AEROSPACE INFORMATION REPORT

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OXYGEN SYSTEMS FOR GENERAL AVIATION

SECTION I - OXYGEN, BASIC PHYSIOLOGY

1. GENERAL

"At what altitude should one use oxygen and what are the effects at various altitudes if it is not used?" Most pilots are vague in their conecpts of oxygen deficiency. The following is an attempt at a concise review of the factors and effects of hypoxia. A table is included for simple reference.

The percentage of oxygen in the air (about 20%) remains constant from sea level to approximately 70,000 feet. The remaining percentage is made up mainly of nitrogen (about 80%). The variable that occurs at varying altitudes is one of partial pressure and not one of concentration. For example, the pressure of the outside air (ambient) at 18,000 feet, 27,000 feet, and 33,000 feet is approximately 1/2, 1/3 and 1/4 respectively of that at sea level.

At altitude in an aircraft without pressurization, it is necessary to increase the concentration or percentage of oxygen inhaled in order to maintain an adequate level of blood oxygen saturation for normal functioning. By adding oxygen, the partial pressure of oxygen is increased and the partial pressure of nitrogen is decreased.

In graphing the ability of the blood to take up oxygen from the inhaled air, it is evident that as the atmospheric pressure and, consequently, the oxygen partial pressure is gradually decreased in a straight line, the ability of the blood to hold adequate amounts of oxygen (% saturation) remains good up to a certain point. Pressures below this point result in a marked and rapid falling off of oxygen content of the blood. This characteristic, when graphed, is normally referred to as the "oxygen dissociation curve" of blood (Fig. 1).

Although the oxygen pressure decreases linearly as a straight sloping line with increasing altitude, the ability of the blood to hold oxygen goes down a slight slope for a short period and then drops over a precipice. As this is true, one cannot think that an individual is only one-half as efficient at 16,000 feet as at 8,000 feet. Let us now consider what the average person can expect at varying altitudes, keeping in mind that variation in tolerance may place these individuals in a condition one or two thousand feet above or below the average.

1.1 Effect on Vision - The retina of the eye, which is an outcropping of the brain, is more demanding of adequate oxygen than any other part of the body. For this reason, the first evidence of hypoxia occurs at 4,000 feet in the form of diminished night vision. It is wisest to use oxygen at 5,000 feet at night. If one is at 8,000 feet or 9,000 feet without oxygen, allowances should be made for a higher margin of safety by avoiding those situations that demand good night vision. Under these circumstances instruments and maps are frequently misread and the features of the dimly lit ground are frequently misinterpreted. The onset of this defect is insidious and must constantly be kept in mind. Bright or white light will destroy the remaining night vision accommodations. For example, under ideal circumstances, even at sea level, an average man requires 30 minutes to reaccommodate to night vision following exposure to even even moderate intensity white light.

1.2 10,000 - Hypoxia - The next level normally considered is 10,000 feet (522.752 mm of mercury or 10.108 psi). At this altitude there is a definite but unrecognizable hypoxia. It is the maximum altitude at which an individual should consider his judgment and ability minimally acceptable. Above these altitudes, oxygen enriched atmosphere must be provided. Above 10,000 feet the percentage of blood oxygen saturation drops quickly (Fig. 2).

1.3 Clouding of Thought - At approximately 14,000 feet (446.633 mm of mercury or 8.636 psi), the percentage of oxygen saturation drops to 84 and the individual is considered "appreciably handicapped." There is a dimming of vision, tremor of hands, clouding of thought and memory and thus, errors in judgment and performance. In individuals who are smoking, the saturation drops even lower. It is frequently thought there is a marked increase in respiratory rate at high altitudes because of hypoxia, but this is usually not noticeable. The major control of respiratory rate is the carbon dioxide accumulation in the lungs which affects the respiratory center of the brain. Because carbon dioxide is being released freely, the respiratory rate is not significantly changed except during exertion. The method of identifying hypoxia by the purplish discoloration of the fingernails is unreliable.

1.4 Disorientation, Belligerence - At 16,000 feet (412.102 mm of mercury or 7.968 psi), the oxygen saturation of the blood is 79% and the individual is considered "considerably handicapped." Disorientation, belligerence, or euphoric behavior and complete lack of rational judgment are observed. The individual is dangerous as a pilot of an aircraft or in other operational

