MILITARY SPECIFICATION

OXYGEN SYSTEMS, AIRCRAFT, GENERAL SPECIFICATION FOR

This specification is approved for use by the Department of the Air Force and is available for use by all Departments and Agencies of the Department of Defense

1. SCOPE

1.1 Scope. This specification establishes the development requirements and verifications for an aircraft oxygen system and its components.

1.2 Use. This specification cannot be used for contractual purposes without supplemental information relating to the unique requirements included herein. The supplemental information relates to system design around the normal and emergency mission profiles.

1.2.1 **Structure.** The required supplemental information is identified by blanks within the specification. Only those paragraphs applicable to the aircraft system under consideration shall be selected. Verification method(s) must be added to each selected requirement. For more effective designs, the oxygen systems are discussed in terms of aircraft missions.

1.2.2 **Instructional handbook.** The instructional handbook contained in Appendix A herein provides for this technical area the rationale for requirements, guidance on document usage, and a lessons learned repository. The need for this information is identified by blanks within the generic requirements and verifications.

1.2.3 **Physiological handbook.** The use of oxygen on an aircraft supports the physiological requirements of crew member(s) and passenger (if applicable) for the intended missions (altitudes, air speeds and ranges). For these reasons physiological criteria is included in Appendix B for background information.

1.2.4 **Existing military oxygen equipment.** Existing oxygen equipment design information is provided in Appendix C. A future oxygen system or a modified existing system will usually be a composite of existing oxygen equipment and some newly developed equipment.

Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document should be addressed to: ASD/ENES, Wright-Patterson AFB, OH 45433-6503 by using the self-addressed Standardization Document Improvement Proposal (DD Form 1426) appearing at the end of this document or by letter.

FSC 1660

1.3 **Deviation.** Any projected design for a given application which will result in improved system performance, reduced life cycle cost, or reduced development cost through deviation from this specification, or where the requirements of this specification result in compromise in operational capability, shall be brought to the attention of the procuring activity for consideration of change.

2. APPLICABLE DOCUMENTS

2.1 Government documents

2.1.1 **Specifications, standards, and handbooks.** Unless otherwise specified, the following specifications, standards, and handbooks of the issue listed in the current Department of Defense Index of Specifications and Standards (DODISS) and the supplement thereto (if applicable) form a part of this specification to the extent specified herein.

SPECIFICATIONS

(Specifications called out in the final specification shall be referenced here.)

STANDARDS

(Standards called out in the final specification shall be referenced here.)

HANDBOOKS

(Handbooks called out in the final specification shall be referenced here.)

2.1.2 **Other Government publications.** The following other Government publications form a part of this specification to the extent specified herein.

PUBLICATIONS

(Other publications called out in the final specification shall be referenced here.)

(Copies of specifications, standards, handbooks, drawings, and publications required by manufacturers in connection with specific acquisition functions should be obtained from the contracting activity or as directed by the contracting officer.)

2.2 Other publications. The following documents form a part of this specification to the extent specified herein. The issues of the documents which are indicated as DOD adopted shall be the issue in the current DODISS and the supplement thereto, if applicable.

(Other publications called out in the final specification shall be referenced here.)

(Technical society and technical association specifications and standards are generally available for reference from libraries. They are also distributed among technical groups and using Federal agencies.)

2.3 Order of precedence. In the event of a conflict between the text of this specification and the references cited herein, the text of this specification shall take precedence.

3. REQUIREMENTS

3.1 System description. The oxygen system shall support ________ crewmembers and ____________ type personnel for the normal and emergency intended missions of the aircraft. The oxygen system consists of the following functional subsystems as applicable:

( ) a. Crew oxygen system (3.2.2.1)

( ) b. Paratroop oxygen system (3.2.2.2)

( ) c. Mission specialist oxygen system (3.2.2.3)

( ) d. Aeromedical oxygen system (3.2.2.4)

( ) e. HALO oxygen subsystem (3.2.2.5)

( ) f. Passenger oxygen (3.2.2.6)

( ) g. Ejection seat bailout oxygen subsystem (3.2.2.7)

( ) h. Manual bailout oxygen (3.2.2.8)

( ) i. Walk-around oxygen assemblies (3.2.2.9)

( ) j. Aircraft firefighter portable assembly (3.2.2.10.1)

( ) k. Chemical defense protective breathing assemblies (3.2.2.10.2)

( ) l. Aircraft pressure suit provisions (3.2.2.11)

3.2 Performance requirements

3.2.1 System characteristics. In the design and installation of the functional subsystems and equipment groups of the entire aircraft oxygen system, the following system characteristics apply as requirements throughout: ______________.

3.2.1.1 Physical characteristics. The physical characteristics of the aircraft oxygen system are oxygen supply source with associated aircraft interfaces, oxygen supply delivery plumbing lines with associated valves, regulators as required for proper delivery of oxygen to on-board personnel, plumbing, hoses, and face masks to provide physiological protection to on-board personnel, portable oxygen equipment for special purposes and emergencies, and ______________.

3.2.1.2 Operational characteristics. The aircraft oxygen system must provide effective operational characteristics that are ______________.

3.2.1.3 Electrical characteristics. The aircraft oxygen system electrical characteristics shall effectively interface with the aircraft electrical subsystem and shall consist of ______________.

3.2.1.4 Environmental conditions. The aircraft oxygen system shall be designed such that it is qualified to the environmental extremes as follows: ______________.

3.2.1.5 Transportability. Certain transportability features are desired in the design of the oxygen system components. The oxygen system components are ______________. The transportability features should consist of ______________.

3.2.2 Functional subsystem characteristics. In the design and installation of the functional subsystems and equipment groups of the entire aircraft oxygen system, the following oxygen subsystems and equipment shall be used: ______________.

3.2.2.1 Crew oxygen system. A crew oxygen system shall be provided that is regulated to the cockpit or cabin pressure altitude and which consists of the following delivery features ______________. A warning shall be provided detectable by all crewmembers that functions when ______________. The primary oxygen supply for crewmembers who operate and monitor the aircraft and its subsystems shall be from a separate supply source than for other personnel (if applicable) and shall have features ______________. The crew oxygen system supply shall be sized to provide pressure demand regulated oxygen for all crewmembers at an average flow rate of ______ litres/hour per crewmember for a minimum of ______ hours. The oxygen system distribution lines shall operate under an internal pressure range of ______ psi and shall allow a maximum gaseous flow rate throughout of ______________.

3.2.2.1.1 Crew controls and displays. Each crewmember shall have oxygen system displays consisting of ______________ and controls consisting of ______________. Emergency quick-donning mask assemblies shall incorporate the intercommunication microphone and headset open to all crewmembers. Test controls shall be provided to check for the proper functioning of all lighted displays, indicators, instruments, and ______________. The controls and displays provided shall be functionally compatible with the crew oxygen system. Emergency oxygen system controls and displays consisting of ________ ______________ shall be provided to alert the appropriate personnel of ______________.

3.2.2.1.2 Physiological features. The crewmember respiratory provisions at normal conditions (NTPD) of sea level altitude, 760 mmHg, 70°F and dry shall be a minimum baseline minute volume per crewmember of ______ litres/minute (NTPD). The crewmember respiratory provisions at high demand flow for breathing while under high workloads and/or stress levels shall be _____ litres/minute (NTPD) per crewmember. The crewmember respiratory provisions for instantaneous peak demand flow for very high stress or workload shall be _____ litres/minute (NTPD) per crewmember. A pressure of ______ in the facepiece and a pressure range of ______ in the inlet delivery tubing shall activate inhalation and exhalation features.

3.2.2.1.3 Oxygen delivery features. The oxygen concentration for air dilution shall be provided to each crewmember within the following limits: ______________. Positive mask pressure is required above ______ feet cabin altitude and for _______. To provide user comfort and to minimize the possibility of hyperventilation due to the sensation of resistance to breathing, mask cavity pressures shall conform to the limits of table 3 or 4. An emergency breathing feature shall be provided that delivers 95-100 percent oxygen at a pressure of ______ and flow rate of ______.

3.2.2.2 Paratroop oxygen system. In the event the cabin pressure altitude exceeds 10,000 feet in a pressurized aircraft, an alarm shall sound that is audible to all passengers under the ambient noise conditions expected in flight. Additionally, the alarm system shall consist of ______________. For an unpressurized cabin, the alarm features are ______________. The oxygen supply shall be activated and the paratroops shall be provided oxygen supply in the following ways ____________. Smoke protection breathing features consisting of ________________ shall be provided. Each fully equipped seated paratroop or passenger shall be capable of breathing supplemental oxygen within ______ seconds after the alarm sounds. In pressurized cabins, an automatic dispensing oxygen subsystem (if provided) shall activate at a minimum of ______ feet cabin pressure altitude in the event of decompression and shut off at ______ feet cabin pressure altitude. A permanently installed emergency oxygen subsystem shall be provided for the integrally installed seats that has following components and features ____________. A removable oxygen subsystem kit shall also be provided for the centerline troop seat kit that incorporates the following components and features ______________. All supply sources and permanently installed components of the oxygen subsystem shall be located such that ________________. Multiple supply and distribution plumbing shall be installed on the aircraft such that ________________. The quantity of oxygen provided from the supply source shall be sized to provide 95-100 percent oxygen for a minimum of _________ troops based on an average flow rate of ______ litres/hour/person for a minimum of _______ hours. The permanently installed and removable oxygen system supply and distribution plumbing shall be designed to operate at an internal pressure range of ______ psi and shall have the capability to supply oxygen at flow rates of _____ litres/hour/person. This rate will vary depending on altitudes such that ___________.

3.2.2.2.1 **Paratroop controls and displays.** Passenger and paratroop oxygen system displays consisting of ______ and controls consisting of ______ shall be provided and located at ______. Emergency oxygen "ON" light(s) shall be provided at ______ to indicate to all persons that oxygen is flowing through the ______. A guarded control shall be provided at the ______ station to manually activate supplemental oxygen to all seated paratroop locations, and it shall have features consisting of ______. Test controls shall be provided to check for the proper functioning of all lighted displays, indicators, and instruments, with features consisting of ______. A separate, manual on/off control shall be provided for each row of seats, with ______ features, that is readily accessible in flight. The controls and displays provided shall be functionally compatible with the passenger oxygen system such that ______. Emergency or impending dangerous conditions shall be displayed in a manner to alert the appropriate personnel such that ______.

3.2.2.3 **Mission specialist oxygen system.** In the event the cabin pressure altitude exceeds 10,000 feet in a pressurized aircraft, an alarm shall sound and be audible to all mission specialists under all expected ambient noise conditions in flight. Additionally, the alarm shall have these features: ______. In the event the cabin pressure altitude exceeds ______ feet, supplemental oxygen shall be readily available to ______ mission specialists. The oxygen subsystem shall consist of supply source(s), distribution plumbing, a manual on/off control that is readily accessible in flight, any required heat exchangers, regulators compatible with the oxygen masks, and storage devices or containers available to each seated mission specialist, and ______. The mask and associated regulator shall provide oxygen to the mission specialists suitable for breathing ______ hours without symptoms of hypoxia. ______ type of oxygen mask assembly with ______ components shall be provided. The quantity of oxygen provided from the supply source shall be sized to provide 95-100 percent oxygen for a minimum of ______ passengers based on an average flow rate of ______ litres/hour/mission specialist for a minimum of ______ hours. The oxygen system supply and distribution plumbing shall be designed to operate at an internal pressure range of ______ psi and shall have the capability to supply oxygen at flow rates of ______ litres/hour/mission specialist.

3.2.2.3.1 **Mission specialist controls and displays.** Mission specialist oxygen system displays consisting of ______ and controls consisting of ______ shall be provided and located at ______. Emergency oxygen "ON" information shall be provided at each mission specialist's station to show that oxygen is flowing in the ______. A guarded override control shall be provided at the ______ station to manually activate the supplemental oxygen to all the seated personnel locations. The audible warning shall be activated from this control or an adjacent control. A separate audible warning silence control shall be provided. Test controls shall be provided to check for the proper functioning of all lighted displays, indicators and instruments. The controls and displays provided shall be functionally compatible with the passenger oxygen system. Emergency or impending dangerous conditions shall be displayed in a manner to alert the appropriate personnel.

3.2.2.4 Aeromedical oxygen system. The oxygen supply source shall be sized for emergency oxygen in the event of a decompression to provide an adequate quantity of 95-100 percent oxygen for a minimum of ______ litter patients, ______ ambulatory patients, and ______ medical personnel at an average flow rate of ______ litres/hour per ______ person for a minimum of ______ hours. The oxygen supply source shall also be sized to provide therapeutic oxygen to accommodate ______ seated patients plus ______ litter patients, ______ ambulatory patients, and ______ medical personnel in the maximum personnel aeromedical configuration for ______ hours. The oxygen system supply and distribution plumbing shall be designed to operate within an internal pressure range of ______ psi.

3.2.2.4.1 Quick conversion aeromedical evacuation. This system consists of the aeromedical kit carried on-board the aircraft at all times to allow quick conversion in flight to aeromedical evacuation. Oxygen must be readily available under any mission scenario for the integrally installed minimum litter capacity of ______. This system shall consist of therapeutic and emergency oxygen masks, regulators, and plumbing to enable patients to use this oxygen without restricting passage through the aisleways. This aeromedical kit shall be stowable on-board the aircraft at all times with features consisting of ______.

3.2.2.4.2 Therapeutic oxygen. A minimum of ______ therapeutic oxygen outlets designed according to ______ shall be provided to support ______ litter and ______ ambulatory patients. All therapeutic outlets shall accommodate flow rates up to ______ litres/hour/outlet and have an outlet delivery operating pressure of 50 ± 5 psi. Provide at least ______ respirator outlets located ______. All respirator outlets shall accommodate flow rates up to ______ litres/hour/outlet and have an operating pressure of 50 ± 5 psi. The oxygen system supply and distribution plumbing shall be designed to operate within an internal pressure range of ______ psi. The therapeutic and respirator outlets maybe located and installed such that ______. Any plumbing provided that must be routed across aisleways to reach litter and seat patient locations shall not restrict passage and ______. Ensure that the therapeutic and respirator oxygen system is operational at all times during both air and ground operations.

3.2.2.4.3 Emergency descent oxygen. Provide masks and distribution components that are suitable for breathing oxygen ______ hours at ______ cabin pressure altitude range at each litter location and seat position. When the cabin pressure altitude reaches 10,000 feet, an audible alarm shall sound that can be heard by all passengers above the expected ambient noise conditions of flight, and the cabin lighting shall automatically illuminate to full brightness. Oxygen supply shall be activated at ______, and oronasal oxygen masks with inhalation/exhalation valves and an activation lanyard shall be provided such that ______. Each litter patient, seated ambulatory patient, and seated medical attendant shall be provided supplemental breathing oxygen within ______ seconds after the alarm sounds. An automatic dispensing oxygen system (if applicable) shall be activated at a minimum of ______ feet cabin pressure altitude in the event of a decompression and shall shut off at ______ cabin pressure altitude.

3.2.2.4.4 Aeromedical oxygen subsystem components. The permanent and required removable components of the oxygen subsystem shall be provided.

These include the supply source, distribution plumbing, any required heat exchangers, altitude compensating regulator(s), pressure-reducing and one-way flow valves, and ____________. Provide manual off and on control(s) that are readily accessible in flight, and ______________. Provide masks and stowage containers available to each patient and medical attendant with ____________ features. All supply sources and permanently installed components of the oxygen subsystem shall be located outside any design cargo volume and away from locations that may be easily damaged during normal cargo handling and use for transport of passengers and ______________. Each supply source shall be easily removable for repair or replacement, and, if more than one supply source is provided, all shall be interconnected through one-way flow check valves such that any one supply source will provide oxygen to all outlets.

3.2.2.4.5 **Aeromedical controls and displays.** Oxygen supply quantity information, status, and low level or loss of supply, and ______________ warning indication shall be provided. Emergency oxygen "ON" information shall be provided and located such that ______________. An aural warning consisting of ______________ with a manual override silence control shall be activated, and the flight and cabin compartment general lighting shall illuminate to full brightness when the cabin pressure altitude reaches 10,000 feet. A manual shutoff control shall be provided to isolate delivery of oxygen supply to ______ sections of litters, _______ seats, and ______ therapeutic/respirator outlets. A guarded manual override emergency oxygen and mask activation control shall be provided at the ______ station for oxygen and mask activation features. The controls and displays provided shall be functionally compatible with the aeromedical oxygen system such that ______________. Emergency or impending dangerous conditions shall be displayed in a manner to alert the appropriate personnel so that ___________.

3.2.2.5 **HALO oxygen subsystem.** A minimum of _____ outlets shall be provided for High Altitude Low Opening (HALO) parachute jumpers. This applies to an HALO oxygen system integral to the aircraft. These outlets shall be provided at ________________ and shall be accessible to each paratroop when seated or standing adjacent to his seat. Outlet connectors shall be compatible with the breathing equipment the paratroop is expected to use consisting of __________. Each outlet shall have provisions consisting of __________ for protection from dust and contaminants when not in use. The HALO oxygen subsystem shall consist of plumbing distribution with only HALO oxygen outlets provided on these lines that connect to the passenger high pressure source through a manual off and on valve. Regulators for this plumbing shall provide positive pressure breathing capability for all HALO jumpers from sea level to ____ feet that allows nonfatiguing breathing from one-half hour for prebreathing to a minimum of _______ hours to complete the mission. The response of all regulators provided shall accommodate a rapid decompression of _____ seconds without adverse affects to the paratroops breathing from the HALO outlets. Each HALO oxygen outlet shall accommodate flow rates of ______ litres/hour/outlet and shall operate within a pressure range of ______ psi.

3.2.2.6 **General passenger oxygen.** In the event of either an unplanned decompression of the aircraft cabin that is normally pressurized, or flight in a nonpressurized cabin, supplemental oxygen is required to support ______ passengers for at least _____ (time period). Flow rates and delivery pressures that consist of ______________ shall be provided. Should the cabin pressure altitude exceed 10,000 feet in a normally pressurized cabin, an alarm shall be automatically sounded and shall be audible to all passengers under the expected ambient noise conditions of flight. The cabin lighting shall illuminate to full brightness. If the oxygen subsystem is permanent, the components shall consist of a supply source that is removable for repair and servicing, any required heat exchangers, distribution plumbing, any required regulators, manual off and on controls that are readily accessible in flight, masks in stowage containers, and ___________. If the oxygen subsystem is portable, it shall consist of ___________. Oxygen shall become available to each seated and restrained passenger in a time period not to exceed _____ seconds. In the event of a smoke-filled cabin, the breathing protection system shall support passengers for ______ minutes.

3.2.2.6.1 <u>**Passenger controls and displays**</u>. Should the general passenger oxygen subsystem be permanently installed, oxygen supply quantity status and low-level or lack-of-supply warning shall be provided at the ___________ station. Emergency oxygen "ON" information shall be provided at the ___________ stations to show that oxygen is flowing through the ___________. A guarded control shall be provided at the ___________ station(s) to manually activate the supplemental oxygen to all the seated passenger locations, and an audible warning shall be activated from this control or an adjacent control. A separate audible-warning silencing control shall be provided. Test controls shall be provided to check for proper functioning of all lighted displays, indicators, and instruments.

3.2.2.7 <u>**Ejection seat bailout oxygen subsystem**</u>. During ejection seat escape from the aircraft, supplemental oxygen is required for the time period of ___________ for descent from higher altitudes. This same oxygen supply shall be designed for use as backup emergency oxygen supply in the event of a cockpit decompression or a failure of the primary oxygen system. This oxygen subsystem shall have the following features: manual actuation for inflight emergencies; automatic oxygen flow upon the onset of the ejection sequence; automatic disconnect of oxygen hose from the crewmember on seat/man separation or on parachute deployment; pull-free hose disconnect capability for ground egress; and ___________. Provide a ___________ guarded control for manual activation of oxygen and a ______ quantity of oxygen display. Should a portable cylinder be used for the supply source, a means to recharge the cylinder shall be provided with features consisting of ___________. The delivery hose shall be flexible and shall be compatible with ___________ type personal connector. If the supply source is a cylinder, it shall have the following features: ___________. Sufficient flow rate and delivery pressure shall be provided at the breathing mask to enable the crewmember to breathe with minimal fatigue from altitudes of ______ feet to ______ feet and in a windblast environment of ___________. The manual activation control shall be activated with a force of ___________.

3.2.2.8 <u>**Manual bailout/emergency oxygen supply**</u>. A minimum of ______ portable manual bailout/emergency oxygen assemblies shall be provided to enable ______ personnel to breathe for an emergency decompression and parachute escape at altitudes up to ______ feet. Each quick-donning assembly shall consist of a supply source, a device for regulation to ___________, and a flexible hose connected to a breathing mask. Each assembly shall have a means to hold and carry it during bailout exiting and parachute descent or to reach a station with oxygen that consists of ___________. To hold and retain the manual bailout/emergency oxygen assemblies while in flight, provide ___________.

Each assembly shall have control features consisting of _________ and display features consisting of _____________. Should a portable cylinder be used for the supply source, a ________ means to recharge the portable cylinder shall be provided. If the supply source is a cylinder, it shall be a ______ pressure vessel filled to a pressure of ______ psi, and pressure relief shall be provided on the valve to vent oxygen at _______ psi. Sufficient flow rate and delivery pressure shall be provided at the breathing mask to enable the crewmember to breathe with minimal fatigue from altitudes of ______ feet to ______ feet.

3.2.2.9 Walk-around oxygen assemblies. To allow crewmembers to move about in the aircraft when it is unpressurized at altitudes above 10,000 feet, portable, replenishable, supplementary oxygen assemblies are required. Provide walk-around oxygen assemblies that have oxygen regulation features of ____________, a flexible hose to a breathing mask with a means for inhalation and exhalation, and a means for replenishing the supply. Locate _______ assemblies on the flight deck, one in each lavatory, and _____ in the cabin or cargo compartment. Support brackets for storage of each assembly on the aircraft shall be provided so that each assembly is readily accessible. If assemblies of the low pressure type portable cylinder are provided, recharging ports that are integral to the aircraft shall be provided at ______ to allow refilling of the assembly while in flight. Each assembly shall incorporate control features consisting of _____________ and display features consisting of ____________. Those assemblies of the low pressure type shall be designed to refill from the standard USAF recharging outlet to the pressure range of 300 to 450 psi and provide pressure relief at 500 psi. Those assemblies of the high pressure type, shall be serviceable from military ground equipment to fill to a pressure of _____ psi and provide pressure relief at _______ psi. Those portable assemblies that incorporate chemical oxygen generation shall have features that consist of ___________. Sufficient flow rate and delivery pressure shall be provided at the breathing mask to enable the crewmember to breathe with minimal fatigue from continuous use at 20,000 to 25,000 feet pressure altitude.

3.2.2.10 Protective breathing equipment. The following protective breathing equipment shall be provided: ____________.

3.2.2.10.1 Aircraft firefighter portable assembly. Provide at least ______ firefighter assemblies that have an oxygen supply source regulated through a valve for pressure breathing, a quick disconnect fitting at the valve on the end of a _______-inch flexible breathing hose, and _____________. The firefighter portable assembly shall have features consisting of: a breathing hose that is connected to a breathing mask integrated into a face mask that protects the eyes, nose, and mouth from smoke, carbon monoxide, and other toxic gases; an assembly which has body mounting features to enable the crewmember to hold fire extinguishing equipment at the same time; an assembly which incorporates communication equipment to allow personnel to communicate with each other while at their assigned duty station; and ____________. Any part of the equipment protecting the eyes shall not cause an appreciable adverse effect on vision and shall allow glasses to be worn. Provide _______ assemblies on the flight deck and ______ assemblies in the cabin or cargo compartment and in areas of the aircraft such as ______________, stored such that assemblies are readily available for use but are secured for flight. If the assembly uses a pressurized vessel as the supply source, it shall have features consisting of __________. If the assembly uses a chemical generator of oxygen as a supply source, it shall have features consisting of _________. The equipment must supply _____ percent oxygen for _____ minutes duration per person at a cabin pressure altitude range of ______ feet. The assembly shall protect the firefighter such that the breathing gas mixture does not exceed the threshold limits as specified by _________ for noxious gases and airborne particles.

3.2.2.10.1.1 **Firefighter controls and displays.** An "ON/OFF" control shall be provided to begin or shut off gas flow when desired. The control shall be easily accessible for use when the assembly is donned and indication of the control position shall be provided. A usable supply or a status quantity indicator shall be provided with _____________ features. The controls and displays shall be functionally compatible with the protective breathing system.

3.2.2.10.2 **Chemical defense protective breathing assemblies.** Provide ______ chemical defense protective breathing assemblies for _________ personnel that supply breathing oxygen regulated ____________ for crewmembers and regulated ___________ for other personnel. The assembly shall protect _________ from adverse chemical effects while allowing the personnel to perform their _______ operational duties. The ____________ assembly shall incorporate __________ type communication equipment to allow crewmembers to communicate with each other while at their assigned duty stations, and ___________. The equipment shall supply ___________ type of breathing oxygen for _____ minutes duration per person at a cabin pressure altitude of ______ feet. The assembly shall protect the personnel such that the breathing air does not become contaminated with chemical warfare agents as specified ____________.

3.2.2.10.2.1 **Chemical defense controls and displays.** Should breathing oxygen be provided through this assembly, controls and displays shall be provided compatible with operational requirements of ______________. Controls and displays to effectively operate any blowers, filters, and oxygen provided shall consist of _____________. Provide at least ______. The controls and displays provided shall be functionally compatible with the protective breathing system such that _____________. Emergency or impending dangerous conditions shall be displayed in a manner to alert the appropriate personnel such that _____________.

3.2.2.11 **Aircraft pressure suit provisions.** A pressure garment system shall be provided for missions above 50,000 feet and for missions above 25,000 feet if, in the event of an unplanned cabin depressurization, it would be impossible to immediately descend to an altitude at which cabin pressure altitude can be maintained at or below 25,000 feet. Pressure-demand oxygen, ventilation, heating, communication, and ______________ aircraft interfaces shall be provided in the inflight and ground-egress system. The controller shall maintain the suit system pressure at a nominal _______ feet when the cabin pressure exceeds ________ feet. A pressure relief device shall be provided located ___________ and calibrated to relieve overpressure in the range of ______. The oxygen or breathing system shall be designed to provide pressure-demand regulated oxygen with the following features: __________. The system shall have the capability to provide oxygen for each crewmember with varying flow rates dependent on altitudes for ______ hours. The system supply and distribution plumbing shall operate under an internal pressure range of _____ psi.

Pressure suit ventilation and comfort provisions shall be provided according to ____________.

3.2.2.11.1 Pressure suit controls and displays. Manual override control of the suit shall be provided, and test features for a preflight check of the assembly shall be provided consisting of ____________. Pressure, flow, and ____________ displays shall be provided for normal operations. Warning displays and alarms shall inform the ____________ crewmembers should the cabin pressure and altitude exceed ________ feet, should the oxygen flow rate to the suit deviate from that normally expected for that cabin pressure altitude, and ____________. The controls and displays provided shall be functionally compatible with the protective breathing system such that ____________.

3.3 Reliability. The reliability of the aircraft oxygen system shall be as follows: ____________. The reliability of each of the critical components of the oxygen system shall be at least:

Component Name	Mean Time Between Failures
************	**********************

3.4 Accessibility, maintainability, and serviceability design considerations. Install all parts of the oxygen system to permit ready removal and replacement on the aircraft without the use of special tools. Ensure that all tubing connections, fittings, valving, regulators, supply sources, controls, displays, and other items required in maintenance and servicing are readily accessible for leak testing with leak-test compound for tightening of fittings, without removal of surrounding parts, for removal, repair and replacement, and ____________. Ensure that all masks, flexible hoses, and associated equipment can be properly stowed and ____________. Ensure that all oxygen gas cylinders, filters, chemical oxygen-generating devices, and liquid-oxygen converters provided are accessible and have supply replenishment features consisting of ____________. Other accessibility, maintainability, and serviceability design considerations are ____________.

3.5 Survivability and safety design considerations. The location and isolation of the oxygen supply and its distribution manifolds shall preclude adverse effects on aircraft flight-critical components when there is a rupture in the oxygen system or an intense oxygen-fed fire due to a single hit by any of the threats specified in ____________. If more than one supply is provided, they shall be manifolded such that the loss of any one supply source will not preclude all personnel from breathing oxygen, and one-way check valves shall prevent the loss of supply from other sources. Oxygen distribution plumbing shall be routed and located such that, if penetrated, oxygen will not initiate or support the combustion of flammable fluids and other materials. Regions of potential over-pressure shall be precluded by design and use of over-pressure devices. Appropriate warning indications, labeling, and markings shall be provided with the oxygen system to preclude adverse effects to all personnel including crewmembers, passengers, and maintenance personnel. If chemical mixtures or bleed air is used to provide breathing gas, methods of filtering out harmful substances such as water, particles, and noxious gases shall be incorporated. Pressure and flow displays shall be provided for normal operations. Other survivability and safety design considerations are ____________.

3.6 Human engineering. The oxygen system design shall meet human engineering design criteria consisting of ______________.

3.7 Interface requirements. The oxygen system shall be installed on the aircraft such that the operational envelope of the components does not violate the operational envelopes of any other aircraft subsystem, and the cabling, wiring, and plumbing routing between aircraft subsystems. All oxygen controls and displays, hoses, masks, and equipment on the personnel shall be installed such that an effective interface has been provided between the personnel using the equipment and the oxygen equipment to maximize mission effectiveness. Where the oxygen system must interface with other aircraft components or subsystems, the operation and design of the oxygen system shall not be degraded. __________ aircraft subsystems shall be effectively interfaced such that the following properties and limits are met: ______________.

3.8 International standardization provisions. The ______________ international agreements shall apply to the oxygen system design.

3.9 Design trade studies. The following design trade studies will be accomplished: ____________. The goal is to determine the following: __________.

3.10 Mockup requirements. Mockups shall be constructed of __________. The goal is to determine ____________.

4. VERIFICATIONS

4.1 Oxygen system verification. Analyses, demonstrations, inspections, and tests are essential in checking for a properly designed oxygen system. The oxygen system installation shall be verified by ______________.

4.2 Verification of performance requirement

4.2.1 System characteristics verification. The system characteristics shall consist of ______________.

4.2.1.1 Physical characteristics tests. The verification of the aircraft oxygen system physical characteristics shall consist of _____________.

4.2.1.2 Operational characteristics tests. The verification of the aircraft oxygen system operational characteristics shall consist of _____________.

4.2.1.3 Electrical characteristics tests. The verification of the electrical characteristics of the aircraft oxygen system shall consist of ____________.

4.2.1.4 Environmental testing. The hardware, materials, and components of the oxygen system shall operate satisfactorily under the following tests: _____________.

4.2.1.5 Transportability verification. The oxygen equipment transportability features shall be verified by ______________.

4.2.2 Verification of functional subsystem characteristics. The functional subsystem characteristics verification shall consist of ____________.

4.2.2.1 Verification of crew oxygen system. The verification of the crew oxygen system shall consist of ____________.

4.2.2.1.1 Verification of crew oxygen controls and displays. The verification of the crewmembers' controls and displays shall consist of ____________.

4.2.2.1.2 Verification of physiological features. The verification of the physiological features shall consist of ____________.

4.2.2.1.3 Verification of oxygen delivery features. The verification of the oxygen delivery features shall consist of ____________.

4.2.2.2 Verification of paratroop oxygen system. The verification of the paratroop oxygen system shall consist of ____________.

4.2.2.2.1 Verification of paratroop controls and displays. The verification of the paratroop oxygen system controls and displays shall consist of ____________.

4.2.2.3 Verification of mission specialist oxygen system. The verification of the mission specialist's oxygen system shall consist of ____________.

4.2.2.3.1 Verification of mission specialist controls and displays. The verification of the mission specialist's oxygen system controls and displays shall consist of ____________.

4.2.2.4 Verification of aeromedical oxygen system. The verification of the aeromedical oxygen system shall consist of ____________.

4.2.2.4.1 Verification of quick-conversion aeromedical evacuation. The verification of quick-conversion aeromedical evacuation shall consist of ____________.

4.2.2.4.2 Verification of therapeutic oxygen. The verification of therapeutic oxygen shall consist of ____________.

4.2.2.4.3 Verification of emergency descent oxygen. The verification of emergency descent oxygen shall consist of ____________.

4.2.2.4.4 Verification of aeromedical oxygen subsystem components. The verification of aeromedical oxygen subsystem components shall consist of ____________.

4.2.2.4.5 Verification of aeromedical controls and displays. The verification of the aeromedical oxygen system controls and displays shall consist of ____________.

4.2.2.5 Verification of HALO oxygen subsystem. The verification of the HALO oxygen subsystem shall consist of ____________.

4.2.2.6 Verification of general passenger oxygen. The verification of the passenger oxygen system shall consist of ____________.

4.2.2.6.1 Verification of passenger controls and displays. The verification of the passenger oxygen system controls and displays shall consist of ____________.

4.2.2.7 **Verification of ejection seat bailout oxygen subsystem.** The verification of the ejection seat bailout oxygen subsystem shall consist of ______________.

4.2.2.8 **Verification of manual bailout/emergency oxygen supply.** The verification of the manual bailout/emergency oxygen shall consist of ______________.

4.2.2.9 **Verification of walk-around oxygen assemblies.** The verification of the walk-around oxygen assemblies shall consist of ______________.

4.2.2.10 **Verification of protective breathing equipment.** The verification of the protective breathing equipment shall consist of ______________.

4.2.2.10.1 **Verification of aircraft firefighter portable assembly.** The verification of the aircraft firefighter portable assemblies shall consist of ______________.

4.2.2.10.1.1 **Verification of firefighter controls and displays.** The verification of the aircraft firefighter's portable assembly controls and displays shall consist of ______________.

4.2.2.10.2 **Verification of chemical defense protective breathing assemblies.** The verification of the chemical defense protective breathing assemblies shall consist of ______________.

4.2.2.10.2.1 **Verification of chemical defense controls and displays.** The verification of the chemical defense protective breathing assembly controls and displays shall consist of ______________.

4.2.2.11 **Verification of aircraft pressure suit provisions.** The verification of the aircraft pressure suit provisions shall consist of ______________.

4.2.2.11.1 **Verification of pressure suit controls and displays.** The verification of the aircraft pressure suit controls and displays shall consist of ______________.

4.3 **Reliability tests.** The verification of reliability shall consist of ______________.

4.4 **Verification of accessibility, maintainability, and serviceability design considerations.** The verification of accessibility, maintainability and serviceability shall consist of ______________.

4.5 **Survivability and safety design consideration tests.** The verification of survivability and safety shall consist of ______________.

4.6 **Human engineering verification.** The verification of human engineering shall consist of ______________.

4.7 **Verification of interface requirements.** The verification of aircraft interface requirements shall consist of ______________.

4.8 **Verification of international standardization provisions.** The verification of international standardization provisions shall consist of ______________.

4.9 Verifying design trade studies. The verification of design trade studies shall consist of ____________.

4.10 Verifying mockup requirements. The verification of mockup requirements shall consist of ____________.

5. PACKAGING

5.1 All deliverable items shall be prepared for shipment as directed by the procuring activity.

6. NOTES

6.1 Intended use. The General Specification for Aircraft Oxygen Systems is intended for use in the procurement of new or modified aircraft oxygen systems. This document is a guide in the preparation of an individual subsystem-level aircraft oxygen specification. This specification may be used for oxygen equipment alone, or the applicable oxygen specification requirements and tests from this document may be included as part of an entire aircraft specification.

6.2 Data item descriptions. The following is a list of data item descriptions associated with the requirements of this specification:

PARAGRAPHS	APPLICABLE DID	TITLE

6.3 Responsible engineering office. The office responsible for development and technical maintenance of this specification is ASD/ENECE, Wright-Patterson AFB OH 45433-6503. Requests for additional information or assistance on this specification can be obtained from Dennis W. Schroll, ASD/ENECE, Wright-Patterson AFB OH 45433-6503; Autovon 785-2165, Commercial (513) 255-2165. Any information obtained relating to Government contracts must be obtained through contracting officers.

Custodian:
Air Force - 11

Preparing Activity:
Air Force - 11

Project No. 1660-F521

APPENDIX A

OXYGEN SYSTEMS, AIRCRAFT, GENERAL SPECIFICATION FOR

HANDBOOK FOR

10. SCOPE

10.1 Scope. This appendix provides rationale, guidance, lessons learned, and instructions necessary to tailor Sections 3 and 4 of the basic specification (MIL-O-87226) for a specific application.

10.2 Purpose. This appendix provides information to assist the government procuring activity in the use of MIL-O-87226.

10.3 Use. This appendix is designed to assist the project engineer in tailoring MIL-O-87226. The blanks of the basic specification shall be filled in to meet operational needs of the equipment being developed.

10.4 Format

10.4.1 Requirement/verification identity. Section 30 of this appendix parallels sections 3 and 4 of the basic specification; paragraph titles and numbers are in the same sequence. Section 30 provides each requirement (section 3) and associated verification (section 4) as stated in the basic specification and provides rationale, guidance, and lessons learned applicable to each.

10.4.2 Requirement/verification package. Section 30 has been so arranged that the requirement and associated verification is an identifiable package to permit addition to, or deletion from the resulting tailored specification. A requirement is not specified without an associated verification.

10.5 Responsible engineering office. The responsible engineering office (REO) for this appendix is ASD/ENECE, Wright-Patterson AFB OH 45433-6503. The individual who has been assigned the responsibility for this handbook is Dennis W. Schroll, ASD/ENECE, Wright-Patterson AFB OH 45433-6503, AUTOVON 785-2165, Commercial (513) 255-2165.

20. APPLICABLE DOCUMENTS

20.1 References. The documents referenced in this appendix are not intended to be applied contractually. Their primary purpose is to provide background information for the Government engineers responsible for developing the most appropriate performance values (filling in the blanks) for the requirements contained in the specification proper.

20.2 **Avoidance of tiering.** Should it be determined that the references contained in this appendix are necessary in writing an RFP or building a contract, excessive tiering shall be avoided by calling out only those portions of the reference which have direct applicability. It is a goal of the Department of Defense that the practice of referencing documents in their entirety be eliminated in order to reduce the tiering effect.

20.3 **Government documents**

SPECIFICATIONS

MIL-D-8683	Design and Installation of Gaseous Oxygen Systems in Aircraft, General Specification for
MIL-C-9177	Connector, Audio, Airborne, General Specification for
MIL-S-9479	Seat System, Upward Ejection, General Specification for
MIL-D-19326	Design and Installation of Liquid Oxygen Systems in Aircraft, General Specification for
MIL-G-27617	Grease, Aircraft and Instrument, Fuel and Oxidizer Resistant

STANDARDS

MIL-STD-210	Climatic Extremes for Military Equipment
MIL-STD-810	Environmental Test Methods and Engineering Guidelines
MIL-STD-1472	Human Engineering Design Criteria for Military Systems, Equipment and Facilities
MIL-STD-1568	Materials and Processes for Corrosion Prevention and Control in Aerospace Weapons Systems
MIL-STD-1587	Material and Processes Requirements for Aerospace Weapons Systems

HANDBOOKS

MIL-HDBK-157	Transportability Criteria

PUBLICATIONS

AFR 60-16	General Flight Rules
AFP 160-5	Physiological Training
TO 15X-1-1	Technical Manual, Maintenance Instructions, Oxygen Equipment
FAR Part 25	Federal Aviation Requirement Airworthiness Standards: Transport Category Airplanes

DH 1-3	Human Factors Engineering
SAM-TR-73-47	Development of the USAF School of Aerospace Medicine, (USAFSAM) Therapeutic Liquid Oxygen (LOX) Breathing System
STANAG 3865	Physiological Requirements for Oxygen Systems in New Generation High Performance Aircraft

(Copies of specifications, standards, handbooks, drawings, and publications required by manufacturers in connection with specific acquisition functions should be obtained from the contracting activity or as directed by the contracting officer.)

20.4.2 Nongovernment documents

AIR-825	Oxygen Equipment for Aircraft

(Copies are available from the Society of Automotive Engineers, Inc., 400 Commonwealth Drive, Warrendale, PA 15096)

(Technical society and technical association specifications and standards are generally available for reference from libraries. They are also distributed among technical groups and using Federal agencies.)

30. REQUIREMENTS AND VERIFICATIONS

3.1 System description. The oxygen system shall support ________ crewmembers and ____________ type personnel for the normal and emergency intended missions of the aircraft. The oxygen system consists of the following functional subsystems as applicable:

( ) a. Crew oxygen system (3.2.2.1)

( ) b. Paratroop oxygen system (3.2.2.2)

( ) c. Mission specialist oxygen system (3.2.2.3)

( ) d. Aeromedical oxygen system (3.2.2.4)

( ) e. HALO oxygen subsystem (3.2.2.5)

( ) f. Passenger oxygen subsystem (3.2.2.6)

( ) g. Ejection seat bailout oxygen subsystem (3.2.2.7)

( ) h. Manual bailout oxygen (3.2.2.8)

( ) i. Walk around oxygen assemblies (3.2.2.9)

( ) j. Aircraft firefighter portable assembly (3.2.2.10.1)

( ) k. Chemical defense protective breathing assemblies (3.2.2.10.2)

( ) l. Aircraft pressure suit provisions (3.2.2.11)

REQUIREMENT RATIONALE (3.1)

The number and type(s) of aircraft occupants is a basic functional requirement that should be called out in the initial portion of the aircraft oxygen system description. The functional subsystems are given by personnel types that must use the oxygen subsystems. The performance features associated with each of these types of personnel are strongly dependent on the aircraft and its mission. Additionally, the primary equipment groups are listed that may apply to one or more of the functional subsystems. These equipment groups have unique design criteria.

REQUIREMENT GUIDANCE

The personnel types that are associated with the functional subsystems for oxygen equipment are given in a through f. The functional assemblies are given in g through l. The selection of this equipment is given by the aircraft type and mission. Some examples are given as follows to illustrate how the functional subsystems and equipment groups are selected:

a. Fighter aircraft - The fighter aircraft will nearly always consist of one or two crewmembers. For crewmember design requirements, refer to 3.2.2.1, Crew oxygen system. Since the fighter aircraft crewmember is on oxygen nearly all times while in flight and he must perform in dynamic environments such as G maneuvers, the design of the functional oxygen subsystem is most critical. For these reasons extensive detail is provided to avoid past problems. Another equipment group that will probably also apply is 3.2.2.7, Ejection seat bailout oxygen subsystem. If special conditions dictate, Chemical defense protective breathing assemblies, 3.2.2.10.1, and/or Aircraft pressure suit provision, 3.2.2.11, will also apply.

b. Transport aircraft - Transport aircraft personnel and mission requirements vary widely. Also, the aircraft types may vary from small prop aircraft to large, wide-body jet aircraft. However, the oxygen equipment needed for all these aircraft will be similar for the crew and passengers (if applicable). What will vary is the location and operation of this equipment. For example, a wide-bodied troop transport may be developed. The Crew oxygen system (see paragraph 3.2.2.7) will be applicable to pilot, copilot, navigator, flight engineer, loadmaster and other crewmembers in the design. Should paratroop, aeromedical, and HALO capability be needed, the applicable paragraphs will apply. Additionally, Walk-around oxygen assemblies (see 3.2.2.9) and Aircraft firefighter portable assemblies (see 3.2.2.10.1) will usually be needed, so these equipment groups should be selected and used in this document.

Another example illustrates the need for oxygen in transport aircraft used only for movement of passengers. In this case, those paragraphs applicable to Crew oxygen (see 3.2.2.1) and Passenger oxygen (see 3.2.2.6) are used. Equipment groups that will apply are Walk-around oxygen assemblies and Aircraft firefighter portable assemblies.

c. Electronic warfare aircraft - Electronic warfare aircraft accomplish surveillance missions that require higher altitudes even in the event of a cabin decompression. As such, oxygen is not only required for all crew and passengers to make an emergency descent to lower altitudes but for sustained flight at altitudes from 20,000 to 40,000 feet. For these reasons, the function subsystem Mission specialist oxygen (see 3.2.2.3) will apply. The functional subsystem Crew oxygen (see 3.2.2.1) will also apply. Equipment groups consisting of Walk-around oxygen assemblies and Aircraft firefighter portable assembly will also apply.

REQUIREMENT LESSONS LEARNED

4.1 <u>Oxygen system verification</u>. Analyses, demonstrations, inspections, and tests are essential in checking for a properly designed oxygen system. The oxygen system installation shall be verified by ______________.

VERIFICATION RATIONALE (4.1)

Verification of specification requirements is essential to the procuring activity such that equipment design and performance is proven or validated prior to commitment to production and aircraft installation. This ensures that a properly designed oxygen system and its associated components are delivered. Verification of the oxygen system design and installation will also minimize hazards to crewmembers and passengers on the aircraft.

VERIFICATION GUIDANCE

The oxygen system design and installation may be verified by inspection, analysis, demonstration, and/or testing (listed in order of increasing importance). Components used may be inspected against applicable requirements. Testing is desired to ensure the oxygen system installation delivers gas within specified limits. Testing may be done in the laboratory or on the aircraft. Aircraft tests may be conducted on the ground or inflight.

Inspections ensure that the designer will provide to the military agency all necessary components of the aircraft oxygen system and ground support equipment, if applicable. These details are not covered by the aircraft oxygen system specification and usually are not in the detailed specifications to the full extent necessary. A receiving inspection list may be developed prior to contract; it will ensure that all oxygen system components are delivered.

VERIFICATION LESSONS LEARNED

3.2 Performance requirements

3.2.1 System characteristics. In the design and installation of the functional subsystems and equipment groups of the entire aircraft oxygen system, the following system characteristics apply as requirements throughout: ______________.

REQUIREMENT RATIONALE (3.2.1)

Certain functional system characteristics, design and installation requirements apply to all functional subsystems and equipment groups of the entire aircraft oxygen system. These requirements should be given in this paragraph.

REQUIREMENT GUIDANCE

Some overall system characteristics that apply are: physical characteristics, operational characteristics, electrical characteristics, environmental conditions, transportability features, electromagnetic radiation protection, materials processes, selection for corrosion protection, and equipment longevity (see MIL-STD-1568 and MIL-STD-1587 for information). Other characteristics may apply and should be specified here.

REQUIREMENT LESSONS LEARNED

4.2.1 System characteristics verification. The system characteristics verification shall consist of ______________.

VERIFICATION RATIONALE (4.2.1)

It is essential that the entire oxygen system properly function with the expected operational environment of the aircraft in which it is to be installed. Verification of the oxygen system will ensure that it is functionally compatible with the aircraft operations.

VERIFICATION GUIDANCE

The verification of the characteristics of the functional subsystems and equipment groups should consist of analyses, inspections, demonstrations, and tests as necessary to ensure that all oxygen system requirements have been met.

VERIFICATION LESSONS LEARNED

3.2.1.1 Physical characteristics. The physical characteristics of the aircraft oxygen system are oxygen supply source with associated aircraft interfaces, oxygen supply delivery plumbing lines with associated valves, regulators as required for proper delivery of oxygen to on-board personnel, plumbing, hoses, and face masks to provide physiological protection to on-board personnel, portable oxygen equipment for special purposes and emergencies, and ________________.

REQUIREMENT RATIONALE (3.2.1.1)

The aircraft oxygen system is a pneumatic system that stores or generates gaseous oxygen supply in one form or another. The physical characteristics are specified to provide necessary information that applies to all aircraft oxygen systems.

REQUIREMENT GUIDANCE

The functional subsystems of the aircraft oxygen system and associated equipment groups are specified in terms of physical characteristics that are common to all types of aircraft oxygen systems. Other physical characteristics that may be given are volume/space constraints, weight and center of gravity constraints, electrical requirements, interface with the environmental control system (if required), and functional interface with any other aircraft subsystem.

REQUIREMENT LESSONS LEARNED

4.2.1.1 **Physical characteristics tests.** The verification of the aircraft oxygen system physical characteristics shall consist of ____________.

VERIFICATION RATIONALE (4.2.1.1)

It is necessary to verify that all physical characteristics of the aircraft oxygen system are within specified envelopes and meet the design constraints specified.

VERIFICATION GUIDANCE

The verification of the physical characteristics of the aircraft oxygen system should consist of analyses, inspections, demonstrations and tests as necessary to ensure that all specified requirements have been met.

VERIFICATION LESSONS LEARNED

3.2.1.2 **Operational characteristics.** The aircraft oxygen system must provide effective operational characteristics that are ____________.

REQUIREMENT RATIONALE (3.2.1.2)

The aircraft oxygen system must meet numerous operational conditions that allow it to effectively interface with aircraft equipment and on-board personnel operations. To ensure that operational constraints are satisfied for all situations expected, these should be called out.

REQUIREMENT GUIDANCE

Aircraft oxygen system design operational constraints will, in many cases, be unique to the type of aircraft in which it is to be installed and the missions that will be planned. A prime consideration for all types of aircraft and missions is that masks, delivery hoses, and outlets do not interfere with the crewmembers in tasks they must accomplish. Another example is that all the oxygen systems should function properly under all the accelerative forces in flight. The face mask and hose should be suitably secured to the face when the pilot pulls Gs. The design and placement of oxygen system controls and displays must functionally interface with the crewmembers and passengers such that use of the equipment is proper and mistakes are minimized.

REQUIREMENT LESSONS LEARNED

4.2.1.2 Operational characteristics tests. The verification of the aircraft oxygen system operational characteristics shall consist of ________.

VERIFICATION RATIONALE (4.2.1.2)

It is essential to verify the proper operation and effectiveness of the aircraft oxygen system with the on-board personnel.

VERIFICATION GUIDANCE

The verification of the operational characteristics of the aircraft oxygen system should consist of analyses, inspections, demonstrations and tests as necessary to ensure that all specified requirements have been met. Functional demonstrations of the equipment with crew members and passengers should be accomplished prior to production commitments. Crewmembers and passengers should be representative of the type of persons that will be expected to use the equipment. Operations performed should also be representative of those expected to be accomplished during the aircraft missions. Should other aircraft subsystems interface with the aircraft oxygen system, functional demonstrations should be performed. An example of this type of interface is the aircraft environmental control system and engine bleed air that may be used with an on-board oxygen-generating system.

VERIFICATION LESSONS LEARNED

3.2.1.3 Electrical characteristics. The aircraft oxygen system electrical characteristics shall effectively interface with the aircraft electrical subsystem and shall consist of ________.

REQUIREMENT RATIONALE (3.2.1.3)

To ensure proper operation of all electrical components that may be included with the aircraft oxygen system, it is desirable to specify all electrical characteristics.

REQUIREMENT GUIDANCE

Electrical characteristics that should be considered are: maximum and average power consumption, power phase, current amplitude, cycle rate, alternating versus direct current, and any electrical connections that will be needed. Intermittent current and power interruptions should be considered in terms of the effect on the proper operation of the aircraft oxygen equipment. Another consideration is loss of electrical power. The aircraft oxygen system is a primary life support system on small aircraft such as fighters. A backup electrical power system may be required. This may be accomplished through connections to the emergency electrical system or aircraft batteries. Another factor that should be kept in mind is that the power allowance should interface effectively with all other equipment and subsystems that use electrical power.

REQUIREMENT LESSONS LEARNED

4.2.1.3 **Electrical characteristics tests.** Characteristics of the aircraft oxygen system shall consist of __________.

VERIFICATION RATIONALE (4.2.1.3)

It is desirable to analyze and perform functional tests and checks on the electrical characteristics of the aircraft oxygen system. This will ensure that all equipment operates properly.

VERIFICATION GUIDANCE

In the initial design layouts of the aircraft oxygen equipment, complete circuit schematics and diagrams shall be accomplished. Electrical systems experts should completely analyze these diagrams to determine adequacy. With the advent of computers, micro-chips, and circuits, trained computer hardware and software technicians and engineers may analyze the equipment to ensure it will be satisfactory. It is also very desirable to breadboard all electrical components and circuits with oxygen equipment and functionally check all operations. At this design stage, it is possible that design improvements may be determined. An installation of electrical equipment on the aircraft, inspections may be accomplished to determine that wiring has been properly installed and restrained. It would then be desirable to perform electrical compatibility checks of the characteristics of the oxygen system electrical equipment with the aircraft electrical characteristics. In other words, the oxygen system and aircraft electrical subsystem(s) must be compatible. The final test will be in flight with the aircraft crew members using oxygen.

VERIFICATION LESSONS LEARNED

3.2.1.4 **Environmental conditions.** The aircraft oxygen system shall be designed such that it is qualified to the environmental extremes as follows: ________________.

REQUIREMENT RATIONALE (3.2.1.4)

It is necessary that the oxygen equipment properly function in the environmental extremes of aircraft flight, aircraft ground basing, and shipment and storage of equipment components.

REQUIREMENT GUIDANCE

The standard environmental qualification requirements that should be considered are:

a. Low temperature exposure and operation

b. High temperature exposure and operation

c. Altitude cycling (low and high pressure)

d. Temperature shock

e. Temperature-altitude cycling

f. Humidity

g. Fungus

h. Salt fog

i. Dust

j. Explosive atmosphere

k. Vibration

l. Acoustical noise

m. Shock in handling, transportation, and service

n. Acceleration loading

o. Explosive decompression

p. Ozone

The most desirable approach in detailing these requirements to the oxygen system under development is to use the handbook format of MIL-STD-810 to tailored environmental requirements. The oxygen equipment under development will have weaknesses in design that should be fully qualified. For example, if many different metals are used, salt fog testing is essential to determine corrosion properties. MIL-STD-210 contains worldwide environment information and may be used for additional assistance in tailoring environmental requirements. It should be kept in mind that these requirements represent accelerated use of the equipment and subject the equipment to extremes possibly not often encountered in actual service. The important point, however, is that the equipment must properly function after these environmental extremes. A good example of this type of situation is a cockpit or cabin-rapid (explosive) decompression. This is not normal service but an emergency situation. However, the equipment for life support must still provide life support to the on-board crewmember(s) and passengers (if applicable).

REQUIREMENT LESSONS LEARNED

An example of design to high temperature, which very early in aircraft oxygen systems was not considered, is hot-purge cleaning. The high temperature limit originally applied to liquid oxygen (LOX) systems was 160°F. Later, it was determined that temperatures in excess of 200°F were necessary for adequate hot-purging of all plumbing components. Clean, dry oxygen and nitrogen could be used for hot-purging all oxygen system plumbing to drive off accumulated moisture and contaminants. Also, the LOX supply source or converter would have to be baked in an oven after overhaul at the depot to drive off moisture. The high temperature exposure limit has been raised from 160°F to 260°F. This places an additional design constraint on the design of the LOX system components.

Reference AFALC/PTL, Wright-Patterson AFB, OH, Abstract of Lessons Learned, 1 Jan 1984. LL #0981--When off-the-shelf equipment of government furnished equipment is used, environmental testing should be accomplished to ensure that the equipment will operate in its new environment. An example is shown where a piece of off-the-shelf equipment did not work in the new application. LL #1004--Electronic subcomponents of tactical equipment end items that must operate outside, away from the end item, must be environment tested during acquisition to ensure they are weatherproof. Electronic equipment must be environmentally safeguarded.

4.2.1.4 **Environmental testing.** The hardware, materials, and components of the oxygen system shall operate satisfactorily under the following tests: ______________.

VERIFICATION RATIONALE (4.2.1.4)

Environmental tests are needed to verify that the oxygen system equipment satisfactorily perform in the expected natural and induced environments.

VERIFICATION GUIDANCE

The environmental testing requirements specified should be used to check the equipment and components for satisfactory operation. Detailed test methods are outlined in MIL-STD-810 and, with environmental background data in MIL-STD-210, test methods may be determined that are tailored to the oxygen system.

VERIFICATION LESSONS LEARNED

Reference AFALC/PTL, Wright-Patterson AFB, OH, Abstract of Lessons Learned, 1 Jan 1984. LL #1399--Failure to complete certain qualification tests (at least temperature, altitude, vibration, and shock tests) prior to development test and evaluation (DT&E) can lead to program delays caused by premature hardware failures. LL #0706--Many times an improper fuel is used in explosive atmosphere testing. When testing for auto-ignition in an explosive atmosphere test chamber, the component being tested should be operated under the full range of conditions it will experience during its service life and be subjected to an explosive atmosphere provided by simple, preferably single, component fuels, with the lowest auto-ignition temperature and flash point.

3.2.1.5 **Transportability.** Certain transportability features are desired in the design of the oxygen system components. The oxygen system components are __________. The transportability features should consist of __________.

REQUIREMENT RATIONALE (3.2.1.5)

Some oxygen system components must be used in or shipped by military air transport aircraft. The transport tie-down method and space constraints should be called out to be consistent with existing techniques.

REQUIREMENT GUIDANCE

MIL-HDBK-157, titled "Transportability Criteria," provides detailed design information that should be considered. Of primary concern is restraint of the oxygen equipment while in the cargo compartment of the aircraft. Another concern is safety while transporting gaseous and/or liquid oxygen equipment. It also may be desired to use the oxygen supply while in transport such as with high altitude paratroops or with aeromedical oxygen equipment for personnel under medical care while in transport.

REQUIREMENT LESSONS LEARNED

4.2.1.5 **Transportability verification.** The oxygen equipment transportability features shall be verified by __________.

VERIFICATION RATIONALE (4.2.1.5)

It is desirable to determine that the transportability design features are adequate for the planned use of the oxygen equipment.

VERIFICATION GUIDANCE

The verification should consist of analyses, inspections, demonstrations, and tests as necessary to determine that the transportability design features will be adequate.

VERIFICATION LESSONS LEARNED

3.2.2 Functional subsystem characteristics. In the design and installation of the functional subsystems and equipment groups of the entire aircraft oxygen system, the following oxygen subsystems and equipment shall be used: ______________.

REQUIREMENT RATIONALE (3.2.2)

Only certain functional oxygen subsystems and equipment apply to the design of the total aircraft oxygen system. Those that apply should be called out in this paragraph.

REQUIREMENT GUIDANCE

Functional oxygen subsystems and equipment are listed in 3.1 and are discussed indepth in the following 3.2.2.X paragraphs. Cite only those subsystems and equipment applicable to the aircraft under consideration.

REQUIREMENT LESSONS LEARNED

4.2.2 Verification of functional subsystem characteristics. The functional subsystem characteristics verification shall consist of ____________.

VERIFICATION RATIONALE (4.2.2)

It is essential that the functional oxygen subsystems perform as expected under all specified performance-oriented requirements.

VERIFICATION GUIDANCE

The verification of the oxygen subsystems and equipment shall consist of analyses, inspections, demonstrations, and tests that verify the adequacy of functional subsystem characteristics.

VERIFICATION LESSONS LEARNED

3.2.2.1 **Crew oxygen system**. A crew oxygen system shall be provided that is regulated to the cockpit or cabin pressure altitude and which consists of the following delivery features ______(a)______. A warning shall be provided detectable by all crewmembers that functions when ______(b)______. The primary oxygen supply for crewmembers who operate and monitor the aircraft and its subsystems shall be from a separate supply source than for other personnel (if applicable) and shall have features ______(c)______. The crew oxygen system supply shall be sized to provide pressure demand regulated oxygen for all crewmembers at an average flow rate of __(d)__ litres/hour per crewmember for a minimum of __(d)__ hours. The oxygen system distribution lines shall operate under an internal pressure range of __(e)__ psi and shall allow a maximum gaseous flow rate throughout of ______(e)______.

REQUIREMENT RATIONALE (3.2.2.1)

a. It is necessary to physiologically support the crewmembers' breathing requirements under all expected aircraft altitudes and g force environments. Breathing regulator, delivery hoses and connectors, and required mask performance characteristics should be specified here.

b. A warning device is required in the event supplemental oxygen is needed in the aircraft under conditions of rapid decompression. Air Force flight regulations require supplemental oxygen be available to all passengers and crewmembers at cabin pressure altitudes exceeding 10,000 feet. Also, a warning may be desired in the event an oxygen supply is not available to the crewmember.

c. An oxygen supply source for crewmembers separate from that of passengers (if applicable) is required to enhance the survivability of the aircraft. Generally, the oxygen requirement of passengers differs from that of crewmembers, thus different type valves and regulation are required. Periods of peak flow rates from the passenger compartment could reduce the availability of oxygen for the pilots and other flight deck crewmembers. From a survivability standpoint, should a converter or pressure vessel burst, oxygen would not be available for pilots or passengers. A separate supply source for crewmembers assures the pilots would have oxygen in this situation. The crewmembers should be in control of the distribution lines.

d. The oxygen sizing requirement is necessary to instruct the designer as to the minimum supply necessary to complete all planned missions. In an emergency (should mission completion not be required), sufficient oxygen should be available for flight to an alternate destination.

e. Many oxygen plumbing components are available that have specified pressure and flow rate ranges. Higher line pressures are needed to maintain desired flow rates for more than two outlets. It is necessary to specify the desired operational pressure range and maximum flow rates for the aircraft under consideration to ensure all equipment will properly integrate.

REQUIREMENT GUIDANCE

a. An increasing percentage of oxygen should be added up to approximately 30,000 feet cabin pressure altitude. Ninety-five to 100 percent oxygen is delivered at all altitudes above this. Slight positive pressure breathing should be provided beginning at 30,000 feet cabin pressure altitude. Increased positive pressure breathing should be provided at cabin pressure altitudes from 30,000 to 40,000 feet. Substantially increased positive pressure delivery to the mask is necessary at 40,000 to 50,000 feet. At altitudes above 50,000 feet, breathing is not possible for time periods longer than a few minutes without a counterpressure applied to exterior of the torso. This is accomplished when the crewmember wears a partial or full pressure suit.

For a LOX and a gaseous system, air dilution should be provided between sea level and 28,000 feet pressure altitude at flow rates ranging from at least 140 to 240 litres per hour according to table I.

TABLE I. Normal oxygen delivery characteristics.

Altitude (ft)	Percent oxygen (typical)	Oxygen flow rate (LPH)
Sea level	30	240
5,000	26	172
8,000	26	151
10,000	27	143
15,000	32	140
20,000	47	159
25,000	73	194
28,000	100	225

The air dilution schedule should be determined to satisfy the partial pressure of oxygen in the alveoli such that the lungs are never at a pressure altitiude higher than 5,000 feet. The limit of 5,000 feet instead of 10,000 feet--the flight regulation altitude without supplemental oxygen--is to ensure the pilot will have adequate night vision. It is not desirable to provide 100 percent oxygen to the crewmember(s) all the time. Breathing high concentrations of oxygen for extended periods of time is unacceptable in noncombat aircraft and transports if the period of exposure is greater than six hours. In combat aircraft such as fighters, breathing 100 percent oxygen is unacceptable for all conditions except emergencies. Physiological data shows that a minimum of 40 percent nitrogen in the inspired gas is necessary to avoid atalectasis. To avoid lung irritation problems at one atmosphere, oxygen concentration should not exceed 60 to 75 percent. Lung irritation is more pronounced when the crewmember is exposed to the acceleration forces of flight.

The crewmember oxygen system should have the capability of delivering 95-100 percent oxygen at all altitudes by manual selection. The means of regulation should deliver the maximum percentage of oxygen that is available at all pressure altitudes above 28,000 feet. To meet the minimum physiological requirements, time-averaged oxygen flow rates should vary from 225 to 801 litres per hour, dependent on the aircraft altitude according to table II.

TABLE II. Minimum oxygen consumption rates.

