TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. FAA-AM-72-10	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle
PHYSIOLOGICAL EVALUATION OF A MODIFIED JET TRANSPORT PASSENGER OXYGEN MASK

5. Report Date
March 1972

6. Performing Organization Code

7. Author(s)
Ernest B. McFadden, M.S.

8. Performing Organization Report No.

9. Performing Organization Name and Address
FAA Civil Aeromedical Institute
P. O. Box 25082
Oklahoma City, Oklahoma 73125

10. Work Unit No.

11. Contract or Grant No.

13. Type of Report and Period Covered
OAM Report

12. Sponsoring Agency Name and Address
Office of Aviation Medicine
Federal Aviation Administration
800 Independence Avenue, S.W.
Washington, D.C. 20591

14. Sponsoring Agency Code

5. Supplementary Notes
Research leading to preparation of this report was performed under Project No. AM-A-69-PRS-13.

6. Abstract This paper describes altitude chamber experiments conducted with human sub- ects using a new continuous-flow disposable passenger mask applicable for emergency se to maximum altitudes of 41,000 feet. This mask design differs in configuration rom the previous omni-directional maska designed to meet the requirements of National erospace Standard 1179 and FAA Technical Standard Order C-64 in that the inner face lap or seal has been eliminated and the cylindrical shape reduced to a modified ne. The primary goal of this study was to determine if design modification of the sk induced an increase or decrease in physiological efficiency. Of paramount con- rn was the possibility that modification of the configuration and facial seal might crease the leakage rate of ambient air into the mask, and thereby compromise its ility to provide the level of protection required at the maximum altitude of the rcraft. Subjects were instrumented to obtain a variety of physiological data. is included EKG impedance pneumograph, ear oximetry, and expiratory nitrogen, and nute volume. The continuous flow of oxygen delivered to the passenger mask was ntrolled and precisely measured. The mask was evaluated at altitudes of 14,000 ,500, 29,000, 35,000 and 40,000 feet. The average inspired tracheal oxygen partial essure remained above 83.8 mm Hg under all conditions of rest and exercise at all titudes except for the third and last minute of exercise at 40,000 feet. If a derate degree of physical activity is to be maintained for more than a few minutes, ygen-flow rates should be increased commensurate with the anticipated level of tivity. Larger subjects with increased body surface areas exhibit lower blood ygen saturations and tracheal oxygen partial pressures at a standardized oxygen ow due to increased oxygen consumption.

Key Words
ygen masks, decompression, hypoxia, otection, altitude, passengers

18. Distribution Statement
Availability is unlimited. Document may be released to the National Technical Information Service, Springfield, Virginia 22151, for sale to the public.

Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 11	22. Price $3.00

m DOT F 1700.7 (8-69)

PHYSIOLOGICAL EVALUATION OF A MODIFIED JET TRANSPORT PASSENGER OXYGEN MASK

Introduction

This report describes altitude chamber experiients conducted with human subjects using new ierra Engineering Series 289–601 disposable assenger oxygen masks. These masks, applicle for emergency use to 40,000-foot altitudes, iffer in configuration from the previous Sierra ask (although both are designed to meet reiirements of NAS 1179 and FAA TSO C–64) that the inner face flap or seal has been elimated and the cylindrical shape reduced to a odified cone.

The unique characteristics of continuous-flow ygen masks, in terms of human respiration, e frequently not well understood. Although ss costly than crew masks and deceptively mple in appearance, continuous-flow passenger asks have physiological performance charactertics that are relatively complex.

Continuous-flow, phase-dilution type masks, signed to the NAS 1179 and FAA TSO C–64 quirements, employ a unique design in which e reservoir is interposed between the delivery be and the mask. The reservoir is separated om the mask by a sensitive check valve. The ntinuous flow of oxygen fills the reservoir bag ring the respiratory pause and exhalation. e flow also continues at the same rate during spiration. The mask-wearer receives 100% ygen from the reservoir during an entire iniration unless the bag is emptied; if this occurs, spring-loaded valve in the mask opens, and bient air is introduced to provide sufficient lume to meet the remainder of the inspiration. e flow of 100% oxygen is provided at the st advantageous point in the respiratory cycle, the beginning of inspiration. For example, a human subject's tidal volume is 650 cc, and reservoir contains only 500 cc at the begin g of inspiration, the 500 cc of 100% oxygen ll be inspired first and delivered to the active as of the lungs. The ambient air valve will then open and deliver 150 cc of ambient 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 process is repeated with each respiratory cycle. In normal practice, the reservoir bags are capable of containing a maximum of 1,100 cc which provides for increased tidal and minute volumes.

In summary, continuous-flow, phase dilution masks offer the following advantages:

1. Oxygen economy is afforded by use of a reservoir bag that fills and retains the oxygen flow during both the respiratory pause and exhalation.

2. At lower altitudes, reduced oxygen flow rates may be employed and the air-oxygen dilution controlled in a manner more reliable than other methods employed in constant-flow oxygen masks.

3. Oxygen concentrations approaching 100%, 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 a (volume/breath) tidal volume of about 550 cc and a minute volume (volume/minute) of 7,700 cc. Emotional and/or physical activity may cause these values to increase greatly. Concern with this problem is reflected in the Federal Aviation Regulations 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 BTPS (body temperature pressure saturated) 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 designed and evaluated.[2 3] Subsequently, standards for passenger oxygen masks were compiled and published. The National Aerospace Standard 1179[4] and Federal Aviation Administration Technical Standard Order (TSO) C–64[5] set forth manufacturing, material, and testing standards for passenger oxygen masks.

An excellent description of the basic physiological rationale of oxygen equipment design for aircraft has been prepared by the SAE A–10, Aircraft Oxygen Equipment Committee.[6] An additional report delineates the basic criteria and design philosophy of jet transport passenger oxygen systems.[7]

II. Methods

Procedure. The altitude chamber flight profile is shown in Figure 1. Six subjects who had received altitude indoctrination within the past two years were employed. Instrumentation i shown in Figures 2 and 3. The mask was no donned until after air-breathing baselines wer established at 10,000 and 14,000 feet. A safet observer accompanied each subject.