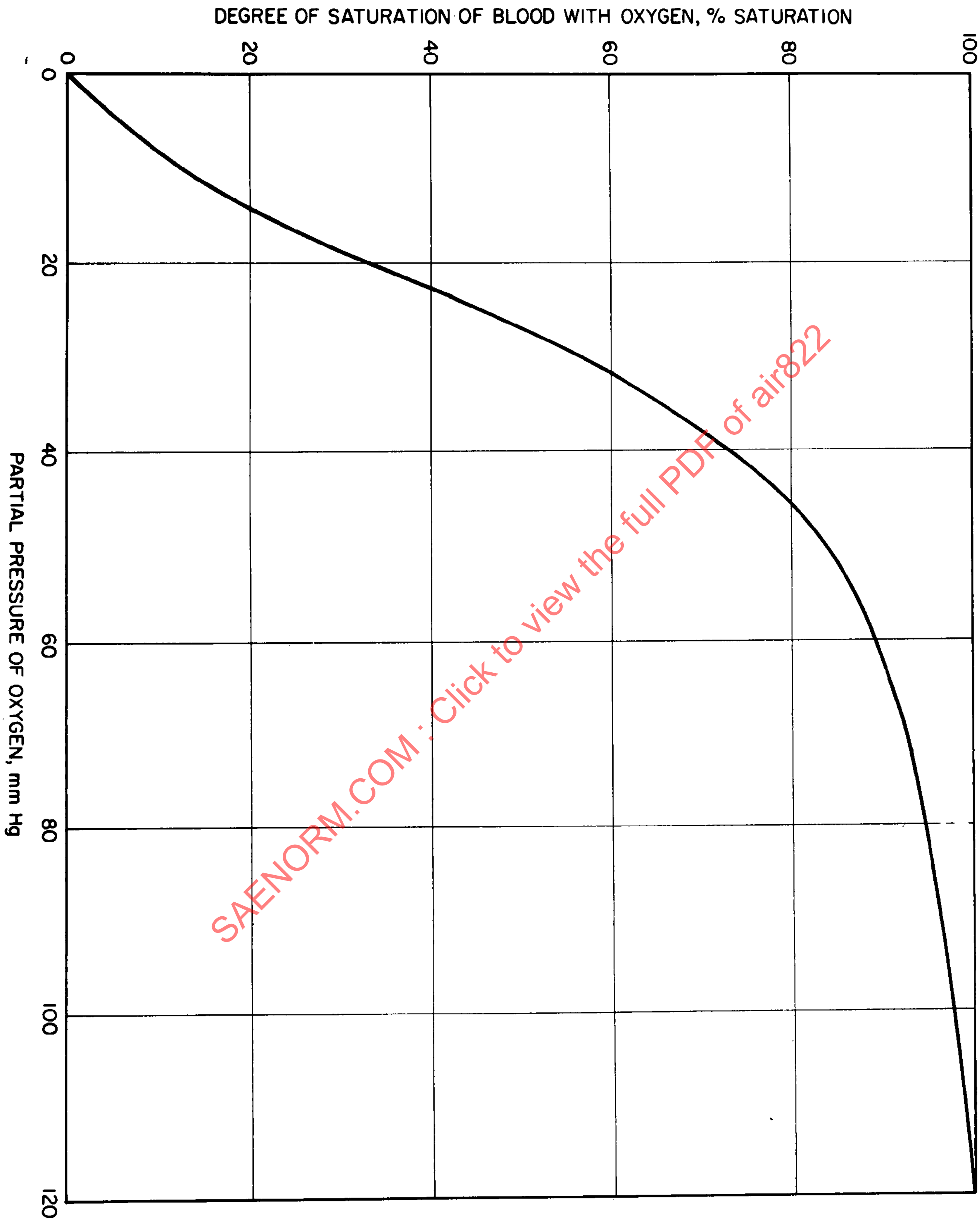

Figure 1
TYPICAL OXYGEN DISSOCIATION CURVE OF BLOOD

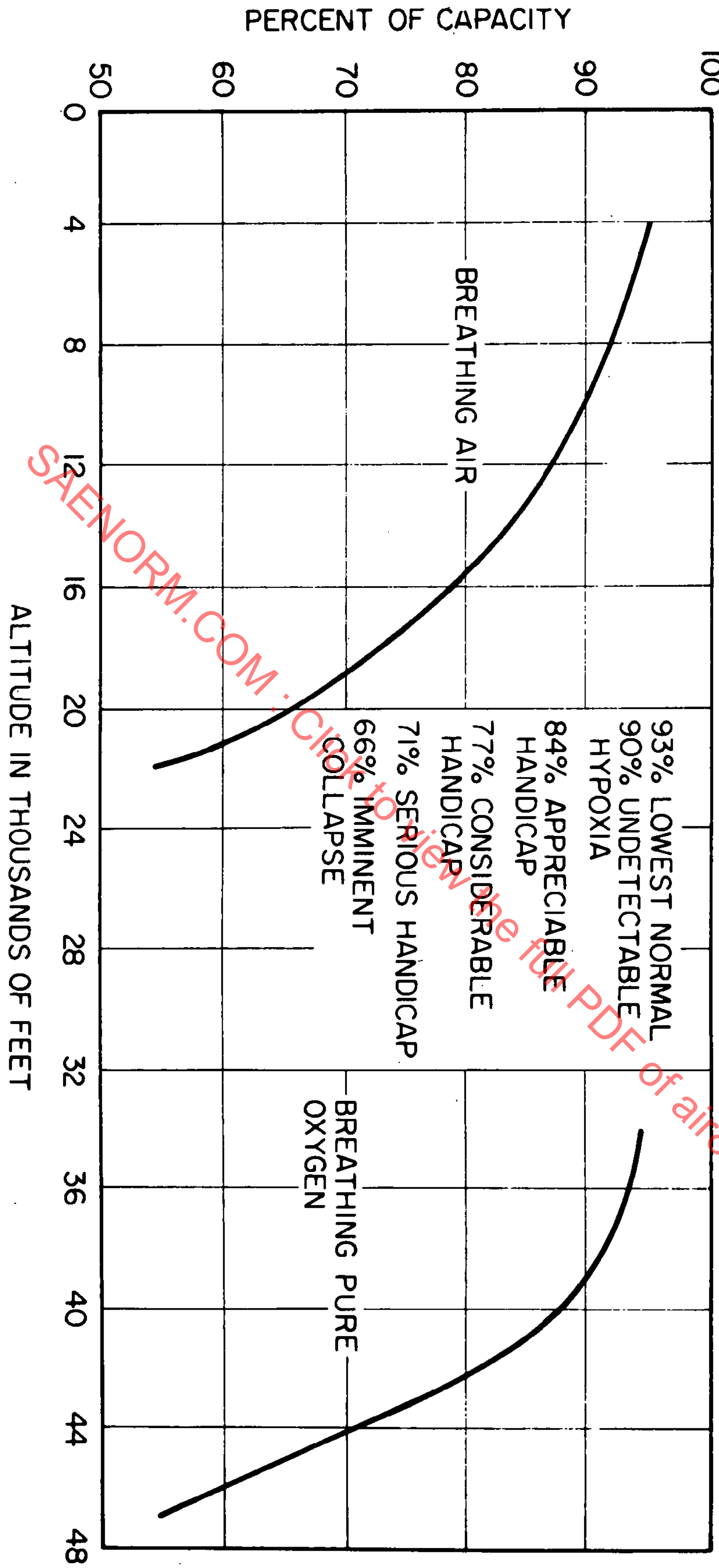

Figure 2

Oxygen saturation (% of capacity) of arterial blood and average range of performance at various altitudes in subjects breathing aid and in subjects breathing oxygen.

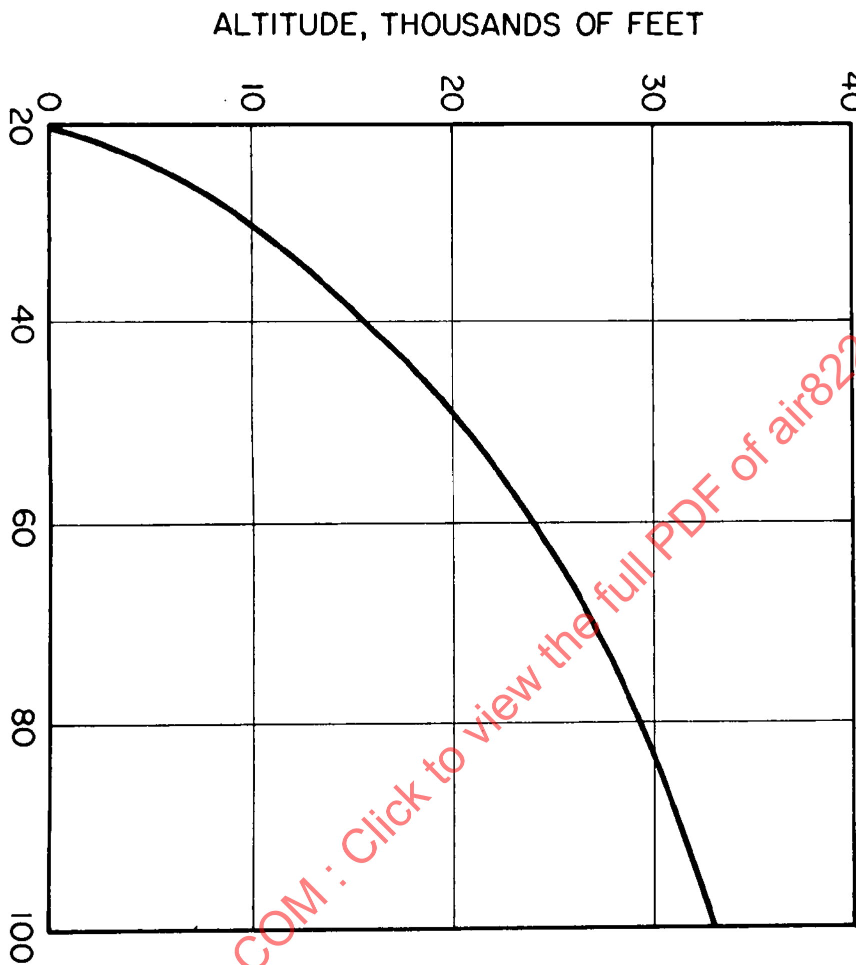

Figure 3
Per cent oxygen required in the inspired air at various altitudes to maintain a normal alveolar oxygen tension.

requirements. This level of hypoxia simulates alcoholic intoxication.

At 18,000 feet (379.773 mm of mercury of 7.343 psi) the oxygen saturation drops to 71% and the individual is considered "seriously handicapped." Between 18,000 feet to 20,000 feet, the individual may become unconscious. This degree of collapse can be compared to fainting. Reoxygenation reverses the hypoxia and consciousness returns.

At higher altitudes more profound collapse occurs and death may follow if the period of hypoxia is prolonged.

1.5 Duration - The duration of hypoxic exposure is an important factor affecting the above symptoms. These responses should be considered in terms of brief (minutes) exposure. This duration may be exceeded by the individual who has an unusual tolerance and resistance to hypoxia. Fatigue, alcohol and all depressant drugs in even small amounts increase the effect of altitude. In individuals who are hypoxic, use of adequate oxygen will return them close to normal efficiency quickly, usually within 15 seconds.

Fifteen seconds represents the circulation time of the blood; that is, the heart will pump and return to itself, in 15 to 20 cycles, a major portion of the body blood. This volume of the blood will be exposed to the lung alveolar membranes for gas exchange and its new oxygen supply pumped to the brain during this period. This applies if carbon monoxide is not an impairing factor.

Carbon monoxide poisoning, which can result from inhalation of engine exhaust gases, creates a different problem. The hemoglobin, or oxygen carrying portion of the blood, has about 200 times greater affinity for carbon monoxide than for oxygen and, therefore, even small amounts of carbon monoxide will block the absorption of oxygen. If the dosage of carbon monoxide is not sufficient to cause death, it requires 100% oxygen inhalation over a prolonged time (frequently in terms of days of hyperbaric oxygen) to recover. This type of hypoxia differs from that which altitude alone will cause. If exhaust gases are suspect in the cabin, the heaters should be turned off, all air vents opened, and concentration of oxygen turned to 100% until landing can be accomplished.

Individuals who smoke should consider themselves 2,000 to 3,000 feet altitude above the non-smoker because of carbon monoxide levels in their blood levels and diffusion impairment in their lung alveoli.

Hypoxia can also occur from imbibing alcohol. This substance interferes with the tissue's ability to absorb the oxygen from the blood. Of course, the degree of impairment is dependent on the amount taken. There are other types of hypoxia, such as occur in partial heart failure or anemias, which are not related to the problems met by a healthy individual at altitude.

1.6 Headache - After descending from a prolonged period at 12,000 feet without oxygen, it is not uncommon to suffer an excruciating headache for the next 4 to 6 hours on the ground. After exposure to higher altitudes, the duration and severity of this ground headache is greater. This is the result of the previously encountered hypoxia.

1.7 Table I can be used to determine the degree of handicap using ambient (outside) air, 100% oxygen at various altitudes, and the percentage of oxygen necessary to maintain the equivalent of a 4,000 to 5,000 feet level.

TABLE I

COL I Altitudes in Ft (Ambient Air Breathing)	COL II Altitudes in Ft (Ambient Pressure Breathing 100% O_2)	Effects of breathing ambient air at Col I altitudes or 100% oxygen at COL II altitudes	Percent inspired oxygen necessary to maintain equivalent of 5,000 ft at altitudes Col. I (only)
0	34,000	Sea Level	Ambient Air
5,000	37,000	Night vision deficiency	
10,000	40,000	Beginning impaired judgment and performance	25%
14,000	41,000	Appreciable handicap	30%
16,000	43,000	Considerable handicap	33%
18,000	44,000	Serious handicap	40%
20,000	45,000	Imminent collapse	44%

Note: Values extracted from NASA Standard Atmosphere.