Pressure altitude (ft)	Flow rate (LPH)
Sea Level	801
5,000	658
8,000	581
10,000	535
15,000	429
20,000	340
25,000	265
28,000 and above	225

b. In a transport aircraft, a warning consisting of at least an audible bell or horn should be provided to alert all passengers to don oxygen equipment. This should be audible in flight with the engines running. It may also be desirable to include visual signals in all crew stations. Should oxygen flow automatically to the mask assemblies, an oxygen "ON" light should illuminate at each crewmember station within his primary field of view. In aircraft such as fighters, small trainers, fighter-bombers, and attack aircraft, the cabin pressure altitude during normal flight ranges up to 25,000 feet depending on the aircraft altitiude. The crewmember uses his oxygen equipment at all times. For this reason, an audible warning for decompression is not essential, but a visual warning is desirable.

c. The requirement for a separate supply source should be added only for larger aircraft that carry passengers. Aircraft with only crewmembers normally carry only one source of oxygen supply, and the requirement is not necessary. A separate supply source for the crew ensures they have control over their breathing gas and have an adequate supply to safely land the aircraft in all emergency situations.

d. The maximum number of crewmembers that can be on-board the aircraft at one time should be stated. This may be more than the number of seats provided. For example, pressure demand oxygen may be available at instructor positions and rest areas. While it is possible to ask the designer to do a detailed analysis considering all aspects of the mission and various regulation control settings, it may not be necessary. Tables I, II, and III of MIL-D-19326F provide information to do this. To determine a value for the average flow rates, the following example is given: Considering that fighter aircraft take off with 100 percent oxygen, use air dilution on climb and descent up to 28,000 feet pressure altitude and 100 percent above 28,000 feet pressure altitude, the average flow rate may be determined. The following calculations are for a fighter aircraft with one crewmember:

Sea level on 100 percent oxygen for 15 minutes

800 litres/hr x 1/4 hr = <u>200 litres</u>

Climb to 35,000 feet for 15 minutes

1.35 x 175 litres/hr* x 1/4 hr = <u>59.1 litres</u>

* 175 LPH is an average flow rate

Cruise at 35,000 feet for 15 hours with cabin pressure altitude at 25,000 feet (consider refueling of the aircraft)

265 litres/hr x 15 hrs = <u>3975 litres</u>

Aerial combat and threat for 30 minutes

1.75 x 265 litres/hr** x 1/2 hr = <u>232 litres</u>

** An average rate based on worst case of cabin pressure altitude of 25,000 feet.

Descent and landing for 15 minutes

1.35 x 175 litres/hr x 1/4 hr = <u>59.1 litres</u>

(200 + 59.1 + 3975 + 232 + 59.1) litres = <u>4525.1 litres total</u>

The average flow rate is calculated as follows:

$$\frac{4525.2 \text{ litres (total)}}{16.25 \text{ hrs}} = 278.5 \text{ LPH}$$

Note that the computation method discussed in the text of in MIL-D-19326 is very complicated and difficult to work with. The above calculation can be determined for all possible missions and is easier to work with. The worst case mission should be used to determine the average flow rate requirement. Should the designer decide to use a LOX system, 3030 litres of oxygen gas are available from a 5-litre converter and 6540 litres of oxygen gas are available from a 10-litre converter 24 hours after servicing. However, most fighter aircraft use a lower supply and have a 5-litre LOX converter. Logically, the designer should choose to use a 10-litre LOX converter. Should a gaseous system be used, the design can determine the minimum size of the pressure vessel at its rated pressure, which is normally 1800 psi. If an on-board oxygen generating system (OBOGS) is used, oxygen is generated continuously. This means the supply need not be sized, but an OBOGS system must deliver normal and peak flow rates for all aircraft flight conditions.

e. Most small aircraft, such as fighters, use oxygen equipment that operates in the low pressure range of 70 psi. This is possible since only a few outlets are plumbed to the supply. Larger aircraft, such as transports, must supply oxygen to many outlets. This means there will be a greater overall pressure drop under moderate and high demand flow rate conditions. The operational pressure range for these systems is 0-500 psi; however, 300 psi is considered the normal operational pressure. Under very high demand the internal pressure range will drop. This high demand or flow rate is needed to meet the physiological requirements of aircraft personnel. Fighter pilots will need the greatest flow rates when accomplishing an M-1 maneuver for high Gs. In LOX systems, after shut-off of supply there will be a pressure rise up to 400-450 psi. Should pressure vessels be used as oxygen supply, the oxygen usually will be stored at 1,800 psi. The reason, of course, is to reduce the volume required for storage. Pressure vessels in the 3,000 to 6,000 psi pressure range are under research at this time. There are limitations on the capability of the 3,000 to 6,000 psi pressure vessels to deliver 100 percent at high velocities without explosion. The unique and bulky support equipment required for recharging is another limitation. On-board oxygen generating systems have components that operate in different pressure ranges. Most molecular sieve OBOGS concentrators draw conditioned air in the 10-120 psi pressure range and deliver breathing gas in the 10-70 psi pressure range. USAF OBOGS have backup oxygen systems that store pressurized oxygen gas in 1,800 psi pressure vessels. This supplements the oxygen delivery system in the event of a failure of the concentrator or related delivery components or if the engine bleed air is outside the envelope needed to support the physiological requirements of the crewmembers.

REQUIREMENT LESSONS LEARNED

a. Before 1955, diluter-demand breathing regulators provided fractional amounts of oxygen to the breathing air at lower altitudes and 100 percent oxygen at higher altitudes. The problem was that the concentration ratios of oxygen-to-air were not precise, and in many cases, the crewmembers manually selected 100 percent oxygen to ensure an adequate supply of oxygen to preclude hypoxia. Additionally, this would preclude the breathing of contaminants that may be in the air and find their way through the dilution intake valve. The slight-positive pressure and increased positive pressure breathing were not provided. This design resulted in increased incidents of hypoxia at higher altitudes. Recent research has shown that alveolar atalectasis may be a problem for the crewmembers that breathe 100 percent oxygen during high g acceleration flight maneuvers. Pressure demand regulators as specified herein minimize these problems.

b. The MBU-5/P used a nylon cord, while MBU-7/P used a steel cable to limit delivery tube stretch. The nylon cord was determined to be significantly better because it has some shock absorbing capability while steel cable has none. If no shock absorbing capability is provided, the mask may be more easily pulled from the pilot's face as he moves about his station.

c. To reduce oxygen waste and servicing, from a logistics standpoint, it is often desirable either to remove the passenger LOX converter or to leave it with only a small amount of LOX. The reason for this is these aircraft spend the majority of the time transporting cargo rather than passengers. A smaller crewmember oxygen supply LOX converter is maintained on the aircraft. Also, most pilots are reluctant to allow passengers or personnel in the passenger compartment to have control over oxygen supply. A separate crewmember oxygen supply source precludes these problems.

d. (To be supplied as acquired)

e. An incident on a larger aircraft used by the USAF, which has many mission specialists, involved the failure of a large number of pressure demand regulators. A large number of regulators puts a very high demand on the aircraft converters, especially when all crewmembers put their regulators in the "100 percent/emergency" control position during an emergency decompression. With a loose face mask and altitudes above 10,000 feet, many current pressure demand regulators nominally supply 15-20 LPM and up to 135 LPM of gaseous oxygen. This pulls LOX from the converter as far downstream as is possible under any operational condition. Should the evaporating heat exchanger not efficiently and rapidly convert LOX to gaseous oxygen, too much LOX will be caught in the evaporating heat exchanger and will either vent overboard or, if trapped, expand in the plumbing to gas. Should the volume downstream in the plumbing not be enough, there will be a pressure rise. A pressure above 500 psi would be hazardous and unacceptable. Regulators will be damaged or leaks may develop at joint couplings if system relief valves are not incorporated or if provisions for overpressure are not provided.

4.2.2.1 **Verification of crew oxygen system.** The verification of the crew oxygen system shall consist of ____________.

VERIFICATION RATIONALE (4.2.2.1)

Verification of the crew oxygen delivery components is needed to ensure that they properly function in the expected operational environment and meet the physiological needs of the crewmembers.

VERIFICATION GUIDANCE

The verification of the crew oxygen system should consist of analyses, inspections, demonstrations, and tests as necessary to ensure that all requirements have not been met. Some past methods of verification that have been used and are considered desirable are:

a. The total crew oxygen should be inspected to ensure that all components have been provided and that the system complies with the approved design detail drawings.

b. After the oxygen equipment has been installed on the aircraft, each component should be inspected to ensure all required military or contractor installation practices have been followed. This should include supply location and mounting, plumbing routing and mounting, regulator and valve installations, and any of the cockpit equipment installations.

c. The oxygen system design should be analyzed and tested as necessary to determine that physiologically compatible oxygen concentrations, flow rates, pressures, temperatures, and contaminant-free oxygen or breathing gas is delivered to each person within the operational envelope of the aircraft. The cabin pressure altitude and the flight altitude of the aircraft for normal and emergency situations should be considered. Oxygen equipment performance in all other emergency situations, such as seat ejection, should be analyzed. The variables involved in the fluid dynamics of the oxygen system plumbing and components is great. Many physiological requirements are specified in terms of oxygen concentrations, flow rates, pressures, temperatures, and air purity. Therefore, these variables need to be considered for final installations

d. The oxygen system, as installed on the aircraft, should be made fully operational and all individual components demonstrated to meet functional performance requirements. While this sort of demonstration has been accomplished on the ground or runway in past aircraft installations, not all equipment may be accurately checked at only one altitude and temperature For example, the pressure altitude compensating regulator on continuous flow subsystems of transport aircraft allows oxygen to flow downstream at a preset altitude of 10,000 to 15,000 feet and flow rates are regulated as a function of altitude. This may not be easily demonstrated on the ground. Another example is that heat exchangers on LOX systems operate most efficiently at ground level where the ambient temperature is highest. Less efficient operation may be encountered at higher altitudes from the lower ambient temperatures for any heat exchanging equipment mounted in an unpressurized compartment. Higher altitudes will be the normal environment in which the oxygen system must operate. This does not mean, however, that oxygen system ground demonstration has no value. Many things may be checked in this procedure: delivery of breathing gas at all outlets may be checked, prior pressurization ranges in all plumbing may be determined, leak checks may be accomplished, proper opening and closing of all valves may be evaluated, and proper connection of all low pressure hoses may be determined.

e. Crewmembers should check the proper functioning of all audible and visual warning devices in the expected environments. For example, visual indicators should be detected in high brightness levels of sunlight. Associated controls should be checked for functional compatibility with the associated displays and components.

f. Crewmembers should demonstrate quick oxygen availability by following and timing the applicable procedure. This may apply to quick donning of oxygen masks and initiating of oxygen supply. The actual procedure expected to be used in the mission should apply to these demonstrations. To make it realistic, try a demonstration without a debriefing and then with a debriefing.

g. For newly developed personal oxygen equipment such as masks, hoses, breathing regulators, and connectors for quick disconnects, laboratory tests should be performed to ensure that the equipment is physiologically compatible with the personnel who will use it. The tests should consist of measurement versus altitude of inhalation and exhalation mask pressure swings, mask and hose breathing resistance, regulator output air dilution, average breathing gas flow rates, and breathing gas peak flow rates. Other altitude chamber tests are also desirable. A critical scenario in which to test equipment in is a rapid high altitude (30,000 to 50,000 feet) decompression. However, the proper functioning of the breathing equipment should be tested from sea level to the expected operational ceiling (50,000 to 65,000 feet).

h. The oxygen system should be instrumented as necessary and used by flight personnel in flight tests to ensure the equipment operates as specified and is functional with all crewmembers during all aircraft missions. Not all conditions may have been encountered in laboratory testing. Use of the equipment in flight tests should provide a thorough evaluation of operational compatibility and the general usability of the oxygen equipment.

VERIFICATION LESSONS LEARNED

a. Past experience has shown that not all essential inspection items are covered by contract specifications. For example, in some military aircraft not enough walk-around breathing assemblies have been provided. Also, on some aircraft not every seated position would have supplemental oxygen available. The military would have to supply more portable assemblies for decompression emergencies. To preclude problems of this sort, complete receiving inspection lists should be included in the contract. These lists should contain the number of oxygen system components provided, such as regulators, masks, hoses, supply containers or generators, valves, heat exchangers, and any other piece of equipment.

b. Problems have been encountered with the plumbing installations. In aircraft ground tests, the lines have been pressurized and leaks have developed. In these situations, the designer may elect to use a lubricant to accomplish closure of all connections without leaks. Many times an improper lubricant has been used. This creates a potential for a severe fire, explosion, and toxic hazard in the oxygen system. For example, a petroleum jelly Rycol 1-R was mistakenly used in a fighter aircraft oxygen plumbing installation and it had to be disassembled, cleaned, and reassembled. This type of installation problem has been encountered quite often. Only a lubricant in accordance with MIL-G-27617 is allowed for use in military aircraft oxygen system installations.

c. Past quick-donning tests in commercial aircraft with crewmembers have shown that it may take up to 90 seconds for crewmembers to pull down the oxygen mask suspension assemblies and place the mask on the face. It has also been verified by testing that these crewmembers may reduce their quick-donning times to 5-10 seconds by classroom instruction and equipment orientation. This experience has proven that more periodic orientation with the quick-donning mask assemblies will ensure more successful use of oxygen when it is required in an emergency decompression.

d. Flight tests are essential to check critical items such as the line pressure during periods of peak flow. Pressure demand regulators used in most military aircraft will not function properly if the line pressure drops below 50 psig. Another possible problem is that continuous flow altitude compensating regulators may have to deliver oxygen supply to too many outlets, resulting in too low a delivery pressure with the associated flow rates. A good example to illustrate how the lack of complete flight testing resulted in oxygen system design problems is the E-4 aircraft. This aircraft is a derivative of the Boeing 747, modified to accommodate 120 mission specialist crew positions and over 20 seated and litter positions. More than 140 crew and passenger positions are available with CRU-73/A type pressure demand oxygen regulators. Emergency decompression operations are being practiced to train and familiarize all the crewmembers and passengers on-board the aircraft. All occupants select the 100 percent emergency oxygen regulator operating mode at once. This supplies positive pressure breathing at flow rates from 15 LPM to 135 LPM depending on cabin pressure altitude and mask fit. Flow rates have been so rapid that the system pulls LOX long distances past the evaporating heat exchangers. When the aircraft reaches a lower, safe breathing altitude of approximately 10,000 feet all regulators are shut off. This results in LOX being trapped within the distribution plumbing past the vaporizing heat exchangers. As time goes by, even after the aircraft has landed and is evacuated, LOX converts to gas and pressure builds up within the distribution plumbing. In one known case, this pressure damaged every breathing regulator on the aircraft. In most LOX systems vaporizing LOX and oxygen gas is vented through the converter overboard vent valving. In this aircraft one way flow LOX check valves preclude this. Engineering design changes will eliminate these check valves to preclude over pressurization in the distribution plumbing. Also, it has been proposed that pressure gages be added to each of four branch lines and the oxygen gas pressure be monitored in flight and after flight by a crewmember. The point to be made is this: had a proper test been conducted right after the design, all these problems would have been discovered. The only test conducted after installation of the oxygen system was on the ground during a warm summer day with regulators set at 100 percent oxygen. This test showed a frost line on the plumbing some 60-80 feet past the vaporizing heat exchanger. This was considered acceptable, but it should not have been. To more realistically simulate the actual aircraft decompression situation in a cold environment on the heat exchanger and plumbing, the emergency breathing regulator mode and some loose mask fittings should have been used as test conditions for a worst case. Altitudes above sea level should have been used, as these regulators increase flow rates at higher altitudes. An emergency decompression in actual flight would be an even better test. A fail-safe design would provide a heat exchanger sized to accommodate the maximum flow rate of the LOX converter.

3.2.2.1.1 **Crew controls and displays.** Each crewmember shall have oxygen system displays consisting of ______(a)______ and controls consisting of ______(a)______. Emergency quick-donning mask assemblies shall incorporate the intercommunication microphone and headset open to all crewmembers (b). Test controls shall be provided to check for the proper functioning of all lighted displays, indicators, instruments, and ______(c)______. The controls and displays provided shall be functionally compatible with the crew oxygen system (d). Emergency oxygen system controls and displays consisting of ______(e)______ shall be provided to alert the appropriate personnel of ______(e)______.

REQUIREMENT RATIONALE (3.2.2.1.1)

a. A minimum of information and control functions should be required for each crewmember to effectively use oxygen equipment on-board the aircraft.

b. Intercommunication microphones and headsets open to all crewmembers provide ease of communication that is essential to complete tasks in an emergency situation in which a rapid cabin decompression occurs.

c. A means for the crewmember to check while in flight for the proper functioning of lighted indicators is required to ensure bulbs have not burned out and lighted displays are illuminated for the proper situation. It is also essential that the crewmember be able to check for the proper functioning of indicators and instruments such as a pressure gage (see figure 1).

d. This requirement ensures that the designer provides controls and displays that have electrical and pressure characteristics compatible with the operating ranges of the oxygen system components to be provided.

e. The selection of proper locations and the method of presentation for emergency displays and operation of emergency controls should ensure the appropriate crewmember will receive his warning in time to take corrective action.

REQUIREMENT GUIDANCE

a. Visual flow information may be provided. Usually this is a blinker assembly to indicate to the crewmember that he is inhaling air-enriched oxygen from the regulator assembly and not from leaks in the mask and hose assembly that connects to the regulator output (see figure 1). Also, visual flow information may be provided consisting of a pressure gage to indicate the pressure of oxygen at the inlet of the regulator assembly. This confirms to the crewmember that oxygen delivery equipment is functioning properly and that the crewmember is receiving air-enriched oxygen and not just air through the air intake port. Quantity and/or pressure information is essential for gaseous and LOX containers so the crewmember may determine during preflight checks that a sufficient supply of oxygen is available for the planned mission. In flight, the crewmember may determine the approximate time available for use of oxygen at higher altitudes. After landing the aircraft, a crewmember may indicate to the ground support crew that a resupply of oxygen is required (see figure 1). Controls that may be provided should be the minimum essential number of controls needed for the proper operation of the crew oxygen system in all flight operation situations. Some controls to consider are an "ON/OFF" oxygen delivery control, an air dilution or normal functioning mode control, a "95-100 percent oxygen" control, an emergency control that allows the crewmember to select positive pressure breathing of 95-100 percent oxygen, and a control for manual selection of backup oxygen supply in the event of a failure of the primary oxygen system.

b. For aircraft with an environmental control system (ECS) that maintains the cabin pressure altitude at 10,000 feet or lower (8,000 feet typically), it is not necessary for the crewmember to wear oxygen equipment at all times. In this case, emergency quick-donning assemblies are usually provided in the event of a rapid cabin decompression (15 seconds or less). In such an emergency, the crewmembers will be preoccupied with activation of many flight-essential controls and must be in contact with all other crewmembers. This requires that emergency quick-donning assemblies incorporate hot mikes open to all crewmembers.

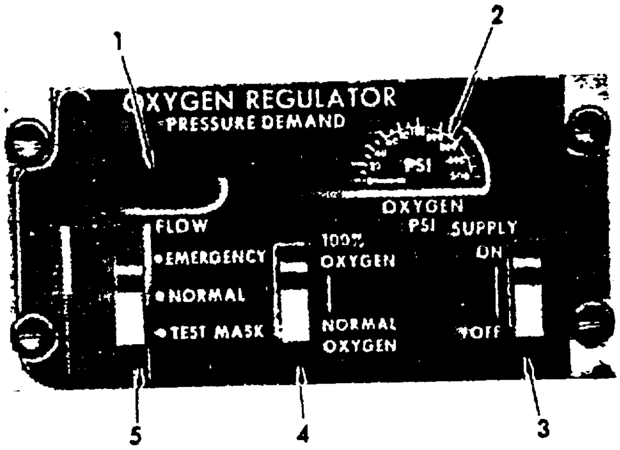
c. These controls are essential in all aircraft that do not incorporate built-in automatic test equipment. Without the proper functioning of all oxygen equipment controls and displays the crewmember could not know the status of his oxygen supply, delivery capability, and proper functioning of all components in the system.

d. It is desirable that all electrical and pressure range characteristics of the controls and displays be specified in the designer's version of the applicable specification. The Request for Proposal, as developed by the procuring activity, should not contain this detailed information because this level of detail cannot easily be specified without having a design solution.

e. Crew station and human factors design criteria have provisions for this design. Warning displays that require immediate corrective action should be red and located in the crewmember's prime visual area (directly in front of him). Warning displays that do not require immediate corrective action may be yellow. Refer to the crew station and lighting Mil Prime for additional guidance.

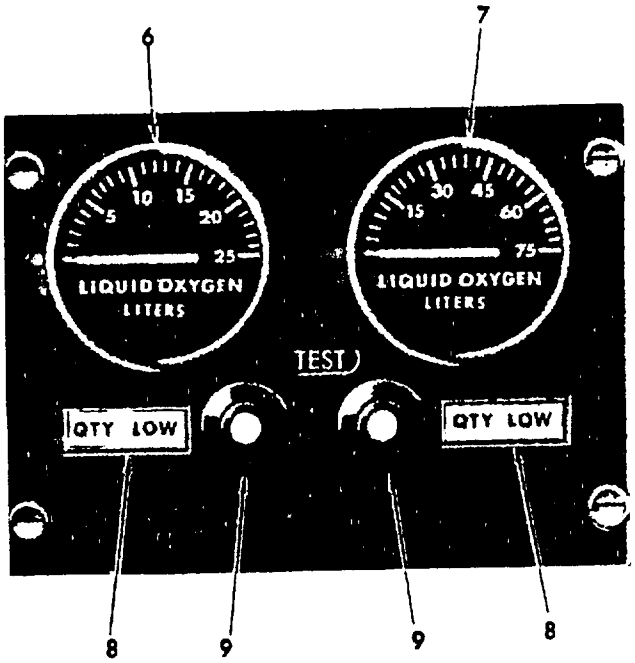
The low quantity or pressure warning is an indication to the pilots that a malfunction or leak of oxygen has provided a lower supply than planned. For crewmembers that have not followed preflight check it indicates that a situation is pending which will require descent to 10,000 feet pressure altitude (see figure 1).

The system malfunction information provided is determined by the type of oxygen supply and plumbing components. Should an on-board oxygen generating system be provided, this information could consist of electrical failure, loss of bleed air pressure, concentrator outlet pressure, or some other failure that causes loss of oxygen generation.



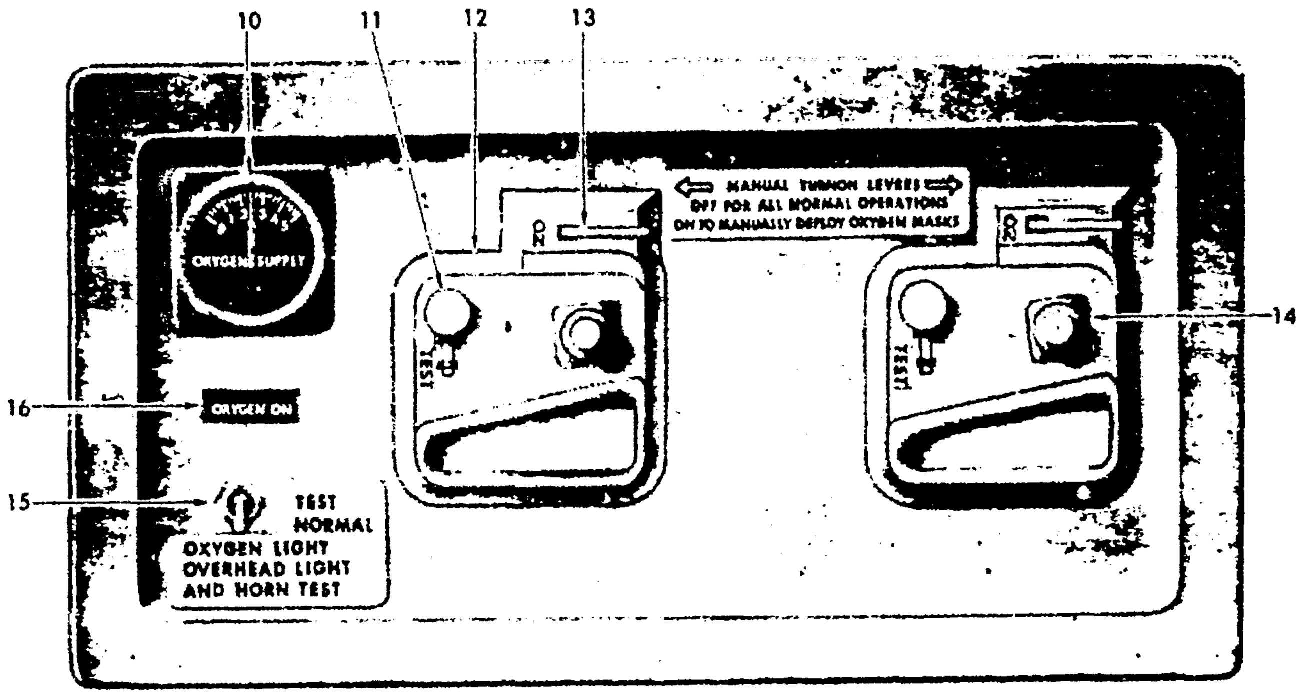
Crew Oxygen Regulator Panel

Pilot's Overhead Panel



Flight Engineer's
Oxygen System Panel
For 25 Litre and
75 Litre Converters

FIGURE 1. Typical example of control and display installation for passenger and crew on C-5A aircraft.



CONTINUOUS FLOW OXYGEN REGULATOR PANEL

1. VISUAL FLOW INDICATOR
2. PRESSURE GAGE
3. SUPPLY LEVER
4. DILUTER LEVER
5. EMERGENCY TOGGLE LEVER
6. LIQUID OXYGEN INDICATOR (25-LITER)
7. LIQUID OXYGEN INDICATOR (75-LITER)
8. LIQUID OXYGEN QUANTITY LOW INDICATORS
9. TEST SWITCHES
10. SUPPLY PRESSURE GAGE
11. CABIN ALTITUDE SENSING AND TEST PORT
12. CONTINUOUS FLOW OXYGEN REGULATOR
13. REGULATOR MANUAL TURN-ON LEVER
14. REGULATOR ON-OFF INDICATOR
15. TEST SWITCH
16. OXYGEN ON LIGHT
17. OXYGEN MASK STORAGE CONTAINER
18. MASK HOSE
19. HEAD STRAP
20. OXYGEN MASK
21. LANYARD
22. CONTAINER DOOR

FIGURE 1 Typical example of control and display installation for passenger and crew on C-5A aircraft - cont'd.

REQUIREMENT LESSONS LEARNED

a. Past experience has shown the primary control and display problem to be accessibility to the crewmember. Another problem was the crewmembers' misinterpreting the control position. For example, on the CRU-68 and CRU-73/A type panel-mounted regulators, an "ON/OFF" switch is provided to initiate oxygen supply to the crewmember's hose and mask. The design incorporates an over center cam design that has a tendency to stick in the center position. Lubrication is not possible without fire hazards. The crewmember may also misinterpret the switch position as oxygen "ON" when it is really "OFF".

(b. through d. to be supplied as acquired)

e. The best design practice for sensing low supply and providing a warning to the crewmember(s) for LOX converters is to illuminate a yellow caution light when the amount of supply reaches a minimum of 10 percent. This practice has been applied successfully on past systems. Only recently has the value at which the caution light illuminates been increased to 40 percent on modern fighter aircraft such as the F-15 and F-16. This supply system is to be used with the new Integrated Chemical Defense System (ICDS) under development consideration for these aircraft in the late 1980s. A low supply caution point of 40 percent will cause display illumination too frequently to be useful, resulting more in a distraction than a caution to crewmember(s). It should be remembered that a quantity indicator is provided as well, and instrument check of this display will indicate to the pilot(s) normal oxygen system functioning. The purpose of the warning indicator is to alert the pilot(s) in the event of an abnormal problem, such as loss of oxygen supply due to a leak.

4.2.2.1.1 **Verification of crew oxygen controls and displays.** The verification of the crewmembers' controls and displays shall consist of __________.

VERIFICATION RATIONALE (4.2.2.1.1)

Verification of the controls and displays of the crew oxygen system is necessary to ensure that they properly function, are accurate, and meet the needs of the crewmembers in the expected operational environment.

VERIFICATION GUIDANCE

The verification of the crew oxygen system should consist of analyes, inspections, demonstrations, and tests as necessary to ensure that all requirements have been met. Some past methods of verification that have been used and are considered desirable are discussed in 4.2.1 and as follows:

a. The suitability of controls and displays may best be checked by outlining operational scenarios in which they are expected to be used, then going through the sequence of events as they are expected to occur. This task analysis may be accomplished on paper, then checked by simulation on the actual prototype equipment. The final tests are accomplished in operational flight test evaluations.

b. The performance of displays within expected operational environments and their location in the crew station should be evaluated. For example, are all displays viewable in high intensity light conditions expected from sunlight and are all displays viewable at night? Controls must be accessible and the crewmember should be able to ascertain the control positions to determine which modes he has selected.

c. Quick-donning mask assembly intercom microphone and headset may be checked for suitability by personnel demonstrations on the aircraft. This should include operation of other electronic equipment while in flight to determine if a functional incompatibility exists.

d. Instruments and gages should be properly calibrated at the manufacturer's facility, but in the installation of this equipment integration problems are likely to occur that require recalibration or changes.

VERIFICATION LESSONS LEARNED

a. The F-16 OBOGS flight test program uncovered numerous difficulties with the oxygen control and display arrangement that needed to be corrected. One problem involved a selector control that was improperly labeled with functions not necessarily consistent with the labeling. Also, the location of the selector control was not functionally grouped with all other oxygen functions. These types of discrepancies will not always be apparent in design and laboratory testing, but will usually be discovered in actual operation and use in the aircraft.

3.2.2.1.2 **Physiological features.** The crewmember respiratory provisions at normal conditions normal temperature, pressure, dry (NTPD) of sea level altitude, 760 mmHg, 70°F and dry shall be a minimum baseline minute volume per crewmember of (a) litres/minute (NTPD). The crewmember respiratory provisions at high demand flow for breathing while under high workloads or stress levels shall be (b) litres/minute (NTPD) per crewmember. The crewmember respiratory provisions for instantaneous peak demand flow for very high stress or workload shall be (c) litres/minute (NTPD) per crewmember. A pressure of (d) in the facepiece and a pressure range of (d) in the inlet delivery tubing shall activate inhalation and exhalation features.

REQUIREMENT RATIONALE (3.2.2.1.2)

a. This minimum baseline minute volume per crewmember requirement establishes the baseline in the oxygen system design.

b. The design of the oxygen delivery system should have the capability to provide breathing gas to all crewmembers during flight periods having high workloads and/or stress levels, such as air-to-air combat, emergency situations, and terrain following.

c. The design of the oxygen equipment should not preclude a crewmember's rapid and instantaneous peak demand flow breathing. It is therefore desirable to specify a value the designer may use.

d. In the past, the contractor's standard approach was to use available military personal equipment such as masks, hoses and inhalation/exhalation breathing valves. With the advent of many new types of oxygen delivery components, this is not always the case; therefore, a necessity for these pressure requirements exists to ensure that the design of oxygen equipment does not compromise breathing performance.

REQUIREMENT GUIDANCE

a. At this time, the minute volume per crewmember has been established at 13.35 (NTPD). Future physiological testing may refine this value.

b. The high demand flow is computed by dividing the total gas consumed during the high workload and/or stress level period by the period length in minutes. The amount of total gas consumed during the type of mission under consideration may be determined by examination of past flight test data. This should be aircraft of similar types. For example, fighter versus fighter and bomber versus bomber. Should NATO requirements be desired, see STANAG 3865.

c. It is most difficult to specify an instantaneous peak demand flow rate that can be used for design and checked in testing. The primary reason for this requirement is to preclude breathing resistance during very rapid inhalation. This is extremely important to the pilot(s) the instant it occurs. For example, when a fighter pilot pulls a high-g maneuver (this applies to aircraft capable of high-g maneuevers in excess of +3Gz), he must grunt and strain his body to keep from blacking out. Effectively, the pilot is trying to keep his blood from pooling to his legs by muscular contractions. To effectively strain, pilots must hold their breath most of the time. Inhalation and exhalation is rapid and difficult. This straining and breathing exercise is referred to as an M-1 maneuver. Peak flows can be as high as 200 LPM in these situations. It should be noted that inspiration flow rates to a maximum of about 600 LPM are physically possible under heavy exertions (e.g. sneeze or cough). At this time, however, 200 LPM has been established as the instantaneous peak demand flow for fighter and attack aircraft crewmembers, and 85-100 LPM is under consideration for bomber crewmembers. While the situations in which these flow rates occur will be seldom when examining the total mission of the aircraft, the times at which they do occur are very important to the survival of the pilot(s). The time interval or bandwidth of these flow rates will be very short (2 seconds and less) when they occur. As such, these flow rates are not relevant to sizing the aircraft oxygen supply, but are relevant to determining the response characteristics of valves and plumbing diameters.

d. In the MBU-12/P mask a pressure of 20 mmHg in the facepiece and a pressure range of 15 to 19.9 mmHg in the inlet tubing causes the exhalation portion of the breathing valve to open and expel exhaled air. Some commercially available breathing masks have rebreathing features. With this type of design, different pressure valves would activate the exhalation device. Except in pressure suits, these types of exhalation devices are not satisfactory for crewmember breathing equipment. The commercial masks with rebreathing features are used as backup or emergency oxygen supply in the event of a cabin decompression. The time period this equipment is used is not usually greater than 2 to 3 hours. This time period approaches the physiological limit of this type of breathing equipment. The baseline for inhalation and exhalation resistance is established with the MBU-12/P mask. This could be improved by lowering the exhalation pressure in the mask cavity, but the corresponding pressure in the delivery hose must be lowered to preclude opening of the inhalation valve. This requires the regulator to be designed to respond to these lower pressures.

REQUIREMENT LESSONS LEARNED

a. (to be supplied as acquired)

b. For a four-man crew on a B-1 combat mission, high demand flow has been determined from past flight test data to be about 40 litres (NTPD)/min/man. Past experience has shown that crewmember inspiration flow rates will triple when workloads are heavy. In fighter aircraft, inspiration rates up to 80 litres (NTPD)/min/man have been recorded. The primary reason for these very high rates of inspiration in fighter aircraft are the accelerative forces of flight imposed on the crewmember in a heavy workload situation.

c. through d. (to be supplied as acquired)

4.2.2.1.2 **Verification of physiological features.** The verification of the physiological features shall consist of ____________.

VERIFICATION RATIONALE (4.2.2.1.2)

Verification of physiological features of the crew oxygen delivery components is necessary to ensure that it properly functions in the expected operational environment and meets the physiological needs of the crewmembers.

VERIFICATION GUIDANCE

The verification of the crew oxygen equipment physiological features should consist of analyses, inspections, demonstrations, and tests as necessary to ensure that all performance requirements have been met. Some past methods of verification that have been used are discussed in 4.2.2.1 (see verification guidance paragraphs a, b, c, d, and g).

VERIFICATION LESSONS LEARNED

a. (to be supplied as acquired)

b. Past standards have not identified crewmember respiratory provisions at high demand flow for breathing while under high workloads and/or stress situations for different types of aircraft versus mission duties. It has generally been left to the option of the designer to estimate breathing rates that apply to each situation.

c. Past designs of oxygen equipment established peak flow rates in the vicinity of 100 to 150 LPM. Further work has adjusted these values for fighter and attack aircraft oxygen equipment. Flow rates delivered to the lungs may now be 200 LPM. The peak flow rates are a function over the time interval which they are measured. Normally, gas flow measurement devices have not had sufficiently quick response to measure these rapid flow rates as they occur. More than one measurement should be taken in a one-second time interval. Peak flow rates measured in flight tests have not exceeded 60-80 LPM even though analyses and laboratory tests show the crewmember may demand greater rates.

d. (to be supplied as acquired)

3.2.2.1.3 **Oxygen delivery features.** The oxygen concentration for air dilution shall be provided to each crewmember within the following limits: ___(a)___. Positive mask pressure is required above ___(b)___ feet cabin altitude and for ___(b)___. To provide user comfort and to minimize the possibility of hyperventilation due to the sensation of resistance to breathing, mask cavity pressures shall conform to the limits of table 3 or 4 (c). An emergency breathing feature shall be provided that delivers 95-100 percent oxygen at a pressure of ___(d)___ and flow rate of ___(d)___.

TABLE III. MBU-12/P mask breathing resistance requirements.

Flow Rate (LPM)	Inspiration (Inches WG)	Expiration (Inches WG)
50	5.23	
100	10.45	8.72

TABLE IV. Integrated chemical defense system breathing resistance requirements.

Flow Rate (LPM) (Inspiration/ Expiration)	Maximum pressure (inches WG)	Pressure swing (inches WG)
30	+3.0	2.0
85	+3.5	2.9
150	+5.0	7.0
200	+6.0	12.0

REQUIREMENT RATIONALE (3.2.2.1.3)

a. It is essential to specify to the designer the oxygen concentration values desired in the design. Oxygen regulation must be designed to meet required physiological limits. Upper (if required) and lower (always required) limits shall be specified as a function of cabin pressure altitude.

b. There is a cabin pressure altitude above which the delivery on 100 percent oxygen will not meet the minimum alveolar partial pressure of oxygen required in the crewmember's lungs. To increase the alveolar partial pressure of oxygen in the lungs, positive pressure is used. The USAF flight regulations places the limit that positive pressure can be provided while still meeting the physiological limits of the crewmember at 50,000 feet cabin pressure altitude. Positive pressure may also be desired to enhance a crewmember's g tolerance in aircraft maneuvers.

c. The primary reason for this requirement is so the designer may know the design goals. Quantitative values should be specified so the composite of breathing equipment including face mask, inhalation/exhalation valves, delivery hoses, and regulator will be provided to enhance user comfort.

d. In emergency situations, such as a rapid cabin decompression and seat ejection, a high positive pressure and oxygen concentration feature is required. This precludes the crewmember from losing consciousness in a critical situation.

REQUIREMENT GUIDANCE

a. This oxygen concentration or air dilution requirement has been and still is the subject of much controversy and debate among various organizations that study oxygen physiology. At one extreme, the US Navy insists that 100 percent oxygen be delivered at all times and altitudes of flights; however, regulators are used to adjust delivery flow rates and pressures. The US Air Force insists, many times, that 100 percent oxygen be used during take-off to preclude aircraft exhaust gases ingested by the Environmental Control System from being breathed through the regulator air dilution intake. While in flight, the crewmember must have a minimum concentration or percentage of oxygen to preclude hypoxia. An upper limit may be established to preclude atalectasis and conserve oxygen supply. The present limit is a maximum of 4 hours to breathe 100 percent oxygen in noncombat aircraft. For combat aircraft, flight acceleration loads are imposed on the crewmember's lungs that aggravate the effects of atalectasis. Laboratory tests show that a minimum of 40 percent nitrogen in the inspired gas is required to completely avoid atalectasis. To avoid lung irritation problems at one atmosphere, a concentration of 60 to 75 percent oxygen should not be exceeded. The following fact should be considered for existing US Air Force systems that use the CRU-73 regulator (applies to all USAF aircraft except the F-111): at a cabin pressure altitude of 25,000 feet, about 75 percent oxygen is added to the air delivered to the crewmember. This equates to a minimum of 36 percent nitrogen in the breathing air, which should completely preclude atalectasis under combat conditions in fighter aircraft. Figure 2 shows the recommended oxygen concentration limits used in the F-16A on-board oxygen generating system (OBOGS) program to preclude acceleration atalectasis. The cabin altitude should exceed 25,000 feet only for short periods when the aircraft flies above 50,000 feet pressure altitude or in the event of a decompression of the aircraft cockpit. Flights above 50,000 feet pressure altitude occur for only short time periods in existing fighter aircraft.

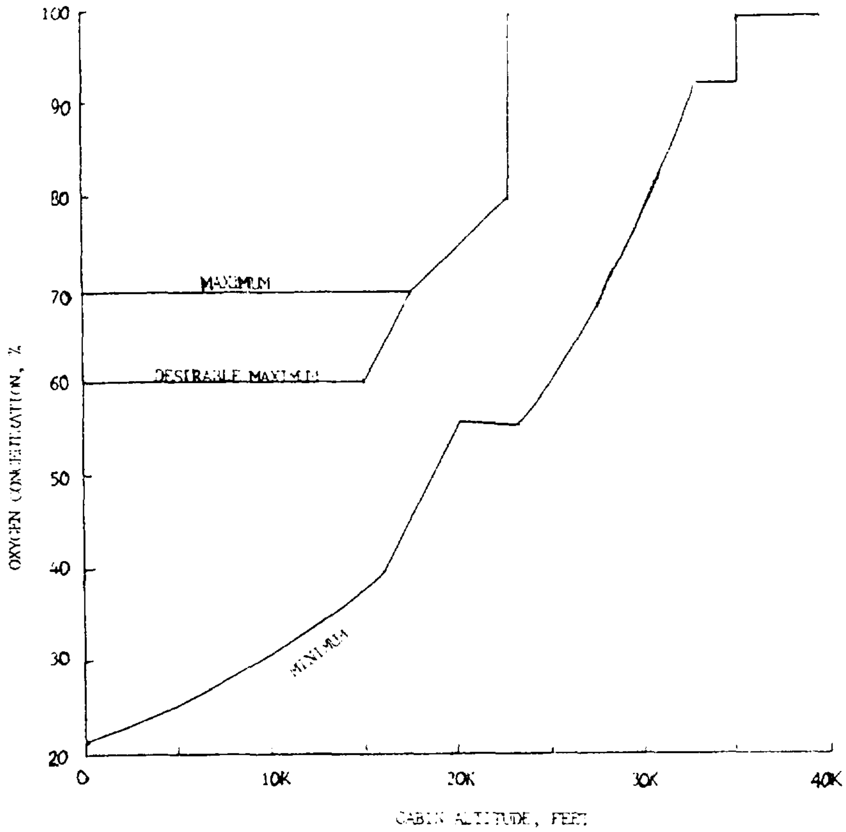


FIGURE 2. Limits to OBOGS oxygen concentration as a function of cabin altitude.

b. Above 50,000 feet cabin pressure altitude, breathing 100 percent oxygen without additional pressure is not sufficient for efficient body performance (see AFP 160-5, pp 4-11 through 4-14). Positive pressure breathing is required and is accomplished by use of an oxygen system that delivers 95-100 percent oxygen at greater than ambient pressures. Most USAF crewmember oxygen regulators are designed to provide positive pressures and 95-100 percent oxygen at altitudes above 28,000 to 32,000 feet cabin pressure altitude. This can be accomplished by either manual or automatic operation of the regulator. The preferred approach is to have an automatic pressure breathing schedule designed into the regulator and have a manual override control in the event of a regulator malfunction or an emergency such as a decompression. The amount of pressure delivered has been engineered into the regulator and is determined by the atmospheric pressure at that particular altitude. Standard USAF oxygen regulators tend to maintain an alveolar partial pressure of oxygen equivalent to breathing air at about 5,000 feet pressure altitude. It should be noted that mask pressures greater than 30 mmHg cannot be tolerated for long periods of time without many undesirable physiological effects. Also, it is extremely difficult to seat a conventional oxygen mask to hold positive pressures in excess of 25 mmHg without leaking about the perimeter of the mask where it is seated on the face. Therefore, 20 to 25 mmHg has been established as an upper limit on positive pressure until newer and better face mask designs allow greater pressures. The fundamental features of a pressure demand oxygen mask are shown in figure 3. Some existing design criteria is given as follows:

(1) The existing CRU-73 regulator provides a positive pressure of 11 inches (plus or minus 5) of water at the outlet of the regulator, and not the mask cavity, to allow the crewmember to test the mask fit. This regulator delivers a pressure in the range of 3 to 4 inches of water at 10 LPM and not less than 2 inches of water at 8 LPM. The OBOGS design requirements for the F-16 provided for a test control that operates from ground level to 35,000 feet to give a mean mask cavity pressure of 14 to 18 inches of water with an outlet flow of 10 LPM.

(2) A regulator and mask combination design for effective chemical defense should incorporate positive pressure breathing. The rationale for this design approach is that the breathing method of slight positive pressure breathing for all breathing modes and altitudes precludes negative pressures in the mask and hose. This precludes the possibility for contaminated cockpit air to be drawn into the oxygen delivery components on crewmember inhalation. Diluter-demand regulated breathing equipment may have negative pressures inside the delivery components under some situations. At high altitudes the regulator should deliver breathing facemask pressures comparable to those delivered by the current CRU-73 regulator.

c. In most past specifications, breathing resistance values have been specified in terms of minimum and maximum pressures and the pressure swing values. These pressures have been specified at sea level, although the values vary considerably as the altitude increases. Usually, these pressures are given as a function of the output peak flow rates. It should always be remembered that breathing resistance is a function of the crewmember's subjective opinion of the oxygen delivery components while in the different modes of operation. As such, tabular breathing resistance pressure values cannot completely substitute for the user's evaluation of the breathing equipment against his operational requirements.

For the F-16 OBOGS program, mask-cavity pressure requirements were determined by the School of Aerospace Medicine at Brooks Air Force Base to be as shown in table V.

TABLE V. F-16 molecular sieve OBOGS breathing requirements.

Peak inspiratory and expiratory flow rates (LPM at ATPD)	Mask cavity pressure with safety pressure (inches WG)		
	Minimum	Maximum	Swing
30	+0.107	+3.00	1.98
110	-1.50	+4.02	4.02
150	-3.48	+4.98	7.02
200	-7.02	+6.59	12.00

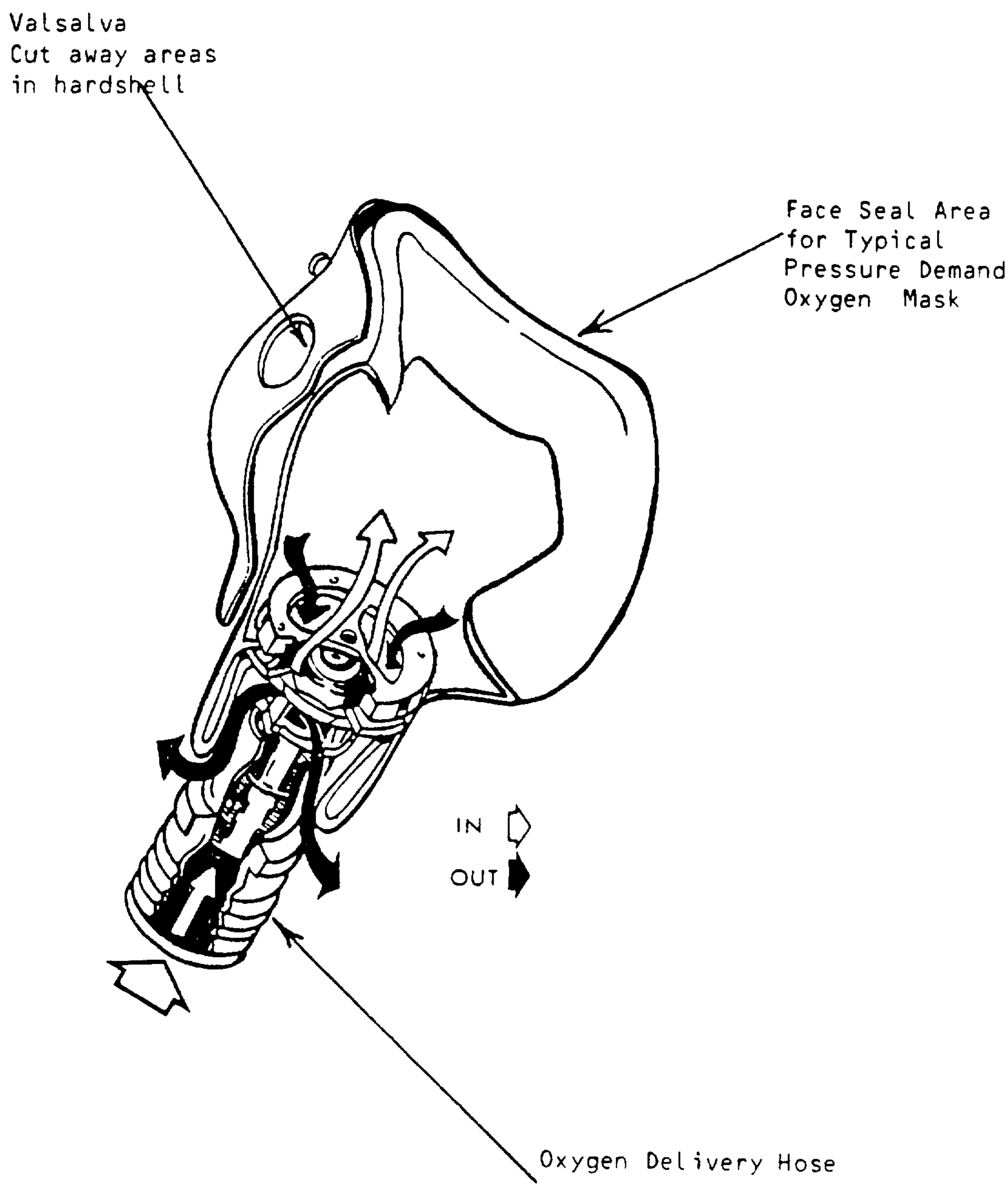


FIGURE 3. Typical characteristics of a pressure-demand oxygen mask with combination inhalation/exhalation valve.

d. An emergency breathing feature may be provided through the existing regulation equipment for normal oxygen needs. Also, emergency breathing may be provided by an alternate piece of equipment such as a high pressure bottle (bailout bottle). The pressures and flow rates required are typically a function of the cabin altitude when existing regulation equipment is used. In an alternate supply source, the pressures and flow rates may be preset to satisfy the worst case situations and not change with cabin altitude.

REQUIREMENT LESSONS LEARNED

a. Some typical concentration values are given in tables VI & VII from past systems. Proposed new regulators have design requirements according to the limits given in table VIII.

TABLE VI. Percentage of oxygen supplied with "normal oxygen" control position on the CRU-73 regulator.

Altitude in 1000-foot increments	Flow Rate in LPM*			
	1-14	15-50	51-85	85-135
0	0-100	0-30	0-30	
5	1-100	1-33	1-33	
10	6-100	6-27	6-27	6-35
15	14-100	14-27	14-30	14-45
20	24-100	24-45	24-55	24-55
25	40-100	40-80	40-80	40-90
28	60-100	60-100	60-100	60-100
32	98-100	98-100	98-100	98-100

* Note that the breathing flow rates average out such that the concentration is approximately as shown.

TABLE VII. Normal CRU-73/A regulator concentration values.

Cabin altitude (1000-foot increments)	Fractional oxygen added to air (percent)
0	30
5	26
10	26
15	38
20	46
25	78
28	100
32	100

TABLE VIII. * Regulator dilution schedule.

Cabin altitude (1000-ft increments)	Percent oxygen minimum 15-200 LPM	Percent oxygen maximum 15-85 LPM	Percent oxygen maximum 85-200 LPM
0	21.0	50.0	60.0
5	21.8	50.0	60.0
10	26.4	50.0	60.0
15	32.2	52.7	60.0
20	39.5	64.7	64.7
25	48.9	80.0	80.0
28	55.8	100.0	100.0
35	77.0	100.0	100.0
38	98.0	100.0	100.0

* All flow values are peak and all percent oxygen values average for sinusoidal breathing cycles.

b. To maintain the minimum physiological limits of the crewmember with the CRU-73 regulator which is in operational use in most USAF aircraft, the positive pressure loading characteristics shown in table IX are used.

TABLE IX. CRU-73/A regulator pressure breathing characteristics.

Pressure alt. 100-foot increments	Positive pressure (inches of water)		
	Flow of 10 LPM	Flow of 70 LPM	Flow of 135 LPM
27	-0.45 to +1.0	-1.35 to +0.1	-1.75 to -0.8
30	+0.01 to +2.5	-0.89 to +1.6	-1.29 to +1.2
32	+0.01 to +2.8	-0.89 to +1.9	-1.29 to +1.5
34	+0.01 to +3.0	-0.89 to +2.1	-1.29 to +1.7
36	+0.01 to +3.2	-0.89 to +2.3	-1.29 to +1.9
38	+0.01 to +3.4	-0.89 to +2.5	-1.29 to +2.1
39	+0.30 to +3.5	-0.60 to +2.6	-1.00 to +2.2
40	+0.30 to +5.6	-0.60 to +4.7	-1.00 to +4.3
41	+2.00 to +7.2	+1.10 to +6.3	+0.70 to +5.9
42	+3.40 to +8.6	+2.50 to +7.7	+2.10 to +7.3
43	+5.30 to +10.2	+4.40 to +9.3	+4.00 to +8.9
47	+11.20 to +15.3	+10.30 to +14.4	+9.90 to +16.7

Safety pressure and altitude pressure breathing limits for the mask cavity when averaged over a respiratory cycle at 85 LPM are as shown in figure 4.

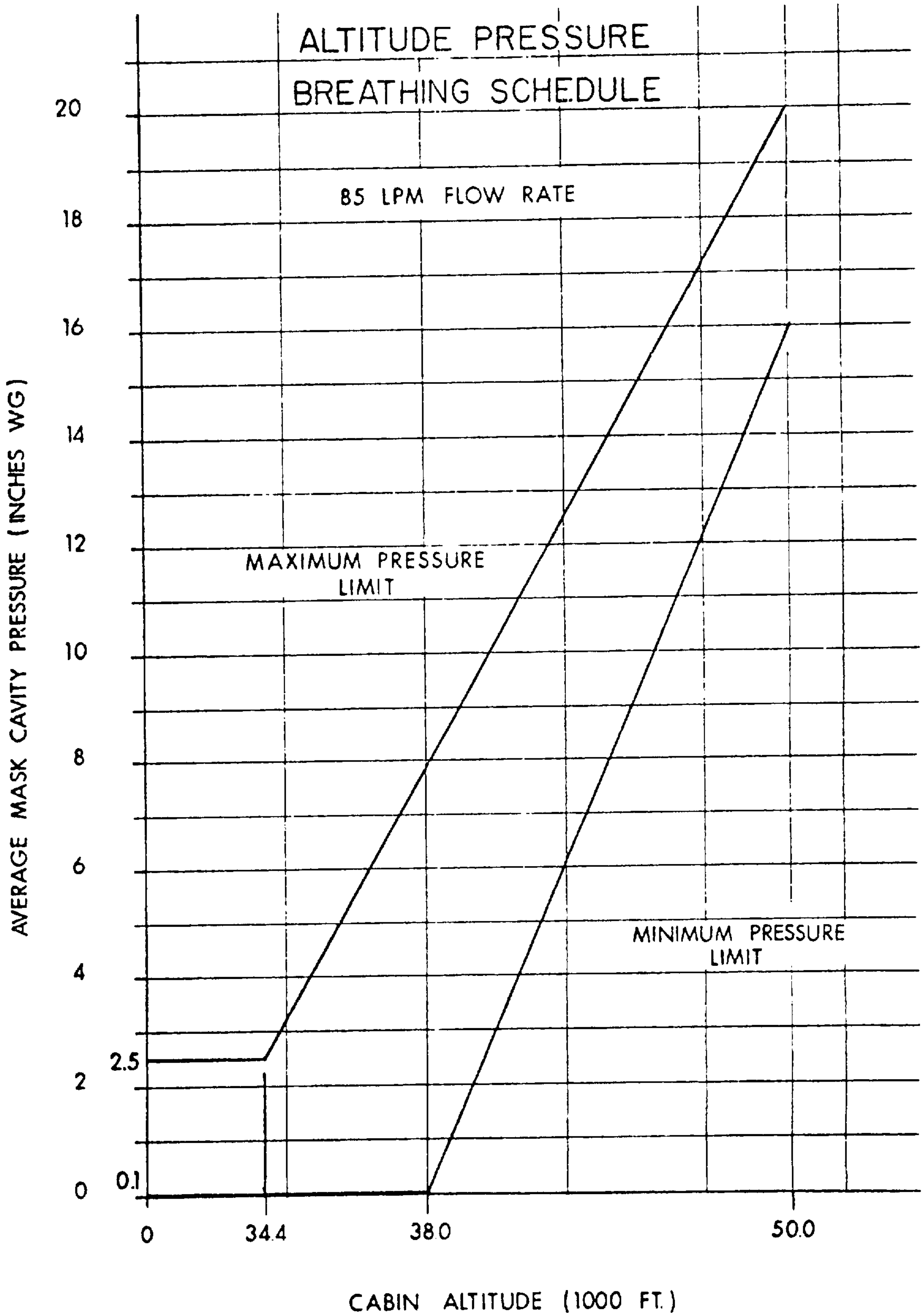


FIGURE 4. ICDS altitude pressure breathing schedule.

c. Values of mask cavity pressure have been determined from testing on the MBU-5/P and MBU-12/P masks, each with a Sierra spring-loaded inhalation/exhalation valve and a new Gentex roller diaphram inhalation/exhalation valve. These values are in the tables X-XII. Note that altitude chamber subjects reported that the Gentex valve appeared to cause a lower breathing resistance, although measured data does not indicate such.

TABLE X. * Cyclic flow tests (valve in mask).

Peak flow (1/m)	Altitude (1000 ft)	Breathing resistance (inches of water)					
		Sierra 5P			Gentex 5P		
		Insp	Exp	Swing	Insp	Exp	Swing
32	GL	-0.65	+1.1	1.75	-1.0	+0.6	1.6
32	8	-0.55	+1.0	1.55	-0.9	+0.6	1.5
32	18	-0.45	+0.9	1.35	-0.8	+0.6	1.4
32	25	-0.45	+0.9	1.35	-0.7	+0.6	1.3
32	35	+0.6	+2.0	1.4	+1.0	+2.4	1.4
32	43	+5.2	+7.0	1.8	+6.2	+8.0	1.8
32	50	+10.2	+12.0	1.8	+12.5	+14.5	2.0
100	GL	-2.1	+2.1	4.2	-4.0	+2.0	6.0
100	8	-1.7	+1.8	3.5	-3.3	+1.5	4.8
100	18	-1.3	+1.5	2.8	-2.5	+1.2	3.7
100	25	-1.1	+1.4	2.5	-2.1	+1.1	3.3
100	35	+0.2	+3.6	3.4	-0.3	+3.7	4.0
100	43	+3.7	+7.5	3.8	+5.0	+8.5	3.5
100	50	+6.8	+11.5	4.7	+11.0	+15.0	4.0
200	GL	-5.8	+5.6	11.4	-13.5	+6.0	19.5
200	8	-4.5	+4.5	9.0	-11.0	+5.0	16.0
200	18	-3.4	+3.5	6.9	-8.0	+3.5	11.5
200	25	-3.0	+2.8	5.8	-6.5	+3.0	9.5
200	35	-0.7	+6.8	7.5	-1.5	+6.0	7.5
200	43	+1.7	+9.3	7.6	+2.2	+7.5	5.3
200	50	+4.8	+13.0	8.2	+8.5	+19.0	10.5

* Resistance of valve, mask, hoses, connectors, and regulator on normal.

TABLE XI. * Cyclic flow tests (valve in mask).

Peak flow (l/m)	Altitude (1000 ft)	Breathing resistance (inches of water)					
		Sierra 5P			Gentex 12P		
		Insp	Exp	Swing	Insp	Exp	Swing
32	GL	-0.6	+0.8	1.4	-1.2	+0.6	1.8
32	8	-0.55	+0.7	1.25	-1.1	+0.5	1.6
32	18	-0.45	+0.7	1.15	-0.9	+0.5	1.4
32	25	-0.40	+0.7	1.1	-0.8	+0.5	1.3
32	35	+0.7	+2.2	1.5	+0.8	+2.6	1.8
32	43	+6.0	+7.5	1.5	+10.8	+12.5	1.7
32	50	+11.5	+13.5	2.0	+13.5	+15.0	1.5
100	GL	-3.1	+2.2	5.3	-4.3	+1.8	6.1
100	8	-2.6	+1.7	4.3	-3.6	+1.3	4.9
100	18	-1.9	+1.4	3.3	-2.7	+1.3	4.0
100	25	-1.6	+1.3	2.9	-2.3	+1.1	3.4
100	35	-0.1	+3.7	3.8	-0.2	+4.3	4.5
100	43	+5.1	+9.4	4.3	+5.7	+9.6	3.9
100	50	+10.0	+14.5	4.5	+10.5	+14.2	3.7
200	GL	-11.5	+9.0	20.5	-13.0	+7.0	20.0
200	8	-9.0	+7.0	16.0	-10.5	+5.5	16.0
200	18	-7.0	+4.8	11.8	-7.5	+4.0	11.5
200	25	-5.5	+3.5	9.0	-6.0	+3.0	9.0
200	35	-1.8	+7.0	8.8	-2.0	+7.3	9.3
200	43	+3.5	+12.0	8.5	+4.8	+12.0	7.2
200	50	+7.5	+15.5	8.0	+8.0	+15.5	7.5

* Resistance of valve, mask, hoses, connectors, and regulator on normal.

TABLE XII. * Cyclic flow tests (valve in mask).

Peak flow (1/m)	Altitude (1000 ft)	Breathing resistance (inches of water)					
		Sierra 5P			Gentex 5P		
		Insp	Exp	Swing	Insp	Exp	Swing
200	GL	-6.3	+8.0	14.3	-10.2	+9.3	19.5
200	8	-4.5	+6.5	11.0	-7.1	+7.0	14.1
200	18	-2.5	+5.5	8.0	-4.4	+6.0	10.4
200	25	-1.8	+5.5	7.3	-3.0	+5.5	8.5
200	35	+0.5	+13.5	13.0	+1.0	+14.2	13.2
200	43	+3.2	+13.5	10.3	+5.5	+18.5	13.0
200	50	+6.5	+16.0	9.5	+12.0	+23.5	11.5
		Sierra 12P			Gentex 12P		
		Insp	Exp	Swing	Insp	Exp	Swing
200	GL	-9.5	+10.0	19.5	-9.0	+6.5	15.5
200	8	-7.0	+8.0	15.0	-7.0	+5.5	12.5
200	18	-4.5	+6.0	10.5	-4.0	+5.0	9.0
200	25	-3.0	+5.0	8.0	-3.0	+5.0	8.0
200	35	+1.0	+13.0	12.0	+1.0	+13.0	12.0
200	43	+7.0	+17.0	10.0	+5.5	+15.0	9.5
200	50	+9.5	+18.5	9.0	+10.0	+18.0	8.0

* Resistance of valve, mask, hoses, connectors, and regulator on normal.

d. The MBU-5/P oxygen mask used a 5/8-inch inside diameter delivery tube, while all previous masks, as well as the later MBU-7/P mask, used a delivery tube with a 3/4-inch inside diameter. Experience in using these different sizes has indicated that a 3/4-inch inside diameter delivery tube is preferred because it creates lower breathing resistance.

4.2.2.1.3 **Verification of oxygen delivery features.** The verification of the oxygen delivery features shall consist of ____________.

VERIFICATION RATIONALE (4.2.2.1.3)

Verification of the crew oxygen delivery equipment is necessary to ensure that all components properly function in the expected operational environment and meet the physiological requirements of the crewmembers.

VERIFICATION GUIDANCE

The verification of the crew oxygen equipment delivery features should consist of analyses, inspections, demonstrations, and tests as necessary to ensure that all performance requirements have been met. Some past methods of verification that have been used are discussed in 4.2.2.1 (see verification guidance paragraphs a, b, c, d and g).

