SOCIETY OF AUTOMOTIVE ENGINEERS, Inc.
485 LEXINGTON AVENUE
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AIR 825

OXYGEN EQUIPMENT FOR AIRCRAFT

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Revised

INTRODUCTION

This report has been prepared as a revision of the previous Aerospace Information Report No. 4A dated February 1, 1949, 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 4A. The publication issue is broken down into six (6) sections as follows:

Section I	Oxygen -- Basic Physiology
Section II	Gaseous Oxygen and Oxygen Equipment, Introductory
Section III	Continuous Flow Oxygen Systems
Section IV	Demand and Pressure Demand Oxygen Systems
Section V	Liquid Oxygen Systems
Section VI	Charts, Tables and Systems Schematics

PREPARED BY SAE COMMITTEE A-10, AIRCRAFT OXYGEN EQUIPMENT

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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 cc. 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, 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

	Dry Air	Tracheal Air	Pulmonary (Alveolar) Air
Oxygen	160	149	109
Water Vapor	-	47	47
CO_2	-	-	40
Nitrogen	600	564	564
Total	760	760	760

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:

	Sea Level	5,000 ft	10,000 ft	14,000 ft
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 feet or 8,000 feet. 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 feet 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 feet 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 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 feet 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 feet or 6,000 feet 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 feet, 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 feet to 8,000 feet, 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, 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 feet. For prolonged protection, continuous flow equipment is generally regarded to be adequate up to 25,000 feet.

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 feet. Pure oxygen delivered at this altitude will produce the same effect as breathing air at 5,000 feet. Beyond 35,000 feet, 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-foot 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 feet 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.

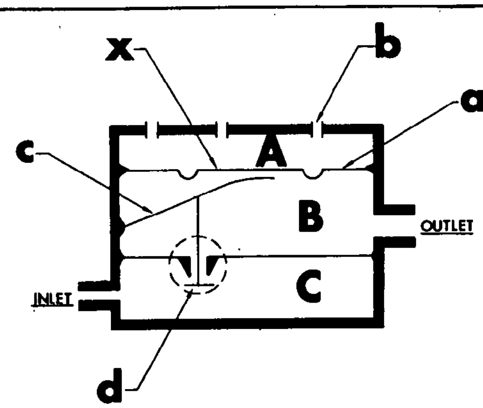

FIGURE I

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 applied to point "X" will be distributed equally over the effective area of the diaphragm. An effective area of 5 square inches would, therefore, produce a pneumatic pressure of 0.20 pounds per square inch 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.

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

SECTION III - CONTINUOUS FLOW OXYGEN SYSTEMS

3. Principal Components of Continuous Flow System: This type of system is that by which a continuous flow of gas is metered to each mask through a fixed orifice. Flow is controlled by regulation of the gas pressure. Refer to 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 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. 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 and 300 psi 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 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.

Automatic 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-inch O. D. with suitable wall thickness. At least one coil is formed between each cylinder to avoid permanent set occurring during cylinder removal and to prevent load being applied due to relative movement between cylinders under the influence of vibration. Use of high pressure lines should be kept at a minimum.

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

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

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

3.2 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 inlet pressure, and when used in an 1800 psi 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. Mass flow in a large transport aircraft can reach 700 liters per minute, so pressure drop in the lines can be critical. To cater to pressures and flows of this order, the aircraft capable of carrying 150 passengers requires lines of at least 5/16-inch I.D. if outlets at the end of the system are to deliver comparable flows with those close to the regulator.

Thus, metallic lines in large low pressure distribution systems are commonly of 3/8 to 1/2-inch O.D. x .028 aluminum alloy. In systems for small aircraft of, say, up to 20 passengers, 5/16-inch 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" 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 disconnection.

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

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

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

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

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 cc 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 reentry 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 feet 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.

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)
   (b) High pressure (1800 psi)
2. Liquid oxygen converters.
   (a) Low pressure (70 psi)
   (b) High pressure (300 psi)

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 feet 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 feet. 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 feet. 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.

4.4 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 a 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.

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°F.) 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, water-like 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 lbs./cu.ft. at -183° C. (-297 F.)
	2.5 lbs./liter
	9.54 lbs./gallon (U. S.)
	11.32 lbs./gallon (Imperial)
Volume Expansion:	1 liter liquid oxygen = 860 liters gaseous oxygen at 70°F. (14.7 psia).
	1 liter liquid oxygen = 30.36 cu.ft. gaseous oxygen at 70°F. (14.7 psia).
Latent Heat of Vaporization:	50.9 cal./gram. (91.7 BTU/lb.)

At higher pressures, the boiling point of liquid oxygen will increase. The critical temperature of -180° F. (-118° C.) is attained at a pressure of 735 psi (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 absorbative 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. A number of converters have been produced that deliver 300 psig 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. 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 build-up 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, four-wheel 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 lbs.

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 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.

	150 Gal. Tank	500 Gal. Tank
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.

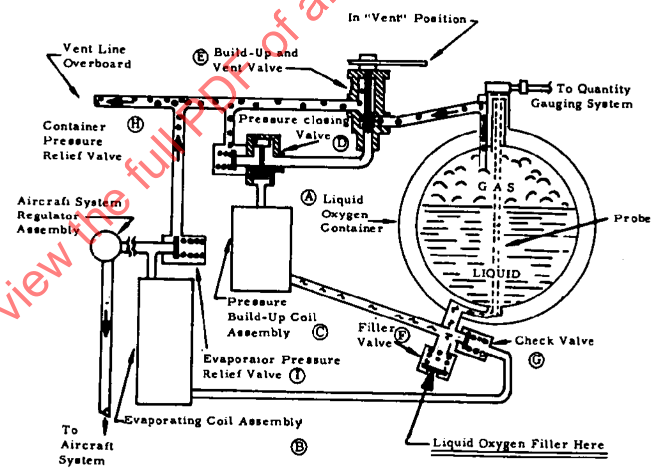

FIGURE I - CONVERTER FILLING PROCEDURE

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. 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 indictates 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.

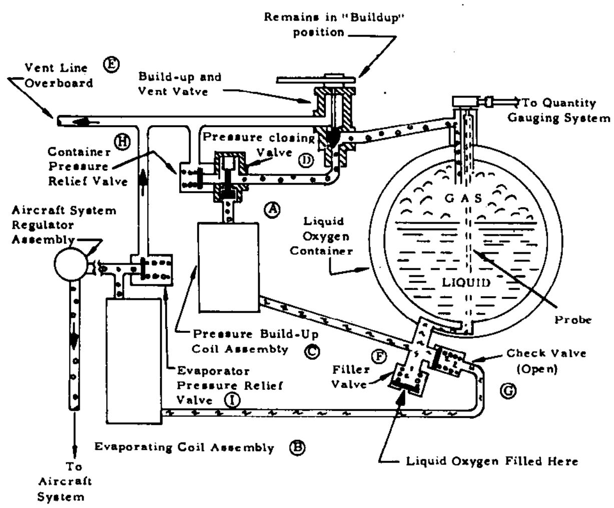

FIGURE II - SYSTEM SUPPLY PROCEDURE

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.). Evaporation of liquid oxygen in a closed, unvented container could develop a potentially dangerous pressure condition of 860 atmospheres (over 12,000 psi).

