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Superseding AIR825C

Oxygen Equipment for Aircraft

RATIONALE

AIR825C is a comprehensive document covering general information on the various types of oxygen equipment and oxygen systems used on aircraft including basic system design information. These requirements and more are covered in greater individual detail by other SAE documents in an AIR825/1 through AIR825/14 document series.

STABILIZED NOTICE

This document has been declared "Stabilized" by the SAE A-10 Aircraft Oxygen Equipment Committee and will no longer be subjected to periodic reviews for currency. Users are responsible for verifying references and continued suitability of technical requirements. Newer technology may exist.

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FOREWORD

Changes in this revision are format/editorial only.

INTRODUCTION

This report has been prepared as a revision of the previous Aerospace Information Report No. 825A dated December 15, 1974, in order to bring that report up to date by including the latest information available on the design and use of aircraft oxygen systems. Accordingly, it supersedes AIR825A. The publication issue is broken down into six (6) sections as follows:

Section I Physiological Oxygen Requirements in Normal and Hypoxic Environments

Section II Gaseous Oxygen and Oxygen Equipment, Introductory

Section III Continuous Flow Oxygen Systems

Section IV Demand and Pressure Demand Oxygen Systems

Section V Liquid Oxygen Systems

Section VI Charts, Tables and Systems Schematics

NOTE: A proposed Section VII on Cabin Pressurization and Rapid Decompression was transferred to SAE Committee AC-9 for incorporation into ARP1270, “Pressurization Control Criteria, Aircraft Cabin.”

1. SCOPE:

This report provides information on the design and use of aircraft oxygen systems. It explains the physiological oxygen requirements of the human body in both a normal environment and in an hypoxic environment.

It includes an overview of the continuous flow, demand and pressure demand, and liquid oxygen systems. A basic understanding of how each system operates is then specifically addressed in its own titled section.

The charts, tables, and schematics provide a specific example of a theoretical oxygen system design and the calculations showing how that system would meet the regulations established by the FAR's. A comprehensive overview of the theoretical oxygen requirements of the human body at altitude is also provided.

A detailed list of specifications and standards applicable to aircraft oxygen systems is included.

SECTION I - PHYSIOLOGICAL OXYGEN REQUIREMENTS IN NORMAL AND HYPOXIC ENVIRONMENTS

1. An understanding of at least the elementary facts about respiration is a prerequisite for everyone having responsibilities in connection with oxygen equipment for civilian, military, commercial or general aviation aircraft. Respiration is the process by which a living organism acquires the oxygen necessary for its essential cellular functions (metabolism) and discharges gaseous products of those functions (primarily CO_2). In man this process consists of ventilation (inhalation/exhalation), diffusion of O_2 from lungs to blood (and CO_2 from blood to lungs), circulation of blood between lungs and tissues, and diffusion of O_2 from blood to tissues (and CO_2 from tissues to blood). The following is an introduction to this subject, expressed (insofar as possible) in an easily understood manner. (For reference, see Figure 1 and Table 1.)

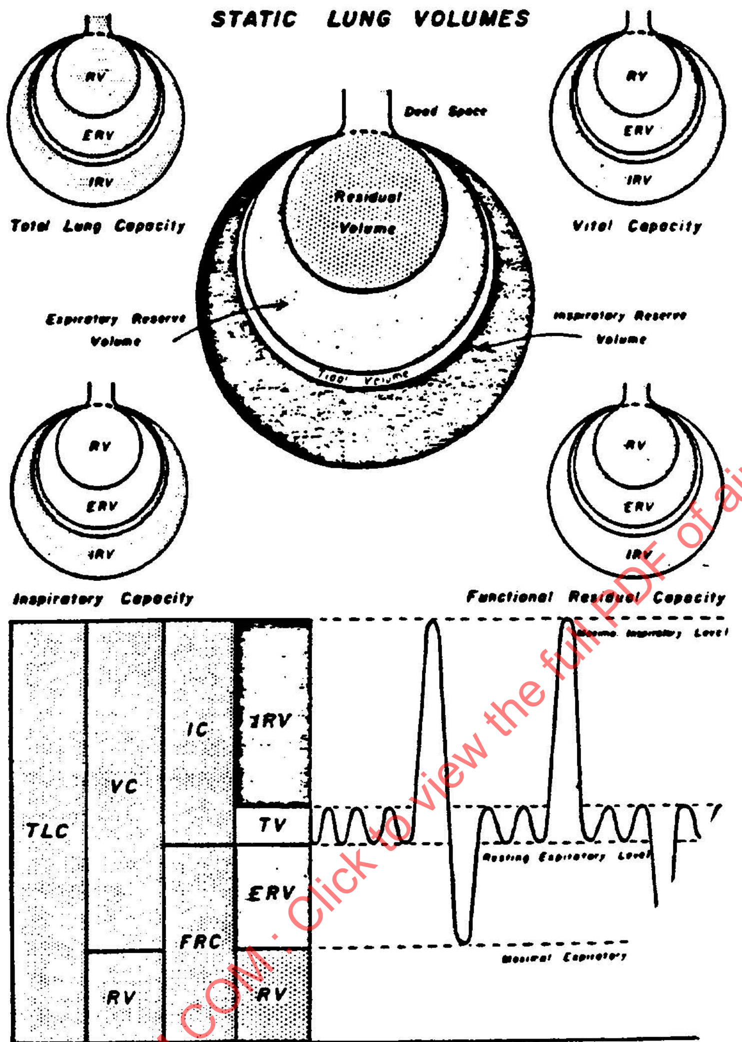
1.1 Definitions and Goals:

Although the work of breathing represents only a small fraction of the total energy expenditure of the body, any additional load imposed upon the physiologic mechanics of breathing by the oxygen equipment will not only disturb the normal breathing patterns but may also cause discomfort and fatigue of the muscles involved in breathing, as well as impose psychological impediment on an almost automatic repetitive physiological function. Every effort must be exerted to minimize impairment of normal breathing.

1.2 Lung Volumes During Breathing:

The quantity of air breathed in one minute is referred to as the minute volume ($\dot{V}$) and is 6-8 Liters in an average healthy normal man at rest. However, respiratory flow is bidirectional within the airways, flowing in (inspiration) and out (expiration) with peak instantaneous flow rates of 20 to 40 liters per minute (LPM) at rest, 80 to 100 LPM in mild exertion. It will increase as exertion and/or anxieties expand peak flow to a maximum of about 500 to 800 LPM (e.g. sneeze or cough). Figure 1 indicates regular evenly spaced respiratory cycles which under normal conditions of respiration is unusual. The normal respiration rate is known as eupnea. Eupnic Respiration is generally irregular in volume, although it may be regular on occasion. There is a normal post expiratory pause following the active-passive cycle of respiration. Ordinarily, inspiration involves an interval of 0.8 seconds, while the expiratory period is 1.2 seconds. Breathing at a rate of 12 times per minute would thus result in a 3 second post expiratory pause. As the respiratory rate increases these three intervals will decrease with the post expiratory pause showing the most marked decrease.

Each breath, in a 70 kg average normal man, has a tidal volume (V_T) (Table 1) of approximately 500 cm^3 (Figure 1) (about 8 cm^3/kg body weight), which at a resting frequency of 12 to 16 per minute (R) results in a total ventilation of 6 to 8 liters in one minute. This is a respiratory minute volume ($\dot{V}$). Moderate activity such as walking leisurely requires more than twice the resting ventilation. The capacity of oxygen equipment should be designed to accommodate the transient peak inspiratory flow rates of 20 to 40 LPM (quiet relaxed breathing) but instantaneous flow rates of 500 to 800 LPM during coughing, strenuous exercises, acceleration or anxiety and excitement (associated with aircraft performance failures or misadventures) can occur and should be considered in system design.



—*Above:* the large central diagram illustrates the four primary lung *volumes* and approximate magnitude. The outermost line indicates the greatest size to which the lung can expand; the innermost circle (residual volume), the volume that remains after all air has been voluntarily squeezed out of the lungs. Surrounding the central diagram are smaller ones; shaded areas in these represent the four lung *capacities*. The volume of dead space gas is included in residual volume, functional residual capacity and total lung capacity when these are measured by routine techniques. *Below:* lung volumes as they appear on a spirographic tracing; shading in vertical bar next to tracing corresponds to that in central diagram above.

Reference: Comroe, J. H., et al., THE LUNG (Second Edition) Chicago: The Year Book Publishers, 1962.

FIGURE 1 - Lung Volumes

TABLE 1 - The Lung Volumes and Capacities

A. VOLUMES - There are four primary volumes which do not overlap (Figure 1):

1. Tidal Volume, or the depth of breathing, is the volume of gas inspired or expired during each respiratory cycle.

2. Inspiratory Reserve Volume (formerly complemental or complementary air minus tidal volume) is the maximal amount of gas that can be inspired from the end-inspiratory position.

3. Expiratory Reserve Volume (formerly reserve or supplemental air) is the maximal volume of gas that can be expired from the end-expiratory level.

4. Residual Volume (formerly residual capacity or residual air) is the volume of gas remaining in the lungs at the end of a maximal expiration.

B. CAPACITIES - There are four capacities, each of which includes two or more of the primary volumes (Figure 1):

1. Total Lung Capacity (formerly total lung volume) is the amount of gas contained in the lung at the end of a maximal inspiration.

2. Vital Capacity is the maximal volume of gas that can be expelled from the lungs by forceful effort following a maximal inspiration.

3. Inspiratory Capacity (formerly complemental or complementary air) is the maximal volume of gas that can be inspired from the resting expiratory level.

4. Functional Residual Capacity (formerly functional residual air, equilibrium capacity or mid-capacity), is the volume of gas remaining in the lungs at the resting expiratory level. The resting end-expiratory position is used here as a base line because it varies less than the end-inspiratory position.

1.3 Breathing Mechanics:

Active, vigorous inspiratory respiration is accomplished by muscular expansion of the chest rib cage, contraction of the muscular diaphragm and accessory muscles of respiration. Quiet inspiratory breathing is mainly due to lowering of the diaphragm muscle by contraction. More vigorous breathing recruits not only the intercostal muscles but other accessory muscles of respiration (strap muscles of the neck, shoulder girdle, abdominal muscles). The work performed in this phase has to overcome (1) the resistance to air flow in the oronasal passage, larynx, trachea, bronchi and bronchioles; (2) the elastic recoil of the lungs; and (3) inertia of the chest wall, abdominal contents (intestine, liver, spleen, etc.) and the abdominal wall. Subject position (standing, sitting or supine), i.e. gravity, G-forces, and tissue densities, influence the importance of these factors. Expiration during normal breathing on the other hand, does not require active muscular respiratory effort since the elastic forces of the lungs and relaxation of the chest wall suffice to expel the inspired tidal volume. This relaxation of the respiratory muscles reverts the chest volume to the initial resting exhalation position. During positive pressure breathing, the normal pattern is reversed and active effort is required to exhale while mask pressure assists in inflating the lungs during inspiration. It is due to this balance of forces and the cyclic nature of the act of breathing that pressure-demand equipment with "safety pressure" requires the least effort and is at the same time the most economical (physiologically, mechanically and for energy). However, transmural airway pressures above 19 mm Hg (10 in H_2O) are abnormal and tax the recipient physiologically and psychologically. His passive exhalation now must become active and he is required to think in order to forcefully expel his inspiratory air. As soon as he relaxes he is again inflated (inspiration). "Torso Restraint", discussed later, is helpful in this type of "reversed"-abnormal-respiratory cycle.

1.4 Respiratory Air Composition:

At sea level the atmospheric pressure is around 101 kPa (14.7 pounds per square inch), which is equivalent to the pressure exerted by a column of mercury 760 millimeters high (in the earth's gravitational field). One of the laws describing the behavior of mixed gases is the law of partial pressures. This simply means that in any given mixture of gases, such as air, at any given total barometric pressure, the partial pressure exerted by each one of the components in this gas mixture is proportional to the volume percent (%) of each component present. Since air (for practical purposes) consists of about 21% by volume oxygen and 79% by volume nitrogen, oxygen exerts a partial pressure of 21% of 760 mm Hg or 160 mm Hg, and nitrogen 79% of 760 mm Hg or 600 mm Hg. Here the term mm Hg refers to the partial pressure (expressed as the height in millimeters of a column of mercury) exerted by each major part of the two gases composing air. (See Section VI, paragraph 6.8 Composition of the atmosphere, page 77.) A small part of our atmosphere, actually around 1% of the air, consisting of the rare gases -- argon, krypton, xenon, and a few others in trace amounts -- has been included in the nitrogen portion. There is also a varying amount of water vapor in the air giving rise to the humidity. This is expressed in terms of percent of saturation or in millimeters of mercury partial pressure exerted by the water vapor present, at a given temperature. Ordinarily the amount of water vapor in inspired air is extremely small and will detract only slightly from the inspired oxygen component. When calculating oxygen partial pressure in the

1.4 (Continued):

expired or alveolar air, carbon dioxide (normally about 40 mm Hg) and water vapor partial pressure at 37 °C (47 mm Hg) -- (which have been added by the lungs to the total alveolar gas volume) -- must be included as part of the total alveolar pressure. Thus these gases must be subtracted from the breathing barometric or mask pressure prior to calculating alveolar oxygen tensions (mm Hg) from inspired gases (air for example).

1.5 Respiratory Gas Passages:

The air we breathe passes into the trachea or windpipe and from there into the lungs (Figure 2). It undergoes considerable changes in composition as it passes through the trachea, mixes with the gases and water vapor already in the lungs, and is again exhaled. First, the inspired air becomes fully saturated with water vapor at body temperature in the nose (passing by the nasal turbinates) and throat so that the delicate tissue in the lungs will not be damaged by drying. It then mixes with the air already in the lungs that contains carbon dioxide and perhaps small amounts of other gases which, like the rare gases, are of insufficient amounts to be of importance here. Sea level, average figures are given below for a sample of air from the trachea (called tracheal air) and from the lungs (called pulmonary or alveolar air), to show the difference in composition. These are typical values measured in young, healthy, non-smoking, disease free individuals. The proportions of these gases are expressed in millimeters of mercury partial pressure, as well as in percent (%):

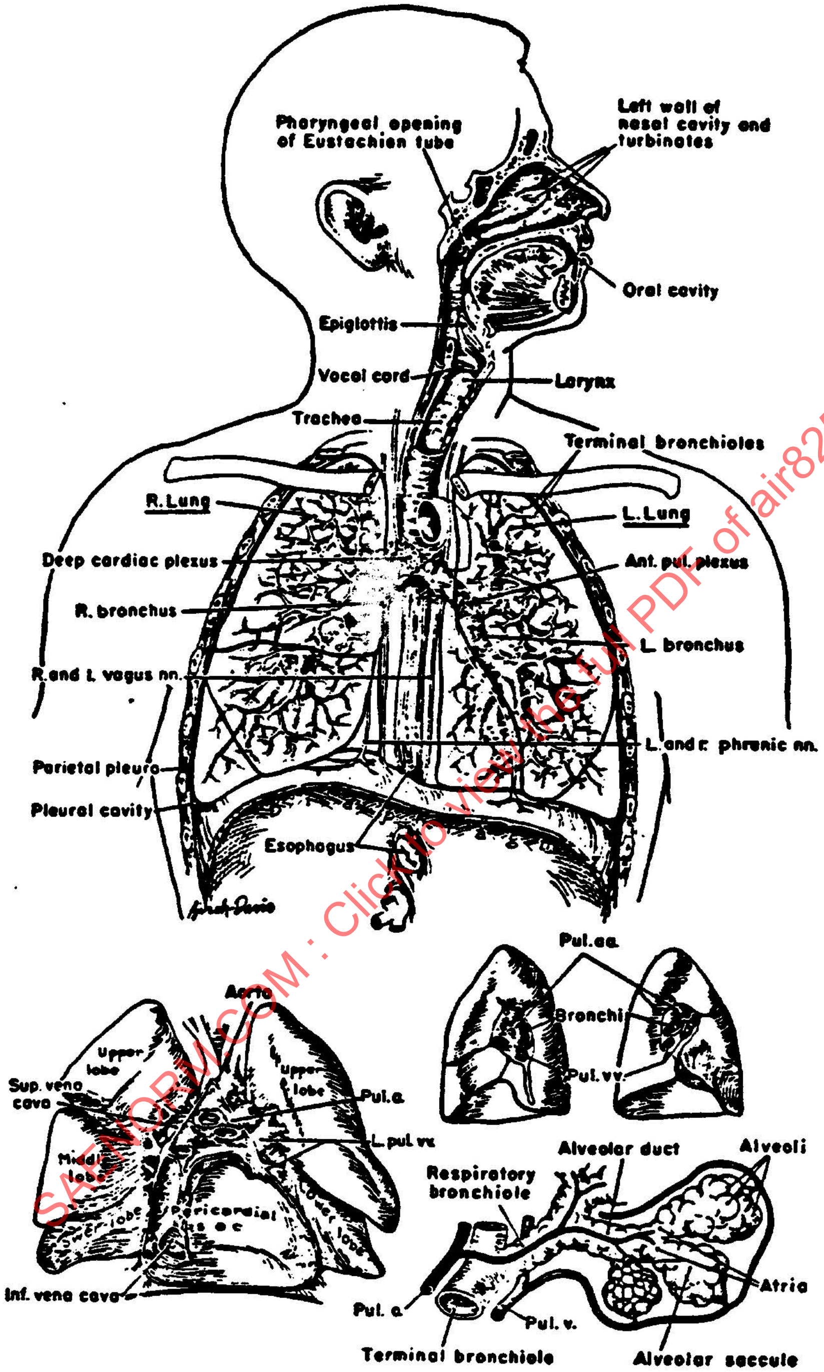
Partial Pressure, mm of Hg (and per cent)

TABLE 2

	Dry Air	Tracheal Air Inspiratory	Alveolar Air (Static) or End Expiratory
Oxygen	160 (21)	149 (19.6)	104 (13.7)
Water Vapor	--	47 (6.2)	47 (6.2)
CO_2	--	--	40 (5.2)
Nitrogen	600	564	569
TOTAL	760	760	760

1.6 Tracheal Partial Pressures:

For practical purposes the inspiratory tracheal partial pressure is generally used as the criterion of oxygen availability to the body because it can be accurately predicted if the barometric pressure and the fraction of oxygen in the inspired gas are known. The figure 149 mm Hg oxygen partial pressure in the tracheal air is derived from the total pressure, 760 mm Hg, minus 47 mm Hg water vapor pressure (saturated air at body temperature), multiplied by the fraction of oxygen (0.21).



Reference: "Dorland's Illustrated Medical Dictionary," 23rd ed., p 1355, Philadelphia: W. B. Saunders Co., 1957.

FIGURE 2 - The Respiratory System: Man

1.7 Alveolar Partial Pressures:

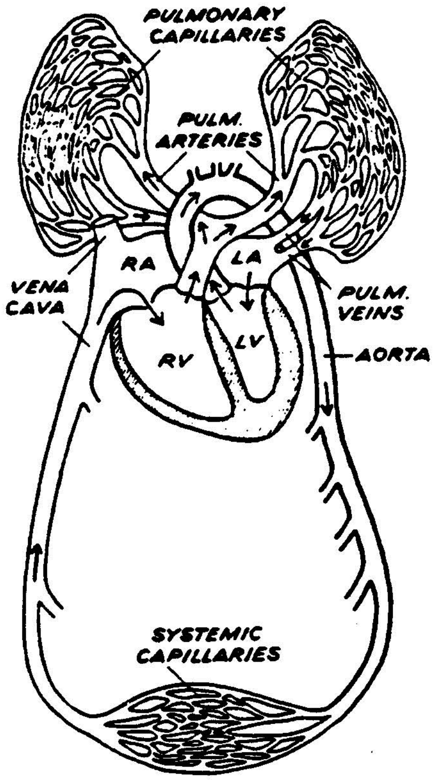
The alveolar partial pressure of oxygen cannot be predicted precisely since it is subject to individual variations in oxygen consumption, pulmonary ventilation and associated pulmonary disease. It must be measured directly from end expired gases by sophisticated instrumentation such as a recording mass spectrometer programmed for expiratory gases.

1.8 Physiologic Oxygen Transport:

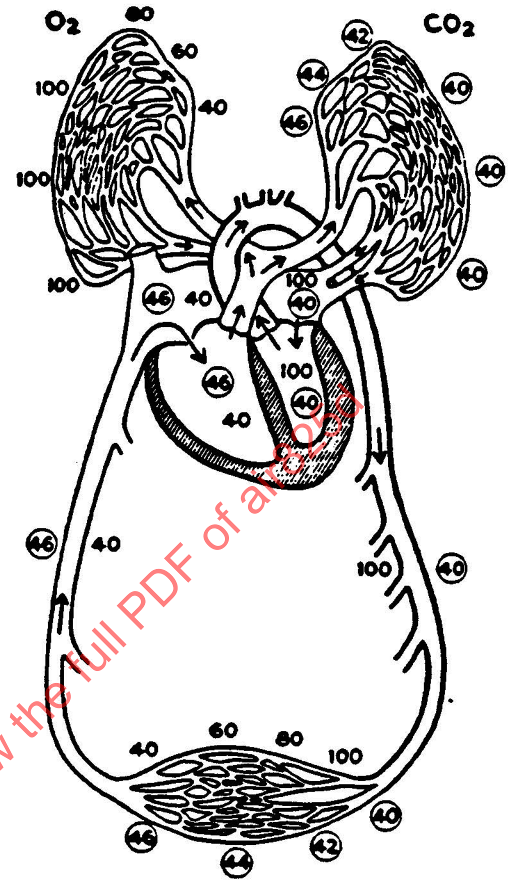
Oxygen in the alveoli diffuses through the thin permeable hydrophilic membrane into the capillaries that envelop the alveoli and thence into the red corpuscles where it binds with hemoglobin. The diffusion rate is proportional to the partial pressure of the oxygen present in the alveoli, intracellular fluid and plasma of the blood. The overall amount of oxygen reaching the blood depends upon several additional factors. These include vascular shunting of venous blood to the arterial side of the circulation without re-oxygenation, diffusion barriers to oxygen at the alveolar membrane (silicosis, pneumoconiosis, other causes of pulmonary fibrosis and/or alveolar membrane thickening -- e.g. tobacco smoking), blood flow differences between the top and bottom of the lung because of gravitational effects, non-blood-perfused alveoli, collapsed alveoli (atelectasis), etc.