It should be noted again that the most rapid and serious changes without oxygen occur between 10,000 and 15,000 feet. Survival above 41,000 feet requires breathing 100% oxygen under pressure, but more effectively by cabin pressurization. Based on the possibility of cabin pressurization failure and a rapid decompression and the short time to imminent collapse (less than one minute at 41,000 feet under these conditions), it is imperative that crew members be impressed and convinced of the need to wear oxygen masks at all times above 41,000 feet, and if a decompression of such nature should occur, it is necessary to have pressurized oxygen supplied to the wearer of the mask. Again, because of the extremely short time (measures in seconds) of consciousness at these altitudes together with fogging of the aircraft and other extensive distractions occurring in association with a rapid decompression to ambient pressure, all occupants should wear, and must be trained in the art of breathing with, pressure breathing equipment unless other provisions in the aircraft are made to eliminate any possibility that cabin pressure altitudes will exceed 41,000 feet. Even so, this requires these people to be in exceedingly good health insofar as their pulmonary system is concerned. In large commercial type aircraft flying above 41,000 feet, it is assumed that the decompression rate, in the event of accidental decompression, will be slow enough to permit sufficient time for descent to lower altitudes.

1.8 It should be noted that partial cabin pressurization alters the problem. If the cabin pressure altimeter reads 15,000 feet and the aircraft is at 30,000 feet, the problems are similar to those of an unpressurized aircraft at 15,000 feet.

1.9 Breathing higher concentrations of oxygen over a long period of time to offset oxygen partial pressure differences at higher altitudes causes no significant ill effects.

1.10 The only way to prevent hypoxia is to be constantly aware of what effects can be expected at altitude and to act accordingly.

SECTION II - OXYGEN SYSTEMS DESCRIPTION

2. GENERAL DISCUSSION

Current aircraft breathing oxygen systems may utilize either gaseous or liquid oxygen. This is the description of the method of storage only, since the oxygen as it reaches the user in either system is gaseous.

Oxygen is colorless, odorless, tasteless, and nontoxic. Above its critical temperature of -180.40 F, oxygen can exist only as a gas regardless of the pressure exerted upon it. Liquid oxygen may be stored at normal temperatures only by allowing constant overpressure bleed off of gaseous oxygen. Breathing oxygen which is 99.5% pure and has a maximum water content of 2.0 milliliters/liter of oxygen should be used.

The gaseous oxygen system may be a higher pressure system with the oxygen stored at 1850 psi or a low pressure system with the oxygen stores at 425 psi.

All oxygen systems contain a storage tank, a regulation system, and a distribution system. The main difference in types of systems is in the regulation of the oxygen to the user, which dictates the type mask. The types of systems are continuous flow, demand flow, diluter-demand flow, and pressure-demand (with or without dilution) flow. Each category of systems is designed to fill the needs of a specific type aircraft operation; therefore, the following system descriptions and mission explanations should be used in selecting a system for any aircraft.

2.1 <u>Systems</u>

2.1.1 <u>Continuous Flow Oxygen Equipment</u> - 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 in the mask by a controlled means, either valving or ports. During inhalation, oxygen flow from the regulator is supplemented by the air which enters through these ports or valves. The amount of air entering the mask depends on the rate of oxygen flow and rate of breathing. A more complex system would include a gas reservoir bag in addition to the air ports. The reservoir or rebreather bag is used to collect oxygen during the exhalation phase and permits a much higher inspiratory rate of flow before air dilution takes place. The rebreather type is designed to collect a fraction of the expired gases for use during the following insporation. 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 the 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 standpoint of design, cost, weight, and maintenance and offers reasonable safety for brief periods approaching 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.

2.1.2 <u>Demand and Diluter-Demand Flow Equipment</u> - Demand flow equipment can be straight demand (a system which delivers 100% oxygen upon inspiration) or can be obtained with an air mixing feature (diluter-demand) to conserve oxygen. This type is pressure altitude sensitive as to percentage of mix (air and 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. The demand system is considered adequate to altitudes of 35, 000 feet and for short periods of time between 35, 000 and 40, 000 feet. Oxygen flow in 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 flows into the user's mask. 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. As a solution to this problem, masks are now available with the demand regulator built in, eliminating the hose.

2.1.3 Pressure-Demand Equipment - Pressure-demand equipment differs from the other oxygen equipment in that oxygen under pressure is delivered to the user at higher altitudes. 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. Between 35, 000 feet and 40, 000 feet it is desirable and between 40, 000 feet and 50, 000 feet it is necessary to increase the pressure of the oxygen in the mask. 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, and also can be obtained with or without safety pressure, which is 2 inches of water pressure in a mask.

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 (decreased density reduces flow resistance). 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.

The pressure-demand systems are most commonly used by the military aircraft for high altitude flying above 40, 000 feet when the flight crew are breathing through oxygen masks. Pressure-demand systems are also used as an integral part of pressure suits.

2.2 From the above descriptions, it can be seen that the continuous flow system is the most easily adaptable system for general aircraft and is the most commonly used. Various continuous flow systems are available along with permanent, semi-permanent, and disposable masks for the individual passengers.

2.3 General aviation aircraft now includes turbine powered aircraft capable of flight to and above 40, 000 feet. On aircraft certified to 41, 000 feet, the minimum oxygen system required should be in accordance with FAR 25.1441. This requires a demand system for the crew and at least a constant flow system for the passengers. A combination system such as this can easily be designed. For aircraft operating above 41, 000 feet, oxygen systems require special approval by FAA.

FAA requirements also stipulate certain protective breathing oxygen requirements with respect to types of cargo compartments commensurate with the use of CO_2 fire extinguishers in non-pressurized cabins. These requirements should also be considered.

SECTION III - DESIGN INFORMATION

3. GENERAL

Oxygen standards, design criteria, and general practice have been developed largely by and for the military services. Reference to military specifications and military standards (AN, AND, and MS) have as a result found their way into the civil aviation usage. Therefore, reference herein to military terms and equipment is inevitable.

The SAE Aerospace Information Report AIR 825, "Oxygen Equipment for Aircraft," contains much basic information on oxygen equipment and systems and should be used to supplement this document.

Because liquid oxygen systems are primarily, if not solely, limited to military usage, no information will be included here on this subject.

In regard to Federal Aviation Regulations, it is recognized that FAR 23, "Airplane Airworthiness, Normal, Utility, and Acrobatic Categories," and FAR 91, "General Operations Rules," do not contain any requirements for the use of oxygen. CAR 4b (FAR 25), "Airplane Airworthiness; Transport Categories," and the Air Carrier Operating Regulations, of course, do contain requirements. Much of the equipment available today has been designed to meet these requirements.

3.1 Safety-Design Practices Recommended - The use of oxygen involves a degree of hazard. The proper design, installation, use and maintenance can reduce the hazards to an acceptable level.

Oxygen in gaseous or liquid form is chemically stable and non-flammable. However, combustible materials ignite more readily and the intensity of a fire increases tremendously in an oxygen-rich atmosphere. For these reasons it is very important to keep separate, to the extent possible or practical, the ingredients of fire: (a) combustibles, (b) source of ignition (heat), and (c) increased concentrations of oxygen.

(a) Combustible materials can be any material including those generally thought of as non-combustibles, such as metals which become combustible at elevated temperatures in the presence of high concentrations of oxygen.

(b) Ignition sources are heat sources. Heat can be conveyed by radiation or by conduction. There are many sources; a few examples are:

1. Electrical arcing, sparking on impact, and static discharges.
2. Friction heat; for example, a small volume, high velocity leak can cause ignition of the material through which it is leaking.
3. Adiabatic heating of a gas developed by rapidly compressing the gas, as in rapid high pressure filling of an oxygen container or system.
4. Resonance heating caused by the vibratory flexing of materials or by resonant pulsing of oxygen into a closed end cavity. Resonant heating can occur at very low pressures (40 psi). This problem can be eliminated or minimized by proper equipment design.

(c) Increased (over atmosphere) concentration of oxygen can be controlled in the main by having a leak-tight system.

A major safety factor is cleanliness, freedom from contaminants. This is most important in the fabrication, installation, and maintenance of the equipment. From the installation design standpoint, the hazard of contamination can be lessened if not eliminated by choosing proper locations for the equipment and by adequate protection and shielding where choice of location is limited.

Choice of materials used in the system definitely affects safety. The materials used in the equipment selected as well as in plumbing will be discussed later.

The FAA regulations are primarily aimed at safety, and FAR 25 contains some requirements for transport category aircraft which are certainly applicable to non-transport aircraft:

(a) Oxygen System Fire Protection
(1) Oxygen equipment and lines shall not be located in any possible fire zone.
(2) Oxygen equipment and lines shall be protected from heat which may be generated in or escape from any possible fire zone.
(3) Oxygen equipment and lines shall be so installed that escaping oxygen cannot cause ignition of accumulations of grease, fluids or vapors which are likely to be present in normal operation or as a result of failure or malfunction of any system.

(b) Flammable Fluid Protection - In areas of the airplane where flammable fluids or vapors might be liberated by leakage or failure in fluid systems, design precautions shall be made to safeguard against the ignition of such fluids or vapors due to the operation of other equipment, or to control any fire resulting from such ignition.

(c) The oxygen system installed shall be free from hazards in itself, in its method of operation, and in its effects upon other components of the airplane.

Many of the following recommendations for design of the installation are based on the requirements for safety as briefly covered above.

3.2 Pressure Level - For reasons of safety, high pressure supply systems are designed to have the pressure reduced to less than 150 psi as near downstream, of the cylinder valve as possible. The actual pressure level to be used depends on the type of regulators and masks and possibly on the number of users in large aircraft, where pressure drop could be a factor.

