



AEROSPACE INFORMATION REPORT

AIR822**REV. C**

Issued	1968-03
Revised	1996-08
Reaffirmed	2001-10
Noncurrent	2006-06
Stabilized	2014-07

Superseding AIR822B

Oxygen Systems for General Aviation

RATIONALE

The A-10 Committee concluded that the content of this document will not be updated in the future. There are no plans to create a replacement document, although the AIR825/ Document Series may be used as reference in lieu of, depending on information of interest. The Committee decided to stabilize this document in its current state.

STABILIZED NOTICE

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

SAE Technical Standards Board Rules provide that: "This report is published by SAE to advance the state of technical and engineering sciences. The use of this report is entirely voluntary, and its applicability and suitability for any particular use, including any patent infringement arising therefrom, is the sole responsibility of the user."

SAE reviews each technical report at least every five years at which time it may be revised, reaffirmed, stabilized, or cancelled. SAE invites your written comments and suggestions.

Copyright © 2014 SAE International

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without the prior written permission of SAE.

TO PLACE A DOCUMENT ORDER: Tel: 877-606-7323 (inside USA and Canada)
Tel: +1 724-776-4970 (outside USA)
Fax: 724-776-0790
Email: CustomerService@sae.org
<http://www.sae.org>

SAE WEB ADDRESS:

Full document details: **SAE AIR822C**

SAE values your input. To provide feedback
on this Technical Report, please visit
<http://www.sae.org/technical/standards/AIR822C>

Documents

Document Sharing Hub

1. SCOPE:

This SAE Aerospace Information Report (AIR) provides a general overview of oxygen systems for general aviation use. Included are a brief review of the factors and effects of hypoxia, system descriptions, and mission explanations for system or component selection, and techniques for safe handling of oxygen distribution systems.

2. SECTION 1 - OXYGEN, BASIC PHYSIOLOGY:

2.1 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 concepts 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 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 (Figure 1).

