NOT MEASUREMENT SENSITIVE

JSSG-2010-10
30 October 1998
SUPERSEDING
AFGS-87226A
29 August 1990
MIL-STD-1776A(USAF)
25 February 1994

DEPARTMENT OF DEFENSE

JOINT SERVICE SPECIFICATION GUIDE

CREW SYSTEMS

OXYGEN SYSTEMS HANDBOOK

This specification guide handbook is for guidance only.
Do not cite this document as a requirement.

AMSC 15GP

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FOREWORD

JSSG RELEASE NOTE

The specification guides support the acquisition reform initiative, and is predicated on a performance based business environment approach to product development. As such it is intended to be used in the preparation of performance specifications. It is one of a set of specification guides. It is the initial release of this guide. In this sense this document will continue to be improved as the development program is accomplished.

1. This specification guide handbook is approved for use by all Departments and Agencies of the Department of Defense (DoD).
2. This Joint Service Specification Guide (JSSG) handbook, in conjunction with its companion JSSGs handbooks, is intended for use by Government and Industry program teams as guidance in developing program unique specifications. This handbook is for guidance only. This handbook cannot be cited as a requirement. If it is, the contractor does not have to comply. This document may not be placed on contract.
3. The complete set of JSSGs, and their respective handbooks, establish a common framework to be used by Government-Industry Program Teams in the Aviation Sector for developing program unique requirements documents for Air Systems, Air Vehicles, and major Subsystems. Each JSSG contains a compilation of candidate references, generically stated requirements, verification criteria, and associated rationale, guidance, and lessons learned for program team consideration. The JSSGs identify typical requirements for a variety of aviation roles and missions. By design, the JSSG sample language for "requirements" and "verification criteria" are written as generic templates, with blanks that need to be completed in order to make the requirements meaningful. Program teams need to review the JSSG rationale, guidance, and lessons learned to: (1) determine which requirements are relevant to their application; and (2) fill in the blanks with appropriate, program-specific requirements.
4. This document is Part 2 of two parts. Part 1 of the JSSG-2010 is a template for developing the program unique performance specification. As a generic document, it contains requirement statements for the full range of aviation sector applications. It must be tailored to delete non-applicable requirements to form the program unique specification. In addition, where blanks exist, these blanks must be filled in for the program unique specification to form a complete and consistent set of requirements to meet program objectives. Part 2 of the JSSG-2010 is a handbook which provides the rationale, guidance, and lessons learned relative to each statement in Part 1. The section 4, verification requirements, must be tailored to reflect an understanding of: (1) the design solution; (2) the identified program milestones; (3) the associated level of maturity which is expected to be achieved at those milestones; and (4) the specific approach to be used in the design and verification of the required products and processes. It must be recognized that the rationale, guidance, and lessons learned are not only generic in nature, but also document what has been successful in past programs and practices. This must not be interpreted to limit new practices, processes, methodologies, or tools.
5. Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document should be addressed to: ASC/ENSID, Bldg. 560, 2530 Loop Road West, Wright-Patterson AFB OH 45433-7101, by using the Standardization Document Improvement Proposal (DD Form 1426) appearing at the end of this document or by letter.

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1. SCOPE

1.1 Scope.

This handbook provides the guidance for the development requirements and verifications for an aircraft oxygen system and its components. This handbook is for guidance only. This handbook cannot be cited as a requirement. If it is, the contractor does not have to comply.

2. APPLICABLE DOCUMENTS

2.1 General.

The documents listed below are not necessarily all of the documents referenced herein, but are the ones that are needed in order to fully understand the information provided by this handbook.

2.2 Government documents.

2.2.1 Specifications, standards, and handbooks.

The following specifications, standards, and handbooks form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those listed in the latest issue of the Department of Defense Index of Specifications and Standards (DoDISS) and supplement thereto.

SPECIFICATIONS

DEPARTMENT OF DEFENSE

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, Aircraft, 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
MIL-V-43511	Visors, Flyers Helmet, Polycarbonate
MIL-P-87141	Parachutes
AFGS-87234A	Personal Protective Equipment, Aircrew
MIL-A-87244	Avionic/Electronic Integrity Program Requirements
AFGS-87249	Mechanical Equipment and Subsystems Integrity Program

STANDARDS

DEPARTMENT OF DEFENSE

MIL-STD-210	Climatic Information to Determine Design and Test Requirements for

Military Systems and Equipment

MIL-STD-810 Environmental Test Methods and Engineering Guidelines

MIL-STD-1568 Materials and Processes for Corrosion Prevention and Control in Aerospace Weapons Systems

MIL-STD-1587 Materials and Process Requirements for Air Force Weapon Systems

MIL-STD-1776 Aircrew Station and Passenger Accommodations

MIL-STD-1791 Designing for Internal Aerial Delivery in Fixed Wing Aircraft

MIL-STD-1798 Mechanical Equipment and Subsystems Integrity Program

MIL-STD-1800 Human Engineering Design Criteria for Systems

HANDBOOKS

DEPARTMENT OF DEFENSE

MIL-HDBK-157 Transportability Criteria

(Unless otherwise indicated, copies of the above specifications, standards, and handbooks are available from the Standardization Document Order Desk, 700 Robbins Ave., Bldg 4D, Philadelphia PA 19111-5094.)

2.2.2 Other Government documents, drawings, and publications.

The following other Government documents, drawings, and publications form a part of this document to the extent specified herein.

AFLC Abstract of Lessons Learned. ALD/PTL, Wright-Patterson AFB, OH. LL #0113, LL #0117, LL #0123, LL #0173, LL. 0175, LL #0330, LL #0331, LL #0332, LL #0333, LL #0334, LL# 0600, LL# 0622, LL #0787, LL #0841, 1 Jan 84; LL# 0055, 1 Jan 1985; LL—(OBOGS) 1 Jan 87.

AFFTC 80-24 Lessons Learned Report

AFP 160-5 Physiological Training

AFI 11-206 General Flight Rules

AFSC DH 1-3 Human Factors Engineering

FAR Part 25 Federal Aviation Requirement Airworthiness Standards: Transport Category Airplanes

MAC 55-2 C-5 Airlift Operations

MAC 55-130 C-130 Tactical Airlift Operations

MAC 55-141 C-141 Combat Airlift Operational Procedures

MAC Flyer, Aug 1987.

SAM-TR-73-47 Development of the USAF School of Aerospace Medicine, (USAFSAM)

Therapeutic Liquid Oxygen (LOX) Breathing System

SD-14 Listing of Toxic Chemicals, Hazardous Substances, and Ozone-Depleting Chemicals. Aug 1994

TO 15X-1-1 Technical Manual, Maintenance Instructions, Oxygen Equipment

Holden, R.D., Ernsting J. and Baumgardner, F.W., Physiological Assessment of Current USAF Integrated Oxygen Delivery Components. Tests by the Crew Protection Branch, USAF School of Aerospace Medicine, Brooks AFB TX.

(Order unclassified, unlimited distribution technical reports from the National Technical Information Service (NTIS), 5285 Port Royal Rd., Springfield VA 22161-.)

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

NORTH ATLANTIC TREATY ORGANIZATION (NATO) AGREEMENTS

STANAG 3053GGS	Breathing Oxygen Characteristics, Supply Pressure and Hoses
STANAG 3054GGS	Characteristics of Compressed Air for Technical Purposes, Supply Pressure and Hoses
STANAG 3056	Marking of Airborne and Ground Gas and Liquified Containers
STANAG 3198AMD	Functional Requirements of Aircraft Oxygen Equipment and Pressure Suits
STANAG 3296GGS	Aircraft Gaseous Oxygen Replenishment Couplings
STANAG 3341AI	Emergency Control Colour Schemes
STANAG 3370AI	Aircrew Station Warning, Cautionary and Advisory Signals
STANAG 3499GGS	Characteristics of Supply Equipment for Liquid Oxygen
STANAG 3545GGS	Characteristics of Breathable Liquid Oxygen
STANAG 3546GGS	Characteristics of Liquid Nitrogen
STANAG 3547GGS	Characteristics of Replenishment Equipment for Liquid Nitrogen

STANAG 3568GGS	Aircraft Gaseous Systems Replenishment Connections
STANAG 3624GGS	Characteristics of Oil-Free Compressed Nitrogen, Supply Pressure, and Hoses
STANAG 3647AI	Nomenclature in Aircrew Stations
STANAG 3688GGS	Characteristics of Breathable Oxygen Supplied by Chemical Solid Generators
STANAG 3705AI	Principles of Presentation of Information in Aircrew Stations
STANAG 3806GGS	Aircraft Gaseous Air/Nitrogen Systems Replenishment Connectors
STANAG 3865	Physiological Requirements for Oxygen Systems in New Generation High Performance Aircraft
STANAG 4155	NBC Protective Mask and Filter Canister Screw Threads

(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.)

(SD-14 is available from the Office of the Assistant Secretary of Defense for Economic Security, Washington DC 20301-3300.)

2.3 Non-Government publications.

The following document(s) form a part of this document to the extent specified herein. Unless otherwise specified, the issue of the documents which are DoD adopted are those listed in the issue of the DoDISS, and supplement thereto.

SOCIETY OF AUTOMOTIVE ENGINEERS (SAE)

SAE AIR-825 Oxygen Equipment for Aircraft

SAE AS 8047 Performance Standard for Cabin Crew Portable Protective Breathing Equipment for Use During Aircraft Emergencies

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

TSO-C64 Oxygen Mask Assembly,Continuous Flow, Air Carrier Aircraft

(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.)

Zalesky, P.J. and Holden, R.D., “Biomedical Aspects of Oxygen Regulator Performance: 1. Static Characteristics," *Aviation, Space and Environmental Medicine*, May 1976.

(Application for copies hsould be addressed to the Society of Automotive Engineers, Inc., 400 Commonwealth Dr., Warrendale PA 15096-0001.)

2.4 Order of precedence.

In the event of a conflict between the text of this document and the references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

3. REQUIREMENTS

3.1 Crew Systems Engineering (see JSSG-2010-1).

3.2 Crew Systems Automation, Information, and Control/Display Management (see JSSG-2010-2).

3.3 Cockpit/Crew Station/Cabin (see JSSG-2010-3).

3.4 Aircrew Alerting (see JSSG-2010-4).

3.5 Aircraft Lighting (see JSSG-2010-5).

3.6 Sustenance and Waste Management (S&WM) Systems (see JSSG-2010-6).

3.7 Crash Survivability (see JSSG-2010-7).

3.8 Energetics (see JSSG-2010-8)**.**

3.9 Life Support/Personal Protective Equipment (JSSG-2010-9)**.**

3.10 Oxygen System Requirements and Verifications

3.10.1 Oxygen system characteristics.

The oxygen system supply shall be appropriate for the mission requirements of the aircraft. Supply types include gaseous oxygen (GOX), liquid oxygen (LOX), and on-board oxygen generating systems (OBOGS). The oxygen system shall operate and be compatible with the operational environment of the air vehicle. System components shall also meet environmental storage requirements.

REQUIREMENT RATIONALE (3.10.1)

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 (3.10.1)

System description. The oxygen system shall support all crew members and other personnel for the normal and emergency intended missions of the aircraft. The oxygen system consists of the following functional subsystems as applicable:

a. Crew breathing system*
b. Paratroop oxygen system
c. Mission specialist oxygen system
d. Aeromedical oxygen system
e. HALO/HAHO oxygen subsystem
f. Passenger oxygen subsystem
g. Emergency crew member oxygen subsystem
h. Manual bailout oxygen
i. Walk-around oxygen assemblies
j. Aircraft fire fighter portable assembly
k. Helicopter emergency egress device (HEED)
l. Aircraft pressure suit provisions

NOTE: Paragraphs a through l are choices the document user may pick depending on the aircraft type and any aircraft oxygen subsystems that may be complimentary. For example, a transport aircraft may include paragraphs a for crew members subsystem, b for paratroops subsystem, d for aeromedical subsystem and f for passenger subsystem. Paragraphs i for walk-around assemblies and j for fire fighter portable assemblies may also apply. Further information is provided in the paragraphs for the crew member oxygen subsystem. This will be found within the first section, which is the specification and in Appendix A of this handbook for rationale, guidance, and lessons learned.

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 k. The selection of this equipment is given by the aircraft type and mission. The following examples illustrate how the functional subsystems and equipment groups are selected:

a. Fighter/attack aircraft - Fighter/attack tactical aircraft usually consists of one or two crew members. For crew member design requirements see 3.10.2.1. Because tactical type aircraft are exposed to extreme environments, such as high speed, high altitude and high dynamic g maneuvers, a breathing gas must be available for use by the crew at all times. The design requirements of the breathing gas system is most critical in order to function properly during all modes of aircraft operations. Another equipment group which applies is an emergency oxygen subsystem used during in-flight emergency, ejection and/or surface escape. During special missions, chemical defense protective assemblies, and/or pressure suite provisions will also apply.

b. Transport aircraft - While transport aircraft personnel and mission requirements vary widely and aircraft types vary from small prop aircraft to large, wide-body jet aircraft, the oxygen equipment needed for all transport aircraft is similar. What varies is the location and operation of this equipment. For example, a wide-bodied troop transport may be developed: The crew

oxygen system will be applicable to pilot, copilot, navigator, flight engineer, load master and other crew members in the design. Should paratroop, aeromedical, and HALO capability be needed, the applicable paragraphs apply. Additionally, walk-around oxygen assemblies and aircraft fire fighter portable assemblies are usually required.

