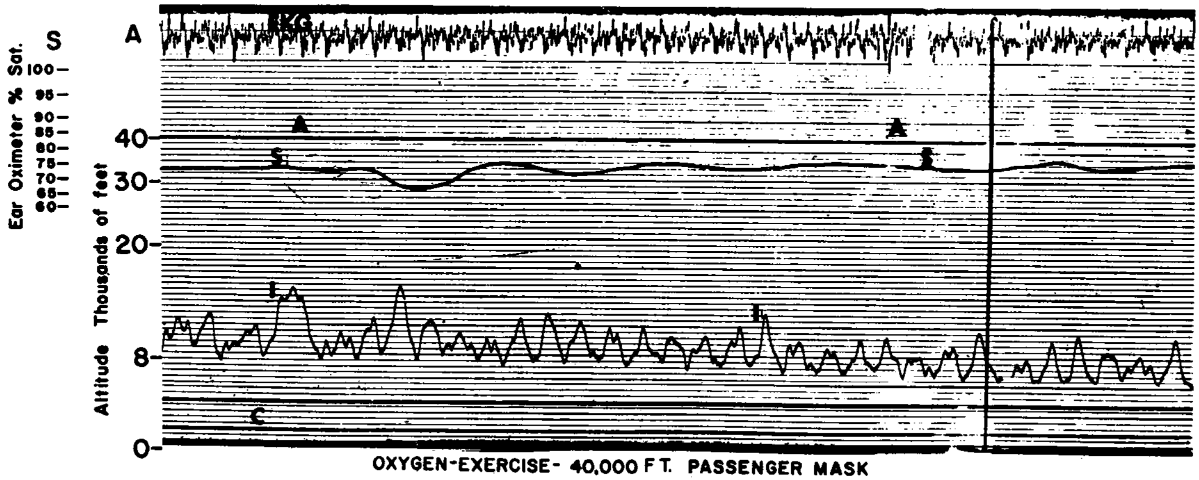
FIGURE 3. Instrumentation of exercising subject following completion of nitrogen washout and establishment of minute and tidal volumes. Subject has completed passenger-mask donning. Oxygen flow to the passenger mask was measured and controlled as illustrated in the upper-left-hand corner.



100% OXYGEN-EXERCISE-14,000 FT. CREW MASK



AIR-RESTING-14,000FT. NO MASK



OXYGEN-EXERCISE- 40,000 FT. PASSENGER MASK

FIGURE 4. Reproduction of portions of a typical recording. Subject E. Mc. EKG — Electrocardiogram. S — Saturation — Ear oximeter. X — Minute volume — Mass flowmeter. C — Heart rate — Cardiotachometer. A — Altitude. I — Impedance pneumograph. Scales to left of record are approximate.

