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## OXYGEN EQUIPMENT FOR AIRCRAFT

### INTRODUCTION

This report has been prepared as a revision of the previous Aerospace Information Report No. 825 dated February 25, 1965, 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 AIR 825. The publication issue is broken down into six (6) sections as follows:

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## SECTION I - OXYGEN -- BASIC PHYSIOLOGY

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, or commercial aircraft. The following is an introduction to this subject, expressed (insofar as possible) in common terms.
  - 1.1 Although the work of breathing represents only a small fraction of the total energy expenditure of the body, any additional load imposed upon the breathing mechanism by the oxygen equipment will not only disturb the natural breathing pattern but may also cause discomfort and fatigue of the muscles involved in breathing. It should also be borne in mind that respiratory flow is of a tidal nature whereby volume flow in the airways alternates in sine wave fashion with peak flow rates of 20-40 liters per minute (LPM) at rest and 80 - 100 LPM in mild exertion.
  - 1.2 Each breath has a tidal volume of approximately  $500 \text{ cm}^3$  which at a resting frequency of 12-16/min. results in a total ventilation of 6-8 LPM. Moderate activity such as walking leisurely requires more than twice the resting ventilation. It is obvious that oxygen equipment must be designed to accommodate to the transient peak flow velocities as well as the total requirements in volume.
  - 1.3 Respiration is accomplished by expansion of the chest cage mainly due to contraction of the muscular diaphragm. The work performed in this phase has to overcome not only the resistance in the airtubes of the lungs, but also the elastic recoil of the lungs. Expiration, on the other hand, does not require active muscular effort during resting breathing since the elastic forces of the lungs and chest suffice to expell the tidal volume and revert to the initial position. During positive pressure breathing the normal pattern is reversed and active effort is required to exhale while the increased 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 least effort and is at the same time the most economical.
  - 1.4 At sea level the atmospheric pressure is usually around 15 pounds per square inch ( $101 \text{ kN/m}^2$ ), which is equivalent to the pressure exerted by a column of mercury 760 millimeters high. 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 pressure, the partial pressure exerted by each one of the components is in proportion to the volume of each component present. Since air for practical purposes may be said to consist of about 21% oxygen and 79% nitrogen by volume, one may say that at sea level oxygen exerts a partial pressure of 21% of 760 mm or 160 mm, and nitrogen 79% of 760 mm or 600 mm. Here the term "mm" refers to the pressure (expressed as the height in millimeters of a column of mercury) exerted by each major part of the two gases composing the air. It is true, of course, that there is 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 -- which has here been included in the nitrogen portion. There is also a varying amount of water vapor in the air giving rise to the humidity. This may be expressed in terms of percent of saturation at a given temperature, or in millimeters of partial pressure exerted by the water vapor present.
  - 1.5 The air we breathe passes into the trachea or windpipe and from there into the lungs. It undergoes considerable changes in composition as it goes in through the trachea, mixes with the gases already in the lungs, and is again exhaled. This comes about because first it becomes fully saturated with water vapor at body temperature in the nose or throat, so that the delicate tissue in the lungs is not damaged by drying. Then it becomes mixed with the air already in the lungs, which contains carbon dioxide and perhaps small amounts of other gases which, like the rare gases, are of insufficient amounts to be of importance here. For practical purposes at sea level, an average figure given below has been selected for a sample of air from the trachea (called tracheal air) and from the lungs (called pulmonary or alveolar air), to show the changing composition. The proportions of these gases are approximate, and are expressed in millimeters of mercury partial pressure in order to be consistent.

Partial Pressure, mm of Hg

	<u>Dry Air</u>	<u>Tracheal Air</u>	<u>Pulmonary (Alveolar) Air</u>
Oxygen	160	149	109
Water Vapor	-	47	47
CO <sub>2</sub>	-	-	40
Nitrogen	600	564	564
<b>Total</b>	<b>760</b>	<b>760</b>	<b>760</b>

- 1.6 For practical purposes the 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 of mercury oxygen partial pressure in the trachea is derived from the total pressure, 760 mm, minus 47 mm water vapor pressure (saturated air at body temperature), multiplied by the fraction of oxygen (21%).
- 1.7 The alveolar partial pressure of oxygen cannot be predicted precisely since it is subject to individual variations in oxygen consumption and pulmonary ventilation.
- 1.8 Oxygen in the little air spaces in the lungs (called alveoli) diffuses through the thin permeable membrane into the red corpuscles in the blood capillaries lying just below. The diffusion rate for this is roughly proportional to the partial pressure of the oxygen present. On their circuit through the body these red cells give up some of the oxygen to the body tissue for use in the life sustaining processes.
- 1.9 As one goes up to the higher altitudes, the total air pressure diminishes and with it also the partial pressure of the various gases. The following table shows the approximate oxygen partial pressure changes (all in mm Hg) for various altitudes:

	<u>Sea Level</u>	<u>5,000 ft (1524 m)</u>	<u>10,000 ft (3048 m)</u>	<u>14,000 ft (4267 m)</u>
Air-Oxygen (dry)	160	132	109	93
Tracheal Oxygen	149	122	100	84
Pulmonary or Alveolar Oxygen	109	82	60	44

- 1.10 Normal individuals living at around sea level may become aware of the effects of altitude, and the diminishing partial pressure of oxygen results in lessened ability to see at low levels of illumination and decrements in other physiological functions which are demonstrable under controlled test conditions at around 6,000 or 8,000 ft (1829 or 2438 m). At about this point, the red blood cells are no longer able to take on a full load of oxygen. The effect of this usually becomes more noticeable for a brief time, and as the body adjusts or acclimates itself after a few days the mild symptoms disappear. Certainly most individuals going as high as 10,000 ft (3048 m) will notice definite symptoms of altitude, particularly if they exercise and after a variable length of time, and for rule-of-thumb purposes the Air Force has selected this as a critical altitude. Pilots flying above this altitude for any length of time should have additional proportions of oxygen in the breathing air, in order to increase the partial pressure of oxygen in the trachea and lungs to the point where the red cells take on more nearly a full complement of oxygen.
- 1.11 Mild conditions of oxygen want are called hypoxia -- meaning, insufficient oxygen. The symptoms usually increase in severity when time of exposure increases. When the oxygen partial pressure in the lungs falls to around 30 mm Hg, oxygen supply to the tissues becomes totally inadequate for maintaining consciousness in unacclimatized individuals.
- 1.12 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 changes in mental function. Even with minor decreases in oxygen supply (as results from 10,000 ft (3048 m) over a period of time) the brain responds with muddled thinking -- often a mistaken belief that all is just dandy, as in mild intoxication -- and poor

1.12 (Continued)

judgment. Further decreases in oxygen produce increasingly severe mental symptoms, culminating in unconsciousness and death if the oxygen levels become low enough. It is the early onset of these altered mental functions, which are not recognized by the individual, that represents the most serious hazard to members of an aircrew, and has been the direct or indirect cause of many accidents, particularly in the "pilot error" category. For those flying at night it should be noted that there is a moderate loss of night vision at altitudes of 6,000 to 8,000 ft (1829 to 2438 m) for those acclimated to sea level so that supplemental oxygen should be considered at lower altitudes at night than in the day, especially if the time of flight is prolonged.