3.3 Type and Number of Oxygen Supply Containers - Quantity of oxygen supply is determined by the number of occupants, the altitude to be flown in an unpressurized cabin, and the maximum flight duration while unpressurized. Oxygen requirements will vary with the regulation and dispensing equipment selected; therefore, oxygen required for each crew member and passenger must be calculated from the information received from the equipment manufacturer.

Knowing the number of cubic feet of oxygen required, the number and size of cylinders can be selected. One consideration will normally be the size and shape of the space available in the aircraft for installing the cylinder(s).

3.4 Filling or Recharging Provisions - Filling or recharging the oxygen cylinder by removal of the cylinder from the aircraft and recharging away from the aircraft is often done; however, central point filler valves accessible from outside the aircraft are available. From the safety standpoint neither method need be hazardous as long as properly trained personnel perform their functions with the necessary care. (See Section V for recommended procedures.)

From the standpoint of time required, the central point filling is to be recommended. Actually this central point filling minimizes a major difficulty in cylinder removal, which is maintaining the mandatory cleanliness of the system. In cylinder removal one or more lines are disconnected and the cylinder and system are subjected to the possible introduction of contaminants.

Fill valves should have sized orifice inlets to control filling time and prevent rapid filling with its attendant hazard of adiabatic compression heating noted above.

From a practical standpoint, then, the choice depends more on (a) the availability of ground recharging equipment at airports, (b) the frequency of recharging anticipated, and (c) the cost and weight effect of the added plumbing and valving.

3.5 Portable Oxygen Cylinder Assemblies - Portables have several uses, not all associated with "portability" or mobility.

Some uses of portables are:

(a) Total supply

(b) Cabin attendants supply

(c) First aid or clinical therapeutic use (high flow rate)

(d) Demand protective breathing supply with emergency capabilities for fire fighting

(e) Crew and passenger mobility during flight

Each portable oxygen cylinder assembly is also a complete oxygen system in itself and should be treated accordingly. For small aircraft, a single portable with continuous flow outlets in the cylinder shut-off valve can supply oxygen for all occupants for relatively short duration flights.

Outlets supplying higher flows for therapeutic oxygen are available on portables. When portables are used as protective equipment in fire fighting, only equipment providing 100% oxygen should be used.

3.6 Oxygen Supply Pressure Gages - It is recommended that a supply pressure gage(s) be visible during flight. If the gage is remote from the oxygen cylinder, it is further recommended that the connecting high pressure line be of small inside diameter (capillary) tube of copper or stainless steel (for high melting point material as well as increased strength).

3.7 Overboard Vents - Oxygen cylinder valves contain safety devices to protect against over pressure caused by an external heat source or by overfilling. These valve outlet ports should be, when practicable, vented overboard by use of stainless steel or copper lines. Copper or stainless steel lines are recommended particularly because of the high pressure exposure possibility. If the parts are so vented, the opening in the fuselage skin should be visible during a walk-around inspection and should contain a frangible disk.

3.8 Oxygen System Schematic - In establishing or determining the system configuration, a system schematic should be prepared. Several sample schematics, actual or fictitious, are shown in Appendix I.

SECTION IV - SYSTEM COMPONENT SELECTION AND INSTALLATION

4. GENERAL

The selection of equipment should be made only after schematic design of the system is complete.

The materials used in the component are largely determined by the equipment manufacturer rather than the airframe manufacturer or aircraft owner or modifier. In general, where a choice exists, the material with the higher melting point should be used as a deterrent to combustion.

Synthetic non-metallic materials such as silicone rubber are preferred to natural rubber because there is no known deterioration with age or exposure to oxygen, ozone, sunshine, etc. However, materials such as Kel-F and Teflon are preferred where applicable (used as valve seats, joint seals) over silicone because they do not burn, but only vaporize. The vapors of all inorganic seal materials are toxic when overheated. However, the temperature at which Teflon vapors are formed in high (above 600 F), somewhat reducing the potential hazard.

4.1 Criteria for Locating Oxygen Components in Aircraft

(a) Proximity to combustibles - All parts of the system, including lines, fittings (plumbing joints), and equipment, should be above and at least 6 inches away from fuel, oil and hydraulic systems or areas where leakage of combustibles can collect. Deflector plates or shields should be used to keep liquids (including high pressure spray) away from oxygen lines, fittings, and equipment.

(b) Proximity to moving aircraft parts - There should be at least a two-inch clearance between oxygen plumbing and equipment components and any moving aircraft parts, such as secondary controls, etc. When in areas where primary flight and engine controls and fuel, oil, hydraulic systems, and electrical wiring exist (and where the possibility of combustion is increased) the clearance between oxygen parts and primary flight and engine controls should not be less than 12 inches.

(c) Proximity of plumbing to electrical wiring - When possible, a six-inch minimum clearance should exist. When this is not possible or practical, a two-inch minimum is acceptable where the electrical wiring or wire bundles are rigidly supported by conduit and/or closely spaced clamps or clips. When less than two inches separation is necessary, wires or wire bundles must have additional insulation and be so supported that they cannot be deflected closer than 1/2 inch from the oxygen components.

4.2 Plumbing Materials and Type Fittings - There are many commercial standard aircraft fittings available. The standard military flared and flareless are generally used.

4.3 High Pressure Lines - In multicylinder installations, the intercylinder lines are of small diameter, generally 3/16 inch OD x .035 wall copper or stainless steel. At least one coil is formed in the line to 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, and 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 and 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. Also, 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 where they are subject to damage during servicing. Use of stainless steel minimizes both problems. One size in common use is 5/16 inch OD x .028 wall thickness. If at all possible, this portion of the system should be installed as one piece of tubing, eliminating the requirement for unions and fittings. When unions are required, access through upholstery, etc., for inspection should be provided.

4.4 High Pressure Fittings - The comments of the preceding paragraphs illustrate some considerations dictating the selection of fittings.

Intercylinder connections should be made with brazed-on nipples and loose coupling nuts (copper and copper alloys) or regular flared tube fittings of stainless steel.

For the main system take-off, flared or flareless fittings are used. (Brass fittings should be used for copper lines and stainless steel for stainless steel 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 oxygen, forming an oxide and when heated cadmium emits highly toxic fumes. Also, cadmium plating is subject to flaking and peeling. These dislodged particles can impair the operation of valves, regulators, etc., as well as create a toxicity problem.

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.

4.5 Low Pressure Tubing - Pressure in the distribution lines from continuous flow regulators is dependent upon the flow required and the mask or outlet orifice characteristics. Pressure variations range from 0 at sea level to 80 psi at altitude. Mass flow in a large 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 longer than 5/16 inch OD if outlets at the end of the system are to deliver comparable flows with those close to the regulator. Thus, metallic lines in large aircraft low pressure distribution systems are commonly of 3/8 to 1/2 inch OD x .035 aluminum alloy. In systems for aircraft of 10 to 20 passengers, 5/16 inch OD lines are sufficient and for less than 10 passengers, 1/4 inch OD should be adequate.

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, along with its oxygen compatibility. It should be noted that flexible hoses may weigh slightly more than their equivalent metal counterparts due to the necessarily heavy wall thickness.

4.6 Low Pressure Fittings - Fittings for metallic low pressure lines are flared or flareless, similar to high pressure lines.

Fittings for plastic hose may be 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.

4.7 Plumbing Leakage - The principal difficulty with the standard flared and flareless fittings is leakage and, as a by product, damaged components and equipment resulting from over-torquing in an attempt to stop the leak.

Standard Military plumbing fittings (AN and MS series) have been qualified to specifications covering the joint: i.e., tubing, sleeve, coupling nut and fitting (union, elbow, etc.). This obviously is a good approach to combining all related parts. The problem has been that the test fluid used has been a liquid (hydraulic fluid) and not a gas because the major uses are for liquid systems. A gas, of course, is much more difficult to contain without leakage.

Several factors have contributed to the leakage problem:

(a) Nut and fitting of like material tends to gall without a lubricant.

(b) Dimensional tolerances too great on threads, concentricity of flare cone, etc.

(c) Surface smoothness requirements not adequate.

(d) Prohibition of use of lubricant on straight thread fittings by Military influencing commercial use.

Some solutions for leakage problems are:

(a) Use of an approved (for oxygen) lubricant on straight thread fittings (for example, a baked-on molydisulphide dry film lubricant on the coupling nut or fitting threads, compounded and applied in a manner to eliminate flaking, peeling, powdering, etc., has been accepted as safe).

(b) Use of soft conical washers between the flared fitting cone and the nut. The soft metal deforms on tightening and affects a seal.

(c) Use of non-standard commercial or industrial fittings and nuts employing some deformation on tightening.

(d) On pipe threads, use of Teflon tape instead of thread compound. The Teflon tape forms a seal by filling in surface irregularities, etc. (Tape per MIL-T-27730 or commercial equivalent.)

4.8 Fill Valve - When using the external fill point, a fill valve from the following may be selected (other fill valves designed specifically for oxygen systems are available):

AN6024 fill valve (low pressure)
MS21211 line check valve
AN6012 line valve (high pressure)
AN780-3 or AN790-3 cone fitting with dust cap and chain

The open end of the valve should be covered with a tethered dust cap assembly. The fill valve should be located so that it is readily accessible from outside the aircraft and not subject to contamination, particularly by oil and grease.