On their circuit through the body the red cells, at the systemic capillary tissue level (Figure 3), release a portion of their oxygen load to the body tissue for use in the life sustaining processes (metabolism). This release is aided by the oxygen partial pressure gradient (O_2 higher in capillaries, lower in adjacent tissues) and greater acidity (pH effects) in the adjacent tissues due to CO_2 and other metabolic acids.

Many factors can reduce the efficiency of oxygen loading/transport/release by the blood. Among these are anemia, sickle-cell disease, acidosis, some genetic enzyme deficiencies, and various toxic substances (alcohol, carbon monoxide, many drugs, etc.).



—Schematic representation of the pulmonary and systemic circulations. *RA* = right atrium; *LA* = left atrium, *RV* = right ventricle; *LV* = left ventricle.



—O_2 and CO_2 tensions in pulmonary and systemic blood. Figures in *circles* are CO_2 tensions; others are O_2 tensions.

FIGURE 3

1.9 Oxygen Partial Pressures Related to Altitude:

As one goes to higher altitude, the total air pressure diminishes and with it the partial pressure of each of the various gases. The percentage relationship of the gases remains unchanged however. The following table shows the approximate oxygen partial pressure (mm Hg) while breathing air at various altitudes:

TABLE 3

	Sea Level	1524 m (5000 ft)	3048 m (10,000 ft)	4267 m (14,000 ft)
Air Oxygen Inspired (dry)	160	132	109	93
Tracheal Oxygen	149	122	100	84
Pulmonary or Alveolar Oxygen	104	82	60	44

Chart II is referenced for altitude and oxygen partial pressures. (See Chart II, pages 91-94.)

It is important to keep in mind that the partial pressure of water vapor at body temperature (37 °C) is 47 mm Hg regardless of altitude. The higher the altitude, the greater is the effect of the water vapor component in decreasing the usable oxygen component.

1.10 Hypoxic Recognition:

Normally, individuals living at sea level may become aware of the effects of altitude at about 1524 m (5000 ft) where the diminishing partial pressure of oxygen results in lessened ability to see at low levels of illumination (night blindness). Decrements in other physiological functions are demonstrable under controlled test conditions at around 1829 or 2438 m (6000 or 8000 ft). Red blood cells are no longer able to acquire a full load of oxygen. However, these altitude effects ebb as the body adjusts and acclimates itself so that after a few days the mild symptoms disappear. Nonetheless most individuals going as high as 3048 m (10,000 ft) will notice definite symptoms of altitude sickness, such as tingling, numbness, tunnel vision and night blindness. These will be particularly evident with exercise. Pilots flying at this altitude or above for any length of time should have oxygen enriched air to breathe in order to maintain the partial pressure of oxygen in the trachea and alveoli sufficient to allow the red cells to take up a nearly normal complement of oxygen.

1.11 Hypoxia:

Mild conditions of oxygen want are called hypoxia -- meaning insufficient oxygen. The symptoms usually increase in severity as time of exposure increases. When the oxygen partial pressure in the lungs falls to 30 mm Hg or less, oxygen supply to the tissues (brain in particular) becomes totally inadequate to maintain consciousness.

1.12 Results of Hypoxia:

Whenever the body tissues fail to receive adequate oxygen from the red blood cells, essential life functions are disrupted. Earliest and most apparent are the severe changes in mental function. Even with minor decreases in oxygen supply (as results from 3048 m (10,000 ft) over a period of time) the brain responds with muddled, confused, uncoordinated thinking, euphoria, and poor judgment. Further decreases in arterial oxygen partial pressure will produce mental symptoms of increasing severity culminating in unconsciousness and death if the oxygen level becomes sufficiently low. Early onset of these altered mental functions, which are not recognized by the individual, represents serious hazard to aircrew, and may be the direct or indirect cause of many accidents, particularly in the “pilot error” category. Even small amounts of alcohol can aggravate and intensify these deleterious effects. For those flying at night it should be noted that there is a moderate loss of night vision at the altitude of 1524 m (5000 ft). Aircrew are recommended to use supplemental oxygen above this altitude during dusk, night flights and night landings.

1.12.1 Beards: Airmen who sport beards, mustaches, and/or side burns of the size and type which interfere with mask-to-face-skin contact cannot be adequately protected from hypoxia because of improper mask fit. During inhalation, “inboard” air leakage dilutes the oxygen enriched inspiratory gases. “Safety Pressure” regulator setting will tend to obviate these beard leaks. The presence of a beard will tend to defeat positive pressure ventilation. Consequently, the low tracheal oxygen concentration during aircraft cabin decompression will significantly reduce the airman’s time of useful consciousness. In addition a beard can be a fire hazard, especially in oxygen enriched atmospheres. A beard together with smoking is an extreme fire hazard in an oxygen enriched atmosphere and must be prohibited whenever oxygen is in use.

1.13 Chronic Hypoxia and Adaptation:

People living at high altitudes adapt to the lower pressure and thus become acclimatized. For altitudes above 1524 or 1829 m (5000 or 6000 ft) acclimatization requires a few days to two weeks for healthy, young individuals, and longer for older persons or those exposed to higher altitudes. It is important to know that acclimatization to altitude does not take place as a result of flying, even with daily flying, because continuous exposure is required.

1.14 Oxygen Requirements Between Flight Levels 340 and 425:

When one reaches an altitude of 10,363 m (34,000 ft), the standard atmospheric pressure is only 187 mm Hg. Even if 100% oxygen is breathed at this pressure, there will be an oxygen partial pressure of 100 mm Hg or less in the lungs, after allowance is made for the 87 mm Hg partial pressure exerted by the combined water vapor and carbon dioxide. This is the minimum level of alveolar oxygen partial pressure in healthy, non-smoking persons which will provide a full oxygen load to the red cells. To maintain full oxygenation at higher altitudes, more pressure must be applied to the oxygen which is to be inspired. Pressure breathing masks accomplish this by raising the pressure in the lungs above that of the surrounding atmosphere.

1.15 Oxygen Requirements Above Flight Level 425:

As still higher altitudes are reached using pressure breathing, the mask pressure required to maintain full oxygenation of the red blood cells becomes increasingly unbearable because of the increased internal pressure inside the chest. At that point, counterpressure to the chest wall and remainder of the body must be applied to make such breathing pressures tolerable, to maintain balanced unimpeded blood flow and to prevent actual physical damage to the lung tissue. “Partial pressure” and “full pressure” altitude suits provide this counterpressure: the first by direct mechanical containment using inflatable bladders on most visceral and muscular areas of the body, and the second by containing the body in a gas pressurized enclosure. As long as these measures are able to maintain adequate counterpressure, the internal pressure of the oxygen to be breathed can be kept at a level which will ensure adequate oxygenation of the red blood cells and corresponding adequate vital tissue function. With this type of protective equipment, man can continue to function at altitudes where essentially no ambient pressure exists, as in the vacuum of outer space. The airman is able to perform this feat only by carrying the equipment necessary to maintain adequate oxygen pressure within his lungs while external counterpressure is applied to make normal breathing possible. An alternate approach, of course, is to pressurize the cabin at an altitude equivalent to 1829 to 2438 m (6000 to 8000 ft) which diminishes the need for highly specialized oxygen equipment. The great danger than arises from loss of pressurization whereupon severe hypoxia, as well as decompression sickness, will occur. Decompression sickness occurs in a large number of people after a few minutes' exposure to low ambient pressures and is aggravated by exercise as well as by prolonged exposure. (Discussed and expanded later in paragraph 1.17 et. seq.)

1.16 The advent of aircraft with pressurized crew and passenger compartments for flying above 4572 m (15,000 ft) altitude introduced the additional hazard of decompression in the event of airframe failure. The speed of the decompression depends on the cabin volume (see ARP1270), the area of the failure orifice (cabin or cockpit window, door or wall area), and the altitude or pressure differential between the cabin and ambient air. From such data it is possible to estimate the area of the leaking orifice for a given cabin volume to decompress from 2438 m to 12,800 m (8000 to 42,000 ft) altitude in a given period of time. Orifice size for ten second decompressions between these altitudes for cabin volumes of 7.5 m^3 (265 ft^3) and 17.8 m^3 (630 ft^3) with compressors inoperable can be computed. The orifice size producing the decompression profile (8000 to 39,000-40,000 ft altitude in ten seconds) for the larger cabin (17.8 m^3) is approximately 25% of the area of a single cabin window. In wide body aircraft with enormous cabin volumes, small leaking orifices permit adequate time to respond to the slowly dropping pressure by supplying supplemental oxygen and initiating a safe rapid aircraft descent. If the rupture or structural failure is large (such as door failure, 1.82 m^2 (20 square ft) area, or bomb damage, etc.) in the wide body aircraft, the effects will be a very rapid to explosive decompression. Rapid decompression is observed in small aircraft decompressing through a single 650 cm^2 (100 in^2) cabin window failure. Experimental data indicate that such failures will produce rapid decompressions of less than a second in smaller volume aircraft, ranging up to 30 seconds in larger volume wide-body aircraft. In the smaller volume aircraft decompressions, many passengers initially breathing air at 8000 ft altitude may lose useful consciousness at flight level 390 to 400 even if successful in donning the presented oxygen mask in less than 3 seconds and inhaling the supplemental oxygen provided.

1.16 (Continued):

To prevent severe hypoxia following decompression to FL550, the crew must breathe 100% oxygen at a positive mask pressure of 40 to 60 mm Hg (21 to 32 in H_2O). Torso restraint vests or chest counterpressure garments enable aircrew to tolerate such high breathing pressures for a short time with little hazard of incapacitation or lung damage. Emergency descent must be initiated as soon as possible following decompression because even these extreme measures provide only limited “get-me-down” protection.

1.17 Decompression Lung Damage:

During very rapid decompressions (less than one second) tears through the lung tissue may occur. This event may occur in some individuals if they hold their breath or close their glottis (as in coughing and some speech) at the instant of decompression. As gas held in the alveoli and airways attempts to expand very rapidly, it can rupture tissues and enter the potential space between the inner chest wall and the lung itself. The trapped gas in the chest cavity collapses the lung, occluding pulmonary blood flow, and preventing oxygenation in the alveoli. Carbon dioxide produced by the body cannot be dissipated, and rapid, severe hypoxia and hypercapnia (elevation of carbon dioxide) result. This condition (asphyxia) can become fatal if not treated quickly.

1.18 Decompression Performance Decrement Prevention:

Despite the rapid availability of 100% oxygen from quick donning masks, crew members in small cabin airplanes experiencing rapid decompression undergo substantial performance decrements due to hypoxia. Alveolar oxygen washout (the oxygen reversal phenomenon) which occurs during such decompressions causes brain deoxygenation unless a high concentration of oxygen is being breathed prior to the decompression. Rapid decompression also accelerates carbon dioxide diffusion into the alveoli, increasing alveolar CO_2 partial pressure which further lowers alveolar oxygen partial pressure. Current experimental data clearly show that moderate or severe performance decrements are virtually inescapable under such circumstances. Therefore, for flights at or above flight level 350, the pilot in control of the small cabin volume aircraft must wear a demand oxygen mask supplied with 100% oxygen or an oxygen-air mixture as determined by a properly functioning dilution regulator. Should cabin pressure altitude exceed flight level 390, this will assure his continued skill and judgment by preventing hypoxia in these excessively low oxygen partial pressures.

The higher the final altitude and the longer the interval between the start of a rapid decompression and the inspiration of 100% oxygen, the greater is the magnitude of the hypoxia. This is minimized by a higher alveolar oxygen partial pressure existing at the start of decompression, and the resulting higher alveolar oxygen partial pressure remaining at the completion of the decompression. Therefore, the partial pressure of the oxygen in the gas breathed by the aircrew in routine flight should approximate breathing air at ground level. However, the equipment required to provide such a cabin pressure at altitude would impose unacceptable weight penalties on aircraft performance and operation. Breathing air at an altitude of 2438 (8000 ft) would provide an alveolar oxygen partial pressure (PAO_2) of 70 mm Hg (assuming alveolar CO_2 pressure of 40 mm Hg), which is the minimum value acceptable for an operating air crew during routine flight. When the crew wears demand oxygen breathing equipment, ground level PAO_2 (109 mm Hg) can be easily provided.

1.18.1 Beards: Beards on operational aircrews usually prevent protective breathing equipment from functioning properly. The inability to provide a tight oxygen mask fit on the bearded face prevents supplying the airman-crew member with suitably oxygen enriched breathing gas to preclude hypoxic decrement in performance. The dilution effect of hypoxic ambient gases to the 100% oxygen mask supply is quickly evident in the decrement of airman operational performance. Adequate protective breathing provisions should, in the event of a loss of cabin pressure, prevent any resultant hypoxia from impairing the performance of aircrew members having essential duties to perform immediately following decompression.

1.19 Aeroembolism:

Rapid decompression experienced with failure of the pressurized aircraft cabin, especially in the smaller aircraft can rapidly lead to aeroembolism (small gas bubbles in the blood vessels). The multiple bubbles found in aeroembolism impair and block blood flow to body parts supplied by the obstructed blood vessel (similar to a vapor lock). If the organ or body parts supplied by the occluded vessel is vital (brain, spinal cord, and/or heart), sudden loss of oxygenated blood perfusion would be rapidly fatal. In other body parts, such as muscle, bone, liver, kidney, spleen, teeth, and joints, disabling pain may well be initiated such that the airman is totally non-functional although still alive. Correction of aeroembolism by rapid recompression is successful if time permits.

1.20 Decompression Sickness:

By definition decompression sickness includes all ailments, excluding hypoxia, associated with barometric pressure changes. Aeroembolism is a form of decompression sickness discussed in 1.19. These ailments manifest themselves as ear pain, sinus blockage and pain, abdominal gas expansion, toothache, bends, chokes, skin sensations or paresthesia, and other neurological symptoms.

Consideration of these effects of barometric changes may be divided into the general topics of trapped gases and evolved gases (see Table 4).

TABLE 4 - Summary of Types, Symptoms, Occurrence and Treatment of Decompression Sickness

Dysbaric Condition	Symptoms	Occurrence	Treatment
Paresthesia (Creeping)	Tingling, itching, cold and warm sensations of skin	During ascent	Descend
The Bends	Pain in and about the joints: possible collapse	During ascent	Descend and refer to flight surgeon
Chokes	Burning sensation beneath sternum; nonproductive cough; sensation of suffocation; collapse	During ascent	Descend and refer to flight surgeon
Aerotitis	Hearing becomes dull; fullness in the ear; pain; severe cases: damage and possible ear drum rupture.	Usually during descent; occurs during ascent when individual has upper respiratory infection or other similar infection.	Swallow, yawn cough. Valsalva[1] and ascend to higher altitude; spray with vasoconstrictors.
Aerosinusitis (Sinus Pain)	Pain; frontal sinus; pain in forehead; cheek sinus; pain in cheekbones, may be referred to teeth.	During ascent and descent	Level aircraft and descend; vasoconstrictors descend slowly; if occurs on ascent, return to ground level.
Gas Expansion (G I Tract)	Discomfort, pain, interference with respiration severe cases; lowered blood pressure, possible collapse and shock.	During ascent usually above 25,000 feet; in rapid ascent may occur as low as 15,000 feet.	Descend. If marked, level aircraft and massage area. If ineffective, individual should return to ground level.
Aerodontalgia (Toothache)	Pain in the area of the affected tooth.	During ascent (usually between 5 to 10 thousand feet). Occasionally during descent.	Level aircraft and descend. Refer to dentist after flight.

[1] Valsalva's maneuver is an attempt to forcibly exhale with the nose and mouth closed in order to equalize the atmospheric pressure over the middle ear tympanic membrane.

1.20.1 Trapped Gases: The gases trapped in the middle ear, sinuses, teeth, and gastrointestinal tract expand or contract (increase or decrease in volume) in accordance with Boyle's Law, which states that the volume of a gas is inversely proportional to the pressure of the gas if the temperature remains constant. This means that as the pressure decreases, as it does when we go to higher altitude, gases expand or increase in volume. Applied to a dry gas, approximate values for increase in volume will be as multiples of the denominator of the fraction of the atmosphere considered. For example, at 1/2 atmosphere (5486 m = 18,000 feet) the volume of a gas will be twice that at sea level: at 1/4 atmosphere (10,363 m = 34,000 feet) the volume will be four times that at sea level. However, in calculating expansion of gases saturated with water vapor (as in the body cavities), the actual increase in volume is greater than that given for dry cases. The following equation will explain how expansion for wet or saturated gases occurs. Let V_1 represent the initial volume; V_2 the final volume at any altitude; P_1 the initial pressure; and P_2 the total pressure at the final altitude concerned. Water vapor exerts a constant pressure of 47 mm Hg in saturated gas at body temperature. You then solve the volume change equation

$$V_2 = \frac{P_1 - 47}{P_2 - 47}(V_1)$$

to calculate the expansion of a wet gas at 5486 m (18,000 feet) from initial conditions at sea level.

$$V_2 = \frac{760 - 47}{380 - 47}(V_1) = 2.14\ V_1$$

The gas expansion of 18,000 feet would then be 2.14 times the volume at sea level. This calculation shows that a wet gas will expand slightly more than a dry gas.

1.20.1.1 The Ear: Of all the body cavities, the ear can be expected to cause trouble most often in flight. Training in clearing the ears will alleviate most of these conditions. With an infection or inflammation of the naso-pharynx, difficulty may be experienced and the airman or passenger should avoid flying.

The middle ear is a closed cavity except for an opening, called the Eustachian tube, which connects with the nasopharynx. With ascent, decreasing atmospheric pressure results in the expansion of the air trapped in the middle ear and the ear drum bulges slightly. Such pressure is normally equalized by escape of some air out of the Eustachian tube. This escape will be noticeable to the individual by a faint popping sound in the ear as the drum snaps back. Because of the structure of the Eustachian tube, equalization of pressure in the ears on descent is more difficult than on ascent. The opening of the Eustachian tube in the naso-pharynx is similar to a flutter or flap valve and although the air is readily forced out of the middle ear, it is more difficult to force the air back in on descent. A cold or similar infection may cause the opening of the Eustachian tube to become inflamed, thereby blocking the passage of air. Increasing pressure of the atmospheric air pushes the ear drum inward so that a retracted drum results. Continued pressure irritates the membrane and it becomes red, swollen and painful. This interferes with hearing and if the drum is stretched far enough, rupture of the membrane may result. The pressure differential may also affect the inner ear mechanism and produce vertigo.

1.20.1.1 (Continued):

Swallowing, yawning, and stretching the neck all aid in opening the eustachian tube and allowing air to equalize the pressure in the middle ear. If these actions fail, the ValSalva or Frenzel maneuver will often cause equalization to take place. This maneuver consists of closing the mouth, holding the nose shut and gently blowing to force air up the eustachian tube. If the ears are so completely blocked and this procedure does not aid the condition, ascend several hundred feet and try to clear the ears again. The important thing is that the ears be cleared frequently upon descent. If clearing is delayed until pain and discomfort are felt, the task becomes more difficult. Use of nose spray and drops is often beneficial. All sleeping personnel should be awakened upon descent since clearing of the ears is not automatic.

1.20.1.2 The Sinuses: As in the ear, air-filled spaces in the skull usually ventilate freely except in cases of a cold when the membranes become swollen and prevent passage of air from the ducts that open into the nose. Be sure the nose and throat are clear before takeoff and again before letdown. Here again, nose spray or drops may be of great value.

1.20.1.3 Gastrointestinal Tract: Gas taken into or evolved in any part of the gut behaves in accordance with the same laws that affect the ears and sinuses. Gas will escape readily at either end of the alimentary canal but expansion in the rest of the tract may cause pain and discomfort. Trapped gas in the intestine will expand in accordance with Boyle's law and at body temperature this expansion may become severe enough to cause such pain as to bring on shock conditions. The only cure for trapped gas expansion is to descend to a lower altitude. Prevention is more important and care should be taken not to eat or drink foods that are known to cause gas in the digestive tract.

1.20.1.4 Teeth: Pain in the teeth, occurring as a result of exposure to lowered barometric pressures, is called aerodontalgia. Some cases of tooth pain are actually due to pain referred from the sinuses. The mechanism which is responsible is somewhat obscure. Some cases of tooth pain and loss of fillings at altitude are believed to be due to the subjects unconsciously increasing their biting force and grinding their teeth together, particularly during the emotional stress. A pocket of gas trapped under a faulty filling and located very near the tooth pulp cavity might cause tooth pain by expanding and creating pressure on a nerve (pulpitis).

1.20.2 Evolved Tissue Gases: The amount of any gas dissolved in the blood and tissue fluids of the body is directly proportional to the pressure of that gas (Henry's Law). With the decreasing pressure that occurs at altitude such gases come out of solution. These gases are normally transported by the blood passing the alveolar membrane of the lung. The gases come out of solution at the alveolar boundary, pass into the lung, and thence to the outside atmosphere. When one ascends to altitudes above 9144 m (30,000 feet) while breathing air, the fluids of the body release their dissolved gases more rapidly than the blood can carry them off.