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/descicating 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 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 and 300 psi pressure ranges compared to the standard gaseous oxygen supply pressure ranges of 400 psi and 1800 psi.

5.4.1.3 A 70 psi 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.)

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_2O at 37° C = 47.00 mm Hg.)
BTPD	=	Body temperature, pressure, dry (37° C, ambient pressure, PH_2O = 0)
STPD	=	Standard temperature, pressure, dry (0° C, pressure = 760 mm Hg, and PH_2O = 0)
NTPD	=	Normal temperature, pressure, dry (70° F, pressure = 760 mm Hg, and PH_2O = 0)
PH_2O	=	Partial pressure of water vapor (PH_2O at 37° C = 47.00 mm Hg.)
PO_2	=	Partial pressure of oxygen
B or P_B	=	Barometric pressure
B-47 or P_B-47	=	Sum of partial pressures of dry gases in an environment saturated with water vapor At 37° C, expressed in mm Hg
$\%O_2$	=	Parts of oxygen in 100 parts of dry gas by volume existing in a mixture saturated with water vapor at 37° C.

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	Atmospheres	K at 32° F.	K at 68° F.
450	30.6	.973	.981
900	61.3	.945	.962
1800	122.5	.915 (approx.)	.938 (approx.)

6.2 Density of Oxygen at Sea Level:

Degree F	Grams/ Liter	Pounds/ Cu. Ft.	Pounds/Cu. In.
-40	1.67	.105	$.602 \times 10^{-4}$
-20	1.60	.100	$.576 \times 10^{-4}$
0	1.53	.095	$.552 \times 10^{-4}$
20	1.47	.091	$.530 \times 10^{-4}$
40	1.40	.088	$.507 \times 10^{-4}$
60	1.35	.085	$.487 \times 10^{-4}$
80	1.30	.081	$.470 \times 10^{-4}$
100	1.26	.078	$.453 \times 10^{-4}$

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.	-0	10	20	25	30	35	40
Oxygen- Pounds per Hour:	.189	.130	.086	.070	.056	.044	.035

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 to evaluate 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 Agency Civil Air Regulations 4b.651 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 feet to and including 18,500 feet, a mean tracheal oxygen partial pressure of 100 mm Hg. when breathing 15 liters per minute, BTPS (body temperature pressure, saturated, i.e. 37C 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 cc. with a constant time interval between respirations.

(ii) At cabin pressure altitudes above 18,500 feet to and including 40,000 feet, 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 cc. 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 feet.

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 feet.

b. 30 LPM in BTPS liters from 18,500 to 40,000 feet.

These values are obtained by multiplying Column "C" by 15 from 10,000 to 18,500 feet and by 30 from 18,500 to 40,000 feet.

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

a. 100 mm Hg from 10,000 to 18,500 feet.

b. 83.8 mm Hg from 18,500 to 40,000 feet.

The values in Column "E" are calculated as follows:

a. $\left(\frac{100}{B - 47}\right) 100$ (B is the value in column "B" up to 18,500 feet.)

b. $\left(\frac{83.8}{B - 47}\right) 100$ (B is the value in column "B" from 18,500 feet up to 40,000 feet.)

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 percent oxygen.

c. F = Fraction of air added.

d. F_T = Total fraction of oxygen in the nitrogen-oxygen mixture.

e. F_A = Fraction of oxygen added

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

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

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

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

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

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

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

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

tude. 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 weight 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 regulator 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 I (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 thousand feet.

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 percent of the passengers above 15,000 feet, 30 percent from 14,000-15,000 feet and to provide for 10 percent from 10, 000-14, 000 feet cruise altitude.)

2. A uniform ten minute emergency descent (from maximum certificated cruise altitude to 10,000 feet).

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, 70F, 760 mm Hg and $P_{H_2O} = 0$).

Q_m = Minimum quantity Q per FAA regulations in L-NTPD.

T = Time in minutes of flight after decompression.

F = Flow rate in LPM-NTPD

The General Equation

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

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

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

$$= 1.03\ (10)\ (2.01) = 20.70 \text{ L-NTPD}$$

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 feet with emergency descent to 14,000 feet.

(2) 40,000 feet maximum demonstrated descent rate of 240 seconds to 14,000 feet (assuming descent can be made to 14, 000 feet).

(3) Emergency cruise at or below 14,000 feet.

b. Basic Formulas:

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

where following required quantities of oxygen are:

Q_e = actual needs

Q_D = delay of 20 seconds at 40,000 feet

Q_{40-14} = descent from 40,000 to 14,000 feet

c. Total Emergency Oxygen per Passenger:

Delay:

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

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

F_{40-14} is essentially the average flow from 40 to 14 thousand feet 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.

$$Q_{40-14} = 1.03\left(\frac{240}{60}\right)2.28$$

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

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

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

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 feet.

The FAA requirement at 14,000 feet 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 feet.

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

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

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

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

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

3. Example 2, decompression at 40,000 feet with emergency descent to 18,000 feet, sixteen minute emergency cruise at 18,000 feet and one hour cruise at 14,000 feet.

a. Basis:

(1) 40,000 feet maximum demonstrated descent rate of 203 seconds to 18,000 feet (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:

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

$$Q = Q_e + Q_{18} + Q_{18-14} + Q_{14}$$

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

Q_e = Quantity of oxygen actually required for emergency delay (Q_D) of 20 seconds and emergency descent (Q_{40-18}).

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

F_{18} = 0.910 LPM-NTPD,

F_{14} = 0.449 LPM-NTPD

F_{40-18} = 2.56 LPM-NTPD,

F_{18-14} = 0.6783 LPM-NTPD

Delay:

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

Descent:

$$Q_{40-18} = 1.03\left(\frac{203}{60}\right)2.56 = 8.92$$

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 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 percent of the rated capacity should be considered available to meet the oxygen requirements. This will allow about a 10 percent 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 CAR 40, 41 and 42.