- 1.13 However, people living at high altitudes become adapted to a somewhat different set of operating circumstances. This is called becoming "acclimated" and for the altitudes above 5,000 or 6,000 ft (1524 or 1829 m) this usually requires a few days even for normal, younger individuals, and longer for higher altitudes and for older persons. It is important to know that little (if any) acclimitization to altitude takes place as a result of flying, even with daily flying, because continuous exposure is required.
- 1.14 When one reaches an altitude of 34,000 ft (10363 m), 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 only 100 mm Hg 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 again the minimum level of oxygen which will provide a full oxygen load to the red cells. To maintain full oxygenation at even higher altitudes, more pressure must be applied to the oxygen which is to be inspired. Pressure breathing masks accomplish this purpose to a limited extent by raising the pressure in the lungs above that of the surrounding atmosphere.
- 1.15 As still higher altitudes are reached using pressure breathing, the mask pressures required to maintain full oxygenation of the red cells become increasingly unbearable because of the increased internal pressure inside the chest. At that point, counterpressures to the chest wall and remainder of the body must be applied to make such breathing pressures tolerable, and to prevent actual physical damage to the lung tissue. "Partial pressure" and "full pressure" altitude suits accomplish this purpose, the first by direct mechanical counterpressure, and the second by sustaining additional air pressure around the body. As long as such measures are able to maintain adequate counterpressure, the internal pressure of the oxygen to be breathed can be kept at a level which will insure adequate oxygenation of the red blood cells and corresponding normal tissue function. With this type of protective equipment, man can continue to altitudes where essentially no ambient pressure exists, as would be true in the vacuum of outer space. He is able to perform this feat only by taking along this necessary equipment to maintain adequate oxygen pressure within his lungs while external counterpressure is applied to make normal breathing possible. A simpler way, of course, is to provide cabin pressurization at a level of approximately 6,000 to 8,000 ft (1829 to 2438 m), which diminishes or eliminates the need for individual oxygen equipment. The danger here comes from loss of this pressurization whereupon severe hypoxia, as well as decompression sickness, may occur. Decompression sickness usually comes on in many people after a few minutes of exposure to low ambient pressures.
- 1.16 The above is a very brief summarization of a very vital subject to aviation. Anyone dealing with aircraft or with oxygen systems should at least know and understand the foregoing background.
- 1.17 Many details have necessarily been omitted. For those interested in more details, any of the standard texts on Aviation Medicine should be consulted.

## 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 is colorless, odorless, tasteless and non-toxic. 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 is controlled by Military Spec. MIL-O-21749 and 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 which may include indicating instruments as an integral part 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 or 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.

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 found 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 up to pressure altitudes as high as 40,000 ft (12192 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 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 (10668 m). Pure oxygen delivered at this altitude will produce the same effect as breathing air at 5,000 ft (1524 m). Beyond 35,000 ft (10668 m), however, it becomes necessary to increase the pressure of the oxygen delivered to the mask where prolonged protection is desired in order to provide a 5,000-ft (1524 m) 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 (10363 m) where a mixture of air can be tolerated for reasons of economy.

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 para. 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 para 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.

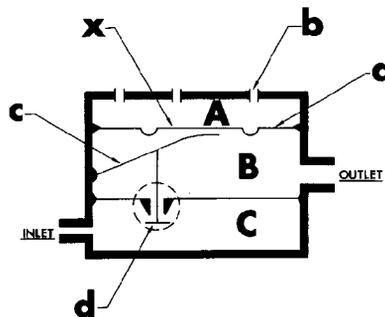


FIGURE I

2.3 Figure I 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.

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 sq in. (32.26 cm<sup>2</sup>) would, therefore, produce a pneumatic pressure of 0.20 psi (1.4 kN/m<sup>2</sup>) 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 Rahm, August 1951, Wright-Patterson Air Force Base, Ohio, pp 128-129.

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### 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 Fig. I in Section II, para. 2.2.1.

The principal components are: (a) Supply system; (b) Distribution system; (c) Dispensing equipment.

- 3.1 Supply System: This comprises a container or containers for liquid or gaseous oxygen, a contents indicating system, and a means of replenishing. 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 off 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 I, Section VI, illustrates the weights and dimensions of those cylinders widely used by commercial carriers. ICC Specification 3AA covers the design and manufacture of regular non-shatterable cylinders. ICC 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 with the 3AA type are:

- (a) Low resistance to shattering.
  - (b) Susceptibility to damage.
  - (c) Stringent service testing is required.
  - (d) Short 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, ICC approved cylinders are available.

Table II, Section VI, illustrates the weights and dimensions of those cylinders widely used by commercial carriers.

- 3.1.3 Supply Accessories:

- 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," "Half," "Empty." They may be direct or remote reading.

Generally, as the presence of an oxygen system postulates the presence of 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 distant 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 para. 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 emptied 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: ICC 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.

ICC-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 para. 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 decreases the possibility of opening them fast enough to obtain adiabatic compression to an extent sufficient to cause explosion.

Automotive 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 para. 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 pipe lines is dictated by the mass flow to be carried and the acceptable pressure drop. In multi-cylinder installations the inter-cylinder lines are of small diameter, 3/16 to 5/16 in. (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 in. or 5/16 in. (6.35 or 7.94 mm) O.D. x .028 in. (0.71 mm) wall thickness.

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 tube fittings with stainless steel.

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

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. 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.

3.1.3.10 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 heat 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.

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 para. 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 in. (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 in. (9.52 to 12.7 mm) O.D. x 0.028 in. (0.71 mm) aluminum alloy. In systems for small aircraft of, say, up to 20 passengers, 5/16 in. (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.

- 3.2.1.7 Low Pressure Fittings: Fittings for metallic low pressure lines are flared or flareless, similar to high pressure lines (see para. 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 .012 to .018 in. (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 close on disconnections.

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.

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<sup>3</sup> 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 16,000 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 are those which cover the mouth, nose, and eyes. They are normally provided for use as protective breathing equipment. However, continuous-flow fullface masks are not considered satisfactory for use in fighting fire due to the possible leakage of oxygen around the facepiece. Also, as described before, a certain amount of air is drawn from ambient and may be contaminated. In some aircraft, fullface masks are replaced by the use of goggles and oronasal masks.