Bubbles may also form in the body tissues following rapid decompression. Such bubbles outside the blood vessels, especially in poorly perfused areas such as joints, can produce pain. Recurring decompression exposure can lead to degenerative tissue changes.

1.20.2 (Continued):

Treatment to correct these bubble-produced dysbaric episodes is recompression to one atmospheric pressure. Sometimes, in decompression shock, recompression to 2 to 3 atmospheres is required and will be life saving. Decompression shock results from bubble formation in extravascular (outside the blood vessels) tissues (brain especially) and is resistant to resolution when reexposed to sea level recompression.

Nitrogen bubbles fall into this category, requiring increased pressure (2 to 3 atmospheres) to drive the nitrogen bubbles back into solution. Their evolution in this situation is most likely from fat tissue cells throughout the body where nitrogen is most soluble but only with a very slow solubility time constant.

1.20.3 Bends and Chokes: These conditions are brought about by decreasing barometric pressure which results in the release of gases, primarily nitrogen, from the various body fluids and tissues. Bends were first encountered by caisson workers and deep sea divers. The reduction in pressure that occurs when a person comes up to the surface of the water (1 atmosphere pressure) from a depth of 10.3 meters = 33.9 feet (2 atmospheres), is similar to that which occurs when one goes from sea level to 5486 m = 18,000 feet (1/2 atmosphere).

The exact mechanisms that produce the symptoms are not fully understood. It is known that the inert nitrogen is a primary factor and that it is difficult to dispose of the excess gas rapidly, with decrease in pressure favoring its release from solution. This is particularly true of tissues which are poorly supplied with blood vessels and that dissolve large amounts of the gas (i.e., fat tissues). All the gases evolved or released from solution may be disposed of by passing into the blood and then diffusing through the lung alveoli for loss by expiration. The release of gases in excess of what can be readily disposed of in this manner results in the formation of gas bubbles in the tissues and blood stream. The first symptoms rarely occur below 9144 m (30,000 feet) but increase above that level with prolonged exposure. At first there is migratory pain in an extremity or joint. This symptom is associated with the bends. With increased altitude, the pain usually becomes more intense and may lead to vascular changes indicating shock conditions. If despite increasing pain the subject remains at altitude or ascends higher, he will probably eventually collapse.

The best cure for bends is immediate descent to ground level and concurrent treatment with 100 percent oxygen. Perhaps compression therapy may also be employed until all symptoms disappear. Breathing 100 percent oxygen for one-half hour before takeoff and using 100 percent oxygen throughout the flight will aid in preventing the bends by allowing nitrogen dissolved in tissues to be “washed out”.

Another symptom of decompression sickness, “the chokes,” occurs when escaped gases involve the lung vessels. There is a deep substernal burning, a nonproductive cough arising from deep within the chest, and a sense of suffocation and apprehension. As in bends, descent to lower altitudes (6096 m = 20,000 feet) usually gives relief, but symptoms may persist to ground level and should be treated until they disappear.

1.20.3 (Continued):

Remember that while bends rarely occur below 10,363 m^2 = (30,000 feet), incidence increases with rapid rate of ascent, prolonged duration at altitude, exercise, age and obesity. Very slow ascent (30 m/min, 100 ft/min) and breathing 100 percent oxygen on the flight will help prevent most symptoms of evolved gases.

1.20.4 Paresthesia and Skin Rashes: Paresthesia (burning or itching sensations) and skin rashes are mild symptoms which occasionally occur and are made worse by exercise and scratching. They are assumed to be due to small gas bubbles in subcutaneous fat or in tissue adjoining nerve endings in the skin.

1.20.5 Flying Following Scuba Diving: Evolved tissue gases (1.20.2) become more medically significant and symptomatic to airmen at hypobaric altitudes following Scuba diving. The National Oceanic and Atmospheric Administration (NOAA) recommend in their diving manual, safety rules for divers who intend to fly as passengers. Any diver who has completed any number of dives on air and decompressed following U.S. Navy standard air decompression tables should wait at sea level breathing air for the computed surface internal that is specified for Group D divers in U.S. Navy Repetitive Diving Table. The aircraft cabin atmosphere must not exceed 8000 feet altitude.

While decompression sickness may, in some rare cases, occur up to 24 hours after exposure to pressure, the vast majority (95 percent) will be evident within 3 hours; one percent will be delayed over 6 hours. It is therefore important that a diver who is flying an aircraft delay his flight for 24 hours to preclude symptoms and signs of decompression sickness.

SECTION II - GASEOUS OXYGEN AND OXYGEN EQUIPMENT, INTRODUCTORY

2. OXYGEN:

Current aircraft breathing oxygen systems may utilize either gaseous or liquid oxygen.

a. Gaseous Oxygen: Gaseous oxygen in the atmosphere is colorless, odorless, and tasteless. It comprises about 21% of normal air by volume and is about 10% heavier than air. Above its critical temperature of -180.4 F (-118 C), oxygen can exist only as a gas regardless of the pressure exerted upon it. Breathing oxygen quality is specified by Military Specification MIL-O-27210.

b. Liquid Oxygen: For information on liquid oxygen, see Section V.

2.1 Oxygen Equipment:

Oxygen equipment to fulfill man's physiological needs in aircraft falls into two general categories, fixed and portable. Fixed equipment is generally provided in those aircraft in which oxygen is frequently required or many passengers are involved. Whether these aircraft have portable equipment in addition depends on FAA requirements for the crew and passengers supply and whether there is a requirement to move from one fixed oxygen station to another.

Cockpit fixed equipment is mounted on the control console or any other convenient location within easy reach. Gauges, indicating instruments, and regulators are placed together and located in the pilot's or co-pilot's normal field of vision so that he can readily see the gauges when in a normal flight position and with minimum interference to his other flight duties.

Portable oxygen equipment consisting of a cylinder of oxygen, a control valve and regulator, and mask are provided for one or more of the crew members where movement of the crew to various stations is involved. Portable equipment is also required for passengers on aircraft not having fixed oxygen installations for first aid use.

2.2 Both portable and fixed oxygen equipment can be obtained for continuous flow, demand flow, diluter-demand and pressure-demand types of oxygen systems.

2.2.1 Continuous Flow Equipment: As its name indicates, continuous flow oxygen equipment provides a continuous flow of oxygen to the mask. There are several types of continuous flow systems ranging from the simplest to more complex systems which afford varying degrees of oxygen economy. At lower altitudes where pure oxygen is not required, air can be added to the mixture of gas delivered into the mask by a controlled means. During inhalation, oxygen flow from the regulator is supplemented by the air which enters through these ports. The amount of air entering the mask depends on the rate of oxygen flow and the rate at which the user inspires. A more complex system would include a gas reservoir in addition to the air ports.

2.2.1 (Continued):

The reservoir is used to collect oxygen during the exhalation phase and permits a much higher inspiratory rate of flow before air dilution takes place. Some systems are designed to collect a fraction of the expired gases for use during the following inspiration. These systems are known as rebreather or economizer circuits. The primary disadvantage of the constant flow system is its inability to adjust itself automatically to various levels of physical exertion of the aircrewman in aircraft. The regulator output for various altitudes can be controlled automatically or by a manual adjustment. This system has been used for many years. It is probably the simplest from a design, cost, weight, and maintenance standpoint and offers reasonable safety for brief periods at altitudes as high as 40,000 ft (12,192 m). For prolonged protection, continuous flow equipment is generally regarded to be adequate up to 25,000 ft (7620 m).

2.2.2 Demand Flow Equipment: Demand flow equipment can be straight demand (a system which delivers pure oxygen) or can be obtained with an air mixing feature (diluter-demand) to conserve oxygen. The distinguishing feature of the demand system is the outlet control valve in the regulator which responds to minute changes in pressure. The slight negative pressure (referenced to ambient) created within the mask at the onset of inspiration opens the valve and permits oxygen flow to pass into the mask until the end of inspiration. At this point the mask pressure has become slightly positive and the valve shuts off the flow. In this manner the demand system operates as the name implies, on demand, supplying flow at the rate required by the user and conserving the oxygen supply during the entire exhalation phase of each breathing cycle.

2.2.3 Pressure-Demand Equipment: Pressure-demand equipment varies from other oxygen equipment previously discussed which provides an oxygen enriched atmosphere for breathing. The technique of increasing the concentration of oxygen can be successfully used up to an altitude of approximately 35,000 ft (10,668 m). Pure oxygen delivered at this altitude will produce the same effect as breathing air at 5000 ft (1524 m). Beyond 35,000 ft (10,668 m), however, it becomes necessary to increase the pressure of the oxygen delivered to the mask in order to provide a 5000-ft (1524 m) equivalent altitude. This is the purpose of the pressure-demand system. Pressure-demand regulators function very much like demand regulators. They can be obtained with or without provisions for air dilution at altitudes below 34,000 ft (10,363 m) where a mixture of air can be tolerated for reasons of economy.

2.2.3 (Continued):

A regulated positive pressure of 100% oxygen is delivered to the outlet and carried to the mask through appropriate tubing and connections. In this manner the lungs are in effect supercharged by the differential pressure between the mask and the surrounding barometric pressure. At lower altitudes the same differential pressure would be more noticeable due to the higher total absolute pressure, but in rarefied atmospheres the total density of the gas even with supercharging is sufficiently low to be tolerable. However, there are disadvantages. The pressure difference is not counterbalanced as would be the case in a pressurized compartment, and this lack of counterbalance does present the possibility of a decrease in cardiac output. In addition, there is an increased effort in breathing. Under normal conditions, the body exerts an effort during inhalation only, and exhalation merely involves relaxing the breathing muscles. During pressure breathing, the reverse is true; exhalation requires effort and inhalation occurs as the muscles relax. Between these two extremes it would seem that a mid-point could be established which would involve less work than either of the extremes. Effortless breathing could then be produced. In actual practice such a condition has not been reached, but in comparing the effort involved in breathing between the demand and the pressure-demand system it can be said that breathing under slight positive pressure is certainly close to effortless. According to Fenn (see paragraph 2.4), there is an intermediate pressure of 3.5 mm Hg where both expiratory and inspiratory work occur; the sum total work, however, is less than the inspiratory work experienced under normal conditions.

As mentioned in paragraph 2.2.2, oxygen flow in straight demand oxygen equipment does not occur until a negative pressure is created by the process of inhalation. The time lag and suction should be minimized between the instant that inhalation commences and new oxygen is forced into the user's mouth. This depends on the length of connecting hose from the regulator, the inside diameter and the number of bends in the hose, the surface condition of its internal bore and the pressure differential required to open the oxygen delivery valve in the regulator. Obviously this lag in response can be reduced by shortening delivery hoses and using regulator designs which possess extremely sensitive valve opening characteristics. It is not always possible to shorten the delivery lines from the regulator to mask, and a regulator with extreme sensitivity will more often than not be unstable in its operation and difficult to maintain. Although not designed primarily for this purpose, the pressure-demand system offers a neat solution to this problem also. In modern oxygen systems the connecting hose problem has been eliminated by using miniature man-mounted demand regulators.

2.3 Figure 4 shows a schematic diagram of a typical demand regulator and its associated controlling mechanism. The outlet is connected to the aviator's facepiece. On inhalation, the diaphragm "a" is displaced downward by the differential pressure created across the diaphragm. Appropriate vent holes "b" in the top of the chamber "A" permit a free exchange of air in and out of the chamber as required when the diaphragm is displaced. Through an appropriate valve linkage "c" diaphragm movement is translated into a reduced linear movement of the valve stem, opening the valve "d" which communicates with chamber "C" and allows a controlled flow of oxygen through chamber "B" into the outlet.

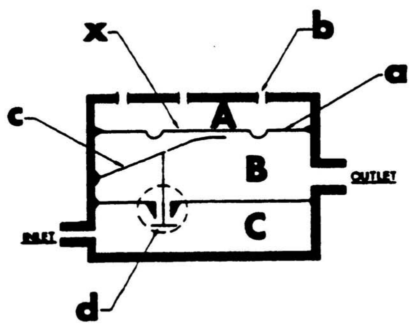


FIGURE 4 - Typical Demand Regulator

2.3 (Continued):

The application of a fixed downward mechanical force at point “X” would have the same effect on the valve as suction applied to the outlet. The pressure of gas developed in chamber “B” will depend on the force applied and the area of the diaphragm. As an example, a force of one pound (4.4 N) applied to point “X” will be distributed equally over the effective area of the diaphragm. An effective area of 5 square inches (32.26 cm^2) would, therefore, produce a pneumatic pressure of 0.20 psi (1.4 kN/m^2) at the outlet. This example and the pressure resulting would only hold under static conditions as occur during exhalation. In the inspiratory part of the aviator’s breathing cycle, however, the pressure developed at the outlet or within the mask will depend on the capacity of the valve and the composite resistance of the entire gas flow passages from the valve to the mask. This method which distinguishes the pressure-demand system from the straight demand system can be used to produce a slight positive pressure within the face mask; the normal lag in regulator response to inhalation is eliminated with gas flow commencing simultaneously at the onset of inhalation. Details of designs vary considerably; however, the principle described is common to all pressure-demand systems. The force applied on the diaphragm is usually accomplished by use of a spring or pneumatic loading. The pressure-demand system, therefore, serves the purpose of producing a flow of oxygen immediately on demand without the attendant lag of the suction demand system. This system is by far more comfortable for breathing and the introduction of positive pressure eliminates all inward leakage of air into the mask and its connecting tubing.

2.4 Bibliography:

Fenn, W. O., Pressure Breathing: Summary of a talk given at a conference held at the Aero Medical Laboratory at Wright Field, October 16, 1945; published in Air Force Technical Report No. 6528, Studies in Respiratory Physiology, prepared by Fenn, Otis and Rahn, August 1951, Wright-Patterson Air Force Base, Ohio, pp. 128-129.

SECTION III - CONTINUOUS FLOW OXYGEN SYSTEMS

3. PRINCIPAL COMPONENTS OF CONTINUOUS FLOW SYSTEM:

This type of system is that by which a continuous flow of gas is metered to each mask through a fixed orifice. Flow is controlled by regulation of the gas pressure. Refer to Figures 15 and 16 in Section VI and paragraph 2.2.1.

The principal components are: (a) Supply system; (b) Distribution system; (c) Dispensing equipment; (d) Sensors, displays and controls.

3.1 Supply System:

This comprises a container or containers for liquid or gaseous oxygen, a contents indicating system, and a means of replenishment. Replenishing of a gaseous supply can be accomplished either by external filling points on the aircraft or by the manual replacement of empty containers with fully-charged units which have been refilled at sites other than on the aircraft.

For a description of liquid oxygen supply systems refer to Section V.

3.1.1 High Pressure Cylinders: These cylinders store gas at 1800 to 2100 psi (12.41 to 14.48 MPa) and are available in a variety of shapes and sizes.

3.1.1.1 Steel Cylinders: Steel cylinders of regular shape with hemispherical ends are commonly in use. Table 18, Section VI, illustrates the weights and dimensions of those cylinders used by commercial carriers. DOT Specification 3AA covers the design and manufacture of regular non-shatterable cylinders. DOT Specification 3HT covers “lightweight” cylinders of the same basic sizes which show a saving in weight of 15 to 30 percent of the weight of the equivalent 3AA type.

Disadvantages of the 3HT type compared wit the 3AA type are:

(a) Lower resistance to shattering.
(b) Greater susceptibility to damage.
(c) More stringent service testing is required.
(d) Limited calendar life.

3.1.2 Low Pressure Cylinders: These cylinders are intended to store gas at 400 to 500 psi (2.76 to 3.45 MPa). They are used mainly in military applications where the smaller energy release on bursting is considered a useful characteristic. For commercial application and use, DOT approved cylinders are available.

Tables 18 through 20, Section VI, illustrates the weights and dimensions of those cylinders widely used by commercial carriers.

3.1.3 Supply Accessories and Components: This section includes items and appurtenances required to provide a complete and workable system. Refer to 3.1.3.1 through 3.1.3.9. The components referred to herein may be optional in some system designs, not applicable or mandatory in others.

3.1.3.1 Gauges: Gaseous systems require pressure gauges as contents indicators. Such gauges may be graduated in psi or contents, i.e., “Full,” “Empty.” They may be direct or remote reading.

Generally, since an oxygen system requires oxygen lines on the flight deck, a direct reading gauge can be used provided that the lines carry cylinder pressure. If a reducer is installed before the piping reaches the flight deck so that the lines do not carry cylinder pressure, a remote reading indicator is sometimes used with a pressure transmitter.

When the installation allows for the removal of the cylinder for charging off the aircraft, the cylinder valve (see paragraph 3.1.3.6) incorporates a pressure gauge to prevent the re-installation of partly charged or leaking cylinders. If the cylinder can be mounted on the flight deck, a second gauge is unnecessary.

Pressure gauges in liquid systems serve little purpose other than indicating the state of the pressure closing valve. Some contemporary installations have no pressure indication. Contents are measured and indicated electronically. A probe is installed in the top of the container extending down into the liquid. The capacitance of the probe is dependent upon the liquid level; thus a conventional bridge circuit and meter can be used to indicate quantity. (Refer to Section V)

3.1.3.2 Warning Devices: Various devices are used to give warning of low contents:

Liquid content gauges are available with flags or illuminated windows built into the dial. Gaseous pressure gauges may have the lower end of the scale colored red. Audible or visual warning devices are also used to show loss of pressure or flow in gas lines. Devices used are mechanical blinkers or pressure switches used with light.

3.1.3.3 Valves: Line valves are installed at strategic points in the system so as to enable the distribution lines to be isolated for servicing. The valve or valves are located as close to the supply as accessibility requirements will allow so that in the event of a ruptured line as much of the system as possible may be isolated.

3.1.3.4 Check Valves for Crew: In systems where both crew and passengers draw oxygen from the same supply source, it is mandatory to reserve a quantity of gas for the exclusive use of the crew in F.A.A. certificated aircraft. In multi-container installations, check valves may be used to prevent the container carrying the crew supply from feeding into the passenger system while allowing the crew to draw off the passenger supply when necessary.

In addition, the check valve installation usually provides a means of preventing losses from good cylinders to those which are damaged or leaking.

In single container installations, the normal method of reservation is by use of a line valve to the passenger system. A form of pressure limiting valve may be used which automatically cuts off the passenger supply when the pressure has reduced to a predetermined value.

In liquid oxygen systems the same type of valving applies.

3.1.3.5 Safety Devices: DOT regulations require that all high pressure cylinders be provided with a safety device to guard against bursting due to excessive pressure. This generally takes the form of a rupture disc incorporated in the cylinder valve.

DOT-3HT cylinders must be equipped with a frangible disc safety relief device, without fusible backing. The rated bursting pressure of the disc shall not exceed 90% of the minimum required test pressure of the cylinders with which the device is used.

A threaded outlet is provided on some designs of cylinder valves so that such a discharge may be piped overboard if desired. Stainless steel lines should be utilized for this overboard piping.

In gaseous filling operations, care must be exercised to avoid accidents, particularly interconnection of high and low pressure systems. Low pressure filling points are of a quite different design from high pressure filling points, and theoretically it is impossible to connect different pressure systems together, provided good control is exercised over ground handling equipment.

In the case of liquid oxygen filler valves, there is no ambiguity about the filling pressure. Both 70 psi (0.48 MPa) and 300 psi (2.07 MPa) systems are filled with the container vented to atmosphere and the pressure in the transfer cart is the only critical factor. A cart pressure of 30 to 40 psig (0.21 to 0.28 MPa) will provide the maximum fill. In addition, the fill valves are either automatic in operation, the system automatically going on “Vent” when the connection is made; or on earlier systems the “Build Up and Vent Valve” and “Fill Valve” are mounted adjacent to each other so that the “Build Up and Vent Valve” handle prevents connection to the “Fill Valve” when the system is on “Build Up.”

3.1.3.6 Cylinder Valves: A variety of cylinder valves are available with pipe threads on the body for screwing into the cylinder neck.

For commercial carrier use, the outlet thread on the side of the valve is a .903-14 Compressed Gas Association No. 540 and an adapter is needed to convert to a standard tube fitting.

The rupture disc outlet mentioned in paragraph 3.1.3.5 can be provided in any desired thread form or capped for inboard discharge.

Modern cylinder valves are available with a “slow-opening” feature. This feature decreases the heat build-up due to adiabatic compression and thus protects downstream non-metallic components from reaching their ignition temperatures.

Automatically opening cylinder valves are also available. Upon installation to system line, the cylinder supply is turned on.

3.1.3.7 Cylinder Gauges: These are desirable when cylinders are to be recharged away from the aircraft (see paragraph 3.1.3.1) and are incorporated as part of the cylinder valve in most designs.

3.1.3.8 High Pressure Lines: The diameter of lines is dictated by the mass flow to be carried and the acceptable pressure drop. In multi-cylinder installations the intercylinder lines are of small diameter, 3/16 to 5/16 inch (4.76 to 7.94 mm) O.D. with suitable wall thickness. At least one coil is formed between each cylinder to avoid permanent set occurring during cylinder removal and to prevent load being applied due to relative movement between cylinders under the influence of vibration. Use of high pressure lines should be kept at a minimum.

Various materials are used: copper, copper alloys or stainless steel. With such small diameters, bursting is hardly a problem and the proximity of adjacent cylinders makes it acceptable to rely on the tube end fittings for support of the line.

In the case of main system take-off, the higher flow through a single distribution line fed by multiple cylinders may necessitate a larger diameter. Convenient locations for line supports may not occur with sufficient frequency. In addition, such lines are bound to pass through zones where other equipment is installed and they are subject to damage during servicing.