Adjacent to the fill valve a placard should state:
OXYGEN FILLER - CAUTION: Keep clean and free of all oils
Fill to 1850 psi at 70 deg.
For other temperatures see temp. chart

4.9 Steel Cylinders - Steel cylinders with hemispherical ends are commonly in use. 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% of the weight of the equivalent 3AA type.

3 HT type cylinders compared to the 3AA type have the following characteristics:

(a) More susceptible to damage
(b) Require stringent service testing (hydrostatic tests every three years)
(c) Life span 12 years or 4,380 fill cycles maximum
(d) Higher cost
(e) Less weight

4.10 Gages - Gaseous systems require pressure gages as contents indicators. Such gages may be graduated in psi or contents i.e., "Half," "Empty"). They may be direct- or remote-reading.

Removable cylinders should incorporate a pressure gage to prevent the re-installation of partly charged or leaking cylinders. If the cylinder can be mounted so that the gage is accessible in flight, a second gage is unnecessary.

A direct reading gage may be provided to indicate system pressure to the pilot or a pressure transducer may be installed and a remote reading indicator provided for the pilot.

4.11 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 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 to assure rupture of this disc rather than the cylinder.

A threaded outlet is provided on some designs of cylinder valves so that such a discharge may be piped overboard if desired.

ICC Regulations require that all high pressure cylinder valves 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 valve. Valves also containing a fusible plug (designed to relieve at a temperature of approximately 200 F) are not recommended since only excess pressure requires relief.

4.12 Cylinder Valves - A variety of cylinder valves are available.

For commercial use where individual cylinders are removed for recharging, the outlet port is generally also used as the fill port. The thread of this port is a Compressed Gas Association Standard No. 540 (.903 inch diameter, 14 threads per inch). An adapter is necessary for connecting to the aircraft plumbing (usually 5/16 inch diameter).

However, some civil aircraft use a cylinder valve which contains an integral but separate fill valve. This requires the use of an adapter for filling by commercial oxygen suppliers.

If it is desired to eliminate all high pressure tubing and its attendant potential hazards, it is necessary to reduce the cylinder pressure to low system pressure at the cylinder valve. This can be accomplished by use of a cylinder valve containing a reducer as an integral part of the ON-OFF valve, or by attaching a separate pressure reducer valve directly to the cylinder valve.

Where the cylinder valve is visible during flight and/or removable for refilling, the cylinder valve should also include a pressure gage indicating cylinder (supply) pressure.

Slow opening cylinder valves are available which decrease the possibility of opening them fast enough to obtain adiabatic compression to a hazardous degree in the system. "Slow opening" means several turns of the handle to fully open or close the valve.

An automatic opening cylinder valve in use by the Military is also available. These valves should be used only where the cylinders will never be removed for recharging. In this case, it is necessary that a line type shut-off valve be installed close to the automatic opening valve so that the supply can be shut off in an emergency such as a fire, prior to an emergency landing, etc.

It is recommended that the pressure relief port be threaded and when installed in the aircraft, connected to stainless steel tubing and vented overboard.

4.13 Oxygen Cylinders Installation - The location chosen for the cylinder should be governed by the

"Proximity Rules" in paragraph 4.1. Even if a central or external fill point is to be used, the cylinder(s) should be located so as to be reasonably accessible for removal and replacement not only for maintenance reasons but for ease of recharging or refilling by cylinder removal as well.

The cylinder support brackets should be designed for crash loads to prevent rupture of the cylinder, cylinder valve or plumbing which might cause a fire or contribute to its intensity. A general rule of design to 10 g forces in all directions is often used. The brackets should be designed such as to prevent abrasions of cylinders and not depend upon clamp friction for restraint.

4.14 Pressure Reducer Valves - In continuous flow systems, pressure is further reduced by the continuous flow regulator, even though already reduced at the cylinder. In both continuous flow and demand type systems separate or integral (to the cylinder valve) pressure reducers have possible applications.

A pressure reducer valve should incorporate a relief valve set at somewhat higher pressure than the reduced pressure level. This relief valve should also be threaded and may be vented overboard as discussed under Cylinder Valves, paragraph 4.12.

4.15 Line Valves

4.15.1 Line ON-OFF Valves - A line valve should be installed in a position accessible in flight when the cylinder valves are not. They may also be used optionally in large systems as a maintenance aid where only a portion of the system need be opened up and purged after repair or replacement of one or more parts. Slow opening type oxygen valves are available for this purpose.

When used in either application they should be wired in the open position or placarded accordingly.

4.15.2 Line Check Valves - A line check valve should be used in each cylinder supply line where two or more cylinders are manifolded together and in the fill line when an external filler valve is used. This prevents loss of oxygen from a "good" cylinder or plumbing to those which are damaged or leaking for any reason.

4.16 Continuous Flow Regulators and Outlets - The regulator controls the pressure of oxygen for delivery to the mask outlets. The regulator may be preset, manually adjustable, or altitude controlled by means of one or more aneroids incorporated in the device. The mask outlet controls the pressure to the mask.

4.16.1 Preset Regulator - This type of regulator is a pressure reducing valve. It reduces the supply pressure to a fixed pressure set for a 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.

4.16.2 Manual Adjustable Regulator - This regulator consists of a valve held off its seat by a bellows or diaphragm. A knob adjusts the bellows spring loading providing a method of setting the required pressure.

A gage registers pressure downstream which is usually presented on the dial in terms of altitude. In operation, the user rotates the knob until the gage 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 cylinder contents pressure gage. Such regulators may supply many outlets but do have a maximum number of outlets dictated by the manufacturer.

4.16.3 Altitude Controlled Automatic Regulator - Basically, this type is that in which the knob 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, pressure is automatically controlled to provide varying pressure vs altitude variation. Almost any combination of altitude vs delivered pressure ratio can be provided. Regulators should be chosen to match the performance requirements of the mask outlet.

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 but should be kept to a minimum of approximately 10 cc per minute.

4.16.4 Outlets for Continuous Flow Systems - The mask plug-in outlet incorporates a flow control orifice which is calibrated to operate with the noted pressure delivery curve of the regulator. The combination of regulator and outlet provides the required oxygen concentration to the appropriately selected mask. These three components must be compatible.

4.17 Demand Flow Regulators - The principal of these regulators was discussed in Section II. Two types of demand regulators are generally used:

1) Diluter-demand
2) Pressure-demand

4.17.1 Diluter-Demand Regulatory - The control of this regulator may be automatic by use of an aneroid. The purpose of air dilution system is to conserve oxygen supply and still maintain a safe partial pressure of oxygen in the lungs. Dilution generally occurs in the regulators up to 32,000 feet altitude. At this altitude the dilution port is automatically closed and the regulator delivers 100% oxygen. These regulators should also have manual levers so the user can select and use 100% oxygen, at any altitude if he desires.

4.17.2 Pressure-Demand Regulator - This regulator can be obtained with or without the dilution feature noted above. As described in Section II, this regulator is required for safe continued operation above 35,000 feet. These regulators supply oxygen pressure to the masks. A proper combination of regulator and mask and exhalation valve will maintain a positive pressure within the mask throughout the entire breathing cycle. If dilution features are desired they should be used only to 32,000 feet altitude and at this point 100% oxygen should automatically be made available to the user.

4.18 Flow Regulator Pressure Reducer Types - Flow regulators may be either single or multistage types. In a continuous flow system the final breathing pressure reduction is accomplished by the metering of the outlet orifice. Demand flow regulators are generally of the multistage type since the final breathing pressure is accomplished within the demand regulator rather than by a metering outlet. The exception is the miniaturized mask mounted demand regulator which requires a supply pressure in the 50 to 90 psi range. The multistage regulator has the advantage of operating over a wide range of supply pressure.

4.18.1 Single Stage Regulator - Single stage regulators are those which contain one pressure reducing stage. The one valve reduces cylinder or supply 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.

4.18.2 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 in continuous flow system. Some multi-stage units will not operate above 500 psi and when used in a 1800 psi supply system require an additional pressure reducer upstream of the regulator. An example is the 500 psi MD-1 crew demand regulator.

4.19 Dispensing Equipment (Masks)

4.19.1 Continuous Flow 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. They may be obtained in permanent or disposable types.

The simplest method of supplying the facepiece with oxygen is a flexible hose from the dispensing outlet which feeds directly into the facepiece. Exhaled gases are discharged through outlets in the facepiece. 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 for breathing needs must be provided.

Oxygen economy is effected when a flexible plastic or rubber reservoir is incorporated in the mask. This is typically between 500 and 1000 cc capacity, and stores gas during the exhalation period to be withdrawn rapidly during inhalation. 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 or ports and exhalation valve or ports 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 outside. On exhalation, used gases are vented through the exhalation valve in the facepiece with the non-return valve preventing re-entry of gases to the reservoir. Such masks are called "reservoir masks" or "phased dilution" masks.

4.19.2 Nasal Mask - The nasal mask should fit snugly around the nose. It should not be used for flights above 12,000 feet where air intake through the mouth would result in excessive dilution. The chief advantages of the nasal mask are (1) light weight and (2) ease of conversing without the use of microphones and earphones. CAUTION: Breathing habits must be established which lead to breathing through the nasal passages only.