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## 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, mask-mounted, or seat-mounted. A blinker may be incorporated to indicate when gas is flowing. Figure III, 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, mask-mounted, or seat-mounted. A blinker may be incorporated to indicate when gas is flowing. The demand system shown in Figure III, 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 (450 psi (3.1 MPa))
  - (b) High pressure (1800 psi (12.4 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:** Refer to Section III, paras. 3.1.3.1 through 3.1.3.7 for typical equipment used and available for 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, Paras. 3.1.3.8, 3.1.3.9, 3.2.1.6, and 3.2.1.7 for further data.)

#### 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 is approximately to 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 to maintain safe partial pressure for the user above 35,000 ft (10668 m). 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.

- 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 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 (approx. 7/8 in. (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 AIR 1069 (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: AS 1194, 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 Mask:

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.

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SECTION V - LIQUID OXYGEN SYSTEMS

5. Liquid Oxygen: Oxygen may be supplied from either gaseous, liquid or solid sources 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  $-377\text{ F} (-227.2\text{ C})$ ) 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. Today, liquid oxygen supply systems are being installed in most of the new U.S. military aircraft; active consideration has been given to these systems in the current commercial jet transport aircraft designs.

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 or MIL-O-21749 (AER) 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 <sup>3</sup> (1140.5 kg/m <sup>3</sup> ) at -183 C (-297 F) 2.5 lb/liter (1.14 kg/dm <sup>3</sup> ) 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 kN/m <sup>2</sup> )) 1 liter liquid oxygen = 30.36 ft <sup>3</sup> (0.86 m <sup>3</sup> ) gaseous oxygen at 70 F (21.1 C) (14.7 psia (101.3 kN/m <sup>2</sup> ))
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  $-180\text{ F} (-118\text{ C})$  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 is not productive of irritating vapors but is highly absorptive of 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 I, II.

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 in Fig. I     |
| b. A pressure build-up coil             | Item C in Fig. I     |
| c. An evaporating coil (or coils)*      | Item B in Fig. I     |
| d. Pressure control valves              | Item D & H in Fig. I |
| e. Pressure relief valve                | Item I in Fig. I     |
| f. Liquid check valve                   | Item G               |
| g. Volume gauging probe                 |                      |
| h. Mounting brackets                    |                      |
| i. Economizer circuit (optional design) |                      |

\*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 assemblies 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 loss 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 supply line is not in use.
- 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 dependent 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 (30-40 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 MA-1 transfer cart assembly is a unit commonly used for direct aircraft servicing. This cart is a mobile assembly, mounted on a steerable; fourwheel utility USAF type MB-1 trailer. It has a capacity of 50 gallons (189 liters) of liquid oxygen. The inner and outer containers are fabricated from aluminum alloy sheet and the total empty weight of the assembly is 1447 lb (656 kg).
- 5.2.2.3 Bulk storage of liquid oxygen at military aircraft bases is presently handled by the use of the 150 or the 500 gallon (568 or 1890 l) storage tank assembly. Both assemblies are built into a skid and hoisting frame for limited mobility in the field. Pertinent details of the storage tank assemblies are listed.

	<u>150 Gal. Tank</u>	<u>500 Gal. Tank</u>
USAF Designation	Type B-1	Type C-1
Capacity	568 liters	1890 liters

After a 15% filling loss, evaporation losses do not exceed 5% per 24 hours.

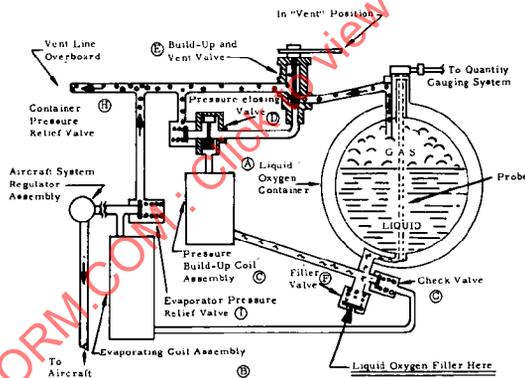
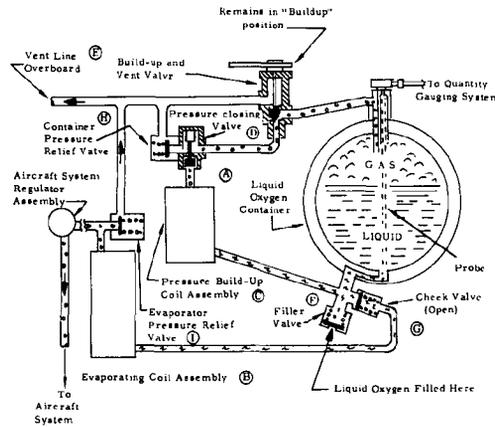


FIGURE 1. CONVERTER FILLING PROCEDURE

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.

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.



SYSTEM SUPPLY PROCEDURE  
FIGURE 2

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-Vent 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.

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 followed:

- 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 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 systems fitting. Only MIL-T-5542 thread sealant may be used on the 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, or a combustible reaction between the concentrated oxygen and the activated charcoal or other organic insulating/desiccating materials within the vacuum space.

#### 5.4 Comparison of Liquid vs. 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 per cent less weight and 50 to 70 per cent 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) pressure ranges compared to the standard gaseous oxygen supply pressure ranges 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 reduces and in some installations eliminates the need for pressure reducing regulator assemblies, which 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 per cent 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-9475A  
MIL-I-19326A  
Tr-56-260 Vol. I & II Air Force Handbook of Liquid Oxygen Systems.

5.6 Liquid Oxygen System Description: (Refer to Figs. I and II.)

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SECTION VI - CHARTS, TABLES AND SYSTEMS SCHEMATICS

6. Definitions and Abbreviations:

- BTPS = Body temperature, pressure, saturated  
(37° C, ambient pressure, saturated with water vapor at 37° C - PH<sub>2</sub>O at 37° C = 47.00 mm Hg.)
- BTPD = Body temperature, pressure, dry (37° C, ambient pressure, PH<sub>2</sub>O = 0)
- STPD = Standard temperature, pressure, dry  
(0° C, pressure = 760 mm Hg, and PH<sub>2</sub>O = 0)
- NTPD = Normal temperature, pressure, dry  
(70° F, pressure = 760 mm Hg, and PH<sub>2</sub>O = 0)
- PH<sub>2</sub>O = Partial pressure of water vapor  
(PH<sub>2</sub>O at 37° C = 47.00 mm Hg.)
- PO<sub>2</sub> = Partial pressure of oxygen
- B or P<sub>B</sub> = Barometric pressure
- B-47 or P<sub>B-47</sub> = Sum of partial pressures of dry gases in an environment saturated with water vapor at 37° C, expressed in mm Hg
- %O<sub>2</sub> = Parts of oxygen in 100 parts of dry gas by volume existing in a mixture saturated with water vapor at 37° C.
- 0° 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 Table)  
 v = Volume of cylinder, Cubic inches  
 k = compressibility factor (See Table)

Pressure:

psi (MPa)	Atmospheres	K at 32° F (0° C)	K at 68° F (20° C)
450 (3.1)	30.6	.973	.981
900 (6.2)	61.3	.945	.962
1800 (12.4)	122.5	.915 (approx.)	.938 (approx.)