In transport aircraft used only for movement of passengers, crew oxygen and passenger oxygen are the applicable paragraphs. Equipment groups that apply are walk-around oxygen assemblies and aircraft fire fighter portable assemblies.

c. Electronic warfare and maritime patrol aircraft - Electronic warfare maritime patrol aircraft (MPA) accomplish surveillance missions that require higher altitudes for long durations. These aircraft must continue their mission even in the event of cabin decompression. Oxygen is required for sustained flight at altitudes from 10,000 to 40,000 feet. For such missions, the applicable systems are the crew breathing system and the mission specialist oxygen system. The applicable subsystem equipment groups include walk-around oxygen assemblies and aircraft fire fighter portable assembly. All systems/subsystems shall be readily available for use in the event of a cabin decompression and other emergency situations.

d. Anti-submarine warfare (ASW) aircraft - ASW aircraft missions may require long duration flights with varying low to high altitude conditions. ASW aircraft can vary from multiple crew ejection seat to multiple crew patrol/surveillance type. In the case of ejection seat type aircraft, oxygen system design requirements shall be consistent with subparagraph a. for fighter/attack aircraft. For patrol/surveillance type aircraft applicable systems are crew breathing system, mission specialist oxygen system, walk-around oxygen assemblies and aircraft fire fighter portable assemblies.

e. Rotary wing aircraft - Rotary wing aircraft may perform special missions that require high altitude flight. For such missions a breathing gas must be available for use by the crew during the higher altitude phase of the flight above 10,000 feet. If oxygen is available it shall be used on all night flights above 5,000 feet. Equipment groups applicable for these missions are the crew breathing system, for mission specialist oxygen system and for chemical defense protective assemblies. For Helicopter emergency egress device (HEED).

System characteristics. Some applicable overall system characteristics 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 applicable characteristics should also be specified here.

REQUIREMENT LESSONS LEARNED (3.10.1)

TBD

4.10 Oxygen System Verification

Program Phase Timeline and Testing Requirements

Milestones to Check or Validate System Requirements

Concept Demonstration & Validation	Engineering & Manufacturing Development	Production & Deployment	Operations & Support

Ground Testing During Each Phase

Laboratory Tests	Laboratory Tests Bench Tests Component Performance Tests Environmental Tests Functional Tests on Air Vehicle	Component Certification Acceptance Procedures Air Vehicle System Functional Testing	Testing Required for Product Improvements

Potential Flight Testing in Each Phase

Concept Demonstration & Validation Flight Testing	DT&E Developmental Flight Testing & Evaluation	OT&E Operational Flight Testing & Evaluation	Flight Demonstration of Product Improvement

Milestones are:

System Requirements Review (SRR)

System Functional Review (SFR)

Preliminary Design Review (PDR)

Critical Design Review (CDR)

Test Readiness Review (TRR)

Functional Configuration Audit (FCA)

Physical Configuration Audit (PCA)

This generic program schedule is given to show how incremental verification may relate to each of the major program phases identified above. Table I has analysis, inspections, demonstrations and tests for a typical engineering manufacturing development phase. The table should be tailored for aircraft program under consideration. The table should also be tailored for other phases of the air vehicle program

TABLE I. Sample incremental verification matrix.

		Verifications Required to Validate Requirements by Milestone						
Requirement	Verification	SRR	SFR	PDR	CDR	TRR	FCA	PCA
3.10	4.10							
3.10.1	4.10.1	A	A	A, I	A, I, D	I, T	I, D, T	I
3.10.2	4.10.2	A, I	A, I, D, T	A, I	A, I, D	A, I, D, T	I, D, T	I
3.10.2.1	4.10.3	A, I	A, I	A, I	A, I, D	I, T	I, D, T	I
3.10.2.2	4.10.2.2	A, I	A, I	A, I	A, I, D	I, T	I, D, T	I
3.10.2.3	4.10.2.3	A, I	A, I	A, I	A, I, D	I, T	I, D, T	I
3.10.3	4.10.3	A	A	A, I	A, I	I, T	I, D	I
3.10.4	4.10.4	A	A	A, I	A, I	I, D	I, D	I

A - Analysis, I - Inspection, D - Demonstration, T - Testing

4.10.1 Oxygen system characteristics verification.

Analyses, demonstrations, inspections, and tests are essential in verifying the performance characteristics of a properly designed oxygen system. Qualification testing under extreme environmental conditions must be accomplished. The system characteristics verification shall be performed within the intended air vehicle for all required operational missions and scenarios. The type of oxygen system must be defined by the Preliminary Design Review. All controls and displays shall be inspected for satisfactory design and proposed for demonstration at the Test Readiness Review.

VERIFICATION RATIONALE (4.10.1)

The procuring activity should prove or validate oxygen equipment design and performance prior to production and aircraft installation. This ensures delivery of a properly designed oxygen system. Such verification minimizes hazards to crew members and passengers on the aircraft.

VERIFICATION GUIDANCE (4.10.1)

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 _____.

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 ensures 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 in flight.

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 (4.10.1)

Past experience in collecting data inflight on the C-17 aircraft showed a problem in that the engineer collected flow data referenced to the aircraft line pressure of 300 psig. The engineer thought that the line pressure is always 300 psig. In fact, this is the LOX converter calibration pressure. Line pressures actually vary from 50 psig (the lowest pressure the panel mounted breathing regulators will work) to about 370 psig (the pressure at which the first LOX converter relief valve vents off excessive pressure). As such, the data collected is not relevant to expected performance criteria. Flow rates should always be calibrated to Normal Temperature Pressure Dry (NTPD) 70^{o}F, 14.7 psig, Dry.

3.10.2 Performance requirements.

The oxygen system shall support the crew members and other personnel for the normal and emergency intended missions of the aircraft. The oxygen system shall meet minimum physiological requirements. The oxygen system may consist of the following functional subsystems as applicable: Crew breathing equipment, Paratroop oxygen, Mission specialist oxygen, Aeromedical oxygen, HALO/HAHO oxygen, Passenger oxygen, Emergency crew member oxygen, Manual bailout oxygen, Walk-around oxygen assemblies, Aircraft fire fighter portable assemblies, Helicopter emergency egress device (HEED), Aircraft pressure suit provisions and/or _____. Safety of flight certification developed from a safety of flight certification plan is required prior to each flight test phase. The safety of flight certification shall be coordinated and approved by the acquisition activity.

REQUIREMENT RATIONALE (3.10.2)

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

Physical characteristics. 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.

Operational characteristics. 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.

Electrical characteristics. All electrical characteristics should be specified to ensure proper operation of all electrical components that may be included with the aircraft oxygen system.

Environmental conditions. The oxygen equipment must function properly when exposed to the environmental extremes of aircraft flight, aircraft ground basing, and shipment and storage of equipment components.

Air transportability. 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.

Functional subsystem characteristics. The functional oxygen subsystems and equipment that apply to the design of the total aircraft oxygen system must be identified.

REQUIREMENT GUIDANCE (3.10.2)

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: _____.

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 _____.

The functional subsystems of the aircraft oxygen system and associated equipment groups are specified in terms of physical characteristics common to all types of aircraft oxygen systems. Other physical characteristics 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.

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

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 crew members' tasks. Another example is that all the oxygen systems should function properly under all the acceleration forces in flight. The face mask and hose should be suitably secured to the face when the pilot pulls G's. The design and placement of oxygen system controls and displays must functionally interface with the crew members and passengers such that use of the equipment is proper and mistakes are minimized.

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

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.

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

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

q. Wind blast

r. Catapult and arrestment

s. Endurance

t. Electromagnetic interference/compatibility

u. Ejection acceleration

The best approach in detailing these requirements to the oxygen system under development is to use the handbook format of *MIL-STD-810* to tailor environmental requirements. The oxygen equipment being developed may 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. Keep in mind that these requirements represent accelerated use of the equipment and subject the equipment to extremes which may seldom be encountered in actual service. The important point, however, is that the equipment must function properly after these environmental extremes. A good example of this type of situation is an emergency cockpit or cabin rapid (explosive) decompression. However, the equipment for life support must still provide life support to the on-board crew member(s) and passengers (if applicable). Refer to Appendix B for existing equipment that is similar to that under consideration. Environment test requirements may be determined as accomplished on past similar equipment environmental test requirements.

If commercial oxygen equipment is used the environmental extremes must be re-examined to see what testing has already been accomplished. Further testing for the military environment may show design modifications are needed for needed ruggedness.

Air transportability. The designated oxygen system components, _____ shall incorporate the following transportability features in their design: _____.

MIL-HDBK-1791 provides detailed design information on air transportability criteria. Of primary concern is restraint of the oxygen equipment in the cargo compartment of the aircraft. Another concern is safety while transporting gaseous and/or liquid oxygen equipment. Also consider oxygen supply which may be required to be used in transport such as for high altitude paratroops or with aeromedical oxygen equipment for personnel under medical care.

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: _____.

Functional oxygen subsystems and equipment are discussed in-depth in the following paragraphs. Cite only those subsystems and equipment applicable to the aircraft under consideration.

REQUIREMENT LESSONS LEARNED (3.10.2)

System characteristics. TBD

Physical characteristics. In new aircraft programs where the type of oxygen system is not defined, but based on a selection by the prime aircraft contractor, the oxygen supply system

choice is always based on a trade-off of these parameters. Development cost (if applicable) and life cycle cost are also trade-off's that need to be considered. Usually a comparative analysis of each type of supply source (pressurized gaseous oxygen (GOX) versus liquid oxygen (LOX) versus on-board oxygen generating systems (OBOGS)) is important to provide insight into making sound decisions. These comparisons are also important to show to contractor management and the procuring activity the rationale for decisions that are made.

Operational characteristics. Past experience has shown that preliminary evaluations with operational mission profiles of time versus altitude are important tools to calculate oxygen consumption and flow rate requirements. Usually these profiles are segments of flight like taxi, take-off, cruise, combat maneuvers and so forth.

Electrical characteristics. On Board Oxygen Generating Systems (OBOGS) generate oxygen continuously, but so far all designs require electrical power. Usually, the operational concept is warn the crew member if electrical power is lost to the OBOGS so that the emergency or backup oxygen is activated. So far no thought has been given to have the emergency BUS tied into the power such that oxygen is continuously generated even if primary electrical power is lost. Future designs should consider this option.

Environmental conditions. 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.

Ref: AFALC/PTL, WPAFB, OH, Abstract of Lessons Learned, 1 Jan 1984. When off-the-shelf equipment or government furnished equipment is used, environmental testing should be accomplished to ensure that the equipment will operate in its new environment. An example is given in which a piece of off-the-shelf equipment did not work in the new application (LL No. 0981). 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 (LL No.1004).

Air transportability. TBD

Functional subsystem characteristics. TBD

4.10.2 Verification of oxygen system performance requirements.

Analyses, demonstrations, inspections, and tests are essential in checking for a properly designed oxygen system that has been properly installed in the aircraft. The oxygen system installation shall be verified by _____. Performance testing is essential in determining the proper and effective operation of aircraft oxygen equipment that must provide life support in normal and emergency operations. Consideration must be given to component testing, system mock-up, man rating, and operational testing of the equipment. On Board Oxygen Generating

Systems must be bench tested for functional performance, qualification tested for environmental extremes, and altitude chamber tested by the Test Readiness Review and subsequent Flight Testing. Flight testing and/or demonstrations shall be conducted on the oxygen system at the end of Concept Validation Demonstration and during engineering evaluation at Developmental Testing and Evaluation and/or user evaluation at Operational Testing and Evaluation. Safety of flight certification shall be conducted prior any flight testing and this shall consist of _____ (e.g., such as functional performance, environmental testing and altitude chamber testing). A detailed list of safety of flight issues for certification is found in the handbook JSGS-1776-11. For DT&E all evaluations must be available at the TRR.

VERIFICATION RATIONALE (4.10.2)

System characteristics. Verification of the oxygen system will ensure that it is functionally compatible with all other aircraft systems.

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

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

Electrical characteristics. Performing functional tests and analyses on the electrical characteristics of the aircraft oxygen system will ensure that all equipment operates properly.

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

Air transportability. The transportability design features must be determined to be adequate for the planned use of the oxygen equipment.

Functional subsystem characteristics. The functional oxygen subsystems must perform as expected under all specified performance requirements.

VERIFICATION GUIDANCE (4.10.2)

System characteristics. 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. When checking the system operation usually the desirable practice is to subject each subsystem equipment and overall breathing system to functional ranges of performance that are expected inflight or on the ground. Flight tests may be appropriate to functionally check all equipment for proper performance. Failure modes analysis will also provide insight into to possibility of any undesired failure mode that may be dangerous.

Physical characteristics. The verification of the aircraft oxygen system physical characteristics shall consist of _____.

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. Demonstrations that the equipment will have the proper form, fit

and function are important to accomplish.