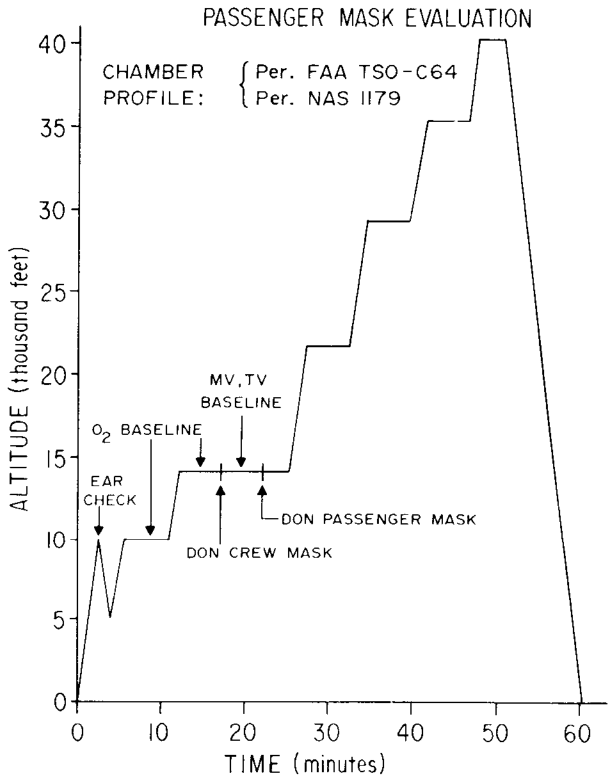


FIGURE 1. Altitude chamber profile used in evaluation of the Sierra 239–601 series prototype disposable passenger oxygen mask.

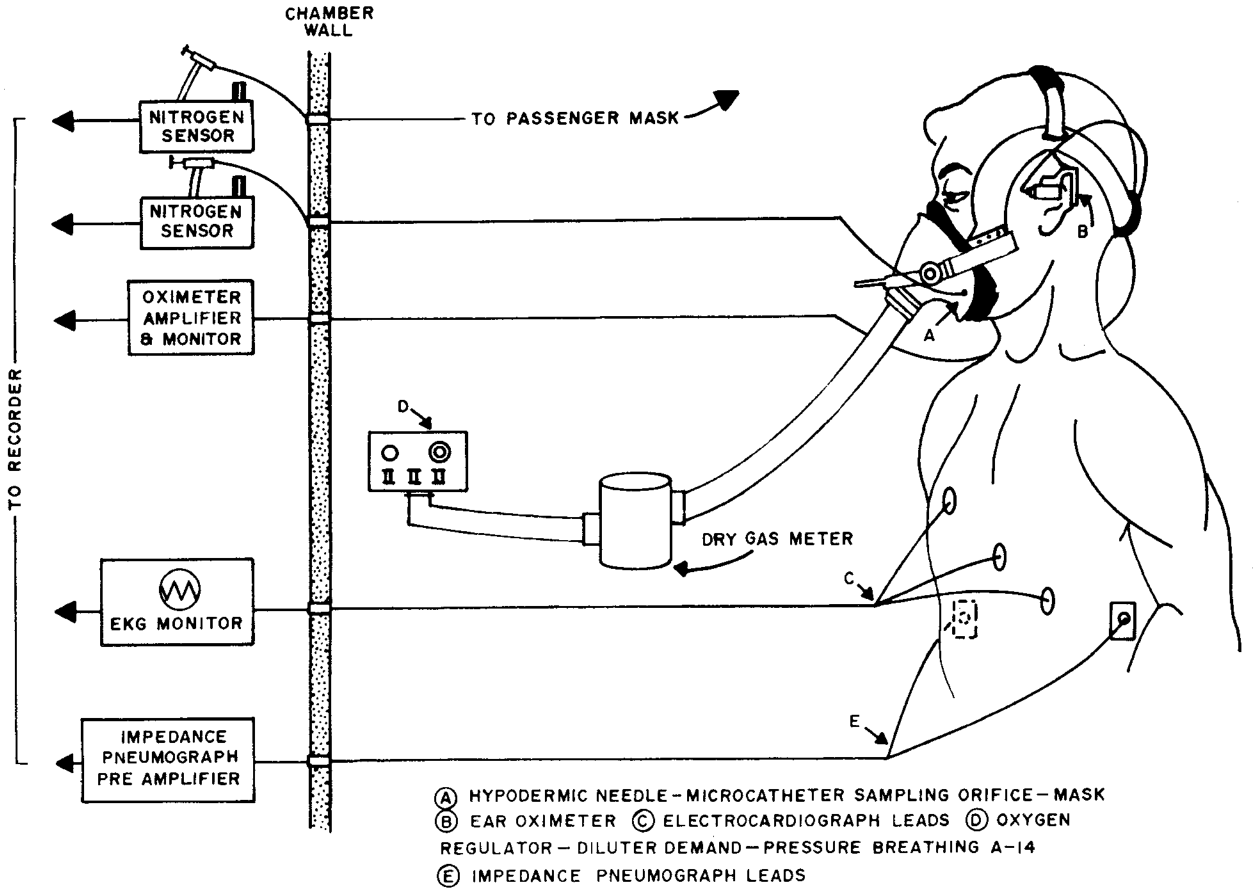
A Waters ear oximeter, Model XE 350, wa affixed to the antihelix of the subject's ear 10 t 15 minutes prior to the chamber flight, to allo stabilization. The output of the earpiece wa fed into an XE–350 oximeter and continuousl recorded on a Physiograph. The latter was als used to record signals from EKG electrodes an the output from impedance pneumograph ele trodes attached to the subjects. The impedan pneumograph was included in the experimen to attempt to determine if changes in the re piratory activity baseline occurred during sub sequent ascent to altitude. At the present tim there is no satisfactory method of measurin respiratory volumes and activity while wearin a passenger mask without compromising th performance of the mask.

After a preliminary assurance of the subjec capability to equalize ear pressures, the subje rested quietly at 10,000 feet until the ear oximet reading indicated a stabilization of blood oxyg saturation. Then the subject was depressuriz to 14,000 feet to establish similar resting a exercise baselines at this altitude.