4.19.3 Oronasal Masks - 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 and should be selected for proper fit. A harness is supplied with the mask to hold it firmly against the face. Some masks include provisions for a microphone for communication purposes.

4.19.4 Fullface Masks - Fullface masks are those which cover the mouth, nose, and eyes. They are normally provided for use as protective breathing equipment in "smoke emergencies." These masks may be obtained in the rebreather or reservoir type masks, but these are not considered satisfactory in smoke or fire fighting emergencies due to outward leakage of oxygen and inward leakage of contaminated air.

4.19.5 Demand Masks - The oronasal and fullface type masks are used for the demand mask. It should fit snugly so that oxygen can be obtained by suction means. A small internal volume is generally used in order to minimize re-breathing of carbon dioxide. An exhalation valve is incorporated in these masks and a microphone may be provided.

4.19.6 Pressure-Demand Masks - The oronasal mask for 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.

4.19.7 Automatic Mask Presentation - Aircraft flying above 30,000 feet altitude with pressurized cabins should provide the passenger mask automatically immediately upon depressurization. Various types of automatic drop out boxes may be obtained with hinged or sliding doors which, when actuated by oxygen pressure, are automatically released when the cabin reaches approximately 13,000 feet altitude during the depressurization. These masks should be located conveniently to each seat. They should also be automatically presented to within reach of each passenger so that they are obvious and so that the passenger knows immediately which mask is his and, more important, that the masks are needed.

Each aircraft installation should be equipped with extra masks to allow for situations where there is a child in arms. The number required would depend upon the number of seats and their arrangement.

SECTION V - HANDLING, INSTALLATION AND MAINTENANCE (High Pressure Oxygen Supply and Oxygen Distribution Systems)

5. GENERAL DISCUSSION

Because oxygen produces rapid oxidation, it is often mistaken as a hazardous gas. This is not true; although oxygen accelerates combustion when it is combined with combustibles, it is not a combustible itself. Properly handled, oxygen is no more dangerous than any other gas, even under pressure. Safe handling is accomplished if recognition is given to the following:

1. High pressure gas (1850 psi) in a cylinder or system must be handled carefully. For example, if a valve is broken off a cylinder, the cylinder will become a jet propelled missile.
2. Exposure to high temperatures causes a rise in pressure and must be avoided. Even though the valve has a safety relief device which will relieve the pressure at approximately 2700 psi, cylinders and high pressure systems should be protected from any rise temperature above 160 F.
3. Combustibles will burn at a rate ranging from rapid combustion to explosion in the presence of 40% to 100% oxygen at ambient pressure. At higher pressures the danger is increased. Therefore, care must be exercised to insure that no contaminants are present during handling of cylinders, charging of cylinders, or in general maintenance practices in connection with any oxygen system components. Also, careful handling is required for high pressure containers.

Cognizance of regulatory and advisory organizations' requirements and recommended procedures and practices is helpful in connection with aviation oxygen systems. These organizations, both Federal and civil, have produced regulatory and recommended procedures for oxygen and oxygen equipment which apply to aviation applications:

1. Department of Health, Education & Welfare
2. Food and Drug Administration
3. Interstate Commerce Commission
4. Federal Aviation Agency
5. Underwriters Laboratory
6. National Fire Protection Association
7. The Compressed Gas Association

Excerpts have been taken from some of these publications for this section; however, it behooves individuals working with oxygen and oxygen equipment to apprise themselves fully of any and all requirements of the regulatory groups and suggested practices of the advisory groups. Some of the regulatory agencies can impose penalties for failure to comply. SAE cannot assume any responsibility for the lack of inclusion in this AIR of any regulation or subsequent changes to quoted regulations of these groups.

5.1 General Equipment Handling - All oxygen equipment should be handled with care to avoid association with with hydrocarbons such as fuels and lubricants which are ever-present where aircraft are serviced and maintained. Because most oxygen components are of an intricate nature and all require cleanliness for proper operation, they should be kept in their original containers or be provided with a proper protective covering until ready for installation in the aircraft. This is also necessary when any of the items from an aircraft are removed for service or overhaul. It is recommended that all products be obtained from properly qualified equipment manufacturers or representatives and that service and overhaul operations on such equipment be performed only by the original manufacturer or an agency authorized by the original manufacturer (such as specifically authorized under FAA Regulations).

5.2 Pre-Installation Cleaning - All components such as pressure regulators, reducer valves, check valves, in-line valves, indicators, and masks designated for oxygen use and obtained from properly qualified manufacturers and repair stations, should be produced or serviced with special care for cleanliness and freedom from contamination. Therefore, no cleaning is required prior to installation; however, the person making the installation should have clean hands, clothing, and tools and should use care so as to prevent any further contamination.

5.3 Plumbing lines, connections and fittings designated for use in oxygen service or removed with the intention of re-installation in oxygen systems should be cleaned in accordance with one of the following suggested practices:

1. Conduct cleaning operations only in an area where there is no close association with con-

taminants such as grease, lubricants, asphalt, or any other combustible.

Each line or fitting should be flushed with trichlorethylene, acetone, hexane, or other suitable solvent. Such solvent must be fresh, not having been used for any other purpose, and should be periodically examined for contamination if the solvent is continually used for oxygen equipment cleaning.

Preferably, this operation should be accomplished in a vapor degreasing unit with the lines hung in a vertical position and the solvent hot, at a minimum temperature of 160 F or as specified by the solvent manufacturer. Blow tubing clean and dry with a stream of clean, dry, water-pumped air or nitrogen. Care should be taken to insure that the interior of the tubing and fittings are thoroughly cleaned and dry and that handling does not introduce additional contamination.

2. Flush with naptha conforming to specification TT-N-95. Blow clean and dry off all solvent with a stream of clean, dry, water-pumped air. Flush with anti-icing fluid conforming to Specification MIL-F-5566 or with anhydrous ethyl alcohol. Rinse thoroughly with clean, fresh water. Dry thoroughly with a steam of clean, dry, water-pumped air or a heating at a temperature of 250 F for a suitable period.

Visual inspection should be conducted to ascertain that lines and fittings are completely free of contamination.

Immediately, cleaned lines and fittings should be covered with clean protective bags, plugs, and caps. Ends of lines or fittings should not be taped because a residue is left when tape is removed. Lines or fittings should not be placed or stored anywhere near machinery or other equipment where they might become contaminated from oils, greases, or water. Protective covers such as packaging and plugs should not be removed until the line is finally installed, and mechanics must be careful that hands and tools do not contaminate the system during installation.

5.4 Oxygen masks may be cleaned by being thoroughly washed with known inorganic cleaning solvents and currently known detergents and disinfectants which will not attach the materials in the mask. Care must be exercised to ascertain that the valving, both inhalation and exhalation, is properly cleaned and not damaged during the cleaning process. The masks should be tested by a qualified manufacturer or repair station to manufacturer's overhaul manual requirements to determine that the valving mechanisms are not sticky and that they function properly after the cleaning process. Cleaning may necessitate the disassembly of the valves and each valve part's being cleaned separately. Manufacturers or approved repair stations should have proper equipment to test the opening pressures and sealing characteristics of the inhalation and exhalation valves. Many oxygen masks in general aviation use are of the inexpensive, disposable type. These are not designed to be serviced but are discarded after being used or when they are damaged or contaminated.

5.5 Oxygen cylinders are the heart of the oxygen system. The cylinders used in general aviation are high pressure type cylinders (1850 psi to 2000 psi) and they must be handled with extreme care because of these high pressures.

Requirements for inspection differ with each type of cylinder. Currently, the requirements are very carefully controlled by ICC Regulations, Tariff No. 15, effective September 25, 1963. Further recommendations for recharging and inspection will be covered under paragraphs 5.8 and 5.9. Oxygen cylinders when handled should be protected from abuse, scratches, and denting; cylinder valves, in particular, should be protected with all ports covered as recommended earlier. Care should be taken to avoid the reduction of oxygen cylinder pressure below 30 psi before recharging, as this will help prevent contamination of the cylinder from ambient air. Protective thread covers should not be removed until the cylinder is installed in the airplane.

5.6 Oxygen System Maintenance - As previously noted, all components should be retained in original packaging with proper protective plugs until immediately prior to installation in the aircraft. No lubricants, excepting those which are approved for oxygen use, should be used in making connections or in lubricating threaded connections.

Chapter 2 of National Fire Protection Association Pamphlet, NFPA No. 410-B, entitled "Aircraft Maintenance," covers recommendations for installation procedures. Care should be taken to protect all lines and fittings from any unnecessary abuse or scratches during installation. Low pressure aluminum alloy plumbing lines are likely to become damaged; therefore, installation and location should be so accomplished as to prevent oxygen equipment or plumbing from subjection to vibration, abrasion, or damage during other maintenance operations. All oxygen systems lines, after installation, should be carefully inspected for damage and leakage. Leak testing can be accomplished by introducing the oxygen pressure into the system and examining connections by the use of a leak detector solution specifically approved for oxygen service. Before any oxygen system component is removed or any connection is loosened, oxygen system pressure should first be dissipated, after first shutting off the cylinder valve.