Operational characteristics. The verification of the aircraft oxygen system operational characteristics shall consist of _____.

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. Crew members and passengers should be representative of those who are expected to use the equipment. Operations performed should represent those expected to be accomplished during the aircraft missions. Functional demonstrations should be performed for all other aircraft subsystems that interface with the aircraft oxygen system. 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.

Electrical characteristics. Verification of the electrical characteristics of the aircraft oxygen system shall consist of _____.

Electrical systems experts should thoroughly analyze all circuit schematics and diagrams of the aircraft oxygen equipment initial design layouts to determine adequacy. Where the electrical components involve computers, micro-chips, and circuits, trained computer hardware and software technicians and engineers should analyze the equipment to ensure it is satisfactory. Bread boarding of all electrical components and circuits within the oxygen equipment is an efficient means of checking these functions and determining the need for design improvements. When the electrical equipment is installed on the aircraft, inspections should be done to ensure that wiring has been properly installed and restrained. Ensure that the oxygen system electrical components are compatible with the other electrical subsystems on the aircraft. Finally, aircraft crew members should test the oxygen system in flight.

Environmental conditions. The hardware, materials, and components of the oxygen system shall operate satisfactorily under the following tests: _____.

The specified environmental testing requirements 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 tailored to the oxygen system. Refer to Appendix B for existing equipment that is similar to that under consideration. Environment test methods may be determined as accomplished on past similar equipment environmental testing.

Air transportability. The oxygen equipment transportability features shall be verified by _____.

The verification should consist of analyses, inspections, demonstrations, and tests as necessary to determine that the transportability design features will be adequate. Formal certification of air transportability of oxygen systems or cargo must be performed by the Air Transportability Test Loading Agency (ASC/ENFC, Wright-Patterson AFB OH).

Functional subsystem characteristics. The functional subsystem characteristics verification shall consist of _____.

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 (4.10.2)

System characteristics. TBD

Physical characteristics. TBD

Operational characteristics. TBD

Electrical characteristics. Past experience has shown that it is absolutely essential that any type software, electronic and electrical equipment be ground tested with simulations prior to installation on an aircraft. This will preclude or minimize any unexpected failures on the aircraft.

Environmental conditions. Ref: AFALC/PTL, WPAFB, OH, Abstract of Lessons Learned, 1 Jan 1984. Failure to complete certain qualification tests (at least temperature, altitude, vibration, and shock tests) prior to development test and evaluation (DTE) can lead to program delays caused by premature hardware failures. (LL No. 1399) 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. (LL No. 0706) For that reason, the use of JP-5 is not a good choice for this type of testing.

Air transportability. TBD

Functional subsystem characteristics. TBD

3.10.2.1 Crew breathing system.

The crew breathing system shall be designed to support the crew members at their stations under all expected normal and emergency situations. The crew breathing system shall meet servicing, duration, production, breathing dynamics, altitude protection, contamination protection, and NBC protection to meet the mission need of the aircrew. The crew breathing system may consist of the following subassemblies or components: Crew mounted breathing equipment (i.e., oronasal mask, delivery hose(s), connectors), Crew regulator breathing equipment, Crew breathing controls, displays and warnings, Crew oxygen supply equipment, High altitude protection, Nuclear, biological and chemical (NBC) protection provisions, High G protection provisions and/or _____. Crew member equipment will apply to the following types of aircraft: Fighter, Attack, Trainer, Mission specialist oxygen system, Transport and Bomber.

REQUIREMENT RATIONALE (3.10.2.1)

Crew breathing system. The aircraft breathing system design must support all crew members, including flight crew and mission essential crew members, when necessary. The required components of the breathing system should be specified to ensure they will be provided.

Crew mounted breathing equipment. Crew mounted equipment usually consists of an oronasal mask, oxygen supply hose(s), special connectors, and filter packs (if applicable). Physiological performance requirements for this equipment must be specified to ensure it is acceptable for use by the crew member.

Crew regulator breathing equipment. Crew member regulator equipment is necessary to supply the proper flow rates and pressures for breathing at all expected aircraft altitudes for normal and emergency situations.

Crew oxygen supply equipment.

a. A sufficient oxygen supply must be provided to support crew member breathing requirements under all normal and emergency situations throughout the entire aircraft mission. Currently the only approved technologies that supply oxygen are a pressurized vessel, a liquid oxygen converter, a MSOGS, and/or a chemical oxygen generating system.

b. The oxygen supply must reach crew members within a temperature range that will not impair breathing nor affect performance.

c. For proper operation of the crew oxygen system, certain valves are needed as pressure reducer valves, check valves, pressure relief valve, etc. To ensure that supply is not lost or that an increased fire hazard does not result, check valve(s) may be provided.

d. Tubing and associated connectors are provided so that oxygen may be supplied to the crew member.

e. A gaseous or liquid oxygen supply will require replenishment. As such, filler valves, pressure relief valves, overboard vent valves, quick disconnects, access to servicing valves and associated ground supply equipment must be available. If a chemical oxygen generating system is used, a means of replenishing the chemical must be provided.

Nuclear, biological and chemical (NBC) protection. NBC protection provisions must be included in the crew member breathing system if that threat cannot be eliminated by another means such as procedure or aircraft cockpit design. Assemblies are needed which will protect the respiratory tract and eyes—both in flight and on the ground—against chemical and biological agents in vapor, aerosol, liquid and particulate form and radioactive particulate matter.

High g protection. When high g protection equipment is needed to support the crew member in high sustained g environments up to nine g's into the seat bottom and high onset rate of g's, certain minimum requirements are necessary to ensure this equipment will provide protection.

Mission specialist oxygen system.

a. In aircraft that employ mission specialist crew members, there will be no flight crew member such as a load master to walk about the cabin to ensure the proper dispensing of supplemental oxygen in an emergency decompression. Therefore, automatic initiation of an emergency decompression alarm system is required. Dispensing of mask assemblies can be automatic or manual. A suspension device or readily accessible stowage method facilitates rapid donning of mask assemblies. A pressure altitude should be specified when automatically activated mask assemblies are used. Oxygen flow to the mask assemblies is automatic.

b. AFI 11-206 requires that oxygen be readily available to all onboard personnel at their seated

position for cabin pressure altitudes that exceed 10,000 feet.

c. Each component necessary to the aircraft oxygen system design must be designated to ensure that the designer includes all detail and components.

d. The aircraft mission 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. The USAF procuring activity must designate to the designer the minimum supply necessary to complete all planned missions. Sufficient oxygen should be available for flight to an alternate destination in an emergency.

f. The delivery pressure range is specified to ensure it can maintain proper operation of the breathing regulator. The flow rate requirement should represent the worst case or highest capacity of the breathing regulator.

REQUIREMENT GUIDANCE (3.10.2.1)

Crew breathing system. The crew breathing system shall be designed to support the crew members at their stations under all expected normal and emergency situations. Oxygen availability and use is determined by the aircraft type and mission profiles. The most common reason for an oxygen system is for aircraft that fly for extended periods at altitudes that exceed 10,000 feet. The crew breathing system shall consist of the following subassemblies or components:

a. Crew masks, hoses and ancillary equipment

b. Crew regulator breathing equipment

c. Crew breathing controls, displays and warnings

d. Crew oxygen supply equipment

e. High altitude protection

f. Nuclear, biological and chemical (NBC) protection provisions

g. High G protection provisions

When designing aircraft with breathing systems, the crew mounted equipment, regulation mechanism, oxygen supply equipment, system distribution plumbing, and controls, displays, and warnings are required. Oxygen is recommended on on all aircraft with night flights operating above 5,000 feet to enhance night vision capability. For example, helicopters incorporate oxygen systems to enhance night vision capability. In fighter type aircraft where the cabin altitudes range from 0 to 25,000 feet for routine operations and up to 60,000 feet for a cockpit decompression emergency, a breathing system is needed to protect the crew member at all times. In transport type aircraft, oxygen is needed only in emergencies, as the cabin altitude is usually 8000 feet or lower. Some special missions such as high altitude cargo or paratroop drops would require extended duration supplemental oxygen. In higher altitude flight, cabin altitude excursion to 12,500 feet is typical. That is why passenger masks usually are not set to drop down until this cabin altitude is experienced. In an emergency decompression, crew members need a sufficient oxygen supply to operate under moderate to extreme workloads.

Pressure demand type equipment is suitable for such situations. Regulators and supply outlets, hoses and masks are also provided at crew member rest areas (seats, bunks and lavatories) since the crew members occupy these areas at some time during most missions.

Naval anti-submarine warfare (ASW) aircraft use oxygen as required which always includes night flights above 5,000 feet. Special mission electronics warfare aircraft in the USAF must be able to stay on station to complete a mission even in the event of an emergency decompression. This may require extended duration flight at 20,000 to 30,000 feet with all flight and mission crew members on oxygen for several hours.

High altitude protection provisions are necessary when sustained aircraft missions exceed 50,000 feet and when missions are above 25,000 feet if, in the event of an unplanned cockpit decompression, immediate descent to an altitude at which cabin pressure can be maintained at or below 25,000 feet is not possible.

The following are USAF requirements for use of oxygen equipment in USAF aircraft derived from AFI 11-206 as of March 1994.

a. Pressure Suits. Each person flying above 50,000 feet must be trained to use and must wear a pressure suit. The MAJCOM may waive this requirement if necessary and if the command surgeon concurs. When a waiver is granted, the MAJCOM must designate specific time or altitude limits and set up recovery procedures to ensure flight safety.

b. Oxygen Requirements. When the cabin altitude exceeds 10,000 feet, each occupant of an Air Force aircraft must use supplemental oxygen.

c. Unpressurized aircraft:

(1) If the minimum enroute altitude or an air traffic controller (ATC) clearance requires flight above 10,000 feet mean sea level (MSL) in an unpressurized aircraft, the pilot at the controls must use oxygen.

(2) If oxygen is not available to other occupants, flight between 10,000 and 13,000 feet MSL must not be longer than three hours. Also, flight above 13,000 feet MSL is not authorized.

(3) If all occupants are equipped with oxygen, flights may be conducted up to 25,000 feet.

d. Pressurized aircraft. When an aircraft is flown over 10,000 feet MSL, but its cabin altitude is maintained at 10,000 feet or less, oxygen equipment is used as specified in table II.

(1) A MAJCOM may establish more restrictive procedures for using oxygen during ground or flight operations of tactical aircraft or jet trainers if required.

(2) Sufficient oxygen must be aboard an aircraft before its takeoff to fly the planned mission.

e. Loss of Cabin Pressure:

(1) If the aircraft loses cabin pressure, the aircraft commander will initiate an immediate descent to the lowest practical altitude, but in no case will cabin altitude be maintained above 25,000 feet, unless the occupants are wearing functional pressure suits.

(2) If the aircraft loses pressure, and any occupant lacks functional oxygen equipment, the aircraft commander will descend to maintain a cabin altitude of 10,000 feet or less and comply with requirements for unpressurized aircraft (c.) above.

(3) The aircraft commander will notify the flight safety office of any unintentional loss of cabin pressurization when cabin altitude exceeds 18,000 feet MSL.

NOTE: If in any case an occupant appears to be suffering decompression sickness, the individual should be administered 100 percent oxygen. The pilot will descend as soon as practical, and land at the nearest suitable installation where medical assistance can be obtained and preferably when compression therapy is available. Before continuing the flight, the affected individual must consult with a flight surgeon or a civilian aeromedical examiner. Decompression sickness may occur up to 12 hours after mission completion.

NOTE: Aircrew in Navy tactical aircraft are required to use oxygen at all times while flying at sea level through 50,000 feet. Oxygen is also required for all Navy night flights above 5,000 feet.

TABLE II. Oxygen requirement for pressurized aircraft.

Ambient Altitude in Feet	Pilot	Pilot*	Occupants
10,000 ft through 25,000 ft	R	R	NA
Above 25,000 ft through 35,000 ft	I	R	R
Above 35,000 ft through 41,000 ft	I	I	R
Or	O	R	R
Above 41,000 ft through 45,000 ft	O	I	R
Above 45,000 ft through 50,000 ft	O	I	I
Above 50,000 ft	P	P	P
LEGEND:			
R - Oxygen must be readily available. A functioning system and mask must be located within arm's reach, and the regulator set to 100 percent and ON, if the system contains an operator adjustable regulator.			
I - Oxygen must be immediately available. Helmets must be worn with an oxygen mask attached to one side, or an approved quick-donning or sweep-on mask properly adjusted and positioned for immediate use. Set oxygen regulator to 100 percent and ON.			
O - Oxygen must be used.			
P - Pressure suit must be worn.			
**These requirements also apply to non pilot crew members occupying crew positions with direct access to flight controls.			

Often the question arises as to the time the crew member should have to be able to don oxygen masks and breath oxygen from the regulator. The FAA requires a time to don and breath oxygen of 5 seconds. For purpose of a time limit in interpreting table II, “Readily Available” means donning oxygen masks and breathing oxygen within 15 seconds or less. “Immediately

Available" means donning oxygen masks and breathing oxygen within 5 seconds or less. These time limits are not arbitrary, but based on physiological limits of crew members in flight.