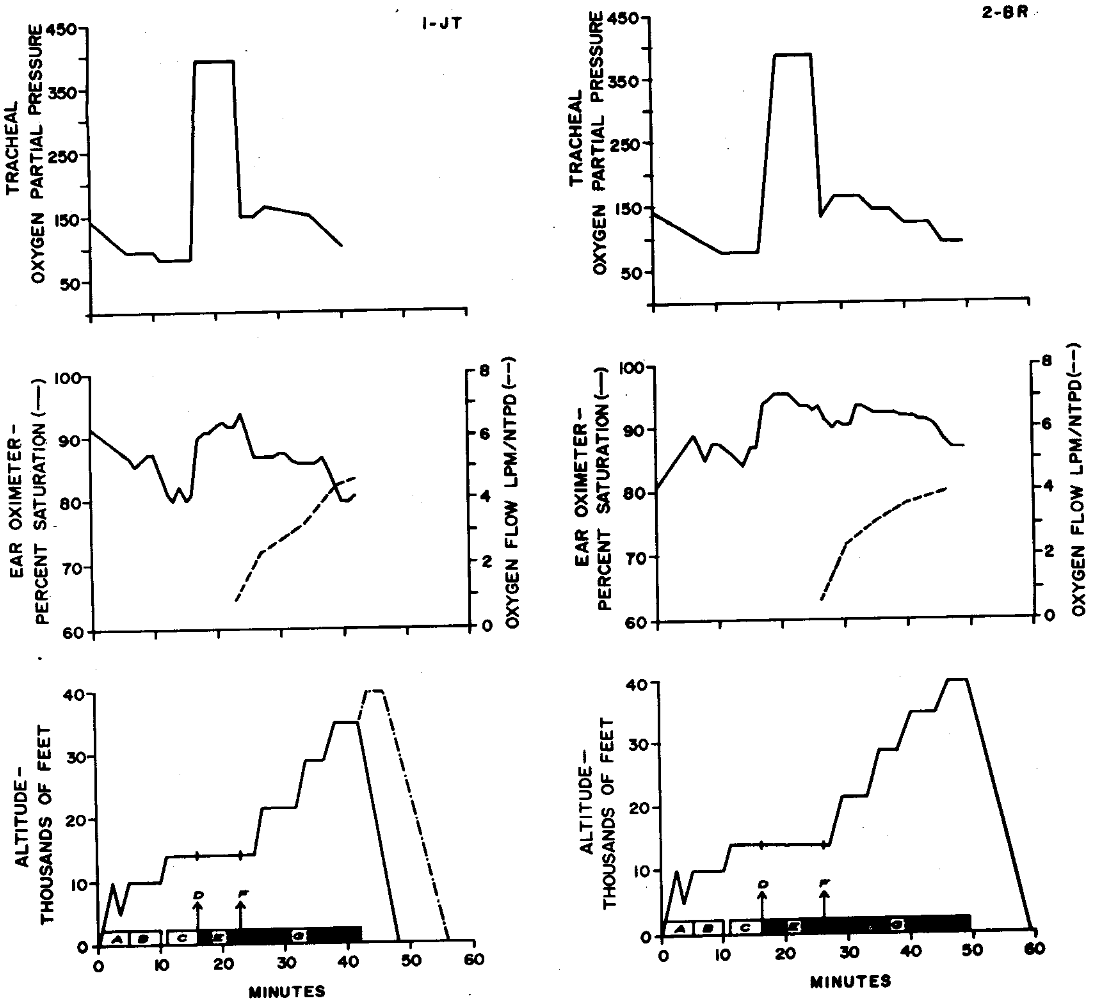


FIGURE 5. Graphic comparison of altitude profile, blood-oxygen saturation, oxygen-flow rate and tracheal-oxygen partial pressures. Shaded area indicates exercise. Subjects J. T. and B. R.

A = Ear check
B = 10,000 Feet, air-breathing baseline
C = 14,000 Feet, air-breathing baseline
D = Don crew mask (100% oxygen)
E = Exercise baseline – Adjust load to obtain desired minute and tidal volumes. Respiratory nitrogen washout.
F = Hold breath and don passenger mask.
G = Continue exercise at baseline. Adjust oxygen flow to mask as altitude is increased.