VERIFICATION LESSONS LEARNED

3.2.2.2 **Paratroop oxygen system.** In the event the cabin pressure altitude exceeds 10,000 feet in a pressurized aircraft, an alarm shall sound that is audible to all passengers under the ambient noise conditions expected in flight. Additionally, the alarm system shall consist of ____(a)____. For an unpressurized cabin, the alarm features are ____(a)____. The oxygen supply shall be activated and the paratroops shall be provided oxygen supply in the following ways ____(b)____. Smoke protection breathing features consisting of ____(b)____ shall be provided. Each fully equipped seated paratroop or passenger shall be capable of breathing supplemental oxygen within __(c)__ seconds after the alarm sounds. In pressurized cabins, an automatic dispensing oxygen subsystem (if provided) shall activate at a minimum of __(d)__ feet cabin pressure altitude in the event of decompression and shut off at __(d)__ feet cabin pressure altitude. A permanently installed emergency oxygen subsystem that has the following components and features shall be provided for the integrally installed seats: ____(e)____. A removable oxygen subsystem kit incorporating the following components and features shall be provided for the centerline troop seat kit: ____(f)____. All supply sources and permanently installed components of the oxygen subsystem shall be located such that ____(g)____. Multiple supply and distribution plumbing shall be installed on the aircraft such that ____(h)____. The quantity of oxygen provided from the supply source shall be sized to provide 95-100 percent oxygen for a minimum of __(i)__ troops based on an average flow rate of __(i)__ litres/hour/person for a minimum of __(i)__ hours. The permanently installed and removable oxygen system supply and distribution plumbing shall be designed to operate at an internal pressure range of __(j)__ psi and shall have the capability to supply oxygen at flow rates of __(j)__ litres/hour/person. This rate will vary depending on altitudes such that ____(j)____.

REQUIREMENT RATIONALE (3.2.2.2)

a. In most transport and military passenger aircraft, an 8,000 foot cabin altitude is normal, and a 10,000 foot cabin pressure is the absolute ceiling at which the ECS maintains the aircraft under normal operational conditions. If the cabin pressure altitude exceeds 10,000 feet, failure of the ECS or decompression of the cabin has occurred. Paratroop personnel are greatly encumbered and restricted in mobility when equipped with parachute packs and other gear required for combat and survival. For this reason, it is essential they have the earliest possible warning to don emergency oxygen masks in the event of a cabin decompression. In an unpressurized aircraft, an alarm system set at 10,000 to 14,500 feet may be desired to remind crew and passengers to don oxygen equipment.

b. The oxygen supply to the paratroop personnel should be released from the secondary heat exchanger or downstream of the supply manifold arrangement either manually or automatically. Manual dispensing requires that one crewmember be provided with the capability to perform this function very quickly. An activation method, such as a pull-down lanyard, should be included at the outlet to preclude dispensing of oxygen at a mask that is not being used.

c. There is no easy way to specify requirements to ensure that the designer locates oxygen mask assemblies that are readily accessible and that untangle easily for use. The statement of this time-to-don requirement guarantees the procuring activity of an operationally effective design. Donning of the mask assembly can be tested for this requirement.

d. The automatic dispensing of oxygen supply and mask assemblies should occur at some altitude above 10,000 feet (or that cabin pressure at which the alarm sounds). This ensures that the oxygen system will not inadvertently activate under normal flight operations with allowances for slow leaks from the cargo door or ramp. When the aircraft descends to a safe breathing altitude where oxygen supply is not needed, automatic shutting off of the supply ensures that oxygen is not wasted.

e. Troop transport aircraft have side-wall seating to facilitate paratroop jump operations, and it is desirable to permanently install the oxygen system components. To ensure that the designer includes all detail and components in the design, it is desirable to call out each component known to be necessary to the aircraft oxygen system design.

f. Troop transport aircraft that use side-wall seating to facilitate paratroop jump operations also carry cargo on most missions. For this reason, it is essential that any seating and oxygen system components which occupy cargo-dedicated space be provided in the form of a removable kit. The oxygen physiological requirements would be the same for the centerline seats as for the outboard side-facing seats. Paratroop personnel are greatly encumbered in movement with all the gear they carry and can only shuffle their feet when they move to the jump doors. Therefore, oxygen plumbing should not restrict troop movement within the aircraft.

g. In transport aircraft that carry paratroop personnel, cargo is also carried the majority of the flight. A volume of the space within the passenger compartment is dedicated to allow unrestricted on- and off-loading and tie down of cargo. This is called the design cargo volume, and the design should avoid permanent oxygen plumbing installations in these locations.

h. As these sources of oxygen supply may necessitate frequent servicing and occasional replacement, units should be designed to be installed or removed within a few minutes on the flight line. Accessibility is also required to check pressurized plumbing for leaks. The interconnection of two or more supply sources for the troop compartment ensures that all personnel will have supplemental oxygen in the event that any one or more supply sources is not obtained.

i. This oxygen quantity requirement is necessary to enable the USAF to tell the designer the minimum supply necessary for the aircraft to complete all planned missions. If the crew oxygen supply is taken from the same source, this must be considered when determining the amount of oxygen required.

j. If a large number of passengers is to be supplied by the oxygen system, it is desirable to have enough pressure in the plumbing to maintain the required flow rates. The flow rate must vary as a function of altitude because of decreasing ambient pressure as altitude increases. This altitude range should be specified. The decompressed cabin pressure altitude limits should be specified and not the pressure limits in a pressurized cabin.

REQUIREMENT GUIDANCE

a. This alarm system is essential in all USAF aircraft that are expected to carry passengers or paratroops. General cabin lighting should illuminate to full-bright when the alarm sounds.

b. Should the aircraft carry more than 20 paratroops, it is highly desirable to specify that dispensing of oxygen masks and release of the oxygen supply should be automatic. The time available for the loadmaster to assist paratroops in donning oxygen masks would not be sufficient for large numbers of personnel. Should smoke protection be required, this will impact breathing equipment design, deployment, and operation. For example, air dilution is not possible from ambient cabin air.

c. In an explosive decompression, a normal, healthy person should have at least 15 seconds of useful consciousness at 35,000 feet cabin pressure altitude. The time period between the dispensing of the masks, donning masks, and breathing oxygen could be added to the 15 seconds for larger aircraft. For smaller aircraft, at 35,000 feet, decompression occurs so quickly that 15 seconds should be used as an absolute maximum, while 5 to 10 seconds is a more realistic requirement.

d. The altitude for automatic dispensing of oxygen and mask assemblies is normally in a range of 12,500 to 14,000 feet for transport aircraft. The oxygen should then shut off again at 10,000 to 11,500 feet or lower cabin pressure altitude, except those systems supplied by solid-state chemical oxygen generators. The lower altitude limits would apply to smaller aircraft; the upper limits would apply to larger aircraft.

e. An oxygen system usually contains: a supply source, distribution plumbing, heat exchangers, altitude compensating regulators, pressure reducing and one-way flow valves, manual on and off controls that are readily accessible in flight, and masks in storage containers readily available to each seated paratroop. In general, the components mentioned above are known to be required for the installation of gaseous oxygen and LOX systems. If the particular oxygen system involved requires other known components, these should be specified. For a molecular sieve on-board oxygen generating system design other components may be needed. The supply source will be a concentrator device that uses a pressurized air source.

f. When the aircraft requirements include centerline troop seats, a requirement should be included for plumbing component kits and oxygen mask assemblies to be removable. Part of this plumbing would be permanently installed aboard the aircraft with conveniently located connectors provided. This would include the plumbing from the distribution manifold to the disconnect(s) which connect to oxygen plumbing kit. Oxygen plumbing to the centerline seats should be routed so the mobility of troops through the aisleways is not restricted.

g. Locate plumbing outside the design cargo volume for aircraft that also carry cargo. Supply containers and plumbing must be located to minimize hazards and damage of equipment during normal handling of cargo on and off the aircraft.

h. The capability to easily remove the supply source is essential for all types of oxygen supply (i.e., LOX converter, high and low pressure oxygen cylinders, OBOGS concentrator(s), and chemical oxygen generator(s)). The schemes for interconnecting more than one supply source are discussed in MIL-D-8683 and MIL-D-19326.

i. In many aircraft designs, the configuration can be varied depending on the mission of the aircraft. For example, in a USAF transport-type aircraft seat pallets are usually used for the greatest passenger-carrying capability. In paratroop missions, fewer passengers will be carried because the seating faces inboard and outboard. In the paratroop configuration, mission completion is very important. In the event of a decompression, the aircraft flies at 20,000 to 25,000 feet pressure altitude with the passengers breathing supplemental oxygen. Any flights above 25,000 feet will increase the chances for decompression sickness and for hypoxia with the continuous flow type of oxygen equipment normally provided. The time period used in these calculations is one-half the leg of the longest mission. In a jet transport, the longest reasonable time for paratroops to use oxygen equipment is 5-6 hours; physiological problems may occur with times in excess of this. For general passengers, the normal required usage is 20-30 minutes for descent. The average flow rate may be determined from MIL-D-19326 and is given in table XIII for convenience.

TABLE XIII. Minimum oxygen supply requirement for each passenger on continuous flow equipment.

Cabin altitude (1000-ft increments)	Average flow rate (NTPH) (gaseous litres per hour)
10	42
15	42
20	120
25	174
30	216

An example illustrates how the supply is sized. The average flow rate at 25,000 feet is 174 litres per hour. This altitude is chosen as a worst case to ferry 100 paratroops in a depressurized cabin for 6 hours.

Gas Volume = 174 litres/hr x 6 hrs x 100 paratroops = 104,400 litres

A 75-litre LOX converter will provide 60,000 litres of oxygen 24 hours after servicing. This means it would require at least two 75-litre LOX converters to complete this planned mission.

j. If the oxygen system supplies more than 10 people on continuous-flow oxygen delivery equipment or more than 2-3 crewmembers on pressure-demand regulation, it is desirable to have a 300 psi system, otherwise a 70 psi oxygen delivery system should suffice. If a high pressure oxygen supply source is used to deliver the oxygen, it is desirable to regulate the pressure to the range of 300-450 psi in the distribution plumbing to reduce hazards. A means of altitude compensation regulation shall be provided upstream of the outlets to the breathing masks. This should vary flow rates and delivery pressures to deliver breathing oxygen at flow rates to meet the physiological requirements of the aircraft occupants. The flow rates shall be in the ranges specified in table XIV.

TABLE XIV. Expected oxygen flow rates on continuous equipment.

Cabin altitude (ft)	Flow rate (LPM) min		max
10,000	42	to	100
15,000	42	to	100
20,000	120	to	150
25,000	174	to	200
30,000	216	to	450
35,000	255	to	550
40,000	282	to	1000

The aircraft should not fly with occupants on a continuous flow supply system at altitudes higher than 25,000 feet for any period in excess of 15-30 minutes. The occupants would be in danger of hypoxia and decompression sickness.

REQUIREMENT LESSONS LEARNED

a. (to be supplied as acquired)

b. Early mask assemblies in commercial aircraft that dispensed automatically also released the oxygen supply automatically. At unoccupied passenger seat stations, oxygen could be released into the cabin resulting in a waste of oxygen and a potential fire/explosion hazard. These problems necessitated that a means be incorporated to discretely activate the oxygen to each mask assembly.

c. The C-141 aircraft has cloth pouches that contain the mask assembly located adjacent to self-sealing outlets. In an emergency decompression, the loadmaster must release the oxygen supply manually from a manifold downstream of the secondary heat exchanger. Also, the paratroop personnel must turn around, grab the pouch, pull the mask assembly from the pouch, don the face mask, and plug the supply line into self-sealing outlets located behind him. Under some situations this can be hazardous. It may take the loadmaster an extended time period to get to the supply manifold. The paratroop personnel could be fully equipped with backpacks, duffle bags, and full harness, making it extremely difficult to accomplish the required procedure. Should the decompression of the aircraft be rapid (less than one minute), there is a strong possibility many paratroop personnel would lose consciousness.

d. Originally, the oxygen mask assemblies on the C-5A aircraft were designed to dispense automatically at 10,000 to 12,000 feet cabin pressure altitude. Service use showed that inadvertent dispensing of the mask assemblies occurred frequently. The repacking of the mask assemblies in the upper passenger compartment required many manhours, and the wear and tear on the mask assemblies required more frequent replacement. There was some risk that if a mask assembly dispensed in a decompression when it was necessary for survival, it would not be usable because of damage from repacking. The reservoir bag easily tears and is necessary for proper use of the mask assembly. The automatic dispensing altitude was moved to about about 12,500 feet to preclude these problems.

e. In a transport aircraft source selection, the aircraft manufacturer did not submit sufficient information in his proposed specification to be sure that all essential subsystem components would be included as part of the proposed designs. This also included some risk that the designs were incomplete. The contractor could submit price information that reflected incomplete oxygen systems designs, be awarded the contract, and later in development claim that additional funds were necessary to provide a complete oxygen system design. To preclude these kind of misunderstandings, and others, it is desirable to list general components that make up the system.

f. Of those designs proposed in a past transport aircraft source selection, several problem areas were discovered. One proposed design incorporated plumbing under the cargo floor from the distribution manifold to the center troop seat kit. Self-sealing quick disconnects were to be provided under removable cover plates that were flush with the floor when installed. Operational and maintenance representatives were concerned that oil and hydraulic spills from vehicles to be transported would seep into these oxygen disconnect cavities and pose an extreme fire/explosion hazard. Additionally, access to this plumbing in the aircraft bilge area was extremely limited. Another design approach was the use of an overhead swing around boom with flexible oxygen delivery plumbing. This would be installed high enough so that personnel movement through the aisle(s) would not be restricted. The drawback to this design approach was that under some situations it would be necessary to carry this boom onboard the aircraft even when not in use.

g. through j. (to be supplied as acquired)

4.2.2.2 **Verification of paratroop oxygen system.** The verification of the paratroop oxygen system shall consist of ____________.

VERIFICATION RATIONALE (4.2.2.2)

Verification of the passenger and paratroop permanently installed and kitted oxygen system components is necessary to ensure that all equipment properly functions in the expected operational environment and meets all physiological requirements for all personnel.

VERIFICATION GUIDANCE

The verification of the passenger and paratroop oxygen system should consist of analyses, inspections, demonstrations, and tests as necessary to ensure that all requirements have been met. Some past methods of verification that have been used are discussed in 4.2.2.1 and additional methods are as follows:

Many transport and tanker aircraft have multi-mision roles that include passenger and aeromedical missions. This means these kits must be easily installed and broken down again for ground storage when not in use. These arrangements will have oxygen subsystems that are included. Depending on the design configurations certain inspections and demonstrations are essential to ensure all components have been provided and function properly. The passenger kit(s) may either consist of a continuous flow system with quick disconnect fittings or portable chemical oxygen generators. All components that are necessary for operation including tubing, mask assemblies and storage devices shall be demonstrated to function properly.

VERIFICATION LESSONS LEARNED

3.2.2.2.1 **Paratroop controls and displays.** Passenger and paratroop oxygen system displays consisting of ____(a)____ and controls consisting of ____(a)____ shall be provided and located at ____(a)____. Emergency oxygen "ON" light(s) shall be provided at ____(b)____ to indicate to all persons that oxygen is flowing through the ____(b)____. A guarded control shall be provided at the ____(c)____ station to manually activate supplemental oxygen to all seated paratroop locations, and it shall have features consisting of ____(c)____. Test controls shall be provided to check for the proper functioning of all lighted displays, indicators, and instruments, with features consisting of ____(d)____. A separate, manual on/off control shall be provided for each row of seats, with ____(e)____ features, that is readily accessible in flight. The controls and displays provided shall be functionally compatible with the passenger oxygen system such that ____(f)____. Emergency or impending dangerous conditions shall be displayed in a manner to alert the appropriate personnel such that ____(g)____.

REQUIREMENT RATIONALE (3.2.2.2.1)

a. Controls and displays are essential for the proper operation of the oxygen system. For example, in a gaseous or liquid oxygen system it is essential to know the level of supply to determine when the supply must be filled or replaced. Leaks in the distribution system would accelerate the loss of oxygen supply. The crewmember responsible for the oxygen system should have oxygen information and controls provided at his crew station.

b. In the event of an emergency decompression, it is imperative the crewmember responsible for the passenger compartment oxygen system and all passengers know that the system is functioning properly. The emergency oxygen "ON" light(s) would indicate to this crewmember that oxygen is flowing to the passenger mask assemblies. Flow indicators may be desirable for each passenger mask assembly.

c. Even though automatic dispensing of supplemental oxygen may be provided in the design of the oxygen distribution system, it may still be desirable to provide manual on and off controls for all oxygen going to the distribution system. An audible warning is desirable so that paratroop personnel can begin the procedure of donning oxygen masks. This warning may activate automatically from this control or manually from a control nearby. It shall be possible to silence the audible warning, because the alarm could disrupt communication and distract required procedures required after the emergency.

d. It is essential that crewmembers be able to check the proper functioning of all oxygen controls and signals while inflight. This will allow them to determine whether abnormal information is a function of the oxygen equipment or a malfunction of the lighted display, indicator, or instrument.

e. The operational crew should be able to shut off oxygen supply to separate sections of seating configuration for missions when not all of the available seating is used. This enables the oxygen to be readily available to seats in use, while oxygen will not be dispersed in the distribution plumbing to seat kits that are removed or sections of seats not occupied.

f. This requirement ensures that the designer provides controls and displays that have electrical and pressure characteristics compatible with the operating ranges of the oxygen system components to be provided.

g. The selection of locations and the method of presentation for these types of displays should be narrowed down to ensure the passengers will receive warning in time to don oxygen before loss of consciousness.

REQUIREMENT GUIDANCE

a. On transport type aircraft that incorporate supplemental oxygen for the troop compartment, the loadmaster should be the crewmember responsible for the troop compartment oxygen system. If there is no loadmaster on the aircraft, the pilot shall be the crewmember responsible for the troop compartment oxygen system. Some typical controls used are delivery regulator on/off, supply line on/off valve(s), alarm and indicator test switches, and pressure or quantity test switches. Some typical displays used are oxygen ON light, supply pressure gage, LOX quantity indicator, line pressure gage, no smoking and general illumination lighting, and a regulator on/off indicator.

b. It would be essential for emergency oxygen "ON" light(s) to be provided at the loadmaster crewstation to enable him to quickly remedy the situation. It may also be necessary to provide this information to the pilots so they will make an immediate descent to 10,000 feet pressure altitude should the paratroop personnel not have immediate access to supplemental oxygen. These lights may not be needed if the supplemental oxygen is dispensed manually.

c. The loadmaster should have the control for manual oxygen activation. If there is no loadmaster, the control should be readily accessible to the flight steward. The audible warning should be a klaxton horn or a loudspeaker device that can be heard over the ambient noise conditions of flight. Since a manual control is likely to be a valve within the distribution plumbing, it may not be desirable to provide this control to the flight deck personnel. The use of remote control devices would need further evaluation.

d. These test controls usually consist of push buttons or toggles located near the display to be checked. Each control should be designed to check proper operation of the display, remote sensor (if applicable), and circuitry between these devices.

e. The best arrangement is to have mechanical valves in line with the distribution plumbing downstream of the manifolding of the supply sources if two or more supply sources are provided. If only one supply source will be used with even a full load of paratroop personnel, then it would be desirable to place these controls in the branch lines of the distribution plumbing.

f. It is desirable for all electrical and pressure range characteristics of the controls and displays to be specified in the designer's version of the applicable specification. The Request for Proposal as developed by the procuring activity may not contain this detailed information because this level of detail cannot easily be specified without having a design solution.

g. Human factors design criteria have provisions for this design. The important factor to consider is quick response time to give the passenger as much time as possible to obtain suitable supplementary oxygen and to preclude impending hazardous and dangerous conditions. Refer to MIL-STD-1472 and to other human factors design handbooks for design guidance.

REQUIREMENT LESSONS LEARNED

a. Many past troop transport aircraft did not have a loadmaster crewstation. Oxygen controls and displays for the troop compartment were located on the flight deck bulkhead and the cabin walls throughout the troop compartment and the loadmaster had to walk about the cabin to determine the status of this oxygen system. This is now considered an undesirable design approach that could result in hazardous situations.

Reference AFALC/PTL, Wright-Patterson AFB, OH Abstract of Lessons Learned, 1 Jan 1984. LL# 0600. If each LOX reservoir is not equipped with its own quantity indicating gage, excessive maintenance manhours will be utilized servicing units that do not require servicing.

b. through d. (to be supplied as acquired)

e. Reference AFALC/PTL, Wright-patterson AFB, OH, Abstract of Lessons Learned, 1 Jan 1984. LL# 0622. Lack of manual shutoff valves to isolate sections of the LOX system results in increased LOX usage and decreased aircraft readiness.

4.2.2.2.1 **Verification of paratroop controls and displays.** The verification of the paratroop oxygen system controls and displays shall consist of ____________.

VERIFICATION RATIONALE (4.2.2.2.1)

Verification of the passenger and paratroop oxygen system controls and displays is necessary to ensure they function properly in the expected operational environment and meet the needs of the crew that uses them. Aircraft passengers must also be able to detect and understand all displays.

VERIFICATION GUIDANCE

Verification of the passenger and paratroop oxygen system controls and displays should consist of analyses, inspections, demonstrations and tests as necessary to ensure that all requirements have been met. Some past methods of verification that have been used are discussed in 4.2.2.1.1.

VERIFICATION LESSONS LEARNED

3.2.2.3 **Mission specialist oxygen system.** In the event the cabin pressure altitude exceeds 10,000 feet in a pressurized aircraft, an alarm shall sound and be audible to all mission specialists under all expected ambient noise conditions in flight. Additionally, the alarm shall have these features: ___(a)___. In the event the cabin pressure altitude exceeds _(b)_ feet, supplemental oxygen shall be readily available to _(b)_ mission specialists. The oxygen subsystem shall consist of supply source(s), distribution plumbing, a manual on/off control that is readily accessible in flight, any required heat exchangers, regulators compatible with the oxygen masks, and storage devices or containers available to each seated mission specialist, and ___(c)___. The mask and associated regulator shall provide oxygen to the mission specialists suitable for breathing _(d)_ hours without symptoms of hypoxia. ___(d)___ type of oxygen mask assembly with _(d)_ components shall be provided. The quantity of oxygen provided from the supply source shall be sized to provide 95-100 percent oxygen for a minimum of _(e)_ passengers based on an average flow rate of (e) litres/hour/mission specialist for a minimum of (e) hours. The oxygen system supply and distribution plumbing shall be designed to operate at an internal pressure range of (f) psi and shall have the capability to supply oxygen at flow rates of (f) litres/hour/mission specialist.

REQUIREMENT RATIONALE (3.2.2.3)

a. In aircraft that comprise mission specialist crewmembers, there will be no flight crewmember such as a loadmaster to walk about the cabin to ensure the proper dispensing of supplemental oxygen in an emergency decompression. It is therefore considered essential to have automatic initiation of an emergency decompression alarm system. Dispensing of mask assemblies can be automatic or manual. A suspension device or readily accessible stowage method could be incorporated to facilitate rapid donning of mask assemblies. Should mask assemblies activate automatically, a pressure altitude at which this occurs should be specified. In either case, oxygen flow to the mask assemblies shall be automatic.

b. Air Force Regulation 60-16 requires that oxygen be readily available to all onboard personnel at their seated position for cabin pressure altitudes that exceed 10,000 feet.

c. To ensure that the designer includes all detail and components in the design, it is desirable to call out each component known to be necessary to the aircraft oxygen system design.

d. The mission of aircraft might require flight at altitudes above 10,000 feet pressure altitude even in the event of a cabin decompression. The type of oxygen mask assembly provided will depend on flight time required at these altitudes.

e. It is necessary to enable the USAF procuring activity to tell the designer the minimum supply necessary to complete all planned missions. Sufficient oxygen should also be available for flight to an alternate destination in an emergency.

f. To ensure that the delivery pressure is sufficiently high to maintain proper operation of the breathing regulator, the delivery pressure range should be specified. The flow rate requirement should represent the worst case or highest rate possible by the breathing regulator.

REQUIREMENT GUIDANCE

a. Should it be necessary to continue the mission in an emergency decompression (mission abort), the continuous flow mask assemblies would be adequate. If it is essential to continue the mission of the aircraft at a pressure altitude above 15,000 feet it would be necessary to provide pressure demand oxygen regulated to the cabin pressure altitude that supplies oxygen to oronasal masks which effectively seal against leaks.

b. Under normal operational conditions, should the tolerance on the upper limit of the cabin pressure altitude from the environmental control system frequently exceed 10,000 feet, supplemental oxygen would dispense when not needed. If this type of situation is anticipated, it would be better to initiate automatic dispensing of oxygen at a higher pressure altitude, not to exceed 15,000 feet. If this type of design is incorporated, a guarded manual override control is necessary to enable mission specialists to select supplemental oxygen at any altitude to satisfy Air Force Regulation 60-16.

c. The components mentioned are, in general, known to be required for the installation of gaseous oxygen and LOX systems. If the particular oxygen system involved for a known aircraft requires other known components, this should also be specified.

d. The flight time at these higher altitudes may vary up to 10 hours or more depending on the available oxygen supply of the aircraft and the physiological limitations of the breathing regulator and mask assembly. Continuous-flow passenger mask assemblies, such as those used on commercial aircraft, can preclude hypoxia up to 2 hours if used properly and if supply is sufficient. Improved versions of the passenger mask assemblies preclude hypoxia up to 3-5 hours. These improved continuous-flow mask assemblies incorporate such devices as a reservoir bag and inhalation valves to increase the partial pressure of oxygen to the lungs in the process of inhalation. Should it be desired to support the mission specialists for longer time periods, pressure demand oxygen equipment is essential.

e. The maximum number of mission specialists on the aircraft for any one flight should be specified. If the crewmembers obtain their oxygen from the same supply source, this should be added to the supply necessary for the mission specialists. If the aircraft mission can be aborted in any expected situation in the event of a decompression, the oxygen may be supplied by a continuous-flow system and is necessary only for a minimum of 30 minutes. If the mission must be continued at pressure altitudes above 10,000 feet and for a time period exceeding 2-3 hours, then pressure-demand regulated oxygen delivery components must be provided for crew and mission specialists. The flight crew should have pressure-demand regulated oxygen available. See 3.2.2.1 to determine average flow rates for a pressure-demand system and 3.2.2.2 to determine average flow rates for a continuous-flow system.

f. Many design features that will be selected by the oxygen system designer will be contingent on these specified values of pressure and flow rates. For example, the maximum flow rate possible from the CRU-73 pressure-demand regulator is 135 litres per minute. This exceeds the minimum physiological oxygen needed in all situations except very high workload conditions. Plumbing diameters, heat exchanger capability, and other oxygen components chosen will be a function of these requirements.

If the oxygen system supplies more than 10 people on continuous-flow oxygen delivery equipment or more than 2-3 crewmembers on pressure-demand regulation, it is desirable to have a 300-450 psi pressure range in the distribution plumbing. This ensures that under high demand conditions the pressure in the plumbing will not drop lower than 50 psi. This minimum pressure is the lowest at which the CRU-73 regulator will properly function. The flow rates specified above should represent the worst case situations. For example, each pressure demand regulator should have the capability to deliver flow rates in the range of 100-200 litres per minute for short time periods and approximately 12-13 litres/min for normal conditions (no physical exertion). Continuous flow equipment should provide a minimum of 4.5 litres/minute/person of breathing gas. Increased flow rates may be required for persons under stress or exertion. A typical upper limit has been 12 litres/min/person.

REQUIREMENT LESSONS LEARNED

4.2.2.3 **Verification of mission specialist oxygen system.** The verification of the mission specialist's oxygen system shall consist of ____________.

VERIFICATION RATIONALE (4.2.2.3)

Verification of the mission specialist oxygen system equipment is necessary to ensure that all components properly function in the expected operational environment and meet the physiological requirements of the mission specialists.

VERIFICATION GUIDANCE

The verification of the mission specialist oxygen system should consist of analyses, inspections, demonstrations, and tests as necessary to ensure that all requirements have been met. Some past methods of verification that have been used are discussed in paragraph 4.2.2.1

VERIFICATION LESSONS LEARNED

3.2.2.3.1 **Mission specialist controls and displays.** Mission specialist oxygen system displays consisting of ___(a)___ and controls consisting of ___(a)___ shall be provided and located at ___(a)___. Emergency oxygen "ON" information shall be provided at each mission specialist's station to show that oxygen is flowing in the ___(b)___. A guarded override control shall be provided at the ___(c)___ station to manually activate the supplemental oxygen to all the seated personnel locations. The audible warning shall be activated from this control or an adjacent control. A separate audible warning silence control shall be provided. Test controls shall be provided to check for the proper functioning of all lighted displays, indicators and instruments (d). The controls and displays provided shall be functionally compatible with the passenger oxygen system (e). Emergency or impending dangerous conditions shall be displayed in a manner to alert the appropriate personnel (f).

REQUIREMENT RATIONALE (3.2.2.3.1)

a. Certain controls and display features are necessary to enable the personnel on the aircraft to monitor and use oxygen equipment. For example, it is essential that the crewmember responsible for the aircraft oxygen system be aware of the quantity of oxygen available if a gaseous or liquid oxygen system is provided. In the event of emergency decompression, this enables the crewmember to determine the amount of oxygen supply remaining to plan alternate aircraft missions. It also allows the crewmember to determine when the oxygen supply container(s) need to be filled by ground support personnel. Warning indication is needed in the event the low level of supply is overlooked by the crewmember, or in the event of a leak, which could rapidly deplete the supply. Additionally, each mission specialist with a breathing regulator must have control and display features to enable him to properly use the oxygen when needed.

b. Each mission specialist, pilot, and crewmember responsible for any passengers using aircraft oxygen supply must be able to determine very rapidly that oxygen is flowing to a mask assembly. Should one of these persons note that the display does not indicate oxygen flow, it should be assumed the display system is not functioning properly and an alternate source of oxygen should be used. This could be either another mask assembly location connected to the aircraft supply or a portable oxygen assembly.

c. The override control shall be provided to enable the crewmember responsible for the oxygen system to dispense oxygen at any altitude. This is necessary because oxygen may be required for smoke protection at cabin pressure altitudes below the automatic dispensing altitude (if applicable) or the automatic dispensing mechanism may fail. An audible warning is necessary for automatic or manual dispensing of oxygen, and it must be silenced after all personnel have been alerted and emergency procedures are underway or complete.

d. Failure of control and display devices, their remote sensors, or associated circuitry may occur in all military aircraft. It is therefore essential that crewmembers and mission specialists be capable of checking at preflight and during flight for the proper functioning of all lighted displays, indicators, and instruments.

e. This requirement ensures that the designer provides controls and displays that have electrical and pressure characteristics compatible with the operating ranges of the oxygen system components to be provided.

f. The selection of locations and the method of presentation for these types of displays should be designed to ensure the aircraft passengers and crewmembers occupying the passenger compartment will receive warnings in time to take the appropriate corrective actions.

REQUIREMENT GUIDANCE

a. Oxygen supply quantity information should always be available to the pilot and copilot (if applicable). Should the aircraft have a crewmember (such as a loadmaster) responsible for oxygen systems, this information should be available to this crewmember in addition to the pilots. LOX quantity information should be displayed in litres of LOX in each converter provided. Gaseous oxygen supply information should be indicated by the pressure of gas remaining in each container. The low supply warning indication should activate when the total quantity of oxygen remaining reaches 10 percent. Also, controls are need for proper operation of breathing regulators. Should an on-board oxygen generation system be provided, status information and control features are needed for proper equipment operation.

b. Emergency oxygen "ON" information is usually provided in the form of an indicator light viewable under all expected ambient illumination conditions. For crewmembers, the display sensor should sense oxygen flow on the downstream side of the generator or within the regulator. For passenger mask assemblies, the sensor should indicate oxygen flow in the plumbing on the upstream side of the mask assemblies. Emergency oxygen "ON" information could also be indication of the proper operating pressure in a standard pressure-demand regulator. In the event of a malfunction of one or more of these oxygen outlet locations which would require the person to use a portable oxygen assembly, the pilot may descend as rapidly as is safely possible to 10,000 feet cabin pressure altitude. Another option would be that these person(s) would connect a portable bottle to a recharger outlet and breathe from this position.

c. An override control is an essential backup control device to enable oxygen to be dispensed at the discretion of the pilots or a flight steward at any time. In addition to an override function, this control also enables the flight crew to shut off the oxygen supply as far upstream as possible to preclude fire hazards and to convey emergency information. These audible warnings can be most distracting and may impair flight duties after the warnings have been conveyed. Therefore, a separate warning silence control is needed.

d. Test controls usually consist of spring-loaded pushbuttons or toggles that when activated, illuminate the lighted display, activate the indicator, and display a preselected reading on the instrument. With the exception of the displays on the annunicator or caution light panel, the test control(s) should be located adjacent to the lighted displays, indicators, and instruments.

e. It is desirable that all electrical and pressure range characteristics of the controls and displays be specified in the designer's version of the applicable specification. The Request for Proposal, as developed by the procuring activity, should not contain this detailed information because this level of detail cannot easily be specified without having a design solution. The control and display locations should be functionally compatible with the personnel who must operate these devices under the operational scenarios they will encounter.

f. The design should provide emergency information as a combination of light-activated signs viewable in all parts of the passenger compartments and an automatic device that puts passenger compartment general illumination to full bright. All personnel need as much ambient general illumination as possible to enable them to don oxygen masks. Coupled with this display should be an aural warning to obtain the passengers' immediate attention. Pressure displays should be in convenient, readily viewable locations.

REQUIREMENT LESSONS LEARNED

4.2.2.3.1 Verification of mission specialist controls and displays. The verification of the mission specialists' oxygen system controls and displays shall consist of ______________.

VERIFICATION RATIONALE (4.2.2.3.1)

Verification of the mission specialists' oxygen controls and displays is necessary to ensure that these components function properly in the expected operational environment and meet the needs of all crew and mission specialists who use them. All personnel must also be able to detect and understand all displays.

VERIFICATION GUIDANCE

The verification of the mission specialists' controls and displays should consist of analyses, inspections, demonstrations, and tests as necessary to ensure that all requirements have been met. Some past methods of verification that have been used are discussed in 4.2.2.1 and 4.2.2.1.1.

VERIFICATION LESSONS LEARNED

3.2.2.4 Aeromedical oxygen system. The oxygen supply source shall be sized for emergency oxygen in the event of a decompression to provide an adequate quantity of 95-100 percent oxygen for a minimum of (a) litter patients, (a) ambulatory patients, and (a) medical personnel at an average flow rate of (a) litres/hour per (a) person for a minimum of (a) hours. The oxygen supply source shall also be sized to provide therapeutic oxygen to accommodate (b) seated patients plus (b) litter patients, (b) ambulatory patients, and (b) medical personnel in the maximum personnel aeromedical configuration for (b) hours. The oxygen system supply and distribution plumbing shall be designed to operate within an internal pressure range of (c) psi.

REQUIREMENT RATIONALE (3.2.2.4)

a. The aircraft designer should design the aircraft oxygen system for the number of different types of passengers that must be provided for in the event of an emergency situation. It should be noted that, should the aircraft designer choose to provide for more than the specified types of passengers, the size of his proposed supply should support the actual or greater number of passengers to be carried on the aircraft.

b. Oxygen supply source sizing should accommodate the maximum expected aeromedical configuration for therapeutic purposes.

c. The operational pressure range should be specified to ensure it will be compatible with existing oxygen components. The delivery pressure for existing therapeutic oxygen equipment is not compatible in the 10,000- to 50,000-foot cabin pressure altitude range. For this reason, it is not desirable to fly a decompressed aircraft with an aeromedical configuration above an altitude of 10,000 feet.

REQUIREMENT GUIDANCE

a. For sizing the emergency oxygen supply, the number of litter patients specified should be the maximum number of litters that can be carried on the aircraft for any of the possible configurations. Ambulatory patients are patients who occupy seats and do not require therapeutic oxygen except in the event of a smoke-filled cabin or a decompression. The maximum number specified should be the seating available for the largest number of ambulatory patients when the litter capacity of the aircraft is at its limit. It is recognized that more ambulatory patient seating is possible if litters are taken from the aircraft and replaced with seat pallets. Oxygen should be supplied for the time period required for an aircraft emergency descent (usually 15 to 30 minutes) to 10,000 feet.

b. If the litter patients are on 100 percent therapeutic oxygen, it will be required it for the entire mission of the aircraft plus some time on the runway ramp. It should be assumed that some percent of the litter patients will be on 100 percent therapeutic oxygen and that some ambulatory patients will not require therapeutic oxygen. The ideal design would be to provide therapeutic oxygen for all litter patients. When calculating the size of the oxygen supply, ensure that no less than 50 percent of the total litter patient capacity may be supplied therapeutic oxygen.

An example is given here for clarification. A 12-hour round-robin mission is flown to an austere airfield to transport a mixture of 40 litter and 50 ambulatory patients. For normal breathing and no leakage, each therapeutic oxygen outlet provides a minimum of 6 LPM. Should respirators be provided, use an average rate of 20 LPM. On emergency oxygen, the flow rate must be a minimum of 3 LPM to physiologically support the passengers.

40 litters	x 6 LPM	x 720 min	=	172,300 litres
50 amb patients	x 3 LPM	x 360 min	=	54,000
		Total	=	226,300 litres

A single 75-litre LOX converter will supply 60,900 gaseous litres of oxygen. This means three to four 75-litre LOX converters would be required. However, as a compromise only two or less 75-litre LOX converters or may be provided. This can be justified because it is not likely that all litter patients will be on therapeutic oxygen. Consider that 20 of 40 litter patients are on oxygen.

20 litters	x 6 LPM x 720 min =	86,400
70 (litter + am patients)	x 3 LPM x 360 min =	75,600
	Total =	162,000 litres

This compares favorably with the use of two to three 75-litre LOX converters. Note that emergency oxygen should be required for only one-half the leg of the longest mission, or 6 hours in this example.

A therapeutic outlet usually supplies two therapeutic oxygen masks. Each litter patient should have a sufficient supply of oxygen at 6 LPM. Each respirator that is used needs about 20 LPM of 100 percent oxygen. It is conventional practice that each therapeutic oxygen outlet accommodate up to 720 litres/hour (two therapeutic oxygen masks). Some outlets should accommodate flow rates up to 2400 litres/hour to support two respirators or 4800 litres/hour to support four respirators. It is also possible to provide outlets that supply up to 1500 litres/hour. This would support four litters in each tier (4 x 6 LPM x 60 min = 1440 litres/hour) or one respirator (20 LPM x 60 min = 1200 litres/hour). The arrangement design should be coordinated with the aeromedical requirements command at Scott AFB.

c. Should only a small number of patients be supported, such as in a rescue helicopter, a 70 psi delivery system with LOX or high pressure supply or an on-board oxygen generating system is satisfactory. Should it be necessary for a greater number of patients to be supported, a 300-450 psi delivery system is required. This ensures that a pressure drop lower than 50 psi not be encountered for the worst-case demand-flow rate.

REQUIREMENT LESSONS LEARNED

4.2.2.4 **Verification of aeromedical oxygen system.** The verification of the aeromedical oxygen system shall consist of ______________.

VERIFICATION RATIONALE (4.2.2.4)

Verification of the aeromedical personnel oxygen system equipment is necessary to ensure that all components properly function in the expected operational environment and meet the physiological requirements of the applicable personnel.

VERIFICATION GUIDANCE

The best approach to verify the sizing and operating pressure range of the aeromedical oxygen supply is by detailed analyses. Should an on-board oxygen system be provided, final verification should also consist of demonstrating the performance of the units.

VERIFICATION LESSONS LEARNED

3.2.2.4.1 Quick conversion aeromedical evacuation. This system consists of the aeromedical kit carried on-board the aircraft at all times to allow quick conversion in flight to aeromedical evacuation. Oxygen must be readily available under any mission scenario for the integrally installed minimum litter capacity of ___(a)___. This system shall consist of therapeutic and emergency oxygen masks, regulators, and plumbing to enable patients to use this oxygen without restricting passage through the aisleways (b). This aeromedical kit shall be stowable on-board the aircraft at all times with features consisting of ___(c)___.

REQUIREMENT RATIONALE (3.2.2.4.1)

a. Many USAF transport and passenger aircraft have multi-mission capabilities; this sometimes includes an aeromedical configuration for emergency situations. Such aircraft should carry some number of litters and seats designed to be stowed away, with the capability for rapid conversion to an emergency aeromedical configuration. Oxygen should be available for this role so that it complements the aeromedical kit configuration without requiring the aircraft to land.

b. Oxygen system components should consist of at least therapeutic and emergency oxygen masks with associated plumbing to support patients under care and provide supplemental oxygen to litter/seat patients in the event of rapid decompression.

c. Because the aeromedical kit must be carried on the aircraft at all times, certain provisions are necessary in the design and installation of the kit(s).

REQUIREMENT GUIDANCE

a. Generally, the number of litters/seats used for this type of mission is about 12 for larger transport aircraft, 6-8 for medium size aircraft, and 4 for small aircraft. However, this is dependent on the stowage space available, the weight of the kit, and the number of litters/seats that are provided.

b. Because the therapeutic oxygen needs for patients will probably be required for the duration of the aircraft mission, portable oxygen supply will be of insufficient quantity. Should the oxygen kit be plumbed into aircraft cabin wall(s) or bulkhead, it should not restrict passage of medical attendants through aisleways or their access to the patients.

c. The rapid conversion aeromedical kit will consist of litter stanchions and litters, seat frames and seats (if applicable), and oxygen masks and plumbing. Stowage areas may be the cargo/flight deck bulkhead, in the lower flight deck (if applicable) or the tail cone. The kit, when in stowage, should be secured for flight and packed such that contamination effects to the kit are minimized.

REQUIREMENT LESSONS LEARNED

4.2.2.4.1 **Verification of quick-conversion aeromedical evacuation.** The verification of quick-conversion aeromedical evacuation shall consist of ________________.

VERIFICATION RATIONALE (4.2.2.4.1)

Verification of the quick conversion aeromedical evacuation oxygen equipment is necessary to ensure that all components properly function in the expected operational environment and meet the physiological requirements of the personnel that will use the equipment.

VERIFICATION GUIDANCE

The verification of the quick conversion aeromedical evacuation kit should consist of analyses, inspections, demonstrations and tests as neccessary to ensure that all requirements have been met. Some past methods of verification are discussed in paragraph 4.2.2.1.

VERIFICATION LESSONS LEARNED

3.2.2.4.2 **Therapeutic oxygen.** A minimum of (a) therapeutic oxygen outlets designed according to (a) shall be provided to support (a) litter and (a) ambulatory patients. All therapeutic outlets shall accommodate flow rates up to (a) litres/hour/outlet and have an outlet delivery operating pressure of 50 ± 5 psi. Provide at least (b) respirator outlets located (b) . All respirator outlets shall accommodate flow rates up to (b) litres/hour/outlet and have an operating pressure of 50 ± 5 psi. The oxygen system supply and distribution plumbing shall be designed to operate within an internal pressure range of ______ psi. The therapeutic and respirator outlets maybe located and installed such that (c) . Any plumbing provided that must be routed across aisleways to reach litter and seat patient locations shall not restrict passage and (c) . Ensure that the therapeutic and respirator oxygen system is operational at all times during both air and ground operations (d).

REQUIREMENT RATIONALE (3.2.2.4.2)

a. It is mandatory that any therapeutic outlets provided be compatible with current USAF aeromedical equipment. Ideally, therapeutic oxygen outlets should be provided with a minimum of two outlets per litter tier for all possible litter locations on the aircraft. A fraction of the patient load will be seated ambulatory patients; they too should have therapeutic oxygen outlets available.

b. The respirator outlet design may be different from the therapeutic outlets, as the flow rate to these units is 80 litres/minute/respirator/outlet (greater than that needed for therapeutic outlets) and any portable supply (other than LOX) is rapidly depleted. Respirator availability is essential on all aeromedical-mission aircraft.

c. Medical attendants must have quick and unimpeded access to all litter and ambulatory patients requiring care and observation. The plumbing could pose a safety hazard in that a medical attendant walking about might trip over it. A possible ruptured oxygen line resulting from this would pose a fire and explosion hazard.

d. Therapeutic and respirator operational readiness is essential while patients are on the aircraft. A ground and flight operation requirement is needed to ensures the designer does not rely upon the operation of some subsystem of the aircraft while on the ground that may not be available.

REQUIREMENT GUIDANCE

a. The therapeutic outlets shall be similar to those provided on the C-9A aeromedical aircraft (see figure 5). These outlets should incorporate dust protection provisions. It may not be practical to provide therapeutic outlets for all patients in multi-mission transport type aircraft. In this case, provide as many outlets as possible. In aeromedical aircraft such as the C-9A, all patients should have therapeutic oxygen immediately available to their litter and seat locations. The flow rates will be a function of the types of therapeutic oxygen equipment that must be operated.

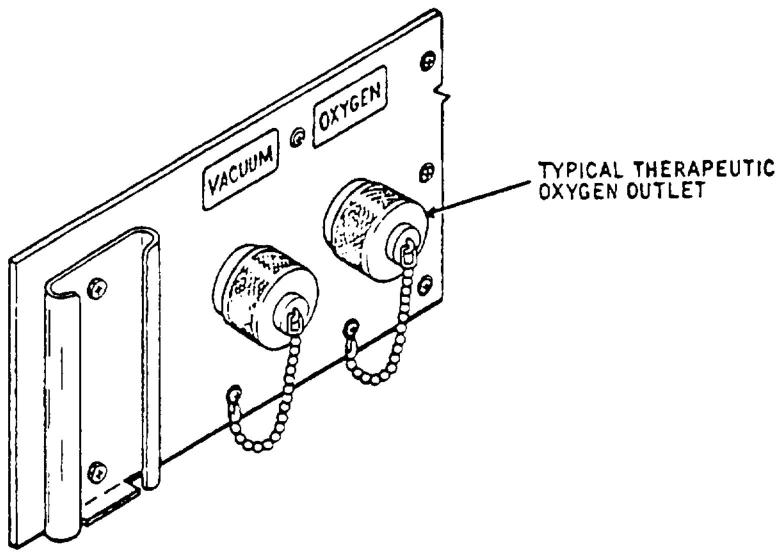


FIGURE 5. C-9A aircraft therapeutic oxygen outlet panel.

b. The respirator outlets should be of the same physical type and configuration as therapeutic outlets. The primary difference is respirator outlets must have plumbing that allows a greater flow rate of oxygen to them. In fact, if all therapeutic outlets were designed to accommodate a respirator, each of these outlets could also accommodate two to three therapeutic oxygen units with the use of an adapter. Such adapters are currently in use in existing USAF transport aircraft used for the aeromedical mission. All outlets should incorporate protective dust covers or dust protection provisions.

If two separate outlets are provided for therapeutic and respirator equipment, the operational crew will be posed with some disadvantages. For example, different connectors would need to be provided to ensure the lines are not improperly connected. This would mean two types of oxygen lines must be available. There would be a problem as to how many of each type should be carried on the aircraft for different types of missions. Should only one respirator-type outlet be provided, then as a worst case, either the patient needing this device would have to be moved, or a long line would need to be routed from the outlet to the patient. Both of these situations are undesirable.

c. In the placement of therapeutic and respirator outlets in aircraft with permanent litter and seat installations, the desired design is to have them adjacent to the litters and seats such that medical attendants may conveniently administer care to patients. In aircraft which have temporary litter and seat installations, plumbing kits may be used. The obvious design approach is to place litters near the cabin walls and medical attendants would approach the litters from the other side. The only difficulty is that integral side-facing seats may be at these locations. In any event, either litters or seats would likely be in the center of the aircraft, requiring aisleways to be outboard. This poses oxygen plumbing problems in that plumbing must be routed either overhead or under the aircraft floor in the bilge area. Another concern is that these outlets should not be subject to damage from equipment and personnel movement.

d. It is necessary to view the aircraft as sitting on the ramp, engines off, and power down. Medical personnel should still be able to draw oxygen from all outlets to aid patients in recovery. Additionally, ambient temperature and pressure conditions should not restrict the maximum flow of oxygen to these outlets.

REQUIREMENT LESSONS LEARNED

a & b. A variety of medical conditions such as hemorrhage, "wet lung" syndrome, cardiovascular disease, detached retina, and many others require oxygen therapy to assist in preventing further degradation of patient condition. Unless sufficient oxygen is made available to the tissues, deleterious changes occur which can rapidly become irreversible and can even cause death. In some instances, respirators are required to artifically maintain patient respiration to keep the patient alive. There is no means available to predetermine which patients will require therapeutic oxygen in flight. However, analysis of Vietnam War data indicates that potentially two out of every three patients originating from tactical operations would benefit significantly from oxygen therapy and for half of those, it is a critical treatment requirement.

c. In some of the very early transport aircraft, very little oxygen supply integral to the aircraft was available for passenger use. The supply provided was primarily for flight crewmember use. Some aircraft such as the early C-130 models had oxygen supply in high pressure vessels. This supply was limited and supported passengers primarily for emergency descent. These aircraft were powered by props and did not need to reach higher altitudes to fly efficiently as jet aircraft do. For the aeromedical mission, large, high pressure (2200 psi), hospital-type "H" size oxygen cylinders were carried on the aircraft. These bottles were awkward and unsafe because they are large and weigh nearly 200 pounds each. The lighter, "D" size oxygen cylinders were also used, but each cylinder provided only a 15-minute supply of oxygen versus several hours provided by the "H" size cylinders. The need for a portable, lightweight, low-pressure liquid oxygen system and aircraft integral supply was identified in 1967 by the Command Surgeon, Pacific Air Forces, when it was reported that "the availability of oxygen resources was a limiting factor when the workload of the 9th Aeromedical Evacuation squadron increased because of hostile action in SEA. Reference: Report SAM-TR-73-47, "Development of the USAF School of Aerospace Medicine (USAFSAM) Therapeutic Liquid Oxygen (LOX) Breathing System," by Constance R. Sturim, Lt Col, USAF, NM, Dec 1973. See also 3.2.2.2 for lessons learned in the design approach for the proper routing of oxygen plumbing.

d. Ensure that the therapeutic and respirator oxygen system is operational at all times during both air and ground operations. Many times in the Vietnam War in Southeast Asia, patients were carried onto aeromedical/airlift aircraft and would be in immediate need of oxygen to survive. The aircraft could be on the ramp for hours before takeoff. It would not be practical to carry portable equipment on-board for this time period then switch to the aircraft oxygen supply prior to takeoff. Additionally, the aircraft would probably make stops enroute to its final destination(s) for refueling, recharging the oxygen supply, or taking on additional medical supplies. Many times the aircraft would be under quarantine during these stops and patients would not be allowed to leave the aircraft. Some of the patients would still need oxygen during these stops.

4.2.2.4.2 **Verification of therapeutic oxygen.** The verification of therapeutic oxygen shall consist of ____________.

VERIFICATION RATIONALE (4.2.2.4.2)

Verification of therapeutic aeromedical oxygen equipment is necessary to ensure all components properly function in the expected operational environment and meet the physiological requirements of the patients and personnel who will use the equipment.

VERIFICATION GUIDANCE

The verification of the therapeutic oxygen equipment should consist of analyses, inspections, demonstrations, and tests as necessary to ensure that all requirements have been met. Some past methods of verification are discussed in 4.2.2.1.

VERIFICATION LESSONS LEARNED

3.2.2.4.3 **Emergency descent oxygen.** Provide masks and distribution components that are suitable for breathing oxygen ___(a)___ hours at ___(a)___ cabin pressure altitude range at each litter location and seat position. When the cabin pressure altitude reaches 10,000 feet, an audible alarm shall sound that can be heard by all passengers above the expected ambient noise conditions of flight, and the cabin lighting shall automatically illuminate to full brightness (b). Oxygen supply shall be activated at ___(c)___, and oronasal oxygen masks with inhalation/exhalation valves and an activation lanyard shall be provided such that ___(c)___. Each litter patient, seated ambulatory patient, and seated medical attendant shall be provided supplemental breathing oxygen within ___(d)___ seconds after the alarm sounds. An automatic dispensing oxygen system (if applicable) shall be activated at a minimum of ___(e)___ feet cabin pressure altitude in the event of a decompression and shall shut off at ___(e)___ cabin pressure altitude.

REQUIREMENT RATIONALE (3.2.2.4.3)

a. Suitable supplemental oxygen should be provided for all passengers (including aeromedical patients) and crewmembers on the aircraft in the event of an emergency decompression.

b. An alarm is essential so that the aeromedical crew may immediately take steps to get all patients and personnel on oxygen equipment.

c. It is necessary to state the components and operation of the passenger emergency oxygen breathing system which past experience has shown to be essential. The designer must know the type of masks desired, whether masks should dispense manually or automatically, and regulation of oxygen supply.

d. A time-to-don requirement for oxygen masks is essential in determining the mode of dispensing oxygen and the location of the mask assemblies. This ensures that the aircraft is provided with the equipment in readily accessible locations without actually specifying the locations. AFR 60-16 requires that each occupant of an Air Force aircraft have supplemental oxygen immediately available when the cabin altitude exceeds 10,000 feet. Alarms and cabin lighting are essential to enable all passengers to don oxygen masks and breathe supplemental oxygen as rapidly as possible.

e. A maximum acceptable altitude to activate oxygen to the mask assemblies and to dispense the mask assemblies automatically (if applicable) is a necessary requirement because this value varies with the type of aircraft. The Federal Aviation Agency requirement is 15,000 feet; most USAF transport aircraft dispense oxygen at about 12,500 feet; and the DC-9 hospital aircraft dispenses oxygen automatically in a range of 11,000 to 15,000 feet (see figure 6). Shutting off the oxygen supply precludes fire hazards after the aircraft is at 10,000 feet cabin pressure altitude or lower.

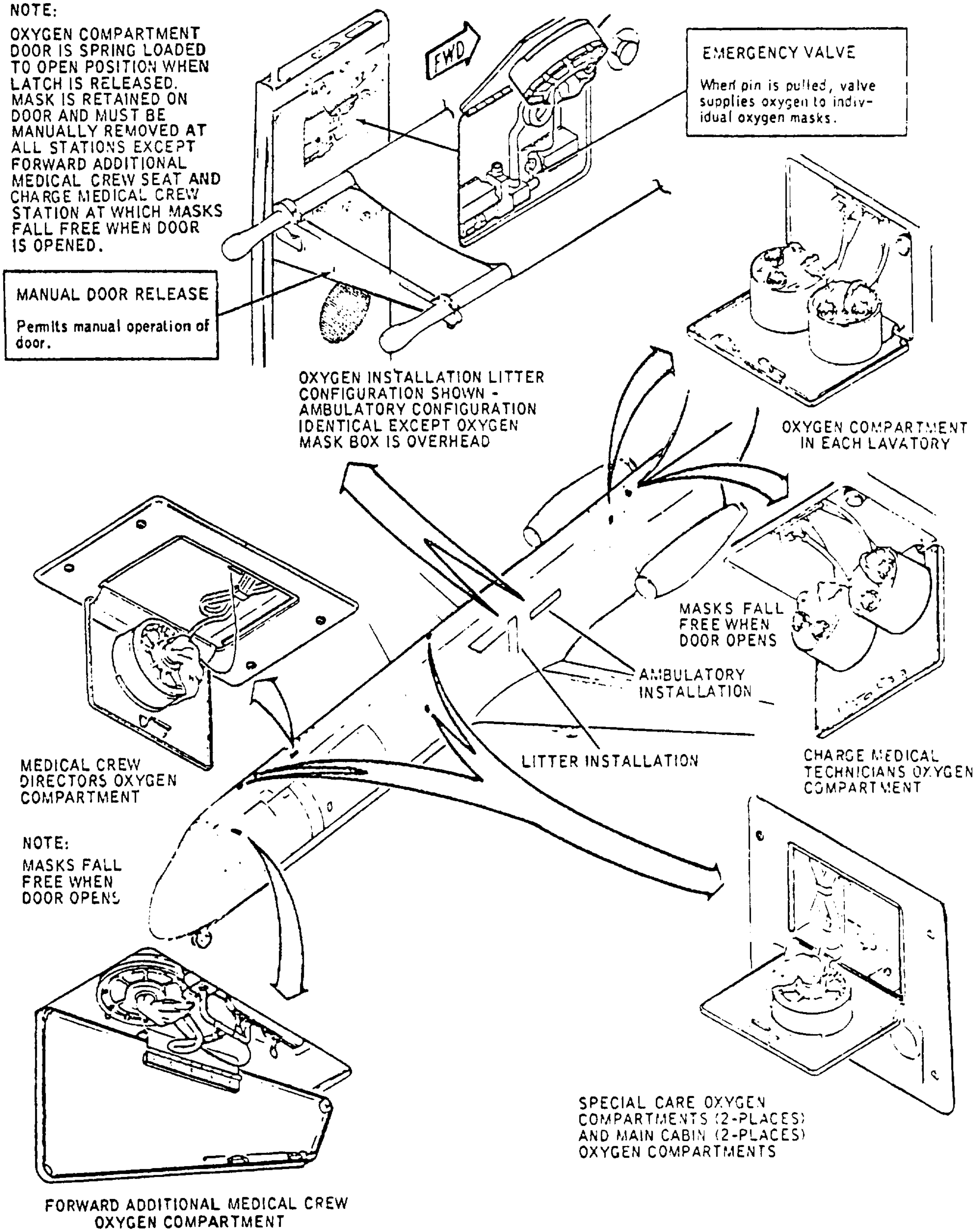


FIGURE 6. Emergency oxygen installations in USAF C-9A aircraft from condinuous-flow regulation.

REQUIREMENT GUIDANCE

a. The amount of oxygen provided for each passenger and the physiological limitations of the oxygen equipment are the factors used in determining the length of time the patients may be supported on supplemental oxygen. The physiological maximum of most continuous flow oxygen equipment is about three hours at 20,000 to 25,000 feet cabin pressure altitude. Use of this type of oxygen equipment with aeromedical patients definitely poses a risk.

b. The audible alarm should be easily heard under all expected flight noise conditions. This includes aerodynamic wind noise, powered engines, and structural vibration. A klaxton type horn is usually provided that is designed to activate automatically from a pressure-sensing device. This alarm should also be designed such that it can be activated manually by the pilots. This enables the alarm to be used for an evacuation signal. Bright ambient cabin illumination is essential to enable all passengers to see masks, straps, and controls that must be handled to breathe this oxygen.

c. Oxygen supply should be initiated within a range of 10,000 to 15,000 feet depending on the aircraft and its mission. It may be desirable to specify the exact type of oxygen mask desired or simply state that continuous-flow type is desired. Pressure-demand types of masks are usually provided for crewmembers and may also be provided for some of the medical staff who have critical duties. The face mask, inhalation/exhalation valves, reservoir bag, and activation lanyard are required components of any mask assembly. It is more desirable to dispense the above stated components automatically but this may be more costly. Manual donning may be acceptable if the mask assemblies are readily accessible. Many factors must be considered when determining the design and location of the emergency oxygen equipment; therefore, it is not desirable to specify all these locations. For example, installing oxygen bottles on passenger seat backs could be a hazard if passengers in the seats behind are thrown forward and strike their heads on a hard steel bottle.

d. All personnel should be able to reach a functional oxygen mask with the supply already initiated and should be able to don the mask assembly between 5 seconds (optimum) and 15 seconds (maximum).

e. It is desirable to activate the oxygen system at 11,000 feet in passenger type aircraft and no higher than 12,500 feet in cargo-type transport aircraft. Oxygen should continue to flow until the cabin pressure altitude drops to 10,000 feet or lower. The automatic shut-off should not stop the flow of oxygen to the flight crew.

REQUIREMENT LESSONS LEARNED

a. The C-141 aircraft aeromedical mission calls for a 5,000, 10,000, or 15,000 foot cabin pressure altitude in the event of a cabin decompression. The flight altitude chosen will depend on the condition of the patients to be carried on the aircraft. The 5,000 foot cabin pressure altitude would be planned when carrying patients in critical condition.

b. (to be added as acquired)

c - d. The C-141 aircraft uses masks and delivery tubes that are stored inside pouches installed along the cabin walls of the aircraft adjacent to self-sealing oxygen outlets. For a passenger to use this mask assembly and breathe oxygen, the loadmaster (or responsible crewmember) must manually activate oxygen from the manifolds to the plumbing. The passenger must reach outboard, pull the mask from the pouch, plug the delivery tube into the self-sealing outlet, and strap the mask to his face. This is time-consuming and some passengers may lose consciousness before completing the procedure.

e. (to be added as acquired)

4.2.2.4.3 Verification of emergency descent oxygen. The verification of emergency descent oxygen shall consist of ______________.

VERIFICATION RATIONALE (4.2.2.4.3)

Verification of the aeromedical emergency descent oxygen equipment is necessary to ensure that all components properly function in the expected operational environment and meet the physiological requirements of the patients and personnel that will use this equipment.

VERIFICATION GUIDANCE

The verification of the aeromedical emergency descent oxygen system should consist of analyses, inspections, demonstrations and test as necessary to ensure that all requirements have been met. Some past methods of verification are discussed in 4.2.2.1.

VERIFICATION LESSONS LEARNED

3.2.2.4.4 Aeromedical oxygen subsystem components. The permanent and required removable components of the oxygen subsystem shall be provided. These include the supply source, distribution plumbing, any required heat exchangers, altitude compensating regulator(s), pressure-reducing and one-way flow valves, and ____(a)____. Provide manual off and on control(s) that are readily accessible in flight, and ____(b)____. Provide masks and stowage containers available to each patient and medical attendant with ____(c)____ features. All supply sources and permanently installed components of the oxygen subsystem shall be located outside any design cargo volume and away from locations that may be easily damaged during normal cargo handling and use for transport of passengers and ____(d)____. Each supply source shall be easily removable for repair or replacement, and, if more than one supply source is provided, all shall be interconnected through one-way flow check valves such that any one supply source will provide oxygen to all outlets (e).

REQUIREMENT RATIONALE (3.2.2.4.4)

a. To ensure that the designer includes all detail and components in the design, it is desirable to call out each component known to be necessary to the aircraft oxygen system design. In the Request for Proposal, care should be taken to not have design solutions that tell the proposers which design to use (i.e., gaseous versus liquid oxygen versus on-board oxygen generating system supply).

b. To preclude fire hazards and minimize loss of oxygen from leaks, it is desirable to have a means to shut off oxygen in segments of the plumbing.

c. Oxygen mask assemblies for emergency decompression will be used only for a short time period, but they should be on the aircraft at all times for permanent seat and litter installations and should be installed with seat and litter kits when provided. To prevent damage to the mask assemblies, they should be carried in protective stowage containers.

d. The supply source of oxygen would present a serious fire and explosion hazard if oxygen from the source or plumbing leaked into the area where cargo containing hydrocarbons was present. Passengers could be injured or killed by exploding vessels or lines. Supply sources should be easily removable for repair replacement and charging.

e. The primary reason for interconnecting supply sources through one-way flow check valves is to allow all outlets to receive oxygen from all supply sources. This allows greater flow rates, and, in the event one of the sources leaks oxygen, the other sources will not leak.