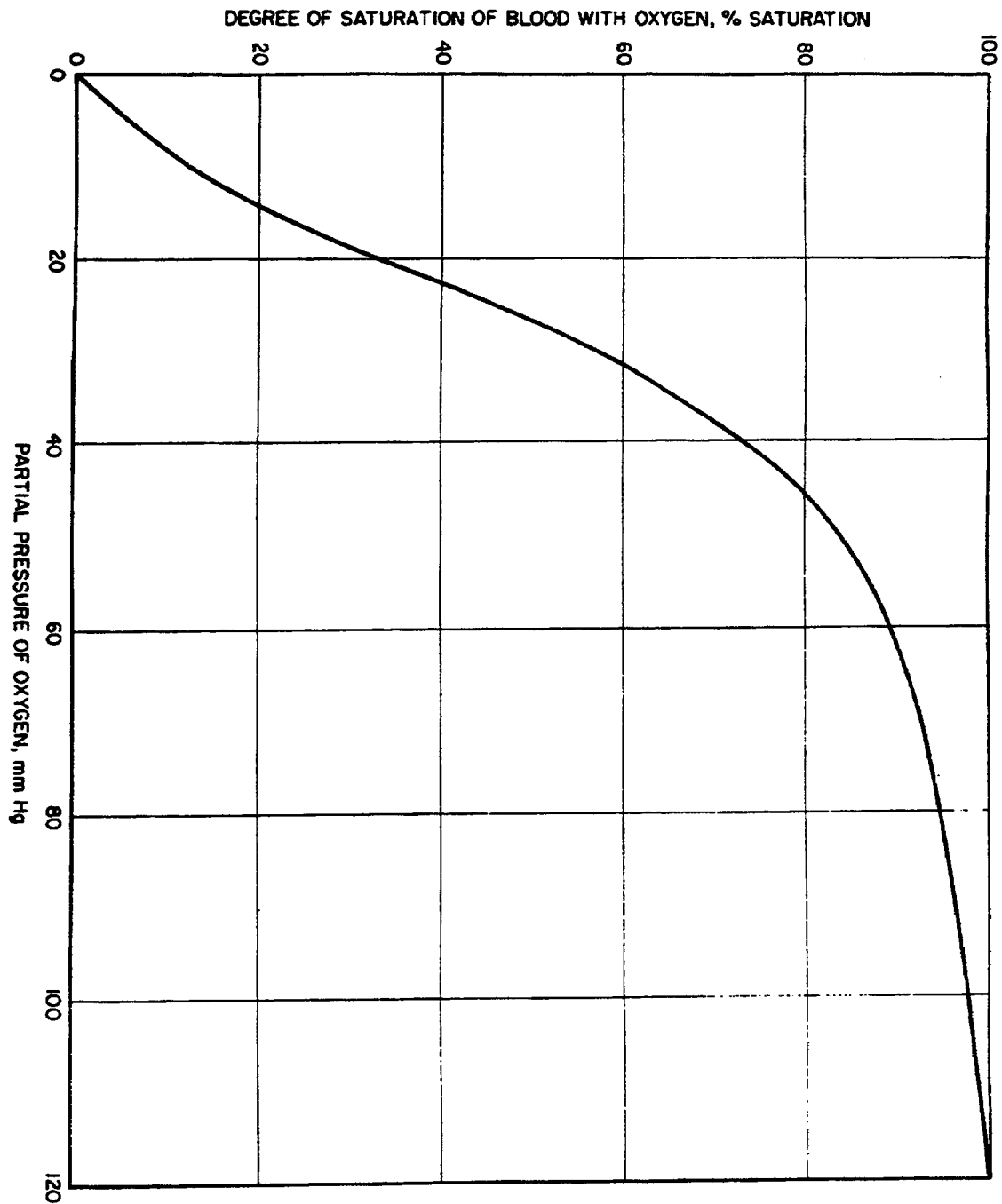


FIGURE 1 - Typical Oxygen Dissociation Curve of Blood

2.1 (Continued):

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.

2.2 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 moderate intensity white light.

2.3 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 (Figure 2).

2.4 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.

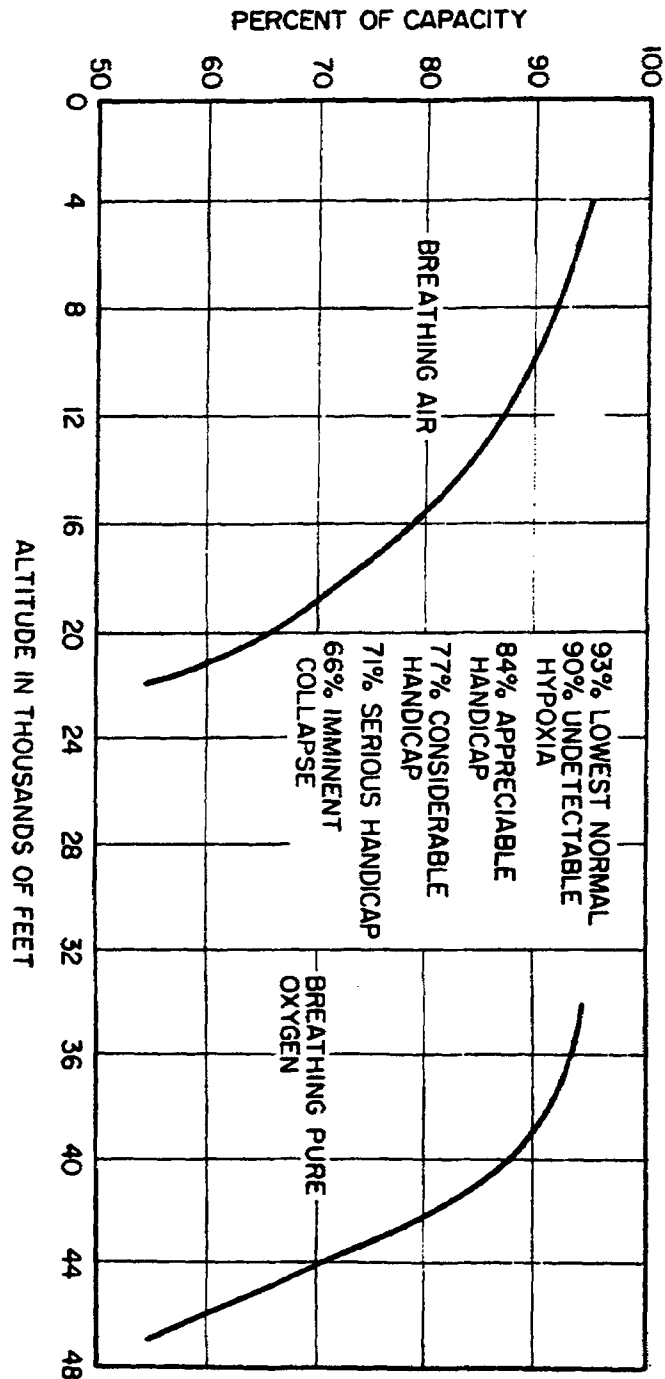


FIGURE 2 - Oxygen Saturation (% of Capacity) of Arterial Blood and Average Range of Performance at Various Altitudes in Subject's Breathing Aid and in Subject's Breathing Oxygen