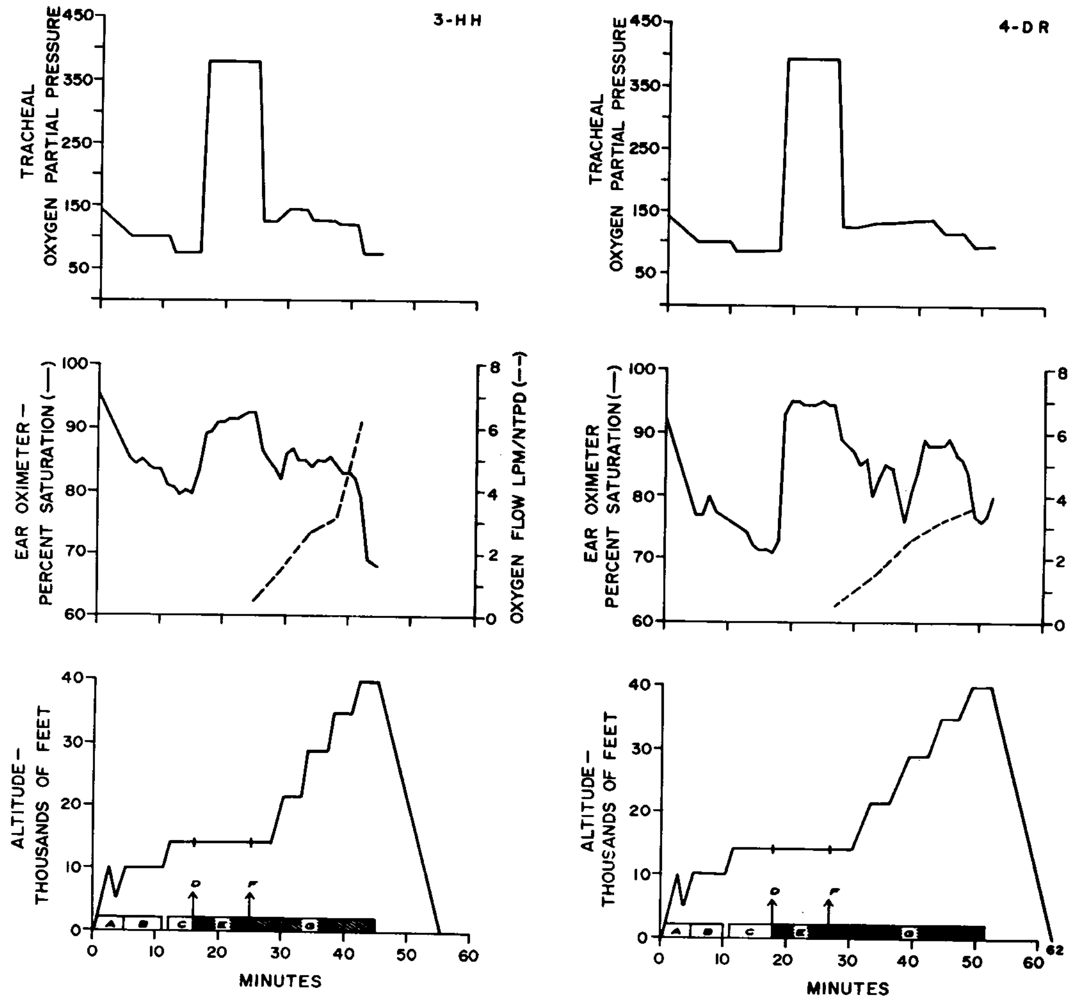


Figure 6. Graphic comparison of altitude profile, blood-oxygen saturation, oxygen-flow rate and tracheal-oxygen partial pressures. Shaded area indicates exercise. Subject H. H. and D. R.

A = Ear check
B = 10,000 Feet, air-breathing baseline
C = 14,000 Feet, air-breathing baseline
D = Don crew mask (100% oxygen)
E = Exercise baseline – Adjust load to obtain desired minute and tidal volumes. Respiratory nitrogen washout.
F = Hold breath and don passenger mask.
G = Continue exercise at baseline. Adjust oxygen flow to mask as altitude is increased.

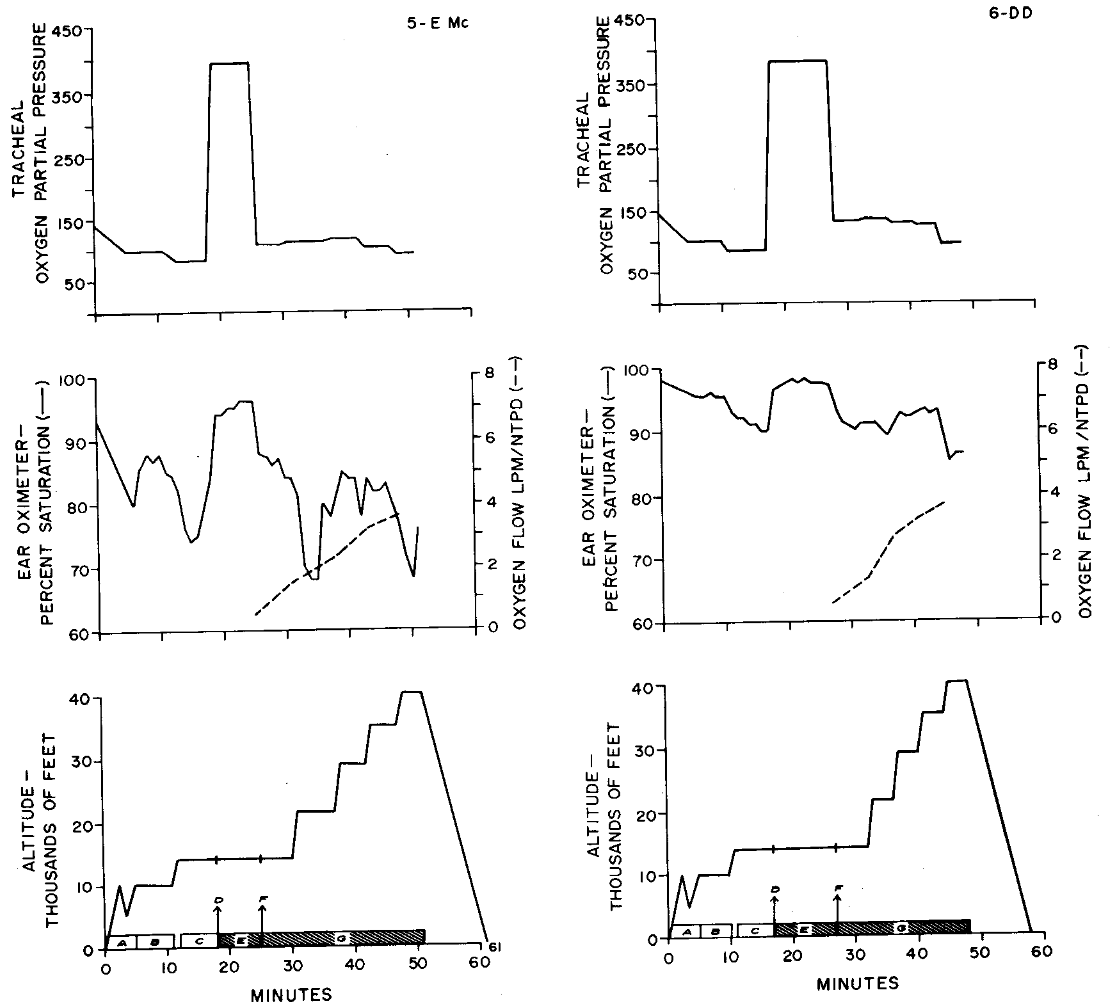


Figure 7. Graphic comparison of altitude profile, blood-oxygen saturation, oxygen-flow rate and tracheal-oxygen partial pressure. Shaded area indicates exercise. Subjects E. Mc. and D. D.