REQUIREMENT GUIDANCE

a. The components mentioned in the requirement are, in general, known to be required for the installation of gaseous oxygen and LOX systems. If the particular oxygen system involved for a known aircraft requires other components, these should also be specified. An on-board oxygen generating system supply source is not currently used on aircraft of this type for aeromedical oxygen systems but could be designed for this application.

b. Manual off and on controls are needed for the aeromedical oxygen system to override automatic controls in the event of a malfunction, and to segment oxygen outlets if sections of the aircraft are not in use.

c. The most desirable method of providing passenger masks from stowage containers is to have a spring-loaded door that opens on a surge of oxygen pressure-to-mask assembly regulator inlet valve. The latching mechanism should also open easily when manually activated by the maintenance personnel for repair or replacement. When the mask and hose are released, they should drop to within easy reach of the passenger. Electrical latching mechanisms are less desirable and, if provided, must be activated from the emergency electrical supply.

d. The most desirable location for the supply sources is generally the wheel wells. The crew supply is usually placed in or near the nose wheel well location and the passenger supply is placed in the main landing gear wheel wells. These locations are readily accessible for repair and replacement. The lower lobe as used for baggage on commercial aircraft is also a desirable location for the supply source.

e. In all multiple supply installations, it is required that one-way flow check valves be installed where they are effective in preventing loss of the complete oxygen supply in the event any one supply source is damaged and leaks to ambient. In a multiple LOX converter installation, all check valves should be located downstream from the converter, vaporizing and warming heat exchangers such that liquid oxygen will not contact the valves. The check valves should not cause an excessive pressure drop or a restriction to required high gas flow rates. If auxiliary oxygen distribution lines are installed, spring-loaded check valves that open at higher pressures may be used, as these lines will be available for use only when the primary lines do not function. This type of design may apply from the passenger oxygen supply to the crew oxygen outlets when the crew uses the passenger oxygen supply as a backup to their primary supply.

REQUIREMENT LESSONS LEARNED

4.2.2.4.4 Verification of aeromedical oxygen subsystem components. The verification of aeromedical oxygen subsystem components shall consist of ______________.

VERIFICATION RATIONALE (4.2.2.4.4)

Verification of the aeromedical oxygen subsystem components is necessary to ensure that the total oxygen system properly functions in the expected operational environment and meets the physiological requirements of the personnel who will use the equipment.

VERIFICATION GUIDANCE

The verification of the aeromedical oxygen subsystem components should consist of analyses, inspections, demonstrations and tests as necessary to ensure that all requirements have been met. Some past methods of verification are discussed in 4.2.2.1.

VERIFICATION LESSONS LEARNED

3.2.2.4.5 **Aeromedical controls and displays.** Oxygen supply quantity information, status, and low level or loss of supply, and ____(a)____ warning indication shall be provided. Emergency oxygen "ON" information shall be provided and located such that ____(b)____. An aural warning consisting of ____(c)____ with a manual override silence control shall be activated, and the flight and cabin compartment general lighting shall illuminate to full brightness when the cabin pressure altitude reaches 10,000 feet. A manual shutoff control shall be provided to isolate delivery of oxygen supply to __(d)__ sections of litters, __(d)__ seats, and __(d)__ therapeutic/respirator outlets. A guarded manual override emergency oxygen and mask activation control shall be provided at the __(e)__ station for oxygen and mask activation features. The controls and displays provided shall be functionally compatible with the aeromedical oxygen system such that ____(f)____. Emergency or impending dangerous conditions shall be displayed in a manner to alert the appropriate personnel so that ____(g)____.

REQUIREMENT RATIONALE (3.2.2.4.5)

a. Oxygen supply quantity status is required so the medical crew director, the loadmaster, and/or the pilot(s) may be cognizant of the status of the oxygen supply. This is essential in planning missions so that ground support personnel may refill the supply source when necessary. Low level or loss of supply warning indication is necessary to alert crewmembers to a potentially hazardous situation.

b. In an emergency decompression it is essential that the crewmember responsible for the oxygen system know whether oxygen is available and flowing to all oxygen outlets. This means oxygen has been released by the cabin pressure altitude sensor which releases oxygen automatically. Additionally, it is desirable that each passenger have some kind of flow indication at the mask assembly to determine availability of oxygen.

c. When the cabin pressure altitude reaches 10,000 feet or higher, a decompression of the cabin has occurred. It may be a slow or rapid decompression. There is no way for the passengers to determine how much time they have to don oxygen masks. For this reason, an aural alarm should sound and cabin lighting should illuminate to "full bright" to enable all passengers to easily and rapidly don oxygen masks. A manual override silence control is essential, as the audible warning would be a nuisance when performing operational procedures after the emergency has been acknowledged.

d. The manual shut-off function allows positive control over individual segments of oxygen outlets to minimize the flow of oxygen in lines not in use. Also, in the event a leak should develop in a segment of the plumbing, this line could be shut off while allowing the flow of oxygen to other outlets.

e. In the event the automatic oxygen delivery function (if provided) should fail, a guarded manual override emergency oxygen and mask activation control should be provided as a backup means of delivering emergency oxygen.

f. This requirement ensures that the designer provides controls and displays that have electrical and pressure characteristics compatible with the operating ranges of the oxygen system components to be provided.

g. The selection of locations and the method of presentation for the displays indicating emergency or impending dangerous conditions should be specified to the extent that appropriate aeromedical crewmembers and passengers will receive warning in time to don oxygen before loss of consciousness.

REQUIREMENT GUIDANCE

a. Oxygen supply quantity information usually consists of a pressure gage for oxygen pressure vessels and a capacitance-type sensor with an indicator graduated in litres for LOX systems. Low-level-of-supply warning is usually indicated by a yellow caution light when 10 to 50 percent LOX is remaining in a converter (10 percent minimum is preferred). If two or more supply sources are provided, these indicators and lights should be provided for each supply source (not for the total system).

b The emergency oxygen "ON" information should, as a minimum, consist of a warning light at the pilot's station. If another crewmember is responsible for the oxygen system, then the same warning light should be provided at his crew station. This light should illuminate when oxygen has been automatically released and is flowing on the downstream side of the release device. If the passenger mask assemblies have reservoir bags that fill with oxygen prior to breathing, inflation of the reservoirs provides oxygen flow indication to each passenger.

c. The aural warning usually consists of a Klaxton horn that is also used as an emergency evacuation signal. The aural warning should be heard by passengers in all areas of the cabin with the worst case ambient noise environment (engines running and aerodynamic noise). An automatic activation of the cabin lighting to "full bright" is desirable. This will provide immediate illumination to enable passengers to rapidly see and don emergency oxygen masks.

d. The designer should specify the number of litters, seats, therapeutic outlets, and respirator outlets that should be controlled by each manual shut-off control valve. Usually this will consist of each row of seats, each group of litter tiers with common plumbing lines, and each group of therapeutic and respirator outlets.

e. The override control should be provided at the pilot's station and at the crewstation of the crewmember responsible for the oxygen systems. Should the automatic activation oxygen release feature fail to properly operate, a manual override control is essential. It is desirable that all electrical and pressure range characteristics of the controls and displays be specified in the designer's version of the applicable specification. The Request for Proposal as developed by the procuring activity may not necessarily contain this detailed information because this level of detail cannot easily be specified without having a design solution.

f. The method of presentation of emergencies that might require the use of oxygen is usually by the use of backlighted signs, aural warnings, and general illumination to full bright. Additionally, oxygen "ON" lights or mechanical flow indication should be provided downstream of any automatic oxygen activation device to ensure that personnel responsible for oxygen flow to passengers know oxygen is available in the plumbing. A good source of information on this subject is available in Federal Aviation Regulations; in particular, FAR Part 25 provides design detail to determine all important details that must be considered.

REQUIREMENT LESSONS LEARNED

4.2.2.4.5 **Verification of aeromedical controls and displays.** The verification of the aeromedical oxygen system controls and displays shall consist of ______________.

VERIFICATION RATIONALE (4.2.2.4.5)

Verification of the aeromedical oxygen system controls and displays is necessary to ensure that they properly function in the expected operational environment and meet the needs of the crew and personnel who use them. Aircraft passengers must also be able to detect and understand all displays.

VERIFICATION GUIDANCE

The verification of the aeromedical oxygen subsystem controls and displays should consist of analyses, inspections, demonstrations and tests as necessary to ensure that all requirements have been met. Some past methods of verification are discussed in 4.2.2.1.1.

VERIFICATION LESSONS LEARNED

3.2.2.5 **HALO oxygen subsystem.** A minimum of (a) outlets shall be provided for High Altitude Low Opening (HALO) parachute jumpers. This applies to an HALO oxygen system integral to the aircraft. These outlets shall be provided at (b) and shall be accessible to each paratroop when seated or standing adjacent to his seat. Outlet connectors shall be compatible with the breathing equipment the paratroop is expected to use consisting of (c). Each outlet shall have provisions consisting of (d) for protection from dust and contaminants when not in use. The HALO oxygen subsystem shall consist of plumbing distribution with only HALO oxygen outlets provided on these lines that connect to the passenger high pressure source through a manual off and on valve (e). Regulators for this plumbing shall provide positive pressure breathing capability for all HALO jumpers from sea level to (f) feet that allows nonfatiguing breathing from one-half hour for prebreathing to a minimum of (f) hours to complete the mission. The response of all regulators provided shall accommodate a rapid decompression of (g) seconds without adverse affects to the paratroops breathing from the HALO outlets. Each HALO oxygen outlet shall accommodate flow rates of ___(h)___ litres/hour/outlet and shall operate within a pressure range of ___(h)___ psi.

REQUIREMENT RATIONALE (3.2.2.5)

a. On those transport aircraft used to drop paratroops, it may be advantageous to provide oxygen outlets compatible with the HALO parachute jumpers' prebreathing equipment rather than rely on the availability of portable HALO units.

b. The primary locations to place the HALO oxygen outlets should be provided . If there is some latitude for the location(s) of these outlets, it is beneficial to state jump operations in which the locations should be compatible. Because the HALO jumpers' mobility is restricted by equipment, outlets must be readily accessible.

c. If the type of man-mounted prebreathing equipment to be provided is known, it is beneficial to specify performance characterisitics for the outlet type that is compatible with this equipment.

d. Dust and contaminants should be kept out of the oxygen lines to prevent health hazards to the HALO jumpers. Additionally, dust and contaminants may preclude valve closure at the outlet, allowing leakage.

e. The HALO oxygen supply shall be from the passenger oxygen supply, not from the crewmember supply. The crew must have adequate oxygen supply after the HALO jumpers have left the aircraft. Manual shut-off is necessary to reduce leaks and associated hazards that could occur if these lines were pressurized. It should be remembered that, in the case the aircraft is multi-mission, the HALO outlets may be used only for a small fraction of the missions. Should HALO oxygen supply be desired on an aircraft whose main mission is HALO flights, this control would assist in maintenance actions.

f. While positive pressure breathing can be a more fatiguing method than demand breathing, it is a design that ensures an oxygen pressure inside the breathing hoses that is always greater than the outside air pressure. Ambient air with 78 percent nitrogen would negate prebreathing or denitrogenation of the HALO jumper should it enter his breathing gas. With demand breathing, the pressure within the breathing hose may be less than the outside air pressure upon demand or inhalation. It is desirable to specify a maximum time period for prebreathing, as the design will have to be subjectively tested to this time period.

g. In rapid decompression, the cabin pressure altitude will increase rapidly to the flight altitude of the aircraft. It is therefore essential that the altitude-compensating mechanism of the regulators adjust the flow rates and pressures to the HALO outlets to assure a satisfactorily rapid response time. This will preclude oxygen starvation to the jumpers.

h. The oxygen flow rate and delivery pressure range will be a function of HALO equipment that is used by the paratroop personnel. Since these paratroop passengers must prebreathe, the oxygen delivery mode will be pressure breathing.

REQUIREMENT GUIDANCE

a. The HALO parachute jumpers usually jump in groups of 12. A minimum of 30 minutes should be allowed for prebreathing to denitrogenate a jumper's body. To ensure that the jumper does not breathe any nitrogen, pressure breathing equipment shall be provided. After several hours, the jumpers who are prebreathing with pressure breathing equipment could become extremely fatigued if using a regulator that is improperly designed. As such, it is desirable to provide a properly designed regulator that minimizes fatigue from pressure delivery. The amount of time paratroops can prebreathe is limited by the fatigue encountered from breathing on the regulation equipment.

b. It may be beneficial to integrate the HALO outlets and plumbing with the cabin walls, as the cabin interior is normally used to transport cargo and passengers. An alternate design approach may necessitate plumbing kits with below-the-floor or bulkhead outlets. The HALO jumpers will be prebreathing oxygen while sitting and fully restrained. They should also be able to stand up, prepare to jump, disconnect from the aircraft oxygen outlets, and jump. The outlets must be compatible with the HALO jumpers' procedures and should not require multiple disconnect and connect procedures.

c. Each HALO jumper will have only about 10 to 20 minutes of oxygen supply provided from his bailout bottle. The HALO jumper must have some type of in-line regulator to reduce the higher pressure oxygen (about 70-400 psi) to appropriate breathing pressures. Each HALO jumper must also have a connector that accepts both the aircraft oxygen supply and the oxygen supply from the bailout bottle after the HALO jumper disconnects from the aircraft supply.

d. The outlet should be a self-sealing type to stop oxygen flow when the HALO jumper disconnects to jump from the aircraft. A protective cover with an attachment or an outlet with positive seal from dust and contaminant entry (even after numerous insertions and disconnects) should be provided.

e. Oxygen lines separate from the emergency oxygen delivery plumbing and aeromedical delivery plumbing appear to be the best design approach. Usually the pressure in the line to the emergency oxygen masks initiates automatic delivery of the mask assemblies. The emergency oxygen lines may be controlled by altitude-compensating regulators upstream to the outlets and the aeromedical oxygen will be controlled by continuous- or constant-pressure regulators upstream to the outlets. The regulators upstream of HALO distribution plumbing probably will not be compatible with the HALO prebreathing equipment. As such, the HALO oxygen plumbing lines should be on separate lines.

f. The ceiling on this equipment will be 40,000 feet pressure altitude for daytime HALO jumps. The partial pressure of oxygen in the alveoli for 100 percent oxygen will be about 60 mmHg at 40,000 feet cabin pressure altitude. This equates to a 10,000 foot pressure altitude in the ambient air. At altitudes above this, hypoxia symptoms will begin to occur. The ceiling on this equipment will be about 35,000 feet pressure altitude for nighttime HALO jumps. The partial pressure of oxygen in the alveoli on 100 percent oxygen will be about 82-90 mmHg, which equates to a 5,000 foot or lower pressure altitude in the ambient air. A 5,000 foot pressure altitude is the ceiling above which dark eye adaptation is destroyed; therefore, it is desirable to maintain an equivalent alveoli partial pressure of 5,000 feet or lower so the HALO jumper may have night vision.

g. It is difficult to determine a time period of decompression without knowing the internal pressurized volume of the aircraft and the area of the opening through which the cabin air escapes. Another type of decompression occurs when a large window or cargo ramp or door opens inflight: this is an explosive decompression. The regulator should have a response time not to exceed 1-5 seconds for the normal decompression and should not adversely affect the HALO jumpers for an explosive decompression.

h. The paratroop personnel shall prebreathe at least 20-30 minutes prior to a high altitude parachute drop. The oxygen delivery device should provide slight positive pressure breathing to preclude the entry of nitrogen into the oxygen delivery hoses, regulator, and mask. The flow rates shall be a minimum of 600 litres/hour/outlet with a delivery pressure of not less than 2 inches of water. The plumbing distribution system should have an altitude-compensating device that regulates flow as a function of cabin pressure altitude. In a transport aircraft with more than 12 paratroops, the upstream plumbing delivery pressure should be in the range of 300-450 psi to ensure adequate flow is provided at all HALO outlets. The most desirable approach is to provide 300 psi in the oxygen supply lines in the aircraft or portable supply unit (70 psi to supply less than 12 paratroops). 70 psi should be provided within flexible supply hoses that have disconnect features to miniature regulators that provide breathing oxygen at slight positive pressure.

The absolute ceiling at which this equipment need be compatible is 50,000 feet pressure altitude. The altitude at which the paratroops jump will be lower than this, but in the event the aircraft flies to this altitude, a safety margin should be incorporated into the design.

REQUIREMENT LESSONS LEARNED

a - b. All earlier types of prebreathing equipment for HALO parachute jumpers consisted of portable carry-on units. Many of these units are bulky and difficult to handle. Additionally, large convoluted hoses were distributed from the oxygen supply to each jumper. These supply hoses were easily tangled and the jumpers were required to gather around the unit because the delivery hose lengths were limited to 8-12 feet. The oxygen supply provided by this unit was limited, and therefore the loiter or standoff time of the aircraft would be limited once the HALO jumpers initiated prebreathing.

c - h. (to be added as acquired)

4.2.2.5 **Verification of HALO oxygen subsystem.** The verification of the HALO oxygen subsystem shall consist of ____________.

VERIFICATION RATIONALE (4.2.2.5)

Verification of the HALO oxygen subsystem equipment is necessary to ensure that all components properly function in the expected operational environment and meet the physiological requirements of the paratroop HALO jumpers that will use the equipment.

VERIFICATION GUIDANCE

The verification of the HALO oxygen subsystems should consist of analyses, inspections, demonstrations, and tests as necessary to ensure that all requirements have been met. Some past methods of verification are discussed in 4.2.2.1.

VERIFICATION LESSONS LEARNED

3.2.2.6 **General passenger oxygen.** In the event of either an unplanned decompression of the aircraft cabin that is normally pressurized, or flight in a nonpressurized cabin, supplemental oxygen is required to support __(a)__ passengers for at least __(a)__ time period. Flow rates and delivery pressures that consist of ____(b)____ shall be provided. Should the cabin pressure altitude exceed 10,000 feet in a normally pressurized cabin, an alarm shall be automatically sounded and shall be audible to all passengers under the expected ambient noise conditions of flight (c). The cabin lighting shall illuminate to full brightness. If the oxygen subsystem is permanent, the components shall consist of a supply source that is removable for repair and servicing, any required heat exchangers, distribution plumbing, any required regulators, manual off and on controls that are readily accessible in flight, masks in stowage containers, and ____(d)____. If the oxygen subsystem is portable, it shall consist of ____(e)____. Oxygen shall become available to each seated and restrained passenger in a time period not to exceed __(f)__ seconds. The breathing protection system shall support passengers for __(g)__ minutes in the event of a smoke-filled cabin.

REQUIREMENT RATIONALE (3.2.2.6)

a. For all aircraft that carry passengers and fly above 10,000 feet cabin pressure altitude, supplemental oxygen is necessary for passengers in the event of an emergency decompression. This will provide oxygen supply to the passengers while the aircraft is in descent to a pressure altitude of 10,000 feet where supplemental oxygen will not be required. General passengers are defined as aircraft occupants, regardless of the type of seating they occupy, who are merely transported from one location to another. Also, there is no requirement for mission completion.

b. Oxygen delivery flow rates and pressures must be provided that are physiologically compatible with the passengers' needs.

c. Passengers need immediate warning of an impending dangerous situation in which they will need to don oxygen masks and breathe oxygen. The alarm must be loud enough to hear over the aircraft engine noise and aerodynamic noise while in flight. To enable passengers to quickly find the oxygen mask assemblies, cabin illumination is needed. At night the lights may be out when the emergency occurs and sufficient time will not be available for a crewmember to find and turn on all the lighting. Therefore, automatic full-bright illumination of the cabin lighting is essential.

d. Aircraft oxygen delivery equipment is necessary no matter what type of system is provided (i.e., LOX, gaseous, chemical, or on-board oxygen generating system). It is good practice to specify the major subsystem components of the aircraft oxygen system to ensure the contractor will provide it.

e. Since portable oxygen subsystems may be provided on the aircraft in various ways, it is beneficial to indicate to the contractor what is desired.

f. It is essential that the aircraft designer or the oxygen subsystem contractor properly install supplemental oxygen dispensing equipment such that quick donning of masks is easily accomplished and oxygen supply is immediately available.

g. An oxygen supply duration requirement enables the designer to determine the size of the oxygen supply required for the passenger personnel who are provided smoke protection breathing equipment.

REQUIREMENT GUIDANCE

a. A general aircraft passenger is carried on the aircraft as transport from a point of departure to a destination and is not normally involved in duties onboard the aircraft as are crewmembers. Other types of passengers are aeromedical patients, medical attendants, HALO paratroop jumpers, and normal paratroop jumpers. These other types of passengers have unique oxygen requirements. The general passenger needs oxygen only for aircraft descent to 10,000 feet pressure altitude as on commercial aircraft.

b. Based on the partial pressure difference of oxygen within the lungs and on the pressure in the aircraft cabin, the following flow rates must be supplied (as a minimum) to each passenger:

Cabin Pressure Altitude (feet)	100 Percent Oxygen Flow Rate (litres/hour)	
10,000	42	
15,000	42	
20,000	120	
25,000	174	*162
30,000	216	
35,000	255	
40,000	282	*270

* Flow rates to be expected from current GFE chlorate candles (CRU-74/P). Initially 270 litres/hour, 3 minutes later flow rate drops to 162 litres/hour gradually over a 7 minute period, then maintains a minimum flow rate of 162 litres/hour for 20 minutes.

c. A low cabin pressure altitude warning is always essential for an aircraft that can fly above 15,000 feet in cruise and carries passengers. It may be desirable to specify the nature of the alarm should it fit in with past procedures of the using command to receive the aircraft. Types of alarms are Klaxton horns and whoopers.

d. If any other subsystem components are known to be essential components of the oxygen system, they should be added to the above requirement.

e. Chlorate candles could be mounted on the seats within passneger reach or another type of portable chemical oxygen generator could be provided. Another possibility is a LOX converter or pressurized oxygen bottles which could be carried on-board as portable equipment and the plumbing routed temporarily to a passenger.

f. The time to don oxygen masks and breathe oxygen should always be less than the time of useful consciousness under the emergency decompression. In large, transport-type aircraft (the size of the C-141 or Boeing 707) a period of 15 seconds is used as a rule of thumb. For smaller aircraft and aircraft that cruise above 40,000 feet cabin pressure altitude, a time period of 6-7 seconds is used.

g. The rule of thumb for protective breathing assemblies is a minimum of 30 minutes on 100 percent oxygen. This enables an aircraft to make a safe, controlled descent to 10,000 feet pressure altitude and land at an alternate airport. This supply time may be satisfactorily provided by portable units. Additional supply exceeding 30 minutes may be desirable on jet aircraft with long range, overseas missions.

REQUIREMENT LESSONS LEARNED

a - d. (to be added as acquired)

e. Chemical oxygen generators, such as chloride candles which are cooled by natural convection, tend to have higher surface temperatures at altitudes above ground level. This trend seems to be related to the lower density at higher altitudes. Any surfaces the user may touch during use should have a maximum temperature limit within human tolerance for pain at the defined altitudes.

f. Reference AFALC/PTL, Wright-Patterson AFB, OH. Abstract of Lessons Learned, 1 Jan 1984. LL# 0055: If emergency breathing equipment is difficult to use, cumbersome, restrictive, and difficult to accept due to psychological constraints, then its effectiveness during emergency situations will be marginal, and personal injury or fatalities may result.

g. (to be added as acquired)

4.2.2.6 **Verification of general passenger oxygen.** The verification of the passenger oxygen system shall consist of ___________.

VERIFICATION RATIONALE (4.2.2.6)

Verification of the passenger oxygen system equipment is necessary to ensure that all components properly function in the expected operational environment and meet the physiological requirements of the personnel who will use the equipment.

VERIFICATION GUIDANCE

The verification of the general passenger oxygen subsystem should consist of analyses, inspections, demonstrations, and tests as necessary to ensure that all requirements have been met. Some past methods of verification are discussed in 4.2.2.1.

VERIFICATION LESSONS LEARNED

3.2.2.6.1 **Passenger controls and displays.** Should the general passenger oxygen subsystem be permanently installed, oxygen supply quantity status and low-level or lack-of-supply warning shall be provided at the ___(a)___ station. Emergency oxygen "ON" information shall be provided at the ___(b)___ stations to show that oxygen is flowing through the ___(b)___. A guarded control shall be provided at the ___(c)___ station(s) to manually activate the supplemental oxygen to all the seated passenger locations, and an audible warning shall be activated from this control or an adjacent control. A separate audible-warning silencing control shall be provided. Test controls shall be provided to check for proper functioning of all lighted displays, indicators, and instruments (d).

REQUIREMENT RATIONALE (3.2.2.6.1)

a. It is necessary that the crewmember responsible for the passenger oxygen system be informed of the oxygen supply status. This enables the flight crew to be prepared for any emergency in which passengers will need supplemental oxygen. In the event there is a malfunction of the quantity indicator or the display is overlooked, a low-level-of-supply warning indication is needed.

b. With the continuous-flow system for emergency oxygen supply, it may not be practical to provide oxygen "ON" information at every passenger station, but warning signs and/or lights should be visible to all in the cabin. Emergency oxygen "ON" information is useful to the crewmembers who monitor the oxygen system to ensure that oxygen is available to all passengers.

c. It is essential that a control be provided to manually activate oxygen to the passenger mask assemblies in the event the automatic activation subsystem fails. It is required that the audible warning activate automatically, but in the event the automatic system fails, a means shall be provided for manual activation of the alarm system. Undue continuation of the alarm will distract further operations; therefore a means should be provided to manually silence this alarm.

d. In the event of inconsistent information from the oxygen system displays relative to the known status of the oxygen system, it is desirable to provide test controls to check for proper operation of instruments and indicator lamps.

REQUIREMENT GUIDANCE

a. Quantity of supply control and display information primarily applies to LOX and gaseous oxygen systems. In a LOX system, the quantity indication applies to LOX in the converter in litres with low-level-of-supply warning given at 10 percent of the supply (see figure 1). In a gaseous system, the quantity indication applies to gas pressure in the supply container with low-level-of-supply warning given at 30-40 percent of the total fill pressure, and warning information is provided for overpressure. Similar information should be provided if an on-board oxygen generating system is provided.

b. Provide emergency oxygen "ON" information at the pilot's station and at the station of any other crewmember, such as a loadmaster or flight engineer, who is responsible to monitor the oxygen supply (see figure 1). The sensor for this display should be on the downstream side of the cabin pressure altitude compensating regulators. This will provide an indication that these regulators (at least two plumbed in parallel) are properly functioning. Provide lighted signs to alert passengers to don oxygen masks.

c. These controls should be provided at the pilot's station and at the flight engineer or loadmaster station (as applicable). A manual shut-off globe valve in the plumbing shall not substitute for this control device (see figure 1). This control is considered a manual override to the automatic oxygen delivery. This globe valve (if provided) may be safety wired to the "ON" position and should be shut off only for maintenance, loss of a converter, or to disable oxygen outlets no longer necessary for seating that has been removed.

d. It is necessary to provide a control to energize all indicator lamps (this applies to caution, advisory, and warning legend lights and bullseye lights) (see figure 1). This allows the crewmember to check for proper functioning of the light bulb or illumination source, as applicable. The crewmember will then be assured of the continuity of the light circuit, and if a problem exists, it will be with the sensor or the circuitry. If a sensor is provided which is not reliable and requires frequent maintenance, a test control should be provided to check the sensor while the aircraft is in flight. Test controls should also be provided for all instruments such as LOX quantity gages and pressure indicators.

REQUIREMENT LESSONS LEARNED

4.2.2.6.1 Verification of passenger controls and displays. The verification of the passenger oxygen system controls and displays shall consist of ____________________.

VERIFICATION RATIONALE (4.2.2.6.1)

Verification of the passenger oxygen subsystem controls and displays is necessary to ensure that they properly function in the expected operational environment and meet the needs of the crew that uses them. Aircraft passengers must also be able to detect and understand all displays.

VERIFICATION GUIDANCE

The verification of the general passenger oxygen subsystem controls and displays should consist of analyses, inspections, demonstrations and tests as necessary to ensure that all requirements have been met. Some past methods of verification are discussed in 4.2.2.1.1.

VERIFICATION LESSONS LEARNED

3.2.2.7 **Ejection seat bailout oxygen subsystem.** During ejection seat escape from the aircraft, supplemental oxygen is required for the time period of ___(a)___ for descent from higher altitudes. This same oxygen supply shall be designed for use as backup emergency oxygen supply in the event of a cockpit decompression or a failure of the primary oxygen system (b). This oxygen subsystem shall have the following features: manual actuation for inflight emergencies; automatic oxygen flow upon the onset of the ejection sequence; automatic disconnect of oxygen hose from the crewmember on seat/man separation or on parachute deployment; pull-free hose disconnect capability for ground egress; and ___(c)___. Provide a ___(d)___ guarded control for manual activation of oxygen and a ___(d)___ quantity of oxygen display. Should a portable cylinder be used for the supply source, a means to recharge the cylinder shall be provided with features consisting of ___(e)___. The delivery hose shall be flexible and shall be compatible with ___(f)___ type personal connector. If the supply source is a cylinder, it shall have the following features: ___(g)___. Sufficient flow rate and delivery pressure shall be provided at the breathing mask to enable the crewmember to breathe with minimal fatigue from altitudes of ___(h)___ feet to ___(h)___ feet and in a windblast environment of ___(h)___. The manual activation control shall be activated with a force of ___(i)___.

REQUIREMENT RATIONALE (3.2.2.7)

a. This oxygen source is required for crewmember life support for free fall following ejection from maximum altitude to the aneroid altitude setting of the recovery parachute.

b. This backup oxygen supply is also necessary to provide life support for the crewmember in the event of a decompression of the cockpit or a failure of the aircraft oxygen supply system. This requires that an in-flight activation control be installed to initiate the oxygen supply.

c. The specified operational features will always be required of this oxygen assembly for satisfactory seat/man/aircraft interface and should be stated.

d. A manual activation of the oxygen supply by a control device is essential in the event of an emergency decompression and/or a loss of the oxygen supply. A quantity display is necessary so that maintenance personnel can determine when to recharge the supply or replace it.

e. It should be possible to recharge the high pressure oxygen bottle (if provided) in its mounted position on the seat or in the survival kit container. The recharger outlet should accommodate the standard military connectors.

f. The oxygen supply hose shall connect to the pressure-reducing valve on the high pressure bottle or chemical generator supply source such that it may be disconnected for maintenance and any necessary operational procedures. The other end of the supply hose shall have a quick-disconnect capability with the personnel connector located on the crewmember's chest.

g. The high pressure bottle is the current method for ejection seat bailout. The high pressure cylinder is compact and safe for ejection seat operation. Pressure relief is an essential built-in safety device to preclude cylinder rupture. Other design features are necessary for safe and proper emergency oxygen delivery.

h. The high pressure cylinder will deliver oxygen via either positive pressure or demand breathing. As such, it is essential to specify the altitude range and windblast environment in which these breathing modes should be delivered to the mask.

i. It is essential to preclude accidental activation of the oxygen supply and at the same time ensure that the supply source may be manually activated by the program's specified percentile range of crewmembers. From this information, specify the range of forces required to activate oxygen from the supply source.

REQUIREMENT GUIDANCE

a. It is necessary that the contractor perform an analysis to determine the maximum supply time of oxygen required for the system under consideration. The maximum ejection altitude of the escape system should be used. Presently, this maximum altitude is 50,000 feet. In this analysis, the following factors should be considered in calculating the time the oxygen supply will be required: the time the crewmember is in the cockpit after jettison of the canopy, catapult or ejection from the aircraft, seat/man stabilization and separation, free fall descent of the crewmember, and parachute descent of the crewmember (if the parachute opens above 10,000 feet pressure altitude) shall all be considered. An additional 20-30 percent reserve supply shall be provided.

b. In a combat situation or any mission, it is possible that damage could occur to cause a decompression of the cockpit and a failure of the oxygen system. If the aircraft is above a 10,000 feet pressure altitude, the crewmember(s) will require supplemental oxygen to descend to 10,000 feet pressure altitude. An analysis shall be accomplished to determine the time period of oxygen required for the worst case situation, and this shall be provided with an additional 20-30 percent supply.

c. These operational requirements are valid if the oxygen supply is provided in the parachute pack, in the survival kit, or elsewhere on the ejection seat. Seat mounting of the oxygen supply is considered the most desirable approach on USAF aircraft, but this is not compatible with naval operations where a crewmember would be required to accomplish underwater egress.

d. The control device for manual activation of the oxygen supply could be a green apple or a green ring located within easy access. These types of controls are used now so crewmembers will be familiar with them. Other types of controls are used on the seat and in the aircraft cockpit. The manual emergency oxygen control should not be similar to any other ejection seat controls, as the crewmember could inadvertently activate the wrong control. The minimum diameter of the green apple has been 1 1/2 inches. The green ring should accommodate a crewmember with two arctic gloved fingers. If the oxygen supply is a high pressure cylinder, a pressure gage will provide an indication of the quantity of oxygen supply available to the crewmember. The gage shall indicate the pressure within the cylinder with an accuracy of about 1 percent, show the full pressure range, have a scale range which indicates overpressure marked with a red bar, and be installed on the high pressure cylinder assembly so that it is easily readable by maintenance personnel without the need to disconnect any mounting provisions.

e. The filler valve to which the ground servicing connection is made in recharging the system shall be a check filler connection, MS22035, or line valve, AN6012, with a cone fitting such as AN780-3. A dust cap and retaining chain, in accordance with 55B3878, may be provided with the filler valve. The cylinder should be filled from a single filler valve. Should the filler connection used by the USAF by other than the above specified, this detailed specification information should be provided instead.

f. Having the oxygen supply hose flexible with some length enables the crewman to lean forward to use cockpit controls and displays. All automatic pull disconnects to be used for crewmember, survival kit, ejection seat and parachute pack shall be compatible with all required operations. This connector also inputs oxygen from the pressure-demand regulator. The primary personal connector currently in use is the CRU-60/P.

g. Most high pressure cylinders are designed to be filled at 1800 to 2150 psi and are usually refilled in operational usage to lower pressures for an adequate safety margin. These cylinders are burst pressure tested at a pressure not less than 4000 psi and usually are designed to relieve pressure at about 3000 psi. Department of Transportation (DOT) Code of Regulations provides detailed information on pressure vessel design requirements.

h. The oxygen regulation means should provide oxygen at positive pressure above 28,000 to 32,000 feet pressure altitude with increasing pressures to 50,000 to 60,000 feet to provide the proper alveolar partial pressure. Either slight positive pressure or demand breathing may be provided from sea level to 28,000 to 32,000 feet pressure altitude; however, a demand breathing mechanism increases the size and weight of the assembly. This would not be desirable. The supply source should provide sufficient oxygen for an aircraft emergency descent from its ceiling, or for free fall following ejection from maximum altitude to the nominal aneroid altitude setting of the recovery parachute. Windblast environments for safe seat ejection are in the range up to 500 to 600 KNEAS.

i. Past supply valves have incorporated a nipple that prevents oxygen flow until broken. This nipple is machined to a radius corresponding to its material to break within a certain range of shearing forces of 12 to 20 pounds. After the nipple breaks, oxygen supply begins to flow through the regulation means, the delivery hose, and into the crewmember's mask until the oxygen supply is exhausted. All new designs should maintain a manual activation force range of 12 to 20 pounds.

REQUIREMENT LESSONS LEARNED

a - b. (to be added as acquired)

c. The CRU-60/P connector serves for automatic and manual disconnect with an anti-suffocation valve. Past experience has shown that the connector causes an undesirable pressure drop in the breathing line. Improvements are desirable.

d - g. (to be added as acquired)

h. Past experience has shown that some crewmembers lose consciousness on seat ejection due to emergency situation that was the cause for seat ejection or the airstream windblast. For this reason, the pressure-breathing delivery mode is more desirable to ensure that oxygen is forced into the crewmember's lungs to enhance the probability of his survival. Also, this oxygen supply source provides supplemental oxygen to the crewmember in the event of a failure of his primary oxygen supply source, supporting him to an altitude of 10,000 feet or lower where supplemental oxygen is not required.

i. There have been several problems with past designs. Oxygen corrosion or oxidation on some past nipples lowered the breaking strength enough to result in inadvertent supply activations. The material chosen for the nipple should maintain a stable breaking shear strength in an oxygen-rich environment. Other problems have occurred with the cable from the manual activation handle to the nipple. Pull-through cable would stick or freeze in a cold environment. Pins and mounting brackets would resist activation.

4.2.2.7 Verification of ejection seat bailout oxygen subsystem. The verification of the ejection seat bailout oxygen subsystem shall consist of ________ ____________.

VERIFICATION RATIONALE (4.2.2.7)

Verification of the ejection seat bailout oxygen subsystem equipment is necessary to ensure that all components properly function in the expected operational environment and meet the physiological requirements of the crewmembers who will use the equipment.

VERIFICATION GUIDANCE

The verification of the ejection seat bailout oxygen subsystem should consist of analyses, inspections, demonstrations and tests as necessary to ensure that all requirements have been met. Some past methods of verification that may be applicable are discussed in 4.2.2.1.

VERIFICATION LESSONS LEARNED

3.2.2.8 **Manual bailout/emergency oxygen supply.** A minimum of (a) portable manual bailout/emergency oxygen assemblies shall be provided to enable (a) personnel to breathe for an emergency decompression and parachute escape at altitudes up to (a) feet. Each quick-donning assembly shall consist of a supply source, a device for regulation to (b), and a flexible hose connected to a breathing mask. Each assembly shall have a means to hold and carry it during bailout exiting and parachute descent or to reach a station with oxygen that consists of (c). To hold and retain the manual bailout/emergency oxygen assemblies while in flight, provide (d). Each assembly shall have control features consisting of (e) and display features consisting of (e). Should a portable cylinder be used for the supply source, a (f) means to recharge the portable cylinder shall be provided. If the supply source is a cylinder, it shall be a (g) pressure vessel filled to a pressure of (g) psi, and pressure relief shall be provided on the valve to vent oxygen at (g) psi. Sufficient flow rate and delivery pressure shall be provided at the breathing mask to enable the crewmember to breathe with minimal fatigue from altitudes of (h) feet to (h) feet.

REQUIREMENT RATIONALE (3.2.2.8)

a. Manual bailout oxygen assemblies enable the personnel to have supplemental oxygen for parachute descent in a manual bailout and for aircraft descent in an emergency decompression.

b. The assembly should consist of basic components regardless of the type of design used. Physiologically compatible breathing pressures should be delivered to the parachute jumper, crewmember, or mission specialist through a regulator.

c. The assembly consists of components connected with flexible hoses that make it difficult to hold and carry but which allow the person to perform his necessary duties or parachute egress after a cabin decompression. Therefore, a means to carry the assembly is needed.

d. A method to retain the manual bailout oxygen assemblies while in flight shall be provided to preclude damage to the units. The storage equipment must retain these assemblies against all flight conditions, yet still allow quick access to them when they are needed. Some unique design constraints on the aircraft mission may necessitate the crewmember to wear his parachute pack and survival kit while seated (a nonejection seat system) on the aircraft. This aircraft may fly at altitudes above 10,000 feet where oxygen is required.

e. The person who uses the assembly must have an indication that oxygen is available or flowing. Specify any known required features. An "ON/OFF" control for initiation of oxygen supply is essential. The type of breathing required may be selectable and all modes should be specified. The breathing modes available include: diluter-demand, slight pressure with and without air dilution, and increased positive-pressure.

f. A pressurized cylinder shall be rechargeable so it may be reused after loss of supply.

g. Manual bailout oxygen pressures are applicable to most existing assemblies. The pressures must be specified to ensure the proper type of assembly is provided. The cylinder size or volume may be specified to ensure that adequate supply is provided.

h. At higher altitudes, delivery pressure to the breathing mask should be great enough to allow the person who is breathing to have total awareness. It is therefore essential that the free fall and parachute inflation altitude ranges be specified. Additionally, the delivery flow rates and pressures must be physiologically compatible with an emergency decompression.

REQUIREMENT GUIDANCE

a. At least one manual bailout oxygen assembly shall be provided for each person parachuting at altitudes above 10,000 to 13,000 feet. In aircraft that use these oxygen assemblies for an emergency decompression, provide at least one oxygen assembly for each crewmember and mission specialist required to be away from his position or station for extended time periods. Crewmembers or passengers who remain seated throughout most of the mission may have aircraft-installed oxygen equipment available and may not need portable oxygen assemblies. However, readily available assemblies would be required if aircraft oxygen supply is not provided. It may be desirable to have a few spare assemblies in the event a malfunction occurs while in flight. The oxygen assemblies shall perform satisfactorily in all situations at all pressure altitudes up to 50,000 feet.

b. A high pressure oxygen cylinder is used as a bailout assembly supply source at this time. Other possible supply sources include chemical oxygen-generating devices. The consideration for satisfactory breathing is a sufficient rate of flow of oxygen to support a person who is physiologically exerting himself by running or parachute jumping and is under a high stress. This must be considered in the design of the regulation device for the flow rate and pressure of oxygen delivered to the person. Flexible hose(s) shall be included in the design of the manual bailout bottle to allow satisfactory operation by the person wearing the assembly such that he is not required to hold bulk and weight near his face. The supply that is delivered to the face mask should usually consist of a larger convoluted hose up to the breathing mask. The mask should include inhalation/exhalation valves, a good seal at the face, and a satisfactory device for securing the assembly to the face.

c. For a parachute jumper, the supply could be carried beside the parachute back pack or alongside the jumper's upper leg. For crewmembers and mission specialists who must reach oxygen in the event of a decompression, a means to carry the assembly should be provided that may have a shoulder strap included.

d. A storage location shall be located to be out of the way of other operations but convenient to pass the assemblies out for each mission when they are needed. The assemblies shall be retained so that the forces of flight do not break them or damage other aircraft components. A chest-type container with a latching cover lid to restrain the oxygen assemblies against negative g's is considered a desirable approach to storing a large number of assemblies.

A portable manual bailout oxygen assembly must be provided that is readily accessible to the crewmember(s). It is possible the design may be built around a mission where the pilots would descend below 10,000 feet, then crewmembers would parachute. Aircraft integral oxygen could be used in this descent in the event of an emergency decompression. These factors should be worked out in the conceptual phase around planned missions to ensure provisions for these manual bailout oxygen assemblies are considered, if required.

e. With a pressurized oxygen supply source, quantity indication (pressure gage) is required, flow indication is good for continuous-flow breathing only. With solid-state chemical oxygen generation only flow indication can be shown. An "ON/OFF" control is applicable to all types of pressurized oxygen supply sources and an initiation control is applicable to a chemical oxygen-generation system. Demand breathing modes can only be provided from a pressurized source. This means an accumulator would be needed with a chemical oxygen generator. Pressure-breathing can be provided from either type of supply.

f. A standard refill valve or fitting compatible with current USAF charging equipment should be used. The logistics agency to receive the portable pressure cylinders shall be questioned as to the type of refill valve that is compatible with their equipment. A source of information on military standard valves is in MIL-D-8683 and MIL-D-19326.

g. The higher pressure type of supply sources provide sufficient oxygen for bailout and ease of carrying. The lower pressure type of assemblies would be a problem when the parachute jumper fails in the ambient. The larger volume of the vessel would affect the aerodynamic stability of the jumper. High pressure cylinders are usually filled to 1800 to 2150 psi and pressure relief is provided at 3000 psi for safety. Chemical oxygen generators may not provide sufficient flow rates and delivery pressures to warrant a pressure-relief device, but this should be evaluated before deleting the valve.

h. It is likely the pressure delivery characteristics will begin at higher values and taper to lower values as the back pressure in the supply cylinder decreases. In fact, it is desirable that the delivery pressure initially provide at least 60 to 100 mmHg in the alveolar. This will provide enough partial pressure of oxygen to the lungs to preclude the jumper from losing consciousness. The amount of pressure will be excessive at higher altitudes and result in extremely difficult breathing. The pressure altitude ceiling at which a jumper may begin free fall is 42,000 feet. This is quite rare, however, as most free-fall jumping is done at 30,000 feet and lower. The lower altitude chosen will be 10,000 feet or lower. This is strictly a function of the amount of oxygen supply, the breathing pressures delivered as a function of time or altitude, and the design ceiling of the regulator. Oxygen delivery at pressure altitudes lower than 20,000 feet is necessary in a contaminated environment, and chemical defense is required.

REQUIREMENT LESSONS LEARNED

a. Manual bailout oxygen assemblies are used on some USAF aircraft by crewmembers and mission specialists to enable them to walk about the cabin of the aircraft to a station remote from their seated station. A high pressure bailout bottle was provided in a canvas carrying pouch with a shoulder sling to enable the crewmembers to carry the oxygen assemblies about the aircraft. When Electronic Warfare Officer (EWO) training instructors are aboard the aircraft to train other EWOs, in many cases they must stand or sit behind the EWO and his console. The instructor usually does not have an aircraft oxygen outlet and will not have enough oxygen to reach his seat where aircraft oxygen is available without a portable supply of oxygen. In this case, the manual bailout oxygen assembly may be carried over the EWO's seat back at the convenience of the instructor for a readily available oxygen supply.

b - h. (to be added as acquired)

4.2.2.8 Verification of manual bailout oxygen. The verification of the manual bailout oxygen shall consist of ______________.

VERIFICATION RATIONALE (4.2.2.8)

Verification of the manual bailout/emergency oxygen equipment is necessary to ensure that all components properly function in the expected operational environment and meet the physiological requirements of the personnel who will use the equipment.

VERIFICATION GUIDANCE

The verification of the manual bailout/emergency oxygen supply equipment should consist of analyses, inspections, demonstrations, and tests as necessary to ensure that all requirements have been met. Some past methods of verification that may be applicable are discussed in 4.2.2.1.

VERIFICATION LESSONS LEARNED

3.2.2.9 Walk-around oxygen assemblies. To allow crewmembers to move about in the aircraft when it is unpressurized at altitudes above 10,000 feet, portable, replenishable, supplementary oxygen assemblies are required (a). Provide walk-around oxygen assemblies that have oxygen regulation features of ___(b)___, a flexible hose to a breathing mask with a means for inhalation and exhalation, and a means for replenishing the supply. Locate ___(c)___ assemblies on the flight deck, one in each lavatory, and ___(c)___ in the cabin or cargo compartment. Support brackets for storage of each assembly on the aircraft shall be provided so that each assembly is readily accessible (d). If assemblies of the low pressure type portable cylinder are provided, recharging ports that are integral to the aircraft shall be provided at ___(e)___ to allow refilling of the assembly while in flight. Each assembly shall incorporate control features consisting of ______(f)______ and display features consisting of ______(f)______. Those assemblies of the low pressure type shall be designed to refill from the standard USAF recharging outlet to the pressure range of 300 to 450 psi and provide pressure relief at 500 psi (g). Those assemblies of the high pressure type, shall be serviceable from military ground equipment to fill to a pressure of __(h)__ psi and provide pressure relief at __(h)__ psi. Those portable assemblies that incorporate chemical oxygen generation shall have features that consist of _____(i)_____. Sufficient flow rate and delivery pressure shall be provided at the breathing mask to enable the crewmember to breathe with minimal fatigue from continuous use at 20,000 to 25,000 feet pressure altitude (j).

REQUIREMENT RATIONALE (3.2.2.9)

a. Certain operational duties on the aircraft require that persons have the capability to move about the cabin when unpressurized. For this reason, portable walk-around oxygen assemblies are necessary on these aircraft. These assemblies differ from manual bailout/emergency oxygen assemblies in that more supply and better breathing regulation are provided.

b. The walk-around assemblies should have oxygen supplied at pressures and flow rates physiologically acceptable for use by people for extended time periods at cabin altitudes of 15,000 to 25,000 feet. The regulation device should be compatible with these operations. To allow operational suitability of the assembly, a flexible hose is necessary to connect the supply source and breathing mask. To preclude too low an alveolar partial pressure of oxygen in the lungs and/or too high or low a saturation of carbon dioxide in the body, a means for controlling inhalation and exhalation of the breathing air is necessary. The most desirable type of walk-around assemblies are rechargeable and a means should be provided in the assemblies to accomplish this.

c. It is normally known by USAF pilots how many portable assemblies will be required on the flight deck of the aircraft to be designed or modified. The minimum number of walk-around assemblies required on the aircraft should be specified to ensure that an adequate number are provided.

d. To be usable, all assemblies must be readily accessible within 6-15 seconds. It is therefore desirable that they be stored in the aircraft where they may be easily seen and reached.

e. Low pressure oxygen assemblies provide only 7-15 minutes of oxygen supply. The supply for some of the portable assemblies should be designed so that replenishment is possible from aircraft outlets. Outlets should be provided at convenient locations throughout the aircraft so a crewmember may move about to replenish his supply when necessary.

f. Controls to initiate oxygen supply and select the different breathing modes are physiologically essential. Quantity and/or flow indication are required so the crewmember may be assured he has oxygen.

g. It may be beneficial to limit those walk-around assemblies to the low pressure type so they may be recharged on the aircraft. High pressure portable oxygen assemblies cannot be recharged on the aircraft. If these assemblies are used, the aircraft plumbing pressures are applicable and pressure relief is a safety device.

h. It is necessary to specify pressure ranges and standard outlet requirements to ensure the high pressure portable walk-around oxygen assembly will be compatible with existing military ground support equipment.

i. If a chemical generator of oxygen is provided for portable assemblies, essential features should be specified.

j. The oxygen delivery characteristics of the regulation device, delivery hose(s), and mask must be physiologically compatible with operation by a person for extended time periods at 15,000 to 25,000 foot cabin altitudes. Breathing fatigue and any adverse effects must be minimized.

REQUIREMENT GUIDANCE

a. Provide these walk-around oxygen assemblies on all aircraft that fly above 10,000 feet pressure altitude unpressurized for time periods in excess of 30 minutes and have enough interior space to allow personnel to move about. This applies to transport aircraft and electronic surveillance aircraft that must fly for extended time periods at higher altitudes of 15,000 to 25,000 feet. On passenger aircraft, these assemblies are required for special situations, such as an ill passenger.

b. The most desirable type of regulation provides pressure-demand breathing capability that is a function of the pressure altitude. This may consist of a diluter-demand, slight positive pressure, and increased positive pressure breathing modes. Other less desirable means of regulation provide a rebreather reservoir and, even less desirable, a continuous flow of oxygen. For a pressure demand system, a larger diameter convoluted hose is necessary, but for other systems smaller diameter hoses will perform satisfactorily.

c. Unless otherwise specified by the using command, a minimum of one assembly should be provided for each crew station on the upper and lower flight decks. Additionally, provide at least one and possibly two assemblies in any rest area provided on the flight deck. In transport aircraft, a walk-around assembly should be provided in each lavatory. In larger passenger aircraft with drop down masks (such as the C-9), two masks are generally provided in the lavatory, as untrained passengers may have difficulty using portable walk-around assemblies. Provide 3-9 walk-around assemblies in the cabin compartment, depending on the mission and aircraft configuration.

d. The best mounting locations for the pilot assembly may be directly aft and to the outboard side of the seats. This will preclude interference with operation of controls and displays. Place portable oxygen assemblies in other flight deck crew stations and rest areas as conveniently as possible. In the cabin area of the aircraft, the assemblies should be along the cabin wall or on a permanent structure about waist high. They should not interfere with personnel movement or pose a safety hazard in the locations used.

e. The requirement to have recharging outlets adjacent to each mounted walk-around bottle is necessary only in transport aircraft that must perform airdrops at altitudes above 10,000 feet pressure altitude. In other types of aircraft, it is more desirable that the recharging outlets be available throughout the aircraft to enable crewmembers to move about the cabin in an emergency decompression. The height of these outlets from the floor should be considered in terms of availability and convenience to the person who must recharge the supply. An effective design uses a flex hose at the outlet to allow easy orientation with the bottle.

The recharging outlet should be a spring-loaded ball-seat female outlet with a spring-loaded flip cover to protect the opening from dust and contaminants. Locate the outlets about 30 to 48 inches from the aircraft floor. Location of these outlets below or above this range will pose a safety problem when the crewmember attempts to recharge the oxygen bottles. Provide 1 to 3 recharging outlets on the upper flight deck, depending on the size of the area and the number of crewmembers with stations. A recharging outlet should be provided in each lavatory that has walk-around oxygen assembly. Provide about one recharger outlet per ten passengers or mission specialists, spacing the outlets uniformly throughout the cabin portion of the aircraft.

f. If the assembly consists of pressurized oxygen, a means to manually initiate and shut off oxygen supply is necessary. Chemical oxygen sources usually cannot be shut off once oxygen supply is initiated. Manual controls for various breathing modes are desirable but not essential. They allow the person breathing from the supply to increase oxygen flow rates under physical exertion or at higher altitudes. Pressure vessels should have a pressure gage to tell the person when his supply is low. Flow indication features tell the person when the supply is being delivered properly to the breathing mask.

g. Low pressure type walk-around oxygen assemblies will hold pressures up to 450 psi but normally fill to only 300-350 psi from the aircraft plumbing. This limits the time of their use to about 10-20 minutes depending on the breathing rate of the person using the assembly.

h. High pressure vessels are usually smaller and heavier than low pressure assemblies. They are more difficult to carry around because of their excess weight if a breathing supply time in excess of 30 minutes is provided. High pressure portable oxygen assemblies currently in use fill to 1800 to 2200 psi. Pressure relief must be provided within the safe limits of the pressure vessel. Care should be taken to keep size and weight of the assembly within usable limits.

i. If for some reason it is desired that chemical generators of oxygen supply be provided for some of the portable assemblies, features should be included consisting of: a replaceable chemical generator cartidge; an enclosure that receives the cartridge; heat vents and shields; a reservoir for demand breathing (if applicable); a regulation device; a supply outlet connector and hoses and face mask; and a carrying case with shoulder strap(s).

j. A 25,000 foot cabin altitude is considered the maximum altitude at which breathing for extended time periods is possible before decompression sickness or bends becomes a problem. On many military transport and electronic surveilliance aircraft, crewmembers and passengers are on extended oxygen supply in the 15,000 to 25,000 cabin pressure altitude range. In many situations, these persons use portable oxygen supply to move about the aircraft or because no aircraft oxygen regulator outlet is available. An example is a loadmaster who moves about a depressurized cargo compartment. This is necessary when cargo airdrops are made. The loadmaster inspects the air-drop equipment with the aft door and ramp open (cabin depressurized).

REQUIREMENT LESSONS LEARNED

a. The walk-around assembly is also considered a backup source of oxygen supply in the event of a failure of the primary supply. While it is true that breathing air will be provided by the Environmental Control System (ECS), transport aircraft operate depressurized for airdrop at pressure altitudes above 10,000 feet. It is likely the crewmember's oxygen supply could be damaged in combat and the crewmembers would need a backup supply of oxygen. Past experience has shown this backup oxygen supply to be necessary in USAF combat aircraft, especially if the aircraft is subjected to small weapons fire or anti-aircraft explosions.

b. Early versions of portable oxygen supply regulation incorporated continuous-flow supply regulation. These were very difficult to use because not enough immediate supply of oxygen would be available for rapid inhalation. Crewmembers could hyperventilate or get hypoxia. Later versions of the regulation of pressurized oxygen was diluter-demand; but experience showed this was not completely desirable as smoke and noxious fumes could get into the breathing air. Later versions of regulation, such as those used today, closed off the air dilution intake and incorporated pressure-demand breathing. One hundred percent oxygen is normally provided, and when at high altitudes or under physical exertion the crewmember may select increased positive-pressure breathing. On aircraft integral regulators, these functions are normally automatic but can also be manually selected.

c - d. (to be added as acquired)

e. On a USAF aircraft that had up to 20 to 30 EWOs, the aircraft had low pressure portable walk-around assemblies mounted on the head liner above the head. Not only were these assemblies difficult to access, but they also fell to the floor of the aircraft a number of times striking EWOs. This was due to an inferior support strap design (fabric straps) that allowed the bottle to drop out under negative g's when just a little loose, and the support straps retained the cylinder such that the top was tilted inboard. This is considered undesirable. The assemblies should always be stored upright in a vertical position and should be located about waist high to facilitate their use. Discussions with loadmasters have shown a deficiency in the location of recharger outlets on past USAF transport aircraft versus operational procedures used in high altitude airdrops of cargo and personnel. These loadmasters state that it is desirable to have each portable cylinder adjacent to a recharger outlet. The reason for this is that under the physical exertions involved, the loadmasters will get only about 7 to 10 minutes of oxygen supply from the bottle charged to about 300 psi. Therefore, the loadmaster grabs the bottle and stands plugged in at the location of the recharger outlet until he must walk to a new location to inspect equipment or operate controls within the aircraft cabin. He then disconnects from the recharger outlet moves about the cabin and plugs into another recharger outlet and repeats the procedure. The low pressure portable cylinders are yellow and thus easy to see, making it easy for the loadmaster to find the recharger outlets. Presently, recharger flex line and outlets are difficult to find because they are not color-coded and warning labels are not placed nearby. When the outlet and bottle are adjacent, the loadmaster will always be assured that when he dashes for a portable bottle, a nearby an unlimited supply of oxygen is available. This design approach reduces confusion and workload for the loadmaster. Labeling isolated recharger outlets would be desirable on future designs.

f. (to be added as acquired)

g. Experience from operational and logistics considerations has shown that the low pressure (300 to 400 psi) oxygen cylinder is the most desirable overall. High pressure cylinders have been used in the past, but these are more hazardous should the valve break. Also, these cylinders cannot be recharged on the aircraft while in flight. Therefore, when the supply is expended the bottle is no longer useful. The low pressure cylinder can be recharged on-board the aircraft and support equipment is not necessary for recharging the assemblies. Although the low pressure cylinders are bulkier, they have more advantages in use and they weigh much less.

h. Past operational experience has shown that the high pressure oxygen assemblies are too bulky and heavy to be operationally suitable. Additionally, several problems have been encountered because of the logistics support required to recharge these cylinders. The first problem is the lack of oxygen-recharging facilities in many operational airfields throughout the world. This may mean additional vessels must be carried. To provide the same operational capability in the US Air Force as do the low pressure walk-around oxygen assemblies, many high pressure recharging stations are necessary and overall logistics support costs are greater. This is considered undesirable by the US Air Force logistics commands at this time, and high pressure walk-around oxygen assemblies and the associated recharging stations are being phased out where possible.

i - j. (to be added as acquired)

4.2.2.9 <u>Verification of walk-around oxygen assemblies.</u> The verification of the walk-around oxygen assemblies shall consist of ____________.

VERIFICATION RATIONALE (4.2.2.9)

Verification of the walk-around oxygen equipment is necessary to ensure that all components function properly in the expected operational environment and meet the physiological requirements of the personnel who will use the equipment.

VERIFICATION GUIDANCE

The verification of the walk-around oxygen assemblies should consist of analyses, inspections, demonstrations, and tests as necessary to ensure that all requirements have been met. Some past methods of verification that may be applicable are discussed in 4.2.2.1.

VERIFICATION LESSONS LEARNED

3.2.2.10 <u>Protective breathing equipment</u>. The following protective breathing equipment shall be provided: ____________.

REQUIREMENT RATIONALE (3.2.2.10)

Protective breathing equipment may be required to protect aircraft personnel from toxic substances while in the performance of their mission. The equipment chosen will be a function of the type of aircraft and its mission.

REQUIREMENT GUIDANCE

This equipment will be required to protect personnel from fire and explosion hazards such as may occur on a transport aircraft or from manmade toxic substances in the case of a war. In either case, many kinds of toxic substances are present in the ambient environment. The type of equipment needed will vary for small aircraft such as fighters and large aircraft such as transports.

REQUIREMENT LESSONS LEARNED

Aircraft in the military which transport many passengers have a wide variety of breathing equipment. Pressure-demand oxygen equipment is also good protective equipment if air dilution is not selected. Smoke goggles could be used for eye protection. Many aircraft use continuous-flow delivery equipment. The cup-shaped masks do not provide respiratory protection as the exhalation valve(s) is also an inhalation valve if the breathing cycle exceeds the regulator flow rate. As such, these passengers have no respiratory protection from a smoke-filled cabin.

4.2.2.10 <u>Verification of protective breathing equipment</u>. The verification of the protective breathing equipment shall consist of ____________.

VERIFICATION RATIONALE (4.2.2.10)

Verification of the protective breathing equipment is necessary to ensure that it properly functions in the expected operational environment and meets the physiological requirements of the personnel who will use the equipment.

VERIFICATION GUIDANCE

The verification of the protective breathing equipment shall consist of analyses, inspections, demonstrations, and tests as necessary to ensure that enough adequate protective breathing equipment has been provided for all hazardous contingencies in locations suitable for use.

VERIFICATION LESSONS LEARNED

3.2.2.10.1 **Aircraft firefighter portable assembly**. Provide at least __(a)__ firefighter assemblies that have an oxygen supply source regulated through a valve for pressure breathing, a quick disconnect fitting at the valve on the end of a __(a)__-inch flexible breathing hose, and __(a)__. The firefighter portable assembly shall have features consisting of: a breathing hose that is connected to a breathing mask integrated into a face mask that protects the eyes, nose, and mouth from smoke, carbon monoxide, and other toxic gases; an assembly which has body mounting features to enable the crewmember to hold fire extinguishing equipment at the same time; an assembly which incorporates communication equipment to allow personnel to communicate with each other while at their assigned duty station; and __(b)__. Any part of the equipment protecting the eyes shall not cause an appreciable adverse effect on vision and shall allow glasses to be worn. Provide __(c)__ assemblies on the flight deck and __(c)__ assemblies in the cabin or cargo compartment and in areas of the aircraft such as __(c)__, stored such that assemblies are readily available for use but are secured for flight. If the assembly uses a pressurized vessel as the supply source, it shall have features consisting of __(d)__. If the assembly uses a chemical generator of oxygen as a supply source, it shall have features consisting of __(e)__. The equipment must supply __(f)__ percent oxygen for __(f)__ minutes duration per person at a cabin pressure altitude range of __(f)__ feet. The assembly shall protect the firefighter such that the breathing gas mixture does not exceed the threshold limits as specified by __(g)__ for noxious gases and airborne particles.

REQUIREMENT RATIONALE (3.2.2.10.1)

a. Firefighting breathing assemblies are required in all aircraft in which there is space to move about. The oxygen should be supplied in a pressure-breathing mode to keep smoke and toxic fumes from the wearer's eyes and respiratory tract. A flexible breathing hose should be provided with a quick disconnect to the regulator to enable the personnel who use the equipment to easily change mask assemblies. The breathing hose should be long enough to enable a person to carry the entire assembly on his person while firefighting with other fire extinguishing equipment.

b. Full-face protection is essential to enable the personnel to rapidly don the assembly. The minimally acceptable type of breathing mask should be specified to ensure a physiologically acceptable design. A means of affixing the breathing device and eye and respiratory protection to the face must be provided. See the attached illustration of an existing system (see figure 7).

If the oxygen delivery hose incorporates the same connector assembly as that used by crewmembers on their oxygen masks to connect to the aircraft supply from the breathing regulators, integral communication equipment is required. This enables the crewmember to connect his smoke mask assembly to aircraft oxygen supply system after the use of the portable supply or filters. The assembly must incorporate communication equipment that is compatible with the aircraft communication intercom system.

Personnel who don the face protection need to have their eyes shielded from smoke and fumes, but they still need a large, clear vision field. This enables the person to see in a smoke filled environment to locate and fight in fire and smoke zones.

c. The minimum number of firefighter assemblies should be specified for different locations in the aircraft to ensure the interior design satisfactorily accommodates these assemblies. The assemblies require support brackets or another means to secure them while in flight to preclude them from potentially hazardous movement under the accelerative forces of flight.

d. Most compressed air and oxygen recharging equipment will be available at logistics facilities and forward operating bases. As such, the recharging port on the supply vessel should be compatible with this existing support equipment. These assemblies could also incorporate low pressure vessels which can be recharged on the aircraft.

e. The necessary features on a portable supply that may be from a chemical generator should be called out.

f. It is essential that a minimum amount of supply be specified; otherwise, a time of supply that is much less than useful may be provided. Additionally, the altitude pressure range within which the equipment will be used should be called out to ensure a proper regulator design.

g. The threshold limits should either be specified within this specification or a source referenced to ensure a proper design.