6.6 Conversion Factors:

To Obtain	From	Multiply by
Standards of Volume		
BTPS	BTPD	$\frac{P_B}{P_B - 47}$
	STPD	$\frac{862.94}{P_B - 47}$
	NTPD	$\frac{801.04}{P_B - 47}$
BTPD	BTPS	$\frac{P_B - 47}{P_B}$

To Obtain	From	Multiply by
	STPD	$\frac{862.94}{P_B}$
	NTPD	$\frac{801.04}{P_B}$
STPD	BTPS	$0.0011588\ (P_B - 47)$
	BTPD	$0.0011588\ (P_B)$
	NTPD	0.92826
NTPD	BTPS	$0.0012484\ (P_B - 47)$
	BTPD	$0.0012484\ (P_B)$
	STPD	1.0773
Volume		
Liters	Cubic centimeters	0.001
	Cubic inches	0.01639
	Cubic feet	28.32
	Gallons (liq.)	3.785
Cubic Centimeters	Liters	1000.
	Cubic inches	16.39
	Cubic feet	28320.
	Gallons (liq.)	3785.
Cubic Inches	Liters	61.02
	Cubic centimeters	0.06102
	Cubic feet	1728.
	Gallons (liq.)	231.
Cubic Feet	Liters	0.03531
	Cubic centimeters	0.00003531
	Cubic inches	0.0005787
	Gallons (liq.)	0.1337
Gallons (liq.)	Liters	0.2642
	Cubic centimeters	0.0002642
	Cubic inches	0.004329
	Cubic feet	7.481
Volume Flow Rate		
Liters/Minute	Cubic feet/hour	0.4717
Cubic Feet/hour	Liters/minute	2.120
Pressure		
mm Hg @ 0° C	Inch Hg @ 0° C	25.40
	Inch H_2O @ 4° C	1.868
	Cm. H_2O @ 4° C	0.7354
	Lb/ft^2	0.3591
	Lb/in^2	51.71
	Millibars	0.7500
	Atmospheres	760.00

To Obtain	From	Multiply by
Lb/in^2	mm Hg @ 0° C	0.01934
	Inch Hg @ 0° C	0.4912
	Inch H_2O @ 4° C	0.03613
	Cm. H_2O @ 4° C	0.01422
	Lb/ft^2	0.006944
	Millibars	0.01450
	Atmospheres	14.696
Length		
Feet	Inches	0.08333
	Meters	3.281
	Centimeters	0.03281
	Millimeters	0.003281
Inches	Feet	12.
	Meters	39.37
	Centimeters	0.3937
	Millimeters	0.03937
Meters	Feet	0.3048
	Inches	0.0254
	Centimeters	0.01
	Millimeters	0.001
Millimeters	Feet	304.8
	Inches	25.4
	Meters	1000.
	Centimeters	10.

Table A

(A) ALTITUDE IN THOUSANDS OF FEET	(B) BAROMETRIC PRESS IN mm Hg.	(C) VOLUME RATIO (NTPD)/(BTPS)	(D) TOTAL LPM-NTPD	(E) % TOTAL O_2 REQUIRED
At 15 (LPM BTPS)				
10	522.76	.5939	8.909	21.02
11	502.79	.5690	8.535	21.94
12	483.46	.5449	8.173	22.91
13	464.77	.5215	7.823	23.94
14	446.63	.4989	7.483	25.02
15	429.08	.4770	7.155	26.17
16	412.09	.4558	6.837	27.39
17	395.66	.4353	6.529	28.68
18	379.78	.4154	6.231	30.05
18.5	372.01	.4057	6.086	30.77
At 30 (LPM BTPS)				
18.5	372.01	.4057	12.172	25.78
19	364.39	.3962	11.887	26.40
20	349.53	.3777	11.330	27.70
21	335.15	.3597	10.729	29.08
22	321.28	.3424	10.272	30.55
23	307.87	.3257	9.770	32.12
24	294.89	.3095	9.284	33.81
25	282.40	.2939	8.816	35.60
26	270.33	.2788	8.364	37.52
27	258.67	.2642	7.927	39.59
28	247.43	.2502	7.506	41.81
29	236.58	.2367	7.100	44.20
30	226.13	.2236	6.709	46.78
31	216.06	.2111	6.332	49.57
32	206.35	.1989	5.967	52.59
33	197.00	.1873	5.618	55.87
34	188.00	.1760	5.281	59.43
35	179.33	.1652	4.956	63.33
36	170.99	.1548	4.644	67.59
37	162.99	.1448	4.344	72.25
38	155.37	.1353	4.059	77.33
39	148.11	.1262	3.787	82.88
40	141.18	.1176	3.527	88.98

Table B

(A) ALTITUDE IN THOUSANDS OF FEET	(F) (E)-20.95	(G) (F)/79.05	(H) THEORETICAL OXYGEN REQ. LPM-NTPD	(I) REQUIRED MIN. OXYGEN FLOW TO MASK IN LPM-NTPD
		At 15 (LPM BTPS)		
10	.07	.00089	.0079	.0178
11	.99	.0125	.1067	.1137
12	1.96	.0248	.2027	.2037
13	2.99	.0378	.2957	.2916
14	4.07	.0515	.3954	.3759
15	5.22	.0660	.4722	.4582
16	6.44	.0815	.5572	.5379
17	7.73	.0978	.6385	.6148
18	9.10	.1151	.7172	.6891
18.5	9.82	.1242	.7558	.7303
		At 30 (LPM BTPS)		
18.5	4.83	.0611	.7437	.7225
19	5.45	.0689	.8190	.7940
20	6.75	.0854	.9676	.9336
21	8.13	.1028	1.1029	1.068
22	9.60	.1214	1.2470	1.204
23	11.17	.1413	1.3805	1.344
24	12.86	.1627	1.5105	1.481
25	14.65	.1853	1.6336	1.612
26	16.57	.2096	1.753	1.738
27	18.64	.2358	1.869	1.860
28	20.86	.2639	1.981	1.992
29	23.25	.2941	2.088	2.122
30	25.83	.3267	2.191	2.247
31	28.62	.3620	2.292	2.359
32	31.64	.4002	2.388	2.499
33	34.92	.4417	2.491	2.630
34	38.48	.4867	2.570	2.754
35	42.38	.5361	2.657	2.891
36	46.64	.5900	2.740	3.025
37	51.30	.6489	2.819	3.164
38	56.38	.7132	2.895	3.307
39	61.93	.7834	2.957	3.453
40	68.03	.8605	3.035	3.603