The Navy requires oxygen/breathing gas for the entire mission in tactical aircraft. In anti-submarine warfare aircraft 100 percent oxygen is required above 5,000 feet. In transport aircraft oxygen requirements are similiar to that for USAF transport aircraft.

If the aircraft is expected to be in a nuclear biological chemical (NBC) environment on the ground or in flight, NBC protection provisions should be incorporated into the breathing system.

Crew mounted breathing equipment. Crew mounted equipment shall be provided that meets the following minimum physiological, environmental and operational requirements: _____.

A primary factor of consideration in any new aircraft program is the locations desired for the breathing regulator(s). Past experience in USAF oxygen systems has shown that when considering all factors, the priority for regulator placement is aircraft panel mounting is first choice, seat mounting is second choice and man mounting is the third choice. This priority is also valid for any Naval aircraft that will not be required for carrier launch and retrevial (in other words, there is an underwater breathing requirement). In this case, man mounting the breathing regulator is necessary. There is an underwater breathing requirement for a crew member egressing from a ditched aircraft. Placing the breathing regulator on the man close to his mouth and nose can mean improved breathing performance, but other penalities such as excess weight while pulling G's can be restrictive.

Background. The oxygen enriched air mixture required by aircrew in flight is generally delivered by means of an oronasal mask. Typically an oronasal mask used by aircrew operating high performance aircraft consists of a face piece, inlet and outlet ports, a valve system, an inlet hose, a microphone and a suspension system whereby it is donned on the crew member's head or attached to the protective helmet. The face piece has a flexible edge which seals against the skin of the face to form a cavity into which gas from the breathing gas supply is delivered by way of the inlet hose and inlet port. Expired gas is conducted out of the mask cavity through the outlet port. A valve system which generally consists of an inlet non-return valve and a pressure compensated outlet valve ensures unidirectional flow of gas through the ports of the mask. The valve system also holds the pressure in the mask cavity when the pressure at which breathing gas is provided by the supply system is increased. The suspension system which is mounted on a rigid portion of the face piece provides the means of achieving a comfortable and effective seal of the mask to the face. It also retains the mask in place when the wearer is exposed to acceleration forces and/or wind blast. The pressure at which gas is delivered through the mask is usually close to that of the cabin environment. Continuous positive pressure breathing at pressures greater than 4.0 kPa (30 mm Hg or 16.1 inch water gage (in. wg)) will be required, however, in the event of loss of cabin pressure leading to exposure to altitudes greater than 50,000 feet (15,000 m). High levels of pressure breathing can also be used to enhance tolerance of sustained positive accelerations. The design of an oronasal mask which will effectively deliver gas at positive pressures greater than 4.0 kPa (30 mm Hg) and impose minimum impairment of aircrew task performance throughout the normal flight, as well as in emergency conditions, must meet certain minimum physiological requirements.

Baseline requirements. For new mask designs, the goal is to improve the performance over existing masks, hoses and connectors. When considering equipment where NBC protection is

not required, the baseline mask is the MBU-12/P with the associated delivery hose and CRU-60/P harness mounted connector used with the CRU-73/A panel mounted regulator. The MBU-5/P mask has breathing performance comparable to the MBU-12/P since they both use the same breathing combination inhalation/exhalation valve. See *Appendix B* for additional information on this existing equipment. During fighter aircraft flight operations, the mask, hoses and connector(s) must accommodate peak respiratory flows ranging from 90 to 150 liters per minute that occur with ventilation's between 30 and 50 liters per minute. Occasionally peak respiratory demands up to 200 liters per minute or more will be encountered during breathing maneuvers to increase the crew member's tolerance to high accelerations.

Through altitude chamber testing in the past, a comparison of the relative contribution of components to the total inspiratory resistance at a 100 liters per minute (lpm) flow rate was determined. The results are given in table III.

This testing has shown the mask and regulator to be the primary contributors to pressure drop or inspiratory resistance. New mask and regulator designs should therefore seek to minimize the breathing resistance and the corresponding pressure drop.

An example of test data on the relationship between peak respiratory flows and the MBU-5/P mask cavity pressures for the complete oxygen delivery equipment, including the CRU-73/A regulator, six foot hose and CRU-60/P connector, is given in table IV for useful background information. Table V gives more data of this type for the MBU-12/P mask.

On reviewing this and other data, inspiration and expiration pressure values which are relatively insensitive to the altitude but are a strong function of the regulator peak outlet flow rate were evident. The exceptions are for all peak flow rates at altitudes exceeding 35,000 feet. This happens because the regulator is in the pressure breathing mode at these altitudes. Additionally, the pressure swings at very high peak flow rates and altitudes below 25,000 become very excessive. This scenario will present the most difficult test of performance for any new mask design, since low pressure swings are desired for lower altitudes and high peak flow rates to improve acceleration protection. Also, regulator designs should be improved to reduce the inspiration and expiration resistances at lower altitudes.

TABLE III. Inspiratory resistance at 100 lpm at various altitudes with equipment added from mask to the regulator.[1/]

Equipment (Type)	Pressure drop in. wg (% of total)			
	Ground level	8000 feet	18,000 feet	27,000 feet
Mask MBU-5/P	5.28 (57)	3.86 (65)	2.68 (65)	1.93 (64)
Connector CRU-60/P	5.67 (4)	4.33 (8)	3.03 (9)	2.13 (7)
Hose 60 inches long	6.42 (8)	4.80 (8)	3.39 (9)	2.44 (11)
Regulator [2/] CRU-73/A	9.33 (31)	5.94 (19)	41.13 (18)	2.99 (18)

[1/] Reference – Holder, R. D., Ernsting J. and Baumgardner, F.W., "Physiological Assessment of Current USAF Integrated Ocygen Delivery Components," tests by the Crew Protection Branch, USAF School of Aerospace Medicine, Brooks AFB TX.

[2/] The oxygen regulator was at a 100 percent oxygen setting.

TABLE IV. Peak respiratory flows with MBU-5/P mask.[1/]

Peak Respiratory Flows (lpm) ATPD[2/]	Mask Cavity Pressures (in. wg)		
Ground Level[3/]	Inspiratory``	Expiratory	Swing
30	-1.02	1.18	2.20
70	-2.95	2.17	5.12
110	-5.09	3.54	9.45
150	-10.24	5.31	15.55
8,000 Feet			
30	-1.02	1.18	2.20
70	-2.52	1.81	4.33
110	-4.41	2.83	7.24
150	-7.87	4.49	12.36
16,000 Feet			
30	-0.94	1.10	2.05
70	-2.05	1.61	3.66
110	-3.74	2.44	6.18
150	-6.10	3.74	9.84
25,000 Feet			
30	-0.79	1.02	1.89
70	-1.73	1.50	3.23
110	-2.95	2.05	5.04
150	-4.72	2.76	7.48

[1/]Regulator is in 100 percent mode. Reference Holden, R.D., et al.
[2/]Volume at ambient temperature and pressure, dry.
[3/]Measurements were taken at the ground level at Brooks AFB, TX.

TABLE V. Cyclic flow tests on MBU-12/P mask.*

Peak Respiratory Flows (lpm) ATPD	Mask Cavity Pressures (in. wg)		
Ground Level	Inspiratory	Expiratory	Swing
32	-1.2	0.6	1.8
100	-4.3	1.8	6.1
200	-13.0	7.0	20.0
8,000 Feet			
32	-1.1	0.5	1.6
100	-3.6	1.3	4.9
200	-10.5	5.5	16.0
18,000 Feet			
32	-0.9	0.5	1.4
100	-2.7	1.3	4.0
200	-7.5	4.0	11.5
25,000 Feet			
32	-0.8	0.5	1.3
100	-2.3	1.1	3.4
200	-6.0	3.0	9.0
35,000 Feet			
32	-0.8	2.6	1.8
100	-2.3	1.1	3.4
200	-2.0	7.3	9.3
43,000 Feet			
32	10.8	12.5	1.7
100	5.7	9.6	3.9
200	4.8	12.0	7.2
50,000 Feet			
32	13.5	15.0	1.5
100	10.5	14.2	3.7
200	8.0	15.5	7.5

[1/]Resistance of valve, mask, hoses, connectors, and CRU-73/A regulator on normal mode.

Reference: Performance tests on MBU-12/P oxygen mask and valve. Qualified at Brooks AFB TX, 1982.

General requirements for new equipment. An oronasal mask which can be used for the delivery of gases at positive pressures greater than 4.0 kPa (30 mm Hg) and which is also

suitable for use in all other conditions of flight in high performance aircraft must:

a. Be of minimal weight and be suitable for continuous wear for at least eight hours.

b. Impose minimum resistance to breathing. This should also include low temperature exposure which is a special problem.

c. Allow continuous positive pressure breathing at pressures up to 34 mm Hg for emergency descent from 50,000 feet and up to 82.5 mm Hg for acceleration protection with no increase of resistance to breathing.

d. Seal effectively to the face, preventing excessive inboard or outboard leakage of gas to preclude hypoxia.

e. Prevent excessive re breathing of expired gas to minimize reduced oxygen and excessive carbon dioxide concentrations.

f. Function effectively during exposure to positive accelerations up to +9 Gz, remain in place on the face, maintain a good seal to the skin and not interfere significantly with breathing.

g. Impose the minimum restriction of vision and head movement.

h. Be easy to remove and replace both on the ground and in flight.

i. Provide effective electrical transmission of speech.

j. Remain in place during and function after exposure to the acceleration and wind blast forces which occur during assisted escape at high speed.

k. Seal effectively against inboard leakage of water and permit breathing when the head is immersed, provided that a supply of breathing gas is maintained to the mask.

l. Be compatible with the wearing of aircrew spectacles, flight helmet (if applicable) and any other eye protective devices.

m. Maintain noise level within the oxygen mask cavity at all frequencies to a miximum 95dB. This shall be referenced to 2.0×10^{-4} dynes per cm^2. The hose and breathing equipment shall also not be allowed to contribute to a noise level in the mask cavity which exceeds 95 dB at all frequencies.

Detailed requirements for new equipment. The oronasal mask includes the mask proper (face piece, supporting harness, valves and microphone) as well as the inlet hose (not including the half coupling at the free end of the hose) and the harness, which attaches the mask to the protective helmet. An oronasal mask for use in high performance aircraft and for the delivery of continuous positive pressure breathing at pressures up to and greater than 30 mm Hg shall meet the following requirements.

a. Weight and dimensions. The weight and dimensions of the mask should be as small as possible. The weight should not exceed 0.4 kg and should be distributed so that the center of gravity of the mask is as close to the face as possible. Larger dimension masks tend to pull away from the face during high accelerations and positive pressure breathing.

b. Sizing. The mask is to be sized so that the range of sizes will fit at least the 5th percentile female through the 95th percentile male of the USAF flying population. The number of different mask sizes required should be as few as possible.

c. Comfort. The shape, flexibility and sealing mechanism of the face piece to the face and the suspension harness should be such that the mask can be worn continuously for up to at least eight hours.

d. Materials. Those parts of the mask which come into contact with the skin of the head and neck should be made of materials which are non-irritating, non-allergenic, and non-toxic to wet and dry skin. The mask should be as flame resistant as is compatible with its primary functions. The material that contacts the face should be as soft and compliant to the facial configuration as possible and practical.

e. Occlusion of nostrils. The mask, while in place on the face, must allow the wearer to occlude his/her nostrils in order to perform the Frenzel and/or Valsalva maneuvers.

f. Resistance to breathing. The mask should be capable of passing inspiratory and expiratory flows up to at least 3.3 liters at ambient temperature and pressure, dry (ATPD) per second. The resistance to respiration imposed by the mask alone (including the inlet hose but not the inlet hose half coupling) at ground level, at altitude, with or without safety pressure and during continuous positive pressure breathing at pressures up to 11 kPa (82.5 mm Hg) should not exceed the values in table VI.

g. Seal to the face. The seal between the mask and the skin of the face should be such that:

(1) The inboard leakage into the mask cavity should not exceed 5 percent of the pulmonary ventilation when the mean pressure in the mask cavity is between 0 and 1 kPa (4 in. wg) less than that of the environment.

(2) The outboard leakage should not exceed the limits given in table VII at the indicated mean pressures in the mask cavity:

TABLE VI. Design goals for mask pressure swings.

Peak inspiratory and expiratory flow (litres (ATPD) per sec)	Maximum change of mask cavity pressure during the respiratory cycle (kPa (in. wg))	
	Goal	Minimum Requirement
0.5	0.4 (1.6)	0.5 (2.0
1.5	0.6 (2.4)	0.85 (3.4)
2.5	1.0 (4.0)	1.75 (7.0)
3.3	1.5 (6.0)	3.00 (12.0)

TABLE VII. Allowable mask leakage.

Mean pressure in mask cavity relative to the environmental pressure (kPa (mm Hg))	Maximum outboard leakage (litres (ATPD) per sec)
+1 (+7.5 mm Hg)	0.03
+4 (+30.0 mm Hg)	0.10
+11 (+82.5 mm Hg)	0.25

a. Performance under sustained acceleration. The resistance to breathing imposed by the mask and mask leakage during exposure to sustained accelerations up to +9 Gz should also be within limits given for impedance to breathing and seal to the face.

b. Respiratory dead space. The respiratory dead space of the mask should not exceed 0.2 liter (ATPD).

c. Restriction of vision. The restriction of the binocular visual field should be no greater than the limits shown on figure 1. Interactions between the mask and the aircrew equipment on the upper part of the trunk should be minimal and not restrict head movement or downward vision.