REQUIREMENT GUIDANCE

a. Provide at least two units in smaller aircraft, four in medium-sized aircraft, and six or more in larger, transport-type aircraft. A pressure-breathing regulation is desirable to minimize the entry of noxious gases into the delivery hose and face mask. An adequate length of delivery hose is needed to enable the firefighter to swing his body around in firefighting. The hose should incorporate a disconnect filling to receive a standard crew pressure-demand mask and hose.

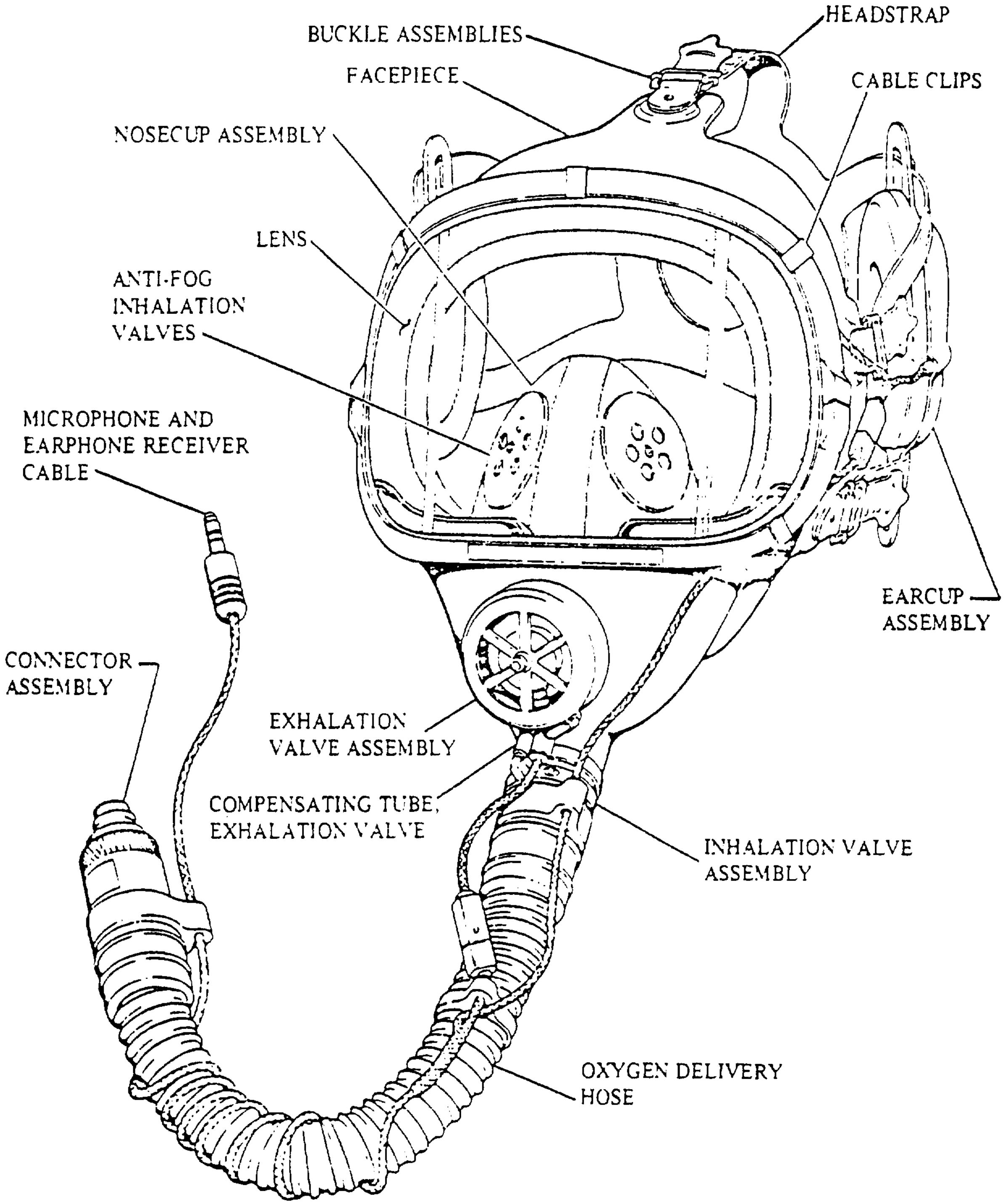


FIGURE 7. Typical firefighter's smoke mask assembly components.

b. The breathing mask should provide as good a face seal as current crewmember masks (such as the MBU-5/P and MBU-12/P) and preclude the entry of smoke and noxious fumes. Additionally, the inhalation and exhalation valve assembly should be designed to preclude the entry of these fumes during the normal breathing cycle. It is desirable that a face shield be incorporated to have positive pressure vented from the mask to stop entry of fumes and to defog the vision area of the face shield. Adjustable straps should be provided on the assembly to enable the user to don it rapidly and keep it in place while under vigorous firefighting activity. An adjustable harness should be included on the supply or filters to enable the user to carry this part of the assembly on the back or shoulders. This harness should prevent movement of the supply or filters when the user bends over.

If the using agency desires to have communication receivers at locations in the aircraft other than at the crew stations, this should be stated. The minimum number of communication receivers required should be specified. Generally, this will be in zones near potential fire hazards. If the smoke mask assembly will never be used at the crew stations or at alternate locations, the communication equipment may be deleted.

In respect to vision through the face shield, the following must be considered: The peripheral field of view should not be restricted by opaque shielding on the face mask assembly. Also, the clear shielding should be distortion-free and have antifog provisions. The eye protection should be large enough to accommodate a user wearing eye glasses.

c. It is desirable to install a minimum of one assembly in the flight deck area. Should the aircraft have an upper and lower flight deck, install at least one assembly on each flight deck level. Some aircraft will have compartmental zones for passengers, cargo, and/or equipment (such as avionics equipment bays that can be accessed in flight). Firefighting assemblies should be available in each of these compartments. The best method to secure these assemblies is with metal bands that have a quick-release mechanism and a flexible pouch to hold the face assembly and connecting hoses. The design must secure the entire assembly but should not preclude rapid access and donning.

d. Reference information is provided in MIL-D-8683. However, it is always desirable to check the logistics and maintenance locations at the USAF bases for which the equipment is intended if they must be recharged from ground support equipment. See 3.2.2.9 for more information.

e. Paragraph 3.2.2.9 contains detailed information for design concerns for a chemical generator of oxygen supply.

f. Generally, the protection of aircraft personnel is incorporated using one of two methods: portable supply containers of oxygen or filter packs that filter cabin air for breathing. Should a portable supply container be used, 20-30 minutes minimum amount of supply should be provided. Longer oxygen supply time requires heavier and bulkier containers. It is desirable that oxygen containers that supply 20-30 minutes of breathing be rechargeable from aircraft outlets. Most aircraft that use firefighting units are of the transport or bomber type and usually have a cabin pressure altitude of 8,000 feet or less.

However, in an emergency it is possible to have a fire along with a cabin decompression. In this event, the protective equipment is also the breathing equipment for higher altitudes up to 50,000 feet. This would be for a short time only, as descent to 20,000 to 25,000 feet is essential to prevent decompression sickness. In those aircraft that must fly above 15,000 to 20,000 feet pressure altitude, the oxygen supply should be 100 percent oxygen. In lower flying aircraft, the supply may be air (21 percent oxygen and 78 percent nitrogen) to reduce the fire hazard to the user.

g. In the selection of the threshold limits, it is important to keep in mind the probable time of exposure to noxious gases and airborne particles and set realistic limits. Attempts to design to safer limits than required may result in bulky equipment which hampers operations.

REQUIREMENT LESSONS LEARNED

4.2.2.10.1 __Verification of aircraft firefighter portable assembly__. The verification of the aircraft firefighter portable assemblies shall consist of ______________.

VERIFICATION RATIONALE (4.2.2.10.1)

Verification of the aircraft firefighter portable equipment is necessary to ensure that all components properly function in the expected operational environment and protect the personnel using the equipment from toxic substances.

VERIFICATION GUIDANCE

The verification of the aircraft firefighter portable assemblies shall consist of analyses, inspections, demonstrations, and tests as necessary to ensure that all requirements have been met. Some past methods of verification that may be applicable are discussed in 4.2.2.1.

VERIFICATION LESSONS LEARNED

3.2.2.10.1.1 **Firefighter controls and displays.** An "ON/OFF" control shall be provided to begin or shut off gas flow when desired. The control shall be easily accessible for use when the assembly is donned and indication of the control position shall be provided (a). A usable supply or a status quantity indicator shall be provided with ____(b)____ features. The controls and displays shall be functionally compatible with the protective breathing system.

REQUIREMENT RATIONALE (3.2.2.10.1.1)

a. Because there is a hazard associated with a supply and regulation that cannot be shut off, a control device must be provided to begin gas flow and shut it off again whenever desired. Venting oxygen unnecessarily in a fire or smoke-filled environment could worsen the situation. The person using the device must know when oxygen is on or off and whether or not breathing air is available.

b. It is essential to know the amount of supply that is available in the supply source so, if required, it can be discarded and replaced for a new mission or recharged (as applicable).

REQUIREMENT GUIDANCE

a. On a pressurized vessel, the control device usually consists of a manual globe valve or a rotary position manual control. Other types of control devices could be used, however, the control(s) must satisfy all operational requirements at least as well as existing fire-fighting assemblies. The best method to control indication is index pointers and labeling.

b. Normally, the quantity indicator gives an indication of the internal pressure within the supply vessel. The gage should have a red zone which indicates an overpressure situation. Correcting such a condition can be accomplished by manually venting pressure to a safe level. A chemical generator supply source should provide status information to indicate that the cartridge(s) are included and have supply available.

REQUIREMENT LESSONS LEARNED

4.2.2.10.1.1 **Verification of firefighter controls and displays.** The verification of the aircraft firefighter's portable assembly controls and displays shall consist of ____________.

VERIFICATION RATIONALE (4.2.2.10.1.1)

Verification of the aircraft firefighter's portable assembly controls and displays is necessary to ensure that the equipment will be used properly in the expected smoke and fire environment. The need for replenishment of supply, if applicable, will also be displayed.

VERIFICATION GUIDANCE

The verification of the aircraft firefighters portable assembly controls and displays should consist of analyses, inspections, demonstrations, and tests as necessary to ensure that all requirements have been met. Some past methods of verification that may be applicable are discussed in 4.2.1.1.

VERIFICATION LESSONS LEARNED

3.2.2.10.2 **Chemical defense protective breathing assemblies.** Provide __(a)__ chemical defense protective breathing assemblies for __(a)__ personnel that supply breathing oxygen regulated __(a)__ for crewmembers and regulated __(a)__ for other personnel. The assembly shall protect __(b)__ from adverse chemical effects while allowing the personnel to perform their __(b)__ operational duties. The __(c)__ assembly shall incorporate __(c)__ type communication equipment to allow crewmembers to communicate with each other while at their assigned duty stations, and __(c)__. The equipment shall supply __(d)__ type of breathing oxygen for __(d)__ minutes duration per person at a cabin pressure altitude of __(d)__ feet. The assembly shall protect the personnel such that the breathing air does not become contaminated with chemical warfare agents as specified __(e)__.

REQUIREMENT RATIONALE (3.2.2.10.2)

a. Much new chemical defense protective breathing equipment is under development and is gradually being provided for use in lieu of the normal crewmember oxygen equipment. Should the using command decide to include chemical defense protective equipment to the aircraft, the type of equipment should be called out in performance requirements. It may be desirable to use different means of regulation for passengers, as the breathing equipment could be different.

b. The designer(s) will depend on the extent of the protection required for the crewmembers and passengers as applicable. A requirement should be specified that personnel still be able to perform their required operational duties to ensure that the designer doesn't provide too bulky or cumbersome a design.

c. It is desirable to state which assemblies will require communication equipment as it is possible that not all chemical defense protective breathing equipment will require integral communication equipment.

d. Depending on the application of the chemical defense equipment, the modes of breathing oxygen should be specified. This includes air dilution, 100 percent oxygen demand breathing, slight positive-pressure breathing, increased positive-pressure breathing, and emergency breathing. The time period required to breathe in a contaminated environment could vary from 15 minutes to many hours. This should be specified so the designer will know how to design the equipment.

e. The threat should be specified so the design will provide adequate protection from respiratory or skin contamination against given chemical agents and specified threat levels.

REQUIREMENT GUIDANCE

a. It is essential to specify the various components of chemical defense protective breathing equipment in performance requirements. For example, the system may incorporate blowers with the breathing devices. This may be necessary to keep the individual cooled and within physiological stress temperature limits as the device may cover the entire face and head. The means of regulation for the crewmembers may be pressure-demand as it is with the existing oxygen equipment. New methods of regulation using continuous flow may be developed that are physiologically acceptable. It may be desirable to incorporate regulation for the protection mode and for the normal mode.

b. Those areas of the body that could be specified for protection from chemical agents are the face, eyes, ears, mouth, and exposed areas of the skin. The design of the protective breathing equipment is a function of the extent of protection required. It is possible the design could be too bulky and heavy and thus restrict personal mobility. The visual quality or field of view could also be restricted. It is therefore desirable to call out operational duties that these persons still be able to perform.

c. In most cases only crewmembers and mission specialists will require integral communication equipment that is connected at their stations. Some crewmembers, such as loadmasters, have alternate communication connector locations to enable them to walk about the cabin of the aircraft. This means that the connector provided should be accessible to the person wearing the assembly.

d. While specifying the type of breathing oxygen may not be desirable in some cases, in other cases this is essential. For example, when it is known that the breathing gas must provide altitude protection up to 50,000 feet, specifying positive pressure breathing is considered essential. Passenger personnel may not need equipment as sophisticated as that required by fighter aircraft crewmembers; more portable equipment may be provided to passengers. Fighter aircraft crewmember operation should not be compromised by the protective breathing equipment. Vision and mobility in the cockpit must be maintained to ensure effective aircraft operation. The equipment must satisfactorily integrate with the ejection seat system.

e. Specifying the chemical warfare agents may be difficult. For agents in which it is known that protection can be realistically provided, specifying threat levels is within reason. In unknown areas, design goals may be called out.

REQUIREMENT LESSONS LEARNED

4.2.2.10.2 **Verification of chemical defense protective breathing assemblies.** The verification of the chemical defense protective breathing assemblies shall consist of ______________.

VERIFICATION RATIONALE (4.2.2.10.2)

Verification of the aircraft chemical defense protective breathing equipment is necessary to ensure that all components properly function in the expected operational environment and protect the personnel using the equipment from toxic chemical agents.

VERIFICATION GUIDANCE

The verification of the chemical defense protective breathing equipment should consist of analyses, inspections, demonstrations, and tests as necessary to ensure that all requirements have been met. Some past methods of verification that may be applicable are discussed in 4.2.2.1.

VERIFICATION LESSONS LEARNED

3.2.2.10.2.1 **Chemical defense controls and displays.** Should breathing oxygen be provided through this assembly, controls and displays shall be provided compatible with operational requirements of ___(a)___. Controls and displays to effectively operate any blowers, filters, and oxygen provided shall consist of ___(b)___. Provide at least ___(b)___. The controls and displays provided shall be functionally compatible with the protective breathing system such that ___(c)___. Emergency or impending dangerous conditions shall be displayed in a manner to alert the appropriate personnel such that ___(d)___.

REQUIREMENT RATIONALE (3.2.2.10.2.1)

a. It is essential that controls and displays be provided that are suitable for all intended operational procedures. Otherwise, the tasks and workload of the crewmembers and mission specialists will be more complex and difficult. Also, it is likely that the rate of accidents will increase if control and display incompatibilities exist.

b. Many oxygen controls and displays will have related chemical defense controls and displays. All controls and displays known to be required should be specified by performance requirements to ensure the designer includes these features.

c. Functional compatability of the controls and displays with the protective breathing system is essential for proper operation of the equipment.

d. All persons must be quickly made aware of emergency or impending dangerous conditions so corrective action may be taken.

REQUIREMENT GUIDANCE

a. The design of the controls and displays should follow accepted design practices of human factors in the USAF. Design guidelines are given in MIL-STD-1472 and task analysis could be applied. Comments from operational personnel are also very useful. Past methods of control and display design of oxygen equipment can be most useful. Operational requirements will be provided by using commands.

b. Some control and display features known to be included in the design for crewmembers are the "ON/OFF" oxygen supply control, air dilution/100 percent oxygen control, and an oxygen-line input pressure gage. Should a blower be a part of the system, there should also be an "ON/OFF" control for this component.

c. All switches, control knobs, indicators, status lights, and control positions should be functionally compatible with the operation of the equipment. Task and fault analyses should be valuable tools to properly design the equipment. Human factors and operational desires will be needed to work out control and display designs. Another area of concern is that the persons wearing the protective breathing equipment must be aware that they are protected and have filtered ventilation air and oxygen breathing gas.

d. Some emergency situations of which the crewmember must be made immediately aware are blower failure, loss of oxygen supply, improper donning of protective equipment, and an inadvertently disconnected line.

REQUIREMENT LESSONS LEARNED

4.2.2.10.2.1 **Verification of chemical defense controls and displays.** The verification of the chemical defense protective breathing assembly controls and displays shall consist of ______________.

VERIFICATION RATIONALE (4.2.2.10.2.1)

Verification of the chemical defense protective breathing assemblies controls and displays is necessary to ensure that they properly function in the expected operational environment and meet the needs of the personnel who use them.

VERIFICATION GUIDANCE

The verification of the protective breathing equipment controls and displays should consist of analyses, inspections, demonstrations, and tests as necessary to ensure that all requirements have been met. Some past methods of verification that may be applicable are discussed in 4.2.2.1.1.

VERIFICATION LESSONS LEARNED

3.2.2.11 **Aircraft pressure suit provisions.** A pressure garment system shall be provided for missions above 50,000 feet and for missions above 25,000 feet if, in the event of an unplanned cabin depressurization, it would be impossible to immediately descend to an altitude at which cabin pressure altitude can be maintained at or below 25,000 feet (a). Pressure-demand oxygen, ventilation, heating, communication, and ___(b)___ aircraft interfaces shall be provided in the inflight and ground-egress system. The controller shall maintain the suit system pressure at a nominal ___(c)___ feet when the cabin pressure exceeds ___(c)___ feet. A pressure relief device shall be provided located ___(d)___ and calibrated to relieve overpressure in the range of ___(d)___. The oxygen or breathing system shall be designed to provide pressure-demand regulated oxygen with the following features: ___(e)___. The system shall have the capability to provide oxygen for each crewmember with varying flow rates dependent on altitudes for ___(e)___ hours. The system supply and distribution plumbing shall operate under an internal pressure range of ___(f)___ psi. Pressure suit ventilation and comfort provisions shall be provided according to ___(g)___.

REQUIREMENT RATIONALE (3.2.2.11)

a. In those aircraft required to fly missions for any time period in excess of a few minutes above 50,000 feet pressure altitude, a means of providing counterpressure to crewmembers' lungs is necessary. This is essential for several reasons. As the flight altitude is increased beyond 43,000 feet pressure altitude, the necessity for breathing 100 percent oxygen at increasingly higher pressures becomes critical. The crewmember cannot tolerate the elevated breathing pressures for an extended period of time, as the normal function of respiration and circulation become seriously impaired. The requirement for high breathing pressures in excess of 30 mmHg, and the application of external counterpressure to offset the resultant undesirable effects, are discussed in Chapter 4 of AFP 160-5 on hypoxia and hyperventilation. Additionally, prolonged exposure to these altitudes in the aircraft cabin in excess of 25,000 feet can cause the bends and decompression sickness.

b. Pressure-demand oxygen, ventilation, and heating capability are essential functions to provide in the full-pressure garment system to keep the crewmember within physiological stress limits. There may or may not be a need for ventilation and heating in a partial-pressure suit or garment. Communication equipment is always required so crewmembers may satisfactorily accomplish their flight duties. For an existing pressure garment, aircraft interfaces are connected to the suit and must be compatible. Even if the pressure garment is developed for this application, the required interfaces will be very similar. Quick disconnects are required to enable crewmembers to egress during either airborne or ground emergencies.

c. The cabin pressure altitude within the suit is normally at the same as the altitude in the cockpit until this altitude begins to exceed the physiological limits of the crewmember within the suit.

d. The pressure relief device is required as a safety measure for the crewmember to preclude overpressurizing his suit. The operational requirements or suit design may make it necessary to locate the device in a specified location.

e. In the design of the aircraft oxygen supply, it is desirable to specify the oxygen delivery characteristics needed for the cxygen subsystem with pressure suits. The number of crewmembers must be specified to determine quantity and flow rates required of the oxygen subsystem.

f. To be compatible with an existing pressure suit design, the delivery pressure range should be specified.

g. Since the suit must cover part or all of the crewmember's body, adequate cooling and ventilation to the body is not available via ambient air. The environmental control system cooling and ventilating air may be provided to the suit interior. Other methods of cooling the body may be applied, such as liquid cooling. The suit should be designed to provide comfort to the crewmember within his expected operational environment and flight durations.

REQUIREMENT GUIDANCE

a. Pressure garments may be partial pressure assemblies or full pressure suits. The entire system includes the coveralls, helmet, boots, gloves, survival kits, integrated clothing, air conditioning, air conditioning units, test equipment, and support equipment. Pressure garments provide excellent aircrew protection, and under the concept of the system, this equipment is tailor-made for each mission profile. Comfort and mobility are prime factors, and the assemblies are adaptable to missions of short or prolonged duration. The partial and full pressure suit systems are discussed as follows in terms of past design considerations.

(1) Partial pressure system. The partial pressure coveralls are form-fitting garments covering the entire body with the exception of the hands, feet, head, and neck. Special items are integrated with the coveralls to provide mechanical counterpressure in the event of decompression. The associated equipment needed to provide the wearer with physiological protection at any altitude includes helmet, pressure gloves, footwear, and the kit-provided oxygen regulator. An important part of the altitude suit assembly is the pressure oxygen helmet (MA-2) designed to deliver oxygen to the lungs at pressures up to 150 mmHg (approximately 0.02 MPa or 3 psi). The cloth neckpiece of the helmet extends down inside the suit to provide a continuous pressure layer. Attached to the bladder neckpiece is an in-turned cuff which effects the pressure seal. The bladder-type helmet consists of an inner layer of pressure-retaining, neoprene-coated nylon bladder cloth with a removable hard shell to provide head protection during buffeting. The visor, which is also removable, contains the breathing valves as well as an electric grid laminated between two layers of plexiglas. The breathing valves are identical in operation with those of the standard pressure-demand oxygen mask. There is one inlet check valve and one pressure-compensated exhalation valve. The suits are used with the seat kit regulator (cushion, seat, oxygen, oxygen regulator, and survival equipment, 0.03 m^3 (1800 $in.^3$)). This special regulator must be used because the small diameter of the hoses on the helmet necessitates the inclusion of an injection stage in the regulator. In use, the regulator provides 100-percent oxygen at 6 to 8 mm of mercury pressure from ground level to approximately 38,000 feet. Above 38,000 feet, an appropriately balanced capstan, helmet, and torso bladder pressure is required. The regulator also automatically reduces the various pressures as descent occurs; thus, no dump or bleed valves are needed in the suit. When the suit user is ejected from the aircraft, the seat kit remains attached to him and the assembly automatically provides properly balanced capstan, torso bladder, and helmet pressures from an emergency oxygen supply in the seat kit. The only occasion when the assembly must be manually activated is when the aircraft oxygen supply has been depleted. When the "green apple" is pulled, the assembly provides properly balanced suit and helmet pressures if the cabin altitude is above 40,000 feet, and 100 percent oxygen at 6 to 8 mm of mercury pressures if the cabin altitude is below 40,000 feet. The seat kit also has a press-to-test button which supplies moderately balanced capstan, torso bladder, and helmet pressures as a preflight check of the assembly. Partial pressure systems are in limited operational use.

(2) Full pressure system. The A/P22S-6A outfit (Dwg 16123G) is designed to provide aircrew members with adequate physiological protection at altitudes exceeding 50,000 feet. It can be used on missions of short or prolonged duration. The wearer is provided with protection against low barometric pressure with ventilation and exposure factors in a single unit. The assembly consists of full-pressure coveralls, gloves, helmet, full-pressure controller, and a helmet-mounted pressure-demand oxygen regulator. The helmet consists of a hard shell of reinforced plastic, an electrically heated plexiglas visor and a sunshade on front of the hard shell (both of which can be raised on top of the shell when not needed), a seal on the outer front edge of the face opening in the shell, an oxygen regulator, and communication devices. A quick-disconnect oxygen inlet hose from the survival kit is routed through the rear of the hard shell to an oxygen regulator which provides the required breathing oxygen when the visor is closed. This visor is automatically sealed to the helmet shell by a compression seal which remains effective as long as the visor is in the closed position. The helmet breathing pressure regulator monitors suit pressure and is preset to deliver oxygen to the helmet face area at a pressure slightly greater than suit pressure. This precludes entry of suit gas into the helmet face area. Oxygen from the regulator enters the helmet through small holes in the spray bar, washing over the inner surface of the visor to prevent fogging. The oxygen regulator used in the helmet is a pressure-demand style. The controller maintains the suit system pressure at a nominal 35,000 feet when the cabin altitude exceeds 35,000 feet. Manual control of suit pressure is also provided by a dial-to-test device. The type A/P22S-6A is the operational pressure suit which is currently used.

b. It has been physiologically determined from past experience and testing that pressure-demand means of oxygen regulation is essential to support crewmembers subject to pressure altitudes in excess of 25,000 feet for prolonged periods. Since pressure garments will be the only protection the crewmember has in a high altitude decompressed aircraft cockpit, ventilation and heating are needed for the suit to keep within physiological thermal stress limits. Ventilation is usually provided from the aircraft engine bleed air to a vent adapter hose which plugs into the suit. A quick disconnect can be provided at the aircraft interface and/or the suit connector. The use of the oxygen will rapidly deplete the available supply, and although the oxygen does provide some ventilation, its use as the primary means of ventilation is not considered desirable. The exception to this could be the unlimited oxygen supply that is available from an on-board oxygen generating system. Heating can be provided from the engine bleed air also or from electrical heating elements. On the suit side of the communication plug, a typical communication connector is U-93A/U and MIL-C-9177.

For emergency ground egress from the aircraft cockpit, all services must release automatically if the aircrewmember stands erect in the crew station or cockpit preparatory to abandonment. Additionally, the crewmember should be able to manually pull free all his personal leads and services from a seated and a standing position.

For ejection seat emergency egress, all services, with the exception of bailout oxygen, should be designed to disconnect automatically during the initial portion of the seat ejection. The bailout oxygen service must disconnect automatically, prior to seat/man separation as specified in MIL-S-9479.

c. The altitude to activate pressure into the suit assembly is a function of the minimally acceptable lower limit of partial pressure of oxygen in the lungs, alveolar, and trachea before symptoms of hypoxia begin to occur. Because the helmet assembly incorporates the oxygen breathing gas which also mixes with expelled carbon dioxide and moisture, it is essential that the vent valves be designed such that inhalation of carbon dioxide be within tolerable physiological limits. All these factors must be considered in the choice of the altitude at which the pressure garment begins inflation.

d. It is necessary to have a pressure range supplied from the aircraft that is compatible with the suit. But an adverse situation may occur in which the pressure supplied to the suit may exceed what is safe. The pressure delivered to the helmet area with the breathing air is slightly greater than that in the suit area. On the High Altitude Full Pressure Flying Outfit, A/P22S-6A, the pressure relief valve is located on the lower left leg and is calibrated to open between 3.5 to 4.0 psi to prevent overpressurization.

e. The need for a pressure suit exists when the aircraft must fly above 50,000 feet pressure altitude for periods in excess of a minute. To maintain the minimum alveolar partial pressure of oxygen in the lungs at these high altitudes, it is necessary to apply counter-pressure to the outside of the body, especially around the lungs. At altitudes in excess of 50,000 ft, counter-pressure must be applied to the major extremities of the body. Crewmember physiological protection and sufficient supply should be provided as discussed in 3.2.2.1.

f. Should the currently available USAF pressure suit be used, then the aircraft must be compatible with the suit throughout the operational environment of the aircraft. Should a new pressure suit be developed, all details for delivery of the oxygen supply should be physiologically compatible to the crewmember. The oxygen supply pressure range shall be 50-120 psig (70 psig normally), 300-450 psig (350 psig normally) or 1800-2200 psig pressure reduced to 300-450 psig in supply distribution. These are the normal pressure supply ranges used in most aircraft. Deviation from these pressure ranges might require the design and development of new components.

g. On aircraft in which pressure suits are used, air ventilation may be provided to the pressure suits by conditioned air from the cabin supply system or from a separate source. Ensure that the conditioned air has a dew point below 4°C (+40°F). Ensure that the airflow for ventilation to the pressure suit is 0.0061 m^3/s (13 cfm) maximum. Install a manually operated flow-control valve in the cabin to permit each suit wearer to shut off the air being supplied to the suit or to regulate the flow at intermediate values up to the design flow. Also, configure this valve to admit and control the pressure-suit air that is delivered to the aircraft by a ground cooling unit. Ensure that the air temperature, as measured at the suit inlet, is adjustable between 12.7° (55°F) and 32°C (90°F). Ensure that the pressure drop through the pressure suit and inlet tubing is no more than 6.9 kPa (1.0 psi) at the design flow rate of 0.0061 m^3/s (13 cfm). During normal use of the pressure suit when the cabin is pressurized, ensure that the control system regulates the suit inlet flow at the pressure of 6.9 $\pm$1.4 kPa (1.0 $\pm$0.2 psi) above cabin pressure. During use of the pressure suit, when the cabin is unpressurized and the cabin altitude is below 10,668 m (35,000 feet), ensure that the differential pressure is at a gage pressure of 6.9 $\pm$1.4 kPa (1.0 $\pm$0.2 psi). During emergency use of the pressure suit when the cabin altitude exceeds 10,668 m (35,000 feet), ensure that the inlet pressure to the pressure suit can be regulated at an absolute pressure of 31 $\pm$1.4 kPa (4.5 $\pm$0.2 psi). This is based on the absolute pressure of 24.1 kPa (3.5 psi) within the pressure suit. The pressure suit system may be designed with an integral liquid cooling system to reduce thermal loads on the crewmember. It may even be desirable to provide heating to the crewmember through the liquid system. This technique is presently under research but is not in production pressure suit systems. The cooling tubes may be used throughout the partial pressure suit system to simplify the suit design. For air cooling and heating, some inflation of the entire suit is needed. It is most difficult, time consuming, and awkward to put one of these suits on. Usually, another person is needed to help put on the suit. A liquid cooling system may minimize these problems.

The pressure suit system is interlayered fabric and harness that has adequate strength to apply counterpressure. Comfort may be difficult to incorporate into the suit design, but comfort of the crewmember is essential to his ability to properly operate the aircraft.

REQUIREMENT LESSONS LEARNED

a - b. (to be added as acquired)

c. The current high altitude full pressure suit, Type A/P22S-6A, begins to pressurize at 36,500 feet cabin pressure altitude. The pressure delivered to the face area of the helmet is slightly greater (0.01 to 1.50 inch H_2O) than the pressure on the rest of the body. This assures that any possible leak past the face seal will be from helmet-to-suit. The suit pressure acts to provide counter-pressure on the surface of the wearer's body to balance the pressure supplied to the wearer's lungs by the helmet. This balancing of lung pressure by suit counter-pressure permits the wearer to breathe the high pressure needed at extreme altitude to maintain adequate oxygenization of the blood.

d. During normal flight, when cabin pressure is maintained, ventilation gas is supplied by the aircraft to the torso through the vent gas hose. Internal suit vent channels carry this gas to the neck, wrist, back, and ankle areas. Gas from the ends of the vent channels and exhaled gases from the helmet breathing compartment flow over the body to the controller. As long as cabin pressure is maintained below 36,500 feet, the controller allows gas to escape freely to the cabin without appreciable pressure build-up in the flying outfit. Should cabin pressure increase above 36,500 feet, either by gradual leakage or explosive decompression, the controller closes immediately and maintains a safe pressure inside the flying suit.

e. A breathing compartment is formed in the helmet between the visor and the face seal when oxygen supplied to the helmet-mounted regulator at 50-90 psi is automatically turned on by closing the visor. The visor is automatically sealed to the helmet shell by the inflatable seal when the visor is closed. The regulator provides oxygen at breathing pressure to the breathing compartment each time the crewmember inhales. The oxygen enters through small holes in the defog tube, washing over the inner surface of the visor to prevent fogging. Exhaled gases pass through the exhalation valve (mounted in the face seal barrier), into the rear portion of the helmet and down into the torso. The visor seal will remain inflated as long as the visor is closed and breathing oxygen is available. To protect against suffocation on the Type A/P22S-2 (but not the type A/P22S-6A suit), should the pilot become unconscious as a result of ejection and subsequent parachute landing, the visor will deflate in 25 to 45 seconds (through a metered bleed valve in the visor latch mechanism) after the emergency oxygen supply is depleted. This delay in deflating the visor seal serves as a loss-of-oxygen warning in the event the normal aircraft oxygen supply is depleted or the aircraft supply malfunctions due to mechanical failure or a hose break. When this occurs, the pilot will find it difficult to breathe and should actuate the emergency oxygen system and descend to an altitude at which it is safe to breathe ambient air.

f. (to be added as acquired)

g. If ventilating air is not available, the controller uses the exhaled gases supplemented with oxygen from the aircraft supply through the make-up valve incorporated in the controller to maintain pressure. A check valve in the vent hose connector on the coverall prevents leakage back through the vent hose.

4.2.2.11 <u>**Verification of aircraft pressure suit provisions.**</u> The verification of the aircraft pressure suit provisions shall consist of ____________.

VERIFICATION RATIONALE (4.2.2.11)

Verification of the aircraft pressure suit provisions is necessary to ensure that all equipment properly functions in the expected operational environment, protects the crewmember(s), and meets the physiological needs of the crew.

VERIFICATION GUIDANCE

The verification of the aircraft pressure suit provisions should consist of analyses, inspections, demonstrations, and tests as necessary to ensure that all requirements have been met. Analyses and inspections should be accomplished to ensure the suit is fully functional under all expected operations and demonstrations/tests should then be accomplished to show that the suit provides adequate altitude protection, is adequately comfortable, and heating/cooling needs are satisfied.

VERIFICATION LESSONS LEARNED

3.2.2.11.1 **Pressure suit controls and displays**. Manual override control of the suit shall be provided, and test features for a preflight check of the assembly shall be provided consisting of ___(a)___. Pressure, flow, and ___(b)___ displays shall be provided for normal operations. Warning displays and alarms shall inform the ___(c)___ crewmembers should the cabin pressure and altitude exceed ___(c)___ feet, should the oxygen flow rate to the suit deviate from that normally expected for that cabin pressure altitude, and ___(c)___. The controls and displays provided shall be functionally compatible with the protective breathing system such that ___(d)___.

REQUIREMENT RATIONALE (3.2.2.11.1)

a. The controller of the suit contains a valve which is automatically controlled by an altitude-sensing aneroid to retain the required pressure within the outfit by utilizing vent air or oxygen from the make-up valve incorporated in the controller. Should a malfunction of the controller assembly occur, manual override provides a safety device. A test control provides an indication to the crewmember that his suit pressurization equipment is performing satisfactorily.

b. It is essential that a suit pressurization display be provided to the crewmembers so they may know that the altitude pressure inside the suit is within safe physiological limits. Flow indication tells the crewmember that oxygen is being delivered to the suit and not just ventilation air. Other displays may be needed depending on the pressure suit design.

c. Should the high altitude aircraft have crewmembers, in addition to the pilot, who also have pressure garments, it should be specified whether these warning displays must be viewable by each crewmember. The crewmembers must be immediately aware of an impending hazardous situation so that they may check their suits for proper inflation and functioning and, if necessary, take corrective actions to obtain suit inflation. Another option to the pilot would be to initiate aircraft descent to a safe altitude.

d. Many interrelated factors are involved in the control and display design that must be compatible throughout. The information that must be displayed to alert personnel to emergency or impending dangerous conditions will be a function of the system and type of component provided.

REQUIREMENT GUIDANCE

a. It is not necessary to specify the exact description of these control features, but it should be noted how the existing Type A/P22S-6A high altitude full-pressure suit incorporates a red press-to-test button that is located on the controller to provide for pressurization (2.0 to 2.5 psig) of the suit and helmet to test the suit assembly preflight. This device may also be used at any altitude to obtain suit pressure.

b. The existing high altitude full-pressure flying outfit, Type A/P22S-6A, has an altimeter display located on the upper left leg of the coverall and it registers absolute pressure inside the coverall in graduated thousands of feet. Ideally, the oxygen flow device should be located on the aircraft interface at the panel from which the oxygen comes. Should the plumbing arrangements make this impossible, locate the flow display at a readily viewable position. The most reliable type of flow display is a mechanical device that actuates by pressure differences. Flow blinkers provide the crewmembers with information that air/oxygen is delivered as expected through all plumbing. Status indicator lights may be desired. Liquid cooling displays will be needed if such a design is used.

c. Usually aircraft of this type is manned only by one pilot, but the possibility exists for a second crewmember. Some bomber-type aircraft carry up to six crewmembers. The warning system should activate at 38,000 feet pressure altitude or higher. The normal range at which the garment begins inflation is 35,000 to 36,500 feet pressure altitude. As long as cabin pressure is maintained below 35,000 to 36,500 feet, the existing pressure garment allows gas to escape to the aircraft cabin without appreciable pressure build-up in the flying outfit. Should the cabin pressure increase above 35,000 to 36,500 feet, either by gradual leakage or explosive decompression, gas venting is stopped and a safe pressure is maintained inside the suit. In the event of a failure of the gas supply or a vent valve, the crewmember should take appropriate action when a warning is received.

d. Should existing control and display components be selected in the design, the electrical and physical characteristics of these parts can be determined from specification details. Sensing devices on other components, such as on the LOX converter or plumbing for pressure readings, must be compatible.

REQUIREMENT LESSONS LEARNED

4.2.2.11.1 **Verification of pressure suit controls and displays.** The verification of the aircraft pressure suit controls and displays shall consist of ______________.

VERIFICATION RATIONALE (4.2.2.11.1)

Verification of the aircraft pressure suit controls and displays is necessary to ensure that they properly function in the expected operational environment and meet the needs of the crewmembers who use them. Crewmembers must be able to detect and understand all displays.

VERIFICATION GUIDANCE

The verification of the aircraft pressure suit controls and displays should consist of analyses, inspections, demonstrations, and tests as necessary to ensure that all requirements have been met. Some past methods of verification that may be applicable are discussed in 4.2.2.1.1.

VERIFICATION LESSONS LEARNED

3.3 **Reliability.** The reliability of the aircraft oxygen system shall be as follows: ______________. The reliability of each of the critical components of the oxygen system shall be at least (list applicable components with their respective MTBFs):

Component Name	Mean Time Between Failures
************	**********************

REQUIREMENT RATIONALE (3.3)

It is always beneficial to specify the MTBF of the entire oxygen system or requirements that provide comparable reliability in components.

REQUIREMENT GUIDANCE

In the development of oxygen components, Mean Time Between Failure (MTBF) or Mean Cycles Between Failure (MCBF) are the very least that should be required. Other reliability and maintainability statistics may be applied, such as Maintenance Manhours per Flying Hour, but these are subject to the discretion of the program structure.

An alternative is to leave these values to be determined (TBD) and allow the designer to determine values he believes are appropriate. Some USAF aircraft programs are going with the aircraft system level reliability and maintainability (R&M) requirements. This means oxygen system and component level R&M values are grouped within the total aircraft system level R&M requirements. In this approach, direct contractual control would not be applied to the oxygen system. Of course, from a life support viewpoint this may compromise an oxygen system's capability to provide all aircraft occupants supplemental oxygen when needed. Certainly, the R&M of the oxygen system and its components should not be worse than what is currently required for existing oxygen equipment or Government Furnished Equipment (GFE). This R&M information should be available, in most cases, from the military specifications that are in effect for that piece of equipment. In this situation, it is up to the designer to provide a reliable and maintainable oxygen system. Those elements of the oxygen system that are essential for breathing, such as valving and movable mechanisms within regulators, shall be as reliable as possible.

Failures shall not preclude breathing to the extent possible or provide explosive pressure to aircraft occupants using the equipment. This is especially critical for aircraft pilots.

The best available information on LOX systems shows an MTBF of approximately 50-100 hours for transport aircraft and 150-250 hours for single-place jet aircraft. The currently available information on an on-board oxygen generating system installation shows calculated analytical values of about 4200 hours and proven values of 250-300 hours from more than 3000 flight hours on the AV-8A Navy Harrier aircraft.

REQUIREMENT LESSONS LEARNED

Past experience has shown that R&M values determined by testing are nearly always much less than calculated values determined analytically during design. Many theories and articles have been written about this subject and its resolution is still pending. Therefore, it is almost always desirable to validate R&M values for oxygen equipment by laboratory and flight testing.

4.3 **Reliability tests.** The verification of reliability shall consist of ______________.

VERIFICATION RATIONALE (4.3)

Verification of the oxygen system reliability is essential to ensure that a dependable system is delivered to the USAF with a minimum repair and replacement of parts and subassemblies required.

VERIFICATION GUIDANCE

The normal method of verifying the reliability of aircraft oxygen systems is by demonstration and test. Information is gathered in laboratory and flight test to determine Mean Time Between Failures, Mean Time To Repair, Maintenance Flight Hours Per Flight, etc.

VERIFICATION LESSONS LEARNED

3.4 **Accessibility, maintainability, and serviceability design considerations.** Install all parts of the oxygen system to permit ready removal and replacement on the aircraft without the use of special tools (a). Ensure that all tubing connections, fittings, valving, regulators, supply sources, controls, displays, and other items required in maintenance and servicing are readily accessible for leak testing with leak-test compound for tightening of fittings, without removal of surrounding parts, for removal, repair and replacement, and ____(b)____. Ensure that all masks, flexible hoses, and associated equipment can be properly stowed and ____(c)____. Ensure that all oxygen gas cylinders, filters, chemical oxygen-generating devices, and liquid-oxygen converters provided are accessible and have supply replenishment features consisting of ____(d)____. Other accessibility, maintainability, and serviceability design considerations are ____(e)____.

REQUIREMENT RATIONALE (3.4)

a. These requirements are important logistics needs that are often overlooked in the design and development of the aircraft oxygen system and its components. Special tools should not be required for ready removal and replacement of components on the aircraft, as this means existing maintenance tool sets must be modified. Also, flight line repair operations may be more complex and time consuming.

b. Leak tests are conducted on the plumbing and components when installed on the aircraft to ensure all fittings will not leak from elevated internal oxygen gas pressures. This is especially important when the oxygen supply is limited.

c. Oxygen breathing masks and delivery hoses that allow the crewmembers and passengers to breathe oxygen supply are subject to damage from personnel and material degradation from environmental extremes if not properly stowed when not in use. Stowage must not compromise rapid donning of the mask assemblies when required.

d. All existing oxygen systems have expendable supply sources that require periodic replenishment and maintenance. Even proposed on-board oxygen generating systems have filters that require periodic inspection and replacement. It is essential that quick and easy service and replacement capability be provided in the oxygen system design.

e. Other accessibility, maintainability, and servicability design considerations may be specified.

REQUIREMENT GUIDANCE

a - e. All these requirements are essential in the model specification for complete coverage of any possible design that the aircraft may have provided. When the aircraft designer has chosen the oxygen subsystems applicable to his proposed aircraft, only those requirements applicable to the subsystems proposed need be included. It is also desirable that the designer include additional reqirements and expand the specification in this area should more information be available from his lessons learned or experience. Additional information is available in Sections V through IX of TO 15X-1-1.

REQUIREMENT LESSONS LEARNED

a - c. (to be added as acquired)

d. Designers have had a tendency to locate LOX converters and associated servicing connections on proposed aircraft designs that were out of reach (too high) for the persons using this equipment. Oxygen servicing capability is severely compromised in such cases. There are plenty of hazards associated with servicing LOX converters, even with an optimum location of the connections. Spillage of LOX on aircraft parts and the ground is possible while servicing a converter which is on the aircraft. Drip pans are usually placed under hoses and service connections to retain spilled LOX. Many fighter, fighter-bomber, and attack aircraft converters are removed from the aircraft and serviced at nearby logistics support facilities; therefore the converters should be readily accessible.

e. Reference AFALC/PTL, Wright-Patterson AFB, OH, Abstract of Lessons Learned, 1 Jan 1984.
LL #0113 - Oxygen regulators should be panel-mounted to prevent damage. Damage by crew or maintenance personnel to oxygen regulators supported only by crew restraint harnesses is described.
LL #0841 - Oxygen systems incorporating dual liquid oxygen converters connected in parallel to a common distribution manifold have been efficient and maintainable.
LL #0117 - In considering liquid oxygen build-up and vent valves, if supports are not provided for ground servicing equipment such as hoses and cables, premature failures and wear can be expected on attachment fittings and servicing points. The weight of the hose and fittings causes the aircraft fittings to break.
LL #0123 - Support equipment that is acquired or designed without full consideration of all operational environments and characteristics can result in unusable or unreliable equipment. Many examples are given where support equipment cannot be used in the field.
LL #0173 - Failure to identify all failure modes during the design and development of equipment and systems results in deficiencies in special tools and repair procedures necessary to repair and maintain equipment.
LL #0175 - Equipment bays designed with easy access for personnel standing on the ground enhance maintenance productivity and reduce support equipment requirements.

4.4 **Verification of accessibility, maintainability, and serviceability design considerations.** The verification of accessibility, maintainability and serviceability shall consist of ______________.

VERIFICATION RATIONALE (4.4)

Verification of accessibility, maintainability, and serviceability of aircraft oxygen system components is essential to ensure that the system may be logistically supported in operational use.

VERIFICATION GUIDANCE

Verification shall consist of analyses, inspections, demonstrations, and tests as necessary to ensure that the oxygen system may be logistically supported in operational use. Demonstrations are always appropriate to validate such requirements.

VERIFICATION LESSONS LEARNED

3.5 Survivability and safety design considerations. The location and isolation of the oxygen supply and its distribution manifolds shall preclude adverse effects on aircraft flight-critical components when there is a rupture in the oxygen system or an intense oxygen-fed fire due to a single hit by any of the threats specified in ___(a)___. If more than one supply is provided, they shall be manifolded such that the loss of any one supply source will not preclude all personnel from breathing oxygen, and one-way check valves shall prevent the loss of supply from other sources. Oxygen distribution plumbing shall be routed and located such that, if penetrated, oxygen will not initiate or support the combustion of flammable fluids and other materials. Regions of potential over-pressure shall be precluded by design and use of over-pressure devices. Appropriate warning indications, labeling, and markings shall be provided with the oxygen system to preclude adverse effects to all personnel including crewmembers, passengers, and maintenance personnel (b). If chemical mixtures or bleed air is used to provide breathing gas, methods of filtering out harmful substances such as water, particles, and noxious gases shall be incorporated (c). Pressure and flow displays shall be provided for normal operations. Other survivability and safety design considerations are ___(d)___.

REQUIREMENT RATIONALE (3.5)

a. Survivability considerations are necessary in the design of combat aircraft or aircraft such as tactical transports that could be in a combat or threat environment. In other aircraft, survivability considerations should be included where possible, but not at the compromise of other important design features. Safety considerations are necessary for all aircraft oxygen systems and are especially critical for LOX and high pressure oxygen types of supply.

b. Application of warning indications, labeling, and markings are considered desirable on future designs.

c. Statements to prevent harmful substances from entering the oxygen supply and distribution plumbing are essential.

d. Should any special situations or unique aircraft design constraints impose additional survivability and/or safety design considerations, these should be specified here.

REQUIREMENT GUIDANCE

a. Survivability requirements should be applied to the oxygen system design on aircraft expected to fly in the threat environment. This applies to fighters, fighter bombers, attack, bomber, tactical transport, and surveillance aircraft. Major components of the oxygen system shall not show any evidence of shattering, and the mounting provisions shall withstand all forces encountered by the gunfire test. The component shall be filled with the LOX or gas at the nominal pressure expected to be used during normal operation while inflight and on the runway. The component shall be fired upon from a distance of approximately 50 yards by a tumbling 50-caliber armor-piercing incendiary projectile. The bullet shall strike the component in the section containing LOX or gaseous oxygen. For minor components such as regulators, the test should be conducted with a 30-caliber tumbling projectile. This is the survivability requirement accomplished on past components. Should it be desired to change the survivability requirement, ensure the new requirement is adequate.

Survivability and safety design considerations must be kept in mind for the design of all aircraft oxygen systems. Care should be taken to locate supply sources and route plumbing to minimize hazards. The oxygen equipment, tubing, and fittings should be located as remotely as practicable from fuel, oil, hydraulic, water injection, storage battery systems, exhaust stacks and manifolds, electrical, radio, and insulating materials. Oxygen lines should not be grouped with electrical lines or lines carrying flammable fluids. Additionally, oxygen lines and supply should not be located above electric and hydraulic components and fuel tanks and lines. Components of the oxygen system should not be installed where they will be subjected to excessive temperatures. The maximum temperature limit shall be 350°F. Where possible, locate liquid oxygen supply in cold regions of the aircraft such as unpressurized compartments. The vaporizing and warming heat exchangers, however, should be located in warm regions such as pressurized regions or the aircraft cockpit. In the placement of valves, such as check valves and pressure reducing valves, care should be taken in the design such that any possibility of overpressurization (500 psig is normally the maximum limit) does not exist.

For LOX converter selection and aircraft installation, consideration shall be given to the impact of other aircraft subsystems, such as fuel or hydraulics on the LOX. LOX chemically reacts very violently by fire and/or explosion with most all hydrocarbon materials. For two or more converters, it is desirable they be separated as much as possible to minimize combat vulnerability. It is especially important to provide a supply source for the crewmembers on the flight deck separate from that supply source for other aircraft occupants. Supply lines may be manifolded such that the crewmembers on the flight deck may draw supply from other sources for the other aircraft occupants. Much thought should be put into the manifolding schemes and one-way flow check valve locations such that hazards are minimized and alternate supply is available to the aircraft occupants in the event one supply source is destroyed by combat weapons. The installation of servicing connections for replenishing the supply should be located and placed to minimize hazards.

In the routing of the tubing or plumbing, the general policy shall be to keep total length to a minimum. This decreases combat vulnerability and reduces the chances for leaks. Plumbing installation shall allow for expansion, contraction, vibration, and component replacement. To further reduce vulnerability to gunfire, the tubing lengths between the check valve and the associated converter shall be separated as much as possible by space or physical barrier. The separation shall not be less than 12 inches. All tubing shall be mounted such that vibration and chafing are prevented. This may be accomplished by the proper use of rubberized or cushion clips installed at no greater than 20-inch intervals and as close to the bends as possible. Holding clips shall be provided near portable recharger outlet connections as the flexible lines and self-sealing outlets may be damaged if allowed to move about while in flight. The tubing, where passing through or supported by the aircraft structure, shall have adequate protection against chafing by the use of flexible grommets or clips. No tubing shall be allowed to strike against the aircraft structure during vibration and shock encountered during normal use of the aircraft.

To minimize LOX loss and fire/explosion hazards due to heat, do not locate LOX converters near equipment that dissipates a large quantity of heat. Do not locate converters in line with the plane of rotation of a turbine or propeller. Fill lines and lines downstream of the primary heat exchangers should be routed or insulated to prevent moisture from contaminating structures or equipment below it. Without this design in the equipment, frost and condensation will form and generate moisture.

The LOX converter vent line should be located from the combination fill-buildup vent such that it drains overboard at the bottom of the aircraft within sight of the filler box and not closer than 24 inches from it measured along the fuselage. Direct the flow from the overboard vent away from the filling valve so the flow does not create a hazard for servicing personnel. LOX must not be allowed to impinge on the aircraft. Hydrocarbon fills or drains should not be located above or before the vent outlet. Pressure relief valves on the LOX converter should be vented overboard.

System cleanliness should be maintained in the aircraft oxygen system plumbing and component installation such that it is free of oil, grease, fuels, water, dust, dirt, objectionable odors, or any other foreign materials not approved for use with 100 percent oxygen. This practice applies both to internal and external plumbing and components of the oxygen system.

b. Safety and emergency situations are always important in the design of all USAF aircraft. For this reason, appropriate warning indications, labeling, and marking should always be applied in the oxygen system design. Crewmembers, passengers, and maintenance personnel will then be able to accomplish all necessary operations on the oxygen system with a minimum of mistakes.

c. Cleaniness and proper maintenance procedures are always critical in the oxygen system, as toxic substances could adversely affect the people using the equipment or fire/explosion hazards could result.

d. Other survivability and safety design considerations will be dictated by special situations such as the type of aircraft.

REQUIREMENT LESSONS LEARNED

Reference AFALC/PTL, Wright-Patterson AFB, OH, Abstract of Lessons Learned, 1 Jan 1984.
LL #0331 - A System Safety Group may be ineffective even though it is established in accordance with safety directives. Lesson illustrates an example where responsibility was delegated but results were not effective.
LL #0332 - If system safety analyses are not correctly time phased to the design effort, the opportunity for maximum benefit at minimum cost will be lost. The timeliness of system safety efforts is stressed.
LL #0333 - Failure to require system safety analyses in the Contractor Data Requirements List (CDRL) may result in an unsatisfactory effort during system development. The value of system safety analysis is shown.
LL #0334 - Failure to involve users in evaluation of Hazard Analyses can result in inadequate reviews. Hazard Analysis, Contractor Data Requirements List (CDRL), and coordination with using commands are explained.
LL #0330 - Failure to monitor subcontractor efforts may result in an unsatisfactory System Safety Program. System safety must be an overall total program. Subcontractors must be monitored.
LL #0787 - Failure to consider the risk associated with flammable and toxic fluids leaking into an aircraft's liquid oxygen compartment will result in hazardous conditions to flight personnel and equipment and also drive up the logistic support cost of the life support system.

4.5 <u>Survivability and safety design consideration tests</u>. The verification of survivability and safety shall consist of ____________.

VERIFICATION RATIONALE (4.5)

Verification of the survivability characteristics of the aircraft oxygen system is desirable to enhance the ability of this life support system to continue to properly operate in the combat operational environment. Verification of the safety design considerations is essential to ensure that hazards to personnel and the aircraft are minimized.

VERIFICATION GUIDANCE

Those applicable verifications shall consist of analyses, demonstrations, and tests as necessary to satisfy a group of experts independent of the engineering designers of the aircraft oxygen system that sufficient survivability and safety considerations have been considered and included in the design.

VERIFICATION LESSONS LEARNED

3.6 **Human engineering.** The oxygen system design shall meet human engineering design criteria consisting of ________________.

REQUIREMENT RATIONALE (3.6)

The oxygen system equipment should be designed to interface with the human operator who must operate the equipment while on the aircraft and breathe under a diverse range of situations. Also, maintenance personnel must keep the equipment properly functioning.

REQUIREMENT GUIDANCE

Most design criteria that should be applied are contained in MIL-STD-1472. One should look through the standard and determine the paragraphs that apply. The main subject material in the standard is 5.1 Controls/Display Integration, 5.2 Visual Displays, 5.3 Audio Displays, 5.4 Controls, 5.5 Labeling, 5.6 Anthropometry, 5.7 Ground Workspace Design Requirement, 5.8 Environment, 5.9 Design for Maintainability, 5.10 Design of Equipment for Remote Handling, 5.11 Small Systems and Equipment, 5.12 Operational and Maintenance Ground/Shipboard Vehicles, 5.13 Hazards and Safety, 5.14 Aerospace Vehicle Compartment Design Requirements, and 5.15 Personnel-Computer Interface. Should additional design guidance be desired, then other sources of information should be quoted. A good source to check for this information is AFSC Design Handbook DH 1-3 and the list of reference books given in the Appendix, "Guidance Documents" of MIL-STD-1472.

REQUIREMENT LESSONS LEARNED

4.6 **Human engineering verification.** The verification of human engineering shall consist of ____________.

VERIFICATION RATIONALE (4.6)

It is desirable to have methods of checking or verifying that the oxygen system has been designed with the human operator and maintenance personnel in consideration.

VERIFICATION GUIDANCE

This may be accomplished by developing a long, detailed checklist from MIL-STD-1472 and applicable reference information. It is probably best to request that the prime contractor do this if he has human engineering personnel. Some vendors do not have this capability. In this case, test and evaluation is usually performed by government personnel. Other methods of checking human engineering include building simulation models and accomplishing controlled tests, and conducting controlled tests with the actual operational equipment.

VERIFICATION LESSONS LEARNED

3.7 Interface requirements. The oxygen system shall be installed on the aircraft such that the operational envelope of the components does not violate the operational envelopes of any other aircraft subsystem, and the cabling, wiring, and plumbing routing between aircraft subsystems. All oxygen controls and displays, hoses, masks, and equipment on the personnel shall be installed such that an effective interface has been provided between the personnel using the equipment and the oxygen equipment to maximize mission effectiveness. Where the oxygen system must interface with other aircraft components or subsystems, the operation and design of the oxygen system shall not be degraded. ___________ aircraft subsystems shall be effectively interfaced such that the following properties and limits are met: ______________.

REQUIREMENT RATIONALE (3.7)

Proper design of the oxygen system shall be such that total aircraft performance and capability is not compromised. Additionally, these requirements ensure that hazards are minimized. Effective interface with aircraft occupants is an important consideration so crewmembers and passengers may properly use the oxygen equipment and other essential flight duties and operations may effectively be accomplished. It is essential that design limits be specified for the oxygen subsystem where there is interface with other aircraft subsystems so that proper equipment may be selected; should adjustments to these limits be required, accountability is provided. This enables other subsystems designers to assess the impact of this change to their designs and equipment.

REQUIREMENT GUIDANCE

It is necessary to include interface requirements to the specification for the design and installation of the oxygen subsystem to an aircraft. The properties and limits depend on which other aircraft subsystems are interfaced. This is usually not called out in the government model specification in the Request for Proposal (RFP) because this provides a design solution. Therefore, when this is left open in the RFP, it is understood that all the information will be provided in the specification proposed by the designer based on his design concept. Some properties that could be included are bleed air (pressure, temperature, flow rates, and toxic limits), electrical power (power, voltage, and current characteristics, normal power consumption, maximum power consumption, connector types, etc.), and properties required for heat exchanger operation or airflow conditioning.

REQUIREMENT LESSONS LEARNED

In an oxygen system design proposed for a trainer aircraft, the contractor had proposed an OBOGS design in his aircraft. He had worked some compatibility studies concerning the aircraft mission profile where the engine supplied bleed air to the inlet of the concentrator and this in turn provided breathing gas to the pilots. The contractor had set up a hypothetical profile where the aircraft experienced a cabin decompression at around 30,000 to 35,000 feet pressure altitude and oxygen was to be supplied continuously to the pilots from the concentrator on aircraft descent to a safe breathing altitude. It was determined that the throttle setting and altitude conditions would result in concentrator output breathing gas with reduced oxygen concentration levels below that considered physiologically acceptable for the given altitudes. This would require either initiating supplementary oxygen or increasing throttle settings. This provides a good example of what must be considered in aircraft interface design and development.

4.7 <u>Verification of interface requirements</u>. The verification of aircraft interface requirements shall consist of ____________.

VERIFICATION RATIONALE (4.7)

It is essential that form, fit, and function of the oxygen system properly interface with all other aircraft equipment and not result in a degradation of the performance of the aircraft's intended mission.

VERIFICATION GUIDANCE

Those interfaces that should be checked are oxygen equipment weight, location, and installation dimensions relative to overall aircraft performance. Other interface requirements to consider are electrical, pneumatic, engine bleed air, and heating/cooling. The final test of the proper interface is to flight-test the aircraft with this equipment installed and check all aircraft systems for proper function. Prior to this, laboratory tests may be conducted to simulate the interface concerns.

VERIFICATION LESSONS LEARNED

Past experience in the installation of an on-board oxygen generation system revealed compatibility problems with the aircraft engine bleed air. It was not easy to route plumbing lines to the oxygen concentrator due to the non-availability of space through bulkhead structural members.

3.8 **International standardization provisions.** The ______________ international agreements shall apply to the oxygen system design.

REQUIREMENT RATIONALE (3.8)

The primary reason international agreements are to be called out in this specification is that USAF military aircraft may be required to operate out of air bases in other countries and ground support must be compatible. Additionally, many USAF military aircraft are sold to other countries for their use, and commonality of aircraft oxygen equipment and associated ground support enhances availability of this equipment and costs may be reduced. Also, repair and maintenance of this equipment is more easily facilitated.

REQUIREMENT GUIDANCE

The following list of some applicable international agreements is given here for reference and use.

NORTH ATLANTIC TREATY ORGANIZATION (NATO) AGREEMENTS

STANAG No. 3053GGS	Breathing Oxygen Characteristics, Supply Pressure and Hoses
STANAG No. 3054GGS	Characteristics of Compressed Air for Technical Purposes, Supply Pressure and Hoses
STANAG No. 3056	Marking of Airborne and Ground Gas and Liquified Containers
STANAG No. 3198AMD	Functional Requirements of Aircraft Oxygen Equipment and Pressure Suits
STANAG No. 3296GGS	Aircraft Gaseous Oxygen Replenishment Couplings
STANAG No. 3341AI	Emergency Control Colour Schemes
STANAG No. 3370AI	Aircrew Station Warning, Cautionary and Advisory Signals
STANAG No. 3499GGS	Characteristics of Supply Equipment for Liquid Oxygen
STANAG No. 3545GGS	Characteristics of Breathable Liquid Oxygen
STANAG No. 3546GGS	Characteristics oi Liquid Nitrogen
STANAG No. 3547GGS	Characteristics of Replenishment Equipment for Liquid Nitrogen
STANAG No. 3568GGS	Aircraft Gaseous Systems Replenishment Connections

STANAG No. 3624GGS	Characteristics of Oil-Free Compressed Nitrogen, Supply Pressure, and Hoses
STANAG No. 3647AI	Nomenclature in Aircrew Stations
STANAG No. 3688GGS	Characteristics of Breathable Oxygen Supplied by Chemical Solid Generators
STANAG No. 3705AI	Principles of Presentation of Information in Aircrew Stations
STANAG No. 3806GGS	Aircraft Gaseous Air/Nitrogen Systems Replenishment Connectors
STANAG No. 4155	NBC Protective Mask and Filter Canister Screw Threads

AIR STANDARDIZATION COORDINATING COMMITTEE (ASCC) AGREEMENTS

AIR STD 61/7B	Minimal Protection for Aircrew Exposed to Altitudes Above 50,000 Feet
AIR STD 61/10B	Developmental Test and Evaluation of Aircraft Oxygen Delivery Systems
DV PUB 61/17	Vibration Exposure Limits
AIR STD 61/20	Methodology of Partial Pressure Suit Evaluation
AIR STD 61/21	Physiological Requirements for Aircrew Oxygen Masks for use at High Breathing Pressures
AIR STD 61/22	The Minimum Physiological Design Requirements for Aircrew Breathing Systems
AIR STD 61/24	Filter-Blower Performance for Aircrew NBC Headgear

REQUIREMENT LESSONS LEARNED

4.8 **Verification of international standardization provisions.** The verification of international standardization provisions shall consist of __________.