Table C

(A) ALTITUDE IN THOUSANDS OF FEET	(J) MIN. OUTLET FLOW 1.05 (I) LPM-NTPD	(K) MAX. OUTLET FLOW 1.06 (J) LPM-NTPD	(L) AVG. OUTLET FLOW (J+K)/2 LPM-NTPD	(M) OUTLET MIN. PRESSURE PSIG*
		AT 15 (LPM BTPS)		
10	.0187	.049**	.034	4.2
11	.1192	.149**	.134	
12	.2139	.244**	.229	17.1
13	.3062	.336**	.321	
14	.3947	.4184	.4065	25.3
15	.4811	.5100	.4955	
16	.5648	.5987	.5817	32.4
17	.6455	.6843	.6649	
18	.7236	.7670	.7452	38.35
18.5	.7668	.8128	.7898	40.0
		AT 30 (LPM BTPS)		
18.5	.7586	.8041	.7813	
19	.8337	.8837	.8587	
20	.9803	1.039	1.0096	47.2
21	1.121	1.189	1.115	
22	1.264	1.340	1.302	56.3
23	1.411	1.496	1.453	
24	1.555	1.648	1.601	65.4
25	1.693	1.794	1.743	
26	1.825	1.934	1.880	73.4
27	1.953	2.070	2.012	
28	2.097	2.216	2.154	80.7
29	2.228	2.362	2.295	
30	2.359	2.501	2.430	88.13
31	2.486	2.636	2.561	
32	2.624	2.781	2.702	95.0
33	2.761	2.927	2.844	
34	2.892	3.065	2.978	101.90
35	3.036	3.218	3.127	
36	3.176	3.367	3.271	109.0
37	3.322	3.522	3.421	
38	3.472	3.680	3.576	115.83
39	3.626	3.843	3.734	
40	3.783	4.010	3.897	123.1

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

Table D

(A) ALTITUDE IN THOUSANDS OF FEET	(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	0.02	4.22	4.43	10.108
12	0.13	17.23	18.09	9.349
14	0.24	25.54	26.82	8.636
16	0.34	32.74	34.38	7.969
18	0.46	38.80	40.74	7.344
18.5	0.5	40.5	42.53	7.194
		AT 30 (LPM BTPS)		
20	0.64	47.84	50.23	6.759
22	0.86	57.16	60.02	6.212
24	1.12	66.52	69.85	5.702
26	1.34	74.74	78.48	5.227
28	1.55	82.25	86.36	4.784
30	1.78	89.91	94.91	4.373
32	2.02	97.02	101.87	3.990
34	2.25	104.15	109.36	3.635
36	2.50	111.50	117.08	3.306
38	2.75	118.58	124.51	3.004
40	3.00	126.1	132.41	2.730

*At Cabin Pressure

Table E

(A) ALTITUDE IN THOUSANDS OF FEET	(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	4.23	4.22	0.018	0.0185
12	17.96	17.90	0.230	0.237
14	27.10	26.98	0.436	0.449
16	35.65	36.48	0.645	0.664
18	43.60	43.37	0.884	0.910
18.5	45.59	45.34	0.925	0.953
		AT 30 (LPM BTPS)		
20	51.24	50.92	1.093	1.126
22	61.86	61.43	1.425	1.468
24	71.75	71.19	1.755	1.808
26	80.97	80.30	2.075	2.137
28	89.56	88.79	2.385	2.457
30	97.54	96.85	2.693	2.774
32	104.97	103.96	2.973	3.062
34	111.86	110.74	3.255	3.352
36	118.24	117.00	3.520	3.626
38	124.10	122.73	3.762	3.875
40	130.00	128.5	4.015	4.135

6.7 Composition of the Atmosphere:

Constituent Gas	Molecular Fraction Percent	Molecular Weight 0 = 16.000
Nitrogen (N_2)	78.09	28.016
Oxygen (O_2)	20.95	32.0000
Argon (A)	0.93	39.944
Carbon Dioxide (CO_2)	0.03	44.010
Neon (Ne)	1.8×10^{-3}	20.183
Helium (He)	5.24×10^{-4}	4.003
Krypton (Kr)	1.0×10^{-4}	83.7
Hydrogen (H_2)	5.0×10^{-5}	2.0160
Xenon (Xe)	8.0×10^{-6}	131.3
Ozone (O_3)	1.0×10^{-6}	48.0000
Radon (Rn)	6.0×10^{-18}	222.0

6.8 List of Oxygen Equipment Specifications and Standards: Specifications and standards listed are only basic publications. Latest revisions should be used as listed in appropriate Air Force, Navy, etc. index.

Adapters:

Adapter - Air Pres. Gage	AN6285
Adapter - Army-Navy to British Supply 0_2 Union	AN6005
Adapter Assembly - 3/16 in. Conduit	AN3069
Adapter - British to Army-Navy Supply 0_2 Union	AN6006
Adapter - Hose to Pipe Thread	AN840
Adapter - Hose to Universal	AN807
Adapter - Low Pres. 0_2 Filler Valve	AN6027
Adapter - Navy to Army Supply 0_2 Union	AN6007
Adapter - Portable 0_2 Recharger Orifice	AN6044
Adapter - Oxygen Filler	AND10070
Adapter - Flareless Tube for 3/8 Bulkhead and Universal to AN Flared Tube	MS21901
Adapter - Flareless Tube to AN Flared Tube	MS21900
Adapters, Cy. Valve (compressed or liquified gases)	MIL-A-16288
Adapters, straight or reducing, brass, pipe thrd. to hose thrd.	MIL-A-17204
Adapter, Cylinder Valve, Brass, Class 320-540, Medical Oxygen, 220 psi Working Pressure	MS35668
Adapter, Cylinder Valve, Brass, Class 540-320, Medical Oxygen, 2200 psi Working Pressure	MS35669
Adapter, Compressed Gas Cylinder Valve Connection, US Regulator to British Oxygen Valve	MS39001
Adapter, Compressed Gas Cylinder Valve Connection, US Regulator to French Oxygen Valve	MS39002

Adapter, Compressed Gas Cylinder Valve Connection, US Regulator to Japanese Oxygen Valve	MS39003
Adapter, Compressed Gas Cylinder Valve Connection, US Regulator to Dutch Oxygen Valve	MS39004
Adapter, Compressed Gas Cylinder Valve Connection, US Regulator to German Oxygen Valve	MS39005

Bonding Electrical:

Bonding, Electrical (for Aircraft)	MIL-B-5087

Breathing Apparatus, Oxygen:

Breathing Apparatus, 0_2 Generating	MIL-B-17675
Cylinder and Reg., portable 0_2, general Spec. for	MIL-C-9003
Cylinder and Reg., Ass'y breathing 0_2 Type MA-2	MIL-C-25151

Canister, Oxygen Breathing:

Canister, 0_2 Breathing Apparatus	MIL-C-17671

Cartridge and Filters:

Cylinder, Oxygen Purifier, Type MB-1	MIL-C-4810
Cartridge, Oxygen Purifier, Type MA-1	MIL-C-4952
Cartridge, Gas Purifier, Extremely Low Dew Point, Type MA-2	MIL-C-26058
Filter Element, Fluid, Pressure, MXU-55/E	MIL-F-27313

Case, Oxygen System:

Case, 0_2 Sys. Maintenance, Type K-3	MIL-C-6127

Coatings:

Chemical Films for Al. and Al. Alloys	MIL-C-5541
Primer-Coating Zinc Chromate	MIL-C-8585
Anodic Coating for Al. and Al. Alloy	MIL-A-8625

Compounds:

Cleaning Compound, 0_2 Sys.	MIL-C-8638
Compound, Anti-seize 0_2 thrd.	MIL-T-5542
Type Anti-Seize Tetrafluoroethylene with Dispenser	MIL-T-27730

Connection Assembly:

Connection Ass'y. - Demand Mask to Reg. Tube External	AN6002
Connector Ass'y. - Hose, Quick Acting, Female Anti "G" Suit Use	AN6532
Connection Ass'y. - Demand mask to regulator tube with bail-out attachment	MS22009
Coupling Ass'y. - Hose, Quick-Disconnect, Male, Anti "G" Suit	MS22011
Connection Ass'y. - Demand mask to reg. tube	MIL-C-19064
Connection Ass'y. - Demand mask to reg. tube, Type MC-3	MIL-C-19246
Connection Ass'y. - Demand mask to reg. tube, External	MS22058

Connector:

Connector, 0_2 mask to reg. Type MC-3, Ass'y of	MS22016
Connector, Hose, quick-acting, Anti "G" Suit (see MS22011)	MIL-C-7942
Connector, 0_2 mask to reg. Type MC-3	MIL-C-19246
Connector, 0_2 mask to reg. Type CRU-8/P	MIL-C-26522

Containers:

Containers, Liquid 0_2, Transportable (supersedes MIL-T-6169, 6170, 6171, 6172, 6173, 6174)	MIL-C-3784

Converter:

Converter, 0_2, Liquid to Gaseous, Skid-mounted, 1200 cu. ft. per hr., 2200 PSI	MIL-C-3495
Converter, Liquid to Gaseous 0_2 Aircraft, Type A-2	MIL-C-6650
Converter, Liquid to Gaseous 0_2 Aircraft, Type A-3	MIL-C-7407
Converter, 0_2, Aircraft, Liquid to Gaseous, Type MB-2	MIL-C-8291
Converter, 0_2, Aircraft, Liquid to Gaseous, General Spec. for	MIL-C-9082
Converter, 0_2, Aircraft, Liquid to Gaseous, Type MB-5	MIL-C-19328
Converter, 0_2, Aircraft, Liquid to Gaseous, Type MB-8	MIL-C-19801
Converter, 0_2, Aircraft, Liquid to Gaseous, Type MB-7	MIL-C-19802
Converter, 0_2, Aircraft, Liquid to Gaseous, Type MB-6	MIL-C-19803
Converter, 0_2, Aircraft, Liquid to Gaseous, Type MA-1	MIL-C-25021
Converter, 0_2, Aircraft, Liquid to Gaseous, Cap. Type Gaging, General Spec. For	MIL-C-25666
Converter, Cap. Gaging Element, Liquid 0_2, 5 liter capacity, Type ME-1	MIL-C-25672

Converter, Cap. Gaging Element, Liquid 0_2, 10 liter capacity Type ME-2	MIL-C-25673
Converter, Cap. Gaging Element, Liquid 0_2, 25 liter capacity, Type ME-3	MIL-C-25674
Converter, Liquid 0_2 Type GCU-2/A	MIL-C-25777
" " " Type GCU-3/A	MIL-C-25781
" " " Type GCU-10/A	MIL-C-25974
" " " Type GCU-11/A	MIL-C-25972
" " " Type GCU-12/A	MIL-C-25973
" " " Type GCU-13/A	MIL-C-26340
" " " Type GCU-14/A	MIL-C-26358
" " " Type GCU-17/A	MIL-C-27336
" " " Type GCU-18/A	MIL-C-27423
" " " Type GCU-20/A	MIL-C-27652

<u>Couplings:</u>

Coupling - Automatic 0_2	AN6009
Coupling - Pipe Thrd. (inactive for design except for use in 0_2 Systems & Ground Service Equipment)	AN910
Coupling - Liquid 0_2 Quick Disconnect	MIL-C-21049

<u>Cylinders:</u>

Cylinders - Nonshatterable Compressed Gas	AN6025
Cylinders - Compressed air, helium, H_2, N_2 or 0_2 nonshatterable	JAN-C-1126
Cylinders - steel, seamless, Type 3A (for compressed gases)	RR-C-901
Cylinder - 0_2 Purifier, Type MB-1	MIL-C-4810
Cylinder - 0_2 Type A-6 (low-pressure-portable)	MIL-C-5435
Cylinder - 0_2 low pressure, Type B-3	MIL-C-5436
Cylinder - 0_2 low pressure, general specification for	MIL-C-5886
Cylinder - 0_2 low pressure, Type D-2	MIL-C-5887
Cylinder - 0_2 low pressure, Type F-1	MIL-C-5888
Cylinder - 0_2 low pressure, Type F-2	MIL-C-5889
Cylinder - 0_2 low pressure, Type G-1	MIL-C-5890
Cylinder - 0_2 low pressure, Type J-1	MIL-C-5891
Cylinders, breathing 0_2 and carbon dioxide, overhaul, charging, and storage of	MIL-C-7796
Cylinders, compressed gas, nonshatterable	MIL-C-7905
Cylinders, compressed gas, with valves (ICC-3A or ICC-3AA)	MIL-C-12661
Cylinders, compressed gas (seamless, nonshatterable, for storing compressed air and 0_2)	MIL-C-15111
Cylinders, nonliquified compressed gas, nonshatterable	MIL-C-16638
Cylinders, nonshatterable compressed gas	MS26545
Cylinders, compressed gas types ICC-3A and ICC-3AA	MIL-C-22491

<u>Diaphragm:</u>

Diaphragm, material, 0_2 regulator	MIL-D-7379

<u>Electric Power:</u>

Electric Power, Aircraft Characteristics of	MIL-E-7894

<u>Environmental Testing:</u>

Environmental Testing, Aeronautical and Associated Equip. General Spec. for	MIL-E-5272
Environmental Testing, Ground Support Equipment	MIL-E-4970

<u>Evacuator:</u>

Evacuator, Insulation Space, Liquid 0_2 Storage Tank	MIL-E-17345

<u>Gages:</u>

Gage Assembly, Air Testing, H. P.	AN6286
Gage - Dial Indicating, Pressure	AN5772
Gage - Panel Mounting, High Pressure 0_2	AN6011
Gage - Panel Mounting Low Pressure 0_2	AN6021
Gage - Regulator Mounting Low Pressure 0_2	AN6026
Gage - Single 1-7/8 Dial Pressure	AN5771
Gages, pressure, dial indicating, low-pressure 0_2	MIL-G-6019
Gages, high pressure 0_2	MIL-G-6035
Gages, emergency 0_2 type L-2	MIL-G-7601
Gages, pres., aircraft (see MS28061, 28063, and 28064)	MIL-G-7734
Gages, pres., Dial Indicating, Liquid Quantity, 0_2 25 liter Converter, Type MF-1	MIL-G-8100
Gage, Liquid Quantity, 0_2 5 liter 70 PSI Converter	MIL-G-8266
Gage, Liquid Quantity, 0_2 8 liter 300 PSI Converter	MIL-G-8283
Gages, pres. dial indicating, general spec. for	MIL-G-8402
Gage, pres., dial indicating	MIL-G-16983