TBD

FIGURE 1. Binocular visual field restrictions.

d. Low temperature performance. The mask should perform satisfactorily and not impose resistance to breathing in excess of the limits in *table V* during exposure to air temperatures down to -26°C with wind speeds up to 7.5 meters per second (15 knots) for at least two hours. In addition, the mask should perform satisfactorily for at least 30 minutes with only a limited increase in resistance to breathing (mask cavity pressure swings up to twice the values specified during exposure to air temperatures between -40°C and -26°C with wind speeds up to 7.5 meters per second (15 knots).

e. Escape. The mask should not be displaced from the face by the accelerations and wind blast to which it and the aircrew member may be exposed during assisted escape from an aircraft flying at indicated speeds of at least 300 meters per second (600 knots).

f. Communication equipment. The mask should include a microphone for personal communication. The microphone and associated cords and slugs should be compatible with the aircraft communication equipment. Low weight, small size, noise canceling and replacement capability are all essential characteristics. *Appendix B* provides additional details.

Crew regulator breathing equipment. Crew member regulator equipment shall be provided that meets the following minimum physiological, environmental and operational requirements: _____.

Breathing equipment regulators which supply air or oxygen or mixtures of these gases are fitted to many military aircraft. These regulators provide protection against hypoxia at cabin altitudes up to 50,000 feet and prevent the inhalation of toxic materials, such as fuels, lubricants, hydraulic and extinguisher fluids and the products of thermal combustion, which may in emergency conditions contaminate the atmosphere of the crew compartment. The composition of the gas and the pressures at which it is delivered to the respiratory tract must meet certain minimum physiological standards to ensure that the aircrew can perform flight tasks without impairment.

The CRU-73/A is the current acceptable regulator in use in many USAF aircraft. *Appendix B* has further details. Tables VIII, IX and X give some background on the performance characteristics of the CRU-73/A regulator tested in 1976 at Brooks AFB, Texas. Tables XIa through XIj give performance characteristics of the Navy CRU-79/P regulator, CRU-82/P and CRU-88/P OBOGS regulator and the CRU-103/P Gz compensated regulator and all Navy panel mounted diluter demand regulators including the CRU-96/A, CRU-97/A, CRU-101/A and CRU-102/A.

However, new regulator designs should exceed the performance of this regulator. The following information should be considered in the design of new regulators.

a. General requirements. Regulator breathing systems for aircrew shall:

(1) Meet respiratory demands without imposing excessive resistance to breathing.

(2) Prevent hypoxia while the cabin is pressurized without inducing acceleration atelectasis (lung collapse) or delayed otitic barotrauma (middle ear block).

(3) Prevent significant hypoxia following decompression of the pressurized cabin to cabin altitudes up to the maximum possible cabin flight altitude. Above altitudes of 50,000 feet, additional altitude protection equipment such as a partial pressure suit is needed.

(4) Prevent, when required, greater than 2 percent admixture of cabin air with the gas from the aircraft oxygen store or onboard generation system.

(5) Not impose excessive re breathing of expired gas.

(6) Provide, when required, safety pressure in the mask cavity to prevent inboard leakage of environmental air.

(7) Provide a press-to-test feature so that the user may test the maximum outlet regulator pressure.

(8) USAF regulator systems provide pressure breathing automatically when the cabin altitude exceeds 30,000 feet (for 100 percent oxygen supply) and, when manually selected, at ground level (press-to-test facility). Navy systems provide pressure breathing automatically when the cabin altitude exceeds 34,000 feet for 100 percent oxygen systems and at 32,000 feet for OBOGS to compensate for the reduce oxygen percentage (90-93 percent).

(9) Not produce significant oscillations of pressure within the mask cavity that would interfere with breathing or produce excessive noise that would interfere with crew member communication.

(10)Prevent the pressure generated by trapped gas on rapid decompression from exceeding acceptable physiological limits.

(11)Provide, when required, positive pressure breathing for high acceleration protection.

(12)Provide metals and elastomers that are compatible with the oxygen enriched environment.

(13)Provide a check valve or disconnect fitting on the aircraft side of the regulator supply line that allows a continuous flow of uninterrupted oxygen to the regulator when connected and acts as a check valve when disconnected. For chest or seat mounted regulators, an uninterrupted flow of oxygen from the emergency supply must be available on ejection.

TABLE VIII. Flow suction characteristics of CRU-73/A regulator with 50 psig inlet presure.[1/]

Altitude	Output Flow (liter/min)	Outlet Pressure (in. wg)	
		Normal or dilution	100% 0_2
ground level	2	-0.27	-0.27
	30	-0.36	-0.36
	50	-0.45	-0.46
	85	-0.65	-1.00
10,000 feet	2	-0.26	-0.26
	30	-0.33	-0.31
	50	-0.38	-0.38
	85	-0.55	-0.54
20,000 feet	2	-0.24	-0.24
	30	-0.30	-0.31
	50	-0.35	-0.33
	85	-0.45	-0.46
27,000 feet	2	-0.25	-0.25
	30	-0.31	-0.30
	50	-0.32	-0.19
	85	-0.40	-0.27

*Reference - Zalesky, P.J. and Holden, R.D., “Biomedical Aspects of Oxygen Regulator Performance: 1. Static Characteristics," *Aviation, Space and Environmental Medicine*, May 1976.

(1) Provide a manual control for selection of air dilution or 93 to 100 percent oxygen when desired. Only molecular sieve oxygen generating systems use 93 percent oxygen as the maximum oxygen concentration. Cabin air leakage is unacceptable when the 100 percent breathing mode is selected.

(2) Provide compatibility with blowers and filter packs, if required, while observing the physiological requirements contained herein.

(3) Provide an anti suffocation valve to permit an unconscious user to breathe air when the oxygen supply is not available. The device should warn a conscious user that the oxygen supply to the regulator is not available by inducing a noticeable breathing resistance.

TABLE IX._Oxygen concentrations of the CRU-73/A regulator while in the normal or dilution mode.*

Altitude	Outlet Flow (liter/min)	PO_2 (mm Hg)	Oxygen added** (percent)
ground level	15	304	25.15
50	207	19.37	
135	366	35.68	
10,000 feet	15	227	28.40
50	194	20.39	
135	253	34.71	
15,000 feet	15	197	31.53
50	165	22.09	
135	181	26.81	
20,000 feet	15	172	26.81
50	150	27.8	
135	192	43.0	
25,000 feet	15	165	47.5
50	160	45.3	
135	220	72.2	
32,000 feet	15	207	100.0
50	206	99.8	
135	204	98.6	

*Reference - Zalesky, P.J. and Holden, R.D.

**Percent Oxygen added = $100(PO_2 - 0.21\ Pa)$, where Pa is defined as the ambient pressure.

$$0.79\ Pa$$

a. Detailed physiological requirements. The following physiological requirements should be considered in the performance of aircrew breathing systems. To ensure that these requirements apply to the complete breathing system, the performance is specified for entry to the nose and mouth or mask cavity of the user.

(1) Respiratory demands. The system should be capable of meeting maximum (peak) inspiratory and expiratory flows of up to 3.3 liters per second (ATPD) with rates of change of flow at least 20 liters per second per second (ATPD) at 3.3 liters per second.

TABLE X._Outlet positive pressure characteristics of CRU-73/A regulator in normal mode.*

Altitude	Outlet Positive Pressure (in. wg)		
	10 liter/min	70 liter/min	135 liter/min
20,441	-0.28	0.16	0.04
29,988	1.49	1.47	1.59
31,990	1.49	1.68	1.40
33,991	1.62	1.52	1.47
35,993	1.62	1.70	1.56
37,994	1.52	1.66	1.43
39,011	1.81	1.82	1.89
39,995	3.83	3.70	3.62
41,013	5.53	5.28	4.99
41,997	6.66	6.55	6.92
43,014	8.29	8.91	8.03
46,984	13.73	13.90	13.77

*Reference - Zalesky, P.J. and Holden, R.D.

TABLE XIa. CRU-79/P miniature chest mounted oxygen breathing regulator outlet pressures (steady state)

Altitude (feet)	Inlet Supply Pressure (psig)	Outlet Pressure at 0.0 LPM Flow (in. water)	Outlet Pressure at 50.0 LPM Flow (in. water)	Outlet Pressure at 100.0 LPM Flow (in. water)
Ground level	40, 80, 120	0.5 to 2.5	0.5 to 2.5	1.0 to 2.5
10,000	40, 80, 120	0.5 to 2.5	0.5 to 2.5	1.0 to 2.5
30,000	40, 80, 120	0.5 to 2.5	0.5 to 2.5	1.0 to 2.5
34,000	40, 80, 120	1.0 to 3.7	1.0 to 3.7	1.0 to 3.7
40,000	40, 80, 120	8.0 to 10.5	8.0 to 10.5	8.0 to 10.5
45,000	40, 80, 120	13.0 to 16.0	13.0 to 16.0	13.0 to 16.0
50,000	40, 80, 120	16.0 to 20.0	16.0 to 20.0	16.0 to 20.0

TABLE XIa. CRU-79/P miniature chest mounted oxygen breathing regulator outlet pressures (dynamic)

Tidal Volume (liters)	Inlet Pressure (psig)	Flow Rate (liters/Min., NTP 2/)		Cycling Rate 3/ (cycles/minute)	Outlet Pressure (inch/water)
2.0	40	15.0	50	8.0	0.5 to +2.5
2.0	40	31.8	100	15.9	1.0 to +2.5
2.0	50	47.8	150	23.9	1.0 to +3.0
2.0	60	57.3	180	28.7	1.5 to +5.0
2.0	70	63.7	200	31.8	2.0 to +6.0

TABLE XIc. CRU-82/P, CRU-88/P Chest Mounted Oxygen Breathing Regulators Dynamic Outlet Pressure Conditions and Requirements.

Breath Volume (liters/breath)	Flowrate (liters/minute)		Breathing Cycling (breaths/minute)	Regulator Outlet Pressure (inch water)
	Average	Peak		
1.0	15.9	50	15.9	0.5 to 1.5
2.0	15.9	50	8.0	0.5 to 1.5
1.0	23.9	75	23.9	0.7 to 2.0
2.0	23.9	75	12.0	0.7 to 2.0
1.0	31.8	100	31.8	1.0 to 2.5
2.0	31.8	100	15.9	1.0 to 2.5
1.5	47.7	150	31.8	1.2 to 3.5
2.0	47.7	150	23.9	1.2 to 3.5
3.0	47.7	150	15.9	1.2 to 3.5
1.5	57.3	180	38.2	1.5 to 4.0
2.0	57.3	180	28.7	1.5 to 4.0
3.0	57.3	180	19.1	1.5 to 4.0
1. 6	76.4	240	47.8	2.0 to 5.0
2.0	76.4	240	38.2	2.0 to 5.0
3.0	76.4	240	25.5	2.0 to 5.0

TABLE XId. CRU-82/P, CRU-88/P Chest Mounted Oxygen Breathing Regulators Steady State Outlet Pressure Conditions and Requirements

Outlet Flowrate (liters/minute)	Altitude (x 1,000 feet)	Outlet Pressure (inches water)
0, 25, 50	0, 15, 30	0.5 to 1.5
75	0, 15, 30	0.7 to 2.0
100	0, 15, 30	1.0 to 2.5
150	0, 15, 30	1.2 to 3.5
180	0, 15, 30	1.5 to 4.0
0, 25, 50	34	0.5 to 2.7
75	34	0.7 to 3.2
100	34	1.0 to 3.7
150	34	1.2 to 4.7
180	34	1.5 to 5.2
0, 25, 50, 75, 100, 150, 180	36	3.0 to 5.5
0, 25, 50, 75, 100, 150, 180	40	8.0 to 10.5
0, 25, 50, 75, 100, 150, 180	45	13.0 to 16.0
0, 25, 50, 75, 100,150, 180	50	16.0 to 20.0

TABLE XIe. Navy COMABT EDGE (NCE) CRU-103/P G compensated oxygen regulator steady state outlet pressure conditions and requirements