5.7 Inspections - The entire aircraft oxygen system should be inspected carefully and tested during the annual aircraft inspection required by the FAA or whenever malfunction occurs. Oxygen system components should be repaired, serviced, and overhauled in accordance with original equipment manufacturers' recommendations. The overhaul time period should not exceed two years or 2,000 hours of flying time, whichever occurs first. This is necessary in order to replace the O-Rings, gaskets, etc., and to remove foreign material inevitably introduced during refilling and servicing. All lines and connections should be carefully examined for leaks and abrasions, scratches or any other damage due to vibration or looseness, since even slight damage may lead to fatigue failure.

Oxygen cylinders should be carefully examined in accordance with paragraph 5.8. Mounting brackets for oxygen cylinders should be examined for security and to ascertain that they do not damage the cylinder in any way. The threads of the connections, etc., must be in good condition. A thorough test of the oxygen system should be conducted after installation to determine that proper flow rates in accordance with original specifications are administered to each of the components or mask units. The oxygen system should be given special attention at all other opportune times to insure it is functioning properly and any oxygen component should be examined carefully whenever it is suspected of failure or malfunction. It is recommended that the malfunctioning component be serviced by an FAA approved oxygen equipment repair station or the original equipment manufacturer.

5.8 Aviation Breathing Oxygen Cylinders and Valves - Aviation oxygen cylinders are currently manufactured under the regulations of the Interstate Commerce Commission. There are three appropriate designations followed by the service pressure:

(a) ICC - 3A
(b) ICC - 3AA
(c) ICC - 3HT (i.e., ICC - 3HT 1800 psi)

Only such designated cylinders should be used for aviation breathing oxygen systems. These designations are metal-stamped on the shoulder of each cylinder near the neck.

The basic important general knowledge about aviation breathing oxygen cylinders is that they are more susceptible to damage than are other types of gas cylinders. They are lighter in construction, and therefore, must be much more carefully handled to prevent damage to the cylinder and valve assembly.

Aviation breathing oxygen cylinders should be clearly marked "Aviation Breathing Oxygen," and no other cylinders should be used for this purpose nor should these cylinders be used for another purpose.

Each cylinder must be periodically hydrostatic tested and the date of such testing metal-stamped on the shoulder of each cylinder. A cylinder should never be refilled if it is near the expiration point of such period. The allowable expired time between testings is defined by ICC Regulation, Tariff No. 15.

In the case of the ICC - 3A and ICC - 3AA cylinders, the Interstate Commerce Commission requires a hydrostatic test once in every five-year period by appropriately qualified facilities to ICC requirements.

In the case of the ICC - 3HT cylinder, the Interstate Commerce Commission requires a hydrostatic test once in every three-year period. The 3HT cylinder must be condemned at the termination of a twelve-year life span or 4,380 pressurizations, whichever comes first.

All cylinders should be examined per Compressed Gas Association Pamphlet, "Standards for Visual Inspection of Compressed Gas Cylinders" (CGA. Pamphlet C-6-1959.) At the time of hydrostatic testing, all cylinders should be examined for evidence of scratches, abrasions, bulges, or mishandling. If cylinder damage is suspected, refer to CGA Pamphlet C-6-1959.
CAUTION: The ICC - 3HT cylinder is very thin-walled and requires special scrutiny for minor scratches and abrasions. Inspectors without experience in detecting hazardous defects should return cylinders to the manufacturer for inspection. (Inspection is defined in C-8 Pamphlet entitled, "Standards for Requalification of ICC - 3HT Cylinders," by the Compressed Gas Association.)

5.9 Oxygen Cylinders and Systems - Recharging - Oxygen cylinders are generally removed from the aircraft for recharging; however, some aircraft are equipped with an external charging valve so the cylinders do not require removal. This valve should be designed to prevent high impact pressures from reaching the aircraft oxygen system. Extreme care must be exercised when filling an oxygen system in an airplane from a high pressure external cylinder or cascade recharging system to prevent the high pressure impact on the recharging valve or the aircraft system; therefore, OPEN ALL CYLINDER VALVES SLOWLY. Reference is made to NFPA No. 410-B, Chapter 2, entitled "Aircraft Maintenance."

During a filling operation, particular attention should be paid to the hydrostatic test date on the oxygen cylinder. This date is required under Tariff No. 15 of the ICC Regulations for each type of cylinder, even if the cylinders are located in the aircraft. Under no circumstances should an aircraft system be recharged if the cylinder is dented, scratched, or damaged beyond recommendations in paragraph "D" or near the hydrostatic test date. Under no circumstances should a system be charged with a pressure in excess of the operating pressure stamped on the shoulder of each cylinder. (See chart appendix.) Cylinders which are removed from aircraft for recharging must be carefully handled. The standard CGA outlet connection should be protected with a clean cap and never allowed to come in contact with contaminants.

General cautions applicable to gaseous oxygen filling operations taken from NFPA No. 410-B, Chapter 2, are:

1. Good househeeping practices are necessary in the vicinity of oxygen charging operations. This is particularly true with combustibles such as grease, lubricating oil, asphalt, etc.
2. Prohibit open flames (including smoking) within 50 feet of charging equipment.
3. Do not permit aircraft servicing or maintenance operations which may inadvertently introduce ignition sources or combustibles concurrent with oxygen charging operations. These include fueling, fuel and hydraulic system repairs, use of flammable cleaning fluids, de-icing fluids, etc. Do not operate electrical system switches or con-

nect or disconnect ground power generators during the oxygen charging operations.

4. Use only charging equipment, containers, etc., suitable for the specific aircraft breathing oxygen system involved. Identify each container by its marking before connecting to the aircraft system. Never interchange equipment with equipment intended or used for other gases. High pressure commercial containers (1800 psi or higher) must be connected through a pressure regulator to service low pressure aircraft systems. Failure to use a high pressure regulator specified for oxygen service is extremely dangerous. Oxygen charging hoses should be kept clean, capped when not in use, and clearly marked or tagged "For Oxygen Use Only."
5. Electrostatically ground the aircraft and electrostatically bond the oxygen charging equipment to the aircraft.
6. The importance of cleanliness cannot be overstressed. Never permit oil, grease or other readily combustible substances to come in contact with containers, flasks, valves, regulators, fittings, or any other part of the aircraft oxygen system or charging equipment. Do not handle oxygen equipment with oily hands, gloves, or tools or perform charging operations wearing oily or greasy clothing. Keep protective caps on equipment in position as long as possible and replace as soon as possible. Before charging, inspect all connections for cleanliness. If dust, dirt, grease or any other contaminant is found, it shall be removed with detergent or solvent approved for oxygen services. Bleed a small amount of oxygen through hose or valve outlet before connecting to the fill fitting to eliminate foreign material which may escape external inspections. CAUTION: Aim hose or valve outlet away from the body and equipment. Merely crack open necessary valves.
7. Use only lubricating and thread compounds specifically approved for oxygen service under the pressures and temperatures involved. Do not use oil or grease.
8. Use only valve packing and transfer hose gaskets which are suitable for oxygen service.
9. Avoid damaging oxygen containers, hoses, flasks, converters, etc. Secure equipment so it cannot fall or roll.
10. Do not tamper with safety devices or mar identifying markings, symbols and nameplates.
11. Should a valve outlet or control become clogged with ice, thaw with warm (not boiling) water.
12. Do not direct gaseous oxygen at the body or clothing because of the possibility of fire and/or personal injury.
13. Desiccant cartridges are always required for aviation breathing oxygen to assure that only dry oxygen is introduced. Check on the need for such cartridges and be sure that the drying medium is fresh. Only desiccant cartridges with filters shall be used.
14. Before commencing charging, turn off oxygen regulators in the aircraft to the OFF position.