Aluminum alloy tubing may be quite satisfactory in respect to burst pressure, but stainless steel tubing is commonly used up to the pressure reducer or continuous flow regulator. Sizes in common use are 1/4 inch or 5/16 inch (6.35 or 7.94 mm) O.D. x .028 inch (0.71 mm) wall thickness.

Refer to ARP1532 Oxygen System Installation and Fabrication for further details on tubing practices.

3.1.3.9 High Pressure Fittings: The comments of the preceding paragraphs illustrate the considerations dictating the selection of fittings.

Inter-cylinder connections are made with brazed-on nipples and loose coupling nuts (copper and copper alloys) or regular flared or flareless tube fittings with stainless steel.

For the main system take-off, flared or flareless fittings are used.

Usually fittings are of the same material as the lines. Some systems have incorporated mild steel or aluminum alloy fittings with stainless steel lines. However, the aluminum alloy fittings have a wide divergence in electrolytic potential with stainless steel and the cadmium plate necessary on mild steel fittings oxidizes rapidly in contact with the gas, forming a toxic compound. Mild steel fittings also present the possibility of a fire hazard. Loose steel filings or particles dislodged from the inside surface of an oxygen cylinder can travel at fairly high velocities. An impact with a steel fitting could result in an oxygen fire.

Titanium fittings must never be used in oxygen systems because of a possible chemical reaction and resultant fire.

3.1.3.10 Fire Safety: The preceding paragraphs illustrate the considerations concerning the selection of components in the system. Fire safety is one other important factor which merits serious consideration. Oxygen by itself is stable and non-flammable. However, it does support and accelerate combustion. Once a fire starts, oxygen will cause adjacent substances to burn rapidly or even explosively. A fire within an oxygen system will require an ignition source to start and fuel to support the combustion.

Fuel accumulation would be best eliminated by the use of compatible materials and by keeping the system clean. Material compatibility may be established by analysis based on test data. However, care must be taken to assure that the test conditions accurately reflect (or exceed in severity) the environment in which the material is to be used and that operational effects are included in the testing procedures.

The other crucial point, elimination of the ignition source, requires controlling temperatures in the system including that of the gas. Oxygen gas temperature tends to increase because of the internal energy changes during compression. This is known as compression heating. The peak temperature of the gas is a function of initial temperature, compression ratio, rate of compression and rate of cooling. In an aircraft oxygen system, the highest temperatures of compression heating will occur at the downstream dead end of the line where the gas is subjected to the highest compression ratio. If heat is developed during the compression at a rate greater than the head dissipation rate the temperature will increase. If the temperature exceeds the ignition point in oxygen of any combustible material which may be present, rapid chemical decomposition (pyrolysis) and ignition of the chemical matter will take place. This internal fire will contaminate the oxygen with combustion gases and may burn through the system tubing or components to cause an external fire.

3.1.3.10 (Continued):

Compression heating may be minimized by incorporating thermal compensators or heat sinks at the inlet ports of all high pressure control components. The thermal compensator may be constructed in many ways depending on its configuration and application. In any case, it should consist of non-combustible materials having high heat capacity and high thermal conductivity. This heat sink material should be housed in a section of tubing or in a long and narrow container with appropriate fittings to permit installation into the system upstream of and adjacent to any high pressure control components likely to be exposed to compression heating. In practice, the thermal compensator should be designed to absorb and dissipate the heat energy rapidly as it is generated thus minimizing the gas temperature rise during pressurization of the system. The required mass of the heat sink material used in the thermal compensator would depend on the upstream pressure and volume, system flow rate, pressure drop characteristics, etc. Design of the thermal compensator should facilitate its removal for cleaning of accumulated debris. The unit should be designed to preclude shedding of pieces during vibration, flow or servicing.

Such thermal compensators, by precluding gas temperature rising to ignition temperatures during compression, will remove a major potential ignition source within the oxygen system.

3.2 Continuous Flow Distribution System:

The high pressure lines from the supply source continue to either a reducing valve or a regulator.

3.2.1 Regulator: The regulator controls the pressure upstream of the mask orifices.

Basically, all regulators function in a similar manner. Pressure is controlled by controlling the flow through a valve (see Section II).

3.2.1.1 Preset Regulator: Strictly speaking, these are not regulators but simple pressure reducing valves. They reduce the supply pressure to a fixed pressure set for some optimum or maximum altitude. Although they maintain a relatively constant reduced pressure, this reduced pressure will vary slightly as the cylinder pressure or contents are depleted. A control may be incorporated in which an alternative ratio may be selected. They may turn on automatically on reduction of cabin pressure or be turned on manually as required.

3.2.1.2 Manual Regulator: This is the simplest form of regulator in use, consisting of a valve held off its seat by a bellows or diaphragm. A knob adjusts the bellows position, providing a method of setting the required pressure.

A gauge registers pressure downstream and is calibrated in altitude. In operation, the user rotates the knob until the gauge indicates the altitude at which he is flying. The resulting pressure is that calculated to supply the correct oxygen flow through the mask orifice.

Some manual regulators incorporate an on-off valve and a contents indicating pressure gauge.

Such regulators may supply from one to fifty outlets.

3.2.1.3 Automatic Regulator: Basically, this type is that in which the knob (see paragraph 3.2.1.2) is replaced by a barometric pressure sensing device which preloads or positions the pressure regulating bellows or diaphragm according to altitude. Thus, once the system has been turned on, line pressure is automatically controlled to the design value for the altitude. Almost any configuration of the altitude/delivery pressure ratio can be provided, but the simplest regulator evolves when the altitude pressure/delivery pressure graph is a straight line.

As with the preset regulator, an automatic or manual turn-on valve, or both, may be provided. Some automatic regulators discharge a small quantity of gas to the atmosphere while they are in operation. This is relatively unimportant when the supply is liquid, but when the supply is gaseous it may not be tolerable.

Automatic regulators are available in various capacity ranges from 1 to 5 outlets to 1 to 200 outlets.

3.2.1.4 Single Stage Regulator: Single stage regulators are those which contain one pressure reducing stage. The one valve reduces cylinder or liquid oxygen pressure to that required in the low pressure distribution lines. Some single stage units will not operate above, say, 500 psi (3.45 MPa) inlet pressure, and when used in an 1800 psi (12.41 MPa) system require an upstream pressure reducing valve to be added as part of the system.

3.2.1.5 Multi-Stage Regulator: This type regulator has two or more stages of pressure reduction built in. The term “multi-stage” is also applied to regulators constructed with several identical units in parallel as is necessary sometimes to obtain very high flows with tight control of outlet pressure.

3.2.1.6 Low Pressure Tubing: Pressure in the distribution lines from the regulators is dependent upon the flow required and the mask or outlet orifice characteristics.

Variations are of the order of zero to 80 psig (0.55 MPa). Mass flow in a large transport aircraft can reach 700 liters per minute, so pressure drop in the lines can be critical. To cater to pressures and flows of this order, the aircraft capable of carrying 150 passengers requires lines of at least 5/16 inch (7.94 mm) I.D. if outlets at the end of the system are to deliver comparable flows with those close to the regulator.

Thus, metallic lines in large low pressure distribution systems are commonly of 3/8 to 1/2 inch (9.52 to 12.7 mm) O.D. x 0.028 inch (0.71 mm) aluminum alloy. In systems for small aircraft of, say, up to 20 passengers, 5/16 inch (7.94 mm) O.D. lines are sufficient.

Where routing is complicated or distribution points are movable, various types of synthetic hose are used. Such hose is selected on the basis of weight and creep characteristics at elevated temperatures.

It should be noted that plastic hoses may weigh slightly more than their equivalent metal counterparts due to the necessarily heavy wall thicknesses. Refer to ARP1532 Oxygen System Installation and Fabrication for further details on tubing practices.

3.2.1.7 Low Pressure Fittings: Fittings for metallic low pressure lines are flared or flareless, similar to high pressure lines (see paragraph 3.1.3.9).

Fittings for plastic hose are fabricated by welding aluminum alloy tubing (T's, Y's, etc.) with standard beaded ends. A hose clamp secures the joint with a means of preventing the clamp from cutting into the plastic.

3.2.1.8 Dispensing Outlets: A dispensing outlet is located at each station, providing one or all of the following, depending on maximum operating altitude of the aircraft:

(a) A metering orifice;
(b) A means of connection for the mask; and
(c) An automatic presentation capability.

A variety of units is available from proprietary sources with orifice sizes ranging from 0.012 to 0.018 inch (0.30 to 0.46 mm) diameter. Orifice size used is dependent on the design of the system.

Bayonet-type connectors to the outlets are most common. They may be fitted with dust caps which spring closed on disconnection.

Various considerations dictate the selection of such outlets; appearance, installation requirements, pressure drop in cases where lines have to by-pass beyond to further fittings, etc.

3.3 Dispensing Equipment (Masks):

Continuous flow masks differ in two basic ways: (a) the shape of the facepiece, and (b) the method by which the gas is fed into the facepiece.

The simplest method of supplying the facepiece with oxygen is a flexible hose from the dispensing outlet which feeds directly into the facepiece through a non-return valve. Exhaled gases return to ambient through the porous walls of the open cell foam plastic facepiece. An indeterminate amount of dilution is available via the same device. This type of mask has limited use.

Such masks are highly uneconomical in consumption because in an operating system the gas flows continuously. Thus, during exhalation, some gas is bound to be wasted. As normal exhalation accounts for nearly half the period of a breathing cycle, a flow of nearly double that actually required must be provided.

3.3 (Continued):

Oxygen economy is effected when a flexible plastic or rubber reservoir is incorporated between the facepiece and the supply hose. This is typically between 500 and 1000 cm^3 capacity, and stores gas during the exhalation period to be withdrawn rapidly during inhalation. If the non-return valve into the facepiece is omitted, a proportion of the exhaled gas passes back into the reservoir on exhalation. A large proportion of this gas will be unused air/oxygen from the “dead” spaces of the mouth and throat. Masks such as this are termed “rebreather types.” Normally, a dilution valve and exhalation valve are built into the facepiece.

A variation in continuous-flow types is a mask similar to the above but with a non-return valve mounted in the facepiece loaded to open before the dilution valve. With this type, once a breathing pattern has been established, the required quantity of 100% oxygen is drawn into the lungs from the reservoir at the beginning of the inhalation. When the reservoir is empty, the dilution valve opens and inhalation is completed with air drawn from ambient. On exhalation, used gases are vented through the exhalation valve in the facepiece with the nonreturn valve preventing re-entry of gases to the reservoir.

3.3.1 Nasal Mask: The nasal mask should fit snugly around the nose. The nasal mask is intended for flights below 16,00 ft (4877 m) where air intake through the mouth would not result in excessive dilution (hypoxia). The chief advantages of the nasal mask are (1) light weight and (2) ease of conversing without the use of microphones and earphones.

3.3.2 Oronasal Mask: This type of mask fits completely over the mouth and nose. Masks to be used by crew members are equipped with facepieces molded to suit the shape of the face. Such masks are available in commonly used sizes: “small,” “medium,” and “large.” A harness is supplied with the mask to hold it firmly against the face. Provision may be made for the inclusion in the facepiece of a microphone for communication purposes.

Some facepieces are detachable from the body of the mask which contains the valve gear. This enables each crew member to maintain a personal item at lower cost, and it provides for easy sterilization.

Facepieces on masks to be used by passengers are generally symmetrical so that the correct position in which the mask is to be donned will be obvious.

3.3.3 Permanent Masks: Masks with facepieces as described above are generally considered to be “permanent”; i.e., they may be used repeatedly as long as it is possible to sterilize them between each usage.

3.3.4 Disposable Masks: These may be similar in design to the masks previously described, or a simple cup and hose with no valves or reservoir. In either case, the design is so inexpensive that it is economically reasonable to dispose of them after one use.

3.3.5 Fullface Masks: Fullface masks as the name implies cover the mouth, nose and eyes. While such a mask can be used to meet protective breathing equipment requirements, it cannot at the same time meet requirements for supplemental oxygen at altitudes where pressure demand masks are necessary (above 35,000 ft). As a result many users have opted for goggles and an oronasal mask.

3.3.6 Continuous Flow Gaseous Oxygen System Limitations: The continuous flow passenger gaseous oxygen system is designed to provide oxygen when cabin altitude does not provide sufficient oxygen to satisfy passenger needs. Adequate oxygen quantity is provided only for a descent from cruise altitude to an altitude where oxygen is not required. When deployed, passenger oxygen masks provide a limited amount of oxygen which is mixed with cabin air. Under normal cabin conditions, oxygen suppled by the passenger masks can be as low as 3% of total air intake. Figure 5 depicts the approximate flow of oxygen in liters per minute (LPM) for different cabin altitudes.

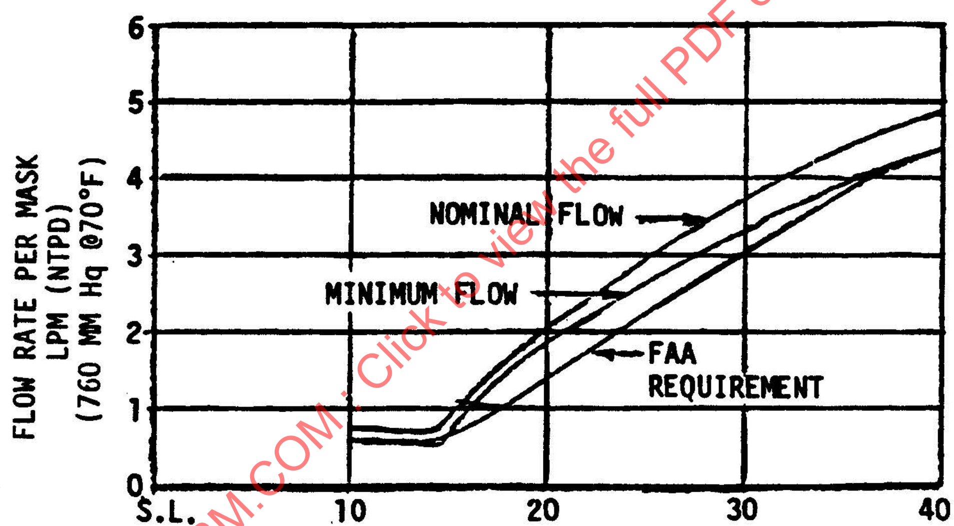


FIGURE 5 - Cabin Altitude - 1000 feet

As shown on the chart, for normal cabin altitudes below 10,000 feet, less than one LPM (NTPD) is available from the passenger gaseous oxygen system. A passenger will normally breathe 10 to 12 LPM (ATP) when calm or at rest. When excited or during heavy exertion, the breathing rate could reach 30 LPM (ATP). This means that the majority of air breathed in through the mask is from the cabin which could be contaminated with heavy smoke.

When fire conditions exist, dropping the masks and pressurizing the oxygen manifold may contribute to combustion.

3.3.6 (Continued):

If masks are donned by passengers, the length of the oxygen hose may restrict their ability to lower their heads down to a lower level where less dense smoke may exist.

In summary, recommended procedures specifically exclude the use of passenger oxygen masks during smoke conditions, because the passenger gaseous oxygen system was not designed for such use. Instead, instructing passengers to breath air from areas where the smoke is least dense, such as near the cabin floor, should be considered. Passenger oxygen masks should not be deployed when there is smoke in the passenger cabin unless cabin altitude is above 14,000 feet. If loss of cabin pressure has caused masks to drop, passenger masks should be used during descent and removed as soon as practical when cabin altitude is below 14,000 feet. Chemically generated oxygen systems provide a flow of oxygen directly from the local source to the adjacent passenger based on a fixed, predetermined flow schedule and are therefore not included in this recommended limitation for gaseous oxygen systems.

SECTION IV - DEMAND AND PRESSURE DEMAND OXYGEN SYSTEMS

4. PRINCIPAL COMPONENTS OF DEMAND AND PRESSURE-DEMAND SYSTEMS:

Demand: A demand type of oxygen system supplies oxygen to the mask only upon inhalation. The oxygen flow stops during the exhalation phase of the breathing cycle. A demand type system generally requires an oxygen regulator for each user which may be panel-mounted, man-mounted, or seat-mounted. A blinker may be incorporated to indicate when gas is flowing. Figure 17, Section VI, shows a typical demand oxygen system in general use on present modern aircraft.

Pressure Demand: A pressure-demand type of oxygen system supplies oxygen under positive pressure to the mask on demand. The flow of oxygen enters the mask immediately as inhalation begins and stops during the exhalation phase of the breathing cycle. The principal components are a mask which will retain positive pressure and a positive pressure oxygen regulator which is either panel-mounted, man-mounted, or seat-mounted. A blinker may be incorporated to indicate when gas is flowing. The demand system shown in Figure 17, Section VI, illustrates the necessary components for a pressure-demand system.

All demand and pressure-demand oxygen systems contain the following basic components:

1. Oxygen supply.
2. Distribution manifold.
3. Demand or pressure-demand regulator.
4. Demand or pressure-demand mask.

Additional components are required for some systems, dependent on the type of oxygen supply and regulator used in the system.

4.1 Supply System:

The oxygen supply containers for the demand and pressure-demand type of oxygen system are the same as used in continuous flow systems. The oxygen supply containers are discussed in more detail in Sections III and V of this Aerospace Information Report. In general, the oxygen containers may be of the following types:

1. Supply bottles for compressed gaseous oxygen.
   (a) Low pressure (400 to 450 psi (2.8 to 3.1 MPa))
   (b) High pressure (1800 to 2100 psi (12.4 to 14.5 MPa))
2. Liquid oxygen converters.
   (a) Low pressure (70 psi (0.48 MPa))
   (b) High pressure (300 psi (2.07 MPa))

4.2 Supply Accessories and Components:

Refer to Section III, paragraphs 3.1.3.1 through 3.1.3.7 for typical equipment used and available fro demand and pressure-demand systems.

4.3 Distribution System:

The distribution system consists of one or more lines of metal tubing with suitable fittings and outlets to distribute the oxygen to various stations. Pressure in these lines may be directly from the gaseous supply cylinder or from the liquid oxygen converter, or it may be reduced by a reducing valve to some uniform low pressure.

Those lines passing through a potential fire zone should be of stainless steel. (Refer to Section III, paragraphs 3.1.3.8, 3.1.3.9, 3.2.1.6, and 3.2.1.7 for further date.)

4.3.1 Demand, Diluter-Demand and Pressure-Demand Regulators:

Demand: This type of regulator is generally used in aircraft for specific applications such as smoke or fire-fighting. Operation and design features of regulators of this type are described in Section II. The regulator is the basic design for a group of regulators which are more commonly used; diluter-demand or pressure-demand.

Diluter-Demand: This demand regulator with oxygen dilution capabilities is commonly used. Control of the air-oxygen ratio may be automatically accomplished by an aneroid. The purpose of air dilution is to conserve the aircraft oxygen supply and still maintain a safe partial pressure of oxygen in the lungs. For safe operating conditions, dilution occurs up to approximately 32,000 ft (9754 m) altitude. At this altitude the dilution port, which is automatically controlled, is shut off and the regulator delivers 100% oxygen. These regulators have manual lever provisions to obtain 100% oxygen delivery throughout the dilution altitude range and some models are also provided with a manual lever which when actuated, will deliver a limited amount of positive pressure (safety pressure) for emergency toxic atmosphere protection.

Pressure-Demand: This demand regulator can be obtained with or without dilution characteristics. As described in Section II, this regulator is required for operation at altitudes above 35,000 ft (10,668 m) to maintain safe partial pressure for the user. The regulator is obtainable with varied output pressure schedules which meet the military minimum pressure requirements. Pressure-demand oxygen regulators supply oxygen under pressure to the mask, and when used with the proper combination of mask and exhalation valve maintain a positive pressure within the mask throughout the entire breathing cycle. As mentioned previously, dilution characteristics can be supplied with the pressure-demand regulator and are physiologically safe for use to altitudes of approximately 32,000 ft (9754 m). At this altitude the dilution port, which is automatically controlled, is shut off and the regulator delivers 100% oxygen typically with safety pressure.

4.3.1.1 Single Stage: The single stage demand or pressure-demand regulator operates directly from the oxygen supply. The regulator should be designed to receive low supply pressure (in the range of 40 to 100 psig) at the demand valve without requiring a built-in pressure reducer. A single stage demand regulator is intended to conserve on size, weight, and cost as compared to the multi-stage type. However, downstream distribution lines are generally restricted to length and I.D. so as to control the pressure drop.

4.3.1.2 Multi-Stage: The multi-stage demand or pressure-demand regulator operates from a high, medium, or low pressure oxygen supply. A built-in pressure reducer is necessary in order to reduce a high supply pressure down to the operating pressure for the demand valve of the regulator. The multi-stage regulator has the advantage of operation over a wide range of supply pressures.

4.3.1.3 Limitations and Recommendations: If loss of cabin pressurization can result in cabin altitudes exceeding 25,000 ft (7620 m), protection of crew members from hypoxia (resulting in impairment of consciousness) must be provided by supplying 100% oxygen immediately on decompression and by assuring that the minimum pre-decompression breathing mixture provides an oxygen concentration of not less than that required by Graph 5 (see Figure 14) in Section VI. This can be accomplished by use of mask mounted regulators or regulators mounted sufficiently close to the user's head so that the volume of that part of the breathing system between the regulator air port and the mouth/nose is limited so that 100% oxygen is delivered in not more than 2 seconds after the regulator shifts to 100% output. The panel or remote mounted regulators, requiring a length of relatively large diameter (approximately 7/8 inch (22 mm)) low pressure breathing hose to connect to the mask, are limited to a maximum altitude of 25,000 ft (7620 m). This requirement can be waived above 25,000 ft (7620 m) when the crew member wears and uses his mask with the regulator set on 100% oxygen delivery. Reference may be made to AIR1069 (Crew Oxygen Requirements Up To A Maximum Altitude of 45,000 Feet) for additional data and recommendations.