Outlet Flowrate (LPM)	Altitude (x 1,000 feet)	Outlet Pressure (inches water) Acceleration G-Signal (psig)			
		0	3.5	5.0	9.5
0	0	0.5 to 1.5	0.5 to 4.3	4.3 to 8.6	23.5 to 27.8
50	0	0.5 to 1.5			
75	0	0.5 to 1.5			
100	0	1.0 to 2.0			
150	0	1.5 to 2.5	1.5 to 5.3	5.3 to 9.6	24.5 to 28.8
180	0	2.0 to 3.0			
240	0	3.0 to 4.0			
0	15	0.5 to 1.5	0.5 to 4.3	4.3 to 8.6	23.5 to 27.8
50	15	0.5 to 1.5			
75	15	0.5 to 1.5			
100	15	0.8 to 1.8			
150	15	1.1 to 2.1	1.1 to 4.9	4.9 to 9.2	24.1 to 28.4
180	15	1.3 to 2.3			
240	15	1.9 to 2.9			
0	30	0.5 to 2.5	0.5 to 4.3	4.3 to 8.6	23.5 to 27.8
50	30	0.5 to 2.5			
75	30	0.5 to 2.5			
100	30	0.6 to 2.6			
150	30	0.8 to 2.8	0.8 to 4.6	4.6 to 8.9	23.8 to 28.0
180	30	0.9 to 2.9			
240	30	1.2 to 3.2			
0	34	0.5 to 4.0	0.5 to 4.3	4.3 to 8.6	23.5 to 27.8
50	34	0.5 to 4.0			
75	34	0.5 to 4.0			
100	34	0.6 to 4.1			
150	34	0.7 to 4.2	0.7 to 4.5	4.5 to 8.8	23.8 to 27.9
180	34	0.9 to 4.4			
240	34	1.1 to 4.6			

TABLE XIf. Navy COMBAT EDGE (NCE) CRU-103/P G compensated oxygen regulator steady state outlet pressure condtions and requirements

Outlet Flowrate (LPM)	Altitude (x 1,000 feet)	Outlet Pressure (inches water) Acceleration G-Signal (psig)			
		0	3.5	5.0	9.5
0, 50, 75, 100, 150, 180, 240	36	2.4 to 6.0	2.4 to 6.8	4.3 to 8.6	23.5 to 27.8
0, 50, 75, 100, 150, 180, 240	40	6.3 to 10.0	6.3 to 10.0	6.3 to 10.0	23.5 to 27.8
0, 50, 75, 100, 150, 180, 240	45	11.2 to 15.0	11.2 to 15.0	11.2 to 15.0	23.5 to 27.8
0, 50, 75, 100, 150, 180, 240	50	16.0 to 20.0	16.0 to 20.0	16.0 to 20.0	23.5 to 27.8

TABLE XIg. Navy COMBAT EDGE (NCE) CRU-103/P G compensated oxygen regulator dynamic outlet pressure conditions and requirements

Breath Volume (liters/breath)	Flowrate (liters/minute)		Breathing Cycle (breaths/minute)	Regulator Outlet Pressure (inches water)
	Average	Peak		
1.0	15.9	50	15.9	0.5 to 1.5
2.0	15.9	50	8.0	0.5 to 1.5
1.0	31.8	100	31.8	1.0 to 2.0
2.0	31.8	100	15.9	1.0 to 2.0
1.5	47.7	150	31.8	1.5 to 2.5
2.0	47.7	150	23.9	1.5 to 2.5
3.0	47.7	150	15.9	1.5 to 2.5
1.5	57.3	180	38.2	2.0 to 3.0
2.0	57.3	180	28.7	2.0 to 3.0
3.0	57.3	180	19.1	2.0 to 3.0
2.0	76.4	240	38.2	3.0 to 4.0
3.0	76.4	240	25.5	3.0 to 4.0

TABLE XIh. Navy COMBAT EDGE (NCE) CRU-103/P G compensated oxygen regulator dynamic outlet pressure conditions and requirements

Breath Volume (liters/breath)	Flowrate (liters/minute)		Breathing frequency (breaths/minute)	Outlet Pressure (inches water) Acceleration G-Signal (psig)		
	Average	Peak				
				3.5	5.0	9.5
2.0	47.7	150	23.9	1.5 to 5.3	5.3 to 9.6	24.5 to 28.8

TABLE XIi. Panel mounted regulator schedule MIL-R-25410 CRU-96/A, CRU-97/A, CRU-101/A and CRU-102/A Oxygen Ratio

Altitude (1000 feet)	Outlet Flow (liters/minute)	Percent Oxygen Addd from Source	
		Minimum	Maximum
0	15	0	30
0	50	0	30
5	15	1	33
5	50	1	33
10	15	7	35
10	50	7	35
10	135	7	35
15	15	16	52
15	50	16	52
15	135	16	70
20	15	27	55
20	50	27	55
20	135	27	80
25	15	43	80
25	50	43	80
25	135	43	80
28	15	60	100
28	50	60	100
28	135	60	100
32	135	98	100

TABLE XIj. Panel mounated regulator schedule MIL-R-25410 CRU-96/A, CRU-97/A, CRU-101/A and CRU-102/A pressure-breathing characteristics

Altitude (1000 feet)	Outlet Flow (liters/minute)	Outlet Pressure Limits (inches of water)	
		Minimum	Maximum
30	0, 10, 50, 100	0.01	2.5
40	0, 10, 50, 100	3.3	8.6
43	0, 10, 50, 100	7.7	12.7
50	0, 10, 50, 100	13.2	20.0

(1) Composition of the inspired gas.

(a) With the pressurized cabin intact: To prevent significant hypoxia, the partial pressure of oxygen in the mixed inspired gas, in which the partial pressure of water vapor is 47 mm Hg, should not be less than 122 mm Hg at cabin altitudes up to 35,000 feet. In order to avoid delayed otitic barotrauma and acceleration atelectasis, the concentration of nitrogen in the dry mixed inspired gas shall be not less than 40 percent at cabin altitudes up to at least 15,000 feet (see figure 2).

(b) On decompression of the pressurized cabin: In order to prevent significant hypoxia on decompression of the cabin (time of decompression between 0.1 second and 90 seconds) the concentration of oxygen in the dry mixed inspired gas breathed before decompression shall be adequate to prevent the alveolar oxygen tension from falling during the decompression to below 30 mm Hg. Within three seconds of the cabin altitude exceeding 27,000 feet, the system shall deliver at least 93 percent oxygen which may be from an emergency supply filled from the onboard system or from ground servicing.

(2) Added dead space. The volume of expired gas which can be re inspired from the breathing system shall not exceed 0.2 liter (ATPD).

(3) Mask cavity pressures. The minimum and maximum pressures and the total change of pressure (pressure swing) during the respiratory cycle should not exceed the following limits at any cabin altitude up to 38,000 feet. Above this altitude, pressure breathing requirements apply

(a) Two sets of limits, one when safety pressure is absent, and the other when safety pressure is present, are specified in table XII.

(b) When safety pressure is selected either manually or automatically the pressure in the mask cavity shall be greater than that of the environment at inspiratory flows of up to at least 1.2 liters per second (ATPD).

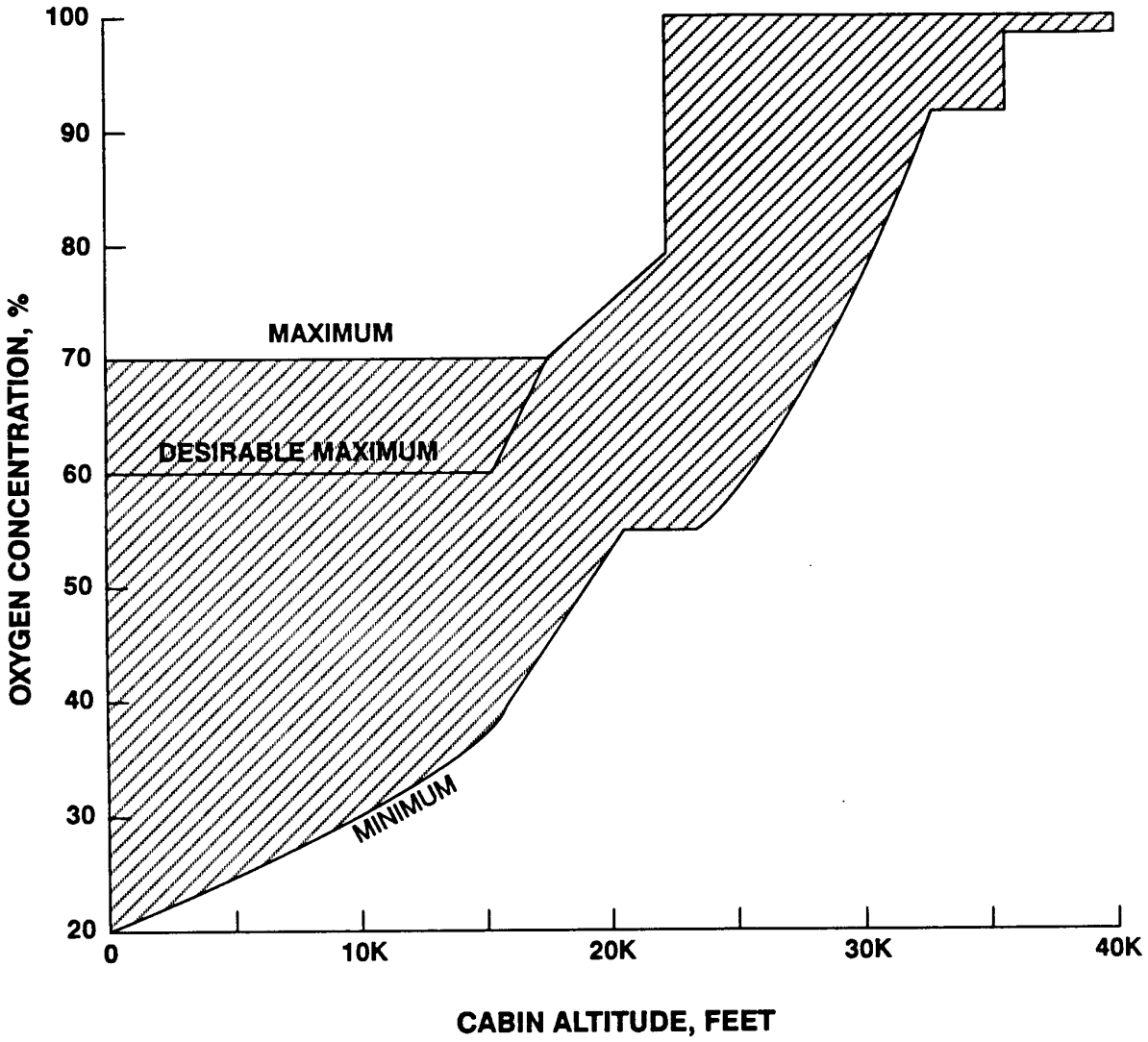


FIGURE 2. Limits to oxygen concentration as a function of cabin altitude

(c) Neither head movement (which may produce changes in volume of the flexible hose to the mask) nor the maximum rate of cabin altitude ascent (with the cabin pressure intact) should increase by more than 0.125 kPa (0.5 in. wg). That is the pressure in the mask cavity above which steady state conditions at that altitude would exist.

(1) Pressure breathing. The mask pressure averaged over the respiratory cycle should increase automatically in a linear manner with fall of environmental pressure from 1.25 to 2.25 kPa (5.0 to 9.0 in. wg) at 43,000 feet to 4.0 to 4.6 kPa (16 to 18 in. wg) at 48,000 to 50,000 feet. The total change of mask cavity pressure during a respiratory cycle shall not exceed 0.5 kPa (2.0 in. wg) with peak inspiratory and expiratory flows of 0.5 liter per second (ATPD) and 1.0 kPa (4.0 in. wg) at peak inspiratory and expiratory flows of 1.8 liters per second (ATPD). The mean mask pressure produced by operation of the press-to-test facility at ground level

shall be between 3.5 and 4.5 kPa (14 to 18 in. wg), and the associated total change of mask cavity pressure during the respiratory cycle shall not exceed 0.75 kPa (3.0 in. wg) with peak inspiratory and expiratory flows of 0.5 liter per second (ATPD).

(2) Oscillatory activity. The double amplitude of any oscillation of pressure in the mask cavity which lasts 0.25 second or longer shall not exceed 0.06 kPa (0.25 in. wg).

(3) Expansion of trapped gas on rapid decompression. The pressure in the mask cavity during and immediately after rapid decompression shall not exceed that of the environment by more than 53.5 inches of water for 250 milliseconds.22 inches of water (5.5 kPa) is an ideal goal to examine.

TABLE XII. Breathing performance goals from regulator.*

Peak inspiratory flows and expiratory flows (liters (ATPD) per sec)	Mask Cavity Pressure (kPa (in. wg)) Limits to Minimum	Maximum	Maximum Swing
	Without safety pressure		
0.5	-0.38 (-1.5)	+0.38 (+1.5)	0.5 (2.0)
1.5	-0.55 (-2.2)	+0.65 (+2.6)	0.85 (3.4)
2.5	-1.12 (-4.5)	+1.0 (+4.0)	1.75 (7.0)
3.3	-1.9 (-7.6)	+1.5 (+6.0)	3.0 (12.0)
	With safety pressure		
0.5	+0.02 (+0.1)	+0.75 (+3.0)	0.5 (2.0)
1.5	-0.2 (-0.8)	+0.95 (+3.8)	0.85 (3.4)
2.5	-0.9 (-3.5)	+1.25 (+5.0)	1.75 (7.0)
3.3	-1.75 (-7.0)	+1.65 (+6.6)	3.0 (12.0)

*Reference - Air Standardization Agreement *ASCC AIR STD 61/22*, “The Minimum Physiological Design Requirements for Aircrew Breathing Systems," dated 18 Aug 1982.