A = Ear check
B = 10,000 Feet, air-breathing baseline
C = 14,000 Feet, air-breathing baseline
D = Don crew mask (100% oxygen)
E = Exercise baseline – Adjust load to obtain desired minute and tidal volumes. Respiratory nitrogen washout.
F = Hold breath and don passenger mask.
G = Continue exercise at baseline. Adjust oxygen flow to mask as altitude is increased.

Table 1. Periodic Measurements of Respiration, work level, and oxygen flow at indicated increments of altitude wearing the prototype Puritan passenger oxygen mask.

Subject and Condition	Altitude	Barometric Pressure	Oxygen Flow L/Min to Mask NTPD	Oxygen Flow to Masks BTPS	Crew Mask Insp. Volume BTPS		Resp. Rate	Impedance Pneumograph Factor	Dry Gas Meter Crew Mask Insp. Volume BTPS		Remarks
					Minute L/Min	Tidal cc			Minute L/Min	cc	
J. T.	1,273	734	Air								Resting
	10,000	523	Air								Resting
	14,000	447	Air								Resting
Don Crew Mask	14,000	447	Regulator O_2								Exercise 30 rpm 30 W
Don Passenger Mask	14,000	447	0.92	1.84			18	1.00			Exercise 30 rpm 30 W
	21,500	328	2.40	6.84			16	0.89			Exercise 30 rpm 30 W
	29,000	237	3.25	13.73			17	0.63			Exercise 30 rpm 30 W
	35,000	179	4.50	27.24			20	0.66			Exercise 30 rpm 30 W
			4.70	28.45							Flight Aborted-Bends
B. R.	1,273	723.7	Air								Resting
	10,000	523.0	Air								Resting
	14,000	447.0	Air				10	0.53			Resting
Don Crew Mask	14,000	447.0	Regulator O_2		23.28	2,116	11	0.73			Exercise 30 rpm 30 W
Don Passenger Mask	14,000	447.0	0.60	1.20			15	1.00			Exercise 30 rpm 30 W
	21,500	328	2.28	6.49			13	0.60			Exercise 30 rpm 30 W
	29,000	237	3.12	13.18			15	0.80			Exercise 30 rpm 30 W
	35,000	179	3.61	21.85			15	0.60			Exercise 30 rpm 30 W
	40,000	141	3.96	33.67			16	0.64			Exercise 30 rpm 30 W
H. H.	1,273	724.7	Air								Resting
	10,000	523.0	Air				15	0.20			Resting
	14,000	447.0	Air				15	0.20			Resting
Don Crew Mask	14,000	447.0	Regulator O_2		18.47	1,318	14	0.55	24.00	1,713	Exercise 35 rpm 40 W
Don Passenger Mask	14,000	447.0	0.50	1.00			19	1.00			Exercise 35 rpm 40 W
	21,500	328.0	1.86	5.30			19	0.88			Exercise 35 rpm 40 W
	29,000	237.0	2.66	11.24			18	0.57			Exercise 35 rpm 40 W
	35,000	179.0	3.15	19.06			23	0.60			Exercise 35 rpm 40 W
Flow Increased During 3-Minute Period	40,000	141.0	3.50	29.76			23	0.73			Exercise 35 rpm 40 W
	40,000	141.0	4.90	41.66							Exercise 35 rpm 40 W
	40,000	141.0	5.40	45.91							Exercise 35 rpm 40 W
	40,000	141.0	6.20	52.72							Exercise 35 rpm 40 W
D. R.	1,273	742.7	Air								Resting
	10,000	523.0	Air								Resting
	14,000	447.0	Air								Resting
Don Crew Mask	14,000	447.0	Regulator O_2		24.90	2,490	10	0.77	26.45	2,645	Exercise 35 rpm 35 W
Don Passenger Mask	14,000	447.0	0.50	1.00			10	1.00			Increased to
	21,500	328.0	1.40	3.99			11	1.10			35 rpm - 40 W
	29,000	237.0	2.60	10.95			10	(....)			"
	35,000	179.0	3.20	19.37			12	(....)			"
	40,000	141.0	3.60	30.61			15	(....)			"