When it appeared the blood saturation w stabilized at 14,000 feet, the subject donned crew-type demand oxygen mask and commenc breathing 100% oxygen. Immediately followi crew-mask donning, exercise on a bicycle ergo eter (modified so that it could be operated each subject while seated in a passenger ty aircraft seat) was initiated. The exercise le was set at 45 rpm (speed) and 45 watts (loa to obtain the desired respiratory activity (proximately 25 to 30 liters/minute). This regarded as a light to moderate work load proximately equivalent to walking at 3.0 to mph.

Exercise was continued until the desired m ute volume, as indicated by a dry gas meter, obtained and stabilized. The subjects beca denitrogenated during this period, thereby ducing the possibility of bends with exercise the subsequent higher altitudes.

After completion of nitrogen washout at 14, feet, the subject removed the crew mask



IGURE 2. Instrumentation of subjects prior to nitrogen washout and determination of minute volume at an altitude of 14,000 feet. Subject wearing a crew-type mask.

apidly donned the Sierra passenger mask Figure 3). Each subject wore a new mask; ius six masks were used in this evaluation. he flow of oxygen to the mask was regulated y an altitude-sensitive regulator of the type sed in multi-passenger oxygen systems of transort aircraft. The flow from this regulator, istead of being transmitted directly to the subect, was first routed outside the chamber through flowmeter and needle-valve arrangement in rder to obtain precise measurement and control f the flow (Figure 3). Excess oxygen as proided by the regulator was vented outboard outde the chamber.

The subject exercised for three minutes at each titude and rested during the climb to each iccessive higher altitude level. The chamber as leveled off at 14,000, 21,500, 29,000, 35,000 id 40,000 feet and readings were taken preercise, during the first minute and last minute exercise followed by post-exercise recordings at 14,000, 21,500, 29,000, 35,000 and 40,000 feet. Motion pictures were taken of the subjects during the maximum altitude portions of the flights and closed-circuit television was used to monitor the subjects at all times.

Mask Efficiency. Two Custom Engineering and Development Company Model 300 AR Nitralyzers were used to continuously measure the mask nitrogen. These instruments exhibit an initial response latency of 0.024 second, 90% response being obtained in 0.044 second. A vacuum pump, regulated to 0.6 mm, set the sampling rate at 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 extensive modification of the mask nor did it add significant weight; thus, fit and operational characteristics of the mask were not compromised.

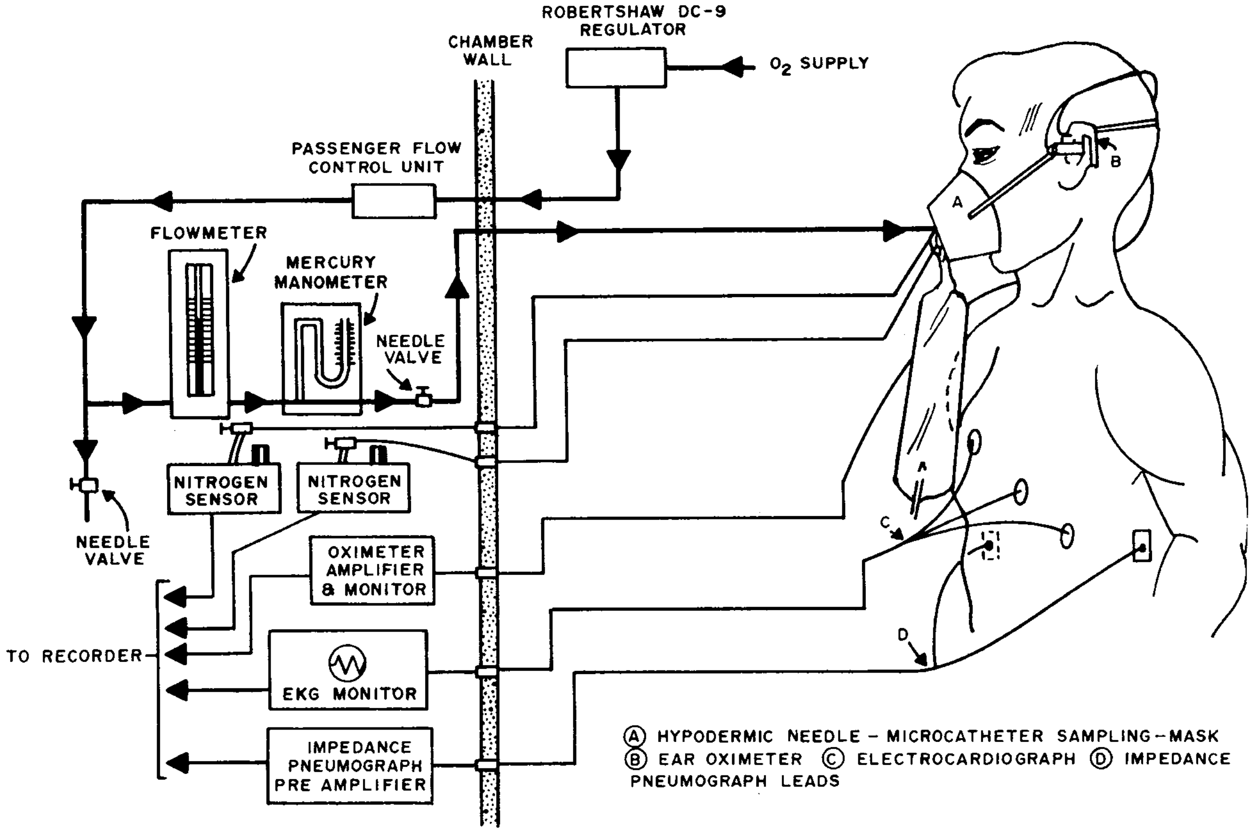


FIGURE 3. Instrumentation of subjects following completion of nitrogen washout and determination of minu volumes. Subject has completed passenger mask-donning. Oxygen flow to the mask was routed from a pre sure control regulator within the chamber through the passenger flow orifices outside the chamber where was reduced to standard conditions and returned to the mask. Excess oxygen from the regulator was dump overboard.