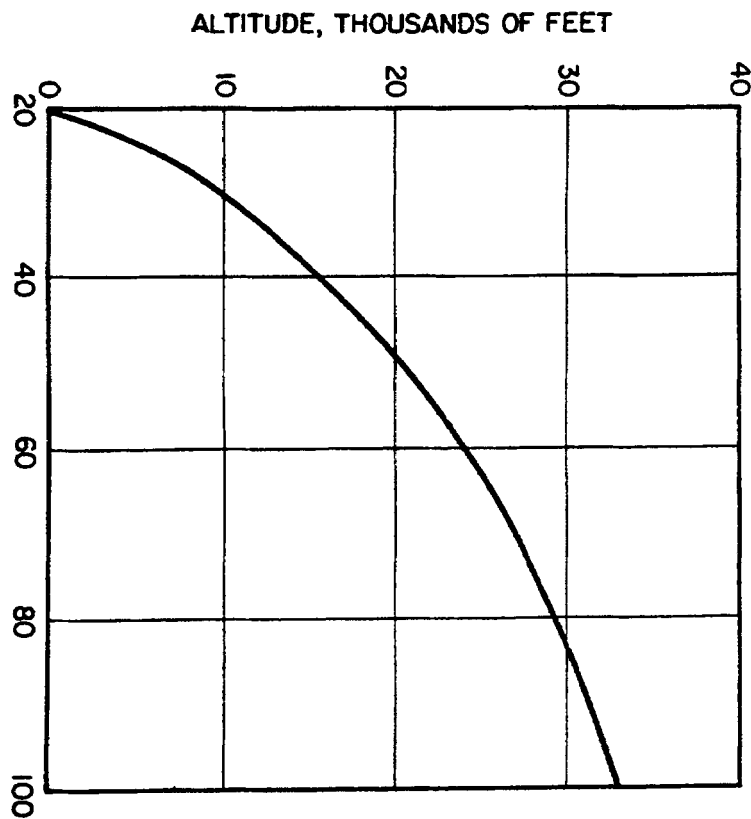


FIGURE 3 - Per Cent Oxygen Required in the Inspired Air at Various Altitudes to Maintain a Normal Alveolar Oxygen Tension

2.5 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 requirements. This level of hypoxia simulates alcoholic intoxication.

At 18,000 feet (379.773 mm of mercury or 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.

2.6 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 nonsmoker because of carbon monoxide levels in their blood levels and diffusion impairment in their lung alveoli.

2.6 (Continued):

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.

2.7 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.

- 2.8 Table 1 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 1

Column 1 Altitudes in Ft (Ambient Air Breathing)	Column 2 Altitudes in Ft (Ambient Pressure Breathing 100% O ₂)	Effects of Breathing Ambient Air at Column 1 Altitudes or 100% Oxygen at Column 2 Altitudes	Percent Inspired Oxygen Necessary to Maintain Equivalent of 5,000 ft at Altitudes Column 1 (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.

2.8 (Continued):

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 1 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.

- 2.9 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.
- 2.10 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.
- 2.11 The only way to prevent hypoxia is to be constantly aware of what effects can be expected at altitude and to act accordingly.

3. SECTION 2 - OXYGEN SYSTEMS DESCRIPTION:

3.1 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 non-toxic. 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.

3.1 (Continued):

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 stored 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.

3.2 Systems:

- 3.2.1 Continuous Flow Oxygen 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 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 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 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.

- 3.2.2 Demand and Diluter-Demand Flow Equipment: 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.
- 3.2.3 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.

3.2.3 (Continued):

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.

- 3.3 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.
- 3.4 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 CO₂ fire extinguishers in non-pressurized cabins. These requirements should also be considered.

4. SECTION 3 - DESIGN INFORMATION:

4.1 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 AIR825, "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.

4.2 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 locations 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.

4.2 (Continued):

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.

4.3 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.

4.4 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).