E. Mc.	1,273	739.8	Air								Resting
	10,000	523.0	Air				10				Resting
	14,000	447.0	Air				8				Resting
Don Crew Mask	14,000	447.0	Regulator O_2		22.33	1,488	15	1.00	27.05	1,803	Exercise 35 rpm 35 W
Don Passenger Mask	14,000	447.0	0.50	1.00			25	1.00			Increased to
	21,500	328.0	1.36-1.50	4.27			25	1.00			35 rpm - 40 W
	29,000	237.0	2.60	10.95			26	1.00			"
	35,000	179.0	3.20	19.37			25	1.00			"
	40,000	141.0	3.60	30.61			27	1.10			"
D. D.	1,273	742	Air								Resting
	10,000	523	Air								Resting
	14,000	447	Air				7	0.55			Resting
Don Crew Mask	14,000	447	Regulator O_2		18.14	2,591	7	0.73	30.57	4,368	Exercise 40 rpm 40 W
Don Passenger Mask	14,000	447	0.50	1.00			8	1.00			Exercise 40 rpm 40 W
	21,500	328	1.36	3.87			9	1.20			Exercise 40 rpm 40 W
	29,000	237	2.62	11.07			(....)	(....)			Exercise 40 rpm 40 W
	35,000	179	3.20	19.37			13	0.85			Exercise 40 rpm 40 W
	40,000	141	3.60	30.61			13	0.85			Exercise 40 rpm 40 W
ME. :	1,273	734.5	Air								Resting
	10,000	523.0	Air								Resting
	14,000	447.0	Air				10.0**	0.43***			Resting
Don Crew Mask	14,000	447	Regulator O_2		20.56	1,913	11.33	0.73			Exercise
Don Passenger Mask	14,000	447.0	0.59	1.17			15.83	1.00			Exercise
	21,500	328.0	1.80	5.13			15.50	0.95			Exercise
	29,000	327.0	2.81	11.85			17.20*	0.75**			Exercise
	35,000	179.0	3.48	21.04			18.00	0.74*			Exercise
	40,000	141.0*	3.65*	31.05*			18.80*	0.83**			Exercise

*N = 5

**N = 4 Where not otherwise indicated N = 6.

***N = 3

Table 2. Periodic measurements of cardiac response, nitrogen dilution of the inspired oxygen, calculated tracheal partial pressure, and indicated blood-oxygen saturation during chamber-flight altitude increments to 40,000 feet wearing the sample prototype passenger oxygen mask.

Subject and Condition	Altitude	Barometric Pressure	EKG	Cardiotach.	% Nitrogen Instantaneous		N_2%	Cal.	Blood O_2	Remarks
					Peak	Min.	Integrated	TPO_2	Sat. %	
J. T.	1,273	734	75					144	91.0	Resting
After 5 Min.	10,000	523	75	65- 90				100	87.5	Resting
After 5 Min.	14,000	447	84	68- 97				84	81.0	Resting
Crew Mask	14,000	447	87	78- 90			20.0	392	93.0	Exercise 30 rpm 30 W
Passenger Mask	14,000	447	97	80-103	71.25	35.6	63.3	147	91.0	Exercise 30 rpm 30 W
3 Min.	21,500	328	88	77- 94	56.25	30.0	42.2	162	87.5	Exercise 30 rpm 30 W
3 Min.	29,000	237	88	82- 95	25.00	12.6	21.4	149	86.0	Exercise 30 rpm 30 W
2 Min.	35,000	179	103	Unreadable	35.60	5.0	22.5	102	......	Emergency Descent – **Bends**
B. R.	1,273	723.7						142		Resting
After 5 Min.	10,000	523.0						100	87.5	Resting
After 5 Min.	14,000	447.0	85	75- 92				84	87.0	Resting
Crew Mask–After 9 Min.	14,000	447.0	88	86- 97			2.5	390	93.5	Exercise 30 rpm 30 W
Passenger Mask–3 Min.	14,000	447.0	94	93-103	69.1	42.2	66.4	134	91.0	Exercise 30 rpm 30 W
Passenger Mask–3 Min.	21,500	328.0	99	95-103	58.1	5.0	41.3	165	93.5	Exercise 30 rpm 30 W
Passenger Mask–3 Min.	29,000	237.0	97	95-102	41.3	0.0	23.6	145	92.5	Exercise 30 rpm 30 W
Passenger Mask–3 Min.	35,000	179.0	......	Unreadable	3.0	0.0	3.0	128	91.0	Exercise 30 rpm 30 W
Passenger Mask–3 Min.	40,000	141.0	104	102-109	4.0	0.6	2.9	91	87.0	Exercise 30 rpm 30 W
H. H.	1,273	724.7						142	96.0	Resting
After 6 Min.	10,000	523.0	76	70- 87				100	83.5	Resting
After 4 Min.	14,000	447.0	83	76- 92				84	79.5	Resting
Crew Mask–After 10 Min.	14,000	447.0	79	94-102			5.0	380	92.5	Exercise 35 rpm 40 W
Passenger Mask–2 Min.	14,000	447.0	104	100-110	70.4	52.8	68.0	128	85.0	Exercise 35 rpm 40 W
Passenger Mask–3 Min.	21,500	328.0	101	98-108	63.2	19.3	48.7	144	85.0	Exercise 35 rpm 40 W
Passenger Mask–3 Min.	29,000	237.0	96	92-108	51.5	8.0	26.8	139	85.0	Exercise 35 rpm 40 W
Passenger Mask–3 Min.	35,000	179.0	99	Unreadable	8.0	3.2	7.2	122	82.0	Exercise 35 rpm 40 W
Passenger Mask–3 Min.	40,000	141.0	91	Unreadable	5.0	2.0	5.0	89	†	Exercise 35 rpm 40 W
D. R.	1,273	742.7						146		Resting
	10,000	523.0	91	80- 98				82		Resting
After 6 Min.	14,000	447.0	99	92-108				84	81.0	Resting
Crew MaskAfter 9 Min.	14,000	447.0	101	92-108			1.8	393	94.5	Exercise 35 rpm 40 W
Passenger Mask–3 Min.	14,000	447.0	109	102-118	70.89	49.17	68.3	127	87.0	Exercise 35 rpm 40 W
Passenger Mask–3 Min.	21,500	328.0	117	109-120	61.80	10.14	53.4	131	85.0	Exercise 35 rpm 40 W
Passenger Mask–3 Min.	29,000	237.0	......	Unreadable	46.90	2.00	27.8	137	89.0	Exercise 35 rpm 40 W
Passenger Mask–3 Min.	35,000	179.0	......	Unreadable	33.75	1.00	11.5	117	87.0	Exercise 35 rpm 40 W
Passenger Mask–3 Min.	40,000	141.0	......	Unreadable	2.00	1.00	2.0	92	77.0	Exercise 35 rpm 40 W