Gage, aircraft, Cap., liquid 0_2 converter, general spec. for — MIL-G-19053
Gage, aircraft, Cap., liquid 0_2 converter, Type MC-5 — MIL-G-19327
Gage, aircraft, Cap., liquid 0_2 converter, Type MC-6 — MIL-G-19804
Gage, aircraft, Cap., liquid 0_2 converter, Type MC-7 — MIL-G-19805
Gage, aircraft, Cap., liquid 0_2 converter, Type MC-8 — MIL-G-19806
Gage, aircraft, Cap., liquid 0_2 Quantity Indicator Repeaters, Types MC-5R, 6R, 7R, 8R — MIL-G-19807
Gage, pres., Dial Indicating, liquid quantity, 0_2 MA-1 Converter — MIL-G-25127
Gage, pres., Dial Indicating, liquid quantity, 0_2 MF-2 — MIL-G-25507
Gage, Low Pressure Oxygen — MIL-G-25520
Gage, Liquid 0_2, Quantity, Cap. type, General Spec. for — MIL-G-25645
Gage, Pres. Dial Indicating, 0_2, 0-500 PSI, General Spec. for — MIL-G-25728
Gage, Pres. Dial Indicating, 0-150 PSI, 0_2 — MIL-G-26395

Generating & Charging Plant:

Generating & Charging Plant, 0_2 and N_2 High Pressure Cycle, General Requirements for — MIL-G-4936
Generating & Charging Plant, 0_2 and N_2 Semi-Trailer Mounted, Type AF/M26A-1 — MIL-G-26234
Generating & Charging Plant, 0_2 - N_2, Skid-mounted, AF/E26A-1 — MIL-G-26238
Generating & Charging Plant, 0_2 - N_2, Skid-mounted, Type MB-2 — MIL-G-26773
Generating & Charging Plant, 0_2 - N_2, Skid-mounted, Type MA-2 — MIL-G-26774
Generating & Charging Plant, 0_2 - N_2, Skid-mounted, Type MB-1 — MIL-G-26790
Generating Plant, Oxygen and Nitrogen, Skid-Mounted, A/E26A-6 — MIL-G-26590
Generating Plant, Oxygen and Nitrogen, Skid Mounted, A/E26A-7 — MIL-G-26687
Generating Plant, Liquid Oxygen, Trailer Mounted, A/M26A-9 — MIL-G-27236
Generating Plant, Oxygen and Nitrogen, Skid Mounted, A/E26A-8 — MIL-G-27253
Generating and Charging Plant, Oxygen and Nitrogen Semitrailer Mounted, A/M26A-10 — MIL-G-27257

Generator, Liquid Oxygen:

Generator, Liquid 0_2 Stationary, Type A4 — MIL-G-26929

Hose Assemblies:

Tube Assembly 0_2 Mask to Regulator — AN6003
Hose Assembly, Oxygen, Low Pressure — MS22052
Hose Assembly, Oxygen, Low Pressure — AN6039
Hose Assemblies, Oxygen Breathing Connector to Regulator — MS22055
Hose Assemblies 0_2 High Pressure Wire Braided — MS22028
Hose Assembly, Tetrafluorethylene, Oxygen — MS24548
Hose Assembly 0_2 High Pressure — MS22029
Hose Assembly High Pressure Breathing 0_2 — MIL-H-4722
Hose, Rubber, Anti-G Suit, Altitude Suit — MIL-H-5581
Hose Assembly, Low Pressure, Breathing Oxygen — MIL-H-6017
Hose Assembly, Oxygen-Breathing Connector to Regulator — MIL-H-7138
Hose Assemblies, Metal, Liquid Oxygen — MIL-H-22343
Hose Assemblies, Oxygen Mask to Connector — MIL-H-22486
Hose Assemblies, Low Pressure, Breathing Oxygen and Air Tubes, Oxygen — MIL-T-26385
Tube Ass'y 0_2 Breathing and Radio — MIL-T-7025
Hose Assembly, Metal, Flexible, Breathing Oxygen — MIL-H-26499
Hose Assembly, Tetrafluorethylene, Oxygen — MIL-H-26626
Hose Assembly, Polytetrafluorethylene, Oxygen — MIL-H-26633
Hose Assembly, Metal, Liquid Oxygen, Transfer — MIL-H-27301

Indicator and Indicator Set:

Indicator 0_2 Flow — AN6029
Indicators 0_2 Flow — MIL-I-7944
Indicators 0_2 Flow — MIL-I-18356
Indicator, Liquid 0_2 Quantity, Cap. Type, General Spec. for — MIL-I-25645
Indicator, Liquid 0_2 Quantity, GMU-5/A — MIL-I-26380
Indicator, Liquid 0_2 Quantity, GMU-8/A — MIL-I-26379
Indicator, Liquid 0_2 Quantity, GMU-9/A — MIL-I-26375

Indicator, Liquid 0_2 Quantity, GMU-11/A	MIL-I-26376
Indicator, Liquid 0_2 Quantity, GMU-10/A	MIL-I-26377
Indicator, Liquid 0_2 Quantity, GMU-14/A	MIL-I-26378
Indicator, Liquid 0_2 Quantity, GMU-15/A	MIL-I-26388
Indicator Set, Liquid 0_2 Quantity, A/A24J-3	MIL-I-26381
Indicator Set, Liquid 0_2 Quantity, A/A24J-4	MIL-I-26382
Indicator Set, Liquid 0_2 Quantity, A/A24J-5	MIL-I-26373
Indicator Set, Liquid 0_2 Quantity, A/A24J-6	MIL-I-26383
Indicator Set, Liquid 0_2 Quantity, A/A24J-7	MIL-I-26384
Indicator Set, Liquid 0_2 Quantity, A/A24J-8	MIL-I-27220
Indicator, Liquid Oxygen Quantity, GMU-21/A	MIL-I-27390
Indicator, Liquid Oxygen Quantity, GMU-28/A	MIL-I-27544
Indicator, Liquid Oxygen Quantity, GMU-30/A	MIL-I-27633
Indicator, Liquid Oxygen Quantity, GMU-34/A	MIL-I-27677
Indicator, Liquid Oxygen Quantity, GMU-32/A	MIL-I-27846

Installation:

Installation of Low Pressure Oxygen Equip. in Aircraft, General Spec. for	MIL-I-5585
Installation of 0_2 Equip. in Aircraft	MIL-I-8683
Installation of Liquid 0_2 Equip. in Aircraft, General Spec. for	MIL-I-9475
Installation of Liquid 0_2 Equip. in Aircraft, General Spec. for	MIL-I-19326
Installation of 0_2 Systems	TM WCRD 55-76
Installation of Liquid 0_2 Equip. in Aircraft	TM WCRD 53-73