VERIFICATION RATIONALE (4.8)

Verification of the international standardization provisions of the oxygen system design and equipment shall be essential to ensure that all requirement provisions have been accomplished.

VERIFICATION GUIDANCE

Those applicable verifications are covered by inspection of the proposed specifications against the requirements of the stated international agreements to ensure the requirements are included.

VERIFICATION LESSONS LEARNED

3.9 **Design trade studies.** The following design trade studies will be accomplished: ___________. The goal is to determine the following: ___________.

REQUIREMENT RATIONALE (3.9)

In many cases controversial and questionable areas of design are encountered that are not easily resolved without some initial study and thought into the options available to the designer.

REQUIREMENT GUIDANCE

Include in the government model specification and statement of work a request that the proposing contractors include requirements for equipment and testing to accomplish trade studies prior to source selection proposal submittal. The pros and cons of this information should then be presented to the government source selection activity. Trade studies may be continued into full scale development and design on issues needing further investigation. In this case, the information should be included in the final negotiated contract.

REQUIREMENT LESSONS LEARNED

The most important and most controversial issue that is always difficult to resolve is the means of supply of oxygen. The three most common potential sources of supply are low or high pressurized oxygen gas, LOX converters with associated heat exchangers and molecular sieve OBOGS. Many factors, including support facilities at air bases the aircraft will frequent, weight and volume constraints within the aircraft, acquisition and life cycle costs, and any other important considerations, must be weighed and tradeoffs made. A good example is the choice of a LOX supply versus an OBOGS on a single or dual-place aircraft prior to the source selection. While there are definite advantages to the use of an OBOGS with reduced support requirements and overall reduced life cycle costs, the penalties might be too great when considering the electrical power and bleed air requirements.

4.9 **Verifying design trade studies.** The verification of design trade studies shall consist of ___________.

VERIFICATION RATIONALE (4.9)

It is desirable to verify trade studies so the information may be available for future reference and use in the follow-on development effort or similar work.

VERIFICATION GUIDANCE

The best approach to recording that design trade studies have been properly accomplished is to request the information be published in report format with associated facts of the studies, conclusions, and recommendations.

VERIFICATION LESSONS LEARNED

3.10 **Mockup requirements.** Mockups shall be constructed of ___________. The goal is to determine ___________.

REQUIREMENT RATIONALE (3.10)

Equipment mockups provide valuable insight into the physical space requirements for the oxygen system and associated components' design. Sketches and drawings often do not sufficiently describe and depict equipment interface so that problems will be discovered early and resolved. Varyious types of mockups provide this insight.

REQUIREMENT GUIDANCE

Varying degrees of mockup simulation may be useful depending on the evaluation objectives. To determine physical space requirements and compatibility with surrounding equipment, cheap materials such as wood and foam board are useful. Actual plumbing components should be used for piping to ensure a proper evaluation. To properly evaluate individual component design, often a mockup constructed of the actual materials and similar materials is most useful. This might apply to a proposed regulator design. Mockups are also useful in determining proper location of portable equipment, and usability and accessability of regulators and quick-donning oxygen masks. So the designer may properly scope his program, it is useful to state the goals. The requirements for mockups should also be included in the statement of work.

REQUIREMENT LESSONS LEARNED

4.10 __Verification of mockup requirements.__ The verification of oxygen system mockup design(s) and goals shall consist of ____________.

VERIFICATION RATIONALE (4.10)

It is desirable to develop an approach and test plan in the use of any mockups to assure they have been constructed for useful purposes. Should test and verification not be accomplished on the mockups, they could also be useful for sales and demonstration tools.

VERIFICATION GUIDANCE

It is worthwhile to request preliminary test plans from the proposing contractors prior to the expenditure of government funds on mockups and models which are usually quite expensive. On the other hand, it should be kept in mind that, with the use of mockups, the initial investment may be repaid many times over in consideration of total development, as required changes discovered later in development may be much more costly. In the development of smaller components, such as valves, masks, and hoses, it is best to request early prototypes made of the actual materials intended for production components.

VERIFICATION LESSONS LEARNED

APPENDIX B

PHYSIOLOGICAL HANDBOOK

10. SCOPE

10.1 Scope. An understanding of at least the elementary facts about respiration is a prerequisite for everyone having responsibilities in connection with oxygen equipment for civilian, military, commercial, or general aviation aircraft. Respiration is the process by which a living organism acquires the oxygen necessary for its essential cellular functions (metabolism) and discharges gaseous products of those functions (primarily CO_2). In man this process consists of ventilation (inhalation/exhalation), diffusion of O_2 from lungs to blood (and CO_2 from blood to lungs), circulation of blood between lungs and tissues, and diffusion of O_2 from blood to tissues (and CO_2 from tissues to blood). The following is an introduction to this subject, expressed (insofar as possible) in an easily understood manner. (For reference, see figure 8 and table XV.)

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

20. APPLICABLE DOCUMENTS

20.1 References. The documents referenced in this appendix are not intended to be applied contractually. Their primary purpose is to provide background information for the Government engineers responsible for developing the most appropriate performance values (filling in the blanks) for the requirements contained in the specification proper.

20.2 Avoidance of tiering. Should it be determined that the references contained in this appendix are necessary in writing an RFP or building a contract, excessive tiering shall be avoided by calling out only those portions of the reference which have direct applicability. It is a goal of the Department of Defense that the practice of referencing documents in their entirety be eliminated in order to reduce the tiering effect.

NOTE: Section I, for the most part, is extracted from the Society of Automotive Engineering AIR 822 and 825A.

20.3 Government documents

20.3.1 Specifications

MILITARY SPECIFICATIONS

MIL-D-8683	Design and Installation of Gaseous Oxygen Systems in Aircraft, General Specification for
MIL-D-19326	Design and Installation of Liquid Oxygen Systems in Aircraft, General Specification for
MIL-C-25969	Capsule, Emergency Escape Systems, General Specification for

20.3.2 Other government publications

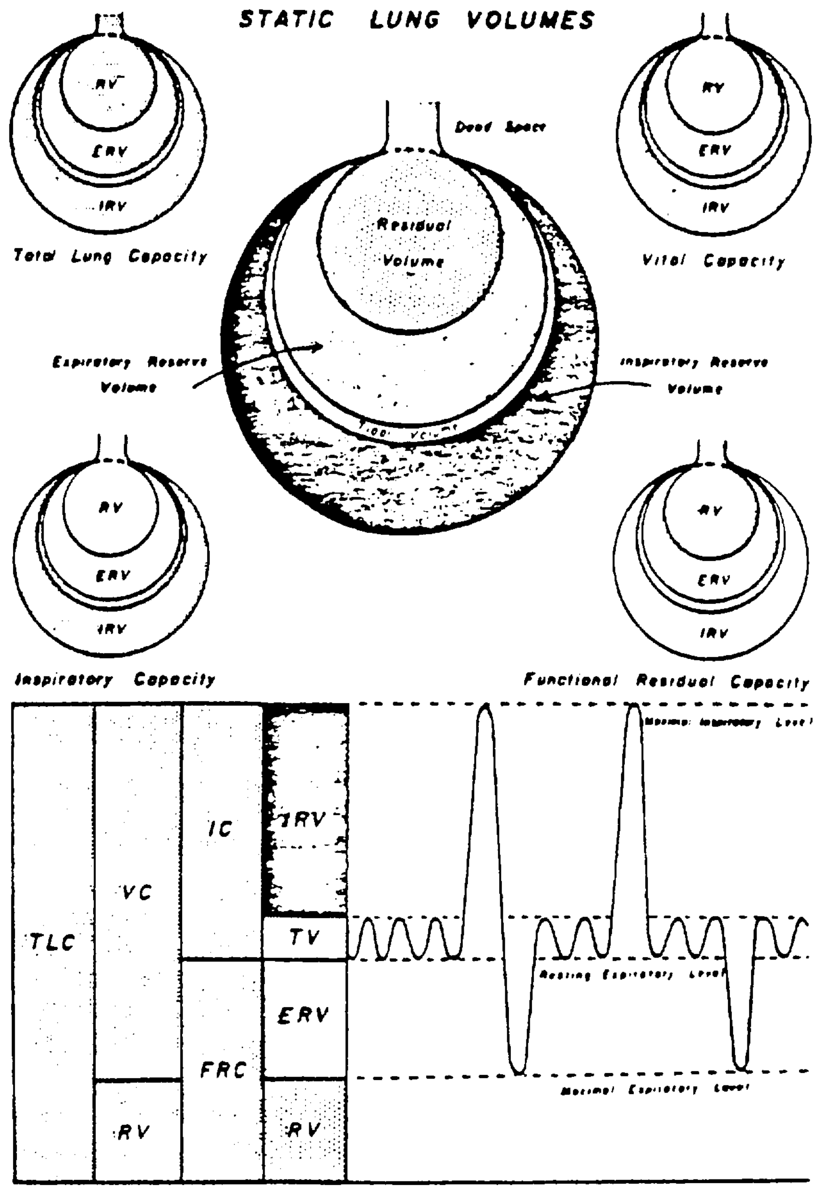
AFR 60-16	General Flight Rules

30. GENERAL PHYSIOLOGICAL OXYGEN CONSIDERATIONS

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

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

30.2 Breathing mechanics. Active, vigorous inspiratory respiration is accomplished by muscular expansion of the chest rib cage, contraction of the



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

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

FIGURE 8. Lung volumes.

TABLE XV - THE LUNG VOLUMES AND CAPACITIES

VOLUMES - There are four primary volumes which do not overlap (Fig 8):

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

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

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

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

CAPACITIES - There are four capacities, each of which includes two or more of the primary volumes (Fig 8):

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

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

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

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

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

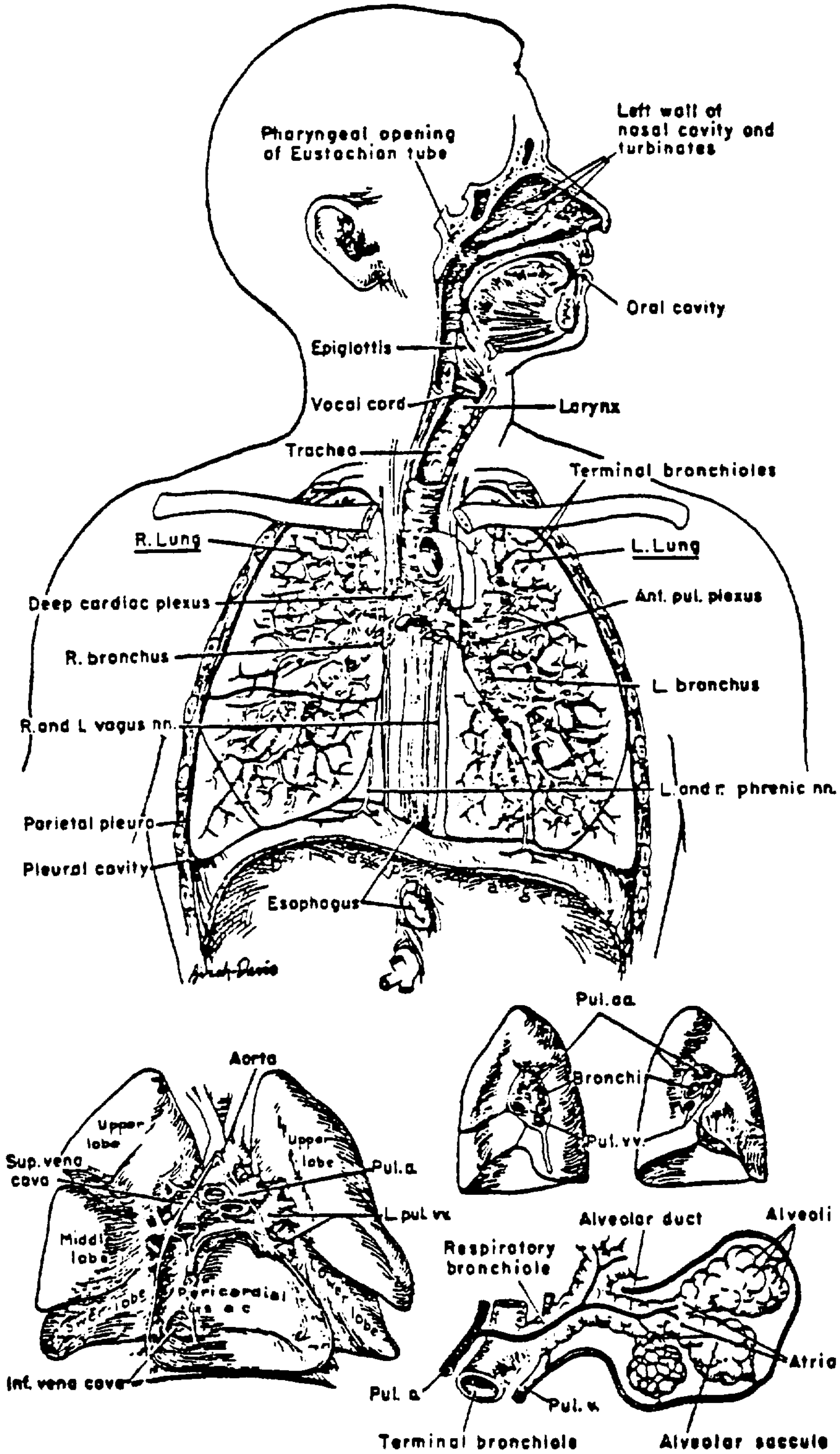
30.3 <u>Respiratory air composition</u>. At sea level, the atmospheric pressure is around 101 kPa (14.7 pounds per square inch), which is equivalent to the pressure exerted by a column of mercury 760 millimeters high (in the earth's gravitational field). One of the laws describing the behavior of mixed gases is the law of partial pressures. This simply means that in any given mixture of gases, such as air, at any given total barometric pressure, the partial pressure exerted by each of the components in this gas mixture is proportional to the volume percent (%) of each component present. Since air (for practical purposes) consists of about 21% by volume oxygen and 79% by volume nitrogen, oxygen exerts a partial pressure of 21% of 760 mmHg or 160 mmHg, and nitrogen 79% of 760 mmHg or 600 mmHg. Here the term mmHg refers to the <u>partial pressure</u> (expressed as the height in millimeters of a column of mercury) exerted by each major part of the two gases composing air. It is true that a small part of our atmosphere, approximately 1% of the air, consists of rare gases--argon, krypton, xenon, and a few others in trace amounts--which have here been included in the nitrogen portion. A varying amount of water vapor is also present in the air, giving rise to humidity. This is expressed in terms of percent of saturation or in millimeters of mercury partial pressure exerted by the water vapor present at a given temperature. Ordinarily the amount of water vapor in inspired air is extremely small and will detract only slightly from the inspired oxygen component. When calculating alveolar oxygen partial pressure in the expired or alveolar air, carbon dioxide (normally about 40 mmHg) and water vapor partial pressure at 37°C (47 mmHg) (have been added to the lungs to the total alveolar gas volume) must be included as part of the total alveolar pressure. Thus, these gases must be subtracted from the breathing barometric or mass pressure prior to calculating alveolar oxygen tensions (mmHg) from inspired gases (air for example).

30.4 Respiratory gas passages. The air we breathe passes into the trachea or windpipe and from there into the lungs (figure 9). It undergoes considerable change in composition as it passes through the trachea, mixes with the gases and water vapor already in the lungs, and is again exhaled. First, the inspired air becomes fully saturated with water vapor at body temperature in the nose (passing by the nasal turbinates) and throat so that the delicate tissue in the lungs will not be damaged by drying. It then mixes with the air already in the lungs that contains carbon dioxide and perhaps small amounts of other gases which, like the rare gases, are of insignificant amounts. Sea level average figures are given in table XVI for a sample of air from the trachea (called tracheal air) and from the lungs (called pulmonary or alveolar air) to show the difference in composition. These are typical values measured in young, healthy, nonsmoking, disease-free individuals. The proportions of these gases are approximate and are expressed in millimeters of mercury partial pressure as well as in percent (%).

TABLE XVI. Respiratory gas passages.

Partial pressure, mm of Hg (and percent)			
	Dry air	Tracheal air	Alveolar air
		Inspiratory	Static or end expiratory
Oxygen	160 (21)	149 (19.6)	109 (14.3)
Water Vapor	-	47 (6.2)	47 (6.2)
CO_2	-		40 (5.2)
Nitrogen	600	564	565
TOTAL	760	760	760

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



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

FIGURE 9. The respiratory system: man.

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

30.7 Physiological oxygen transport. Oxygen in the alveoli diffuses the thin permeable hydrophilic membrane into the capillaries that envelope the alveoli and thence into the red corpuscles where it binds with hemoglobin (see figure 10). The diffusion rate is proportional to the partial pressure of the oxygen present in the alveoli, intracellular fluid and plasma of the blood. The overall amount of oxygen reaching the blood depends upon several additional factors. These include vascular shunting of venous blood to the arterial side of the circulation without re-oxygenation, diffusion barriers to oxygen at the alveolar membrane (silicosis, pneumoconiosis, other causes of pulmonary fibrosis and/or alvelor membrane thickening - e.g., tobacco smoking), blood flow differences between the top and bottom of the lung because of gravitational effects, nonblood perfused alveoli, collapsed alveoli (atelectasis), etc.

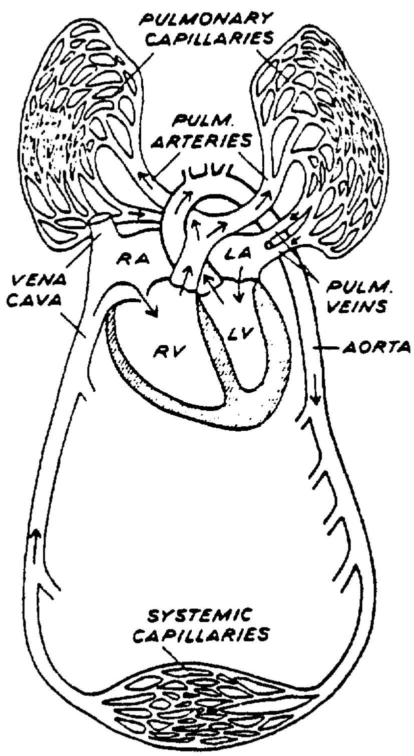
On their circuit through the body, the red cells at the systemic capillary tissue level release a portion of their oxygen load to the body tissue for use in the life sustaining processes (metabolism). This release is aided by the oxygen partial pressure gradient (O_2, higher in capillaries, lower in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

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

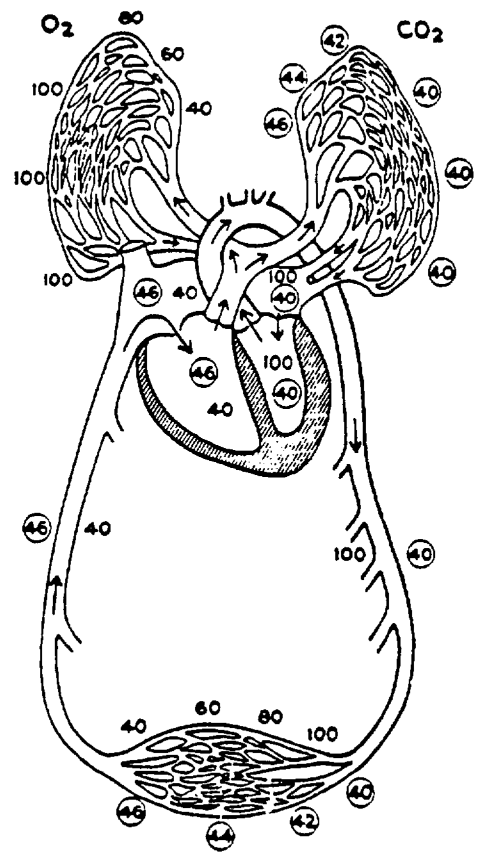
30.8 Oxygen partial pressures related to altitude. As one goes up to high altitude, the total air pressure diminishes and with it the partial pressure of each of the various gases. The percentage relationship of the gases remains unchanged, however. Table XVII shows the approximate oxygen partial pressure (mmHg) while breathing air at various altitudes.

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

30.9 Hypoxic recognition. Normal individuals living at sea level may become aware of the effects of altitude at about 1514 m (5000 ft) where the diminishing partial pressure of oxygen results in lessened ability to see at low levels of illumination (night blindness). Decrements in other physiological functions are demonstrable under controlled test conditions at around 1819 or 2438 m (6000 or 8000 ft). Red blood cells are no longer able to acquire a full load of oxygen. However, these altitude effects ebb as the body acclimates itself so that after a few days the mild symptoms disappear. Nonetheless, most individuals going as high as 3048 m (10,000 ft) will notice symptoms of altitude sickness, such as tingling, numbness, tunnel vision, and



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



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

FIGURE 10. Heart diagrams.

TABLE XVII. Oxygen partial pressures in the lung related to altitude.

	Sea Level	1514 m (5,000 ft)	3048 m (10,000 ft)	4267 m (14,000 ft)
Air Oxygen Inspired (Dry)	160	132	109	93
Tracheal Oxygen	149	122	100	84
Pulmonary or Alveolar Oxygen	109	82	60	44

night blindness. These will be particularly evident with exercise. Pilots flying at this altitude (or above) for any length of time should have oxygen-enriched air to breathe in order to maintain the partial pressure of oxygen in the trachea and alveoli sufficient to allow the red cells to take up a nearly normal complement of oxygen.

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

30.10.1 **Results of hypoxia.** Whenever the body tissues fail to receive adequate oxygen from the red blood cells, essential life functions are disrupted. Earliest and most apparent are the severe changes in mental function. Even with minor decreases in oxygen supply (as results from 3048 m (10,000 ft) over a period of time) the brain responds with muddled, confused, uncoordinated thinking, euphoria, and poor judgment. Further decreases in arterial oxygen partial pressure will produce mental symptoms of increasing severity, culminating in unconsciousness and death if the oxygen level becomes sufficiently low. It is the early onset of these altered mental functions, which are not recognized by the individual, that represents the most serious hazard to members of an aircrew, and has been the direct or indirect cause of many accidents, particularly in the "pilot error" category. Small amounts of alcohol can aggravate and intensify these deleterious effects. For those flying at night, it should be noted that there is a moderate loss of night vision at the altitude of 1514 m (5000 ft). Aircrew are recommended to use supplemental oxygen above this altitude during dusk, night flights, and night landings.

30.10.2 **Chronic hypoxia and adaptation.** People living at high altitudes adapt to the lower pressure and thus become acclimatized. For altitudes above 1514 or 1829 m (5000 or 6000 ft) acclimation requires a few days to two weeks for healthy, young individuals, and longer for older persons or those exposed to higher altitudes. It is important to know that acclimation to altitude does not take place as a result of flying, even with daily flying, because continuous exposure is required.

30.11 **Oxygen requirements between flight levels 340 and 425.** When one reaches an altitude of 10,363 m (34,000 ft), the standard atmospheric pressure is only 187 mmHg. Even if 100% oxygen is breathed at this pressure, there decompression. If the rupture or structural failure is large (such as door failure, 1.81 m^2 (20 sq ft) area, or bomb damage, etc) in the wide-body aircraft, the effects will be a rapid to explosive decompression. Rapid decompression is observed in small aircraft decompressing through a single 650 cm^2 (100 in^2) cabin window failure. Experimental data indicate that such failures will produce rapid decompressions of less than a second in smaller volume aircraft, ranging up to 30 seconds in larger volume wide body aircraft. In the smaller volume aircraft decompressions, upwards of 60% of the passengers initially breathing air at 8000 ft altitude may lose useful consciousness at flight level 390 to 400, even if successful in donning the presented oxyen mask in less than 3 seconds and inhaling the approximate supplemental (100%) oxygen thus available.

TABLE XVIII. Aircraft types, typical aproximate volumes, and cabin window areas.

Aircraft Model	Pressurized Volume		Cabin Window Area	
	m^3	ft^3	cm^2	$in.^2$
LR-24,25	7.5	265	2684	416 *
B-NA-265	12.2	430	839	130
NAR-1121	12.5	440	903	140
DH-125-400	16	565	652	101
DH-125-600	17.8	630	652	101
L-1329	35	1,250	1407	218
G-1159	52.4	1,850	2510	389
DC-9	165	5,840	884	137
B-737	227	8,010	903	140
B-727	256	9,045	903	140
DC-8-50	366	12,920	1786	274
B-707	411	14,495	903	140
DC-10	935	33,000	1019	158
L-1011-1	953	33,640	774	120
L-1011-500	838	29,580	774	120
B-747	1671	59,000	903	140

* Later model 24 and all 25 aircraft are 664 cm^2 (102 $in.^2$).

Some small, general aviation aircraft have been certificated to 550 flight level. Very rapid decompression occurs in these aircraft when structural failure occurs. Positive-pressure 100% oxygen must be breathed up to 20 cm of water pressure. Torso restraint vests are used to protect aircrew against chest over-expansion in very rapid decompression over 50,000 feet while breathing positive pressure mask oxygen. Emergency descent is made possible under torso restraint to permit tolerable ventilation and maintain useful consciousness.

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

30.15 Decompression performance decrement prevention. Despite the rapid availability of 100% oxygen from quick-donning masks, crew members in small cabin airplanes experiencing rapid decompression undergo substantial performance decrements due to hypoxia. Alveolar oxygen washout (the oxygen reversal phenomenon) which occurs during such decompressions causes brain deoxygenation unless a high concentration of oxygen is being breathed prior to the decompression. Rapid decompression also accelerates carbon dioxide diffusion into the alveoli, increasing carbon dioxide occupancy of alveolar partial pressure space and further lowers aveolar oxygen partial pressure. Current experimental data clearly show that moderate or severe performance decrements are virtually inescapable under such circumstances. Therefore, for flights at or above flight level 350, the pilot in control of the small cabin volume aircraft must wear a pressure demand oxyen mask supplied with 100% oxygen or an oxygen-air mixture as determined by a properly functioning dilution regulator. Should cabin pressure exceed 39,000 feet, this will assure his continued skill and judgment by preventing hypoxia in these excessively low oxygen partial pressures.

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

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

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

30.18 **Decompression sickness.** By definition, decompression sickness includes all ailments, excluding hypoxia, associated with barometric pressure changes. Aeroembolism is a form of decompression sickness discussed in 30.17. These ailments manifest themselves as ear pain, sinus blockage and pain, abdominal gas expansion, toothache, bends, chokes, skin sensations or paresthesia, and other neurological symptoms.

Consideration of these effects of barometric changes may be divided into the general topics of trapped gases and evolved gases. (See table XVIV).

30.18.1 **Trapped gases.** The gases trapped in the middle ear, sinuses, teeth, and gastrointestinal tract expand or contract (increase or decrease in volume) in accordance with Boyle's Law, which states that the volume of gas is inversely proportional to the pressure of the gas if the temperature remains constant. This means that as the pressure decreases, as it does when we go to higher altitude. gases expand or increase in volume. Applied to a dry gas, approximate values for increase in volume will be multiples of the denominator of the fraction of the atmosphere considered. For example, at 1/2 atmosphere (5,480 m = 18,000 feet) the volume of a gas will be twice that at sea level: at 1/4 atmosphere (10,363 m = 34,000 feet) the volume will be four times that at sea level. However, in calculating expansion of gases saturated with water vapor (as in the body cavities), the actual increase in volume is greater than that given for dry gases. The following equation will explain how expansion for wet or saturated gases occurs. Let V_1 represent the initial volume; V_2 the final volume at any altitude; P_1 the initial pressure; and P_2 the total pressure of 47 mmHg in saturated gas at body temperature. You then solve the volume change equation:

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

to calculate the expansion of a wet gas at 5,480 m (18,000 ft) from initial conditions at sea level:

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

TABLE XIX. Summary of types, symptoms, occurrence and treatment of decompression sickness.

Dysbaric condition	Symptoms	Occurrence	Treatment
Paresthesia (creeping)	Tingling, itching, cold and warm sensations of skin	During ascent	Descend
The bends	Pain in and about the joints: possible collapse	During ascent	Descend and refer to flight surgeon
Chokes	Burning sensation beneath sternum; nonproductive cough; sensation of suffocation; collapse	During ascent	Descend and refer to flight surgeon
Aerotitis (see also aero-otitis)	Hearing becomes dull; fullness in the ear; pain; severe cases: damage and possible ear drum rupture	Usually during descent when individual has upper respiratory infection or infection	Swallow, yawn, cough, Valsalva; ascend to higher altitude; spray with vasoconstrictors
Aerosinusitis (sinus pain)	Pain, frontal sinus, pain in forehead; cheek sinus; pain in cheekbones, may be referred to teeth	During ascent and descent	Level aircraft and descend; vasoconstrictors descend slowly if occurs on ascent, return to ground level
Gas expansion (GI tract)	Discomfort, pain, interference with respiration severe cases; lowered blood pressure, possible collapse and shock	During ascent usually above 25,000 feet; in rapid ascent may occur as low as 15,000 ft	Descend. If marked, level aircraft and massage area. If ineffective, return to ground level
Aerodontalgia (toothache)	Pain in the area of the affected tooth	During ascent and usually between 5000 ft. Occasoinally during descent	Level aircraft and descend. Refer to dentist after flight

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

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

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

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

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

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

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

30.18.2 Evolved tissue gases. The amount of any gas dissolved in the blood and tissue fluids of the body is directly proportional to the pressure of that gas (Henry's Law). With the decreasing pressure that occurs at altitude, such gases come out of solution. These gases are normally transported by the blood passing the alveolar membrane of the lung. The gases come out of solution at the alveolar boundary, pass in the lung, and then to the outside atmosphere. When one ascends to altitudes above 9,120 m (30,000 feet) while breathing air, the fluids of the body release their dissolved gases more rapidly than the blood can carry them off.

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

The remedy for these bubble-produced dysbaric episodes is recompression to one atmospheric pressure. Sometimes, in decompression shock, recompression to 2 to 3 atmospheres is required and will be life saving. Decompression shock results from bubble formation in extravascular (outside the blood vessels) tissues (brain especially) resistant to resolution when re-exposed to sea level recompression. Nitrogen bubbles fall into this category, and increased pressure (2-3 atmospheres) is required to drive the nitrogen bubbles back into solution. Their evolution in this situation is most likely from fat tissue cells throughout the body, where nitrogen is most soluble but only with a very slow solubility time constant.

30.18.3 Bends and chokes. These conditions are brought about by decreasing barometric pressure which results in the release of gases, primarily nitrogen, from the various body fluids and tissues. Bends were first encountered by caisson workers and deep sea divers. The reduction in pressure that occurs when a person comes up to the surface of the water (1 atmosphere pressure) from a depth of 10 meters (33 feet or 2 atmospheres), is similar to that which occurs when one goes from sea level to 5,480 m (18,000 feet or 1/2 atmosphere).

The exact mechanisms that produce the symptoms are not fully understood. It is known that the inert nitrogen is a primary factor and that it is difficult to dispose of the excess gas rapidly, with decrease in pressure favoring its release from solution. This is particulary true of tissues which are poorly supplied with blood vessels and that dissolve large amounts of the gas (i.e., fat tissues). All the gases evolved or released from solution may be discarded by passing into the blood and then diffusing through the lung alveoli for loss by expiration. The release of gases in excess of what can be readily discarded in this manner results in the formation of gas bubbles in the tissues and blood stream. The first symptoms nearly occur below 10,363 m (30,000 feet) but increase above that level with prolonged exposure. At first migratory pain occurs in an extremity or joint. This symptom is associated with the bends. With increased altitude, the pain usually becomes more intense and may lead to vascular changes indicating shock conditions. If, despite increasing pain, the subject remains at altitude or ascends higher, he will eventually collapse.

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

Another symptom of decompression sickness, "the chokes," occurs when escaped gases involve the lung vessels. There is a deep substernal burning, a nonproductive cough arising from deep within the chest, and a sense of suffocation and apprehension. As in bends, descent to lower altitudes 6080 m (20,000 feet) usually gives relief, but symptoms may persist to ground level and should be treated until they disappear.

30.18.4 **Paresthesia and skin rashes.** Paresthesia (burning or itching sensations) and skin rashes are mild symptoms which occasionally occur and are aggravated by exercise and scratching. They are assumed to be caused by small gas bubbles in subcutaneous fat or in tissue adjoining nerve endings in the skin.

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

30.19 **Flying following scuba diving.** Evolved tissue gases become more medically significant and symptomatic to airmen at hypobaric altitudes following scuba diving. The National Oceanic and Atmospheric Administration (NOAA) recommend in their diving manual, safety rules for divers who intend to fly as passengers. Any diver who has completed any number of dives on air and decompressed following US Navy standard air decompression tables should wait at sea level breathing air for the computed surface interval that allows him to be classified as a Group D diver in US Navy Repetitive Diving Table. The aircraft cabin atmosphere must not exceed 8000 feet altitude.

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

40. PHYSIOLOGY OF RESPIRATION FOR MILITARY AIRCRAFT CREWMEMBERS

40.1 **Alveolar oxygen partial pressure.** The aircrew need for oxygen is based on the physiological requirement of oxygen in the human body. Oxygen in the breathable gas mixtures interfaces with the body at the lung surfaces. The tissues of the body acquire the oxygen at a certain partial pressure of oxygen. This normal function at sea level is at 103 mmHg of oxygen in the alveoli of the lungs. As the atmopsheric pressure is reduced (as by an increase) in altitude, the ratio of oxygen in the ambient air stays the same but the partial pressure of oxygen decreases as the altitude increases. This relationship to 30,000 feet is given in table XIX.

TABLE XX. Oxygen change with altitude.

Altitude	Atmosphere Pressure	Oxygen Partial Pressure
Feet	mmHg	mmHg
0	760	160
5,000	632	132
10,000	522	109
14,000	446	93
20,000	349	73
25,000	281	59
30,000	225	47

The 103 mmHg partial pressure of oxygen in the lungs provides for the diffusion of oxygen into the blood. The blood is circulated throughout the body and provides for the diffusion of oxygen into tissues of lower oxygen partial pressure resulting from oxygen utilization in physiological chemical cellular reactions. This cellular oxygen diffusion must provide for at least 30 mmHg partial pressure of oxygen in the cellular tissues or the tissues will not function normally. Nerve tissues in the optic system, the brain, and the mental processes, suffer degraded performance at less than 30 mmHg oxygen. Thus, there is a minimum partial pressure of oxygen below which the crewman will die due to lack of adequate oxygen in tissues. Between the normal and the minimum is a range in which a graduation of symptoms exists due to the lack of oxygen and provides the basis for oxygen addition to the breathing gas mixture for aircrews.

40.2 **Hypoxia.** There is a gradually decreasing oxygen content in breathing air and the resulting physiological effect of the low oxygen partial pressures increases as altitudes increase. Oxygen deficiency effects are shown in table XXI.

TABLE XXI. Oxygen content and deficiency effects.

Alveolar ppO_2 mmHg	Tracheal ppO_2 mmHg	Cabin Altitude ft	Altitude Equivalent Breathing 100%-ft	Oxygen Deficiency Effects
103	149.7	0	33,000	Normal vision and performance
82	123	5,000	36,000	Night vision deficiency
61	100	10,000	39,000	Impaired judgment/ performance
44	84	14,000	41,000	Appreciable handicap
41	70	16,000	42,500	Considerable handicap
38		18,000	44,000	Serious handicap
35	64	20,000	45,000	Imminent collapse

The deficiency of oxygen in the tissues produces hypoxia, affecting the subject in various ways, depending on physical well being, the rate of change of atmospheric pressure, and on the subject's psychological makeup. Stages in the occurrence of hypoxia are indicated in table XXII.

TABLE XXII. Stages of hypoxia.

Stage	Breathing air	Breathing 100% oxygen
indifferent	0 - 10,000 ft	33,000 - 39,000 ft
compensatory	10,000 - 15,000	39,000 - 42,200
disturbance	15,000 - 20,000	42,200 - 45,200
critical	20,000 - 23,000	45,200 - 46,800

Subjective symptoms of hypoxia usually develop at about 10,000 to 12,000 ft altitude. The body has compensatory mechanisms which counteract the effects of hypoxia by adjusting to reduced oxygen pressures. With a normal rate of climb, the symptoms of hypoxia are not as pronounced.

Symptoms evident in some individuals are inconsistent, and the individuals may become euphoric with outbursts of hilarity, uncontrolled laughter or pugnaciousness, or behavior which appears ludicrous or unnatural.

The symptoms usually are: sleepiness, headache, altered respiration, lassitude, fatigue, psychological impairment, and euphoria.

At about 25,000 ft, coma occurs suddenly, usually without any subjective warning.

On a sudden exposure to high altitude as with sudden cabin decompression with loss of oxygen, the subject becomes dizzy, sees spots before his eyes, and has a sensation of suffocation. Acute symptoms follow after a few minutes.

Altitudes at which hypoxic death has occurred range from 7000 to 20,000 ft with 2 deaths, 25,000 to 28,000 ft with 23 deaths, 28,000 to 30,000 ft with 13 deaths. A total of 75 deaths due to hypoxia has been attributed to lack of oxygen at altitude.

These fatal cases of altitude hypoxia occurred in B-17 and B-24 flights during World War II. The cases were analyzed in a USAF school of aviation medicine in 1948 and positively related altitude with hypoxia incident.

40.3 Hyperventilation. The oxygen utilization process at the cellular level also depends upon the partial pressure of carbon dioxide in the cells and in the blood. This partial pressure for carbon dioxide is 40 mmHg. When the carbon dioxide is depleted by rapid breathing, as in hyperventilation, the oxygen diffusion into the tissues is reduced. There is a one-for-one exchange of oxygen for carbon dioxide. When carbon dioxide is depleted, reduced diffusion of oxygen into the cells occurs, resulting in a hypoxic state, and the effects of hypoxia become evident. The rate of breathing must be consciously controlled by the crewman. Oxygen must be supplied at high concentrations to assure that the required partial pressure oxygen within the lung is attained.

40.4 Pressure breathing 100% oxygen. The physiological effects of breathing high concentrations of oxygen at elevated pressures upon biological processes include some adverse effects. High-pressure oxygen acts as a driving force in the usually slow oxygen utilizing reaction in living tissues. Splitting of unsaturated bonds in biological compounds, formation of toxic organic peroxides, and inhibition of oxidation reduction reactions are some of the effects of high oxygen concentrations on biological processes.

Some of the body responses to pressure breathing high oxygen content are listed in table XXIII.

TABLE XXIII. Symptoms of oxygen pressure breathing.

night blindness	decreased cardiac output
	increased intrapulmonary pressure
	decreased venous return to heart
pain in the chest	tachycardia
fainting (syncope)	alveolar rupture

40.5 Lung inspiration-expiration requirements. The quantitative oxygen requirements for aircrew respiration can be estimated from man/lung measurements and the variation in these measurements as shown by table XXIV.

TABLE XXIV. Lung inspiration-expiration relationships.

Tidal volume	normal inhalation/exhalation, 0.5 litres
Lung volume	4 to 6 litres
Vital capacity	up to 4 litres
Residual volume	up to 2 litres
Vital capacity	inspiratory reserve volume tidal volume expiratory reserve volume

The frequency of breathing and the volume of inspired gas would provide a measure of the amount of gas exchange per minute and subsequently per hour. The aircraft flight mission would place a total time requirement and the altitude of the mission would prescribe the amount of oxygen to be added to the breathing gas mixture. The basic or minimal amount of oxygen needed for a specific aircraft mission could be calculated. For a safety factor and for providing operational standby requirements, the oxygen supply requirement is provided significantly over the minimal amount needed.

Respiration rate or breathing frequency at rest is in the range of 12-16 per minute. This rate increases with exertion and activity. High rates of 30 to 40 per minute can be considered hyperventilation and can lead to physiological difficulties.

The breathing gas flow rate usually is given on a minute basis at 20-40 litres per minute at rest, 80-100 litres for mild exertion, and 400 to 600 litres during severe exertion or anxiety. The high flow rate during a single inspiration may approach 200 litres per minute when the crewman is involved in high G maneuvers. The high flow rate requirement defines the sizing and design of valving, tubing, regulator, and control equipment. High flow rates in a low pressure system may require design changes or a supplemental system to attain required flow rates.

50. OXYGEN EQUIPMENT DESIGN PHYSIOLOGICAL CONSIDERATIONS IN MILITARY AIRCRAFT

50.1 **Introduction.** This section presents information on the atmosphere for man and covers specific aircraft oxygen equipment design requirements.

because of man's recognized susceptibility to environmental extremes, the environmental systems and subsystems are designed so that man will not be exposed to an environmental condition that:

a. may be physiologically damaging or is unnecessarily dangerous.

b. may be physically uncomfortable or painful and is likely to interfere with critical and safe performance.

c. may contribute to reduction of motivation and alertness and impairment of critical or safe operational performance.

50.2 **Atmosphere and oxygen.** Oxygen is a vital consideration in any discussion of life-supporting atmospheres. The only oxygen stored by the body is what is actually being transported by the bloodstream. The tissues most sensitive to oxygen deficiency, such as the central nervous system (brain and eyes), cannot function without oxygen. The crew must be provided sufficient oxygen so that the alveolar partial pressure of oxygen (PPO_2) is not permitted to drop below 61 mmHg, except for transitory conditions of very short duration. Since man must function in the aerospace vehicle's environment, the data presented here bear on the relation between gaseous composition and both hypoxic and hyperoxic states. The charts and figures provide design information with some basic guidelines, constraints, and tolerance limits that may aid in arriving at safe and survivable artificial environments for man in aerospace vehicles. A great deal of research and development is still being conducted. Consequently, consider this information as currently understood and accepted data, and supplement it with the latest available technical advancements. Figure 11 points out that physiological equivalence is useful as a first approximation in steady-state conditions, but do not use it for evaluating such transient and complicated conditions as pressure breathing. Man can go above these altitudes only if he balances the oxygen pressure needed inside the body by applying counter-pressure to the outside of the body, as accomplished by the various types of pressure garments.

50.3 **USAF aircraft oxygen requirements.** Oxygen breathing systems for aircraft make human flight and functions possible and less hazardous at otherwise impractical altitudes. Include aircraft oxygen systems or consider them early in the design to provide reliable and effective installations for the safe operation of the aircraft and to ensure crew safety. Current USAF policy concerning the use of oxygen is contained in AFR 60-16. Additional detailed information is given by figures 12, 13, and 14 and the associated tables XXV and XXVI.

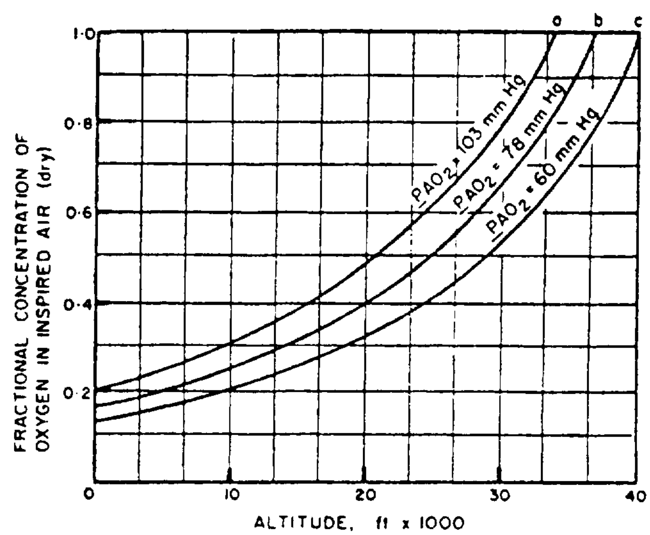


FIGURE 11. The fractional concentration of oxygen in inspired air (dry).

NOTE: The fractional concentration of oxygen in inspired gas (dry) at various altitudes, in order to maintain alveolar oxygen tensions of 103 mmHg (equivalent to breathing at sea level); 78 mmHg (equivalent to breathing air at 5000 ft); and 60 mmHg (equivalent to breathing air at 10,000 ft).

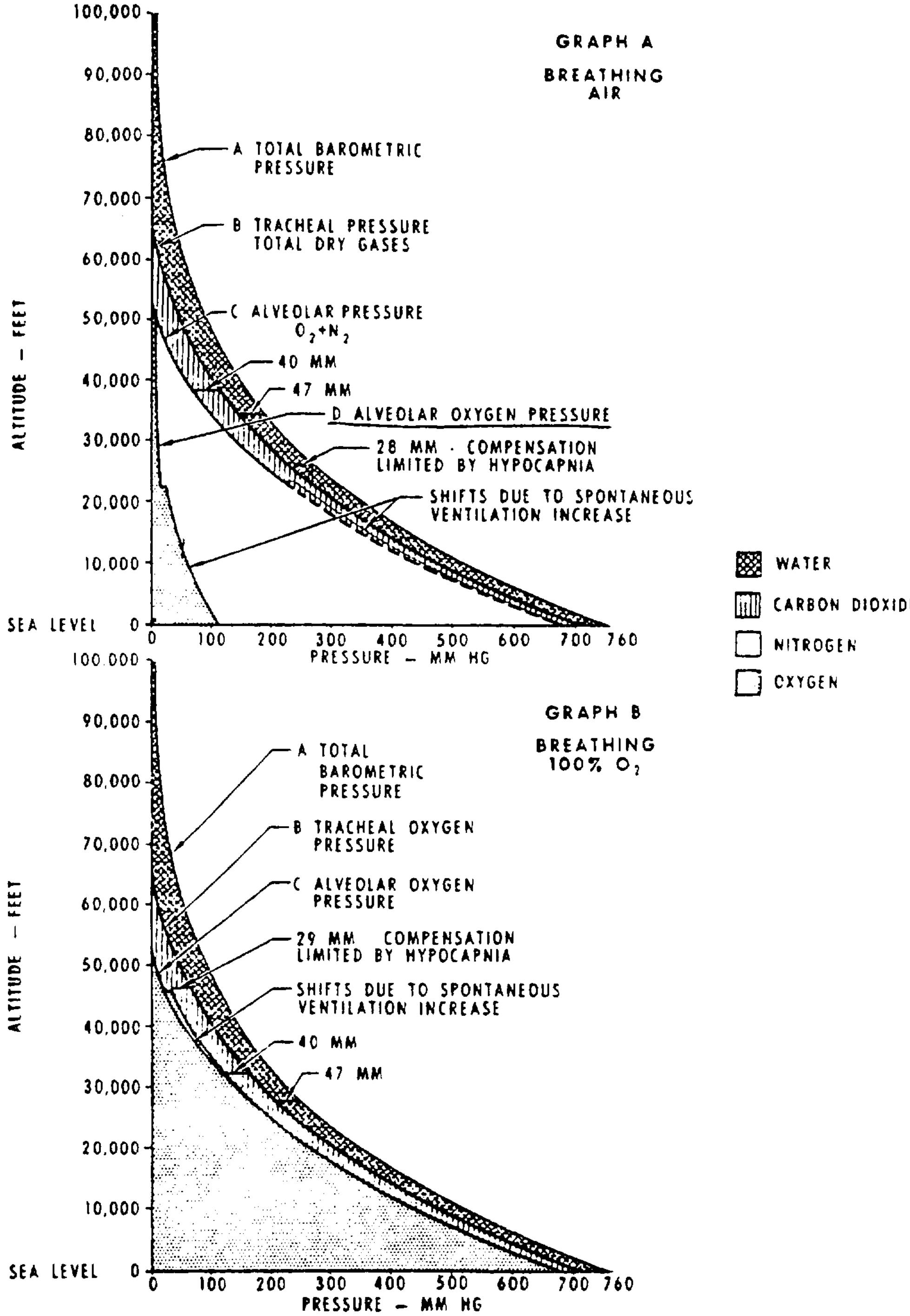


FIGURE 12. Interaction between atmosphere and lung-body system.

Altitude (Feet)	Total Pressure (mm Hg)	N_2 Percentage	H_2O Percentage	CO_2 Percentage	O_2 Percentage	O_2 Pressure (mm Hg)
AMBIENT DRY ATMOSPHERE						
0	760.0	79.02	0	0.03	20.95	159.2
5,000	632.3	79.02	0	0.03	20.95	132.5
10,000	522.6	79.02	0	0.03	20.95	109.5
15,000	428.8	79.02	0	0.03	20.95	89.8
20,000	349.1	79.02	0	0.03	20.95	73.1
22,000	320.8	79.02	0	0.03	20.95	67.2
TRACHEAL GAS						
0	760.0	74.13	6.18	0.03	19.66	149.4
5,000	632.3	73.14	7.43	0.03	19.39	122.6
10,000	522.6	71.91	8.99	0.03	19.06	99.6
15,000	428.8	70.31	10.96	0.03	18.66	80.0
20,000	349.1	68.38	13.46	0.03	18.13	63.3
22,000	320.8	67.46	14.65	0.03	17.85	57.4
ALVEOLAR GAS						
0	760.0	75.00	6.18	5.26	13.55	103
5,000	632.3	74.06	7.43	6.01	12.49	79
10,000	522.6	72.45	8.99	6.89	11.67	61
15,000	428.8	70.62	10.96	7.70	10.73	46
20,000	349.1	68.49	13.46	8.59	9.45	33
22,000	320.8	67.27	14.65	8.73	9.35	30

Altitude (feet)	Total Pressure (mm Hg)	N_2 Percentage	H_2O Percentage	CO_2 Percentage	O_2 Percentage	O_2 Pressure (mm Hg)
AMBIENT DRY OXYGEN						
33,000	196.3	0	0	0	100	196.3
36,000	170.3	0	0	0	100	179.3
39,000	147.5	0	0	0	100	145.5
42,000	127.9	0	0	0	100	127.9
45,000	110.9	0	0	0	100	110.9
46,000	105.6	0	0	0	[illegible]	105.6
TRACHEAL GAS						
33,000	196.3	0	23.94	0	76.06	149.3
36,000	170.3	0	27.60	0	72.40	123.3
39,000	147.5	0	31.96	0	68.04	100.4
42,000	127.9	0	36.75	0	63.25	80.9
45,000	110.9	0	42.38	0	57.62	63.9
46,000	105.6	0	44.51	0	55.49	58.7
ALVEOLAR GAS						
33,000	196.3	0	23.94	20.26	55.80	109.0
36,000	170.3	0	27.60	22.32	50.08	85.3
39,000	147.5	0	31.96	24.41	43.63	64.4
42,000	127.9	0	36.75	25.30	37.95	47.9
45,000	110.9	0	42.38	27.05	30.57	33.9
46,000	105.6	0	44.51	27.46	28.03	29.6

This summarizes the key physiological interaction between the atmosphere and the lung-body system. It compares the composition (partial pressure) of tracheal and alveolar gases at different altitudes in subjects breathing air and 100% oxygen. In both cases, inspired gases pick up water from the wet respiratory passages until partial pressure of the water vapor reaches saturation pressure of 47 mm Hg at body temperature (98.6°F or 37°C). The total pressure of dry gases in the trachea is 47 mm Hg less than the total barometric pressure (Curves A and B), the tracheal oxygen and nitrogen pressures always being, respectively, 9.9 mm and 37.1 mm Hg less than their dry air ambient pressures. As inspired gases pass into the lungs, they mix with residual air in the alveoli, lose oxygen to the blood, and pick up carbon dioxide released by the blood. The carbon dioxide mixes with the alveolar gases to an equilibrium partial pressure of 40 mm Hg. The total partial pressure of oxygen and nitrogen in the lungs (alveolar gas, Curve C) is therefore 40 mm Hg less than that in the tracheal gas. In most subjects, the body compensates automatically (within a limited range) for low oxygen pressure by increasing the breathing rate and depth (hyperventilation) until hypocapnia (too low carbon-dioxide concentration) sets in. This increases slightly the alveolar partial pressure of oxygen (P_{O_2}), within the compensatory range, as shown on Curve D. The abrupt cessation of the hyperventilation effect at 23,000 ft in Graph A and at 45,000 ft in Graph B represents lack of experimental points, since a subject cannot be held at these conditions long enough to obtain an equilibrium value. Above approximately 50,000 ft altitude, whether on air or 100% oxygen, the alveoli contain only water and carbon dioxide. Comparison of Graphs A and B indicates that enriching the inspired air with supplementary oxygen will move Curve D toward the right, as nitrogen is replaced with oxygen. As more oxygen is added, the curve shifts farther to the right until, at 100% oxygen, it becomes the same as Curve C except for the portion shifted by the spontaneous increase in ventilation. The term "equivalent altitudes" is used to describe the various altitudes at which, under different specific breathing conditions, alveolar and tracheal oxygen pressures are similar. In the tables of both Graphs A and B, note that the tracheal and alveolar pressures correspond closely. At 40,000 ft breathing pure oxygen is equivalent to breathing air at 10,000 ft. Physiological conditions (as regards oxygen) and performance will be identical under the two conditions. This level (60 mm Hg alveolar P_{O_2}) represents the minimum permissible during daytime operation. At altitudes above 40,000 ft the 100% oxygen must be supplied under positive pressure. To maintain an alveolar P_{O_2} of 60 mm Hg, the positive pressure should be equal to the difference between that of the ambient altitude and 40,000 ft. Thus, in theory, the alveolar P_{O_2} and ability to function at 50,000 ft with a positive pressure of 100% oxygen of 53.4 mm Hg should be equivalent to 40,000 ft on 100% oxygen. This reverses the normal effort of breathing, which is quite fatiguing, and also causes a circulatory stagnation from pressure effects on the veins returning to the heart. Hypocapnia is another common problem in positive pressure breathing. Positive pressure equipment may be used routinely up to 40,000 ft and to a maximum of 50,000 ft briefly during an emergency.

FIGURE 12. Interaction between atmosphere and lung-body system - cont'd.

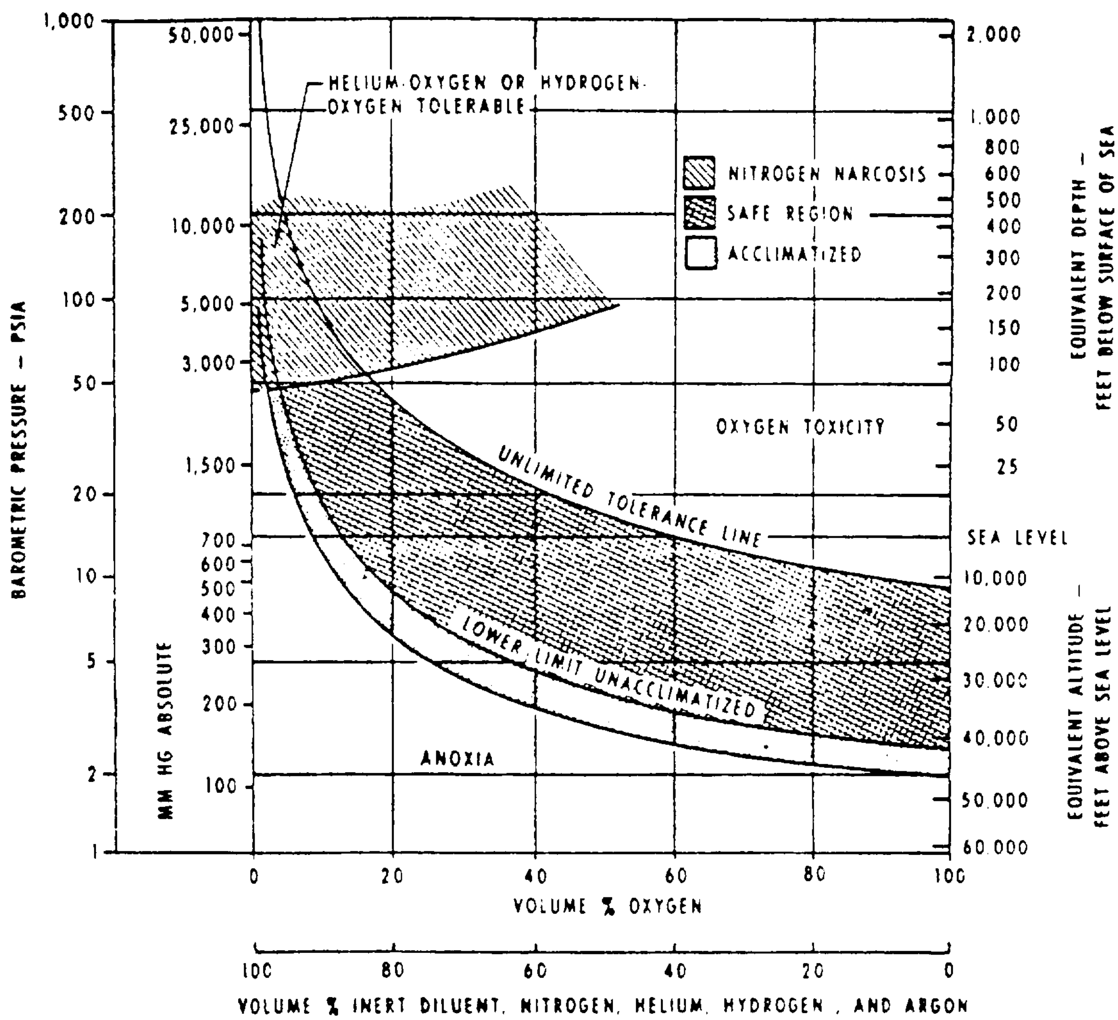
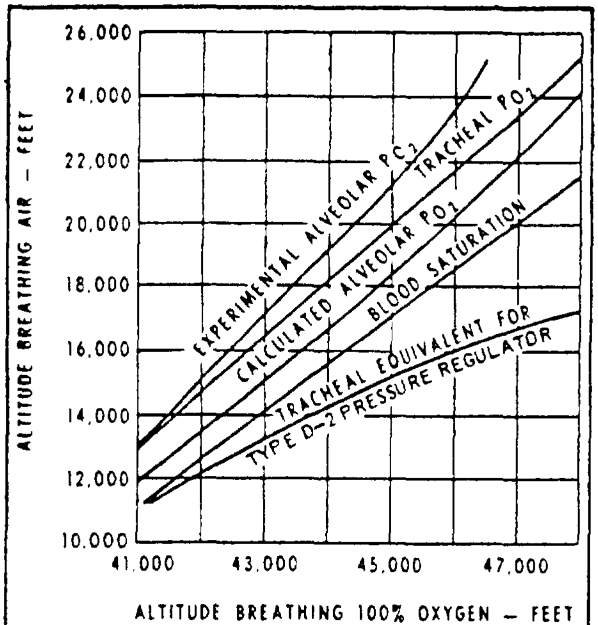


FIGURE 13. Atmospheric pressures and oxygen mixture.



THIS GRAPH COMPARES SEVERAL WAYS OF EXPRESSING EQUIVALENCE OF ALTITUDES WHEN BREATHING 100% OXYGEN. IT ELABORATES ON THE POINT THAT EQUIVALENT ALTITUDES VARY WITH THE SPECIFIC RESPIRATORY MEASUREMENT IN QUESTION.

THE PHYSIOLOGICAL EQUIVALENCE IDEA IS USEFUL ONLY FOR FIRST APPROXIMATIONS IN STEADY STATE CONDITIONS. IT SHOULD NOT BE USED FOR TRANSIENTS, PREDICTION OF INDIVIDUAL BEHAVIOR, OR OTHER DETAILED COMPUTATIONS.

FIGURE 14. Altitude equivalences; air vs. oxygen breathing.

TABLE XXV. Human altitude limits.

Altitude (ft)	Limits
5,000	Maximum for normal night vision without supplemental oxygen
8,000	Altitude at which supplemental oxygen should be used
10,000	Maximum without continuous use of oxygen
18,000	Maximum for emergency without use of oxygen
20,000	Altitude at which consideration should be given to use of pressurized cabins
23,000	Altitude at which there is evidence of depressurization sickness
25,000	Approximate time of consciousness without oxygen is 115 sec
28,000	Maximum to avoid decompression sickness. Approximate time of consciousness without oxygen is 70 sec
30,000	Altitude above which slight positive pressure breathing should supplement demand oxygen to avoid air leaks into oxygen mask. Approximate time of consciousness without oxygen is 55 sec
35,000	Maximum for continuous use of demand oxygen system. Approximate time of consciousness without oxygen is 30 sec
40,000	Approximate time of consciousness without oxygen is 23 sec
42,000	Maximum for continuous use of pressure breathing. Bomber and fighter aircraft not having escape capsules but having a requirement to remain above this altitude for periods in excess of five minutes after loss of cabin pressurization require provisions for use of pressure suits.
43,000	Maximum for emergency use of demand oxygen--time of useful consciousness without oxygen is 15 sec
50,000	Maximum for emergency use of pressure breathing demand oxygen. Bomber and fighter aircraft not having escape capsules but having combat ceilings above this altitude require provisions for the use of pressure suits.

TABLE XXVI. Routine and emergency flight ceilings used in the USAF.

Condition	Routine flight (ft)	Emergency for a few minutes (ft)
without oxygen	10,000	18,000
continuous flow oxygen	25,000	40,000
with demand oxygen	35,000	40,000
with pressure demand oxygen	42,000	50,000
with pressure demand oxygen and pressure suit	*50,000	*50,000
* Indicated altitude or above. See AFR 60-16 for further routine flight information.		

USAF policy requires the use of oxygen when aircraft with nonpressurized crew compartments are operated (1) at 10,000 ft and above on all flights, (2) from the ground up on all combat missions at night and on all other night missions, and (3) between 8000 and 10,000 ft on all flights lasting 4 hrs or more.

Most large transport, passenger, and bomber aircraft have pressurized cabins which provide cabin altitudes not to exceed 8000 ft at maximum cruise altitude. As a result, a breathable cabin atmosphere can be maintained throughout the mission with no need for supplemental oxygen. Emergency oxygen systems are provided in the event of the loss of cabin pressurization due to cabin structural failure, engine failure, or environmental control systems failure. Also, an emergency oxygen system can be required in event of smoke, fumes or dust, or a fire in the cabin. For aircraft with selectable isobaric control, the cabin altitude can be maintained at sea level essentially up to 20,000 to 25,000 ft and then increase in a curvilinear fashion up to 8000 ft when the aircraft altitude is 40,000 to 60,000 ft. This design is based on a 8 to 10 psi pressure differential between the aircraft cabin and the ambient environment. Some early transport aircraft such as the C-118, C-121, C-131 and current fighter, attack, and trainer aircraft have a pressurization schedule of only 2.75 to 5.0 psi difference. For fighter aircraft, a cabin pressure altiude of up to 25,000 ft can occur at the operational ceiling. Typically a 5 psi pressure differential is maintained between the cockpit pressure altitude and the aircraft altitude on fighter aircraft. The basic physiological premise for fighter aircraft is that the pressure-demand oxygen equipment is used most of the time and will adequately support all percentile crewmembers without decompression sickness with a cabin altitude that is always 25,000 ft or less.

50.4 **Regulated pressure and diluter demand oxygen equipment.** Up to 34,000 ft, the need for oxygen can be met by increasing the percentage of oxygen being breathed. Efficient demand-type oxygen equipment has been designed for this purpose. Above 35,000 ft, breathing of 100% oxygen is not adequate for safe routine operation because the margin of safety is too small. With the oxygen equipment functioning perfectly at 40,000 ft, the saturation of the blood with oxygen is equivalent to breathing air at 10,000 ft. At 43,000 ft, it is equivalent to breathing air at 18,000 ft.