6.2 Density of Oxygen at Sea Level:

Degree F (C)		Grams/ Liter	Pounds/ Cu. Ft.	Pounds/Cu. In.
-40	(-40)	1.67	.105	.602 x 10 <sup>-4</sup>
-20	(-28.9)	1.60	.100	.576 x 10 <sup>-4</sup>
0	(-17.8)	1.53	.095	.552 x 10 <sup>-4</sup>
20	(-6.7)	1.47	.091	.530 x 10 <sup>-4</sup>
40	(4.4)	1.40	.088	.507 x 10 <sup>-4</sup>
60	(15.6)	1.35	.085	.487 x 10 <sup>-4</sup>
80	(26.7)	1.30	.081	.470 x 10 <sup>-4</sup>
100	(37.8)	1.26	.078	.453 x 10 <sup>-4</sup>

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

Altitude- Thousands of Ft. (Meters)	-0	10	20	25	30	35	40
	(-0)	(3048)	(6096)	(7620)	(9144)	(10668)	(12192)
Oxygen- Pounds per Hour: (kg per Hour)	.189 (.086)	.130 (.060)	.086 (.039)	.070 (.032)	.056 (.025)	.044 (.020)	.035 (.016)

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

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 Supplement 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.

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 the Civil Air Regulation:

"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 -  $P_{H_2O}$  at 37°C = 47.00 mm Hg.) and having a tidal volume of 700 cm<sup>3</sup> with a constant time interval between respirations.
- (ii) At cabin pressure altitudes above 18,500 ft (5639 m) to and including 40,000 ft (12192 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 1,100 cm<sup>3</sup> 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 Civil Air Regulation as quoted under design requirements. Table A indicates the procedure used.

1. Column "A" shows altitude in increments of thousands of feet from 10,000 to 40,000 ft (3048 to 12192 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  $P_{H_2O} = 0$ ). 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:

$$C = \frac{(B - 47)}{760} \frac{(459.69 + 70.000)}{(450.69 + 98.6)}$$

$$C = \frac{(B - 47)}{760} (.94877)$$

where

B = the numerical values in Column "B"

C = the numerical values in Column "C"

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 ft. (3048 to 5639 m).

b. 30 LPM in BTPS liters from 18,500 to 40,000 ft. (5639 to 12192 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 12192 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<sub>2</sub>) 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 12192 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 12192 m)).

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<sub>T</sub> = Total fraction of oxygen in the nitrogen-oxygen mixture.

e. F<sub>A</sub> = Fraction of oxygen added

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

$$F + F_A = 1 \quad F = 1 - F_A$$

$$F_T = F_A + .2095 F = F_A + .2095 (1 - F_A)$$

$$F_T = F_A + .2095 - .2095 F_A = .2095 + .7905 F_A$$

$$F_A = \frac{F_T - .2095}{.7905}$$

or on a percent basis, where O<sub>T</sub> = % 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 B).

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

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  $\left(\frac{F}{MV}\right)$  plotted against percent total oxygen (%  $O_2$ ). By multiplying these  $\left(\frac{F}{MV}\right)$  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, Regulations of the Administrator, Part 514 -- 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 B, 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.

D. Determination of Outlet Flow and Pressure Schedule Requirements:

1. Column "J" of Table C 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. 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 from the data in Column "A" and "J" of Table C. 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.
5. Curve "B" has been drawn in at random 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 4,000 feet or less). The pressure values from Curve "B" are read from abscissa and recorded in Column "M" of Table C. 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 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 D are read from Graph 2.
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, 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.
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. 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 (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 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 E is plotted as Curve "V" on Graph 4. 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 to 10,000 ft (12192 to 3048 m).

G. System Efficiency:

1. Column "I", the required minimum oxygen flow to the mask, from Table B is plotted as Curve "I" on Graph 4. The average flow value of Column "I" is found to be 1.6578.
2. The system efficiency to the mask then equals:

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

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 which must be available (per FAA regulations) 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 (4572 m), 30% from 14,000-15,000 ft (4267-4572 m) and to provide for 10% from 10,000-14,000 ft (3048-4267 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 P<sub>H<sub>2</sub>O</sub> = 0).

Q<sub>m</sub> = 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

$$Q = 1.03 T (F)$$

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

$$\begin{aligned} Q_m &= 1.03 T (F) \\ &= 1.03 (10) (2.01) = 20.70 \text{ L-NTPD} \end{aligned}$$

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

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 CAR 40, 41, and 42.

(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 (12192 m) with emergency descent to 14,000 ft (4267 m).
- (2) 40,000 ft (12192 m) maximum demonstrated descent rate of 240 seconds to 14,000 ft (4267 m) (assuming descent can be made to 14,000 ft (4267m)).
- (3) Emergency cruise at or below 14,000 ft (4267 m).

b. Basic Formulas:

$$Q = 1.03 T (F) \quad Q_e = Q_D + Q_{40-14}$$

where following required quantities of oxygen are:

$Q_e$  = actual needs

$Q_D$  = delay of 20 seconds at 40,000 ft (12192 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 to 14,000 ft (12192 to 4267 m)

and may be determined by graphical integration of the area below the Curve "V" on Graph 4 from 14 to 40 thousand feet. This value, 2.28 LPM-NTPD, may also be obtained numerically from Column "V", Table E.

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

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

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

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

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

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

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

- 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 per cent of the number of passenger cabin occupants . . .".

The general equation would be:

$$Q_{sm_{14}} = .1 (1.03) (F_{14})$$

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

$$9.89 = .103 (.449) T_{14}$$

$$9.89 = .046247 T_{14}$$

$$T_{14} = \frac{9.89}{.046247} = \underline{213.85 \text{ minutes}} = 3.56 \text{ hours}$$

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 (12192 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 (12192 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.