For regulator requirements SAE has published a standard: AS1194, Regulator Oxygen, Diluter Demand, Automatic Pressure Breathing.

4.4 Dispensing Equipment:

A breathing mask which will retain the positive pressure of oxygen delivered from the regulator is necessary for use in the pressure-demand system. The mask should be close-fitting around the mouth and nose to prevent outward flow of oxygen around the sealing edges of the mask.

For the demand system, the mask should be close-fitting around the nose and mouth because oxygen is obtained by suction demand, and loose-fitting mask would impair the delivery of oxygen when a suction demand is registered.

4.4.1 Oronasal Mask:

Demand: The oronasal mask is intended to cover the nose and mouth only and should fit snugly so that oxygen can be obtained by suction means. Small internal volume should be the design goal of the oronasal mask in order to minimize the rebreathing of carbon dioxide. An exhalation valve is provided, and a microphone is usually provided with this type of mask when used by the crew.

Pressure-Demand: The oronasal mask for use with this system differs from the demand mask in several respects. The mask must be constructed to withstand positive pressures as well as to resist collapse. The sealing edges which contact the face are designed to prevent outward leakage while still maintaining a leaktight seal when suction is applied to the inside of the mask. In addition, a special exhalation valve is required to compensate for the positive pressures delivered from the regulator. Without such a valve there would be an uncontrolled flow of oxygen through the valve throughout the entire cycle of operation. Typical valves in use employ a sensing diaphragm which automatically adjusts the valve opening pressure slightly above the regulator pressure. As the exhalation phase begins, the user raises the pressure within the mask cavity. This pressure stops flow from the regulator, and as the mask pressure continues to increase, the exhalation valve opens.

4.4.2 Fullface Masks:

Demand: The fullface mask is intended to cover the nose, mouth, and eyes. Since oxygen is obtained by suction demand, the mask must fit snugly to the face so that it is leaktight. Internal volume of the mask should be as small as practicable to minimize the rebreathing of carbon dioxide. An exhalation valve is provided with this type of mask, and a microphone is usually provided. The fullface mask is generally used as an emergency mask to protect against smoke and other fumes.

Pressure-Demand: A fullface mask intended for use with this system differs from the demand system application in the same respects as those described above for the pressure-demand oronasal mask.

SECTION V - LIQUID OXYGEN SYSTEMS

5. LIQUID OXYGEN:

Oxygen may be supplied from either gaseous, liquid, solid or chemical block sources or concentrated from air by on-board oxygen concentrators for use in aircraft systems. (However, the solid state source is considered to be impractical for this since it is almost impossible to provide in practice (with a freezing point of -377 F (-227.2 C)) and its use offers no further advantage when compared to the liquid state). Gaseous oxygen has been commonly used in aircraft installations ever since flights were made at altitude requiring supplemental oxygen for occupant survival. A practical liquid oxygen system for aircraft use was developed as the result of past U.S. and foreign military aircraft design programs. Liquid oxygen supply systems are installed in many of the new U.S. military aircraft; active consideration has been given to these systems in the current commercial jet transport aircraft designs. Refer to AS1304 Continuous Flow Chemical Oxygen Generators for further details on chemical oxygen generation.

5.1 Liquid Oxygen Properties:

5.1.1 Liquid oxygen is a light, blue, transparent, waterlike fluid, produced by the fractional distillation of purified liquid air. MIL-O-27210 promulgates the requirements for liquid oxygen.

5.1.2 At sea level, atmospheric pressure (760 mm Hg or 14.7 psia), liquid oxygen has the following properties:

Boiling Point:	-297 F (-183 C)
Density:	71.2 lb/ft^3 (1140.5 kg/m^3) at -183 C (-297 F) 2.5 lb/liter (1.14 kg/dm^3) 9.54 lb/gallon (U.S.) 11.32 lb/gallon (Imperial)
Volume Expansion:	1 liter liquid oxygen = 860 liters gaseous oxygen at 70 F (21.1 C) (14.7 psia (101.3 kPa)) 1 liter liquid oxygen = 30.36 ft^3 (0.86 m^3) gaseous oxygen at 70 F (21.1 C) (14.7 psia (101.3 kPa))
Latent Heat of Vaporization:	50.9 cal/gram (91.7 BTU/lb (213.1 J/g))

At higher pressures, the boiling point of liquid oxygen will increase. The critical temperature of -180 F (-118 C) is attained at a pressure of 735 psi (5.07 MPa) (50 atmosphere). Regardless of pressure increase, oxygen will not remain in a liquid state above this temperature.

5.1.3 Pure liquid oxygen does not produce irritating vapors but absorbs various types of odors.

5.2 Liquid Oxygen Converters and Ground Servicing Equipment:

The utilization of liquid oxygen in airborne installations has been facilitated by the development of a practical system for the conversion of cold liquid oxygen to gas at an acceptable ambient temperature for breathing. This system based on a proposal of the U.S. National Bureau of Standards, depends on no external source of energy other than the surrounding atmosphere for converting the liquid oxygen to gas. Ground storage and airborne containers operate on the same basic principle of liquid to gaseous state conversion for their respective purposes. Operation of a typical liquid oxygen converter and component parts of the system to provide gaseous oxygen to the aircraft supply line is shown in Figures 6 and 7.

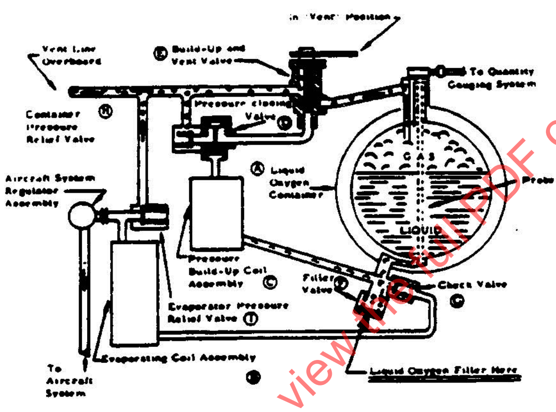


FIGURE 6 - Converter Filling Procedure

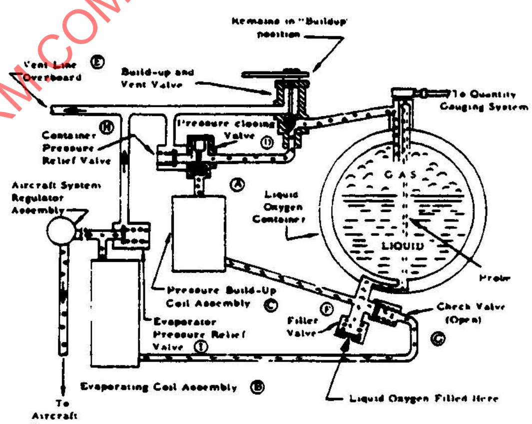


FIGURE 7 - System Supply Procedure

5.2.1 Liquid Oxygen Converter Assembly:

5.2.1.1 A converter assembly is a self-powered system for the storage of liquid oxygen and for its conversion to gaseous oxygen as and when required. Major parts of the assembly package are:

a. A double-walled container	Item A	
b. A pressure build-up coil	Item C	
c. An evaporating coil (or coils) *	Item B	
d. Pressure control valves	Item D & H	Refer to
e. Pressure relief valve	Item I	Figures
f. Liquid check valve	Item G	6 and 7
g. Volume gauging probe		
h. Mounting brackets		
i. Economizer circuit (optional design)		
j. Build up and vent valve	Item E	
k. Filler valve	Item F	

* Can be remotely located.

5.2.1.2 Two additional assemblies must be provided with the converter assembly as part of the over-all system; i.e., the filler valve assembly, and the build-up and vent valve assembly. In portable converter designs, these assembles may be part of the converter assembly. Some designs are available that combine the functions of the two assemblies into one unit.

5.2.1.3 The principal part of the converter is a vacuum insulated container. It consists of an inner and an outer shell with an evacuated air space between the two walls. Connections for filling and removing the liquid oxygen, and for venting the gaseous oxygen are provided between the two concentric containers. Heat transfer from outside the converter to the inner shell can be reduced by the following design features:

a. Evacuated space between the shells.

b. Use of insulating powder between the walls, silvered and/or highly polished surface treatment of the walls forming the evacuated space.

c. Use of low thermally conductive materials in the assembly and a minimum number of support and/or assembly points between the two shells.

5.2.1.4 Despite the low heat transfer through the walls and assembly points of the converter assembly, there will always be some heat transfer and some evaporation of liquid oxygen. Pressure relief valves must be provided to allow the escape of gas and to prevent dangerously excessive pressure build-up when the oxygen in the oxygen converter is not being expended to the supply line.

5.2.1.5 In present day equipment, losses of liquid oxygen from a converter assembly range from 5 to 20% per 24 hours depending on size of container.

5.2.1.6 Most airborne converters of the past and present designs deliver gaseous oxygen at a pressure of 70 psig (0.48 MPa). A number of converters have been produced that deliver 300 psig (2.07 MPa) gas. The high pressure assemblies are installed in bomber-type aircraft to permit the crew to refill their portable oxygen bottles directly from the aircraft's oxygen system. The higher pressure assemblies have also been proposed for use in the commercial jet transport aircraft where long supply tubing runs are required (with increased line pressure drop), and where high flow rates are required during emergency use of the system.

5.2.1.7 Converter assemblies may be filled at the aircraft or removed and filled at a remote location depending on converter design.

5.2.1.8 Liquid quantity indicating equipment utilized with converters is available in three types using different design features: Capacitance gauging, electro-mechanical transducer indication or differential pressure type of indication.

5.2.2 Liquid Oxygen Ground Servicing Equipment: Ground servicing equipment for aircraft liquid oxygen systems is provided by special storage tank and transfer cart assemblies. Liquid oxygen can be stored indefinitely at sea level as long as it is kept at a temperature below its boiling point, but to maintain a temperature below -297 F (-182.8 C) by mechanical refrigeration is expensive and generally impractical. Therefore, liquid oxygen is usually stored and handled in a vacuum-insulated container similar in general design and operational principles to the airborne converter assembly. Since pressure buildup within the container is obtained by vaporization of the liquid oxygen and regulated by control valves, this energy can be used to provide the optimum pressure (30 to 40 psig) for transfer of liquid oxygen from the ground equipment to an aircraft converter installation or to another storage tank.

5.2.2.1 A typical liquid oxygen ground servicing assembly consists of a double-wall container with the space between the walls filled with an insulating material such as silica-aerogel and evacuated to a very low pressure. An adsorbent "molecular getter" such as activated charcoal or activated alumina may also be placed within the evacuated space to supplement the mechanical evacuation process. Component equipment in the assembly such as pressure buildup coils; vent, check and relief valves; and capacitance gauges serve the same function as similar units in the airborne converter assembly. Multiple safety devices are incorporated in this equipment to assure safe and proper operation.

5.2.2.2 The USAF type TMV-27/M storage and transfer cart assembly is a unit commonly used for servicing aircraft liquid oxygen converters when installed or not installed in the aircraft. The Navy type TMV-70/M storage and transfer cart is used for servicing liquid oxygen converters not installed in the aircraft. These carts are mobile assemblies mounted on steerable three wheel trailers and have a capacity of 50 gallons (189 liters). The cart is a complete self-contained liquid oxygen transport, storage and servicing unit with a total empty weight of approximately 720 pounds (327 kg).

5.2.2.3 Liquid oxygen storage tanks having capacities of 400, 500 and 2000 gallons (114, 1892 and 7570 liters) are generally used at military aircraft bases for bulk storage. The 400 and 500 gallon tanks can be skid mounted and semipermanently installed or trailer mounted on four wheel steerable trailers, for the purpose of receiving, holding, transporting and dispensing liquid oxygen. The 2000 gallon tanks are permanently installed. Currently there are different configurations of these tanks, each configuration requiring a different type designation (see 6.9)

5.2.2.4 Liquid Oxygen System Operation Details: Liquid oxygen is supplied to the container through the springloaded Filler Valve (F) from the service cart. As liquid oxygen flows into the warm container (A), it vaporizes very rapidly and cools down the inner area of the container, eventually to the liquid oxygen temperature of -297.4 F (-183 C) at atmospheric pressure. The oxygen gas created by the cool down process is forced through the top of the container into the Build-Up-Vent Valve (E), which is set on the "VENT" position during the filling operation. This valve setting permits the escaping gas to flow overboard through the vent line. This procedure continues until liquid oxygen flows overboard in a steady stream from the vent line which indicates the container is full of liquid oxygen. After a 15% filling loss, evaporation losses do not exceed 5% per 24 hours.

During the filling operation, some liquid oxygen could flow into the pressure Build-Up Coils (C) and through the Check Valve (G) into the Supply Evaporator Coils (B). The minor quantity of liquid oxygen so trapped will remain in these lines until a demand for gaseous oxygen is created in the supply line. If the trapped gas (vaporized liquid oxygen) does build up a pressure exceeding the relief valve settings, in the respective systems, the relief valves will open and vent the gas overboard.

To develop pressure within the container and permit the Converter Assembly to supply breathing oxygen to the aircraft system, the Build-Up-Vent Valve (E) is manually set in the "Build-Up" position. This action blocks the line from the top of the container to the overboard vent and connects the liquid oxygen supply to the gaseous side of the container. The liquid oxygen flows by gravity into the Pressure Build-Up Coils (C) and vaporizes because of exposure to ambient temperature surrounding the coils. The gas flows through the Pressure Closing Valve (D) and the Build-Up-Valve (E) into the top of the container where it collects and assists in a higher pressure development. This cycle continues until the working pressure of the system is reached; the Pressure Closing Valve (D) closes and prevents further flow of liquid oxygen from the container. Pressure in the gaseous area of the container is regulated by the Container Pressure Relief Valve (H) which will reduce excessive pressure levels by venting the gas overboard.

When oxygen is required in the aircraft system, liquid oxygen flows into the supply system, through the Check Valve (G) into the Supply Evaporation Coils (B), where it is vaporized. The gas then flows into the aircraft system until the demand is shut off. Pressure source for the flow is the pressure on the gaseous side of the container. If this pressure value drops below the required system pressure, the Pressure Closing Valve (D) opens and admits more vaporized liquid oxygen into the gaseous side of the container, raising the pressure level and continuing the cycle operation.

5.2.2.4 (Continued):

Purpose of the Check Valve (G) is to prevent gaseous oxygen in the supply system from backing up into the liquid oxygen within the container and increasing the vaporization rate of the liquid oxygen by exposure to the gas. This condition can develop during a period of large oxygen demand on the aircraft system with a high flow rate and then encountering a sudden cutoff in oxygen delivery to the aircraft system. A relief valve (I) is installed in the system to prevent excessive build-up of system pressure.

5.3 Precautionary Measures:

The general precautions to be observed in the handling, storage and use of compressed gaseous oxygen shall also be observed with liquid oxygen and are covered in National Fire Protection Association Standard No. 410 B. Listed below are precautions peculiar to liquid oxygen which should be follows:

5.3.1 Due to the extremely low temperature of liquid oxygen, proper safeguards should be taken by all personnel working with the product. Severe frostbite which produces lesions identical with a burn will result if liquid oxygen comes in contact with the skin during any handling operation. Burns will also result if a non-insulating container, tubing, valves and other equipment containing liquid oxygen is handled without the minimum protection specified in paragraph 5.3.2.

5.3.2 Personnel handling liquid oxygen should be protected by loosefitting, clean coveralls of tightly woven material with cuffless trousers, a cotton helmet, gauntlet-type gloves of leather or rubber with loose-fitting cotton inner liners, high-top shoes under the trouser legs and a face shield.

5.3.3 If liquid oxygen is spilled on the clothing, the garments should be shed as quickly as possible. Liquid oxygen trapped in a pocket, glove, or boot can cause serious frostbite injury, in addition to the fire hazard created by the combination of concentrated oxygen and a combustible material.

5.3.4 If liquid oxygen is spilled on exposed skin, wash it off immediately with cold water, apply cold compress to the affected area and get immediate medical attention.

5.3.5 When transferring liquid oxygen from one container to another, the receiving container should be filled very slowly until it has been cooled to a temperature comparable to that of the liquid oxygen. Rapid filling might, besides causing boiling or splashing, result in damage due to thermal shock.

5.3.6 Caution must be exercised in introducing any material or object at normal room temperature into liquid oxygen. This action will cause violent ebullience and evolution of gaseous oxygen with considerable boiling and splashing.

5.3.7 In filling liquid oxygen systems, the liquid should not be allowed to spill on the ground, especially on a ramp surface contaminated by oil or grease. If spillage does occur, the area should be isolated until all the liquid oxygen (especially that trapped in cracks or crevices) has evaporated.

5.3.8 Liquid oxygen equipment and the aircraft being serviced must be electrically grounded during the servicing operation to prevent an accumulation of static electricity and discharge.

5.3.9 It is emphasized that no lubricant shall be used on liquid oxygen system male pipe fittings. Only MIL-T-27730 Teflon tape thread sealant may be used on male pipe fittings when required.

5.3.10 Liquid oxygen must be stored in the containers designated for the purpose which will maintain the vapor above the liquid at atmospheric pressure or at a low positive pressure level. The temperature of the liquid will thus remain at or near its boiling point (-297.4 F (-183 C)). Evaporation of liquid oxygen in a closed, unvented container could develop a potentially dangerous pressure condition of 860 atmospheres (over 12,000 psi (82.7 MPa)).

5.3.11 Bulk liquid oxygen storage containers should be located in a well-ventilated area to prevent high concentration of gaseous oxygen in the atmosphere. Outdoor storage is recommended. Indoor storage area where required, should be force-ventilated.

5.3.12 Leakage of liquid oxygen into the space between the inner and outer containers of storage vessels or converters can result in a pressure build-up and fracture of the safety “rupture” disc.

5.4 Comparison of Liquid Versus Gaseous Oxygen Supply Installations:

5.4.1 Advantages of Liquid Oxygen:

5.4.1.1 A weight and space savings will be obtained by the use of a liquid oxygen supply installation compared to a gaseous system that provides an equal volume of oxygen to the aircraft system. For the same weight as a gaseous system more oxygen can be supplied to the aircraft by a liquid oxygen supply. For a given volume of a gaseous oxygen to the system, it is estimated that a liquid system will require 60 to 80 percent less weight and 50 to 70 percent less space than an 1800 psi (12.4 MPa) high-pressure gaseous supply.

5.4.1.2 Safety aspects of the liquid oxygen installation are enhanced by the lower supply and system pressure. Present liquid oxygen converters operate at 70 psi (0.48 MPa) and 300 psi (2.07 MPa) pressures compared to the standard gaseous oxygen supply pressures of 400 psi (2.76 MPa) and 1800 psi (12.4 MPa).

5.4.1.3 A 70 psi (0.48 MPa) liquid oxygen supply source in some installations eliminates pressure reducing regulator assemblies. The elimination of these assemblies further reduces weight, cost, complexity, and maintenance of the installation.

5.4.1.4 Problems and hazards in the handling, storage and use of high pressure gaseous oxygen are eliminated.

5.4.2 Disadvantages of Liquid Oxygen:

5.4.2.1 A liquid oxygen supply is constantly being reduced by evaporation whereas a constant volume of gaseous oxygen can be stored in cylinders for an indefinite period, available for use whenever required. Evaporation losses generally range from 5 to 20 percent in a 24 hour period. A regular replenishment schedule of the liquid oxygen converter must, therefore, be maintained.

5.4.2.2 See paragraphs 5.3 through 5.3.12 for other problems and hazards.

5.4.2.3 During filling operation liquid losses can be encountered during transfer or filling if not carefully controlled.

5.5 Referenced Publications:

MIL-I-19326
Tr-56-260 Vol. I & II Air Force Handbook of Liquid Oxygen Systems

5.6 Liquid Oxygen System Description:

Refer to Figures 6 and 7.

SECTION VI - CHARTS, TABLES AND SYSTEMS SCHEMATICS

6. DEFINITIONS AND ABBREVIATIONS:

ATPD = Ambient temperature and pressure, dry (PH_2O = 0)
BTPS = Body temperature, pressure, saturated (37 °C, ambient pressure, saturated with water vapor at 37 °C-PH_2O at 37 °C = 47.00 mm Hg)
BTPD = Body temperature, pressure, dry (37 °C, ambient pressure, PH_2O = 0)
STPD = Standard temperature, pressure, dry (0 °C, pressure = 760 mm Hg, and PH_2O = 0)
NTPD = Normal temperature, pressure, dry (70 °F, pressure = 760 mm Hg, and PH_2O = 0)
PH_2O = Partial pressure of water vapor (PH_2O at 37 °C = 47.00 mm Hg)
PO_2 = Partial pressure of oxygen
B or P_B = Barometric pressure
B-47 or P_B-47 = Sum of partial pressures of dry gases in an environment saturated with water vapor at 37 °C, expressed in mm Hg
%O_2 = Parts of oxygen in 100 parts of dry gas by volume existing in a mixture saturated with water vapor at 37 °C
O °C = 273.16 °K = 32 °F = 491.69 °R
21.11 °C = 294.27 °K = 70 °F = 529.69 °R
37.00 °C = 310.16 °K = 98.6 °F = 558.29 °R

6.1 Weight of Oxygen in Supply Cylinders:

$$W = P \times d \times \frac{v}{k}$$

where:

P = gauge pressure, atmospheres
W = weight of oxygen in pounds
d = density of oxygen pound per cubic inch (see 6.2)
v = volume of cylinder, cubic inches
k = compressibility factor (tabulated below)

TABLE 5

Pressure psi (MPa)	Atmospheres	K at 32 °F (0 °C)	K at 68 °F (20 °C)
450 (3.1)	30.6	0.973	0.981
900 (6.2)	61.3	0.945	0.962
1800 (12.4)	122.5	0.915 (approx.)	0.938 (approx.)