Crew oxygen supply equipment. Crew oxygen supply equipment shall be provided that supplies breathing gas enriched with oxygen to support the crew member(s) for all expected missions. The supply equipment shall provide sufficient oxygen to support the crew member(s) for all normal and emergency situations and shall consist of:

a. Supply source (type and quantity)

b. Heat exchanging (if required)

c. Valve arrangements

d. Tubing and connectors

e. Servicing or replenishment provisions (if required)

f. Water separater (if required)

g. Outlet filter(s)

a. In the USAF, the usual approach in aircraft development programs prior to source selection is to let the contractor determine which type of supply source best satisfies the overall aircraft mission. If the user requirements state which system is needed, then this may be incorporated into the oxygen system specification.

Navy aircraft incorporates liquid oxygen (LOX) and gaseous oxygen (GOX) systems as the primary oxygen supply source. In addition, the On Board Oxygen Generating System has been incorporated into new Navy aircraft to replace LOX systems. Current OBOGS are designed for one and two aircrew aircraft.

The following types of oxygen systems and their associated pressure ranges of operation are considered satisfactory for use in military aircraft:

(1) Low pressure gaseous oxygen systems (50 to 450-500 psig).

(2) High pressure gaseous oxygen systems (100 to 1800-2150 psig).

(3) Low pressure LOX systems (50 to 70-120 psig).

(4) High pressure LOX systems (50 to 300-500 psig).

(5) Molecular sieve oxygen generating system (MSOGS) (5 to 90 psig). Also called on-board oxygen generating system (OBOGS).

(6) Chemical oxygen generating system (pressure range a function of design).

(7) Ceramic oxygen generating systems are being investigated as a possible viable alternate system (pressure range is a function of design).

Further detailed information on these systems is given in *Appendix B*. Detailed oxygen system specifications may be determined from this information. Most existing USAF and US Navy fighter and attack aircraft have incorporated low pressure LOX systems. The current trend is that most USAF fighter/attack and bomber aircraft developments are incorporating MSOGS. Most existing Navy aircraft and new fighter/attack aircraft developments are going to MSOGS usually called On-Board Oxygen Generating Systems (OBOGS). Most transport type aircraft incorporate high pressure LOX systems. This higher pressure enables large demand or high flow rates necessary for a large number of passengers and crew members to breathe oxygen simultaneously. The MSOGS is suitable for continuous supply up to six crew members. To supply more crew members, larger supply tubing and more or larger molecular sieve separation beds are required. Feasibility studies have been conducted to adapt MSOGS to aircraft with larger numbers of crew members. This may mean storage vessels that must be filled while oxygen is not in use and is drawn on in an emergency requiring oxygen.

High pressure gaseous oxygen systems have the advantage over LOX systems for use in some transport type aircraft that carry only passengers (not paratroops) because oxygen supply is needed only in an emergency for descent. The high pressure gaseous oxygen supply will be on standby with very little loss of supply whereas LOX systems boil off and must be filled periodically. Usually all the pressure vessels (cylinders typically) are the same size to enhance ease of replacement and reduce the number of parts used on any one aircraft system.

Sometimes, however, it is acceptable to use a different size pressure vessel for the flight crew system versus the passenger and/or non flight crew system because different considerations for oxygen supply exist for each. The required oxygen supply may be excessive and the number of pressure vessels may thus result in a weight penalty. When the number of pressure vessels becomes excessive and the associated weight penalty is too great, alternate storage means should be considered. Lightweight high strength metal alloys may be used for weight reduction, but they should meet the same design requirements as the heavier metal cylinders in *MIL-C-7905* for cylinders that are spun and *MIL-C-29576* for cylinders that are welded. **For new applications, wire-wrapped cylinders are not used by the Navy.**

For U.S. Navy and Air Force use, composite oxygen cylinders with aluminum liners are not acceptable. This is especially critical for military aircraft with a gunfire threat and of grave concern on other types of aircraft. Fragmentation resistance testing conducted by the Navy has revealed a problem with the use of composite oxygen cylinders with aluminum liners on military aircraft. Gunfire testing resulted in a significantly larger blast over pressure than that experienced with steel cylinders of the same size without a composite over wrap. When penetrated, the heat released ignites the aluminum liner adding more energy than that contained by the pressurized gas. The superior strength from the construction of the cylinder with the glass or Kevlar over wrap contains this energy allowing it to build to very high proportions until it is released through the openings caused by the projectile and the burning aluminum. Gunfire tests have shown that the blast over pressure of a composite aluminum lined cylinder pressurized with 100 percent oxygen was 5 times greater than that of a comparable size steel cylinder pressurized with 100 percent oxygen. See Appendix A for additional detailed information on this topic.

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 or isolated as much as practicable to minimize combat vulnerability. Sufficient space is needed to replace cylinders and to perform maintenance on all parts.

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 to connect the external filling source does not exceed one man-minute and does not create a hazard for servicing personnel. See 3.10.3 herein for important information on hazards analysis and contamination investigation of primarily on gaseous oxygen systems. Of special concern has been the need generated for filtering any gaseous oxygen serviced into a fill valve. Also new fill valve designs are needed to reduce fire and explosion accidents.On fighter type aircraft that use an MSOGS, a backup of 93 to 99.5 percent oxygen supply must be available in the event of a loss of bleed air supply or an electrical power failure. Physiological evaluations have approved the acceptability for use of 93 percent oxygen for emergency oxygen supply to support a crew member at 43,000 feet and above so he may rapidly descend after a cockpit decompression. Slight adjustments to the regulator dilution and pressure breathing schedule are needed. Also of primary concern is the need for emergency oxygen supply in the event the crew member must bail out of a transport aircraft or eject from an ejection seat-equipped aircraft.

For USAF aircraft oxygen systems, air dilution is provided between sea level and 28,000 feet at flow rates ranging from 140 to 240 liters per hour as given in table XIII. Tables XIII, XIV and XV are used to size the aircraft oxygen supply based on the aircraft missions. These consumption tables are based on pulmonary ventilation rates determined from flight and laboratory testing with subjects (WADD Technical Report 60-106 (AD 244294)). Oxygen supply sizing is not a concern with an MSOGS, as oxygen supply is continuously available. The MSOGS, however, must be capable of delivering breathing air at the required delivery flow and pressures including instantaneous peak flow rates and sustained large ventilation rates for heavy workloads.

The maximum number of crew members 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. The designer may be requested to do a detailed analysis considering all aspects of the mission and various regulation control settings. However if the information given in tables XIII, XIV, and XV can be applied to the particular system, an analysis will not be necessary. 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 crew member:

Sea level on 100 percent oxygen for 15 minutes. Multiplier is 1.20 for one crew member:

801 liters/hr x $^{1}/_{4}$ hr x 1.2 = 240 liters

Takeoff for three minutes. Multiplier is 1.20 for one crew member and 1.35 for takeoff.

801 liters/hr x $^{1}/_{20}$ hr x 1.20 x 1.35 = 65 liters

Climb to 35,000 feet for 15 minutes. Multiplier is 1.2 for one crew member.

190 liters/hr* x $^{1}/_{4}$ hr x 1.2 = 57 liters

*190 LPH is an average flow rate for a cabin altitude between sea level and 15,000 feet with regulator on dilution.

TABLE XIII. Baseline oxygen for each crew member.*

Cabin Altitude (feet)	Percent Oxygen Available (minimum)	Flow rate at 14.7 psia and 70°F (101.3 kPa and 21.1°C) 100 Percent Oxygen				Air Dilution**	
		liters/hr	ft^3/hr	cm^3/hr	liters/hr	ft^3/hr	cm^3/s
Sea level	21	801	28.3	222.5	240	8.**4**	66.7
5,000	26	658	23.2	182.5	172	6.1	47.8
8,000	26	581	20.5	161.4	151	5.3	41.9
10,000	27	535	18.9	148.6	143	5.1	39.7
15,000	32	429	15.1	119.2	140	4.9	38.9
20,000	47	340	12.0	94.4	159	5.6	44.2
25,000	73	265	9.3	73.6	194	6.8	53.9
28,000 and above	100	225	7.9	62.5	225	7.9	62.5

*The oxygen supply requirement is based on an inspiratory minute volume (volume of gas per minute) of 15 liters per minute (lpm) (250 cubic cm per sec) per crew member determined at BTPS conditions; i.e., body temperature 98.6 $^{1}@_{4}$• F (37 $^{1}@_{4}$• C), body pressure (cabin altitude), and saturated with water vapor, 47 mm Hg (6.27 kPa). At normal conditions (NTPD) of sea level altitude, 760 mm Hg (101.3 kPa) 70 $^{1}@_{4}$• F (21.1• C), and dry, the baseline minute volume per crew member is 13.35 lpm (223 cubic cm per sec) (NTPD). For oxygen system design, the baseline oxygen requirements given apply to all aircraft with six or more crew aircrew members. For aircraft which have less than six crew members, the oxygen quantity should be increased by the multipliers given in table XVI which are estimated to cover the 90th percentile of normal aircrew populations.

**Based on dilution performance of typical CRU-73/A oxygen regulator.

TABLE XIV. Oxygen requirement adjustment for number in aircrew.

Aircrew Number	Multiplier
1	1.20
2	1.10
3	1.06
4	1.03
5	1.02

TABLE XV. Oxygen requirement multiplier for specific flight activities.

Specific Flight Activity	Multiplier
Breathing safety pressure	1.10
Wearing pressure suit	1.20
Terrain following	1.25
Take off and landing	1.35
Carrier launch and landing	1.50
Aerial combat and threat	1.75
Night flight	*
Air-to-air refueling	*

*Assume a multiplier of 1.25 until data is available to validate.

TABLE XVIa. Alternative method of an oxygen consumption analysis using computer spreadsheet with simple equations to sum values.

Trainer Aircraft Oxygen System Consumption Analysis

Navigation Mission (High Altitude) Profile
Mission with Divert Option - Regulator in Air Dilution Mode

Mission Phase	Aircraft Altitude Feet	Cabin Altitude * Feet	Duration Hours	Oxygen Consumption Air Dilution (Liters per Hr)	Aircrew Number Multiplier	Activity Factor Multiplier	Crew Size Multiplier	Oxygen Consumption Air Dilution Mode (Liters)
Taxi and Takeoff	Sea Level	Sea Level	0.25	240.00	1.1	1.35	2	178.20
Climb, Maximum Rate	Climb SL - 8,000	Mean is 4,000	0.090909	185.60	1.1	1.35	2	50.11
	Climb 8,000 - 18,000	8000	0.11364	151.00	1.1	1.35	2	50.96
	Climb 18,000 - 22,000	Mean is 9,500	0.0454545	145.00	1.1	1.35	2	19.57
300 NM Cruise	Assume 22,000	11000	0.75	142.40	1.1	1.00	2	234.96
On-Course Descent	Descend 22,000 - 18,000	Mean is 9,500	0.095238	145.00	1.1	1.00	2	30.38
	Descend 18,000 - 15,000	8000	0.0714286	151.00	1.1	1.00	2	23.73
On-Course Descent	Descend 15,000 - 8,000	8000	0.0583333	151.00	1.1	1.00	2	19.38
	Descend 8,000 - 5,000	4250	0.025	182.20	1.1	1.00	2	10.02
Approach and Cruise	Cruise 5,000	5000	0.1333333	172.00	1.1	1.00	2	50.45
Missed Approach	Descend 5,000 - 500	2750	0.0333333	202.60	1.1	1.35	2	20.06
Climb for Divert Option	Climb 500 - 8,000	4250	0.0697674	182.20	1.1	1.00	2	27.97
	Climb 8,000 - 18,000	8000	0.0930233	151.00	1.1	1.00	2	30.90
	Climb 18,000 - 22,000	Mean is 9,500	0.0372093	145.00	1.1	1.00	2	11.87
Maximum Range Cruise	Assume 22,000	11000	0.666667	142.40	1.1	1.00	2	208.85
Descend from Divert Option	Descend 22,000 - 18,000	Mean is 9,500	0.0392157	145.00	1.1	1.00	2	12.51
	Descend 18,000 - 8,000	8000	0.0980392	151.00	1.1	1.00	2	32.57
	Descend 8,000 - 5,000	6500	0.0294118	161.50	1.1	1.00	2	10.45
Approach and Cruise	Approach 5,000	5000	0.13333333	172.00	1.1	1.00	2	50.45
Approach and Descend	Descend 5,000 - 500	2750	0.0333333	202.60	1.1	1.00	2	14.86
Approach and Climb	Climb 500 - 8,000	4250	0.0394737	182.20	1.1	1.00	2	15.82
	Climb 8,000 - 10,000	8000	0.0105263	151.00	1.1	1.00	2	3.50
Approach and Cruise	Cruise 10,000	8000	0.2833333	151.00	1.1	1.00	2	94.12
Approach, Descend, Land	Descend 10,000 - 8,000	8000	0.0166667	151.00	1.1	1.35	2	7.47
	Descend 8,000 - SL	4000	0.0666667	185.60	1.1	1.35	2	36.75
		TOTAL IS	3.28333703				TOTAL IS	1245.93

* Note: Trainer Aircraft Cabin Altitude is SL - 8,000 ft (unpressurized), 8-18,000 ft (8,000 ft), and 18,000 and higher (3.5 psi difference)
** Note: For purposes of these calculations, mean cabin altitudes are used for the mean aircraft altitudes where there is a range of altitudes.