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 ( $Q_{40-18}$ ).

$$Q_e = Q_D + Q_{40-18}$$

$$F_{18} = 0.910 \text{ LPM-NTPD,}$$

$$F_{14} = 0.449 \text{ LPM-NTPD}$$

$$F_{40-18} = 2.56 \text{ LPM-NTPD,}$$

$$F_{18-14} = 0.6783 \text{ LPM-NTPD}$$

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:

$$Q_e = Q_D + Q_{40-18} = 10.34 \text{ L-NTPD}$$

$$Q_{18} = 1.03 (0.910) (16) = 14.996 \text{ L-NTPD}$$

$$Q_{18-14} = 1.03 (F_{18-14}) (T_{18-14}) \\ = 1.03 (.6783) (1) = .699 \text{ L-NTPD}$$

$$Q_{14} = (0.1) (1.03) (0.449) (60) = 2.775 \text{ L-NTPD}$$

$$Q = Q_e + Q_{18} + Q_{18-14} + Q_{14} \\ = 10.34 + 14.996 + 0.699 + 2.775$$

$$Q = 28.77 \text{ L-NTPD}$$

It can be seen that this value of "Q" (28.77 L-NTPD) exceeds the "absolute minimum requirement" ( $Q_m = 20.70 \text{ L-NTPD}$ ) 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: For Transport Category airplanes the requirements of FAR 25 (or old CAR 4b) are applicable. If the airplane is used to carry persons or property for hire the requirements of FAR's 121 or 135 apply. For airplanes with a gross weight of 12,500 lb (354.4 kg) or less (FAR 23) and not carrying passengers for hire, FAR 91.32 applies.

The existing FAA requirements in the FAR's used as a basis here are normally based on cabin altitude. However, FAR's 121 and 135 additionally require that for pressurized airplanes operating above 25,000 ft (7620 m) flight altitude, unless quick-don masks are used, one pilot at the controls shall wear and use an oxygen mask. FAR 121 further specifies that whenever operating above 41,000 ft (12496 m) flight altitude, one pilot at the controls will wear and use an oxygen mask. In FAR 135 the limiting altitude is 35,000 ft (10668 m). The minimum cabin altitude requiring use of oxygen is 10,000 ft (3048 m). FAR 121 further requires that when one pilot leaves his duty station while operating above 25,000 ft (7620 m), the remaining pilot shall wear and use his oxygen mask. FAR's 25 and 121 require, under certain conditions, a 300 liter (STPD) supply for protective breathing purposes but permits this supply to be included in the normal crew supply.

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

Where conventional demand equipment is used duration may be calculated using flow rates from Table F. 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.

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.

$$Q = N (R_1 T_1 + R_2 T_2 + \dots + R_n T_n)$$

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).

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 hr 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).

$T_1 = 3 \times 60 = 180$  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, times to continue flight at 25,000 ft (7620 m) to termination of flight.

$$Q = N_1 R_1 T_1 + N_2 R_2 T_2$$

$$Q = 1 \times 2.4 \times 180 + 2 \times 3.3 \times 180$$

$$Q = 432 + 1188 = 1620 \text{ liters NTPD}$$

or,  $Q = 1620/28.32 = 57.2 \text{ cubic feet NTPD}$

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.

Example No. 2

A pressurized Transport Category airplane with 2 crewmen flying at 38,000 ft (11582 m) with quick-donning masks using demand equipment on a continental 4 hr 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 hr 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.

$$R_1 = 3 \text{ LPM - using average rate for 10 minute descent.}$$

$$T_1 = 10 \text{ minutes - descent time.}$$

$$R_2 = 2.4 \text{ LPM - continued flight at 14,000 ft (4267 m).}$$

$$T_2 = 110 \text{ minutes - continued flight at 14,000 ft (4267 m).}$$

$$Q = (N R_1 T_1) + (N R_2 T_2)$$

$$Q = (2 \times 3 \times 10) + (2 \times 2.4 \times 110)$$

$$Q = 60 + 528 = 588 \text{ LPM, NTPD}$$

or,  $Q = 588/28.32 = 20.8 \text{ cubic feet, NTPD}$

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 hr flight at 18,000 ft (5486 m) using demand equipment.

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

$$R_1 = 2.7 \text{ LPM, by interpolation of Table F to obtain rate for 18,000 ft (5486 m).}$$

$$T_1 = 1-1/2 \text{ hours} = 90 \text{ minutes.}$$

$$Q = N_1 R_1 T_1 = 1 \times 2.7 \times 90$$

$$Q = 243 \text{ liters NTPD}$$

or,  $Q = 243/28.32 = 8.6 \text{ cubic feet NTPD}$

6.7 Conversion Factors:

To Obtain	From	Multiply by	To Obtain	From	Multiply by	
<b>Standards of Volume</b>						
BTPS	BTPD	$\frac{P_B}{P_B - 47}$	Cubic Feet	Liters	0.03531	
		$\frac{862.94}{P_B - 47}$	Cubic centimeters	Cubic centimeters	0.00003531	
			Cubic inches	Cubic inches	0.0005787	
STPD	NTPD	$\frac{801.04}{P_B - 47}$	Gallons (liq.)	Liters	0.1337	
			Cubic centimeters	Cubic centimeters	0.0002642	
		Cubic inches	Cubic inches	0.004329		
BTPD	BTPS	$\frac{P_B - 47}{P_B}$	Volume Flow Rate	Cubic feet/hour	7.481	
			Liters/Minute	Liters/minute	0.4717	
		STPD	$\frac{862.94}{P_B}$	Cubic Feet/hour	Liters/minute	2.120
STPD	NTPD	$\frac{801.04}{P_B}$	Pressure	Inch Hg @ 0° C	25.40	
			mm Hg @ 0° C	Inch H <sub>2</sub> O @ 4° C	1.868	
		Cm. H <sub>2</sub> O @ 4° C	Cm. H <sub>2</sub> O @ 4° C	0.7354		
STPD	BTPS	0.0011588 (P <sub>B</sub> - 47)	Lb/ft <sup>2</sup>	Lb/ft <sup>2</sup>	0.3591	
			Lb/in <sup>2</sup>	Lb/in <sup>2</sup>	51.71	
			Millibars	Millibars	0.7500	
NTPD	BTPS	0.92826	Atmospheres	Atmospheres	760.00	
			0.0012484 (P <sub>B</sub> - 47)	Lb/in <sup>2</sup>	mm Hg @ 0° C	0.01934
		0.0012484 (P <sub>B</sub> )	mm Hg @ 0° C	Inch Hg @ 0° C	0.4912	
STPD	NTPD	1.0773	Inch H <sub>2</sub> O @ 4° C	Inch H <sub>2</sub> O @ 4° C	0.03613	
			Cm. H <sub>2</sub> O @ 4° C	Cm. H <sub>2</sub> O @ 4° C	0.01422	
		0.0011588 (P <sub>B</sub> )	Lb/ft <sup>2</sup>	Lb/ft <sup>2</sup>	0.006944	
Liters	Cubic centimeters	0.001	Millibars	Millibars	0.01450	
			0.01639	Atmospheres	Atmospheres	14.696
			28.32			
Cubic Centimeters	Cubic inches	3.785	Length Feet	Inches	0.08333	
				Meters	3.281	
		28320.	Centimeters	0.03281		
Cubic Inches	Gallons (liq.)	3785.	Inches	Millimeters	0.003281	
				61.02	Feet	12.
		0.06102	Meters	39.37		
Cubic Feet	Liters	1728.	Meters	Centimeters	0.3937	
				231.	Millimeters	0.03937
		0.0011588 (P <sub>B</sub> )	Feet	0.3048		
Gallons (liq.)	Cubic feet	0.1337	Inches	Inches	0.0254	
				0.0002642	Centimeters	0.01
		0.004329	Millimeters	0.001		
Gallons (liq.)	Cubic feet	0.0002642	Millimeters	Feet	304.8	
				0.004329	Inches	25.4
		7.481	Meters	1000.		
Gallons (liq.)	Cubic feet	0.0002642	Millimeters	Centimeters	10.	
				0.004329	Feet	304.8
		7.481	Inches	25.4		
Gallons (liq.)	Cubic feet	0.0002642	Millimeters	Meters	1000.	
				0.004329	Centimeters	10.