An additional increase in altitude for safe flight has been gained by using pressure-demand oxygen equipment that delivers oxygen to the lungs at pressures from 50.8 to 431.8 mm (2 to 17 in) of water above ambient pressure. With this system, routine flights up to 42,000 ft are considered safe, and in emergencies, flights of a few minutes duration are permissible up to 50,000 ft. At 50,000 ft, a positive pressure of above 30 mm Hg is transmitted to the mask, resulting in an alveolar PPO_2 of about 40 mm Hg, provided there is no excessive mask leakage. This is equivalent to breathing oxygen at 44,000 ft or breathing air at 18,000 ft. In all these cases, this represents a severe degree of hypoxia, being compounded still further at 50,000 ft by the high degree of unsupported pressure breathing and its effect on the cardiovascular system. For these reasons, this type of pressure breathing at altitudes above 45,000 ft provides inadequate protection except for brief periods, in extreme emergencies, followed by immediate descent. For adequate protection, the pressure suit is mandatory to effectively bring the equivalent altitude for pulmonary oxygenation below 40,000 ft. Man's ceiling for safe routine flight and for emergency flight can be set as shown in table XXVI. Aircraft with capsule emergency escape systems (see MIL-C-25969) do not fall under these limitations.

The regulated oxygen systems are controlled by the oxygen regulator with altitude pressure sensitive aneroids in the regulator which provide the supplemental oxygen on demand by the user of the oxygen regulator. The design of the regulator provides for a range of oxygen flows dependent upon the altitude. The design provides for 100% oxygen flow at some specified altitude. The regulators are designed for operation at specified altitudes as given in table XXVII.

Pressure breathing systems, demand flow systems and pressurized systems utilize pressurized oxygen either from high or low pressure gaseous oxygen supply or from low pressure liquid oxygen supply.

TABLE XXVII. Operational characteristics of regulators.

Portable high pressure oxygen unit		Altitude for 100%
A-14	Pressure Breathing, Diluter Demand	34,000 and above
A-21	Used on MA-1	
MA-1	Portable Breathing Oxygen	43,000 ft to 45,000 feet
CRU-66	Man-Mounted Oxygen Regulator	
CRU-68	Panel-Mounted Oxygen Regulator, Diluter Demand Positive Pressure	43,000 to 50,000 ft
CRU-69	Panel-Mounted Oxygen Regulator, Diluter Demand Positive Pressure	43,000 to 50,000 ft
CRU-73	Panel-Mounted Oxygen Regulator, Diluter Demand Positive Pressure	43,000 to 50,000 ft
NOTE: At altitudes above 41,000 ft, pressurized oxygen is provided to a pressure suit with a helmet and mask for maintaining physiological oxygen pressure requirements. The oxygen partial pressures must be maintained at 70 to 103 mmHg. The pressure suit with the helmet provides the pressurized enclosure for protection against low atmospheric pressures and must be adequate for maintaining the oxygen at the required partial pressure.		

50.5 **Continuous-flow oxygen systems.** Continuous-flow systems are the simplest oxygen systems for providing the aviator with supplemental oxygen. Such systems consist of an oxygen source, tubing or piping, and a mask. The firefighter oxygen system provides the simplest continuous-flow oxygen system and does not directly involve the aircraft. The portable oxygen system is an independent oxygen system similar to the firefighter oxygen system but with provision for aircraft mounting and for repressurization from the aircraft oxygen system. The walk-around oxygen system is portable. Provision is made on the regulator on the tank for attaching the crewman oxygen mask hose, thus permitting the crewman to disconnect from the aircraft regulator oxygen stations and reconnect to the portable oxygen tank regulator.

An aircraft continuous-flow oxygen system consists essentially of the same components as the portable emergency oxygen system, but the components are permanently mounted at specific stations in the aircraft. The oxygen source, either high pressure oxygen tanks or LOX (liquid oxygen converters), is connected with valving and tubing to individual stations with regulators and masks available to crewmen or passengers. The oxygen flow is initiated when the masks are manually released from a storage site and mounted on the person, and the oxygen flow is initiated automatically when emergency conditions are encountered. At stations with regulators, the 100% oxygen valving provides for continuous flow.

A chemical oxygen generator, the chlorate candle CRU-74/P, provides continuous-flow oxygen for 20-30 minutes during loss of cabin pressure and is an emergency oxygen system on airlines and at individual seat assemblies on the C-5A. The chlorate candle oxygen generator is utilized by the indiviudal crewman for a one-time use with no reuse or recharge capability.

Many USAF transport and passenger aircraft incorporate continuous-flow equipment of one type primarily for use as a backup breathing system for aircraft occupants in the event of an emergency cabin decompression. Continuous-flow equipment is not used for pilots or mission-essential crewmembers and should not be because of the extended time period the oxygen equipment is used.

50.6 **Sizing the oxygen supply or oxygen duration calculations.** On most past aircraft designs, oxygen duration calculations were made according to MIL-D-8683 for gaseous oxygen systems and MIL-D-19326 for liquid oxygen systems. These specifications contain average light work duty oxygen requirements for crewmembers wearing masks using "normal" oxygen, 100% oxygen, 100% oxygen with safety pressure, or wearing a pressure suit and helmet. The oxygen requirement for passengers using continuous flow equipment is based on the minimal flow determined to be necessary for healthy, inactive adults. In addition, the specifications state the oxygen available from each supply size, and the design flow rate from each supply type. Also, a procedure for determining the number of cylinders or converters required for the aircraft is discussed.

It should be remembered that these flow rates apply to sizing the required supply based on the minimum physiological needs of the aircraft occupants. Allowance should be made for expected flight conditions that occur in the mission of the aircraft which result in increased oxygen consumption. Multiplying factors are given in these specifications.

Select components such as converters, heat exchangers, valves, plumbing and regulators for the system that allow flow rates that equal or exceed the maximum flow rates required for all crewmembers and passengers. The number of converters or the size of the converter could be determined by the maximum flow rate of the crewmembers and passengers rather than by the quantity of oxygen required. This would be especially true of a short duration oxygen requirement and a high flow requirement for crewmembers and passengers. However, the size of converter required is also determined by the quantity of oxygen required and the servicing plans. Usually, servicing more frequently than once in the evening is undesirable as support costs will increase considerably. Quick turnaround servicing or converter change at the aircraft is considered desirable only in a combat situation where risks are accepted.

APPENDIX C

EXISTING AIRCRAFT OXYGEN SYSTEMS

AND DESIGN CONCEPTS UNDER ADVANCED DEVELOPMENT

10. SCOPE

10.1 Scope and purpose. The intent of the information provided in this appendix is primarily to give background information on many existing military aircraft oxygen systems. Some information is also provided on designs under research and advanced development. The majority of past and existing military oxygen systems have been gaseous oxygen (GOX) supply and liquid oxygen (LOX) supply. Under research and advanced development are on-board oxygen generating systems (OBOGS). These systems provide an oxygen-enriched air supply directly from a pressurized air source such as engine bleed air. This would negate the need to frequently replenish a GOX or LOX supply vessel.

Much detail has been provided in this appendix on existing military oxygen equipment and components. Table XXXI is provided for quick reference on advantages and disadvantages of aircraft oxygen systems. Military specifications and standards are cited which contain invaluable information on the equipment under discussion. It is not necessarily intended that these documents be cited as requirements for the oxygen system design and development program on which appendix A is used. Not all this equipment is necessarily applicable to any one oxygen system. The designer may, however, desire to incorporate existing equipment in his oxygen system. For that purpose, this appendix will provide useful information on the equipment and the associated military specifications. Caution should be exercised in using this government furnished equipment (GFE) as it may not be as readily available as anticipated. Usually only enough of this GFE is procured to maintain existing aircraft due to failure and destruction of this equipment in normal service. Lead time of at least one to two years should be allotted to assure delivery of this equipment for new or modified oxygen system development programs. Additionally, some of this equipment has been phased out of production and is not available for use in development programs. This equipment is, however, maintained in the military by repair and overhaul in the aircraft in which it is currently installed.

Although subsystems and equipment vary in detail, all oxygen systems consist of the following equipment categories: (1) oxygen supply equipment and applicable mounting provisions, (2) plumbing, valves, and fittings, and (3) flight station equipment.

20. APPLICABLE DOCUMENTS

20.1 References. The documents referenced in this appendix are not intended to be applied contractually. Their primary purpose is to provide background information for the Government engineers responsible for developing the most appropriate performance values (filling in the blanks) for the requirements contained in the specification proper.

20.2 Avoidance of tiering. Should it be determined that the references contained in this appendix are necessary in writing an RFP or building a contract, excessive tiering shall be avoided by calling out only those portions of the reference which have direct applicability. It is a goal of the Department of Defense that the practice of referencing documents in their entirety be eliminated in order to reduce the tiering effect.

20.3 Government documents

20.3.1 Specifications and standards

SPECIFICATIONS

Federal

O-T-236	Tetrachloroethylene (Perchloroethylene), Technical Grade
O-T-634	Trichloroethylene, Technical
WW-T-700	Tube, Aluminum and Aluminum Alloy, Drawn, Seamless, General Specification for

Military

MIL-V-5027	Valves, Check, Oxygen, High Pressure
MIL-B-5087	Bonding, Electrical, and Lighting Protection, for Aerospace Systems
MIL-W-5088	Wiring, Aerospace Vehicle
MIL-E-5400	Electronic Equipment, Aerospace, General Specification for
MIL-C-5886	Cylinder, Oxygen, Low Pressure, Nonshatterable
MIL-R-6018	Regulator, Oxygen, Diluter Demand
MIL-G-6019	Gage, Pressure, Dial Indicating, Low-Pressure Oxygen
MIL-V-7529	Valve, Gas, Oxygen Line
MIL-R-7605	Regulator, Oxygen, Demand, Pressure Breathing, Type A-21
MIL-V-7908	Valve, Check, Aircraft Low Pressure Oxygen Systems
MIL-T-8506	Tubing, Steel, Corrosion-Resistant, (304), Annealed, Seamless and Welded
MIL-V-8612	Valve, High Pressure Oxygen Line
MIL-A-8625	Anodic Coatings, For Aluminum and Aluminum Alloys

MIL-D-8683	Design and Installation of Gaseous Oxygen Systems in Aircraft, General Specification for
MIL-V-9050	Valve, Oxygen Cylinder, High Pressure
MIL-V-18318	Valve, Pressure Regulating
MIL-D 19326	Design and Installation of Liquid Oxygen Systems in Aircraft, General Specification for
MIL-C-19328	Converter, Liquid Oxygen, 5 Liter, MBA-5A
MIL-C-19803	Converter, Liquid Oxygen, 10 Liter, GCU-24/A
MIL-C-21049	Coupling Assemblies, Quick Disconnect, Aircraft Liquid Oxygen Systems
MIL-H-22343	Hose Assemblies, Metal, Liquid Oxygen
DOD-L-24574	Lubricating Fluid for Low and High Pressure Oxidizing Gas Systems
MIL-V-25513	Valve, Check, for 300 PSI Liquid Oxygen Converter Systems, Type MH-1
MIL-I-25645	Indicator, Liquid Oxygen Quantity, Capacitance Type, General Specification for
MIL-C-25666	Converter, Liquid Oxygen, Capitance Type Gaging, General Specification for
MIL-V-25961	Valve, Fill-Buildup-Vent, Liquid Oxygen Converter, CRU-50/A
MIL-V-25962	Valve, Liquid Oxygen Drain
MIL-C-25969	Capsule, Emergency Escape Systems, General Specification for
MIL-T-26069	Trailer, Compressed Gas Cylinder AF-M32R&3, High Pressure 2 Wheel 6 Cylinder Capacity
MIL-I-26376	Indicator, Liquid Oxygen Quantity GMU-11/A
MIL-I-26380	Indicator, Liquid Oxygen Quantity GMU-5/A
MIL-I-26382	Indicator Set, Liquid Oxygen Quantity, A-A24J&4
MIL-H-26385	Hose, Oxygen and Pressurization, Ozone Resistant
MIL-D-26392	Dummy Converter, Liquid Oxygen Indicator System, 10 Liter CRU-23/A
MIL-D-26393	Dummy Converter, Liquid Oxygen Indicator System, 25 Liter CRU-24/A

MIL-H-26626	Hose Assembly, Nonmetallic Tetrafluoroethylene, Oxygen
MIL-O-27210	Oxygen, Aviator's Breathing, Liquid and Gas
MIL-I-27220	Indicator Set, Liquid Oxygen Quantity, A/A24J-8
MIL-M-27274	Mask, Oxygen MBU-5/P
MIL-A-27471	Adapter, Pressure-reducer, In-line CRU-43/A
MIL-T-27730	Tape, Antiseize, Tetrafluoroethylene, With Dispenser
MIL-C-38271	Connector, Oxygen Mask to Regulator, CRU-60/F
MIL-I-81387	Indicator, Liquid Oxygen Quantity
MIL-H-81581	Hose Assembly, Breathing Oxygen and Air, General Specification for
MIL-R-83178	Regulator, Oxygen, Diluter Demand, Automatic Pressure Breathing, General Specification for

STANDARDS

Military

MIL-STD-203	Aircrew Station Controls and Displays for Fixed Wing Aircraft
MIL-STD-411	Aircrew Station Signals
MIL-STD-889	Dissimilar Metals
MIL-STD-1247	Marking, Functions and Hazard Designations of Hose, Pipe, and Tube Lines for Aircraft, Missiles, and Space Systems.
MIL-STD-1472	Human Engineering Design Criteria for Military Systems, Equipment and Facilities
MS 21227-1	Cylinder, Oxygen, Low Pressure
MS 22001	Mask Assemblies Oxygen, Pressure Breathing
MS 22012	Valve--High Pressure Oxygen-cylinder, Automatic Opening
MS 22032	Recharger Assembly, Portable Oxygen
MS 22055	Hose Assemblies, Oxygen Breathing, Connector to Regulator
MS 22058	Connector, Oxygen Hose to Regulator
MS 24548	Hose Assembly & Tetrafluoroethylene, Oxygen

MS 26545	Cylinder, Compressed Gas, Nonshatterable
MS 33583	Tubing End, Double Flare, Standard Dimensions for
MS 33584	Tubing End, Standard Dimensions for Flared
MS 33611	Tube Bend Radii
MS 33656	Fitting End, Standard Dimensions for Flared Tube Connection and Gasket Seal
MS 90341	Mounting Bracket, Mating Portion for 5 and 10 Liter Liquid Oxygen Converters

20.1.2 <u>Other Government documents, drawings, and publications</u>

AIR FORCE - NAVY AERONAUTICAL STANDARDS

AN 780-3	Nipple, Union
AN 929-5	Cap Assembly, Tube, Pressure Seal
AN 6010-1	Regulator and Automatic Continuous Flow Oxygen
AN 6011	Gage and Panel Mounting High Pressure Oxygen
AN 6012	Valve, High Pressure Oxygen Line
AN 6014	Valve, High Pressure Oxygen Check, Style A
AN 6015	Valve, High Pressure Oxygen Check, Style B
AN 6021	Gage, Panel Mounting Low Pressure Oxygen
AN 6024-5	Valve, Filler Low Pressure Oxygen
TO 00-20-1	General Technical Order on Maintenance Management
TO 15X-1-1	Technical Manual, Maintenance Instructions, Oxygen Equipment
FAR Part 25	Federal Aviation Requirement Airworthiness Standards: Transport Category Airplanes

20.2 <u>Other publications</u>

SAE AS-1046	Society of Automotive Engineers Aerospace Standard on Minimum Standard for Portable Gaseous Oxygen Equipment
SAE AS-8026	Society of Automotive Engineers Aerospace Standard on Crew Member Demand Oxygen Masks

30. OXYGEN SUPPLY EQUIPMENT

30.1 Gaseous oxygen supply systems. Aviator's breathing gaseous oxygen is designated Grade A, Type I oxygen according to MIL-O-27210. The oxygen gas must meet a minimum purity requirement, excluding moisture content, of 99.5 percent by volume, and may not contain more than 0.005 mg of water vapor per litre at 760 mmHg and 68°F (20°C). The moisture content must be low to preclude freezing and sticking of valves and moving parts that meter oxygen delivery according to pressure altitude. It is also possible that orifices and openings may be blocked, resulting in a lack of oxygen delivery to aircraft occupants or the destruction of the pressure vessel(s) from overpressure when a pressure relief is precluded. Aviator's breathing oxygen is not the same as "technical" oxygen or "medical" oxygen that is used at ground facilities. It is more pure to be compatible with aircraft operation. Moisture in the oxygen gas would be desirable from the physiological standpoint to prevent drying of respiratory tract, but with the temperature drop encountered at higher altitudes, oxygen delivery components would freeze and restrict the oxygen flow through the aircraft oxygen system. MIL-D-8683 has been used to design low and high pressure gaseous oxygen systems for Army, Navy, and Air Force aircraft. This document provides details for equipment installation.

Gaseous oxygen systems use pressure vessels as sources of supply. Most of these pressure vessels are metal cylinders, but occasionally spherical vessels are used. Kevlar or fiberglass may be used to strengthen oxygen pressure vessels in newer designs to achieve vessel strength against higher pressures while minimizing weight. When Kevlar or fiberglass wrapping is used, it is desirable the design be such as to place a maximum limit on the stress in the filament winding so as to maximize stress-rupture life. For fiberglass, the fiber stress design limit should not exceed 35 percent as past experience has shown this to be a valid limit.

Cylinder size is based on the cylinder capability to support the specified crew. Space is provided in the aircraft based on the maximum cylinder specification envelope dimensions. If two or more cylinders are installed in the aircraft, they are separated as much as practicable to minimize combat vulnerability. Sufficient space is needed to replace cylinders and to perform maintenance on all parts. The replenishment of all cylinders of the oxygen supply is provided by connecting an external filling source directly to a single filling valve. The filling point is located so that the time for gaining access for connecting the external filling source does not exceed one man-minute and does not create a hazard for servicing personnel.

30.2 Low pressure gaseous oxygen supply systems. Aviator's breathing oxygen may be stored in yellow, lightweight, non-shatterable cylinders. These cylinders carry a maximum charge of 450 to 500 psi and are normally filled to a pressure of 400 to 450 psi from ground servicing containers. Portable walk-around containers filled onboard the aircraft will fill to the pressure in the supply lines which is normally 300 to 350 psi under demand. The low pressure supply system does reduce the possibility of explosions, over high pressure systems, but the volume of oxygen gas that may be stored is somewhat limited. Many large bulky containers are required to store any significant supply of oxygen. Immediate aircraft descent should be initiated when the system pressure drops to 100 psi, as an inadequate supply of oxygen will be available for all aircraft occupants to breathe for a 15-20 minute descent from higher altitudes to a safe breathing altitude of 10,000 feet. A system that drops below 50 psi needs to be filled within several hours to prevent condensation contamination. Should this occur, the supply containers would need to be purged to eliminate moisture that could cause malfunctions on later flights. Low pressure cylinders are currently used in many aircraft. Cylinders which will resist shattering by gunfire when punctured at a pressure of 2.8 MPa (400 psi) are called shatterproof or nonshatterable. This resistance to shattering is achieved either by the use of a heat-treated alloy or by metal bands welded to the outside surface. Cylinders that are made of the special alloy are marked "nonshatterable." Banded cylinders, although some are not marked, are also nonshatterable. Cylinders which have neither the welded bands nor the marking "nonshatterable" are not recommended for use in combat aircraft. Low pressure cylinders are distinguished by their yellow color. Identifying characteristics of the various types of supply containers and their available gas capacities are given in table XXVIII.

In low pressure systems, military GFE oxygen cylinders are designed according to MIL-C-5886. The size of the cylinder usually is selected for individually manifolded systems so that there is a minumum of two cylinders per individual manifold. In single place aircraft, two or more cylinders are used.

30.3 **High pressure gaseous oxygen supply systems.** Many commercial and military aircraft are equipped with high pressure cylinders to store oxygen for use when supplemental oxygen is needed. Most commercial aircraft use this type of supply to provide pilots with supplemental oxygen and to provide all aircraft occupants emergency oxygen in the event of a decompression. Many military aircraft, including tactical fighters, bombers, and trainers, are equipped with high pressure emergency systems in addition to primary aircraft oxygen supply. High pressure oxygen cylinders are typically filled to a pressure of 1800 to 2200 psi.

In high pressure systems, military GFE high pressure oxygen cylinders conform to MS26545 and include an MS22012 automatic opening valve. Where possible, the size of the cylinders is selected so that at least two cylinders are used. Pressure-reduction valves are located as close to the cylinder as possible within the design constraints imposed on the oxygen system.

Resistance to shattering may be achieved by the use of treated alloy or wire wrapping applied to the outside of the container. The most distinguishing characteristics of those types of cylinders are their bright green color and heavy weight. Similar cylinders painted other colors contain other gases and must not be used for oxygen. Identifying characteristics of the high pressure oxygen cylinders and their available gas capacities are given in table XXIX. Cylinder types are named according to the applicable standard. The letters "AX" signify "high pressure oxygen cylinder" and the number after the letters indicates internal volume in cubic inches. Thus, the MX26545AX205 cylinder listed in the table conforms to MS26545 and has an internal volume of 0.003 m^3 (205 in^3). The chief advantage of the high pressure cylinder is that a larger amount of oxygen is stored in a small space as compared to the lower pressure cylinder.

TABLE XXVIII. Characteristics of low pressure oxygen cylinders.

Cylinder		Internal volume		Length		Diameter		Available oxygen 2.8 to 0.3 MPa (400 to 50 psi)	
Type	Drawing	m^3	in^3	mm	in	mm	in	m^3	ft^3
A-6	MS21227-1	0.004	280	368.3	14-1/2	146	5-3/4	0.108	3.8
B-3	-2	0.004	280	381.0	15	146	5-3/4	0.108	3.8
D-2	-3	0.008	500	596.9	23-1/2	146	5-3/4	0.195	6.9
F-1	-4	0.016	1,000	1,457.2	18	257.2	10-1/8	0.391	13.8
F-2	-5	0.016	1,000	1,130.3	44-1/2	146	5-3/4	0.391	13.8
G-1	-6	0.034	2,100	621.3	24-1/2	317.5	12-1/2	0.821	29.0
J-1	-7	-.294	18,000	1,250.9	49-1/4	622.3	24-1/2	8.022	248.0

TABLE XXIX. Characteristics of high pressure oxygen cylinders.

Cylinder	Internal volume		Length		Diameter		Available oxygen 12.4 to 1.0 MPa (1800 to 100 psi)	
Type	m^3	in^3	mm	in	mm	in	m^3	ft^3
MS26545AX205	0.003	205	356.6	14	135.6	5-11/32	0.387	13.7
MS26545AX295	0.005	295	469.9	18-1/2	135.6	5-11/32		
MS26545AX386	0.006	386	390.3	15-3/8	175.8	6-59/64	0.725	25.6
MS26545AX514	0.008	514	488.9	19-1/4	175.8	6-59/64	0.968	34.2
MS26545AX646	0.010	646	596.9	23-1/2	176.2	6-15/16	1.214	42.9

These subsystems are designed similar to low pressure gaseous supply subsystems except that a pressure valve should be installed in the distribution line near the supply pressure vessel(s). This valve would be located as near as possible to the pressure vessel(s) to minimize leaks and associated high pressure tubing hazards. Manifolding for two or more vessels has been accomplished through high pressure lines for past USAF oxygen systems, but this practice on future designs is discouraged. A better design approach is to install pressure-reducing valves at the cylinder opening (reducing 1800 psi to 300-450 psi) with manual off and on control, a servicing port, and pressure relief all on one regulator assembly. Manifolding and oxygen distribution would be accomplished downstream of these regulators. Oxygen system designs on commercial aircraft use this design approach with much success.

30.4 **Liquid oxygen supply systems.** The liquid oxygen supply system incorporates a container commonly called a converter that typically operates and is serviced according to figure 15. The system converts liquid oxygen to gaseous oxygen by the use of a heat exchanger and needs no external source of power except the ambient to warm the liquid and gaseous oxygen. Presently the liquid oxygen system is the predominant system in use by the USAF and Navy. A liquid oxygen supply system may be a single converter with only one distribution line or two or more converters with one or more distribution lines depending on the demand or flow rate required from the system. Liquid oxygen vaporizes more rapidly from the smaller converters because a more rapid heat transfer accompanies the high area-to-volume ratio. For this reason, converters with capacities of five litres or more are used. For the same reason, it is desirable to install a minimum number of converters on the aircraft. In other words, larger converters should be used rather than many smaller converters when extended supplies of oxygen are required. These systems are designed to a working pressure of 70 to 120 psi or 300 to 450 psi to meet all design needs.

Greater demand is required on larger aircraft that must supply oxygen to many crewmembers and passengers. These types of aircraft use 300 psi systems to maintain delivery pressures above 50 psi under maximum demand. Most existing breathing regulators will not properly function with input pressures of less than 50 psi. Also, when these aircraft incorporate portable refillable cylinders, a working pressure of at least 300 psi is necessary to recharge the supply of oxygen. On smaller aircraft, such as fighters, that have only one or two crewmembers, a converter working pressure of 70 psi is adequate. See table XXX for a listing of many existing converters.

Storage space and weight has become increasingly critical in modern military aircraft. Oxygen stored in the form of liquid oxygen in converters minimizes the need for storage and space. The liquid oxygen converter is a storage container with the necessary valves and tubing for vaporizing the liquid and warming the gas for use by crewmembers. Such a container is doublewalled with an insulation barrier between the walls. In spite of the insulation barrier around the converter, some heat is transferred to the liquid oxygen because of the large temperature difference. The aluminum tubing around the converter receives the liquid oxygen, vaporizes it, and delivers the gas at nearly ambient air temperature to the oxygen distribution lines.

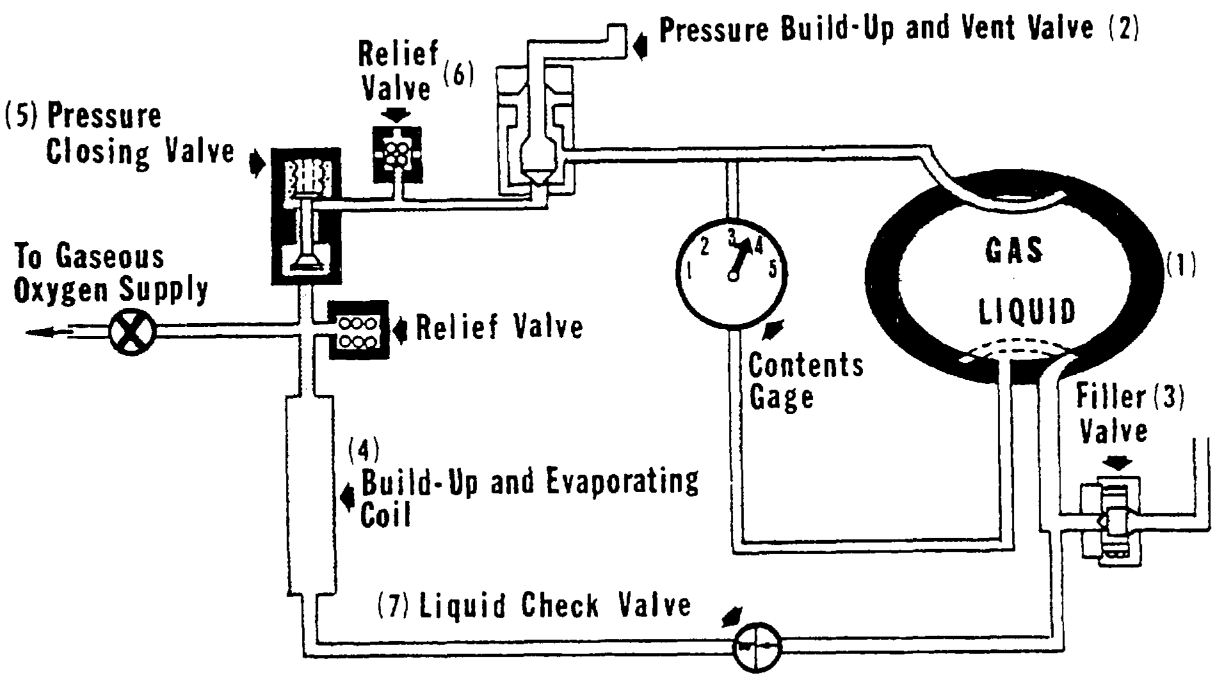


FIGURE 15. Liquid oxygen converter flow diagram.

TABLE XXX. Characteristics of liquid oxygen converters.

Type	LOX capacity (litres)	Working pressure (psi)	Design flow (LPM)	Duration of flow (mins)
A-2	8	300	80	75
A-3	5	70	72	45
MA-1	20	300	120	75
ME-3	25	300	150	120
GCU-2/A	10	70	72	90
GCU-3/A	10	70	72	90
GCU-10/A	10	300	80	60
GCU-11/A	10	300	100	60
GCU-12/A	5	70	72	45
GCU-13/A	5	70	72	45
GCU-14/A	5	70	72	45
GCU-17/A	25	300	150	120
GCU-18/A	10	70	72	90
GCU-20/A	75	300	400	135
GCU-21/A	25	300	150	60
GCU-24/A	10	70		

In filling the system, the pressure build-up and vent valve (a two-position valve) is placed in the VENT position. This prevents the flow of liquid through the lower circuit, and allows free passage from the container to the atmosphere. The filler valve is connected to the liquid oxygen storage tank by means of an insulated, flexible hose. Pressure in the servicing tank forces liquid oxygen into the system.

Initially, greater quantities than normal of liquid oxygen are vaporized in cooling the inner shell. The gas is vented to the atmosphere. When the inner shell becomes cool, it fills with liquid; when full, the liquid oxygen slowly sprays from the vent. The vent is located away from the servicing hatch to prevent servicing personnel from being sprayed with liquid oxygen, but personnel are still in a position where they can observe the spray.

30.5 Mounting provisions for oxygen storage containers. Oxygen is stored in containers attached to various portions of the airframe. These containers are designed to be checked periodically for load and recharged with aviator's oxygen from a field supply container. Three types of oxygen containers have been used in aircraft: (1) the low pressure cylinder, (2) the high pressure cylinder, and (3) the liquid-oxygen converter. Cylinders are designed to be easily replaced by loosening the brackets and removing the fittings with which they are attached to the lines. Gaseous oxygen containers are designed to be attached to the airframes by metal brackets and straps, with fireproof felt linings to prevent metal-to-metal contact and to ensure maximum support area. Brackets and straps are used that have sufficient strength to prevent rocketing of the cylinders should the cylinder be punctured by enemy gunfire.

Converters are configured to be line replaceable units that bolt to the airframe, or, in the case of smaller capacity units, have a base to fit the MS90341 quick-change mounting bracket. Provide converters of this type conforming to MIL-C-19328 or MIL-C-19803. The removable converters should be capable of being removed and replaced from the aircraft in 5 minutes. The converter base should be within 5 degrees of horizontal when the aircraft is in normal cruise altitude. The converter may require an evaporator heat exchanger to adquately warm the oxygen for high mass flow periods. Converters are designed for easy installation to facilitate replacement. The general requirements for converters using capacitance gauging are in MIL-C-25666. Quantity indicators for converters and dummy converters are also provided. See MIL-V-9050 for converter pressure relief valves and MIL-V-25962 for converter liquid-oxygen drain valves. Converter check valves are also included in the system.

When passenger cylinders are removed, the line valve may be closed and a disconnect for the tubing from the fittings in the passenger cylinders is provided. The tubing with plugs conforming to AN806 and the cylinder fittings may be capped with caps conforming to AN929. A sufficient number of these plugs and caps is provided for the disconnected lines and cylinders in a suitable, clean, dry box or compartment that is readily visible. The box or compartment is clearly marked in accordance with MIL-D-8683.

40. OXYGEN SYSTEM DISTRIBUTION PLUMBING

Plumbing in an oxygen system includes tubing, fittings, nipples, and valves. The high pressure (12.4 MPa (2150 psi)) plumbing is corrosion-resistant steel and plumbing for low pressure and liquid oxygen subsystems is either aluminum alloy or corrosion resistant steel. A design goal of at least a 50.8-mm (2-in.) clearance between oxygen subsystem components and control cables or other moving parts of aircraft has existed for many years. Tubing has been mounted in a manner to prevent vibration and chafing by the use of additional clips or flexible grommets, as necessary. To the maximum extent possible, electrical wiring should be routed outside of any compartment containing oxygen supply or plumbing. When this is not possible, a 152.4-mm (6-in.) clearance should be maintained between oxygen tubing and electrical wires. If this cannot be done, all electrical wires are to be tied down so that they come no closer than 50.8 mm (2 in.) to the oxygen tubing. In the event it is impossible to maintain a 50.8-mm (2-in.) clearance, the electrical wires are covered with an electrical insulating material and secured so that the wires cannot be closer than 12.7 mm (1/2 in.) under any condition. This does not apply to mask or regulator tubing.

40.1 Check valves for gaseous systems. Various types of single, dual, and triple check valves are in use. On each valve, the direction of oxygen flow is indicated by an arrow molded or stamped on the casing. High pressure check valves for oxygen systems are specified by MIL-V-5027; low pressure by MIL-V-7908. AN6014 and AN6015 are military GFE check valves for high pressure systems and MS21211 are military GFE check valves for low pressure oxygen systems. The valves are installed to be effective in preventing additional loss of oxygen in the event any one oxygen cylinder or line is destroyed by gunfire. The check valves are installed in accordance with the applicable system schematic diagram. The following information applies to most military aircraft:

a. When more than one cylinder is installed in the aircraft, each cylinder, or the tubing to and from each cylinder, is equipped with check valves.

b. A check valve is installed where a line from a cylinder or group of cylinders is connected to a main distribution line.

c. A line for each group of three cylinders is provided.

40.2 Tubing for gaseous oxygen system. The seamless, corrosion-resistant (304), annealed stainless steel tubing is provided for high pressure systems conforming to MIL-T-8506. The outside diameter of the tubing is at least 4.8 mm (3/16 in.) and the wall thickness is a minimum of 0.9 mm (0.035 in.). The tubing for low pressure systems conforms to WWT-700 with a nominal outside diameter of 7.9 mm (5/16 in.) and a wall thickness of 0.9 mm (0.035 in.). An anodic film conforming to MIL-A-8625 is used when a protective coating is required. The tubing diameters conform as much as possible to existing tubing already in Government inventory. Larger diameters may be required to accommodate large gas flows that would result in choked flow if the small diameters were incorporated.

In routing the tubing, the total length is kept to a minimum. Provisions are incorporated for expansion, contraction, vibration, and component replacement. For two or more cylinders using check valves, a minimum length of tubing is installed between the regulator and the nearest check valve in the distribution line. To further reduce vulnerability to gunfire, as much separation as possible is provided in the tubing lengths between this check valve and the cylinders. The separation between the tubing length is not less than 304.8 mm (12 in.). All tubing is mounted to reduce vibration and chafing effects by installing rubberized or cushion clips at no greater than 508-mm (20-in.) intervals for 7.9-mm (5/16-in.) tubing, 381 mm (15 in.) intervals for 4.8-mm (3/16-in.) tubing, and as close to the bends as possible. Clips are provided near portable recharger connections. Tubing that passes through or is supported by the aircraft structure should have adequate protection against chafing by the use of flexible grommets or clips. The tubing is installed so that it does not strike against the aircraft during vibration and shock encountered during normal use of the aircraft.

The tube flaring for 7.9 mm (5/16 in.) and 9.4 mm (3/8 in.) outside diameter aluminum alloy tubing is double flared to conform to MS33583, and the flaring for 12.7 mm (1/2 in.) outside diameter aluminum alloy and seamless stainless steel tubing is single flared conforming to MS33584. Tubing bends are uniform, without kinks, and placed to fit the space between fittings without tension. The minimum bend radius to tube center lines conforms to MS33611.

All tubing should be marked in accordance with MIL-STD-1247. The bonding should conform to MIL-B-5087.

40.3 Line valves. Line valves are not desirable for use in combat aircraft except for a few of the following cases. One authorized installation of line valves is in the filler manifold of transport-type aircraft where the line valves separate the oxygen subsystem into sections for the crew and passengers. The valve is closed if the crew station is to be filled and opened when both the crew and passenger sections are to be filled. MIL-V-7529 is representative of line valve requirements for low pressure use and MIL-V-8612 for high pressure use. Line valves are desirable in crossover plumbing between LOX converter installations.

40.4 Low pressure vessel filler valves. Low pressure gaseous oxygen subsystems are provided with an AN6024-5 ground filler valve. High pressure gaseous oxygen subsystems are provided with a ground filler valve. Multiple gaseous oxygen cylinders are filled from a single filler valve. On most aircraft, the filler valve is located close to the edge of the access hatch or directly behind a special removable cover plate in the skin. In either case, the valve is placed so that it may be reached by a man standing on the ground. The location of the valve is marked by a sign stenciled on the exterior access door. The human engineering design practices of MIL-STD-1472 provide access information.

40.5 LOX fill-buildup-vent valves. Permanently installed liquid oxygen converters are designed to be filled from a separate combination fill-buildup-vent valve. Combination fill-buildup-vent valves (MIL-V-25961) are used in liquid oxygen systems with gage pressures of 0.5 MPa (70 psi) and 2.1 MPa (300 psi).

The fill-buildup-vent valves are located in an access compartment usually five feet or less above the ground to be readily accessible with ground servicing equipment. Clearance is provided around the fill-mating section of the combination fill-buildup-vent valve to allow the insertion of the two-inch diameter female section of the ground servicing valve.

The distance from the fill section of the combination fill-buildup-vent valve to the LOX converter is kept as short as possible. The fill line is usually no longer than 10 feet. It has been good practice to insulate fill lines to prevent frosting and sweating if they pass over equipment which would be harmed by the water dripping from the lines. Another practice is the addition of drip pans under these lines that drain liquid overboard.

The vent line is located from the combination fill-buildup-vent valve to drain LOX and cold oxygen gas overboard at the bottom of the aircraft. This has been located within sight of the fill valve compartment, but not closer than 24 inches from it measured along the fuselage. The LOX flow from the overboard vent may be directed away from the filling valve so the LOX flow does not create a hazard for servicing personnel. LOX is not allowed to impinge on the aircraft. To preclude a fire or explosion, hydrocarbon materials are not used near these valves.

To drain a converter in a permanently installed configuration, a LOX drain valve conforming to MIL-V-25962 is used in the fill line between the combination valve and the converter. The plumbing is terminated from the outlet of the liquid oxygen drain valve in an end fitting conforming to MS 33656. The fitting is located in the fill valve compartment. The fitting has a cap that conforms to AN929-5 with a suitable chain permanently attached to the cap.

40.6 **Pressure-reducing valves.** In high pressure subsystems, a pressure-reducing valve is installed between the supply cylinders and the flight station equipment. This valve reduces the pressure from the high pressure cylinders to 2.8 MPa (400 psi) so that normal low pressure oxygen equipment may be used at the flight station. MIL-V-18318 covers an oxygen pressure regulating valve for use in the aircraft oxygen system for reducing the high pressure from the oxygen cylinders to the lower working pressure of the oxygen dispensing equipment.

40.7 **LOX pressure relief valve.** The pressure-relief valve on the liquid oxygen converter is vented overboard, using a 7.9-mm (5/16-in.) minimum outside diameter tubing. The relief valve overboard vent may be the same as that used for the combination fill-buildup-vent valve. It should be remembered that under conditions of high demand and subsequent supply shut-off, LOX will vent overboard through this valve. This is considered in the location of the valve such that aircraft components will not be damaged. Also, valves used will withstand cryogenic temperatures.

40.8 **Check valves for LOX systems.** Check valves are installed conforming to the system schematic design. Installation of liquid oxygen check valves is effective in preventing additional loss of oxygen in the event any one converter or line is destroyed by gunfire. Many check valves that are used in primary distribution lines conform to MIL-V-7908. When more than one converter is installed in a multiplace aircraft, a spring-loaded check valve conforming to MIL-V-25513 is used in each of the auxiliary distribution lines to each station. Check valves that will be installed in locations that LOX may enter must withstand cryogenic temperatures without loss of performance. These check valves are placed in the plumbing such that LOX may be trapped and overpressurization results. If more than one supply source is used, check valves are used to preclude loss of supply from one container when another is bursted by gunfire or an aircraft explosion.

40.9 **Converter disconnects.** The disconnects for removable LOX converters conform to MIL-C-21049. The plumbing openings are either self-sealing outlets or have contaminant protection covers.

40.10 **Hose for LOX systems.** On removable converters, metal hose assemblies are used conforming to MIL-H-22343. The flexible supply lines are 7.9 mm (5/16 in.) equivalent inside diameter and the flexible vent lines are 12.7 mm (1/2 in.) equivalent inside diameter. The bend radius is not less than that specified in the flexibility test of MIL-H-22343. Where there is relative motion between two connections, a metal hose is installed so that torsion (twisting) will not occur under any condition of operation. There should be no tendency for connection fittings to loosen. Clamp-type flexible tubing installations are not used. The supply and vent lines should contain metal hoses of sufficient length to provide for satisfactory connection or disconnection of the disconnect couplings at the converter. All metal hoses are protected against chafing, where necessary. Tetrafluoroethylene hose is used on permanently installed converters. Flexible hose usually conforms to MIL-H-26626 and the applicable part number of MS24548.

40.11 Tubing for LOX systems. Tubing of aluminum alloy conforming to WW-T-700/4 or of corrosion-resistant annealed steel conforming to MIL-T-8506 is used. If the converter does not include warming coils or a heat exchanger, table VI in MIL-D-19326 is used for the minimum length of tubing required between the converter and first crew station for the required flow rate. Table VII in MIL-D-19326 provides the appropriate length of supply tubing along which frost and condensation can be expected for the indicated flow rate. If other equipment might be affected by the condensation, the supply tubing is provided with drip shields or other suitable means of protection. Tubing for all lines other than fill lines and vent lines which connect to the fill-buildup-vent valves have a minimum nominal outside diameter of 7.9 mm (5/16 in.) and a wall thickness of 0.9 mm (0.035 in.). Tubing for the fill line has a minimum nominal outside diameter of 9.5 mm (3/8 in.) and a wall thickness of 0.9 mm (0.035 in.). Tubing is designed for the vent line connecting to the fill-buildup-vent valve to have a minimum nominal outside diameter of 12.7 mm (1/2 in.) and a wall thickness of 0.9 mm (0.035 in.).

40.12 High pressure vessel filler valve. The filler valve is used when recharging the system. The ground servicing trailer is connected to the valve. The following applies:

a. The filler valve is designed for high pressure systems using an AN6012 line valve and a fitting, such as AN780-3, with a Dwg 55B3878 dust cap and retaining chain. All cylinders are filled from a single filler valve.

b. The filler valve is located inside the fuselage within a closed box behind a cover plate with a direct and oil-tight seal, approximately midway between the nose and the tail on the left side of the aircraft and at a convenient height from the ground. The filler valve is not located where there is any possibility of oil coming in contact with the inlet. The filler valve is designed to be easily accessible from the outside of the aircraft; to make connections for recharging with an oxygen servicing trailer conforming to MIL-T-26069; and to be manipulated with a heavily gloved hand without entering the aircraft. The cover plate is provided with a spring-loaded latch. The plate is always hinged from the leading edge so that in the event it is left open after ground maintenance or inadvertently opens while in flight, the windblast will not tear it away from the aircraft but close it.

40.13 Fittings in oxygen plumbing. All fittings should conform to applicable standards. Unless the fittings are suitably protected against electrolytic corrosion, dissimilar metals are not used in intimate contact with each other. Dissimilar metals are defined in MIL-STD-889. Antiseize tape conforming to MIL-T-27730 is used on all male pipe thread fittings. Antiseize tape is not used on the straight threads of flare tube fittings, on coupling sleeves, or on the outer side of tube flares. The tape is not allowed to enter the inside of a fitting. Compounds are not used on tapered pipe threads that are not approved for use with 95-100% oxygen. Presently, greases qualified to MIL-G-27617 only are applied sparingly on oxygen fittings and only if necessary.

40.14 Torquing of joints. Tube and pipe connections are tightened in accordance with the best commercial practice. The torque applied is within the limits specified in MIL-D-8683 and MIL-D-19326. Torque applied in excess of these limits may wrinkle and fatigue plumbing ends and associated fittings. Usually, if the maximum torque application does not properly close the fitting, it is because of improper flaring of the tubing end, poor quality control on fitting threads or inside diameter, metal burrs on the tubing or joint, or a combination of these factors. In many cases, a grease in accordance with MIL-G-27617 is applied only if absolutely necessary. This allows closure of the joint with less torque and facilitates sealing in the joint. Research has shown that ignition can occur when a lubricant (even MIL-G-27617 oxygen-compatible lubricant) is used in places of high shearing forces with metal-to-metal contact. Specification torque limits are not applicable after lubrication of the joint(s).

40.15 Lubricants in oxygen systems. To ensure that fire, explosion, and toxic hazards are minimized, only certain types of lubricants are approved for use in USAF oxygen systems. Oils and greases should be used only when absolutely necessary and then very sparingly. Only oils in accordance with DOD-L-24574 and greases in accordance with MIL-G-27617 are approved for use on military aircraft oxygen systems.

40.16 Markings on oxygen components and aircraft. Permanent and legible markings are applied in the locations specified in MIL-D-8683 and MIL-D-19326.

40.17 System cleanliness. Maintenance procedures are implemented to ensure that the completed installation is free of oil, grease, fuels, water, dust, dirt, objectionable odors, or any other foreign matters (both internally and externally) prior to introducing oxygen in the system. Cleaniness and purging procedures are given by TO 15 X-1-1. Additionally, many other cleaniness criteria are given by individual equipment TOs.

40.18 Plumbing and component closures. Suitable closures are provided for exposed connections on lines required to be disconnected during aircraft maintenance checks or overhaul. Caps which introduce moisture or tapes that leave adhesive deposits are not used. The closures are designed to remain with the aircraft at all times and are to be stored (when not in use) near the connections in such a manner as not to become contaminated. All openings of lines, fittings, valves, and regulators are designed to be kept securely capped until closed within the installation.

40.19 Degreasing oxygen system components. Parts of the oxygen system not covered by cleaning procedures are degreased using a vapor phase degreaser conforming to O-T-236 or O-T-634. The compatiblility of the material to be degreased must be considered; many solvents destroy non-metals. Further degreasing requirements are contained in MIL-D-8683 or MIL-D-19326.

40.20 Purging. Prior to system closure, after the initial assembly of the oxygen system, and whenever the oxygen system has been left open to atmospheric conditions for a period of time or is opened for repairs, the system is purged with hot, dry oxygen, conforming to MIL-O-27210, Type I. Temperature at the inlet to the system should not exceed 121.1°C (250°F) during purging. Past purging procedures that have been developed that are available in maintenance TOs, and may be used to develop purging procedures for new oxygen systems.

40.21 Oxygen system maintenance and replacement. The components of most military oxygen systems are installed to permit ready removal and replacement without the use of special tools. All tubing connections, fittings, regulators, converters, brackets for indicating instruments, and other items usually are readily accessible for leak testing with leak test compounds and for tightening of fittings without removal of surrounding parts. Flexible hoses may be used to connect indicating instruments mounted on shock-mounted panels to permit easy maintenance. An adequate length of line is available to connect tubing and flexible hoses.

50. FLIGHT STATION EQUIPMENT

50.1 Oxygen regulator installation. Automatic diluter demand, pressure breathing regulators as specified by MIL-R-83178 are installed at all permanent and temporary crew stations in the aircraft. Newer OBOGS use different breathing regulators, but their performance should equal or exceed that as specified in MIL-R-83178. Some special considerations require chest- or seat-mounted breathing regulators, but these are less desirable than panel mounting the regulator. The performance of these regulators should also equal or exceed that in MIL-R-83278. In continuous-flow systems the regulator is used with many passengers and its mounting location is not critical.

The crew panel-mounted regulators are located in accordance with MIL-STD-203. The crewmember's regulator is located in his field of vision so that he can readily read the regulator without moving or turning his head and with minimum interference with his flight duties. The regulator is located at the crew station so it can be reached by normal extension of the crewmember's arm. The regulators are designed and located so that the toggles cannot be accidentally actuated by movement of personnel around them. The regulators are mounted vertically on the forward panel or horizontally on the console. Installation of the panel-mounted breathing regulator with flexible hose for both inlet and outlet ports is good design practice, so the regulator may be front serviced for both installation or removal. Installation of the non-panel mounted regulators should be specified and reviewed by the procuring activity. Unless otherwise specified, a manual shutoff valve should be incorporated on unmanned regulators. When regulators incorporating shutoff valves are not used, a manual shutoff valve should be installed to prevent loss of oxygen when the system is not in use.

In single-pilot and tandem-pilot aircraft, the oxygen regulator, pressure gauge, and flow indicator should be located forward on the right console readily visible and accessible to the pilot. In side-by-side pilot aircraft, the regulators, pressure gauge, and flow indicator should be located on the left and right consoles so that the equipment may be easily read and monitored by the pilot and copilot. The location of the oxygen regulator is checked to ensure that no odor sources or exhausts from other equipment (such as pressure vents) are present to mix with the air entering the oxygen regulator. There have been instances of oil vapors entering a crewmember's oxygen subsystem. The regulator is located so that the possibility of accidental actuation of control toggles is precluded. Oxygen regulators should require no maintenance or lubrication while installed on the aircraft. However, most regulators are located and installed to permit easy removal and installation as the present USAF policy requires checking and/or replacement of the regulators at scheduled intervals in fighter and trainer aircraft. Organizational level checks may be performed with portable test sets on the CRU-73/A regulator whenever a regulator problem is encountered by the crewmember and at the regular time interval as scheduled by the operational unit. Service inspection of aircraft oxygen systems are performed in accordance with TO 00-20-1 and the applicable -6 aircraft technical manual.

50.2 Oxygen breathing regulator types. There are three oxygen delivery systems used in the USAF. Continuous flow; diluter demand; and diluter demand pressure breathing. Continuous-flow equipment has disappeared from the flight deck of military aircraft and other crewmember stations because of the limitations of the equipment. Breathing from a continuous-flow regulator can be quite fatiguing after several hours and hypoxia symptoms occur in some people after three hours. For these reasons, regulators that provide oxygen only on demand were developed. Continuous-flow delivery of oxygen is still used by passengers and noncritical crewmembers who do not have control of the aircraft or its mission.

50.2.1 Continuous-flow regulators. This system will supply an adequate amount of oxygen to the passenger who does not require as much oxygen as flight-essential crewmembers. The operational altitude of this system is sea level to 25,000 feet. Above this altitude, the regulators serves an emergency function to get the passenger down to the normal operating range of this equipment. The purpose of these regulators is to deliver a continuous flow of 100-percent oxygen to the mask. Air dilution is usually accomplished with a two-way air-flow mask-mounted valve. Reducing oxygen flow rates at lower altitudes forces the person to draw in cabin air which dilutes his oxygen intake.

The continuous-flow regulator delivers oxygen to the crewmember's or passenger's mask at a continuous rate of flow. Flow may be controlled either manually or automatically. This is accomplished by a pressure-reducing mechanism and a needle valve. Many aircraft have continuous-flow regulators which reduce oxygen flow rate with lower cabin altitudes.

The following paragraphs cover military types of continuous-flow regulators:

a. Types A-8, A-8A, A-9 and A-9A. These regulators include a pressure gauge, a flow indicator, and a manual control knob for adjusting oxygen flow so that it corresponds to altitude. This regulator is still used in some training, transport, and patrol aircraft, but is not used on combat aircraft because it does not satisfactorily meet the varying oxygen requirements imposed by differing degrees of activity, especially at altitudes above 30,000 ft. A-9 and A-9A regulators are limited to a back pressure of 500 psi.

b. Type A-11. This automatic regulator supplies a continuous flow of 100-percent oxygen. An aneroid increases the oxygen flow rate during ascent to altitude from 10,000 to 30,000 feet and above. The regulator is a multi-outlet regulator that accommodates up to 15 persons on one regulator. These regulators should be installed in banks of two plumbed in parallel as a safety precaution in the event one fails. This is necessary because there is no visual indication to aircraft occupants when this might happen. This regulator will not deliver oxygen unless the mask bayonet connector is plugged into one of the line outlets. This regulator operates with inlet pressure of 50 to 500 psi. No manual control is necessary nor is any provided with this regulator. Various models of the Type A-11 regulator are summarized in table XXXI.

TABLE XXXI. Type A-11 regulators.

Type	Inlet pressure range--PSI	Altitude operating range--ft	Maximum flow at 70°F, 760 mm LPM
USAF A-11	50-500	8,000-30,000	36
Army-Navy AN-6010-1	50-500	8,000-30,000	36
ALAR A-100 Series			
0-999	50-500	8,000-30,000	48
1000-on	50-500	sea level-30,000 ft	48
ALAR A-2000	35-2200	sea level-30,000	48

c. Type ARO part number 17970-4. This continuous-flow regulator consists of one first- and two second-stage reducing stations, mounted on a common manifold. The second stages operate in parallel. The first stage is back loaded from the final outlet pressure to maintain a constant pressure drop across the second stages. This regulator operates on an inlet pressure range of 75-400 psi, from sea level to 41,000 feet, provides an outlet flow from 0-527 LPM as a function of altitude and provides an outlet pressure up to 55 psig dependent on flow rate.

d. Type part number 26651-3. This continuous-flow oxygen regulator operates from an inlet pressure range of 200 to 315 psi and delivers flow rates up to 10 to 900 LPM. This regulator is designed to be used in aircraft pressurized cabins and provides emergency oxygen as a function of cabin altitude.

e. Type CRU-5/P. An automatic continuous-flow regulator has one major disadvantage. During an emergency, there is no way to provide an additional flow of oxygen. The manual override feature has eliminated this problem, however. The CRU-5/P regulator includes a pressure gage and the manual override control valve. The user must plug an oxygen mask connector into the regulator and the aneroid feature will deliver the correct flow of 100-percent oxygen. If an emergency arises, a manual override setting of 1, 2, or 3 may be selected as applicable to the situation to increase the flow rate of oxygen. This regulator is installed on the A/U 26S-2 portable oxygen assembly.

f. Type AN6010. The AN6010-1 regulator is used in transport aircraft to supply oxygen to inactive personnel on the aircraft. It provides a continuous flow of oxygen automatically regulated by an aneroid. There are no manual controls, no flow indicator, and no pressure gauge. However, a pressure gauge is installed at some point in the distribution line. This regulator is used in conjunction with a number of automatic couplings which dispense the oxygen to the passengers or troops. The regulator delivers oxygen to the automatic couplings which (in turn) meter the oxygen to the masks. When the mask bayonet connector is plugged into the automatic coupling, a check valve is opened to allow oxygen flow to the mask. When the connector is removed, the check valve automatically closes to prevent loss of oxygen.

50.2.2 **Diluter demand regulators.** The diluter-demand regulator will deliver adequate oxygen on inhalation, and will protect an individual at altitudes up to 35,000 feet. During each inhalation, negative pressure closes a one-way exhaust valve in the mask and opens the demand valve in the regulator. This action is reversed during exhalation.

To prolong the oxygen supply, suitable amounts of ambient air are automatically mixed with oxygen in the regulator. There is dilution at altitudes up to 34,000 feet, and above this altitude, the regulator delivers 100-percent oxygen. The normal maximum operational altitude of this system is 35,000 feet and in an emergency, it may be used to 40,000 feet.

The essential feature of a diluter-demand regulator is a diaphragm-operated valve, called the demand valve, that opens by slight suction on the diaphragm when the user inhales, and closes on exhalation. A reducing valve upstream from the demand valve provides a controlled working pressure, while downstream from this valve is the diluter mechanism. This consists of an aneroid assembly that controls the air inlet.

When the diluter lever is placed in the position marked NORMAL OXYGEN, at ground level, the breathing medium is predominantly atmospheric air with very little added oxygen. During ascent, the air inlet is partially closed by the aneroid to provide a higher concentration of oxygen. The air inlet is closed at 34,000 feet and the regulator delivers 100-percent oxygen. This process is reversed on descent.

The regulator incorporates an automix lever which is used to select the normal oxygen mode (air dilution) and the 100-percent oxygen mode depending on the needs of the crewmember. An emergency valve or control may also be included to select a continuous-flow mode of operation delivering 100-percent oxygen to the mask. In this mode, oxygen supply is depleted rapidly; therefore, this mode is used only under emergency situations and for short time periods. Also included with the regulator should be an oxygen pressure gage to indicate inlet line pressure, and an oxygen flow indicator to tell the crewmember when the oxygen is flowing to his mask. This flow indication is useful as the crewmember has an indirect indication of hose or mask leaks if it fails to function.

The following paragraphs cover the types of diluter-demand regulators used on military aircraft:

a. Type A-12, A-12A, AN6004-1, and A-14. This regulator design is covered by MIL-R-6018 and has an operational altitude up to 35,000 feet and an emergency altitude up to 40,000 feet. This regulator is used with the A/U22S-4 portable unit when an extended time is desired and higher altitudes than that provided by continuous-flow regulators. The regulator has a control for normal oxygen (air dilution) or 100-percent oxygen. An emergency valve is also provided.

b. Type numbers 2872-A1, 2872-A1B, 2872-B1 and 2872-B2. This diluter-demand oxygen regulator automatically mixes air and oxygen at a ratio dependent upon altitude, and delivers this mixture at the proper pressure to the mask upon demand. A pressure-breathing mask, such as type A-13, must be used with this regulator. With a tight mask fit, this regulator has a maximum operating altitude up to 32,000 feet. This unit operates on an inlet pressure range of 50-2000 psi. Types 2857-A1, 2857-A1A, 2858-A1B, 2858-A1A, 2858-B1B and 2858-C1B are very similar.

c. Type part numbers 29276-A3 and 29276-C1. This diluter-demand oxygen breathing regulator is used to control the flow and pressure of gaseous oxygen to one occupant of the aircraft. A mixture of oxygen and cabin air is automatically controlled in proportions varying with altitude. A manual control knob allows the user to select 100-percent oxygen when desired. The unit operates from an inlet pressure range of 40 to 120 psi and at altitudes up to 50,000 feet.

50.2.3 <u>Pressure demand regulators</u>. With the diluter-demand equipment, a crewmember can ascend to about 35,000 feet with an oxygen intake adequate for any reasonable activity. Between 35,000 and 40,000 feet (because of the declining pressure of the oxygen in the lungs), there will be some reduction in the oxygen load of the blood. If relatively quiet and if the mask does not leak, there is no danger of serious hypoxia. Above 40,000 feet, as the oxygen load of the blood continues to fall with decreasing atmospheric pressure, hypoxia becomes more severe. With a leak-tight system, 40,000 feet is considered the absolute ceiling for the diluter-demand regulator. There are two ways of obtaining oxygen above 40,000 feet: (1) by means of a pressurized cabin which maintains a relatively high pressure both outside and inside the crewmember's body and (2) by means of the positive-pressure diluter-demand oxygen regulator which supplies oxygen to the crewmember's lungs at a pressure slightly higher than the pressure outside his body. In human lungs only a minimal amount of internal pressure may be tolerated. For this reason, the effectiveness of the pressure-demand regulator is limited. From a safety-of-flight standpoint, the regulator may be routinely used up to about 42,000 feet and for very short periods in emergencies up to 50,000 feet. Exposure to 42,000 feet and above should not be allowed for extended periods unless it is essential to the flight mission. If possible, the altitude should be reduced to 25,000 feet. A pressure suit is required for extended flight at altitudes above 50,000 feet. The pressure-demand regulator corresponds to the diluter-demand regulator except for the positive-pressure feature. The pressure-demand regulator is provided with a diluter mechanism which functions the same as that of a diluter-demand regulator. It also is provided with a manual and automatic control for supplying positive pressure to the mask. There are various types of positive-pressure diluter-demand regulators. They are used in aircraft having an operational ceiling above 35,000 feet.

The following paragraphs cover the pressure-demand types of breathing regulators in service:

a. Type A-13. This pressure-demand oxygen regulator assemembly, when used in conjunction with the type A-4 or D-2 oxygen cylinders, forms a portable oxygen supply for use at high altitude by persons moving about in the aircraft for supplemental oxygen in the event of an emergency. This regulator operates on an inlet pressure range of 100 to 500 psi.

b. Type 2885-5C-A1. This automatic pressure-breathing diluter-demand oxygen regulator automatically mixes air and oxygen at a ratio dependent upon altitude, and delivers this mixture at the proper pressure to the breathing mask upon demand. A pressure-breathing mask, such as type A13A, must be used with this regulator. With a tight mask fit, this regulator, supplying 100-percent oxygen, can be used up to 50,000 feet. At altitudes above 39,000 feet, positive pressure is supplied to the user. This unit operates within an inlet pressure range of 50 to 500 psi.

c. Type CRU-69A/A and CRU-69/A. This pressure-demand regulator automatically mixes air and oxygen, at a ratio dependent upon altitude, and delivers this mixture at the proper pressure to the mask upon demand. A pressure-demand mask must be used with this regulator. With proper mask fit and the diluter lever in the "normal oxygen" position, the regulator provides correct breathing mixtures at altitudes up to 43,000 feet for normal use and to 50,000 feet for short time periods during an emergency. This unit operates from an inlet pressure range of 50 to 500 psi.

d. Type ARO part numbers F4255000-1, F4255000-3 and F2400-12. This pressure-demand regulator provides oxygen in an altitude range of sea level to 70,000 feet. This unit operates from an inlet pressure of 50 to 80 psi and provides flow rates up to 90 LPM.

e. Type CRU-68A/A and CRU-68/A. This pressure-demand oxygen regulator is for use by aircrew members at high altitudes up to 48,000 feet and operates from an inlet pressure range of 50 to 500 psi. The regulator is connected to a pressure-breathing mask such as Type MS22001 by means of a flexible hose which is attached to the regulator outlet. The regulator provides air dilution as a function of altitude. Positive pressure is provided in increasing amounts from 43,000 to 50,000 feet.

f. Type part numbers 29270-10A-A1 and 68B850059-1003. This pressure-demand regulator operates nearly the same as the CRU-68/A regulator assembly and is interchangeable.

g. Type CRU-73/A. This pressure-demand regulator operates nearly the same as the CRU-69A/A and CRU-69/A regulator assemblies. This regulator is designed according to MIL-R-83178 and is presently the primary panel-mounted regulator used in most USAF aircraft (see figure 16).