6.2 Density of Oxygen at Sea Level:

TABLE 6

Degree F (C)	Grams/ Liter	Pounds/ Cubic Foot	Pounds/ Cubic Inch
-40 (-40)	1.67	0.105	0.602×10^{-4}
-20 (-28.9)	1.60	0.100	0.576×10^{-4}
0 (-17.8)	1.53	0.095	0.552×10^{-4}
20 (-6.7)	1.47	0.091	0.530×10^{-4}
32 (0)	1.43	0.089	0.515×10^{-4}
40 (4.4)	1.40	0.088	0.507×10^{-4}
60 (15.6)	1.35	0.085	0.487×10^{-4}
80 (26.7)	1.30	0.081	0.470×10^{-4}
100 (37.8)	1.26	0.078	0.453×10^{-4}

6.3 Weight in Pounds per Hour of an Oxygen Flow of one liter per Minute at 32 F and Ambient Pressure:

TABLE 7

Altitude - Thousands of Feet (Meters)	-0 (-0)	10 (3048)	20 (6096)	25 (7620)	30 (9144)	35 (10,668)	40 (12,192)
Oxygen - Pounds per Hour: (kg per Hour)	0.189 (0.086)	0.130 (0.060)	0.086 (0.039)	0.070 (0.032)	0.056 (0.025)	0.044 (0.020)	0.035 (0.016)

6.4 Oxygen from Tank Supply to Produce Required Mixtures of Oxygen and Air at Mask:

TABLE 8

Percent of Oxygen at mask:	21	30	40	50	60	70	80	90	100
Percent of total volume which is drawn from tank	0	11	24	37	49	62	75	87	100
Percent of total volume which is drawn from ambient	100	89	76	63	51	38	25	13	0

6.5 Supplemental Passenger Oxygen System Design Calculations:

This section presents an analytical method for calculating the oxygen requirements needed to provide for a continuous-flow, passenger oxygen system and evaluating the component performance requirements. The oxygen system is designed to provide all passengers with the minimum tracheal oxygen partial pressure specified by the Federal Aviation Administration Federal Aviation Regulations Parts 25.1441 through 25.1453. These regulations supersede CAR 4b.651 dated September, 1962. Although the analysis is based on regulations, the system is based on a hypothetical airplane, and on hypothetical oxygen system components.

Briefly, the system analysis will begin with the requirements of the system’s most remotely located passenger, where the oxygen distribution line pressure drop is maximum. The specific mask performance characteristic will determine the flow requirement to the mask. This in turn, on the basis of outlet performance, will determine the pressure schedule requirement to the outlet. The pressure schedule required at the outlet, plus the system line pressure drop will determine the pressure schedule of the passenger regulator.

6.5 (Continued):

The choice as to which system components are to be the system's independent variables, and which are to be dependent variables, is somewhat arbitrary. For our purposes, the performance of both the passenger mask and the passenger outlet are considered to be the independent variables; their performance will be determined empirically. The establishment of these values will allow the calculation of the dependent variables, the regulator performance curves and an oxygen requirement curve. The oxygen requirement curve is then used to evaluate the oxygen quantity requirements. The required cylinder oxygen flow is that quantity of oxygen flow required by the system to insure that all passengers will have at least the minimum oxygen design requirement.

Once the required quantity of oxygen has been established, an average or overall value of system oxygen utilization efficiency can be determined. The overall efficiency utilization is equal to the minimum average oxygen flow requirement (or design flow requirement) per passenger, divided by the required cylinder oxygen flow per passenger.

6.5.1 Requirements: The basis for the following calculations is Section 25.1443(c) of Part 25 of the Federal Aviation Regulations (FAR). Part 25 applies to Transport Category airplanes.

"For passengers and cabin attendants the minimum mass flow of supplemental oxygen required for each person at various cabin pressure altitudes shall not be less than that which will maintain during inspiration the following mean tracheal oxygen partial pressures when using the oxygen equipment provided, including masks:

(i) At cabin pressure altitudes above 10,000 ft (3048 m) to and including 18,500 ft (5639 m), a mean tracheal oxygen partial pressure of 100 mm Hg when breathing 15 liters per minute, BTPS (body temperature pressure, saturated, i.e. 37 °C, ambient pressure, saturated with water vapor at 37 C-PH_2O at 37 °C = 47.00 mm Hg) and having a tidal volume of 700 cm^3 with a constant time interval between respirations.

(ii) At cabin pressure altitudes above 18,500 ft (5639 m) to and including 40,000 ft (12,192 m), a mean tracheal oxygen partial pressure of 83.8 mm Hg when breathing 30 liters per minute, BTPS, and having a tidal volume of 1100 cm^3 with a constant time interval between respirations."

6.5.2 Calculations:

A. Variables:

Independent Variables -

1. Passenger mask performance determined by performance testing.
2. Passenger outlet performance determined empirically.
3. Design safety margin.
4. Oxygen system line pressure drop by analysis or by previous tests.

Dependent Variables -

1. The oxygen requirement curve, i.e., the cylinder oxygen flow required per passenger versus altitude.
2. The supplemental oxygen line pressure regulator performance curve.

B. Determination of the Theoretical Oxygen Requirements:

Although the theoretical oxygen requirements bear no direct relation to the actual cylinder oxygen-flow requirements, they will be evaluated first since they will be needed subsequently to evaluate the "overall efficiency of the passenger oxygen utilization" and serve to establish "ball park" figures of the actual needs. These calculations are based on the Federal Aviation Regulations as quoted under design requirements. Table 9 indicates the procedure used.

1. Column "A" shows altitude in increments of thousands of feet from 10,000 to 40,000 ft (3048 to 12,192 m).
2. Column "B" indicates the barometric pressure in mm Hg for each of the thousand-foot increments.
3. Column "C" calculates the conversion factor for reducing BTPS to NTPD (normal temperature, pressure, dry, i.e. 70 °F, 760 mm Hg and $PH_2O = 0$). This factor is equal to Barometric Pressure at Altitude (Column "B") minus the water vapor, 47 mm Hg divided by 760 mm Hg. The ratio is then corrected for temperature:

$$C = \frac{(B - 47)}{760} \frac{(459.69 + 70.000)}{(459.69 + 98.6)}$$

$$C = \frac{(B - 47)}{760} (0.94877)$$

where:

B = the numerical values in Column "B"
C = the numerical values in Column "C"

TABLE 9

(A) Altitude in Thousands of Feet (Meters)		(B) Barometric Press in mm Hg *	(C) Volume Ratio (NTPD) (BTPS)	(D) Total LPM-NTPD	(E) % Total O_2 Required
At 15 (LPM BTPS)					
10	(3048)	522.76	0.5939	8.909	21.02
11	(3353)	502.79	0.5690	8.535	21.94
12	(3657)	483.46	0.5449	8.173	22.91
13	(3962)	464.77	0.5215	7.823	23.94
14	(4267)	446.63	0.4989	7.483	25.02
15	(4572)	429.08	0.4770	7.155	26.17
16	(4877)	412.09	0.4558	6.837	27.39
17	(5182)	395.66	0.4353	6.529	28.68
18	(5486)	379.78	0.4154	6.231	30.05
18.5	(5639)	372.01	0.4057	6.086	30.77
At 30 (LPM BTPS)					
18.5	(5639)	372.01	0.4057	12.172	25.78
19	(5791)	364.39	0.3962	11.887	26.40
20	(6096)	349.53	0.3777	11.330	27.70
21	(6401)	335.15	0.3597	10.729	29.08
22	(6705)	321.28	0.3424	10.272	30.55
23	(7010)	307.87	0.3257	9.770	32.12
24	(7315)	294.89	0.3095	9.284	33.81
25	(7620)	282.40	0.2939	8.816	35.60
26	(7925)	270.33	0.2788	8.364	37.52
27	(8230)	258.67	0.2642	7.927	39.59
28	(8534)	247.43	0.2502	7.506	41.81
29	(8839)	236.58	0.2367	7.100	44.20
30	(9144)	226.13	0.2236	6.709	46.78
31	(9449)	216.06	0.2111	6.332	49.57
32	(9754)	206.35	0.1989	5.967	52.59

TABLE 9 (Continued)

(A) Altitude in Thousands of Feet (Meters)		(B) Barometric Press in mm Hg *	(C) Volume Ratio (NTPD) (BTPS)	(D) Total LPM-NTPD	(E) % Total O_2 Required
33	(10,059)	197.00	0.1873	5.618	55.87
34	(10,363)	188.00	0.1760	5.281	59.43
35	(10,668)	179.33	0.1652	4.956	63.33
36	(10,973)	170.99	0.1548	4.644	67.59
37	(11,278)	162.99	0.1448	4.344	72.25
38	(11,582)	155.37	0.1353	4.059	77.33
39	(11,887)	148.11	0.1262	3.787	82.88
40	(12,192)	141.18	0.1176	3.527	88.98

* For conversion to m bar multiply by 1.33322.

6.5.2 (Continued):

4. Column “D” is the flow rate in NTPD LPM (liters per minute) required to maintain the following regulator minimum mass flow of supplemental oxygen.

   a. 15 LPM in BTPS liters from 10,000 to 18,500 feet (3048 to 5639 m).
   b. 30 LPM in BTPS liters from 18,500 to 40,000 feet (5639 to 12,192 m).

   These values are obtained by multiplying Column “C” by 15 from 10,000 to 18,500 ft (3048 to 5639 m) and by 30 from 18,500 to 40,000 ft (5639 to 12,192 m).

5. Column “E” is the percent of total oxygen concentration in the dry gas trachea necessary to maintain the regulatory partial pressure of oxygen (O_2) of:

   a. 100 mm Hg from 10,000 to 18,500 ft (3048 to 5639 m).
   b. 83.8 mm Hg from 18,500 to 40,000 ft (5639 to 12,192 m).

   The values in Column “E” are calculated as follows:

   a. $\frac{100}{B-47}100$ (B is the value in column “B” up to 18,500 ft (5639 m)).
   b. $\frac{83.8}{B-47}100$ (B is the value in column “B” from 18,500 ft up to 40,000 ft (5639 to 12,192 m)).

6.5.2 (Continued):

6. Column “E” shows the percent of total oxygen required to meet the FAA regulations or requirements for tracheal oxygen partial pressure at each altitude indicated in Column “A”. The fraction of added oxygen theoretically required will now be determined:

   Basis

   a. Dry gases.
   b. Air is 20.95% oxygen.
   c. F = Fraction of air added.
   d. F_T = Total fraction of oxygen in the nitrogen-oxygen mixture.
   e. F_A = Fraction of oxygen added

   $$= \frac{\text{oxygen added}}{\text{total mixture air + oxygen}}$$

   $F + F_A = 1$
   $F = 1 - F_A$
   $F_T = F_A + 0.2095\ F = F_A + 0.2095\ (1 - F_A)$
   $F_T = F_A + 0.2095 - 0.2095\ F_A = 0.2095 + 0.7905\ F_A$

   $$F_A = \frac{F_T - 0.2095}{0.7905}$$

   or on a percent basis, where O_T = % total oxygen, this is:

   $$F_A = \frac{O_T - 20.95}{79.05}$$

   The above equation is now evaluated at each altitude for F_A, the fraction of added oxygen. This is accomplished by first evaluating the numerator, O_T - 20.95, shown in Column “F”. The values of Column “F” are then divided by 79.05 and recorded in Column “G”. The values in Column “G” thus represent the theoretical fraction of added oxygen (Table 10).

7. The theoretical oxygen requirements for each altitude are shown in Column “H” of Table 10. These values were obtained by multiplying the required minute volume (Column “D”) by the theoretical fraction of added oxygen (Column “G”).

TABLE 10

(A) Altitude in Thousands of Feet (Meters)		(F) (E)-20.95	(G) (F) / 79.05	(H) Theoretical Oxygen Req. LPM-NTPD	(I) Required Minimum Oxygen Flow to Mask in LPM-NTPD
At 15 (LPM BTPS)					
10	(3048)	0.07	0.00089	0.0079	0.0178
11	(3353)	0.99	0.0125	0.1067	0.1137
12	(3657)	1.96	0.0248	0.2027	0.2037
13	(3962)	2.99	0.0378	0.2957	0.2916
14	(4267)	4.07	0.0515	0.3854	0.3759
15	(4572)	5.22	0.0660	0.4722	0.4582
16	(4877)	6.44	0.0815	0.5572	0.5379
17	(5182)	7.73	0.0978	0.6385	0.6148
18	(5486)	9.10	0.1151	0.7172	0.6891
18.5	(5639)	9.82	0.1242	0.7558	0.7303
At 30 (LPM BTPS)					
18.5	(5639)	4.83	0.0611	0.7437	0.7225
19	(5791)	5.45	0.0689	0.8190	0.7940
20	(6096)	6.75	0.0854	0.9676	0.9336
21	(6401)	8.13	0.1028	1.1029	1.068
22	(6705)	9.60	0.1214	1.2470	1.204
23	(7010)	11.17	0.1413	1.3805	1.344
24	(7315)	12.86	0.1627	1.5105	1.481
25	(7620)	14.65	0.1853	1.6336	1.612
26	(7925)	16.57	0.2096	1.753	1.738
27	(8230)	18.64	0.2358	1.869	1.860
28	(8534)	20.86	0.2639	1.981	1.992
29	(8839)	23.25	0.2941	2.088	2.122
30	(9144)	25.83	0.3267	2.191	2.247
31	(9449)	28.62	0.3620	2.292	2.368
32	(9754)	31.64	0.4002	2.388	2.499

TABLE 10 (Continued)

(A) Altitude in Thousands of Feet (Meters)		(F) (E)-20.95	(G) $\frac{(F)}{79.05}$	(H) Theoretical Oxygen Req. LPM-NTPD	(I) Required Minimum Oxygen Flow to Mask in LPM-NTPD
33	(10,059)	34.92	0.4417	2.481	2.630
34	(10,363)	38.48	0.4867	2.570	2.754
35	(10,668)	42.38	0.5361	2.657	2.891
36	(10,973)	46.64	0.5900	2.740	3.025
37	(11,278)	51.30	0.6489	2.819	3.164
38	(11,582)	56.38	0.7132	2.895	3.307
39	(11,887)	61.93	0.7834	2.967	3.453
40	(12,192)	68.03	0.8605	3.035	3.603

6.5.2 (Continued):

C. Oxygen Flow Schedule to the Mask:

During the initial development of jet transport passenger mask performance specification, it was common practice to give the added oxygen flow requirement (f) and minute volume (MV) as a ratio $\frac{F}{MV}$ plotted against percent total oxygen (% O2). By multiplying these $\frac{F}{MV}$ values by the minute volume, the minimum oxygen-mask-flow requirements were obtained for the particular mask.

Presently, however, the minimum oxygen-flow requirements, established during passenger-mask-qualification tests are presented directly as minimum oxygen-mask-flow requirements. The results of these tests are analyzed and presented as “guaranteed Minimum Performance Curve,” with the coordinates “Added Oxygen Flow to Mask in LPM-NTPD,” and “Cabin Altitude in 1000 Feet.” For specific details see Federal Aviation Agency Technical Standard Order No. C64, Oxygen Mask Assembly, Continuous Flow, Passenger.

For our purposes we shall assume hypothetical performance which we will assume meets the above TSO specification. These guaranteed performance values, given in Column “I”, Table 10, form the numerical basis for the entire system design.

NOTE: Only masks which qualify to the particular TSO dash number may be used with this particular hypothetical oxygen system. Any mask which falls below these minimum required tracheal oxygen percentages fails to meet the mask type specification and cannot be used with an oxygen system which has been designed to this particular mask type specification or better.

6.5.2 (Continued):

D. Determination of Outlet Flow and Pressure Schedule Requirements:

1. Column “J” of Table 11 is computed by multiplying Column “I” by 1.05. This is to allow a design safety margin of five percent. It is extremely wise to include a safety margin not only as a buffer for future production and equipment design problems but also because it allows tolerance in the measuring devices used for checking out the system. Five percent is considered minimal. Column “J” is then the minimum flow required from the outlet.

   The calculations from this point forward become more graphical in nature. The reason for this is that an outlet performance curve is best chosen empirically. In other words, several outlets are built and tested. These may be orifices and/or packed restrictor materials which will give a particular test curve as shown in Graph 1 (see Figure 10). The important thing is to be sure that the outlet restrictor performance is easily reproducible within reasonable tolerances, because once the outlet performance (i.e. the outlet flow versus inlet pressure) is established it will form the basis for the regulator performance requirements.

2. Column “K” is the design upper limit of the outlet flow. Column “K” has been calculated by multiplying Column “J” by 1.06. This established a six percent outlet design tolerance. As is the case with most oxygen system components, the design performance tolerance can be made larger or smaller. Inevitably the initial cost of equipment manufactured to close tolerances will be high when compared to those manufactured to more liberal tolerances. There is, however, a “trade off” since the parts with wider tolerances will require more weight in cylinder oxygen to cover excessive oxygen flow.

3. Column “L” gives the mean design flow of all outlets and is calculated by adding Columns “J” and “K” and dividing by two or multiplying Column “J” by 1.03.

4. Curve “A” is constructed on Graph 1 (see Figure 10) from the data in Column “A” and “J” of Table 11. This curve represents the required minimum outlet flow rate of oxygen at each altitude. The flow rate is plotted along the ordinate while the altitude is plotted across the top abscissa.

TABLE 11

(A) Altitude in Thousands of Feet (Meters)		(J) Minimum Outlet Flow 1.05 (I) LPM-NTPD	(K) Maximum Outlet Flow 1.06 (J) LPM-NTPD	(L) Average Outlet Flow $\frac{J+K}{2}$ LPM-NTPD	(M) Outlet Minimum Pressure psig *	(M) Outlet Minimum Pressure (kN/m^2)
			At 15 (LPM BTPS)			
10	(3048)	0.0187	0.049 **	0.034	4.2	28.9
11	(3353	0.1192	0.149 **	0.134		
12	(3657)	0.2139	0.244 **	0.229	17.1	117.9
13	(3962)	0.3062	0.336 **	0.321		
14	(4267)	0.3947	0.4184	0.4065	25.3	174.6
15	(4572)	0.4811	0.5100	0.4955		
16	(4877)	0.5648	0.5987	0.5817	32.4	224.1
17	(5182)	0.6455	0.6843	0.6649		
18	(5486)	0.7236	0.7670	0.7452	38.35	264.7
18.5	(5639)	0.7668	0.8128	0.7898	40.0	275.8
			At 30 (LPM BTPS)			
18.5	(5639)	0.7586	0.8041	0.7813		
19	(5791)	0.8337	0.8837	0.8587		
20	(6096)	0.9803	1.039	1.0096	47.2	324.0
21	(6401)	1.121	1.189	1.115		
22	(6705)	1.264	1.340	1.302	56.3	386.1
23	(7010)	1.411	1.496	1.453		
24	(7315)	1.555	1.648	1.601	65.4	448.2
25	(7620)	1.693	1.794	1.743		
26	(7925)	1.825	1.934	1.880	73.4	505.9
27	(8230)	1.953	2.070	2.012		
28	(8534)	2.097	2.216	2.154	80.7	556.4
29	(8839)	2.228	2.362	2.295		
30	(9144)	2.359	2.501	2.430	88.13	607.3
31	(9449)	2.486	2.636	2.561		
32	(9754)	2.624	2.781	2.702	95.0	655.0
33	(10,059)	2.761	2.927	2.844		

TABLE 11 (Continued)

(A) Altitude in Thousands of Feet (Meters)		(J) Minimum Outlet Flow 1.05 (I) LPM-NTPD	(K) Maximum Outlet Flow 1.06 (J) LPM-NTPD	(L) Average Outlet Flow $\frac{J+K}{2}$ LPM-NTPD	(M) Outlet Minimum Pressure psig *	(M) Outlet Minimum Pressure (kN/m^2)
34	(10,363)	2.892	3.065	2.978	101.90	702.8
35	(10,668)	3.036	3.218	3.127		
36	(10,973)	3.176	3.367	3.271	109.0	751.4
37	(11,278)	3.322	3.522	3.421		
38	(11,582)	3.472	3.680	3.576	115.83	798.7
39	(11,887)	3.626	3.843	3.734		
40	(12,192)	3.783	4.010	3.897	123.1	847.7

* At Cabin Pressure
** (K) = (J) + .03

6.5.2 (Continued):

5. Curve “B” has been drawn in arbitrarily as the hypothetical performance curve. As mentioned previously, in actual practice the curve would be established by tests, forming performance specification.

   Although the outlet performance may be presented numerically in the form of tables, sufficient data must be given to allow accurate interpolation. Where the graphical method is used, as is the case in this example, it is recommended that the plotting be done using a fairly large scale to insure accuracy. Ten inches per liter flow and fifty inches per hundred psi were used in the example. To reduce the paper sizes two ranges were used.

6. From Curve “A” minimum flow rate - altitudes are marked on Curve “B”. (In altitude increments of 4000 feet or less.) The pressure values from Curve “B” are read from abscissa and recorded in Column “M” of Table 11. These pressure values are the minimum pressure in psig (at altitude) required at the inlet of the oxygen outlets.