In the evaluation of oxygen mask efficiency, one of the most important measurements is that of the partial pressures of inspired gases. A continuous flow mask, while worn by a human subject, defies direct measurement of these parameters (without compromise of mask performance) due to the rapid changes in gas composition at the facepiece. The percentage of gases in the facepiece of the mask may be averaged by an integrating reservoir; this average indicates a trend, but is influenced by the inactive gases of the facepiece and anatomical dead space. In order to estimate the composition of inspired gases an indirect approach was used; this technique is based on the assumption that the end-expiratory gases are completely mixed and have equilibrated with the blood in the alveoli.

Nitrogen is not involved in metabolic exchange. If the absorption of O_2 and the production of CO_2 were exactly the same, the amou of nitrogen inspired would equal the amou expired; i.e., nitrogen molecules inspired = nitr gen molecules expired. The metabolic respir tory quotient (R.Q.) would equal one. Howeve

the metabolic R.Q. $= \frac{CO_2 \text{ produced}}{O_2 \text{ consumed}}$ and is n

normally equal to one, or unity. Under the conditions there may be a relative difference the nitrogen composition of inspired and expir gases. The metabolic R.Q. depends upon t predominance of carbohydrates (1.0), prote (0.82), or fat (0.71) being metabolized and usually about 0.83. The respiratory R.Q. m vary temporarily from the metabolic R.Q. d ing unsteady states such as hyperventilati The increased lung ventilation produces a blo off of CO_2 from the blood with an apparent, b misleading, increase in CO_2 production and an R.Q. greater than 1.0. Conversely, hypoventilation and retention of CO_2 indicate an apparent, *but misleading*, decrease in CO_2 production resulting in a decreased R.Q. which may be less than 0.7.

One must keep in mind that in a steady state condition the unequal exchange of oxygen and carbon dioxide involves only that portion of the gases consumed and produced. For example, if during a one-minute period at rest 0.3 liters of O_2 were consumed and 0.25 liters of CO_2 were produced (R.Q.=0.83), the resultant volumetric difference of 0.05 liters in the seven or eight liters passing through the lungs during this one minute would be relatively small, and the error (only a few per cent) would be well within the experimental error of the determinations of end expiratory nitrogen.

All of the nitrogen which dilutes the inspired gas originates from air by mask leakage or dilution-valve activation with the exception of that derived from the tissues; after six to eight minutes of breathing oxygen under a steady state condition this constitutes less than one per cent of the lung volume.

Using calculations suggested by Luft,[8] the admixture of air can be determined; i.e.:

$$\frac{\text{Admixture of air}}{100} = \frac{\text{Inspired nitrogen fraction}}{\text{Nitrogen fraction of air}}$$

By substituting end expiratory nitrogen for inspired nitrogen:

$$\text{Admixture of air} = \frac{\text{End expiratory nitrogen}}{\text{Nitrogen fraction of air}} \times 100$$

Using these formulas, the percentage of dilution, supply oxygen, oxygen from the ambient air, and total oxygen may be derived according to the following calculations:

$$\text{Per Cent Dilution} = \frac{\text{End expired } N_2 \text{ x } 100}{N_2 \text{ of air } (79.03)}$$

% Oxygen from Supply=100%−% dilution

Oxygen from Ambient =Per cent dilution x oxygen contained in ambient air.

Total oxygen=oxygen from supply+oxygen from ambient air.

Calculated inspired oxygen partial pressure$=(P_B-47)$ x Per cent total O_2.

Where: P_B=Total pressure in mm Hg at ambient altitude.

47=Pressure, in mm Hg, of saturated water vapor at body temperature.

III. Results

The oxygen flow of the passenger mask NTPD (normal temperature pressure dry, 70° F.—760 mm-dry) and BTPS (body temperature pressure saturated, 37° C.—ambient—saturated) is shown in Figure 4. The flow to Subject 5 was increased at 29,000 and 35,000 feet during exercise due to a precipitous fall in blood oxygen saturation. Flows to the remaining subjects were adjusted to the minimal values, according to FAR Part 25.

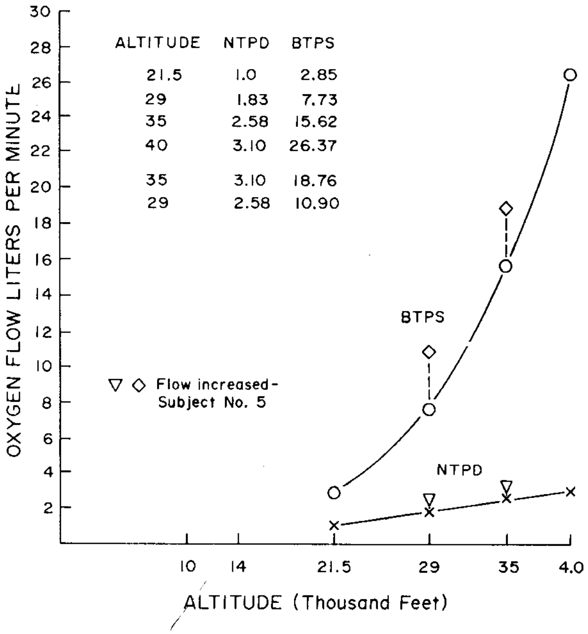


FIGURE 4. Oxygen flow rate.

Heart Rate. Predictably, the mean heart rates increased with exercise, this being more pronounced in the third minute of exercise. There was also an over-all increase in mean heart rate with increase in altitude (Figure 5). These latter increases at similar exercise levels may have been partially due to subject apprehension with increase in altitude; however, the main stimulus appears to be hypoxic stress as indicated by lower blood oxygen saturations and lower oxygen partial pressures at the higher altitudes (Figures 6 and 7). At 40,000 feet, the average tracheal oxygen partial pressure dropped from 86.4 mm Hg at the end of the first minute to 77.2 at the end of the third minute (Figure 7). A typical nitralyzer record is shown in Figure 8. The oximeter earpiece used on Subject