APPENDIX I
A LISTING 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 Pressure Gage	AN6285
Adapter - Army-Navy to British Supply Oxygen Union	AN6005
Adapter - Hose to Pipe Thread	AN840
Adapter - Hose to Universal	AN807
Adapter - Low Pressure Oxygen Filler Valve	AN6027
Adapter - Portable Oxygen Recharger Orifice	AN6044
Adapter - Oxygen Filler	AND10070
Adapter - Flareless Tube to AN Flared Tube	MS21900
Adapter - Flareless Tube for 3/8 Bulkhead and Universal to AN Flared Tube	MS21901
Adapter - Cylinder Valve (compressed or liquified gases)	MIL-A-16288
Adapters, straight or reducing, brass, pipe thread to hose thread	MIL-A-17204
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
<u>Bonding Electrical</u>	
Bonding, Electrical (for Aircraft)	MIL-B-5087
<u>Breathing Apparatus, Oxygen</u>	
Cylinder and Reg., portable Oxygen, general Spec. For	MIL-C-9003
Cylinder and Reg., Assy. breathing oxygen Type MA-2	MIL-C-25151
<u>Coatings</u>	
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
<u>Compounds</u>	
Cleaning Compound, Oxygen System	MIL-C-8638
Compound, Anti-Seized Oxygen Thread	MIL-T-5542
Tape Anti-Seize Tetrafluoroethylene with Dispenser	MIL-T-27730
Leak Test Compound, Oxygen Systems	MIL-L-25567
<u>Connection Assembly</u>	
Connection Assy. - Demand mask to regulator tube	MIL-C-19064
Connection Assy. - Demand mask to regulator tube, Type MC-3	MIL-C-19246
Connection Assy. - Demand mask to regulator tube, External	MS22058
<u>Connector</u>	
Connector, Oxygen mask to regulator Type MC-3, Assy. of	MS22016
Connector, Oxygen Mask to regulator Type CRU-8/p	MIL-C-26522
<u>Couplings</u>	
Coupling - Automatic Oxygen	AN6009
Coupling - Pipe Thrd. (Inactive for design except for use in oxygen Systems and Ground Service Equip.)	AN910
<u>Cylinders</u>	
Cylinders - Compressed Air, helium, H_2, N_2. or oxygen nonshatterable	JAN-C-1126
Cylinders - Steel, seamless, Type 3A (for compressed gases)	RR-C-901
Cylinders - Breathing Oxygen and Carbon dioxide, overhaul, charging and storage of	MIL-C-7796
Cylinders, compressed gas, with valves (ICC-3A or ICC-3AA)	MIL-C-12661
Cylinders, compressed gas (seamless, nonshatterable for storing compressed air and oxygen)	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, oxygen regulator	MIL-D-7379
<u>Environmental Testing</u>	
Environmental Testing, Aeronautical and Associated Equipment General Spec. for	MIL-E-5272
Environmental Testing, Ground Support Equipment	MIL-E-4970
<u>Gages</u>	
Gage - Panel Mounting, High Pressure Oxygen	AN6011
Gage - Panel Mounting Low Pressure Oxygen	AN6021
Gage - Regulator Mounting Low Pressure Oxygen	AN6026
Gages, pressure, dial indicating low pressure oxygen	MIL-C-6019
Gages, pressure, dial indicating, oxygen 0-2000 psi Type MF-2	MIL-G-25507
Gages, high pressure oxygen	MIL-G-6035
Gages, Emergency Oxygen Type L-2	MIL-G-7601
Gages, pressure aircraft (see MS28061, 28063, 28064)	MIL-G-7734
Gage, Low Pressure Oxygen	MIL-G-25520
Gage, Pres., Dial Indicating, Oxygen 0-500, psi, General Spec. for	MIL-G-25728
Gage, Oxygen Pressure, Dial Indicating, 0-150 psi	MIL-G-26395

Hose Assemblies	
Hose Assembly, Oxygen, Low Pressure	MS22052
Hose Assemblies, Oxygen Breathing Connector to Reg.	MS22055
Hose Assemblies Oxygen High Pressure Wire Braided	MS22028
Hose Assembly, Tetrafluorethylene, Oxygen	MS24548
Hose Assembly Oxygen High Pressure	MS22029
Hose Assembly High Pressure Breathing Oxygen	MIL-H-4722
Hose Assembly, Low Pressure, Breathing Oxygen	MIL-H-6017
Hose Assembly, Oxygen-Breathing Connector to Regulator	MIL-H-7138
Hose Assemblies, Oxygen Mask to Connector	MIL-H-22486
Hose Assemblies, Low Pressure, Breathing Oxygen & Air	MIL-H-22489
Hose, Flexible, Low Pressure, Air	MIL-H-23927
Hose Assemblies, Low Pressure, Breathing Oxygen & Air Tubes, Oxygen	MIL-T-26385
Hose Assembly, Metal, Flexible, Breathing Oxygen	MIL-H-26499
Hose Assembly, Tetrafluorethylene, Oxygen	MIL-H-26626
Hose Assembly, Polytetrafluorethylene, Oxygen	MIL-H-26633
Indicator and Indicator Set	
Indicator Oxygen Flow	AN6029
Indicator Oxygen Flow	MIL-I-7944
Indicators Oxygen Flow	MIL-I-18356
Installation	
Installation of Low Pressure Oxygen Equipment in AIRCRAFT, General Spec. for	MIL-I-5585
Installation of Oxygen Equipment in Aircraft	MIL-I-8683
Installation of Oxygen Systems	WCRD TM55-76
Joints, Oxygen Swivel	
Joints, Oxygen Swivel, Low Pressure	MIL-J-7773
Leak Test Compound	
Leak Test Compound, Oxygen System	MIL-L-25567
Leakage Test Kit	
Leakage Test Kit, Oxygen Mask & Regulator	MIL-I-7096
Tester, Leakage, Oxygen Reg., MA-2	MIL-T-8429
Mask and Valves	
Masks - Oxygen Pressure Breathing	MS22001
Masks - Oxygen Pressure Breathing (see MS22001)	MIL-M-6482
Mask - Oxygen Type A-14A	MIL-M-7585
Inhalator, Mask Type, Oxygen Theraphy Apparatus	MIL-I-16596
Mask, Oxygen and Smoke, Full Face	MIL-M-19417
Oxygen Mask Facelet Kit	MIL-C-25543
Valve Oxygen Mask Inlet Check	MIL-V-21701
Valve Oxygen Mask Exhalation Pressure Compensating	MIL-V-25126
Oxygen Mask Mod. Kit, Sponge	MIL-O-25748
Mask, Oxygen Type MBU-3/p	MIL-M-25981
Mask, Oxygen Type MBU-4/p	MIL-M-25990
Mask, Oxygen Type MBU-5/p	MIL-M-27274
Oxygen	
Oxygen Aviator's Breathing	MIL-O-27210
Commodity Specification for Oxygen (Compressed Gas Association)	CGA G-4.3
Oxygen Recharge Equipment	
Recharger Assembly, Portable Oxygen	AN6041
Oxygen Recharge Equipment (power driven)	MIL-O-6705
Recharger Assembly Portable Oxygen	MS22032
Reducer, Oxygen Pressure	
Valve, Oxygen Press. Reduction	MIL-V-18318
Reducer Oxygen Pres. (on-off type)	MIL-R-17852
Reducer Oxygen Pres.	MIL-R-18318
Reducer Oxygen Pres. (emergency type)	MIL-R-21561
Valve, Automatic Regulating, Pressure	MIL-V-4501
Valve, Reduction, Oxygen	MIL-V-25559
Reducer, Oxygen Pres. General Spec. for	MIL-R-25575
Adapter Pressure Reducer in line CRU-43/A	MIL-A-27471

Regulator, Oxygen	
Reg. Automatic Continuous Flow Oxygen	AN6010
Reg. Diluter-Demand Oxygen	AN6004
Reg. Oxygen Diluter-Demand	MIL-R-6018
Reg. Oxygen Pres. Type C-1	MIL-R-6125
Reg. Diluter-Demand Oxygen Pres. Breathing Type A-14	MIL-R-6371
Reg. Oxygen Diluter-Demand Automatic Pressure Breathing	MS22062
Regulator, Oxygen, Diluter-Demand, Automatic Pressure Breathing	MS27465
Reg. Automatic Diluter-Demand, Oxygen Pres. Breathing Type D-2A (Supercedes MIL-R-6352)	MIL-R-8202
Reg. Automatic Continuous Flow Oxygen	MIL-R-8636
Reg. Diluter-Demand, Oxygen Type A-15	MIL-R-9057
Reg. Oxygen High-Press. Type MA-1	MIL-R-9198
Reg. Oxygen Demand, Type A-13	MIL-R-9338
Reg. Oxygen Diluter-Demand, Automatic Pres. Breathing High Pres. Type MB-2	MIL-R-9494
Reg. Pres., and Flowmeter, Oxygen & Helium - Oxygen	MIL-R-16595
Reg. Oxygen Automatic positive Pres. and Composite Diluter-Demand	MIL-R-18059
Reg. Aviator's Miniature Oxygen Breathing, 100% Demand Type, with Safety Pres. and Automatic Pres. Breathing	MIL-R-19121
Reg. Pres., Compressed Gas	MIL-R-19180
Reg. Oxygen, Automatic Pres. Breathing High Altitude General Spec. for	MIL-R-25572
Reg. Oxygen Continuous Flow, Walk-Around	MIL-R-25693
Reg. Oxygen Diluter-Demand, Automatic Pres. Breathing General Spec. for	MIL-R-25916
Reg. Oxygen Diluter-Demand, Automatic Pres. Breathing General Spec. for	MIL-R-25410
Storage & Charging System Oxygen	
Storage & Charging Sys., Oxygen	MIL-S-15913
Test, Aircraft Oxygen Equipment	
Test, Aircraft Oxygen Equipment, Functional, L. P.	MIL-T-6037
Environmental Testing Aeronautical and Associated Equipment, General Spec. for	MIL-E-5272
Trailer	
Trailer, Compressed Gas Cylinder, Oxygen Servicing, 4-Wheel, 12 Cylinder, 450 psi, Type MB-2	MIL-T-4701
Trailer, Compressed Gas Cylinder, Oxygen Servicing, L. P. 2-Wheel, t Cylinder Capacity Type MB-4	MIL-T-4974
Trailer, Oxygen Servicing, Type I	MIL-T-6706
Trailer, Oxygen 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
Trailer, Compressed Gas Cylinder, A/M32A-19	MIL-T-26252
Tubing	
Tubing End - Hose Connection, Std. Dimensions for	MS33660
Tubing - Min. Bend Radii for Conduit and Fluid Line	MS33611
Tubing End - Std. Dimensions for Double Flare	MS33583
Tubing End - Std. Dimensions for Flared	MS33584
Tubing - Std. 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 Assy., Oxygen Mask to Reg.	MIL-T-7138
Tubes, Oxygen	MIL-T-26385