7. Curve “C” is constructed from the values shown in Column “K” by plotting at corresponding altitudes with the identical Curve “B” pressures. This then provides the maximum (Curve “C”) and minimum (Curve “B”) oxygen outlet flow performance at each pressure-altitude.

8. Curve “D”, the average outlet flow curve is constructed in the same manner as Curve “C” by using the data in Column “L”.

E. Calculation of Passenger Regulator Performance:

1. Graph 2 (see Figure 11) shows line pressure drop from the regulator to the most remote outlet as a function of pressure.

   Although this curve is hypothetical, such a curve can be arrived at by a straight-forward, step-wise, system-pressure-drop calculation. It is recognized that pressure drop is a function of both weight flow and density (Darcy’s equation). However, for convenience, and since flow is a function of pressure, pressure drop is plotted here against regulator pressure, with flow rate at a maximum.

   The pressure drop will depend on the piping configuration and on line sizing. Here again, there is a weight trade off. Smaller lines and fittings will weigh less and be easier to install, but the increase in pressure drop will mean an increase in regulator pressure. The higher the upstream pressure the larger the excessive flow of oxygen from outlets upstream of the most remote outlet will be, thus increasing the weight of required cylinder oxygen. A system pressure-drop flow test is strongly recommended.

2. The maximum system pressure drop values shown in Column “N”, Table 12 are read from Graph 2 (see Figure 11).

TABLE 12

(A) Altitude in Thousands of Feet (Meters)		(N) Maximum System Pressure Drop in psi	(O) Regulator Minimum Pressure psig *	(P) 1.05 (O)	(R) Barometric Pressure psi
		At 15 (LPM BTPS)			
10	(3048)	0.02	4.22	4.43	10.108
12	(3657)	0.13	17.23	18.09	9.349
14	(4267)	0.24	25.54	26.82	8.636
16	(4877)	0.34	32.74	34.38	7.969
18	(5486)	0.46	38.80	40.74	7.344
18.5	(5639)	0.5	40.5	42.53	7.194
		At 30 (LPM BTPS)			
20	(6096)	0.64	47.84	50.23	6.759
22	(6705)	0.86	57.16	60.02	6.212
24	(7315)	1.12	66.52	69.85	5.702
26	(7925)	1.34	74.74	78.48	5.227
28	(8534)	1.55	82.25	86.36	4.784
30	(9144)	1.78	89.91	94.91	4.373
32	(9754)	2.02	97.02	101.87	3.990
34	(10,363)	2.25	104.15	109.36	3.635
36	(10,973)	2.50	111.50	117.08	3.306
38	(11.582)	2.75	118.58	124.51	3.004
40	(12,192)	3.00	126.1	132.41	2.730

* At Cabin Pressure

NOTE: Values in kN/m^2 can be obtained by multiplying psig figure by 6.894757. Values of Barometric Pressure in m bars can be obtained by multiplying psi figure by 68.948.

6.5.2 (Continued):

3. Column “O”, the minimum regulator pressure output is the sum of required outlet input pressure (Column “M”) and the system pressure drop (Column “N”).

4. Column “P”, is equal to minimum regulator pressure output (Column “O”) plus five percent for regulator tolerance.

5. Column “R” indicates the barometric pressure in pounds per square inch.

6. To evaluate regulator feasibility, Graph 3 Regulator Pressure schedule (see Figure 12), is drawn. Column “O” and “P” the regulator outlet minimum and “minimum plus 5%” pressures are plotted against altitude in barometric pressure Column “R”, and are designated as Curve “O” and “P” respectively.

7. While not necessarily true of all altitude compensating regulators, usually the output pressure varies directly with changes in atmospheric pressure. Thus, for convenience in regulator design, Curve “S” is added as the maximum tolerance. This curve is composed of two straight line functions laid out graphically as close as reasonably possible to Curve “P”. The values recorded in Column “S” are read from Curve “S”. Thus Columns “O” and “S” and Curves “O” and “S” represent the regular pressure performance requirement.

F. Calculation of Required Cylinder Oxygen Consumption Per Passenger:

1. We must assume that the system regulator output will be maximum as shown in Column “S” since this is an allowable situation.

2. Column “T”, the average pressure at the average outlet is equal to Column “S” minus half the system pressure drop shown in Column “N”. For an average type system, this is considered to be very close to the actual average pressure conditions; however, where manifolds are unbalanced or there is a long length of plumbing to the most remote outlet, an average pressure drop calculation may need to be performed by standard pressure drop calculation procedures.

6.5.2 (Continued):

3. Once the average pressure at the outlet has been calculated for each altitude as shown in Column "T", the average flow rate at each of these altitudes can be determined. This evaluation may be accomplished by either of 2 methods:

(1) The direct approach uses the average outlet flow curve, Curve "D", Graph 1 (see Figure 10). The pressure values of Column "T" are plotted on Curve "D" and flow values (the average oxygen consumption) are recorded in Column "V".

(2) Where it is desired to use a single curve to represent the outlet flow performance, Curve "B", Graph 1 (see Figure 10) (the minimum flow at a given pressure) can be used to calculate average flow or maximum flow by multiplying the value by 1.03 or 1.06 respectively. Using this method the pressure values of Column "T" are plotted on Curve "B", Graph 1 (see Figure 10) and the minimum flow values are recorded in Column "U". The values in Column "U" are then multiplied by 1.03 giving the average outlet flow Column "V".

The use of the average outlet flow is justifiable where there is a large number of outlets.

WARNING: It should be emphasized that where the population of outlets is small, Curve "C" must be used, or Column "U" should be multiplied by 1.06 or possibly a figure between 1.03 and 1.06.

Column "V" from Table 13 is plotted as Curve "V" on Graph 4 (see Figure 13). The average flow value may be calculated by graphical integration of the area below the curve from 10 to 40 thousand feet, or by averaging the values in Column "V". This value, approximately 2.01 LPM NTPD, will be valuable in calculating the oxygen required for even descents from 40,000 to 10,000 ft (12,192 to 3048 m).

G. System Efficiency:

1. Column "I", the required minimum oxygen flow to the mask, from Table 10 is plotted as Curve "I" on Graph 4 (see Figure 13). The average flow value of Column "I" is found to be 1.6578.

2. The system efficiency to the mask then equals:

$$E_S - M = \frac{1.6578}{2.01} 100 = 82.48\%$$

TABLE 13

(A) Altitude in Thousands of Feet (Meters)		* (S) Regulator Maximum Pressure psig **	* (T) Average Pressure at Outlet psig **	(U) Minimum Flow at Pressure in (T) LPM-NTPD	(V) Average Flow LPM-NTPD
			At 15 (LPM BTPS)		
10	(3048)	4.23	4.22	0.018	0.0185
12	(3657)	17.96	17.90	0.230	0.237
14	(4267)	27.10	26.98	0.436	0.449
16	(4877)	35.65	36.48	0.645	0.664
18	(5486)	43.60	43.37	0.884	0.910
18.5	(5639)	45.59	45.34	0.925	0.953
			At 30 (LPM BTPS)		
20	(6096)	51.24	50.92	1.093	1.126
22	(6705)	61.86	61.43	1.425	1.468
24	(7315)	71.75	71.19	1.755	1.808
26	(7925)	80.97	80.30	2.075	2.137
28	(8534)	89.56	88.79	2.385	2.457
30	(9144)	97.54	96.85	2.693	2.774
32	(9754)	104.97	103.96	2.973	3.062
34	(10,363)	111.86	110.74	3.255	3.352
36	(10,973)	118.24	117.00	3.520	3.626
38	(11,582)	124.10	122.73	3.762	3.875
40	(12,192)	130.00	128.5	4.015	4.135

* At Cabin Pressure

** Multiply psig by 6.894757 to get kN/m^2

6.5.2 (Continued):

3. The overall system efficiency is equal to the average theoretical required minimum oxygen, that is, the average of Column “H” divided by the average system flow:

$$E_S = \frac{1.5732}{2.01} 100$$

$$E_S = 78.27\%$$

H. Minimum Quantity of Emergency Oxygen Required Per Cabin Occupant:

The minimum quantity of emergency and sustaining supplemental cylinder oxygen (Reference FAR 121.333) must be sufficient to provide each cabin occupant (passenger or cabin attendant) for:

1. Emergency descent at maximum demonstrated descent rate, to emergency cruise altitude and to provide at cruise altitude sustaining supplemental oxygen for the duration of decompressed flight. (For 100% of the passengers above 15,000 ft (4752 m), 30% from 14,000 to 15,000 ft (4267 to 4572 m) and to provide for 10% from 10,000 to 14,000 ft (3048 to 4267 m) cruise altitude.)

2. A uniform ten-minute emergency descent (from maximum certificated cruise altitude to 10,000 ft (3048 m)).

It is not the intent of the regulation to provide for item 1 plus item 2 but to provide for the largest value so that the quantity of oxygen can meet either condition. Item 2, in a sense, can be considered the absolute minimum, and the quantity of oxygen which exceeds that actually required for the demonstrated emergency descent rate may be considered to be used to partially meet the requirement for sustaining oxygen.

(1) The Absolute Minimum Required Quantity of Oxygen

Let Q = Required quantity of emergency and sustaining supplemental oxygen in L-NTPD (liters of normal temperature pressure dry, 70 F, 760 mm Hg and $PH_2O = 0$).

Q_m = Minimum quantity Q per FAA regulations in L-NTPD
T = Time in minutes of flight after decompression
F = Flow rate in LPM-NTPD

The General Equation

$$Q = 1.03\ T\ (F)$$

6.5.2 (Continued):

The value "1.03" is used to include a 3 percent margin for infants-in-arms.

Q_m = 1.03 T (F)
= 1.03 (10) (2.01) = 20.70 L-NTPD

The value "2.01" is the average flow in LPM from 40 to 10 thousand feet. (Column "V", Table 13.)

The "20.70 L-NTPD" of oxygen is the minimum (required FAA regulations) per passenger and cabin attendant specifically for this particular hypothetical oxygen system.

NOTE: This system evaluation and calculation has not included an analysis of the required first aid oxygen system and cylinder oxygen required for air carrier aircraft operating under Part 121 of the FAR.

(2) Example 1, Available Oxygen for Sustaining Supplemental Oxygen

As stated above, the oxygen provided by the minimum required quantity which exceeds that oxygen actually required for the demonstrated emergency descent rate may be used as sustaining oxygen.

An example of actual emergency oxygen needs will now be calculated based on the hypothetical performance capability.

a. Basis:

(1) Decompression at 40,000 ft (12,192 m) with emergency descent to 14,000 ft (4267 m).

(2) 40,000 ft (12,192 m) maximum demonstrated descent rate of 240 seconds to 14,000 ft (4267 m) (assuming descent can be made to 14,000 ft (4267 m)).

(3) Emergency cruise at or below 14,000 ft (4267 m).

b. Basic Formulas:

$$Q = 1.03\ T\ (F)$$

$$Q_e = Q_D + Q_{40-14}$$

6.5.2 (Continued):

where the following required quantities of oxygen are:

Q_e = actual needs
Q_D = delay of 20 seconds at 40,000 ft (12,192 m)
Q_{40-14} = descent from 40,000 to 14,000 ft (4267 m)

c. Total Emergency Oxygen per Passenger:

Delay:

$$Q_D = 1.03 \frac{20}{60} \times 4.135 = 1.420 \text{ L-NTPD Descent}$$

$$Q_{40-14} = 1.03\ (T_{40-14})\ F_{40-14}$$

F_{40-14} is essentially the average flow from 40,000 to 14,000 ft (12,192 to 4267 m) and may be determined by graphical integration of the area below the Curve "V" on Graph 4 (see Figure 13) from 14 to 40 thousand feet. This value, 2.28 LPM-NTPD, may also be obtained numerically from Column "V", Table 13.

$$Q_{40-14} = 1.03 \frac{240}{60} 2.28$$

$$= 9.39 \text{ Liters NTPD}$$

$$Q_e = Q_D + Q_{40-14} = 1.42 + 9.39$$

$$Q_e = 10.81 \text{ L-NTPD}$$

d. Available Sustaining Supplemental Oxygen: The quantity difference between the minimum required quantity and the actual needs may be used for sustaining supplemental oxygen (Q_{sm}).

$$Q_{sm} = Q_m - Q_e$$

$$Q_{sm} = 20.70 - 10.81 = 9.89 \text{ L-NTPD}$$

6.5.2 (Continued):

e. Determine the duration in minutes for the minimum sustaining supplemental oxygen: Where emergency cruise is made at 14,000 ft (4267 m).

The FAA requirement at 14,000 ft (4267 m) and below is for "... 10 percent of the number of passenger cabin occupants ..."

The general equation would be:

$$Q_{sm_{14}} = 0.1\ (1.03)\ (F_{14})$$

where:

$Q_{sm_{14}}$ = quantity of minimum sustaining supplemental oxygen at 14,000 ft (4267 m)
F_{14} = Flow at 14,000 feet in LMP-NTPD
T_{14} = Time at 14,000 feet

If Q_{sm} = 9.89 L-NTPD, then

$$9.89 = 0.103\ (.449)\ T_{14}$$
$$9.89 = 0.046247\ T_{14}$$
$$T_{14} = \frac{9.89}{0.046247} = 213.85 \text{ minutes} = 3.56 \text{ hours}$$

NOTE: Where the duration of minimum sustaining supplemental oxygen is insufficient, additional supplemental oxygen must be carried.

(3) Example 2, decompression at 40,000 ft (12,192 m) with emergency descent to 18,000 ft (5486 m), sixteen minute emergency cruise at 18,000 ft (5486 m) and one hour cruise at 14,000 ft (4267 m).

a. Basis:

(1) 40,000 ft (12,192 m) maximum demonstrated descent rate of 203 seconds to 18,000 ft (5486 m) (assuming descent can be made to 18,000 feet).

(2) At an emergency cruise at 18,000 feet (above 15,000 feet) the FAA requires oxygen for 100 percent of the number of cabin occupants.

(3) Descent from 18,000 to 14,000 feet is one minute (assumed 100 percent).

(4) Emergency cruise at 14,000 feet and below, FAA requires oxygen for 10 percent of cabin occupants.

6.5.2 (Continued):

b. Calculations:

$Q = 1.03\ (T)\ (F)$
$Q = Q_e + Q_{18-14} + Q_{14}$
$Q_e = Q_D + Q_{40-18}$
Q_e = Quantity of oxygen actually required for emergency delay (Q_D) of 20 seconds and emergency descent (Q_{40-18})
$Q_e = Q_D + Q_{40-18}$
F_{18} = 0.910 LPM-NTPD
F_{14} = 0.449 LPM-NTPD
F_{40-18} = 2.56 LPM-NTPD
F_{18-14} = 0.6783 LPM-NTPD

Delay:

$$Q_D = 1.03\ \frac{20}{60}\ 4.135 = 1.420 \text{ L-NTPD}$$

Descent:

$$Q_{40-18} = 1.03\ \frac{203}{60}\ 2.56 = 8.92$$

Emergency Delay Descent:

$Q_e = Q_D + Q_{40-18}$ = 10.34 L-NTPD
Q_{18} = 1.03 (0.910) (16) = 14.996 L-NTPD
$Q_{18-14} = 1.03\ (F_{18-14})\ (T_{18-14})$
= 1.03 (0.6783) (1) = 0.699 L-NTPD
Q_{14} = (0.1) (1.03) (0.449) (60) = 2.775 L-NTPD
$Q = Q_e + Q_{18} + Q_{18-14} + Q_{14}$
= 10.34 + 14.996 + 0.699 + 2.775
Q = 28.81 L-NTPD

It can be seen that this value of “Q” (28.81 L-NTPD) exceeds the “absolute minimum requirement” (Q_m = 20.70 L-NTPD) and in so doing becomes the minimum required quantity of emergency oxygen per passenger or cabin attendant.

6.5.3 Selection of Cylinders: In the selection of cylinders no more than about 90% of the rated capacity should be considered available to meet the oxygen requirements. This will allow about a 10% service margin for topping.

NOTE: This system evaluation and calculation has not included an analysis of the required first aid oxygen system and cylinder oxygen required for Air Carrier Aircraft operation under FAR 121.333 (e) (3).

6.6 Crew Oxygen System Duration Determination:

FAA Regulations prescribe oxygen use based on the type of operation and whether the airplane is pressurized or unpressurized. The types of operations are as follows:

FAR 91, the General and Flight Operating Rules, govern flights not carrying passengers for hire. Such flights may be conducted in Transport, Normal, Utility and Acrobatic Category Airplanes.

FAR 121, the rules for Domestic, Flag and Supplemental Air Carriers and Operators of Large Aircraft, govern flights only in Transport Category Airplanes where passengers are being carried for hire.

FAR 135, the rules for Air Taxi and Commercial Operators, govern flights inn Transport Category Airplanes of 30 passengers or less as well as flights in Normal and Utility Airplanes where passengers are carried for hire. This includes single-engine airplanes.

In unpressurized airplanes, crew members are required to use oxygen in FAR 91 operations above cabin altitudes of 12,500 feet and in FAR 121 and FAR 135 operations above cabin altitudes of 10,000 feet.

In pressurized airplanes, crew member oxygen use is also dependent upon whether or not quick-donning oxygen masks are used. Inasmuch as almost all operators use quick-donning masks, only those aspects will be considered. When airplanes are flown at altitudes of 18,000 feet or more, the altimeter barometric reference is set to 29.92 inches Hg and the altitude is called a flight level (FL) i.e. 29,000 feet is called FL 290, 33,000 feet is FL 330, etc.

If both pilots are seated at the controls and have quick-donning masks, the airplane can be operated up to FL 410 under either FAR 91 or FAR 121 rules, or up to FL 350 under FAR 135 rules without either of the pilots wearing oxygen masks. For flights above these altitudes the pilot wearing the mask does not need to be breathing oxygen but oxygen must be automatically supplied if the cabin altitude goes to 10,000 feet or above.

Duration is based on flow of oxygen per minute versus time at altitude multiplied by the number of crew. However, the FAA in FAR 121 and 135 specify a 2 hour minimum.

6.6 (Continued):

Where conventional demand equipment is used duration may be calculated using flow rates from Table 14. For new or unconventional demand equipment, data should be obtained from the manufacturer. Where continuous flow equipment is used for crewmen, oxygen flow rates versus altitude should be obtained from the manufacturer of the oxygen regulator and mask metering orifice. Also FAR 23.1443 prescribes oxygen flow rates for continuous flow systems.

TABLE 14

Altitude in Thousands of Feet (Meters)		Oxygen Consumption "100% Oxygen" LPM-NTPD	Oxygen Consumption "Normal Oxygen" LPM-NTPD
0	(0)	13.1	2.4
5	(1524)	10.6	2.4
10	(3048)	8.4	2.4
15	(4572)	6.75	2.4
20	(6096)	5.4	2.9
25	(7620)	4.1	3.3
30	(9144)	3.17	3.1
35 and above	(10668)	2.3	2.3

Oxygen Duration requirements are determined on the basis of cabin pressure altitudes and flight duration. The requirements for airplanes with pressurized cabins are determined on the basis of cabin pressure altitude and the assumption that a cabin pressurization failure will occur at the altitude or point of flight that is most critical from the standpoint of oxygen need and that after the failure the airplane will descend in accordance with emergency procedures to a flight altitude that will allow successful termination of the flight with the cabin altitude considered the same as the flight altitude.

Duration can be computed using the following equation.

$$Q = N (R_1T_1 + R_2T_2 + ... + R_nT_n)$$

Where

Q = quantity required in liters - NTPD
N = number of crewmen affected
R = rate of flow for each crewman in liters per minute (from Table)
T = time at unpressurized cabin altitude above 10,000 ft (3048 m)

6.6 (Continued):

Example No. 1

A pressurized Transport Category airplane with 2 crewmen flying above 25,000 ft (7620 m) without quick-donning masks on a 6 hour overwater flight, using demand equipment.

R_1 = 2.4 LPM - one crewman on oxygen above flight altitude of 25,000 ft (7620 m), cabin altitude below 10,000 ft (3048 m).

T_1 = 3 x 60 = 180 minutes - time to point of no return and assumed loss of cabin pressurization.

R_2 = 3.3 LPM - rate for each of 2 crewman on oxygen at 25,000 ft (7620 m) altitude to continue flight after loss of pressurization.

T_2 = 180 minutes, time to continue flight at 25,000 ft (7620 m) to termination of flight.

$Q = N_1R_1T_1 + N_2R_2T_2$

Q = 1 x 2.4 x 180 + 2 x 3.3 x 180

Q = 432 + 1188 = 1620 liters NTPD

or,

Q = 1620/28.32 = 57.2 cubic feet NTPD

NOTE: This is slightly conservative since the times to ascend to and descend from 25,000 ft (7620 m) have not been included, and 25,000 ft (7620 m) is the altitude of maximum oxygen consumption, whereas flight after loss of pressurization would normally be at much lower altitudes because of low ambient temperatures at the higher altitudes and the susceptibility of the occupants to the bends.

6.6 (Continued):

Example No. 2

A pressurized Transport Category airplane with 2 crewmen flying at 38,000 ft (11,582 m) with quick-donning masks using demand equipment on a continental 4 hour flight with enroute capability to make an emergency descent to 14,000 ft (4267 m) or lower and continue flight to destination.

Since oxygen is not required prior to loss of cabin pressurization except for the possible short time either pilot would be away from his duty station and oxygen used after decompression would be only for the few minutes required for the emergency descent, the FAA 2 hour minimum would be required. This minimum should be based on the anticipated flight profile to be used after loss of cabin pressure. Assume a maximum descent time of 10 minutes and continued flight at 14,000 ft (4267 m) for a total of 2 hours.