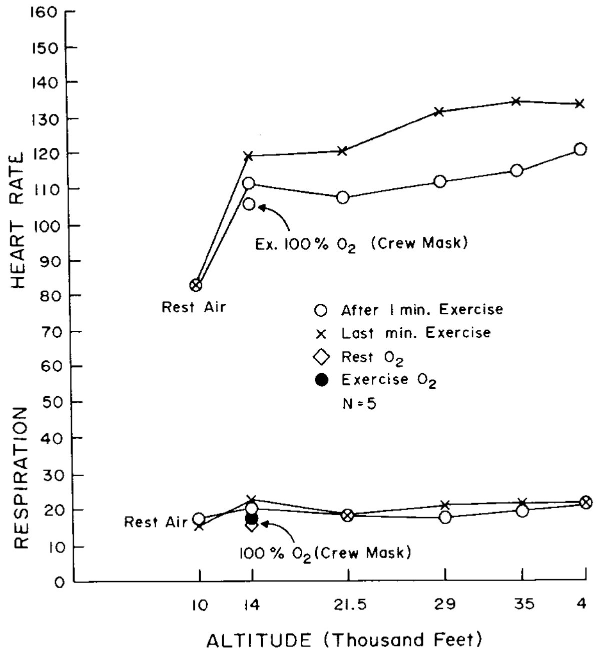


FIGURE 5. Average heart and respiratory rates. Note the increase in heart rate from the first to the last minute of exercise at altitude.

No. 1 appeared erratic and unstable with readings, for example, of 90% blood saturation while breathing 100% oxygen at 14,000 feet. The ear-piece and amplifier were replaced. The average blood oxygen saturation dropped to its minimum value at the end of three minutes of exercise at 40,000 feet (83.6%); however, re-saturation to an average of 90.8% occurred within a short period of time (30–45 seconds) following cessation of exercise (Figure 6).

Blood Oxygen Saturation. The National Aerospace Standard states that blood oxygen saturation baselines established at 10,000 and 14,000 feet should be obtained with the subject engaged at the same level of activity as during the evaluation at higher altitudes. Comparison as the mean blood oxygen saturation of the subjects at rest breathing air at 14,000 feet (93.8%) to that at the last minute of exercise (89.9%) indicates a difference of 3.9% which agrees with results obtained in a previous study.[9] Average blood oxygen saturation levels prior to exercise exceeded the resting baseline (93.8%) at all altitudes. Post-exercise saturations were 1.3% to 4.6% lower than the above baselines.

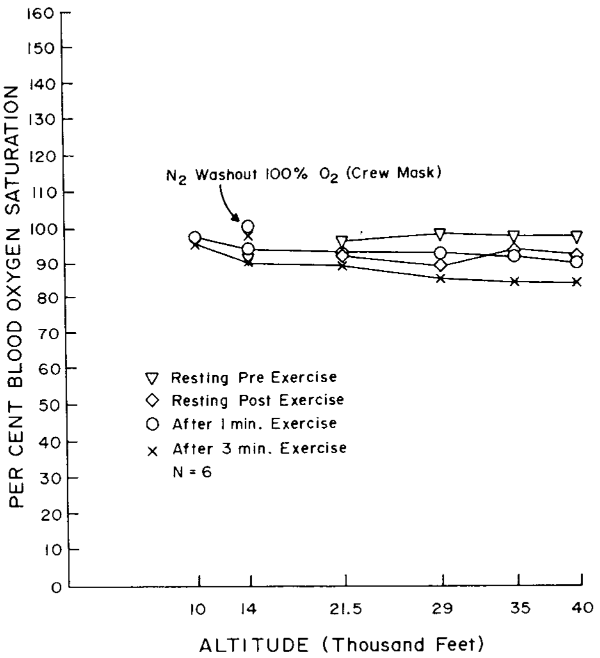


FIGURE 6. Average blood oxygen saturation as determined by ear oximetry. Note the decrease in bloo oxygen saturation from the first to the third minut of exercise.

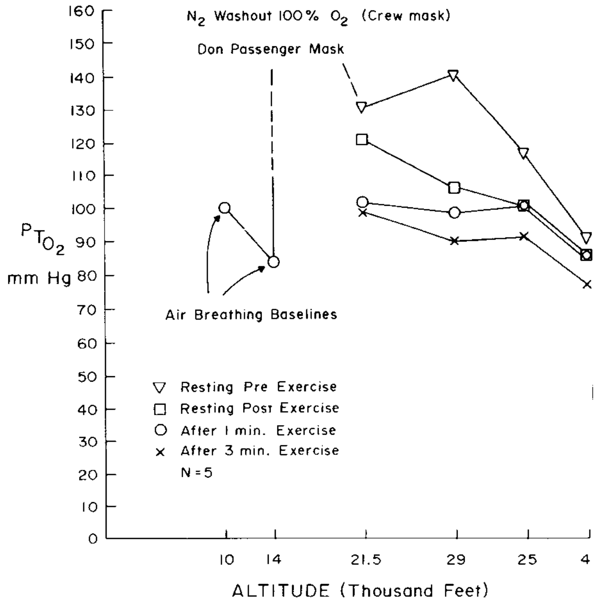
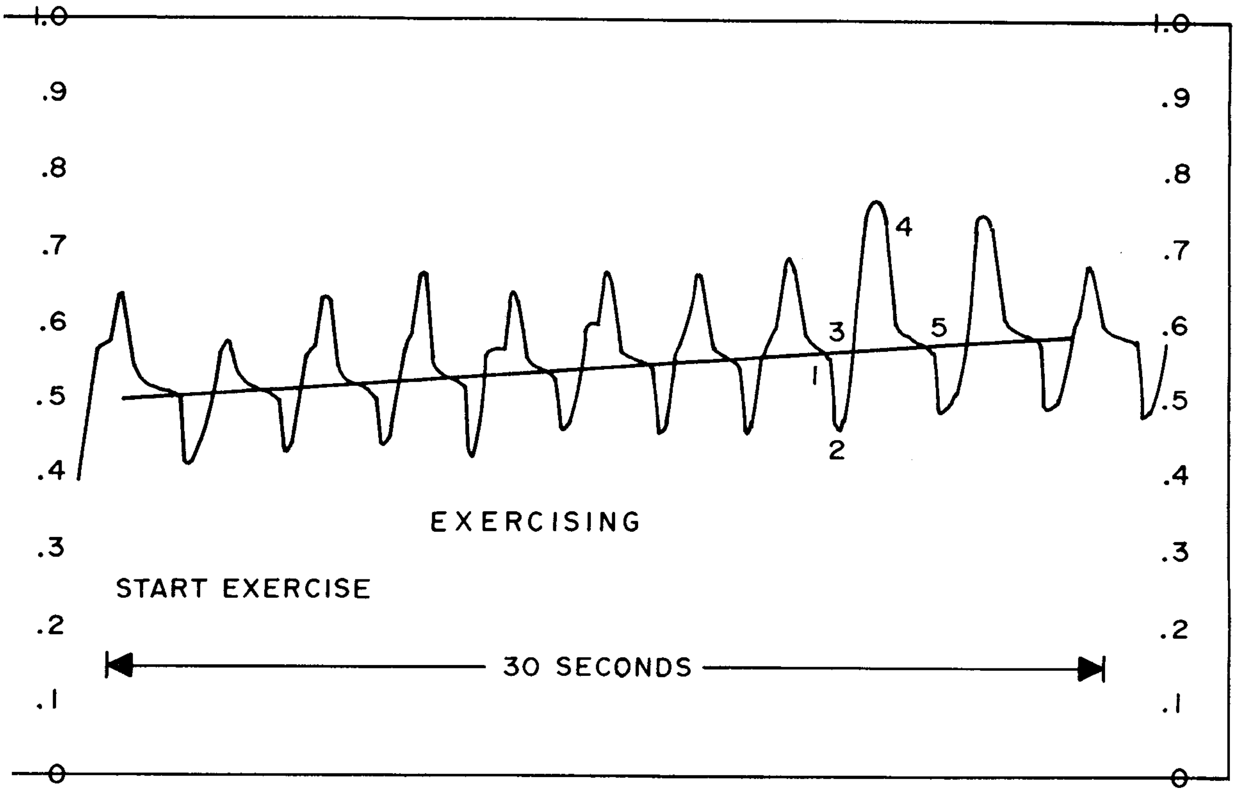