E. Mc.	1,273	739.8						145		Resting
After 6 Min.	10,000	523.0	83	78- 98				100	85.0	Resting
After 6 Min.	14,000	447.0	90	80-102				84	84.0	Resting
Crew Mask—After 6 Min.	14,000	447.0	101	95-118			1.4	394	96.0	Exercise 35 rpm 40 W
Passenger Mask—3 Min.	14,000	447.0	117	111-120	74.11	65.80	72.5	110	87.5	Exercise 35 rpm 40 W
Passenger Mask—4 Min.	21,500	328.0	109	110-118	69.07	37.26	60.0	112	80.0	Exercise 35 rpm 40 W
Passenger Mask—3 Min.	29,000	237.0	116	112-118	52.50	12.66	38.4	117	84.0	Exercise 35 rpm 40 W
Passenger Mask—3 Min.	35,000	179.0	......	Unreadable	39.37	8.00	21.4	103	83.0	Exercise 35 rpm 40 W
Passenger Mask—3 Min.	40,000	141.0	......	Unreadable	3.50	2.00	2.9	91	74.0	Exercise 35 rpm 40 W
D. D.	1,273	742						146		Resting
	10,000	523	NOT RECORDED							Resting
After 6 Min.	14,000	447	96	84-118				84	90.0	Resting
Crew Mask—After 10 Min.	14,000	447	125	108-130			5.0	380	97.0	Exercise 40 rpm 40 W
Passenger Mask—4 Min.	14,000	447	139	118-Off-Scale	72.70	41.20	67.4	130	90.5	Exercise 40 rpm 40 W
Passenger Mask—3 Min.	21,500	328	......	Unreadable	65.40	15.00	53.4	131	89.0	Exercise 40 rpm 40 W
Passenger Mask—3 Min.	29,000	237	138	‡	48.70	8.00	32.8	128	92.0	Exercise 40 rpm 40 W
Passenger Mask—3 Min.	35,000	179	136	Off-Scale	8.00	5.0	8.0	121	93.0	Exercise 40 rpm 40 W
Passenger Mask—3 Min.	40,000	141	152	Off-Scale	6.0	1.5	4.3	90	86.0	Exercise 40 rpm 40 W
Mean:										
	1,273	734.4	75.0					144.2	93.5	Resting
After 5.5 Min.	10,000	523.0	81.3	73- 93				96.4	85.9	Resting
After 5.3 Min.	14,000	447.0	89.5	79-102				84.0	83.8	Resting
Crew Mask—After 8.8 Min.	14,000	447.0	96.8	92-108			2.95	388.2	94.4	Ex. 34.2 rpm 36.7 W
Passenger Mask—3 Min.	14,000	447.0	110.0	97-111	71.40	47.80	67.65	108.2	88.7	Ex. 34.2 rpm 36.7 W
Passenger Mask—3.2 Min.	21,500	328.0	102.8	98-109	62.30	19.45	49.83	140.8	86.6	Ex. 34.2 rpm 36.7 W
Passenger Mask—3 Min.	29,000	237.0	107.0	95-108	44.30	7.21	28.46	135.8	88.1	Ex. 34.2 rpm 36.7 W
Passenger Mask—3 Min.	35,000	179.0	112.7		21.30	3.70	12.27	115.5	87.2	Ex. 35 rpm 38 W
Passenger Mask—3 Min.	40,000	141.0	115.7	102-109	4.10	1.42	3.41	90.6	78.5	Ex. 35 rpm 38 W

N Numbers (Mean) vary in relation to condition and measurement omission.