TABLE A

(A) ALTITUDE IN THOUSANDS OF FEET (Meter)	(B) BAROMETRIC PRESS IN mm Hg.	(C) VOLUME RATIO (NTPD) (BTPS)	(D) TOTAL LPM- NTPD	(E) % TOTAL O <sub>2</sub> REQUIRED
At 15 (LPM BTPS)				
10 3048	522.76	.5939	8.909	21.02
11 3353	502.79	.5690	8.535	21.94
12 3657	483.46	.5449	8.173	22.91
13 3962	464.77	.5215	7.823	23.94
14 4267	446.63	.4989	7.483	25.02
15 4572	429.08	.4770	7.155	26.17
16 4877	412.09	.4558	6.837	27.39
17 5182	395.66	.4353	6.529	28.68
18 5486	379.78	.4154	6.231	30.05
18.5 5639	372.01	.4057	6.086	30.77
At 30 (LPM BTPS)				
18.5 5639	372.01	.4057	12.172	25.78
19 5791	364.39	.3962	11.887	26.40
20 6096	349.53	.3777	11.330	27.70
21 6401	335.15	.3597	10.729	29.08
22 6705	321.28	.3424	10.272	30.55
23 7010	307.87	.3257	9.770	32.12
24 7315	294.89	.3095	9.284	33.81
25 7620	282.40	.2939	8.816	35.60
26 7925	270.33	.2788	8.364	37.52
27 8230	258.67	.2642	7.927	39.59
28 8534	247.43	.2502	7.506	41.81
29 8839	236.58	.2367	7.100	44.20
30 9144	226.13	.2236	6.709	46.78
31 9449	216.06	.2111	6.332	49.57
32 9754	206.35	.1989	5.967	52.59
33 10059	197.00	.1873	5.618	55.87
34 10363	188.00	.1760	5.281	59.43
35 10668	179.33	.1652	4.956	63.33
36 10973	170.99	.1548	4.644	67.59
37 11278	162.99	.1448	4.344	72.25
38 11582	155.37	.1353	4.059	77.33
39 11887	148.11	.1262	3.787	82.88
40 12192	141.18	.1176	3.527	88.98

TABLE B

(A)	(F)	(G)	(H)	(I)
ALTITUDE IN THOUSANDS OF FEET (Meter)	(E)-20.95	$\frac{(F)}{79.05}$	THEORETICAL OXYGEN REQ. LPM-NTPD	REQUIRED MIN. OXYGEN FLOW TO MASK IN LPM-NTPD
At 15 (LPM BTPS)				
10 (3048)	.07	.00089	.0079	.0178
11 (3353)	.99	.0125	.1067	.1137
12 (3657)	1.96	.0248	.2027	.2037
13 (3962)	2.99	.0378	.2957	.2916
14 (4267)	4.07	.0515	.3854	.3759
15 (4572)	5.22	.0660	.4722	.4582
16 (4877)	6.44	.0815	.5572	.5379
17 (5182)	7.73	.0978	.6385	.6148
18 (5486)	9.10	.1151	.7172	.6891
18.5 (5639)	9.82	.1242	.7558	.7303
At 30 (LPM BTPS)				
18.5 (5639)	4.83	.0611	.7437	.7225
19 (5791)	5.45	.0689	.8190	.7940
20 (6096)	6.75	.0854	.9676	.9336
21 (6401)	8.13	.1028	1.1029	1.068
22 (6705)	9.60	.1214	1.2470	1.204
23 (7010)	11.17	.1413	1.3805	1.344
24 (7315)	12.86	.1627	1.5105	1.481
25 (7620)	14.65	.1853	1.6336	1.612
26 (7925)	16.57	.2096	1.753	1.738
27 (8230)	18.64	.2358	1.869	1.860
28 (8534)	20.86	.2639	1.981	1.992
29 (8839)	23.25	.2941	2.088	2.122
30 (9144)	25.83	.3267	2.191	2.247
31 (9449)	28.62	.3620	2.292	2.368
32 (9754)	31.64	.4002	2.388	2.499
33 (10059)	34.92	.4417	2.481	2.630
34 (10363)	38.48	.4867	2.570	2.754
35 (10668)	42.38	.5361	2.657	2.891
36 (10973)	46.64	.5900	2.740	3.025
37 (11278)	51.30	.6489	2.819	3.164
38 (11582)	56.38	.7132	2.895	3.307
39 (11887)	61.93	.7834	2.967	3.453
40 (12192)	68.03	.8605	3.035	3.603

TABLE C

(A) ALTITUDE IN THOUSANDS OF FEET (Meter)	(J) MIN. OUTLET FLOW 1.05 (I) LPM-NTPD	(K) MAX. OUTLET FLOW 1.06 (J) LPM-NTPD	(L) AVG. OUTLET FLOW $\frac{J+K}{2}$ LPM-NTPD	(M) OUTLET MINIMUM PRESSURE PSIG* (kN/m <sup>2</sup> )
At 15 (LPM BTPS)				
10 (3048)	.0187	.049**	.034	4.2 28.9
11 (3353)	.1192	.149**	.134	
12 (3657)	.2139	.244**	.229	17.1 117.9
13 (3962)	.3062	.336**	.321	
14 (4267)	.3947	.4184	.4065	25.3 174.6
15 (4572)	.4811	.5100	.4955	
16 (4877)	.5648	.5987	.5817	32.4 224.1
17 (5182)	.6455	.6843	.6649	
18 (5486)	.7236	.7670	.7452	38.35 264.7
18.5 (5639)	.7668	.8128	.7898	40.0 275.8
At 30 (LPM BTPS)				
18.5 (5639)	.7586	.8041	.7813	
19 (5791)	.8337	.8837	.8587	
20 (6096)	.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 (10059)	2.761	2.927	2.844	
34 (10363)	2.892	3.065	2.978	101.90 702.8
35 (10668)	3.036	3.218	3.127	
36 (10973)	3.176	3.367	3.271	109.0 751.4
37 (11278)	3.322	3.522	3.421	
38 (11582)	3.472	3.680	3.576	115.83 798.7
39 (11887)	3.626	3.843	3.734	
40 (12192)	3.783	4.010	3.897	123.1 847.7