FIGURE 7. Average inspired oxygen partial pressure The air breathing baseline at 10,000 and 14,000 fe is merely a function of barometric pressure; i.e $(P_B–47)$ x 20.94% and is identical irrespective physical activity. The combination of a crew mas and breathing 100% oxygen at 14,000 feet caus the inspired tracheal oxygen partial pressure to off scale to a calculated value of approximate 400 mm Hg.



URE 8. Nitralyzer record of Subject No. 4 at 29,000 feet. Slope of line indicates increased dilution and re-
ed P_TO_2 due to exercise. Numbers 0–1.0 equal 0–100% nitrogen subject to calibration correction. Nitrogen
ve should not be confused with flow, volume or mechanics of respiration. (1) Inspiration of oxygen from
rvoir. (2) Dilution valve activated. (3) Continuing. (4) Oxygen, inspired primarily at (1) above, exhaled.
End expiratory nitrogen concentration.

xygen Partial Pressure. The tracheal oxy-
partial pressure remained above 83.8 mm Hg
ll subjects under all conditions of altitude for
first minute of exercise except for Subject
5, who experienced a drop in P_TO_2
71 mm Hg at the end of the first
ute of exercise at 40,000 feet. In the third
t) minute of exercise, the P_TO_2 of this sub-
dropped to 70, 71, and 64 mm Hg at altitudes
9, 35, and 40 thousand feet, respectively. To
t the precipitous drop in P_TO_2 and blood
gen saturation at 35,000 feet, the flow was
eased from 2.58 lpm to 3.10 lpm; the post-
cise P_TO_2 climbed to 93 mm Hg and 99%.
id recovery after 1½ minutes of exercise, in
h the P_TO_2 and blood oxygen saturation
pped to 64 mm Hg and 80%, was accom-
ed at 40,000 feet by merely discontinuing
cise; this produced a rapid climb in P_TO_2
blood oxygen saturation to 93 mm Hg at
.

espiration. Subject No. 5 was the oldest (age
and the largest (225 lbs.) of the subjects used in this series of experiments. His larger body surface area undoubtedly increased his oxygen consumption in comparison to the other subjects. He exhibited marked increases in respiratory rate from 14 respirations per minute at 14,000 feet (at which time the baseline minute volume was determined) to 24, 25 and 24, respectively, at 29, 35 and 40 thousand feet. A crude estimate of this effect may be made by assuming that the baseline tidal volume (determined during exercise at 14,000 feet) remained constant (1,857 cc) during subsequent ascent to higher altitudes. The indicated increase in respiratory rate would, therefore, increase the baseline minute volume from 26 lpm (BTPS) at 14,000 feet to 44.6 lpm at 29,000 and 40,000 feet, and 46.4 lpm at 35,000 feet, an overall minute volume increase of 48% to 54% above the specified lpm. With these conditions prevailing, the basic design criterion of the mask is exceeded by approximately 50%.

Subject No. 2 exhibited satisfactory P_TO_2 and blood oxygen saturation levels at the end of the first minute of exercise; however, oximetry indi-

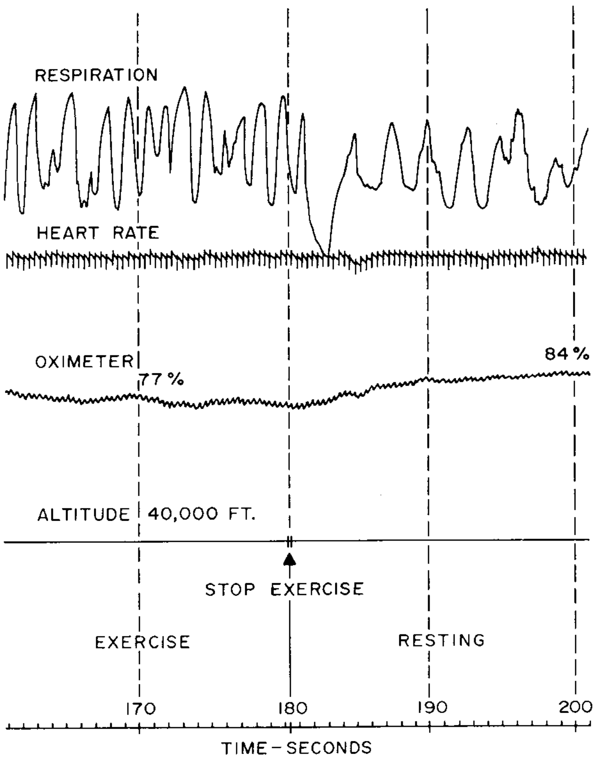


FIGURE 9. Sample. Physiograph recording showing rapid blood oxygen re-saturation following cessation of exercise at 40,000 feet. Subject No. 2.

cated a relatively low blood oxygen saturation (without a commensurate lowering of tracheal oxygen partial pressure) at the end of the third minute at 29, 35, and 40 thousand feet. Rapid recovery of blood saturation following cessation of exercise is shown in a sample recording from this subject (Figure 9). This subject did not exhibit a marked change in respiration when compared to the 14,000-foot baselines; however, he exhibited one of the most consistently elevated heart rates during exercise at 35 and 40 thousand feet, which may be indicative of his response to hypoxic stress, state of physical condition, or both.