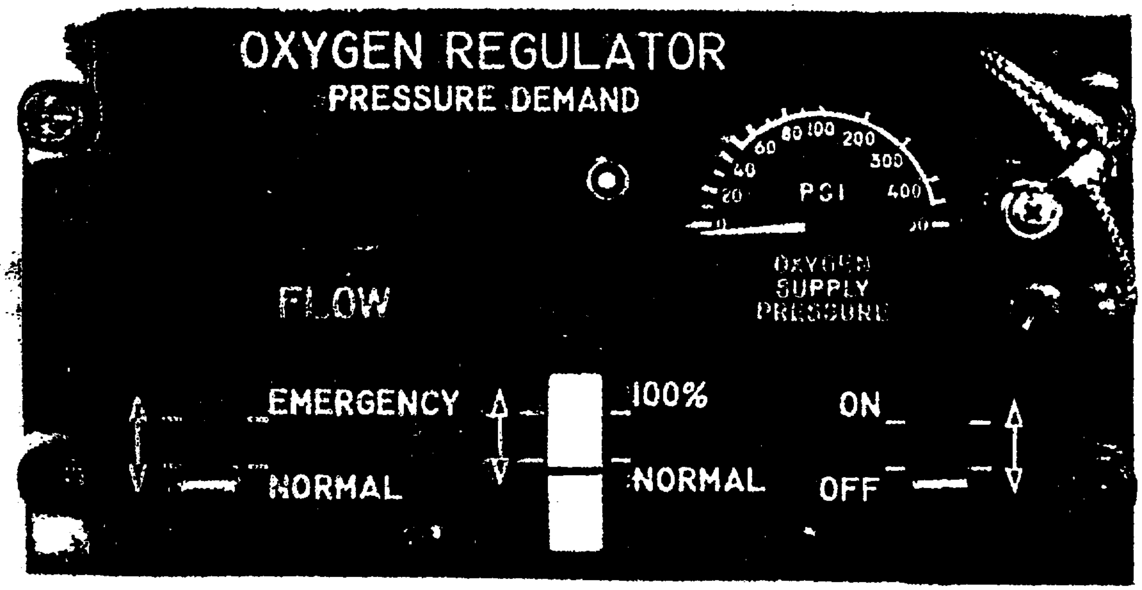


FIGURE 16. CRU-73/A typical panel-mounted pressure-demand oxygen regulator.

h. Type A-21. This pressure-demand oxygen regulator is for use on portable units (reference Dwg 53C3794) up to an emergency altitude of 45,000 feet. This unit design is covered by MIL-R-7605 and is compatible for use with the A-13A, MS22001, and MBU-5/P breathing masks.

i. Type D-2 and D-2A. This automatic positive-pressure diluter-demand oxygen regulator is designed to furnish oxygen diluted with air, 100-percent oxygen, or oxygen under pressure to masks compatible with pressure breathing. The functions are selected automatically as a function of aircraft altitude. This unit is effective for use up to 43,000 feet and in an emergency may be used up to 50,000 feet. Manual controls are also provided to select 100-percent oxygen or emergency setting.

j. Type 2881-5C-A1. This pressure-breathing diluter-demand regulator operates similarly to the D-2 unit. Positive pressure is provided automatically in increasing amounts at 39,000 feet up to 50,000 feet.

k. Type MB-2. This pressure-breathing diluter-demand regulator operates similar to the D-2 unit also. Positive pressure is provided automatically in increasing amounts at 32,000 feet up to 48,000 feet.

l. Type CRU-44/A, CRU-21/A, CRU-34/A, CRU-47/A, CRU-49/A, CRU-48/A and CRU-52/A. These regulators are very similar to the CRU-68/A pressure demand oxygen regulators and are interchangeable with them.

m. Type part number 29258-A1. This oxygen regulator is a diluter-demand automatic pressure-breathing regulator, and is a component of the oxygen system assembly used to supply both normal and emergency oxygen to the crewmember. This unit operates from an inlet pressure range of 50 to 140 psi from altitudes of sea level to 75,000 feet.

n. Type CRU-66/A. This barometric-demand oxygen regulator is designed to be chest mounted on the crewmember with a wedge-plate mounting on the restraint harness. This regulator is used by the two crewmembers in the F-111 USAF aircraft. A large knob control has the normal setting for automatic air dilution, a 100-percent oxygen setting and an emergency setting for manual selection of 100-percent positive-pressure breathing oxygen. This unit weighs 0.75 pound, functions from an inlet pressure of 40 to 120 psi and delivers flow rates up to 100 LPM. In the normal operating mode, the regulator performs as a demand type, which requires suction at the outlet to deliver a flow, and provides an air/oxygen mixture from sea level to 20,000 feet. Between 20,000 and 30,000 feet, 100-percent oxygen is supplied upon demand. With the regulator in the emergency mode, 100-percent oxygen at a positive pressure (safety pressure) of 0.01 to +2.0 inches of water is supplied on demand from sea level to appproximately 30,000 feet. At 30,000 feet, the regulator provides pressure breathing with the pressure increasing proportionately with altitude to a maximum pressure of 15 inches water at 50,000 feet.

o. Type MD-1, CRU-52/A, CRU-54/A and CRU-55/A. These panel-mounted pressure-demand regulators operate from an inlet pressure range of 50 to 500 psi and are very similar in design and operation to the CRU-73/A panel-mounted regulators in use in the USAF.

p. Type MD-2 and CRU-72/A. These panel-mounted pressure-demand oxygen regulators operate from an inlet pressure range of 50 to 2000 psi and are very similar in design and operation to the CRU-73/A regulators in use in the USAF.

q. Type CRU-79/P. This miniature oxygen breathing regulator is designed to regulate 100-percent oxygen to the crewmember during flight. This unit operates from an inlet pressure of 40 to 120 psi, delivers an oxygen flow rate up to 100 LPM, is operational up to an altitude of 50,000 feet and weighs 5 ounces. The safety pressure feature automatically maintains a positive pressure in the mask of 2.0 to 5.0 inches of water at all altitudes up to 34,000 feet. The pressure-breathing feature maintains a positive pressure in the mask of up to 20 inches of water at altitudes between 35,000 and 50,000 feet, with the positive pressure increasing in proportion to the altitude. This unit may be used routinely up to 43,000 feet, but only for short times at higher altitudes.

50.3 <u>USAF oxygen regulator development considerations</u>. There are numerous complex factors that must be considered in the design and development of a new oxygen breathing regulator. Included are factors such as a selection of the inlet pressure as a function of the proper delivery of breathing pressures and flow rates that are physiologically compatible with the crewmembers or passengers as the case may be. Practically all past regulator designs have functioned from an inlet pressure of 50 psi minimum to 500 psi maximum; the nominal delivery pressure is 70-120 psi. A reducing inlet valve is provided to be compatible with 300-500 psi systems. This has been very satisfactory for use with LOX and pressurized oxygen supply systems, but the new molecular sieve On-Board Oxygen Generation System (OBOGS) functions at lower pressures. Depending on the aircraft in which the system is designed to function, the delivery pressure will vary because of differences in aircraft engine revolutions per minute which varies pressures in the bleed air. Smaller fighter and trainer aircraft may provide a range of 5-70 psi with the nominal being 30-60 psi. This means that lower and wider ranges of inlet pressure variations must be accommodated in OBOGS breathing regulators. Another difference is that the OBOGS regulator may not provide the air dilution function. In an OBOGS, a component called a monitor senses the partial pressure of oxygen in the delivery air and may sense the cabin pressure altitude. In an OBOGS concentrator, the flow rates across the molecular sieve material may be adjusted to provide the proper oxygen concentrations for air dilution. Air dilution does not necessarily get metered at the breathing regulator. It is also a design consideration to develop OBOGS regulators to function at higher pressures to be compatible with LOX and gaseous oxygen supply systems.

The regulator location is critical. Most past USAF oxygen regulators are panel mounted with the exception of the F-111 aircraft that incorporate chest-mounted regulators. The using commands have not liked the chest-mounted regulators, as they are considered personal equipment to be checked out and accounted for by each crewmember. Like helmets and masks, a separate item must be provided for each crewmember. This means more regulators must be provided than in panel and seat mounted designs, and the chest-mounted regulator would be more easily lost or damaged. Additionally, the chest-mounted regulator would be an encumbrance in the cockpit because, when disconnected, it would either be tossed to the side (possibly damaging a control panel or instrument) or be thrown over the shoulder (possibly damaging the regulator, mask or helmet). Control settings on chest-mounted regulators are more difficult to ascertain because of vision and orientation problems. Chest-mounted regulators add weight to the crewmember which is fatiguing in normal operation and, in many cases, unbearable in high-G combat maneuvers. The weight of the reguator is multiplied by 7-9 G's in this case. For example, a 1-pound chest-mounted regulator could weigh 7-9 pounds and bear down on the chest. This hinders the crewmembers' flight and combat operations. For these reasons, the using commands have decided not to accept any more chest-mounted regulator designs. Seat-mounted regulators are another possibility, but they have problems also. Compatibility with ejection seat sequencing components, space, weight, and center of gravity must all be determined to ensure that seat ejection capability is not degraded. Also, should regulator mode control(s) be provided on the regulator, settings will be difficult to ascertain because of vision and orientation.

Panel-mounted regulators solve all these problems provided panel space is available in locations that are easily viewed. In the design and development of all future breathing regulators, panel-mounted regulators are most desirable and seat-mounted regulators are least desirable. Chest-mounted regulators are no longer considered to be acceptable in USAF aircraft.

50.4 **Oxygen mask assemblies.** Oxygen masks are items that are either a part of the personal equipment of the crew or are permanently installed in the aerospace vehicle. The mask type depends on the vehicle flight altitude and the type of regulator used. In addition to the normal function of supplying oxygen, the mask also aids in communications, helmet retention, and provides some face protection. Two types of masks are presently used in the Air Force: the pressure demand, and the continuous flow. The continuous-flow mask, which is more wasteful of oxygen than the other, can be used very satisfactorily at lower altitudes. The pressure-demand type is mandatory for high altitude flights. The continuous-flow mask is usually used for passengers and for transporting hospital patients. In pressure suit garments for flights above 50,000 feet, masks are not usually provided, but breathing gas is provided through valves to a helmet assembly which totally encloses the crewmember's head. This incorporates air dilution from regulator to provide increased pressures to the entire head. Anti-fogging and air conditioning is also provided.

50.4.1 **Pressure-demand mask assemblies.** This assembly consists of the mask facepiece; inhalation and exhalation valve assemblies; communications microphone, electrical line, and quick disconnects; flexible low pressure delivery hose(s); a connector device like the CRU-60/P that incorporates a quick disconnect; an integral anti-suffocation valve that diverts oxygen flow from another emergency oxygen supply source; and another connector for this emergency oxygen. See figure 17 for an illustration of all these components.

A pressure-demand oxygen mask is designed to hold pressure in excess of ambient pressure. This requires two features not found in the demand mask. First, the face seal forms a ring around the inside of the mask, which serves as a pressure seal. Second, a special inhalation-exhalation valve located at the bottom of the mask is designed to allow oxygen to enter the mask on inhalation and sustain a positive pressure until regulator is overcome during exhalation.

50.4.1.1 **MBU-5/P pressure-demand oxygen mask.** The MBU-5/P mask was the standard USAF pressure-breathing oxygen mask (see figure 18), but its use in aircraft is being phased out and replaced by the MBU-12/P mask. However, the MBU-5/P mask may have use with portable walk-around units. The mask is lightweight with a facepiece molded of silicone rubber for comfort and maximum service life. The delivery hose is also silicone rubber and the hard shell is of a semirigid plastic material. The mask is equipped with a combination inhalation/exhalation valve. The M-100/AIC microphone is used with it, but is not a part of the MBU-5/P mask. This mask can be used at altitudes up to 42,000 feet under normal flying conditions and up to 50,000 feet for short periods in emergencies. The MBU-5/P pressure-demand mask is designed to

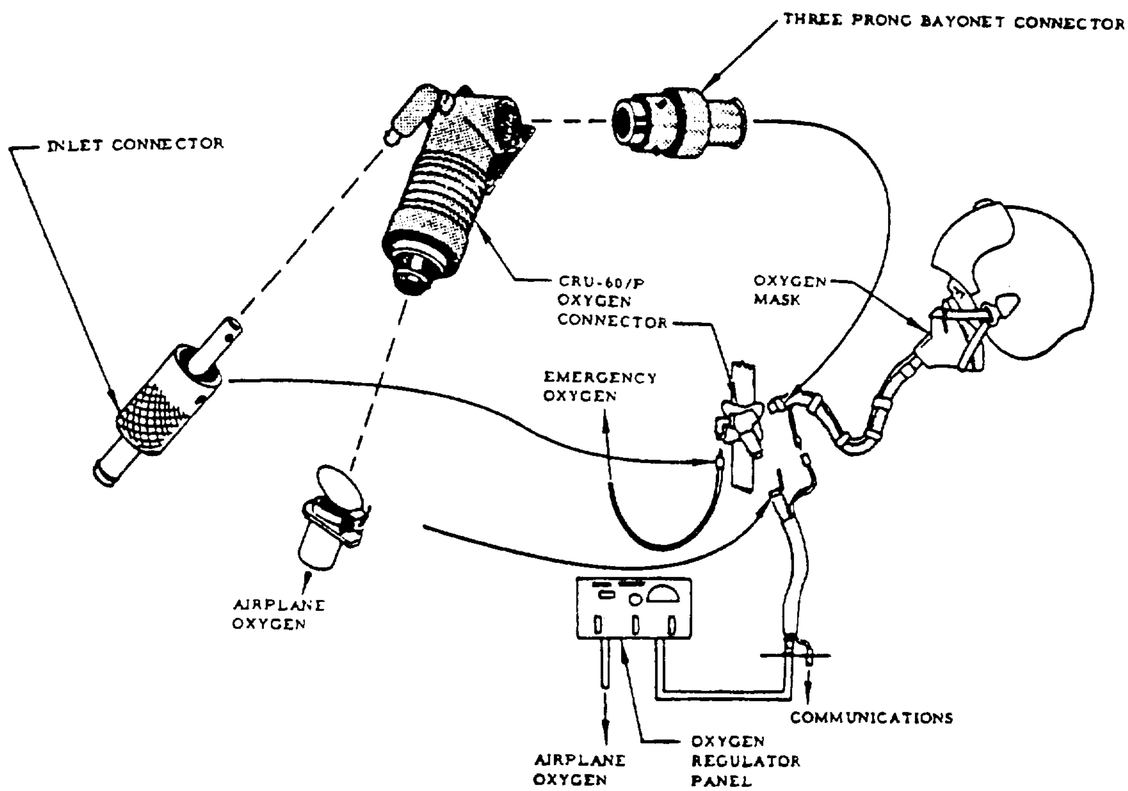


FIGURE 17. CRU-60/P oxygen connector arrangement.

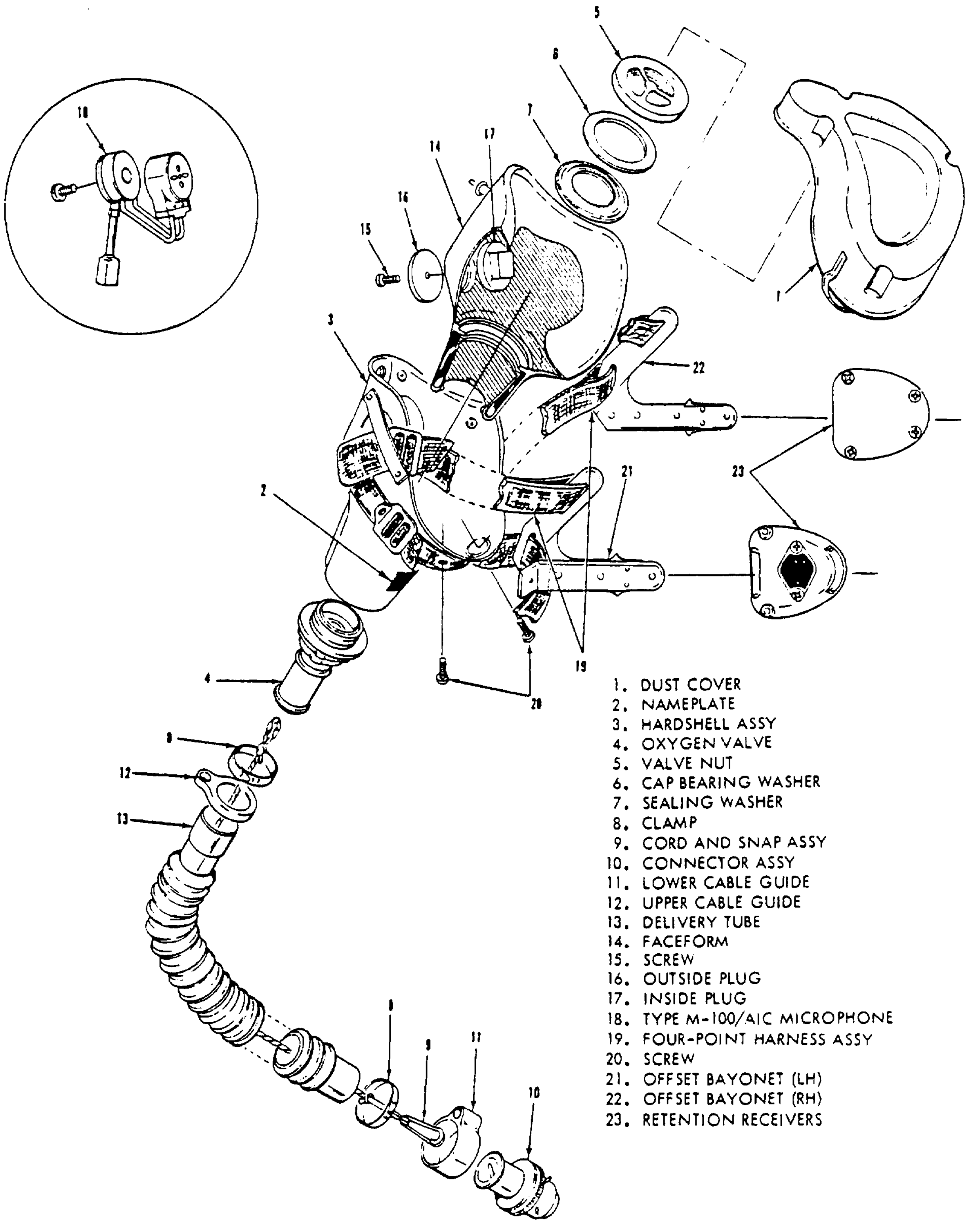


FIGURE 18. Type MBU-5/P oxygen mask assembly.

retain positive pressure. The pressure mask is used with types A-14, CRU-68/A, CRU-73/A, and equivalent regulators. Since the pressure-demand mask is used in aircraft operating at high altitudes, it is used with a CRU-60/P combination connector for use with emergency assembly. Detailed information on the MBU-5/P is contained in MIL-M-27274.

The main components of the MBU-5/P are the face form, hardshell body, combination inhalation-exhalation valve, harness strap assembly and retention devices, and the oxygen delivery tube assembly. Oxygen enters the face form through the valve located at the bottom of the mask. Exhaled air passes out through the same valve.

The exhalation portion of the valve is constructed so that a pressure of 1 mmHg greater than the pressure of the oxygen being supplied by the regulator will open the valve and allow exhaled air to pass to the atmosphere.

The mask is manufactured in four sizes: short narrow, regular narrow, long narrow, and regular wide. It has a high-impedance microphone and a 44.5-cm (17.5-in.) oxygen delivery tube. It can be used with the CRU-8/P or CRU-60/P connector. For special application, the CRU-43/A connector is provided for use with a high-altitude seat kit.

The oxygen delivery tube contains a nylon cord which prevents elongation during ejection. A three-prong push, turn, and lock bayonet adapter is provided to connect the delivery tube to one of the connectors listed above.

50.4.1.2 **MBU-10/P pressure demand oxygen mask**. The MBU-10/P quick-don oxygen mask is a pressure-demand oxygen mask similar to the MBU-5/P and is installed on many MAC transport aircraft.

50.4.1.3 **A-13A pressure demand oxygen mask**. The A-13A oxygen mask may be used routinely in flights up to 43,000 feet altitude. In emergency situations this mask may be used up to 50,000 feet altitude, but due to human limitations, only for short periods of time. The A-13A oxygen mask consists of a facepiece, two inhalation valves, a pressure compensating exhalation valve, microphone cavity, harness and adapter assembly, and a breathing hose assembly. The mask is supplied in three sizes: large, medium, and small. The facepiece has two cheek flaps for protection to the face from flash fire, windblast, etc. The newer (silicone) masks are constructed of elastomer material and are dark olive in color. The silicone masks have a longer shelf life, contain ozone-resistant properties, are free of odor, and cause less facial irritation. The silicone mask does not require a laminar seal unless irregular facial features cause poor fit and sealing. The older A-13A masks are constructed of Buna-N rubber, and require a laminar seal to improve fit and insure proper sealing. The masks are mildew-resistant and remain flexible at low temperatures. The adapter and harness assembly is constructed of fiberglass with nylon straps for adjustment. The adapter and harness assembly is supplied in three sizes: large, medium, and small. Size of mask and adapter must correspond. The oxygen delivery hose is supplied as a subassembly.

50.4.1.4 MBU-4/P demand oxygen mask. This oxygen-breathing mask provides altitude protection up to 37,500 feet. This mask operates on the intermittent-flow principle in which oxygen is supplied only when the wearer inhales. On each inhalation, the slight suction created automatically operates the demand regulator causing it to open and deliver oxygen to the mask. When the wearer exhales, the demand regulator automatically shuts off and the exhaled gases pass out of the mask through the flutter valve. Correct fit of the mask is imperative or the unit will not function.

50.4.1.5 MBU-12/P pressure-demand oxygen mask. This mask (see figure 19) was designed as an improvement and replacement for the MBU-5/P crewmember pressure-demand oxygen mask. Improvements were to achieve a more effective seal with the face, thus allowing greater mask cavity pressures for increased altitude protection; to shift the mask assembly center of gravity closer to the face such that accelerative forces of flight are less likely to pull the mask from the face and allow mask leakage; and to reduce mask breathing resistance. The mask uses the same combination inhalation/exhalation valve as the MBU-5/P mask. The mask incorporates a silicone rubber facepiece molded to a plastic hardshell. This mask is becoming the standard equipment in USAF fighter and attack aircraft. The mask is also used extensively by the Navy.

50.4.1.6 MS22001 and MBU-3/P pressure breathing oxygen mask. This mask is intended to permit breathing of gaseous oxygen when it is necessary to function under internal mask pressure in excess of ambient pressure. The MBU-3/P pressure-breathing oxygen mask consists of a facepiece, inhalation valves, pressure-compensating exhalation valve, microphone housing, harness assembly, plastic nose piece and breathing tube assembly. Oxygen enters the facepiece through a valve in the bottom of the mask. The later valve is so constructed that a pressure of only one millimeter of mercury greater than the oxygen being supplied by the regulator will force it open. At the lower end of the mask tube is a bayonet. The bayonet engages a CRU-8/P connector which is secured to a metal plate on the parachute harness. The swiveling feature of the connector's fitting which receives the emergency oxygen supply hose provides equal adaptability of the block to seat-type parachutes, which have the emergency oxygen source located below the position of the connector, or to back-type parachutes, which have the emergency oxygen hose traversing the right vertical parachute harness strap above the connector. The connector consists of three main components: (1) a side bayonet-type connector for attaching the type H-2 bailout assembly; (2) a two-way flapper valve; and (3) a quick-disconnect type of fitting to connect into a regulator tubing socket. The two-way flapper valve permits normal operation when connected to aircraft oxygen supply. Disconnecting from the aircraft oxygen supply and activating the type H-2 bailout assembly will cause a pressure of approximately 12 to 14 inches of water to build up within the mask. This, in effect, creates pressure breathing in the mask with which the user can accomplish a free-fall parachute escape from a maximum altitude of 50,000 feet. Upon ejection, the distal end of the oxygen mask hose remains rigidly connected to the block by means of a bayonet fitting which precludes flailing and the dangers inherent therein.

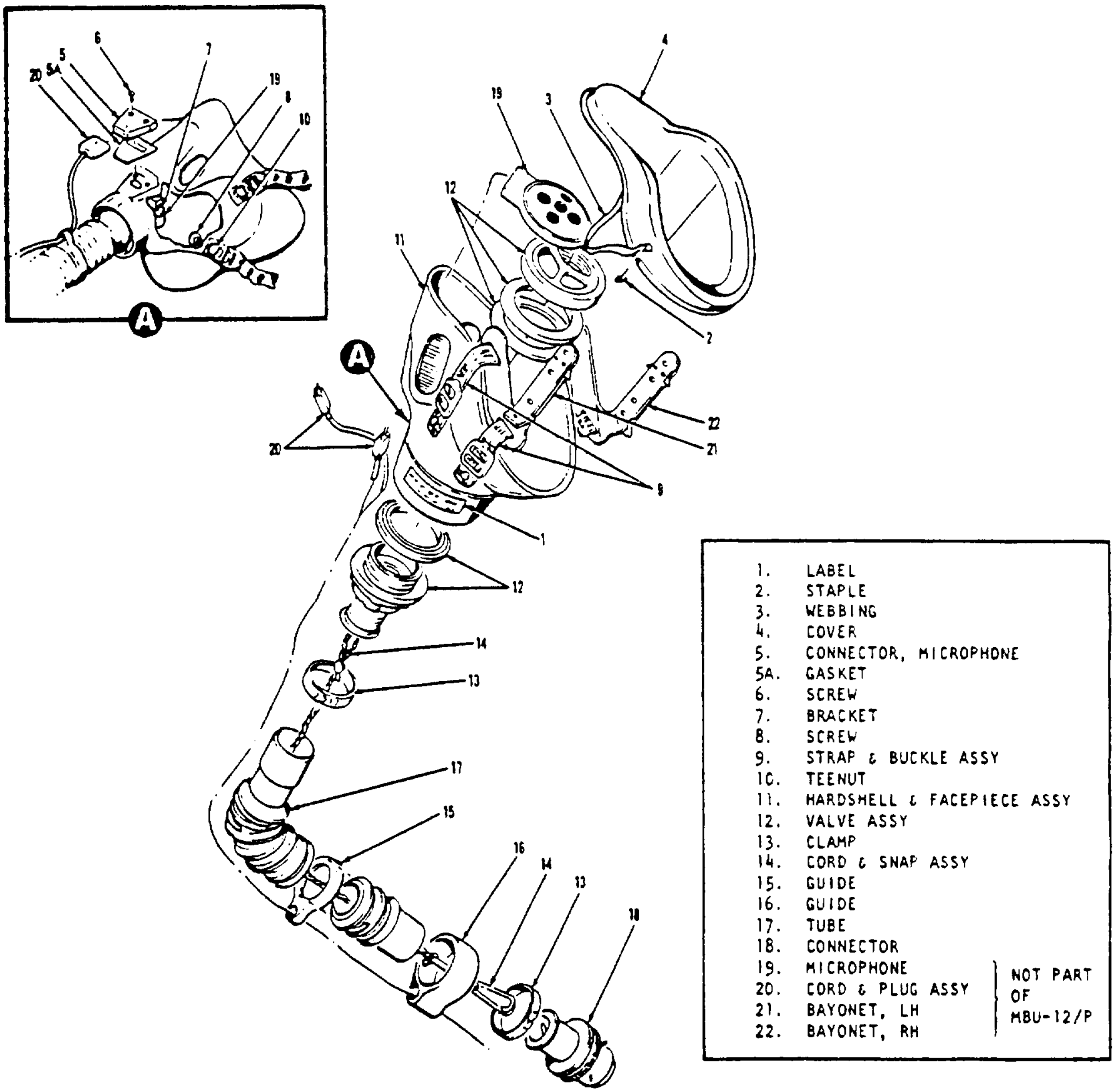
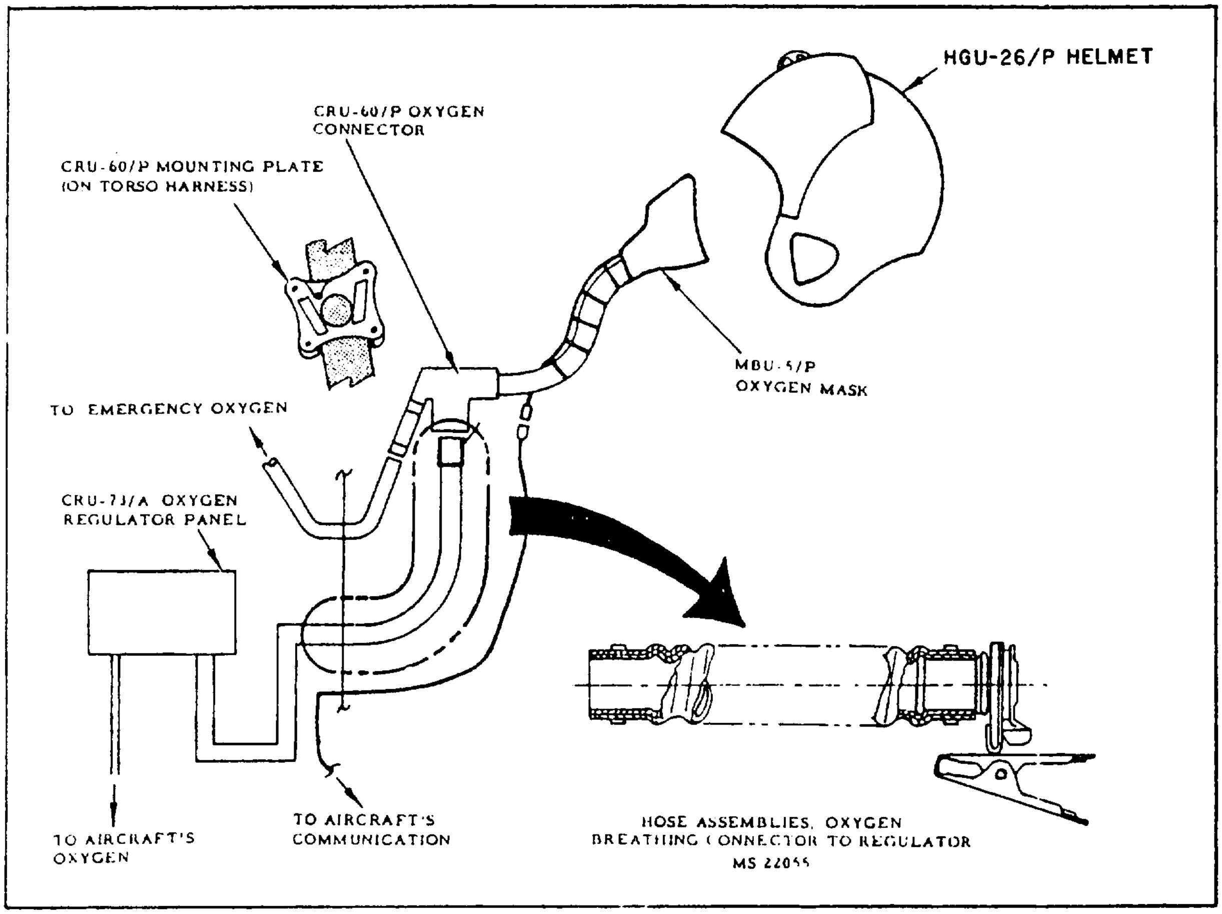


FIGURE 19. MBU-12/P pressure demand oxygen mask.



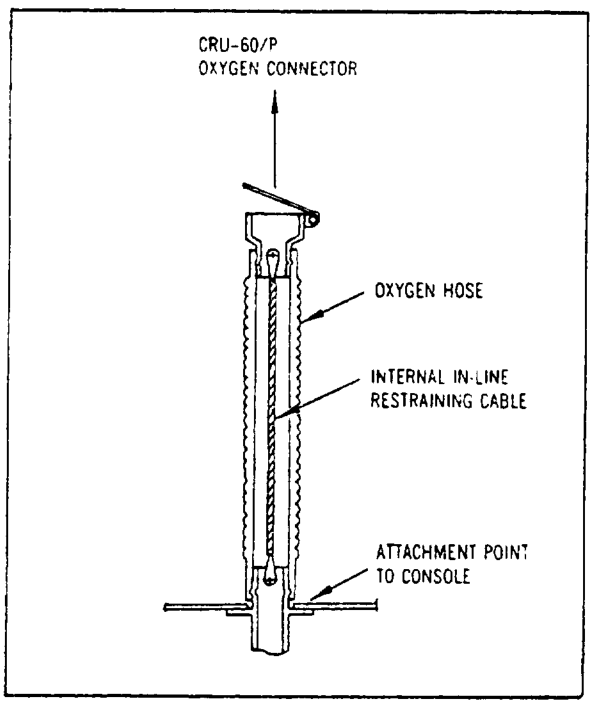


FIGURE 20. Typical oxygen hose assembly with hose cutaway shown at left.

50.4.2 Breathing hose assembly. The delivery tube passes oxygen from the regulator to the mask (see MS22055). A spring clip or retainer strap is available to attach the tube to the crewmember's clothing. This feature takes the weight of the delivery tube off the oxygen mask. When not in use, the delivery tube may be stowed by attaching the spring clip to the cloth tab provided at the flight station. The hose used is subject to the requirements of MIL-H-81581. On aircraft equipped with ejection seats, route the delivery tube through the automatic separation of the oxygen hose and other personal leads when the ejection seat is fired. The disconnection force is not applied to the crewman. See figure 20 for a typical oxygen hose assembly and related personnel services for an ejection seat-equipped aircraft. Stations supplied by AN6010-1A regulators do not have delivery tubes, as the automatic coupling is mounted on the wall next to the station. The user's movements should not be restricted by the installation of the oxygen hoses and related personal services and by the length of hoses chosen. Excessive hose lengths which result in bulkiness and resistance to breathing are avoided. The length and routing of hoses should not cause the user to inadvertently activate crew station controls. When applicable, suitable spring clips or dummy receptacles are provided in the aircraft to anchor personal leads while not in use. In some cases, it may be desirable to integrate the oxygen hose and communication lead into one molded unit. Requirements for oxygen and pressure hose which ozone-resistant and suitable for use with air or breathing oxygen are in MIL-H-26385.

50.4.3 Oxygen equipment connectors and personal leads disconnects. The personal leads automatic disconnects provide the best operation during ejection. The disconnects separate with a pull of not less than 53 N (12 lbf) nor more than 97 N (22 lbf). Personal leads are routed for minimum interference with crew duties.

Combination connector (CRU-60/P) is utilized in ejection seat-equipped aircraft to provide an oxygen disconnect feature which is required during seat/man separation. Connectors provide an airtight connection between the oxygen mask assembly and the mask-to-regulator assembly. They are normally attached to a connector mounting plate on the personal restraint harness. During the ejection sequence or during emergency ground egress, the connector provides an automatic separation point at the lower intake port, thereby severing the oxygen leads between the aircraft and the crewmember. The emergency oxygen supply from the bailout cylinder also attaches to his connector. For additional information regarding the connectors and related hoses, see MIL-C-38271, MS22055, and MS22058.

The CRU-43A/A (MIL-A-27471) model adapts high altitude seat-kit oxygen systems to a standard MBU-5/P pressure/breathing oxygen mask. These adapters include a pressure-reduction mechanism to change the helmet pressure delivered by the seat-kit regulator to a pressure compatible with the MBU-5/P oxygen mask. The flow capacity is insufficient for prolonged use above 9,144 m (30,000 ft), so that an immediate descent to 9,144 M (30,000 ft) or below is mandatory if cabin pressure is lost while using these adapters.

50.4.4 Continuous-flow mask assemblies. The MBU-8/P type mask assembly is the recommended passenger continuous-flow equipment. It is connected to the automatic coupling by a slender rubber oxygen supply tube and a bayonet connector. Oxygen is delivered in a continuous stream to a rubber reservoir bag which is attached to the facepiece of the mask. When open, the bag contains about 1/2 litre (pint) (the approximate volume of a normal breath taken at rest). If the user inhales so deeply as to empty the bag, a valve in the facepiece admits atmospheric air. This enhances the partial pressure of the alveolar, but also admits smoke to the lungs in a smoke-filled cabin situation. When the flow is increased by adjusting the regulator, it is possible to get almost 100-percent oxygen, provided the depth of breathing does not exceed the capacity of the bag. During exhalation, the mask inlet valve prevents the inflation of the reservoir bag with exhaled gases. The exhaled gases pass through the exhalation valve into the atmosphere.

50.4.4.1 Drop-out emergency oxygen masks. For applications in passenger and troop aircraft, consider the installation of "drop-out" emergency oxygen units as a part of the emergency oxygen system.

This type of continuous-flow system consists basically of an oxygen supply (either gaseous or chemical) and several self-contained mask storage units. Usually, the oxygen mask storage units are installed overhead but, in some cases, the unit may be mounted on the back of the seats. Each unit or container will have two or three passenger-type oxygen masks stowed within. If a decompression occurs within the aircraft, the masks will automatically deploy within the reach of the passengers. The act of the passenger pulling on the mask to don it extracts a pin from a lanyard operating valve assembly. This allows the oxygen to flow to the mask. Consider the following design and installation information when utilizing a drop-out system and see figure 21.

a. Locate the oxygen mask stowage unit so that the mask is readily accessible to the intended user when deployed. Accessibility is defined as being within the reach of a seated 5th-percentile man with the seat belt attached.

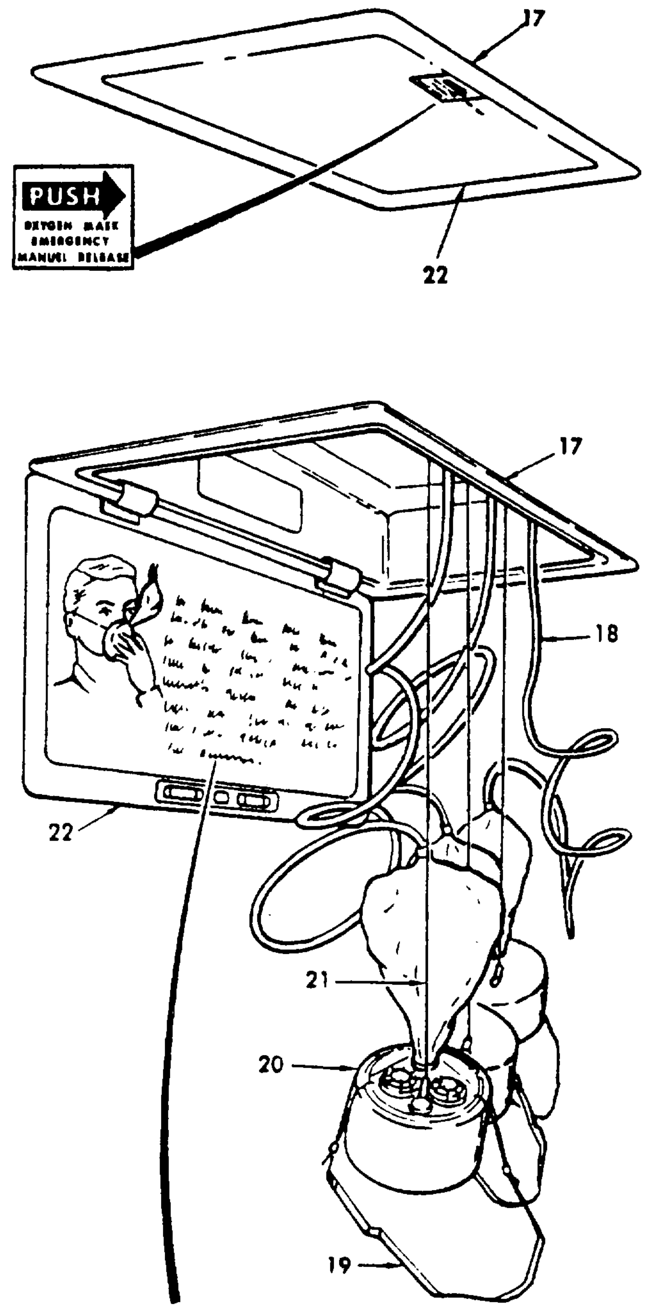
b. Ensure that instructions for donning and using these units are available.

c. Provide a retaining strap for holding the mask in place.

d. The cabin altitude at which automatic deployment occurs is a function of the aircraft's cabin size. For small volume cabins, deployment occurs at approximately 12,000 to 14,000 feet. For large volume cabins the range may be from 13,000 to 15,000 feet. The system shuts off upon descending to approximately 11,000 to 13,000 feet.

e. The flow rates for the system are based upon the size of the crew. (General guidance is provided in FAR 25.)

f. Deployment of the mask should not be is obstructed by surrounding or adjacent equipment.



1. GRASP MASK BY FACE CONE AND PULL DOWN TO OPEN OXYGEN VALVE.
2. PLACE FACE CONE OVER MOUTH AND NOSE AS SHOWN.
3. POSITION ELASTIC HEAD BAND AND ADJUST MASK TO MINIMUM DRAFT IN EYES DURING EXHALATION.
4. BREATHE NORMALLY.

FIGURE 21. MBU-8/P type oxygen mask assemblies shown in overhead oxygen mask storage container.

50.4.4.2 Quick donning emergency oxygen masks. Also for application in passenger, aeromedical, and troop aircraft, some or all MBU-8/P type mask assemblies may be donned manually. The supply source could be a chlorate candle, chemical oxygen generator of another type, LOX converter, or high/low pressurized oxygen gas. The type of oxygen supply is a strong consideration in placement and dispensing of the breathing-mask assembly. A hard shell or soft canvas container must be used to hold the mask assembly to protect it from dust, humidity, sunlight, and personal abuse. Locations above or in front of the passenger are more desirable than locations under the seat or to the left or right of the seat. From the moment the alarm is seen or heard, the passenger should be able to reach, unstow, don, and breathe oxygen from the assembly within 5-15 seconds depending on the altitude capability of the aircraft. Donning instructions, a head-retaining strap, and suitable oxygen flow rates are provided for these masks.

50.4.4.3 Mask assemblies for use in escape capsules. A shirt-sleeve environment is one in which the crew is not required to wear a pressure suit, oxygen mask, parachute, or anti-exposure suit. This environment is found in a crew module or a capsule system and provisions must be made for individual emergency oxygen and mask. Provide a mask for each crewmember for use in case of fire, smoke, or fumes within the cockpit. Store the mask in an easily accessible place in the headrest area (see MIL-C-25969).

50.4.4.4 Aeromedical passenger and patients mask assemblies. Oxygen masks for passengers and transported hospital patients are normally permanently installed or disposable and are normally not part of the personal equipment. Continuous-flow masks are commonly used. Specifically, the MBU-8/P (MIL-M-83191) is the standard passenger continuous-flow mask which is utilized. Ensure that oxygen masks used to provide emergency oxygen to patients and medical crew deploy automatically. Include provisions for maintaining proper oxygen mask placement for incapacitated patients and for walk-around oxygen assemblies and masks used by the medical crew. The aeromedical oxygen requirements for patients and medical crews are covered in AFSC DH 2-2, DN 6A4.

50.4.5 High-altitude breathing assemblies. Survival at altitudes above 50,000 feet presents many problems. There must be an artificial environment compatible with human existence. Pressure garments have been developed to afford protection to crewmembers in the event of exposure at high altitude, either through loss of cabin pressurization or high altitude ejection. Pressure garments may be partial pressure assemblies or full pressure suits. The entire system includes the coveralls, helmet, boots, gloves, survival kits, integrated clothing, air conditioning, air conditioning units, test equipment, and support equipment. Pressure garments provide excellent aircrew protection, and under the concept of the system, this equipment is tailor-made for each mission profile. Comfort and mobility are prime factors, and the assemblies are adaptable to missions of short or prolonged duration. Their use on missions over 50,000 feet is required. Also, for missions over 25,000 feet, in case of cabin depressurization, where it would be impossible to immediately descend to a point at which cabin pressure can be maintained at or below 25,000 feet.

50.4.6 Breathing mask assembly development considerations. There are many important design considerations that should be considered in the development of any new mask assembly, crew or passenger. The face mask should be oronasal covering the mouth and nose. In the case of chemical defense, smoke protection, and high altitude protection, the eyes or entire face and/or head may be covered. In the selection of the materials for the assembly, consideration should be given to many factors. Materials must be of type, grade, and quality which experience and/or tests have shown to be suitable for the purpose intended. Materials must not be used which contaminate oxygen. Materials should not present a hazard to the user when in the 100-percent oxygen environment. The materials should exhibit resistance to flammability, ozone degradation, ultraviolet degradation, wear/tear/abrasion, aging, deformation in storage, shatter, skin reactions, and environmental extremes. See SAE Aerospace Standard AS 8026 for important design detail considerations and additional references.

Materials in contact with the skin should be selected to be as nonirritating, nonallergenic, soft, and compliant to the facial configuration as possible and practical. All components of the assembly should be designed to be resistant to snags, breaks, tears, and other harmful actions which could lead to malfunction of the mask due to normal handling and use during its service life. The respiratory assembly should take into account proper fit and function for the entire population range for which it is intended to be used. This will require different sizes for crewmember masks and special consideration for passenger masks and firefighter's full face mask that are designed in one size to fit all potential users. Much anthropometric survey information is available for male and female military and commercial personnel. With good and proper fit of the facepiece, leakage should be minimized. This should enhance the capability of the mask to provide respiratory protection. For fighter aircraft mask design, the cg of the mask should be as close to the face as possible without adversely compromising design considerations to ensure good face seal even under high g maneuvers. For commercial and transport mask designs, special consideration is necessary for enabling the user to quickly don the assembly. Also, especially important is breathing flow resistance consideration for inhalation and exhalation.

50.5 Portable oxygen assemblies. In transport-type aircraft where extended flight is required in the 10,000 to 25,000 feet altitude range when the aircraft is not pressurized, low pressure portable walk-around assemblies that fill up to 300-400 psi pressure range are desirable. The cargo transport and mission specialist aircraft fall into this category.

Portable assemblies (usually called walk-around assemblies) are installed in multiplace aircraft to allow crewmembers to move about in the aircraft. Portable assembly rechargers are installed at flight stations to enable refilling portable units during flight. A portable assembly recharger (MS22032), usually available at each flight station and latrine, consists of a flexible hose (MS24548) with a standard AN6024-5 filler valve at its end. A spring clip is provided at the flight station for stowing the filler valve end of the recharger assembly. When refilled in flight, pressure in the portable assembly will be somewhat less than the system pressure at the time of refilling. By leaving the portable assembly attached to the portable assembly recharger, it is possible to use the portable assembly at any extra oxygen station. When continuous-flow portable equipment is used, the regulator valve must be adjusted before any oxygen will flow. Since the portable unit is ordinarily used only during some form of activity, it is wise, especially at high altitudes, to allow a somewhat greater flow than would be required for the same altitude when at rest. When active, set the flowmeter to read at least 5,000 feet above the indicated altitude. After use, the regulator valve is turned off. The Society of Automotive Engineers Aerospace Standard 1046 contains general information on portable oxygen equipment.

In passenger aircraft, where only 15 to 30 minutes of flight time is required to enable an emergency descent, portable oxygen supply sources that do not incorporate a refill capability may be provided. In all these aircraft, several assemblies should be provided on the flight deck and a number of these should be provided at strategic locations throughout the aircraft cabin.

50.5.1 **Low pressure portable assemblies.** The most commonly used portable low pressure assembly in the USAF now is designed according to Dwg 53C3794 and consists of an A-21 regulator and an MS21227-1 metal cylinder.

The A-21 (MIL-R-7605) regulator is a straight demand, positive-pressure regulator. This portable assembly has approximately a 25-minute duration for altitudes higher than 25,000 feet. Below 25,000 feet, the oxygen duration of this assembly will decrease to about 5 minutes at sea level. It does not have a diluter valve.

50.5.2 **High pressure portable assemblies.** High pressure portable assemblies store oxygen gas at about 2150 psi and have pressure-reducing regulators that may provide pressure-demand or continuous-flow pressure breathing. The disadvantages to these assemblies are mainly the heavy weight and bulkiness (if a pressure-demand regulator is included), and the lack of the onboard recharge or refill capability. An advantage is the extended time of supply that may be provided (as much as 2-3 hours of supply). Commercially available assemblies may be provided if all essential features are included.

50.5.3 **Aircraft firefighter assemblies.** These assemblies may be either low or high pressure type. The low pressure type typically used consists of an A-21 regulator and an MS21227-1 cylinder per Dwg 53D3970. The high pressure type is not commonly used in USAF aircraft, but is acceptable provided all essential features are included. Either assembly should have a full-face smoke mask that precludes entry of smoke and noxious gases. The face mask should also have an integral anti-fog capability and as much vision as possible.

50.5.4 **Chemical oxygen generator portable assemblies.** The chemical oxygen portable assembly has been available for many years in commercial aircraft, but has limited use in military aircraft. The main disadvantage of this assembly is that a continuous mode of breathing is provided rather than pressure demand. Under physical exertion, much higher flow rates of oxygen are needed by the passenger who is moving about the aircraft. The continuous mode of breathing does not satisfactorily perform in this situation. These assemblies are small and reasonably lightweight. With the advent of smoke protection designs, chemical oxygen generator portable assemblies may find wider application and acceptance in military aircraft oxygen systems.

50.6 **Oxygen system controls and displays.** Past design experience in oxygen systems maintenance and operation has shown that control capability and information should be provided for safe and effective operation. Oxygen supply quantity information is required from pressurized oxygen gas and liquid oxygen storage container devices. Certain visual information for proper operation of equipment is useful. This could be flow indicators and malfunction information. Also, controls are needed to select the proper operation of the breathing regulator depending on the situation.

50.6.1 Oxygen quantity information for LOX supply. Quantity indicators show (in litres) the amount of liquid oxygen in a converter. A puncture of one or more converters will be indicated directly by the quantity gauge. The indicators may differ in type according to liquid oxygen capacity and operating pressure of the converter. In a multiplace aircraft, a quantity indicator is installed for each converter supply at the pilot's or co-pilot's station to permit monitoring of the total aircraft oxygen supply. Repeater indicators are provided at the station of the crewmember responsible for oxygen. In most installations the indicators are within normal vision of the crewmember. Liquid oxygen quantity indicators are designed to conform to MIL-I-25645 or MIL-I-81387, as applicable. The components consist of a sensing element, one or more indicators, and possibly a separate amplifier, as denoted below:

a. Sensing element. The sensing element (MIL-C-25666) is an open capacitor, mounted in a vertical position so that the liquid oxygen is the dielectric material separating the terminals below the liquid level. Gaseous oxygen is the dielectric above the liquid level. As the level of the oxygen in the converter changes, the electrical capacitance of the sensing element changes. This varying capacitance is connnected to the bridge circuit of the indicator where a corresponding current is developed. This current is amplified and applied to the bridge which establishes a null or balance point. The indicator pointer is mechanically driven by the servomotor. The readout is in litres of oxygen.

b. Indicators, GMU/A series. Typical indicators of the GMU/A series are specified in MIL-I-26376 and MIL-I-26380.

c. Indicator sets. Typical indicator sets are specified in MIL-I-26382 and MIL-I-27220. The sets consist of a master indicator and a repeater indicator.

d. Dummy converters. Dummy converters are fixed electrical capacitors with a capacitance equivalent to a transducer sensing an empty oxygen converter. They are connected in the gauging circuit in place of the transducer when a converter is removed from a vehicle. The inserting of the dummy converter produces an "empty" reading on the indictors associated with that converter, thereby producing a reading which correctly describes the quantity of oxygen in other converters on indicators giving a total quantity readout summed from several converters. Typical dummy converters are specified in MIL-D-26392 and MIL-D-26393.

e. Quantity light indicators. An oxygen low-level light is provided usually in the caution indicator panel. This indicator light complies with MIL-STD-411 and is activated by a switch integral with the quantity indicator. When illuminated, the light indicates that the oxygen quantity indicator has sensed that the quantity of liquid oxygen in the converter is low, usually that the quantity indicated is below 10 percent of full scale.

f. Quantity indicator installation. The installation wiring of the indicator is defined by the detail indicator specification. Near the quantity indicator, a press-to-test switch is provided for use in checking satisfactory operation of the indicator. Other design factors to consider are:

(1) On single-place aircraft, a single liquid-oxygen quantity indicator is provided to show the total quantity of liquid oxygen aboard the aircraft. The indicator is located to be readily visible to the pilot.

(2) On side-by-side pilot (two-place) aircraft, a single liquid-oxygen quantity indicator is provided to show the total quantity of liquid oxygen aboard the aircraft. The indicator is located to be readily visible to both crewmembers.

(3) On tandem-pilot (two-place) aircraft, an indicator set, consisting of master and repeater indicators, is provided to show the total quantity of liquid oxygen aboard the aircraft. Each indicator is located to be readily visible to each crewmember.

(4) On bomber, cargo, or transport aircraft, LOX quantity indicators are provided to show the total quantity of liquid oxygen aboard the aircraft and quantity of LOX in each converter. The indicators are located to be readily visible to the co-pilot or systems engineer.

g. Gauging system requirements. The gauging system, when installed in the aircraft, indicates the amount of liquid oxygen in the converter within an accuracy of plus or minus 2 percent of indication and plus or minus 4 percent of full scale indication at any other major dial divisions on the oxygen quantity indicator. The system is capable of satisfactory operation using external wiring in accordance with the applicable requirements of MIL-W-5088. The gauging system is designed for the use of cables and connectors which conform to the requirements of MIL-E-5400. The length of the cables does not affect the accuracy of the system. Adequate clearance between the indicator connectors are provided so that they can be readily disconnected by servicing personnel. Storage for the aircraft connectors are provided when the converter is removed.

50.6.2 **Pressure information requirements.** The following pressure information is provided on military aircraft:

a. Gauges. Pressure gauges are provided for low and high pressure oxygen systems. The pressure gauges should indicate actual pressure in the subsystem. Pressure gauges are installed at each permanent and temporary crew station in the aircraft only when nonpanel-mounted regulators are installed. A pressure gauge is also provided for the passenger oxygen system to be readily visible by a responsible crewmember. In subsystems having a gaseous supply, the pressure indicator shows the oxygen pressure in the distribution line to which it is connected. The indicated pressure is independent of the number of cylinders supplying the distribution line. Puncturing one or more cylinders protected by check valves will not appreciably change the pressure reading so long as one intact cylinder remains connected to the manifold. However, the duration of the supply obviously will be reduced. The AN6021 (MIL-G-6019) pressure gauge is used to indicate pressure in low pressure cylinders. This gauge is usually installed at flight stations. The AN6011 pressure gauges indicate oxygen pressure in high pressure cylinders installed in aircraft. The gauge is also incorporated in the panel face of the oxygen regulator (CRU-73/A).

Low pressure, low-level warning. When using a liquid oxygen system, a low pressure, low-level indicator light is incorporated in the caution annunciator panel. The low pressure caution light is activated when the converter system pressure drops to a gage pressure of 0.3 plus or minus 0.001 MPa (50 plus or minus 2 psi). If an oxygen regulator is used, the pressure sensor is located upstream of the regulator. The momentary drop in supply line pressure upon inhalation will not activate the low pressure warning. The low-level caution light is actuated when the quantity indication is below 10 percent of full scale. MIL-I-19316 has more details.

50.6.3 **Flow information.** The function of the flow indicator is to show that oxygen is flowing through the regulator and that the demand valve is operating satisfactorily. The flow indicator does not show how much oxygen is flowing or that the user is getting enough oxygen. Depending on the regulator design, the "eye" or "flag" will either open or close upon inhalation. The flow indicator is incorporated in the panel face of the oxygen regulator (CRU-73/A). Flow information may be used to provide a crewmember indication that the breathing regulator is properly functioning and that all connections are properly made. In the design of the sensitivity of the indicator, the lower threshold should consider this most useful function.

50.6.4 **Chemical generator emergency oxygen supply indicators.** In the design of chemical generator emergency oxygen supply units, a visual means is provided for determining that the candle has been ignited, used, or expended. A method should be used that does not require disassembly of the emergency oxygen supply or removal of the housing cap to determine if the candle has been ignited, used, or expended. Temperature-sensitive paint or temperature-sensitive decals are two methods which may be used.

50.6.5 **Breathing mode control.** These types of breathing mode controls are usually provided:

a. Air dilution. Air dilution control is provided for crewmember oxygen regulation to reduce oxygen waste for flight at lower altitudes and preclude the adverse effects to the crewmember's physiology from prolonged use of 100-percent oxygen. A control toggle or switch should be provided to select this mode such as on the CRU-73/A regulator. The air dilution schedule should be automatic with increasing percentages of oxygen added at higher altitudes. In continuous-flow systems, air dilution is presently provided by incorporating inhalation valves that allow air into the mask based on pressure differentials. This mixing is therefore accomplished automatically.

b. 100-percent oxygen. A control is nearly always provided to manually select 100-percent oxygen as there are a number of situations such as takeoff and landing in which the use of air dilution could allow contaminated cockpit air to enter the breathing air. In chemical defense and OBOGS breathing delivery components, air-dilution air may be filtered and this would not necessarily be a problem. For this type of design, it would still be desirable to allow the operator to select 100-percent slight-positive pressure breathing for situations in combat maneuvering and occurrence of hypoxia symptoms to ensure the crewmember has adequate physiological protection.

c. Test mask. A control that provides manual selection of increased positive pressure in the mask assembly. This enables the operator to check for proper mask fit and connection of all associated delivery components. The flow rate and delivery pressure should be determined as functions of the equipment design.

60. OXYGEN CONCENTRATING SYSTEMS ON AIRCRAFT

60.1 **The molecular sieve oxygen generating system (MSOGS) concept.** The concept of molecular sieve on-board oxygen separation and concentration is intended to reduce logistics of base oxygen stores that are used for resupplying the oxygen. Prime targets are to reduce costs and maintenance requirements. Reduction in logistics and operational costs of an aircraft would increase the capability of the aircraft to meet mission requirements.

The molecular sieve oxygen generation system (MSOGS) is a system which separates oxygen from engine or ECS-conditioned bleed air. The bleed air at 50-60 psig is "compressed" onto molecular sieve in a canister in which the nitrogen, carbon dioxide, many organic contaminants, and water vapor are adsorbed, leaving oxygen and argon to pass through to a plenum. The valving then is changed on a 1- to 3-second cycle to allow an alternate canister to be pressurized. Some of the oxygen is bypassed back through the depressurized canister to desorb the nitrogen and other adsorbed material so that the molecular sieve can be desorbed and thus be effective for further oxygen separation. The oxygen concentration at maximum effectiveness is 94-95 percent with 5 percent argon. The system is pressure dependent and may require low pressure valving and regulators, and oxygen monitoring equipment. The MSOGS may require a backup oxygen source (BOS) to supplement the product gases from the sieve beds on an intermittent basis and to provide 100-percent oxygen in a cockpit decompression. The MSOGS product gas at high mass flows of air through the molecular sieve beds will contain less oxygen than the lower mass air flows.

A proposed design for an on-board oxygen concentration system using molecular sieve contains the following components:

a. cooled-dried bleed air from the environmental control system
b. timed-cycling valving
c. molecular sieve canisters with prefilters
d. plenum
e. low pressure O_2 distribution system
f. oxygen sensor/pressure monitor
g. backup oxygen system

The MSOGS with the molecular sieve has some limitations. The bleed air pressure dependency places a maximum on the amount of breathable gas mass flow with high oxygen content. If a large inspiratory volume of 95 to 100 percent oxygen is required, there would be an insufficient gas flow at the lower pressures of 30-40 psi in the system. Supplementary oxygen provided by a backup oxygen system was proposed to provide oxygen when the OBOGS output is out of the oxygen requirement regime. The oxygen monitoring instrumentation could be used for the OBOGS to control the oxygen content and mass flow to provide for the high oxygen demand incidents.

60.2 The open loop oxygen generating system (OLOGS) - fluomine concept. The open loop oxygen generating system (OLOGS) utilizes a chemical, a cobalt chelate, which reacts with oxygen from bleed air from the ECS when the bleed air is compressed in a canister of the chemical. With later improvements, an improved cobalt chelate called fluomine was used in the B-1 OLOGS. This chemical fluomine requires a considerably involved synthesis to provide active material. The cobalt chelate has a hazard rating and must be handled and packaged with considerable care. In the proposed use, the fluomine has several prefilters and is packed so that only authorized personnel will have access to it.

This oxygen reaction of the fluomine is reversible with application of heat at 240°F and at reduced pressures. A vacuum compressor removes the released oxygen which is compressed into a receiver. The heating and vacuum reactivates the oxygen absorption property of fluomine. By a cycling of the pressurization and depressurization of the fluomine canister, a 99.5 percent oxygen is produced.

The product oxygen from the OLOGS is compressed into a receiver to 1800 psi and is used as a high pressure gaseous oxygen source. The oxygen line, valving, regulators and masks are the same as in a high pressure oxygen system.

The fluomine OLOGS has the following components:

a. cooled-dried bleed air from ECS
b. timed cycling valving
c. fluomine canisters with prefilters
d. temperature cycling with electric heaters, Coolanol recirculating system, and cyclic timers
e. vacuum compressor with pressure switch
f. high pressure receivers
g. O_2 distribution system

The OLOGS has been flight tested on the B-1 (#4), and flight data has indicated a satisfactory oxygen supply. The logistics of the system shows a rather high cost system. The aircraft is freed of any on-base oxygen stores or resupply needs and presents a true bare-base capability for oxygen management. The reliability of the components has limited data for basing an optimistic assessment. The OLOGS on the B-1 included an air drier to reduce the water content of bleed air to a moderate dew point. Water will poison the fluomine and reduce its operational life. With this drier in place, however, no problems of this sort were encountered on the B-1 flight test program. The molecular sieve oxygen generating system was eventually chosen for application to the B-1B bomber aircraft because of lower weight, increased reliability, and lower costs associated with this system.

TABLE XXXII. Unique advantages and disadvantages of oxygen systems.

Oxygen Storage System	Advantages	Disadvantages
Gaseous Low Pressure	Reduced fragmentation Reduced leakage over high pressure Reduced fire hazard over high pressure No handling temperature problem	Heavy - large volume Requires in-place refill Requires handling equipment and service area Pressure regulation required Requires sophisticated ground handling equipment
Gaseous High Pressure	Less volume than low pressure Lighter than low pressure No handling temperature problem	More pressure regulation required Highest fragmentation hazard Highest leak rates Higher spontaneous fire hazard Requires sophisticated ground handling equipment
Liquid	Less volume than high pressure Lighter than gaseous Less pressure hazard	Requires special maintenance and service facilities Requires protective garments for personnel Requires ground handling equipment No traps in system Cold handling temperature Properly located overboard discharge Liquid drop/run problems Heat leakage
Super Oxide	No pressure regulation required Requires minimum service crew Requires minimum ground facilities	Requires pumping, air Relatively slow starting Requires filtering (dust)

TABLE XXXII. Unique advantages and disadvantages of oxygen systems - cont'd.

Oxygen Storage System	Advantages	Disadvantages
	No unit size limitation Low contributor to fire Smallest volume - lowest weight Bacterial depressant No static pressure problem Indefinite storage if hermetically sealed No pressure regulation required Non-Toxic	Exothermic (moderate) lower than chlorate Closed circuit system only
Chlorate Candle	Requires minimum service crew Requires minimum ground facilities Small volume - lightweight Simplicity of operation No distribution system Indefinite storage life Non-Toxic No pressure problem Easy, quick start Can withstand gunfire fragmentation Low fire contributor Normal size limitation High Installation Flexibility No pressure regulation required	Programmed flow schedule - not infinite flow control Moderate exothermal insulation required Must be kept free of hydrocarbon
Electro-Chemical	Minimum ground servicing Unlimited oxygen supply (from environment) Relatively free of contamination	Requires demineralization and particulate free water Requires particulate free air Maintenance characteristics not established Some explosive hazard Heat sink requirement High power requirement Large size, weight

TABLE XXXII. Unique advantages and disadvantages of oxygen systems - cont'd.

Oxygen storage system	Advantages	Disadvantages
Fluomine OLOGS	Intermittent oxygen production fills accumulator with no need for ground support servicing. Indefinite extended mission capability Qualified and demonstrated on B-1 aircraft flight test program.	Fire hazard, requires fire-extinguishing agent Fluomine is a handling hazard Requires 1800 psi compressor and accumulator combination Total system weight excessive for small aircraft Pre-filtering and bleed air drying required.
Molecular Sieve On-Board Oxygen Generating System	Light-weight comparable to LOX systems. No gas pressure hazard. Low contributor to fire. Non-Toxic Qualified and demonstrated on AV-8A Navy aircraft flight test program.	Breathing gas delivery pressures lower than existing systems. Pre-filtering and bleed air drying required. Larger plumbing lines may be required.

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