\* At Cabin Pressure

\*\* (K) = (J) + .03

TABLE D

(A) ALTITUDE IN THOUSANDS OF FEET (Meter)	(N) MAX. SYS. PRESSURE DROP IN PSI	(O) REG. MIN. 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 (10363)	2.25	104.15	109.36	3.635
36 (10973)	2.50	111.50	117.08	3.306
38 (11582)	2.75	118.58	124.51	3.004
40 (12192)	3.00	126.1	132.41	2.730

\* At Cabin Pressure

NOTE: Values in  $\text{kN/m}^2$  can be obtained by multiplying psig figure by 6.894757

TABLE E

(A) ALTITUDE IN THOUSANDS OF FEET (Meter)	*(S) REG. MAX. PRESSURE PSIG**	*(T) AVG. PRESS. AT OUTLET PSIG**	(U) MIN. FLOW AT PRESS. 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 (10363)	111.86	110.74	3.255	3.352
36 (10973)	118.24	117.00	3.520	3.626
38 (11582)	124.10	122.73	3.762	3.875
40 (12192)	130.00	128.5	4.015	4.135

\* At Cabin Pressure

\*\* Multiply PSIG by 6.894757 to get kN/m<sup>2</sup>

TABLE F

ALTITUDE IN THOUSANDS OF FEET (Meter)	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

6.8 Composition of the Atmosphere:

<u>Constituent Gas</u>	<u>Molecular Fraction Percent</u>	<u>Molecular Weight</u> 0 = 16.000
Nitrogen (N <sub>2</sub> )	78.09	28.106
Oxygen (O <sub>2</sub> )	20.95	32.0000
Argon (A)	0.93	39.944
Carbon Dioxide (CO <sub>2</sub> )	0.03	44.010
Neon (Ne)	1.8 x 10 <sup>-3</sup>	20.183
Helium (He)	5.24 x 10 <sup>-4</sup>	4.003
Krypton (Kr)	1.0 x 10 <sup>-4</sup>	83.7
Hydrogen (H <sub>2</sub> )	5.0 x 10 <sup>-5</sup>	2.0160
Xenon (Xe)	8.0 x 10 <sup>-6</sup>	131.3
Ozone (O <sub>3</sub> )	1.0 x 10 <sup>-6</sup>	48.0000
Radon (Rn)	6.0 x 10 <sup>-18</sup>	222.0

6.9 Military Specifications and Standards Applicable to Aircraft Oxygen Systems:

	<u>DOD Document Number</u>	<u>Preparing Activity</u>
Adapter Low Pressure Oxygen Filler Valve	AN6027	Army ASC
Adapter Portable Oxygen Recharging Orifice	AN6044	AF OCAMA
Adapter Oxygen Filler	AND10070	AF ASD
Adapter Pressure-Reducer In-Line CRU-43/A	MIL-A-27471	AF OCAMA
Cap Assembly Liquid Oxygen Filler Valve	MS27566	AF OCAMA
Clamp, Oxygen Hose	MS22064	AF OCAMA
Cleaning Methods and Procedures for Breathing Oxygen Equipment	MIL-STD-1359	Navy AS
Container Liquid Oxygen Transportable	MIL-C-3784	Army-Mobility Eqpt
Connector Bayonet 3 Pin Oxygen Mask	MS27796	AF OCAMA
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

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	<u>DOD Document Number</u>	<u>Preparing Activity</u>
Connector Oxygen Mask to Regulator CRU-60/P	MIL-C-38271	AF OCAMA
Connector Partial Pressure Helmet to Regulator	MIL-C-26662	AF OCAMA
Controller Oxygen Flow Emergency Cylinder Valve	MS29597	AF OCAMA
Converter Oxygen Liquid to Gaseous General Specification For (Mechanical Gaging)	MIL-C-9082	AF OCAMA
Converter Oxygen Liquid to Gaseous Type A-3 (5 Liter 70 PSI Mechanical Gaging)	MIL-C-7407	AF OCAMA
Converter Oxygen Liquid to Gaseous Type MA-1 (20 Liter 300 PSI Mechanical Gaging)	MIL-C-25021	AF OCAMA
Converter Liquid Oxygen Capacitance Type Gaging, General Specification For	MIL-C-25666	AF ASD
Converter Liquid Oxygen GCU-12/A (5 Liter 70 PSI)	MIL-C-25973	AF ASD
Converter Liquid Oxygen GCU-14/A (5 Liter 70 PSI)	MIL-C-26358	AF OCAMA
Converter Liquid Oxygen MB-5A (5 Liter)	MIL-C-19328	Navy AS
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 OCAMA
Converter Liquid Oxygen GCU-10/A (10 Liter 300 PSI)	MIL-C-25974	AF OCAMA
Converter Liquid Oxygen GCU-11/A (10 Liter 300 PSI)	MIL-C-25972	AF OCAMA
Converter Liquid Oxygen ME-3 (25 Liter 300 PSI)	MIL-C-25674	AF ASD
Converter Liquid Oxygen GCU-17/A (25 Liter 300 PSI)	MIL-C-27336	AF ASD
Converter Liquid Oxygen GCU-20/A (75 Liter 300 PSI)	MIL-C-27652	AF ASD
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 and Regulator Portable Oxygen, General Specification For	MIL-C-9003	AF OCAMA
Cylinder Assembly, Emergency Oxygen	MS22069	AF OCAMA
Cylinder Oxygen, Low Pressure	MS21227	AF OCAMA
Cylinder Oxygen Low Pressure	MIL-C-5886	AF OCAMA
Cylinder Oxygen Purifier	MIL-C-4810	AF WRAMA
Cylinder, Breathing Oxygen and Carbon Dioxide, Overhaul, Charging, and Storage of	MIL-C-7796	Navy AS
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-19326E	Navy AS
Disconnect, Personal, Oxygen and Electrical	MIL-D-27702	AF ASD
Dummy Converter Liquid Oxygen Indicator System 10 Liters CRU-23A	MIL-D-26392	AF ASD
Dummy Converter Liquid Oxygen Indicator System 25 Liters CRU-24A	MIL-D-26393	AF OCAMA
Emergency Oxygen Supply Chlorate Candle, Aircraft CRU-74/P	MIL-E-83252	AF ASD
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 Pressure Dial Indicating Oxygen, High Pressure	MS18043	Navy AS
Gage Emergency Oxygen Type L-2	MIL-G-7601	AF SAAMA