IV. Discussion

The National Aerospace Standard (NAS) recognizes 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 designed to measure both of these variables simultaneously.

Exercise time at altitude was held to a mi
mum in order to minimize the probability
bends and to reduce fatigue.

Previously, high altitude evaluations of p
senger masks have been carried out on resti
subjects. In some evaluations, a brief epis
of voluntary hyperventilation took place to
crease minute volumes to 30 liters/minute. T
procedure is recommended in NAS 1179, but
is practically impossible for a sedentary subj
to maintain this level of respiration for m
than 30 to 45 seconds without experiencing sev
symptoms of hypocapnia (dizziness, paraesthe
muscular cramps, etc.).

In addition, voluntary hyperventilation
duces the alveolar and blood carbon diox
partial pressures by the washout effect. By
mere physical reduction of the carbon diox
partial pressure, an increase in alveolar oxy
partial pressure is induced. As pointed
previously, this physiologically unsteady s
may be maintained for only brief peri
Changes in blood chemistry and cerebral bl
flow induced by voluntary hyperventilation
detract from its usefulness in mask evaluati

A controlled and measured work load
used in these experiments to stimulate resp
tion to the 30 liters/minute standard wit
imposing severe changes in respiratory
blood-gas composition.

Admittedly, increased work load produce
increase in oxygen consumption. The leve
work load used in these experiments should
duce an increase in oxygen consumption of
proximately .35 to .50 liters/minute above
resting value.[10]

Neither voluntary hyperventilation nor e
cise is entirely a satisfactory means of eleva
the minute volume; voluntary hyperventila
tends to over-estimate the physiological effec
ness of a mask, and exercise tends to un
estimate this value. The use of exercise, how
increases the margin of safety and assur
that an adequate blood oxygen saturation
be maintained during periods of increased
piration.

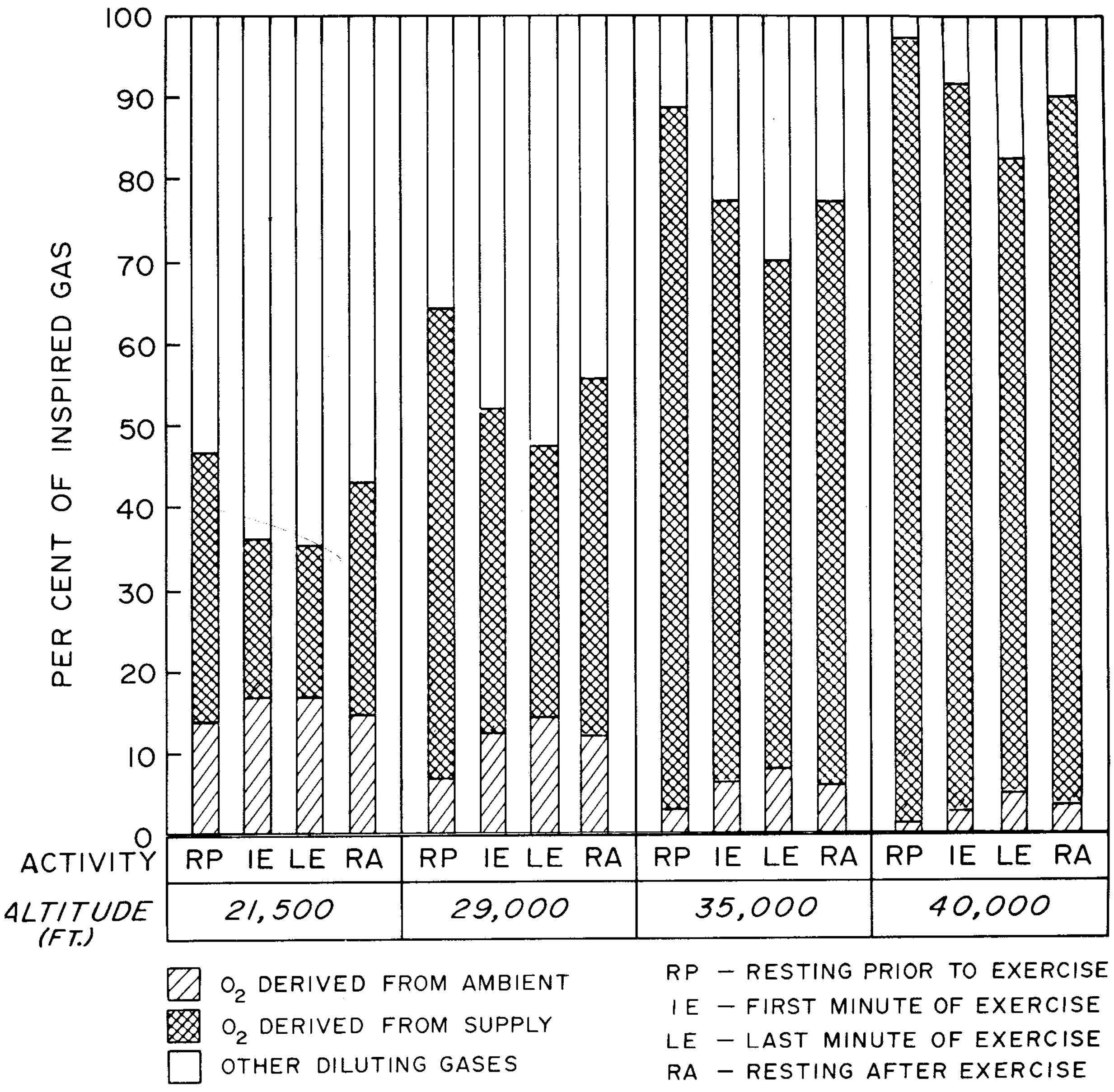
One disadvantage of using exercise in
evaluations at altitude is the increased susc
bility to the development of bends. The d
of denitrogenation, altitude profile, and exp
time must be carefully considered in relati
the use of exercise.