† All saturation readings within 3 minutes
79.0 - 71.0 - 70.0
69.0 - 69.5 - 69.0
68.5 - 68.5 - 68.5

‡ Not On Record

Table 3. Periodic ear-oximeter readings during a chamber-flight profile to 40,000 feet. Subject baselines established at 10,000 and 14,000 feet breathing air. Work and respiratory-response baselines established at 14,000 feet wearing crew mask and inspiring 100% oxygen. Remainder of flight conducted with subject wearing Puritan prototype passenger mask and eyercising at the established baseline.

Subject and Condition	Altitude	Preflight	% Saturation — Ear Oximeter Time - Minutes 1	2	3	4	5	6	7	8	9	10
J. T.												
Resting — Air	1,273	91.5										
Resting — Air	10,000		81.0	85.5	......	8.75	87.5					
Resting — Air	14,000		82.0	80.0	82.5	80.0	81.0					
Exercise — Crew Mask — O_2	14,000		90.0	91.0	91.0	92.0	92.5	92.0	92.0			
Exercise — Passenger Mask — Air — O_2	14,000		94.0	91.0								
Ascend To	21,500		87.0	87.0								
Level To	21,500		87.0	87.0	87.5	87.5						
Ascend To	29,000		86.5	86.0								
Level To	29,000		86.0	86.0	86.0							
Ascend To	35,000		87.0	85.0								
Level To	35,000		80.0	80.0	81.0							
Subject experienced bends and flight to 40,000 feet discontinued.												
B. R.												
Resting — Air	1,273	80-81										
Resting — Air	10,000		89.0	87.0	85.0	87.5	87.5					
Resting — Air	14,000		86.0	85.0	84.0	87.0	87.0					
Exercise — Crew Mask — O_2	14,000		94.0	94.5	95.5	95.5	94.5	93.5	93.5	93.0	93.5	
Exercise — Passenger Mask — Air — O_2	14,000		91.5									
Ascend To	21,500		90.0	90.5	91.0							
Level To	21,500		90.5	90.5	93.5	93.5						
Ascend To	29,000		93.0	92.5								
Level To	29,000		92.5	92.5	92.5							
Ascend To	35,000		92.0	92.0								
Level To	35,000		92.0	91.5	91.5	91.0						
Ascend To	40,000		90.0	88.0								
Level To	40,000		87.0	87.0	87.0							
H. H.												
Resting — Air	1,273	95-96										
Resting — Air	10,000		85.5	84.5	85.0	84.0	83.5	83.5				
Ascending To	14,000		81.0									
Resting — Air	14,000		80.5	79.5	80.0	79.5	83.0					
Exercise — Crew Mask — O_2	14,000		89.0	89.5	91.0	91.0	91.5	91.5	92.0	92.5	92.5	92.5
Exercise — Passenger Mask — Air — O_2	14,000		87.0	85.0	84.0							
Ascend To	21,500		82.0	86.0								
Level To	21,500		87.0	85.0	85.0							
Ascend To	29,000		84.0									
Level To	29,000		85.0	85.0	85.5							
Ascend To	35,000		84.0									
Level To	35,000		83.0	83.0	82.0							
Ascend To	40,000		79.0									
Level To	40,000		69.0	68.5	68.0							