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	<u>DOD Document Number</u>	<u>Preparing Activity</u>
Gage Liquid Oxygen Dial Indicating 5 Liter 70 PSI Converter	MIL-G-8266	AF SAAMA
Gage Liquid Oxygen Dial Indicating 0 to 20 Liters	MIL-G-25127	AF SAAMA
Gage Liquid Oxygen 8 Liter 300 PSI Converter	MIL-G-8283	AF SAAMA
Gage Pressure Dial Indicating 25 Liter Converter Type MF-1	MIL-G-8100	AF SAAMA
Gage Pressure Dial Indicating Low Pressure Oxygen	MIL-G-6019	AF SAAMA
Gage Pressure Dial Oxygen 0-500 PSI Type MF-3	MIL-G-25520	AF SAAMA
Gage Pressure Dial Oxygen High Pressure	MIL-G-23676	Navy AS
Gage Pressure Dial Oxygen 0-500 PSI General Specification	MIL-G-25728	AF SAAMA
Gage Pressure Dial Oxygen 0-2000 PSI Type MF-2	MIL-G-25507	AF SAAMA
Gage Pressure Dial Oxygen High Pressure	MIL-G-6035	AF SAAMA
Hose Assemblies Oxygen High Pressure Wire Braided	MS22028	Navy AS
Hose Assemblies Oxygen High Pressure	MS22029	Navy AS
Hose Assemblies Oxygen High Pressure	MS22030	Navy AS
Hose Assemblies Oxygen High Pressure	MIL-H-4722	AF SAAMA
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 Oxygen Breathing Connector to Regulator	MIL-H-7138	AF OCAMA
Hose Assembly Tetrafluoroethylene Oxygen	MIL-H-26626	AF OCAMA
Hose Assembly Tetrafluoroethylene Oxygen	MS24548	AF OCAMA
Hose Assembly and Pressurization, Ozone Resistant	MIL-H-26385	AF OCAMA
Hose Assembly and Pressurization, Ozone Resistant	MS27797	AF OCAMA
Indicator Repeaters Liquid Oxygen Quantity	MIL-I-81388	Navy AS
Indicator Liquid Oxygen Quantity	MIL-I-81387	Navy AS
Indicator Set Liquid Oxygen Quantity A/A24J-4	MIL-I-26382	AF ASD
Indicator Set Liquid Oxygen Quantity A/A24J-6	MIL-I-26383	AF SAAMA
Indicator Set Liquid Oxygen Quantity A/A24J-8	MIL-I-27220	AF ASD
Indicator Set Liquid Oxygen Quantity	MIL-I-27544	AF ASD
Indicator Liquid Oxygen Quantity Capacitance Type General Specification For	MIL-I-25645	AF ASD
Indicator Liquid Oxygen Quantity GMU-11/A	MIL-I-26376	AF ASD
Indicator Liquid Oxygen Quantity GMU-37/A	MIL-I-27882	AF ASD
Indicator Liquid Oxygen Quantity GMU-39/A	MIL-I-38021	AF SAAMA
Indicator Liquid Oxygen Quantity GMU-5/A	MIL-I-26380	AF SAAMA
Indicator Liquid Oxygen Quantity GMU-59/A	MIL-I-38468	AF ASD
Insert Installation and Detail, Full Face Oxygen and Smoke Masks	MS90340	Navy AS

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	<u>DOD Document Number</u>	<u>Preparing Activity</u>
Installation and Tests of Liquid Oxygen Systems In Aircraft (General Specification) For	MIL-I-19326	Navy AS
Installation of Low Pressure Oxygen Equipment In Aircraft, General Specification (Superseded by MIL-D-8683)	MIL-I-15585	AF OCAMA
Leak Test Compound Oxygen Systems	MIL-L-25567	AF SAAMA
Mask Assemblies, Oxygen Pressure Breathing	MIL-M-6482	Navy AS
Mask Assemblies, Oxygen Pressure Breathing	MS22001	Navy AS
Mask Assemblies, Oxygen Demand Breathing	MIL-M-7585	AF OCAMA
Mask Oxygen and Smoke, Full Face	MIL-M-19417B	Navy AS
Mask Oxygen MBU-5/P (Pressure-Demand)	MIL-M-27274D	AF OCAMA
Mask Oxygen MBU-8/P (Emergency)	MIL-M-83191	AF ASD
Mounting Bracket, Mating Portion For 5 and 10 Liter Oxygen Converters	MS90341	Navy AS
Nipple, Break Off, Emergency Oxygen Cylinder Valve	MS21965	AF OCAMA
Nut Assembly - Oxygen Converter Mount	MS90342	Navy AS
Oxygen Recharge Equipment (Power Driven)	MIL-O-6705	Navy AS
Oxygen Aviators Breathing Liquid and Gas	MIL-O-27210	AF SAAMA
Oxygen, Technical, Gas and Liquid	BB-O-925	Navy Ships
Oxygen System Portable 295 Cu. In.	MS22059	Navy AS
Oxygen System Portable 96 Cu. In.	MS22061	Navy AS
Oxygen Systems Portable	MIL-O-23678	Navy AS
Oxygen System Survival Container	MIL-O-27335	AF OCAMA
Purging Kit Converter System Liquid Oxygen KMU-78/E	MIL-P-27431	AF SAAMA
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 ASD
Regulator - Automatic Continuous Flow Oxygen	MIL-R-8636	AF OCAMA
Regulator - Automatic Continuous Flow Oxygen	AN6010	AF OCAMA
Regulator Chest Mounted 100% Oxygen Positive Pressure	MIL-R-81553	Navy AS
Regulator Mask Mounted 100% Oxygen Positive Pressure	MIL-R-19121	Navy AS
Regulator Oxygen Diluter Demand	MIL-R-6018C	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 ASD
Regulator Oxygen Continuous Flow Walk Around	MIL-R-25693	AF OCAMA
Regulator Oxygen Demand, Pressure Breathing Type A-21	MIL-R-7605	AF OCAMA
Regulator Oxygen Diluter Demand	MS27599	AF ASD
Regulator Oxygen Diluter Demand	MS27465	AF ASD
Regulator Oxygen Diluter Demand Automatic D-2A	MIL-R-8202	AF OCAMA
Regulator Oxygen Diluter Demand Automatic	MS-22062	Navy AS
Regulator Oxygen Diluter Demand Automatic Pressure Breathing General Specification For	MIL-R-25916	AF ASD
Regulator Oxygen Diluter-Demand, Automatic-Pressure- Breathing General Specification For (With Test Port)	MIL-R-83178	AF ASD
Regulator Breathing Full Pressure Suit	MIL-R-23975	Navy AS
Regulator Oxygen, Automatic Positive Pressure and Composite Diluter Demand	MIL-R-18059	Navy AS
Regulator Oxygen Pressure Demand Full Pressure Helmet CRK-45/P22S-2	MIL-R-27689	AF SAAMA
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