The increased minute and tidal volumes deeloped during exercise impose efficiency requireients of mask performance in excess of similar valuations conducted on the sedentary, resting ubject.

At 40,000 feet, 3.1 liters/minute NTPD equals 6.4 liters/minute BTPS. A subject breathing 0 liters/minute will empty the reservoir bag and raw in air through the ambient air valve. The verage composition of inspired gas is shown in 'igure 10.

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

The ear-oximeter determinations exhibit some degree of variability, depending upon physical activity and subject movement. Fluctuation of the ear oximeter was pronounced during resting and air breathing at 14,000 feet, became more stable with 100% oxygen and exercise at 14,000



URE 10. Histogram showing dilution of inspired gas with ambient air as calculated from the end expiratory nitrogen concentrations.

feet, and again fluctuated to a marked degree at 40,000 feet on oxygen. It appeared that this "hunting" phenomenon was more marked when some degree of hypoxia was present. In general, the ear-oximeter readings appeared to be more stable during exercise than at rest.

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 oxygen 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 leak-free passenger mask, capable of delivering undiluted 100% oxygen to the alveoli throughout inspiration would therefore exhibit maximum efficiency. The resulting oxygen partial pressure, therefore, becomes merely a function of the ambient barometric pressure minus the vapor pressure of saturated gas inspired, i.e.: (P_B-47).

It should be pointed out that a discrepancy exists between the performance of any oxygen equipment evaluated at constant altitude, as presented in this report, and the dynamic changes which occur during rapid decompression. Experiments have been conducted in this area by Bryan and Donaldson,[11][12] but are beyond the scope of this report.

V. Conclusions

1. The average inspired tracheal oxygen partial pressure remained above 83.8 mm Hg under all conditions of rest and exercise at all altitudes except for the third (last) minute of exercise at 40,000 feet.

2. The average blood oxygen saturation during exercise remained above the 14,000-foot air breathing baseline (90.8%) during the first minute of exercise except at an altitude of 40,0 feet where it dropped to 89.6%.

3. Following three minutes of exercise, mea blood oxygen saturation dropped below t 14,000-foot air breathing control baselines at a altitudes by differences of 0.7, 4.8, 5.9, and 6 per cent at 21.5, 29, 35 and 40 thousand fe respectively.

4. The average respiratory rate at the ma mum altitude increased 20% during the fi minute of exercise, and 37% during the la minute of exercise when compared to baseli minute volumes determined at 14,000 feet breat ing 100% oxygen. Providing tidal volumes mained constant, the mean volumes wou approximate 28.8 to 32.8 liters minute. Th were large individual variations, however, wi the 30 lpm minute volume requirements of T C-64 being exceeded by as much as 50%.

5. As in previous evaluations[13][14] larger s jects with increased body surface area exhibit lower blood oxygen saturations and tracheal p tial pressures at a standardized oxygen flow to increased oxygen consumption.

6. An ideal technique for increasing the r piratory minute volume to the levels specified NAS-1179 and TSO C-64 is not readily atta able. Originally formulated by general conc sus of a number of physiologists, physicians, a engineers, these levels are representative of anticipated minute volume that a naive pass ger would exhibit during the excitement of aircraft rapid decompression.

7. Voluntary hyperventilation leads to overestimation of the efficiency of a mask desi whereas evaluation during exercise undere mates mask efficiency within the framework intent of NAS 1179 and the Federal Aviat Regulations.

8. If a moderate degree of physical acti is to be maintained for more than a few minu oxygen flow rates should be increased c mensurate with the anticipated level of activ

REFERENCES

. Federal Aviation Regulations, Part 25. Airworthiness Standards, Transport Category Airplanes.

. Evaluation of Prototype Passenger Oxygen Mask Assemblies, Boeing Airplane Company Report D6–1954, Transport Division, Renton, Washington, Feb. 9, 1959.

. Qualification Test Report, Passenger Oxygen Mask, QTR–59–6. Aro Equipment Company of California, Los Angeles, Calif., Jun. 24, 1959.

National Aerospace Standard, 1179, Revised. Aerospace Industries Association of America, Washington, D.C., Mar. 31, 1961.

Federal Aviation Agency: Technical Standard Order C–64, Aug. 23, 1961.

Oxygen Equipment for Aircraft, Aerospace Information Report 825. Society of Automotive Engineers, New York, N. Y., Feb. 25, 1965.

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, March 1963.

Luft, U. C.: Evaluation of the K-S Disposable Oxygen Mask. Special Project. USAF School of Aviation Medicine, January 1951.

9. McFadden, E. B.: Evaluation of the Physiological Protective Efficiency of a New Prototype Disposable Passenger Oxygen Mask. Office of Aviation Medicine Report AM 66–7, Federal Aviation Agency, April 1966.

10. NASA Life Sciences Data Book, First Edition, June 1962.

11. Bryan, C. A., and Leach, W. G.: Physiological Effects of Cabin Failure in High Altitude Passenger Aircraft. *Aerospace Medicine* 31(4):267–275, 1960.

12. Donaldson, R. T.: A Study of Arterial Oxygen Saturation During Rapidly Changed Barometric Pressure. Ohio State University. M. S. Thesis, 1957, Department of Physiology.

13. McFadden, E. B., Harrison, H. F., and Simpson, J. M.: Performance Characteristics of Constant-Flow Phase Dilution Oxygen Mask Designs for General Aviation, Office of Aviation Medicine Report AM 67–9, Federal Aviation Administration, May 1967.

14. McFadden, E. B., Harrison, H. F., and Simpson, J. M.: Physiological Evaluation of a Cessna Mask Design for Unpressurized General Aviation Aircraft, unpublished report. Office of Aviation Medicine, Federal Aviation Administration, April 1966.