R_1 = 3 LPM - using average rate for 10 minute descent.
T_1 = 10 minutes - descent time.
R_2 = 2.4 LPM - continued flight at 14,000 ft (4267 m).
T_2 = 110 minutes - continued flight at 14,000 ft (4267 m).
$Q = (NR_1T_1) + (NR_2T_2)$
$Q = (2 \times 3 \times 10) + (2 \times 2.4 \times 110)$
$Q = 60 + 528 = 588$ LPM, NTPD

or,

$Q = 588/28.32 = 20.8$ cubic feet, NTPD

Example No. 3

An unpressurized FAR 23 airplane (under 12,500 lb (354.4 kg) gross), not flying for hire, one pilot on a 1-1/2 hour flight at 18,000 ft (5486 m) using demand equipment.

Since the airplane is not carrying persons or property for hire the 2 hour minimum supply required by FAR 135 is not applicable. To be conservative ignore the time to climb to and descend from altitudes requiring oxygen.

R_1 = 2.7 LPM, by interpolation of Table 14 to obtain rate for 18,000 ft (5486 m).
T_1 = 1-1/2 hours = 90 minutes.
$Q = N_1R_1T_1 = 1 \times 2.7 \times 90$
$Q = 243$ liters NTPD

or,

$Q = 243/28.32 = 8.6$ cubic feet NTPD

6.7 Conversion Factors:

TABLE 15

To Obtain	From	Multiply by
Standards of Volume		
BTPS	BTPD	$\frac{P_B}{P_B - 47}$
	STPD	$\frac{862.94}{P_B - 47}$
	NTPD	$\frac{801.04}{P_B - 47}$
BTPD	BTPS	$\frac{P_B - 47}{P_B}$
	STPD	$\frac{862.94}{P_B}$
	NTPD	$\frac{801.04}{P_B}$
STPD	BTPS	$0.0011588\ (P_B - 47)$
	BTPD	$0.0011588\ (P_B)$
	NTPD	0.92826
NTPD	BTPS	$0.0012484\ (P_B - 47)$
	BTPD	$0.0012484\ (P_B)$
	STPD	1.0773
Volume		
Liters	Cubic centimeters	0.001
	Cubic inches	0.01639
	Cubic feet	28.32
	Gallons (liq.)	3.785
Cubic Centimeters	Liters	1000.
	Cubic inches	16.39
	Cubic feet	28320.
	Gallons (liq.)	3785.
Cubic Inches	Liters	61.02
	Cubic centimeters	0.06102
	Cubic feet	1728.
	Gallons (liq.)	231.

To Obtain	From	Multiply by
Cubic Feet	Liters	0.03531
	Cubic centimeters	0.00003531
	Cubic inches	0.0005787
	Gallons (liq.)	0.1337
Gallons (liq.)	Liters	0.2642
	Cubic centimeters	0.0002642
	Cubic inches	0.004329
	Cubic feet	7.481
Volume Flow Rate		
Liters/Minute	Cubic feet/hour	0.4717
Cubic Feet/hour	Liters/minute	2.120
Pressure		
mm Hg @ 0°C	Inch Hg @ 0°C	25.40
	Inch H_2O @ 4°C	1.868
	Cm. H_2O @ 4°C	0.7354
	Lb/ft^2	0.3591
	Lb/in^2	51.71
	Millibars	0.7500
	Atmospheres	760.00
Lb/in^2	mm Hg @ 0°C	0.01934
	Inch Hg @ 0°C	0.4912
	Inch H_2O @ 4°C	0.03613
	Cm. H_2O @ 4°C	0.01422
	Lb/ft^2	0.006944
	Millibars	0.01450
	Atmospheres	14.696
kN/m^2	Lb/in^2	6.8948
Length		
Feet	Inches	0.08333
	Meters	3.281
	Centimeters	0.03281
	Millimeters	0.003281
Inches	Feet	12.
	Meters	39.37
	Centimeters	0.3937
	Millimeters	0.03937
Meters	Feet	0.3048
	Inches	0.0254
	Centimeters	0.01
	Millimeters	0.001
Millimeters	Feet	304.8
	Inches	25.4
	Meters	10000.
	Centimeters	10.

6.8 Composition of the Atmosphere:

TABLE 16

Constituent Gas	Molecular Fraction Percent	Molecular Weight 0 = 16.000
Nitrogen (N_2)	78.09	28.106
Oxygen (O_2)	20.95	32.0000
Argon (A)	0.93	39.944
Carbon Dioxide (CO_2)	0.03	44.010
Neon (Ne)	1.8×10^{-3}	20.183
Helium (He)	5.24×10^{-4}	4.003
Krypton (Kr)	1.0×10^{-4}	83.7
Hydrogen (H_2)	5.0×10^{-5}	2.0160
Xenon (Xe)	8.0×10^{-6}	131.3
Ozone (O_3)	1.0×10^{-6}	48.0000
Radon (Rn)	6.0×10^{-18}	222.0

6.9 Military Specifications and Standards Applicable to Aircraft Oxygen Systems:

TABLE 17

	DOD Document Number	Preparing Activity
Adapter, Compressed Gas Cylinder Valve Connection, US Regulator to British Oxygen Valve	MIL-A-16288/1	Army-ME
Adapter, Compressed Gas Cylinder Valve Connection, US Regulator to French Oxygen Valve	MIL-A-16288/2	Army-ME
Adapter, Compressed Gas Cylinder Valve Connection, US Regulator to Japanese Oxygen Valve	MIL-A-16288/3	Army-ME
Adapter, Compressed Gas Cylinder Valve Connection, US Regulator to Dutch Oxygen Valve	MIL-A-16288/4	Army-ME
Adapter, Compressed Gas Cylinder Valve Connection, US Regulator to German Oxygen Valve	MIL-A-16288/5	Army-ME
Adapter, oxygen Servicing, USAF Ground Equipment to RAF Aircraft	MS27589	AF 11
Adapter, Oxygen Supply, Chemical Biological Mask, ABC-M8	MIL-A-51306	Army-EA

TABLE 17 (Continued)

	DOD Document Number	Preparing Activity
Adapter Portable Oxygen Recharging Orifice	AN6044	AF 71
Adapter Oxygen Filler	AND10070	AF 11
Adapter Pressure-Reduce In-Line CRU-43/A	MIL-A-27471	AF 82
Air, Compressed, for Breathing Purposes	BB-A-1034	Navy AS
Bonding, Electrical and Lightning Protection for Aerospace Systems	MIL-B-5087	AF 11
Cap Assembly Liquid Oxygen Filler Valve	MS27566	AF 71
Clamp, Oxygen Hose	MS22064	AF 82
Cleaning Methods and Procedures for Breathing Oxygen Equipment	MIL-STD-1359	Navy AS
Cleaning Compound, Solvent, Trichlo-rofluroethane	MIL-C-81302	Navy AS
Concentrator, Oxygen, GGU-7/A	MIL-C-85521	Navy AS
Connector, Bayonet 3 Pin, Oxygen Mask	MS27796	AF 82
Connector, Oxygen Hose to Regulator	MS22058	Navy AS
Connector, Oxygen Hose to Regulator	MIL-C-19064	Navy AS
Connector, Oxygen Mask Hose, Type MC-3A	MS22016	Navy AS
Connector, Oxygen Mask Hose, Type MC-3A	MIL-C-19246	Navy AS
Connector, Oxygen Mask to Regulator, CRU-60/P	MIL-C-38271	AF 82
Connector, Oxygen Mask Hose, Non-Ejection Type	MIL-C-83867	AF 82
Controller, Oxygen Flow Emergency Cylinder Valve	MS29597	AF 71
Converter, Liquid Oxygen, GCU-2A/A	MIL-C-25777	AF 71
Converter, Oxygen, Liquid to Gaseous, General Specification For (Mechanical Gaging)	MIL-C-9082	AF 71
Converter, Oxygen, Liquid to Gaseous, Type MA-1 (20 Liter 300 PSI Mechanical Gaging)	MIL-C-25021	AF 71
Converter, Liquid Oxygen, Capacitance Type Gaging, General Specification For	MIL-C-25666	AF 11
Converter, Liquid Oxygen, GCU-12A/A (5 Liter 70 PSI)	MIL-C-25973	AF 71
Converter, Liquid Oxygen, MB-5A (5 Liter)	MIL-C-19328	AF 71

TABLE 17 (Continued)

	DOD Document Number	Preparing Activity
Converter, Liquid Oxygen, GCU-24/A (10 Liter 70 PSI)	MIL-C-19803	Navy AS
Converter, Liquid Oxygen, GCU-3/A (10 Liter 70 PSI)	MIL-C-25781	AF 71
Converter, Liquid Oxygen, GCU-10/A (10 Liter 300 PSI)	MIL-C-25974	AF 71
Converter, Liquid Oxygen, GCU-11/A (10 Liter 300 PSI)	MIL-C-25972	AF 71
Converter, Liquid Oxygen, ME-3 (25 Liter 300 PSI)	MIL-C-25674	AF 71
Converter, Liquid Oxygen, GCU-17/A (25 Liter 300 PSI)	MIL-C-27336	AF 71
Converter, Liquid Oxygen, GCU-20/A (75 Liter 300 PSI)	MIL-C-27652	AF 11
Coupling Half, Quick Disconnect	AN6027	Army-AV
Coupling - Automatic Oxygen	AN6009	AF 71
Coupling Assemblies Quick Disconnect, Aircraft Liquid Oxygen Systems	MIL-C-21049	Navy AS
Coupling Assemblies Quick Disconnect, Aircraft Liquid Oxygen Systems	MS22068	Navy AS
Cylinder Assembly, Emergency Oxygen	MS22069	AF 71
Cylinder, Oxygen, Low Pressure	MS21227	AF 71
Cylinder, Oxygen Low Pressure	MIL-C-5886	AF 71
Cylinder, Oxygen, Nonshatterable, Welded, 1800 PSI, Straight, "U" and Spiral Types	MS90389	Navy AS
Cylinder, Compressed Gas, Nonshatterable	MIL-C-7905	Navy AS
Cylinder, Compressed Gas, Nonshatterable	MS26545	Navy AS
Delamination Test Stand for Oxygen Hose	MS22057	Navy AS
Design and Installation of Gaseous Oxygen Systems in Aircraft, General Specification For	MIL-D-8683	Navy AS
Design and Installation of Liquid Oxygen Systems in Aircraft	MIL-D-19326	Navy AS
Design and Installation of On-Board Oxygen Generating Systems in Aircraft, General Specification For	MIL-D-85520	Navy AS
Dummy Converter, Liquid Oxygen Indicator System, 10 Liters, CRU-23A	MIL-D-26392	AF 71

TABLE 17 (Continued)

	DOD Document Number	Preparing Activity
Dummy Converter, Liquid Oxygen Indicator System, 25 Liters, CRU-24A	MIL-D-26393	AF 71
Emergency Oxygen Supply Chlorate Candle, Aircraft, CRU-74/P	MIL-E-83252	AF 71
Environmental Test Methods	MIL-STD-810	AF 11
Fitting End, Standard Dimensions for Flared Tube Connections and Gasket Seal	MS33656	AF 82
Gage, Aircraft, Capacitance, Liquid Oxygen, MC-5	MIL-G-19327	Navy AS
Gage, Aircraft, Capacitance, Liquid Oxygen, MC-6	MIL-G-19804	Navy AS
Gage, Aircraft, Capacitance, Liquid Oxygen Repeater	MIL-G-19807	Navy AS
Gage, Aircraft, Capacitance, Liquid Oxygen Converter, General Specification For	MIL-G-19053	Navy AS
Gage - Panel Mounting, High Pressure Oxygen	AN6011	Navy AS
Gage - Panel Mounting, Low Pressure Oxygen	AN6021	AF 82
Gage Pressure Dial Indicating Oxygen, High Pressure	MS18043	Navy AS
Gage, Liquid Oxygen, Dial Indicating, 0 to 20 Liters	MIL-G-25127	AF 82
Gage, Pressure, Dial Indicating, Low Pressure Oxygen	MIL-G-6019	AF 82
Gage, Pressure, Dial Indicating, Oxygen, High Pressure	MIL-G-23676	Navy AS
Gage, Pressure, Dial, Oxygen, High Pressure	MIL-G-6035	AF SAAMA
Hose and Hose Assemblies, Air Duct, Air Breathing, Oxygen Systems, General Specification For	MIL-H-87961	AF 71
Hose Assembly, Metal, Flexible, Breathing Oxygen	MIL-H-26499	AF 82
Hose Assembly, Polytetrafluorethylene, Oxygen	MIL-H-26633	AF 82
Hose Assemblies, Oxygen, High Pressure	MS22030	Navy AS

TABLE 17 (Continued)

	DOD Document Number	Preparing Activity
Hose Assemblies, Oxygen, Breathing Connector to Regulator	MS22055	Navy AS
Hose Assemblies, Metal, Liquid Oxygen	MIL-H-22343	Navy AS
Hose Assemblies, Metal, Liquid Oxygen	MS90457	Navy AS
Hose Assembly, Breathing Oxygen and Air, General Specification For	MIL-H-81581	Navy AS
Hose Assembly, Air, Low Pressure, Highly Flexible	MIL-H-81581/1	Navy AS
Hose Assembly, Breathing Oxygen, High Pressure With Connections for an Integrated Communication System	MIL-H-81581/2	Navy AS
Hose Assembly, Breathing Oxygen, High Pressure Without Connections for Communication System	MIL-H-81581/3	Navy AS
Hose Assembly, Breathing Oxygen, Low Pressure With/Without Connections for an Integrated Communication System	MIL-H-81581/4	Navy AS
Hose Assembly, Breathing Oxygen Low Pressure Connector to Regulator	MIL-H-81581/5	Navy AS
Hose Assembly, Breathing Oxygen and Air, Hose Kits and Mated Assemblies	MIL-H-81581/6	Navy AS
Hose Assembly, Combined Assemblies, Hose and Communication Cable	MIL-H-81581/7	Navy AS
Hose Assembly Cable Assemblies, Communication Associated	MIL-H-81581/8	Navy AS
Hose Assembly, Metal, Transfer, Liquid Oxygen	MIL-H-23799	Navy AS
Hose Assembly, Oxygen Mask to Connector	MS90339	Navy AS
Hose Assembly, Tetrafluoroethylene, Oxygen	MIL-H-26626	AF 71
Hose Assembly, Tetrafluoroethylene, Oxygen	MS24548	AF 71
Hose Assembly and Pressurization, Ozone Resistant	MIL-H-26385	AF 71
Hose Assembly and Pressurization, Ozone Resistant	MS27797	AF 71
Indicator, Liquid Oxygen Quantity	MIL-I-27677	AF 82
Indicator Set, Liquid Oxygen Quantity, A/A24J-21	MIL-I-83449	AF 82
Indicator Repeaters, Liquid Oxygen Quantity	MIL-I-81388	Navy AS

TABLE 17 (Continued)

	DOD Document Number	Preparing Activity
Indicator, Liquid Oxygen Quantity	MIL-I-81387	Navy AS
Indicator Set, Liquid Oxygen Quantity, A/A24J-4	MIL-I-26382	AF 11
Indicator Set, Liquid Oxygen Quantity, A/A24J-8	MIL-I-27220	AF 11
Indicator Set, Liquid Oxygen Quantity	MIL-I-27544	AF 82
Indicator, Liquid Oxygen Quantity, Capacitance Type, General Specification For	MIL-I-25645	AF 11
Indicator, Liquid Oxygen Quantity, GMU-11/A	MIL-I-26376	AF 82
Indicator, Liquid Oxygen Quantity, GMU-37/A	MIL-I-27882	AF 82
Indicator, Liquid Oxygen Quantity, GMU-39/A	MIL-I-38021	AF 82
Indicator, Liquid Oxygen Quantity, GMU-5/A	MIL-I-26380	AF 82
Indicator, Liquid Oxygen Quantity, GMU-59/A	MIL-I-38468	AF 82
Insert, Installation and Detail, Full Face Oxygen and Smoke Masks	MS90340	Navy AS
Leak Detection Compound, Oxygen Systems	MIL-L-25567	AF 68
Marking, Functions and Hazard, Designation of Hose, Pipe and Tube Lines for Aircraft, Missile and Space Systems	MIL-STD-1247	Army-MI
Mask Assembly, Oxygen Fire Fighter	MIL-M-83869	AF 82
Mask, Oxygen, MBU-10P	MIL-M-87113	AF 82
Mask Assemblies, Oxygen Pressure Breathing	MIL-M-6482	Navy AS
Mask Assemblies, Oxygen Pressure Breathing	MS22001	Navy AS
Mask, Oxygen and Smoke, Full Face	MIL-M-19417	Navy AS
Mask, Oxygen, MBU-5/P (Pressure-Demand)	MIL-M-27274	AF 82
Mask, Oxygen, MBU-12/P	MIL-M-87163	AF 11
Mask, Oxygen, MBU-8/P (Emergency)	MIL-M-83191	AF 11
Monitor, Oxygen, CRU-12/P	MIL-M-85522	Navy AS
Mounting Bracket, Mating Portion for 5 and 10 Liter Oxygen Converters	MS90341	Navy AS

TABLE 17 (Continued)

	DOD Document Number	Preparing Activity
Nipple, Break Off, Emergency Oxygen Cylinder Valve	MS21965	AF 71
Nitrogen, Technical	BB-N-411	Army-ME
Nut Assembly - Oxygen Converter Mount	MS90342	Navy AS
Oxygen, Aviators, Breathing, Liquid and Gas	MIL-O-27210	AF 68
Oxygen System, Portable, 295 Cu. In.	MS22059	Navy AS
Oxygen System, Portable, 96 Cu. In.	MS22061	Navy AS
Oxygen Systems, Portable	MIL-L-23678	Navy AS
Oxygen System Survival Container and Oxygen Kit	MIL-O-27335	AF 71
Purging Unit, Air, Liquid Oxygen Storage Tanks, GSU-62/M	MIL-P-27456	AF 82
Purging Kit, Converter System, Liquid Oxygen, KMU-78/E	MIL-P-27431	AF 82
Recharger Assembly, Portable Oxygen	MS22032	Navy AS
Reducer, Oxygen Pressure	MIL-R-17852	Navy AS
Reducer, Oxygen Pressure, General Specification For	MIL-R-25575	AF 11
Regulator - Automatic Continuous Flow Oxygen	MIL-R-8636	AF 71
Regulator - Automatic Continuous Flow Oxygen	AN6010	AF 71
Regulator, Chest Mounted 100% Oxygen, Positive Pressure, CRU-79/P	MIL-R-81553	Navy AS
Regulator, Chest Mounted, 95% Oxygen, Positive Pressure, CRU-82/P	MIL-R-85523	Navy AS
Regulator, Diluter Demand, Oxygen Pressure Breathing, Type A-14	MIL-R-6371	AF 71
Regulator, Oxygen, High Pressure, Type MA-1	MIL-R-9198	AF 82
Regulator, Oxygen, Diluter Demand	MIL-R-6018	Navy AS
Regulator, Oxygen, Diluter Demand	AN6004	Navy AS
Regulator, Oxygen, Diluter Demand, Automatic Pressure Breathing	MIL-R-25410	Navy AS
Regulator, Oxygen, Automatic, Pressure Breathing, High Altitude, General Specification For	MIL-R-25572	AF 71

TABLE 17 (Continued)

	DOD Document Number	Preparing Activity
Regulator, Oxygen Demand, Pressure Breathing, Type A-21	MIL-R-7605	AF 71
Regulator, Oxygen, Diluter Demand	MS27599	AF 71
Regulator, Oxygen, Diluter Demand	MS27465	AF 71
Regulator, Oxygen, Diluter Demand, Automatic D-2A	MIL-R-8202	AF 71
Regulator, Oxygen, Diluter Demand, Automatic	MS22062	Navy AS
Regulator, Oxygen, Diluter Demand, Automatic Pressure Breathing, General Specification For	MIL-R-83178	AF 71
Regulator, Oxygen, Diluter Demand, Automatic Pressure Breathing, General Specification For (With Test Port)	MIL-R-83178	AF 71
Sampler, Cryogenic Liquid	MIL-S-27626	AF 68
Servicing Adapter, High Pressure Oxygen	MS90331	Navy AS
Servicing Adapter, Low Pressure Oxygen	MS90330	Navy AS
Survival Kit Container, Aircraft Seat With Oxygen RSSK-1A	MIL-S-81018/3	Navy AS
Survival Kit Container, Aircraft Seat With Oxygen RSSK-6	MIL-S-81018/1	Navy AS
Survival Kit Container, Aircraft Seat With Oxygen RSSK-8	MIL-S-81018/2	Navy AS
Survival Kit Container, Aircraft Seat With Oxygen General Specification For	MIL-S-81018	Navy AS
Survival Kit Container, Aircraft Seat CNU-111/P	MIL-S-83047	AF 82
Tank, Storage, Liquid Oxygen, Transportable	MIL-T-3784	Army ME
Tank, Storage, Liquid Oxygen, TMU-27/M	MIL-T-38170	AF 68
Tank, Storage, Liquid Oxygen, TMU-20/E	MIL-T-27483	AF 68
Tank, Storage, Liquid Oxygen, TMU-24/E	MIL-T-27720	AF 68
Tank, Storage, Liquid Oxygen, TMU-7A/E	MIL-T-27892	AF 68
Tank, Storage, Liquid Oxygen, Low Loss Closed Cycle, TMU-70/M	MIL-T-85418	Navy AS
Tape Antiseize, Tetrafluoroethylene, With Dispenser	MIL-T-27730	AF 84
Test Procedures for Aircraft Environmental Systems	MIL-T-18606	Navy AS