Joints, Oxygen Swivel:

Joints, 0_2 Swivel	AN6042
Joints, 0_2 Swivel, Low Pressure	MIL-J-7773

Leak Test Compound:

Leak Test Compound, 0_2 Sys.	MIL-L-25567
Soap, Lubricating, 100% Olive Oil Base, 0_2 Compressor	MIL-S-11465

Leakage Test Kit:

Leakage Test Kit, 0_2 Mask & Reg.	MIL-I-7096
Tester, Leakage, 0_2 Reg., MA-2	MIL-T-8429

Masks and Valves:

Masks - 0_2 Pressure Breathing	MS22001
Masks - 0_2 Pressure Breathing (see MS22001)	MIL-M-6482
Mask - 0_2 Type A-14A	MIL-M-7585
Inhalator, Mask Type, 0_2 Theraphy Apparatus	MIL-I-16596
Mask, 0_2 and smoke, full face	MIL-M-19417
0_2 Mask Facelet Kit	MIL-C-25543
Valve 0_2 Mask Inlet Check	MIL-V-21701
Valve 0_2 Mask Exhalation Pressure Compensating	MIL-V-25126
0_2 Mask Mod. Kit, Sponge	MIL-O-25748
Mask, 0_2 Type MBU-3/P	MIL-M-25981
Mask, 0_2 Type MBU-4/P	MIL-M-25990
Mask, 0_2 Type MBU-5/P	MIL-M-27274
Valve - 0_2 Mask Combination Inhalation and Exhalation	MIL-V-27296

Nipple, Emergency 0_2 Cylinder Valve:

Nipple, Emergency 0_2 Cyl. Valve, Break-off	MIL-N-25087

Oxygen:

Oxygen Aviator's Breathing	MIL-O-21749
Oxygen Aviator's Breathing Liquid and Gas	MIL-O-27210

Oxygen Recharge Equipment:

Recharger Assembly, Portable 0_2	AN6041
Oxygen Recharge Equipment, (power driven)	MIL-O-6705
Recharging Unit, Liquid N_2 or 0_2, Heat Conversion Method, Type MA-1	MIL-R-26291
Recharger Assembly Portable 0_2	MS22032

Packaging:

Packaging and Packing of Aircraft Material in Steel Shipping Containers	MIL-P-5633

Purging Equipment:

Purging Kit, Converter System, Liquid Oxygen, KMU-78/E	MIL-P-27431
Purging Unit, Air, Liquid Oxygen Storage Tanks, GSU-62/M	MIL-P-27456

Reducer, Oxygen Pressure:

Valve, 0_2 Pres. Reduction	MIL-V-6607
Reducer 0_2 Pres. (on-off type)	MIL-R-17852
Reducer 0_2 Pres.	MIL-R-18318
Reducer 0_2 Pres. (emergency type)	MIL-R-21561
Valve, Reduction, 0_2	MIL-V-25559
Reducer, 0_2 Pres. General Spec. for	MIL-R-25575
Adapter Pressure Reducer in Line CRU-43/A	MIL-A-27471

Regulator, Oxygen:

Reg. Ass'y. - Demand 0_2	AN6022
Reg. Automatic Continuous Flow 0_2	AN6010
Reg. Diluter-Demand 0_2	AN6004
Reg. 0_2 diluter-demand	MIL-R-6018
Reg. 0_2 Pres. Type C-1	MIL-R-6125
Reg. Diluter-Demand 0_2 Pres. Breathing, Type A-14	MIL-R-6371
Reg. 0_2 Pres. Demand, Bail-out, Type F-1	MIL-R-7427
Reg. 0_2 Demand, Pres. Breathing, Type A-21	MIL-R-7605
Reg. 0_2 Diluter Demand Automatic Pressure Breathing	MS22062
Reg. Automatic Diluter-Demand, 0_2 Pres. Breathing, Type D-2A (supersedes MIL-R-6352)	MIL-R-8202
Reg. Automatic continuous flow 0_2	MIL-R-8636
Reg. Diluter-Demand, 0_2 Type A-15	MIL-R-9057
Reg. 0_2 high-press. Type MA-1	MIL-R-9198
Reg. 0_2 demand, Type A-13	MIL-R-9338
Reg. 0_2 diluter-demand, automatic pres. breathing, high-pres. Type MB-2	MIL-R-9494
Reg. 0_2 and acetylene, single and two-stage	MIL-R-13877
Reg. Pres., and flowmeter, 0_2 and helium - 0_2	MIL-R-16595
Reg. 0_2, automatic positive pres. and composite diluter demand	MIL-R-18059
Reg. aviator's miniature 0_2 breathing; 100% demand type, with safety pres. and automatic pres. breathing	MIL-R-19121
Reg. pres., compressed gas	MIL-R-19180
Reg. 0_2, Automatic Pres. Breathing High Altitude, General Spec. for	MIL-R-25572
Reg. 0_2 Continuous Flow, Walk-Around	MIL-R-25693
Reg. 0_2 Diluter-Demand, Automatic Pres.-Breathing, General Spec. for	MIL-R-25916
Reg. 0_2 Diluter-Demand, Automatic Pres.-Breathing, General Spec. for	MIL-R-25410

Storage & Charging System Oxygen:

Storage & Charging Sys., 0_2	MIL-S-15913

Tank, Liquid Oxygen:

Tank, Liquid 0_2, Storage and Transfer, 150 Gallon Capacity, Type B-1	MIL-T-4832
Tank, Liquid 0_2, Storage and Transfer, 500 Gallon Capacity, Type C-1	MIL-T-4831
Tank, Liquid 0_2, Storage and Transfer, 1700 Gallon Capacity, Type E-1	MIL-T-4830
Tank, Storage, Liquid Oxygen, TMU-20/E	MIL-T-27483
Tank, Storage, Liquid Oxygen, A/M32A-40	MIL-T-27600
Tank, Storage, Liquid Oxygen, TMU-24/E	MIL-T-27720

Tank, Storage, Liquid Oxygen:

Tank, Storage, Liquid 0_2, 50 gallon capacity, trailer mounted, Type MA-1	MIL-T-4796
Tank, Storage, Liquid 0_2, General Spec. for	MIL-T-4829
Tank, Storage, Liquid 0_2, 50 gallon capacity, trailer mounted, Type No. 4	MIL-T-21282

Test, Aircraft Oxygen Equipment:

Test, Aircraft 0_2 Equipment, Functional; L. P.	MIL-T-6037

Test Stand and Tester:

Test Stand, 0_2 Reg.	MS33567
Test Stand, Diluter-Demand 0_2 Reg., Flowmeter Type	MIL-T-18328
Tester, Leakage, Demand 0_2 Reg. Type MH-2	MIL-T-8429
Tester, High Altitude Coveralls & Helmet, Preflight, Type TTU-17/E	MIL-T-25629
Tester, 0_2 Mask, Headset, and Microphone, Type MQ-1	MIL-T-25620
Tester, Capacitance Type, Liquid Oxygen System, TTU-85/E	MIL-T-27352

Sampler, Liquid Oxygen, TTU-131/E	MIL-S-27626
Tester, Liquid Oxygen Converter System, TTU-162/E	MIL-T-27714

Trailer:

Trailer, Compressed Gas Cylinder, 0_2 Servicing, 4-wheel, 12 cylinder, 450 PSI, Type MB-2	MIL-T-4701
Trailer, Compressed Gas Cylinder, 0_2 Servicing, L. P. 2-wheel, 6 cylinder capacity, Type MB-4	MIL-T-4974
Trailer, 0_2 Servicing, Type 1	MIL-T-6706
Trailer, 0_2 Servicing, Type MB-1	MIL-T-9025
Trailer, Compressed Gas Cylinder, AF/M32R-3	MIL-T-26069
Semitrailer, Tank, Liquid Oxygen, Storage and Servicing, Type MD-1	MIL-S-26132
Semitrailer, Tank, AF/M32A-4A	MIL-T-26196
Trailer, Compressed Gas Cylinder, A/M32A-19	MIL-T-26252
Semitrailer, Tank, A/M32R-6	MIL-T-26530

Tubing:

Tubing End - Hose Connection, Std. Dimensions for	AND10060
Tubing - Minimum Bend Radii for Conduit and Fluid Line	AND10111
Tubing End - Standard Dimensions for Double Flare	AND10078
Tubing End - Standard Dimensions for Flared	AND10061
Tubing - Standard Dimensions for Round Seamless Corrosion-Resisting Steel	AND10104
Tubing - Std. Sizes for Al. Alloy (52SO) Round	AND10106
Tubing - Std. Sizes for Al. Alloy (61S) Round	AND10108
Tubing - Al. Alloy (52S) round, seamless drawn	WW-T-787a
Tubing - Copper, seamless (for use with solder-joint or flared-tube fittings)	WW-T-799a
Tubing - Copper seamless, for pres. up to 4,000 PSI	MIL-T-873

Tubes and Tube Assemblies:

Tube Ass'y, 0_2 Breathing & Radio	MIL-T-7025
Tube Ass'y, 0_2 Mask to Reg.	MIL-T-7138
Tubes, 0_2	MIL-T-26385

Valves:

Valve - H. P. 0_2 Check, Style A	AN6014
Valve - H. P. 0_2 Check, Style B	AN6015
Valve - H. P. 0_2 Check, Style C	AN6016
Valve - H. P. 0_2 Check, Style D	AN6017
Valve - H. P. 0_2 Check, Style E	AN6018
Valve - H. P. 0_2 Line	AN6012
Valve - L. P. 0_2 Check, Style A	AN6030
Valve - L. P. 0_2 Check, Style B	AN6031
Valve - L. P. 0_2 Check, Style C	AN6032
Valve - L. P. 0_2 Check, Style D	AN6033
Valve - L. P. 0_2 Check, Style E	AN6034
Valve - L. P. 0_2 Check, Style F	AN6035
Valve - L. P. 0_2 Check, Style G	AN6036
Valve - L. P 0_2 Check, Style H	AN6037
Valve - L. P. 0_2 Filler	AN6024
Valve - Reg., Jet Type Aircraft, Anti "G" Suit	AN6538
Valve - Static Pres. Selector	AN5831
Valves - Pres. Gage Lines Bleeder and Filler Check	AN5832
Valve - H. P. 0_2 Cyl., Automatic Opening	MS22012
Valve - Pneumatic Check	MS28888
Valve - check, pres. gage lines bleeder and filler	MS28052
Valves - gas cyl. (compressed or liquified gases)	MIL-V-2A
Valves - Cyl. 0_2 (for standard industrial cylinders)	WW-V-61
Valve - Automatic Regulating, Pres.	MIL-V-4501
Valve - 0_2 Line, H. P., Aircraft Servicing	MIL-V-4719
Valves - H. P. 0_2 check	MIL-V-5027
Valve - Reg., jet-type aircraft, anti "G" suit	MIL-V-5064
Valve - 0_2 Pres. Reduction	MIL-V-6607
Valve - 0_2 mask exhalation, pres. compensating	MIL-V-7053
Valve - L. P. 0_2 Line	MIL-V-7529
Valve - 0_2 mask, inlet check	MIL-V-7553
Valve Assembly, 0_2 Cyl., Bailout	MIL-V-7560
Valve - L. P. 0_2 filler	MIL-V-7891
Valves - L. P. 0_2 check	MIL-V-7908
Valve - 0_2, pres. buildup and vent	MIL-V-8057
Valve - High Pressure 0_2 line	MIL-V-8612

Valves - High Pressure 0_2 check filler connection	MIL-V-8620
Valves - High Pressure 0_2 cyl. automatic opening (Aeronautical use) (See MS22012)	MIL-V-8622
Valve - 0_2 aircraft, pres. relief, general spec. for	MIL-V-9050
Valve, automatic regulating pres. anti "G" coveralls, jet aircraft, general spec. for (See MS24350) (ASG)	MIL-V-9370
Valves - 0_2, cyl. high pressure	MIL-V-9439
Valve, outlet C15, gas mask	MIL-V-10134
Valve, pres. equalizing, gaseous products	MIL-V-17203
Valve, pres. regulating; 0_2 System	MIL-V-18318
Valves, reducing, compressed gas	MIL-V-18500
Valve, 0_2, mask exhalation, pres. compensating	MIL-V-25126
Valve, Filler: Liquid 0_2, Aircraft Type	MIL-V-25469
Valve, check liquid 0_2 Converter, 300 psi, Type MH-1	MIL-V-25513
Valve, 0_2 check, for 70 PSI 0_2 Converters	MIL-V-25514
Valve, Reduction, 0_2	MIL-V-25559
Valve, Combination- Fill - Build-up-Vent, Liquid Oxygen	MIL-V-25772
Valve, Combination- Fill - Build-up-Vent, Liquid Oxygen 300 psi	MIL-V-25961
Valve, Liquid 0_2 Drain	MIL-V-25962
Valve, 0_2 Pres. Build-up and Vent	MIL-V-26394

Vaporizer System:

Vaporizer System, Liquid 0_2 to High Pressure Gaseous Skid Mounted	MIL-V-19615

6.9 Bibliography:

Manufacturers' Catalogs, etc.
Your Body in Flight AFP160-10-3
Technical Manual, Maintenance Instruction Oxygen Equipment Technical Order ISX-1-1 (USAF)
Physiology of Flight AFP160-10-4
Technical Manual, Maintenance Instruction Oxygen Equipment Technical Order NAVAER03-50-1