D. R.												
Resting — Air	1,273	**93.0**										
Resting — Air	10,000		87.0	87.0	90.0	87.5	87.0					
Resting — Air	14,000		85.0	84.0	82.0	81.5	81.5	81.0	83.0			
Exercise — Crew Mask — O_2	14,000		93.0	95.0	95.0	94.5	94.5	94.5	95.0	**94.5**	**94.5**	
Exercise — Passenger Mask — Air — O_2	14,000		89.0	88.0	87.0							
Ascend To	21,500		85.0	86.0	80.0							
Level To	21,500		83.0	85.0	84.5							
Ascend To	29,000		80.0	76.0	81.0							
Level To	29,000		84.0	89.0	88.0							
Ascend To	35,000		88.0	88.0								
Level To	35,000		89.0	87.0	87.0							
Ascend To	40,000		84.0	77.0								
Level To	40,000		76.0	77.0	80.0							
E. Mc.												
Resting — Air	1,273	**93.0**										
Resting — Air	10,000		90.0	86.0	88.0	87.0	88.0	85.0				
Ascending To	14,000		84.5									
Resting — Air	14,000		82.0	76.0	74.0	75.0	79.0	84.0				
Exercise — Crew Mask — O_2	14,000		94.0	94.0	95.0	95.0	96.0	96.0	**96.0**			
Exercise — Passenger Mask — Air — O_2	14,000		88.0	87.5	86.0	87.0	84.0					
Ascend To	21,500		84.0									
Level To	21,500		81.0	70.0	68.0	68.0	80.0	78.0				
Level To	29,000		85.0	84.0	84.0	78.0						
Ascend To	35,000		84.0									
Level To	35,000		82.0	82.0	83.0	80.0						
Level To	40,000		72.0	68.0	76.0							
D. D.												
Resting — Air	1,273	**98.0**										
Resting — Air	10,000		95.5	95.5	96.0	95.5	95.5					
Ascending To	14,000		93.5			91.0	90.0	90.0				
Resting — Air	14,000		92.0	92.0	91.0	98.0	97.5	98.0	**97.5**	**97.5**	**97.5**	**97.0**
Exercise — Crew Mask — O_2	14,000		96.5	97.0	97.5	90.0	91.0					
Exercise — Passenger Mask — Air — O_2	14,000		93.0	91.0	90.5							
Level To	21,500		91.0	90.0	89.0							
Level To	29,000		92.5	92.0	92.0							
Level To	35,000		93.0	92.5	93.0							
Level To	40,000		85.0	86.0	86.0							
MEAN:												
Resting — Air	1,273	**91.9**										
Resting — Air	10,000		89.0	87.6	88.8	88.2	88.2	84.2				
Resting — Air	14,000		84.6	82.8	82.3	82.3	83.6	85.0	83.0			
Exercise — Crew Mask — O_2	14,000		92.75	93.5	93.5	94.3	94.4	94.25	94.3	**94.4**	**94.5**	**94.8**
Exercise — Passenger Mask — Air — O_2	14,000		90.4	88.5	86.9	88.5	87.5					
Level To	21,500		86.6	84.6	84.6	83.0	80.0	78.0				
Level To	29,000		87.5	88.1	88.0	78.0						
Level To	35,000		86.5	86.0	86.3	85.5						
Level To	40,000		77.8	77.3	79.4							

Note: Immediately after ascending from 35,000 to 40,000 feet saturation dropped as follows: 79.0, 71.0, 70.0, 69.0, 69.5, 69.0, 68.5, 68.0, 68.5. All of these readings were within a 3-minute period and the descending nature of this subject's saturation was not reversed by increased oxygen flows during this period. Subject did not appear to be severely hypoxic. Possible ear-oximeter error.

Table 4. Chamber flight to 14,000 feet to establish air-breathing baselines during resting, work and recovery.

Subject and Condition	Altitude	Preflight	% Saturation — Ear Oximeter Time — Minutes 1	2	3	4	5	6	7	8	9	Mean
H. H.												
Resting	1,273	100.0										
Resting	14,000		93.0	92.0	91.0		93.0.	92.0	92.0			92.2
Exercise 35 rpm, 40 W	14,000		87.0	87.0	87.0	87.0	91.0	87.0				87.6
Resting — Recovery	14,000		01.0	02.0	92.0	92.0	92.0	92.0	91.0			91.7
D. R.												
Resting	1,273	97.0										
Resting	14,000		88.0	90.0	88.0	88.0	87.0	86.0	87.0	85.0	83.0	86.9
Exercise 35 rpm, 40 W	14,000		81.0	80.0	81.0	80.0	80.0	80.0	80.0	80.0		80.3
Resting — Recovery	14,000		80.0	79.0	78.0	76.0	79.0	76.0	75.0	77.0		77.5
E. Mc.												
Resting	1,273	99.0										
Resting	14,000		95.0	95.5	95.5	95.0	94.0	94.0	94.0	95.0		94.8
Exercise 35 rpm, 40 W	14,000		92.0	93.0	92.5	93.0	91.0	92.5	90.0	88.0		91.5
Resting — Recovery	14,000		90.0	91.0	92.0	92.0	93.0	94.0	94.0	94.0		92.5
D. D.												
Resting	1,273	95.5										
Resting	14,000		95.0	94.0	94.5	94.0	94.0	94.0	94.0	94.0		94.2
Exercise 40 rpm, 40 W	14,000		93.0	91.5	91.0	91.5	90.5	90.5	91.0	90.0		91.1
Resting — Recovery	14,000		94.0	95.0	94.0	94.0	94.5	94.0	94.0	94.0	93.0	94.1
J. S.												
Resting	1,273	95.5										
Resting	14,000		91.5	90.0	87.0	85.0	85.0	86.0	85.0	84.0		86.7
Exercise 35 rpm, 40 W	14,000		81.0	79.0	76.0	78.0	82.0	80.0				79.3
Resting — Recovery	14,000		84.0	83.0	84.0	83.0	82.0	83.0	84.0	82.0		83.1

MEANS
N = 5

Resting	14,000	Resting — Breathing Air	90.9
Exercise	14,000	Exercise — Breathing Air	86.0
Resting — Recovery	14,000	Difference = 4.9	87.8