Cruise at 35,000 feet for 15 hours with cabin pressure altitude at 15,000 feet (consider refueling of the aircraft). Multiplier is 1.20 for one crew member.

140 liters/hr x 15 hrs x 1.2 = 2520 liters

Aerial combat and threat for 30 minutes. Multiplier is 1.75 and 1.20 for one crew member.

167 liters/hr** x 1/2 hr x 1.75 x 1.20 = 175 liters

**An average rate based on the cabin pressure altitude between 15,000 and 25,000 feet.

Descent for 15 minutes from 35,000 feet to sea level. Multiplier is 1.20 for one crew member.

190 liters/hr*** x 1/4 hr x 1.20 = 57 liters

***An average rate based on the cabin altitude between 15,000 feet and sea level.

Landing for three minutes. Multiplier is 1.35 and 1.20 for one crewmember.

240 liters/hr x 1/20 hr x 1.35 x 1.20 = 19 liters

(240 + 65 + 57 + 2520 + 175 + 57 + 19) liters = 3133 liters total

An alternative method of doing an oxygen consumption analysis is to use a computer spreadsheet with mission segments in rows and all variables in the columns. An example of analysis for a trainer aircraft is shown in table XIIa. Simple equations can be built in to sum flow rates to determine the amount of oxygen supply needed.

The above calculation can be determined for all possible missions. The worst case mission should be used to determine the amount of oxygen supply needed. In a LOX system, 3030 liters of oxygen gas are available from a 5-litre converter and 6740 litres of oxygen gas are available from a 10-litre converter 24 hours after servicing (see *Appendix B*). However, most USAF fighter aircraft use a 5-litre LOX converter and US Navy fighter aircraft use a 10-liter LOX converter. (Navy regulators use 100 percent oxygen at all times increasing the consumption rate.) Logically, the designer should choose to use a 10-liter LOX converter. If a gaseous system is used, the design will determine the minimum size of the pressure vessel at its rated pressure, which is normally 1800 psig.

Tables are provided in *Appendix B* to determine the volume of gas that may be supplied from different sizes of pressurized gas containers. These volumes are referenced to sea level so a direct comparison to the physiological demands may be easily determined. Note that current breathing regulators do not allow a depletion of pressure from these vessels below 50 psig as they will not function properly. This must be considered when selecting the size and number of gaseous containers as this volume of gas will not be available for breathing.

b. The temperature of oxygen or breathing gas delivered to crew members should be within physiologically tolerable limits. The temperature of gas delivered to breathing regulators is customarily within the range of -20°F to +110°F (-11°C to 5.5°C) of the cabin ambient temperature expected for normal operations. This temperature range may be exceeded for emergency situations as long as temperatures do not reach an extreme which would be severely harmful or fatal to crew members.

The temperature of liquid oxygen (LOX) is -297.4°F (-183°C). Therefore, when LOX systems

are used the breathing gas must be warmed using supply tubing and heat exchangers (see *Appendix B* for information on selecting minimum lengths of supply tubing). The LOX system should be designed for worst case conditions; that is, the highest sustained flow rates when breathing regulators are selected on the emergency or safety pressure setting and 100 percent setting. The temperatures used in these calculations should be the lowest temperatures expected in the heat exchanging equipment. Past designs have incorporated a combination of supply tubing and heat exchanger(s) to warm the gas. Usually in fighter type aircraft, the heat exchanger is located within the cockpit where it is warmer than in unpressurized compartments at higher altitudes. More heat can be provided for warming; therefore a smaller heat exchanger is required. In transport aircraft, the heat exchanger(s) are usually located beside the LOX converter in the lower lobe as the entire upper and lower lobes of the aircraft are warmed and pressurized. The exception is military cargo transport aircraft which have the LOX converters in the wheel well and the heat exchangers in the pressurized compartment.

When MSOGS are used, the primary concern is that the zeolites used for gas separation are insufficient at temperatures below 40°F or above 160°F. This can be a problem on aircraft start-up in cold environments and under conditions in which air supplied to the MSOGS concentrator is hot. Usually, engine bleed air or the environmental control system (ECS) air is used to supply air for gas separation to the MSOGS in the pressure range of 5 to 90 psig. However, the air from the engine usually reaches 400°F to 500°F. Heat exchanging is needed to bring temperatures down to acceptable limits. Past schemes used air-to-air heat exchanging with ram air through the heat exchanger to obtain maximum efficiency. Also, placing a heat exchanger in the fuel tanks has been proposed to increase the efficiency somewhat over ambient air cooling.

In pressurized oxygen gas systems, heat exchanging to warm the gas to within acceptable temperature limits will not be a concern unless the pressure vessels are in unpressurized compartments which may get very cold at high altitudes. Usually, the supply tubing will be the only method of heat exchanging required. A special concern in servicing high pressure systems is that a temperature rise is associated with pressurizing these vessels. Hazards may be minimized by servicing slowly to allow time for heat buildup to dissipate from the pressure vessel. However, when filament-wrapped pressure vessels are used, the filament acts as an insulator to preclude heat dissipation.

c. An oxygen system is a pneumatic system which uses many types of valves. Some valves used are the LOX drain valve, LOX fill-buildup-vent valve, check valve (cryogenic fluid and gas types), quick disconnect valve, pressure relief valve, pressure reducing valve, gas filler valve and various other types of valves required for effective system operation. *Appendix B* gives detailed descriptions and diagrams of all the existing types of oxygen system valves. Manual shutoff valves or line valves may be used in gaseous, LOX and MSOG systems for maintenance purposes to isolate sections of the system. They are also used as emergency oxygen shutoff controls in the event of a fuselage fire. No more than one valve appropriately marked and guarded as an emergency control should be used for the entire flight crew distribution system or for the entire passenger distribution system to minimize time for shutoff. Such controls must be readily accessible and a means of indicating whether the control is ON or OFF should be provided.

A MSOGS usually will incorporate a pressure regulating valve at the concentrator inlet to preclude pressure oscillations in the concentrator zeolite beds. Valves are also required to

divert flow from one zeolite bed to the next and to allow back flow for flushing a bed saturated with nitrogen (it is desorbed by pressure swing or reduction). A check valve will also be needed to keep the breathing gas from flowing back into the concentrator.

The designer of the aircraft oxygen system is responsible for ensuring that a proper layout of valves is provided for effective operation and servicing (if required).

d. Tubing and associated connectors deliver the aircraft oxygen supply from a supply source to the breathing regulator. *Appendix B* contains detailed information on tubing and coupling connectors including torque and lubrication requirements for the connectors.

Generally, high pressure systems incorporate seamless steel tubing that is corrosion resistant type 304 and annealed. With a 3/16 inch (4.76 mm) diameter tubing, the wall thickness is no less than 0.035 inch (0.89 mm). Low pressure gaseous and LOX systems use aluminum alloy tubing with a suitable coating to preclude oxidation of the tubing in the high concentration oxygen environment. Either tubing usually has a flared type connection to eliminate any gas leakage with higher internal pressures. Metal fittings should be suitably protected against electrolytic corrosion from the use of dissimilar metals. The use of porous fittings should be avoided to preclude slow leakage. Oxygen system tubing should be marked throughout the aircraft to distinguish it from other tubing such as that used for hydraulics. The use of gaskets and both non oxygen compatible lubricants and anti-seize compounds is avoided to preclude fire and explosion hazards. All fittings should be readily accessible for ease of replacement and leak testing.

e. Any gaseous or liquid oxygen supply systems provided on the aircraft must incorporate provisions for replenishment of supply. *Appendix B* contains much detail on existing filler valves and servicing trailers. The aircraft gaseous or LOX supply filler valve must be compatible with existing cart servicing valves used worldwide. Filler valves should be appropriately marked and located so that they may be easily reached without the use of any special devices such as platforms or ladders (if possible). LOX systems include vent valves that vent LOX overboard when the converter is topped off or filled. The liquid vent should be located so that LOX may be drained into stainless steel drain pans on the runway without impinging on the aircraft or becoming trapped in aircraft cavities, as LOX has the tendency to accelerate fatigue in metals of the aircraft structure.

When chemical oxygen generation devices are used, provisions for the replenishment of the chemical cartridge should be incorporated so that the unit may be easily replaced when expended. Usually, chemical generators use a cartridge that is heat insulated as the chemical becomes very hot when it burns. This cartridge—not the mask, regulator, supply tubing, nor mounting equipment—is replaced.

f. Water separator (if required). Past investigations have shown that the worst problem in extending the life of On Board Oxygen Generating System zeolite crystals and clay binds used in the pressure swing absorption process is moisture and water. Water filtering at the inlet is necessary to prevent liquid and aerosol water entering the zeolites and deactivating them. Water and moisture can also reduce the strength of the clay binder accelerating zeolite attrition causing dusting. This affect can be minimized by not allowing the zeolite pellets to move about in the beds or canisters. That way, the purge cycle will vent away in seconds any moisture weakly held by the zeolite crystals. Any liquid water or aerosol will rapidly deactivate the zeolite

crystals and pressure swing absorption process will not prevent crystal deactivation.

g. Outlet filters. Outlet filters are needed in many oxygen systems for a variety of purposes. In gaseous oxygen systems, outlet filters should be located in strategic locations to minimize metal particles and nonmetal contamination from spreading into components. Component malfunctions can occur from the physical jamming of operating parts. Also, metal particles and flammable contaminate may lead to a oxygen fed fire in the system explosively propagating. Oxygen fed fires cannot be extinguished. See other sections in this handbook for additional details on this concern. On On Board Oxygen Generating Systems, outlet filters are needed to prevent any fine zeolite crystals and binder dust from entering into the system. Zeolite dust can be very small down to 0.1 microns. High efficiency particulate filters may be needed to prevent entry of this dust into the breathing system. All zeolite crystals and binders used to date have no toxic health hazard associated with them, but the dust is very discerning the flight crew. The dust can also prevent proper operation of the components if jammed with powder.

Nuclear, biological and chemical (NBC) protection. The NBC protection provisions in crew member equipment shall consist of _____.

Baseline requirements:

The USAF's most recent development, the Aircrew Eye/Respiratory Protection (AERP) was developed in the late 1980's to replace the MBU-13/P full face mask and shroud system with the CRU-80/P filter pack. The MBU-13/P full face mask and shroud system with the CRU-80/P filter pack performance requirements were the baseline for AERP development. For new designs, the goal should be to improve the protection factor and overall system performance, including respiratory performance.

Refer to AFGS-87234A, 3.2.2 and sub paragraphs for additional information concerning the overall chemical and biological protection, threats and decontamination.

In 1987, respiratory performance tests were accomplished on the MBU-13/P and CRU-80/P system to compare it to other proposed NBC protection equipment. This is provided here for background information.

The AERP or MBU-19/P system consists of four subsystems strapped to the aircrew as shown on figure 3c, the MBU-19/P hood/mask subsystem, the MBU-19/P breathing subsystem, the CQU-7/P blower subsystem with a 6 foot hose, and the MXU-835/P communication subsystem. Figure 3d show the configuration worn by an aircrew member. The MBU-19/P hood/mask subsystem consists of a bromobutyl rubber hood and integrated standard MBU-12/P oxygen mask, clear plastic visor, neckdam, drinking port, and communication connections. The subsystem is attached to the standard USAF HGU-55/P flight helmet with standard offset bayonet connectors. The MBU-19/P breathing subsystem consists of a chemical-biological filter canister, in-line filter, chemically resistant delivery hose, and manifold assembly with an emergency oxygen connection. The subsystem uses filtered ambient air for ground operation and filtered aircraft normal oxygen in flight, providing both breathing capability to the mask and de-mist ventilation for the visor. The CQU-7/P blower subsystem consists of a variable speed motor and two BA-5588/U lithium-sulphur dioxide batteries in a housing assembly, an external power supply cable, and a chemical-biological filter canister. The communication subsystem consists of the MXU-835/P intercommunication unit, communication cord connection to a

person wearing the system, microphone, and bracket.

The test set-up was basically identical to that used for earlier tests on respiratory equipment. The protection equipment was mounted on a mannequin head form and connected to a standard CRU-73/A panel mounted breathing regulator. This was supplied with a gaseous oxygen source at 70 to 80 psig measured about four feet from the regulator inlet. Cyclic flows were generated by a bellows type breathing simulator programmed to develop sinusoidal wave forms at a rate of 60 cycles per minute. The regulator was placed in both modes, normal (air dilution mode) and 100 percent. Tables XVII, XVIII, and XIX give the results of these tests.

TBD

FIGURE 3c. AERP or MBU-19/P equipment and arrangement.

TBD

FIGURE 3d. AERP or MBU-19/P as worn by an aircrew member.

Design goals for new equipment.

When designing new NBC personal protective equipment, the following factors should be considered:

a. Design philosophy. A protection factor (ratio of the level of contaminants outside the head gear to the level inside the eye and respiratory compartments) of at least 10^4 against contaminants can only be assured by an assembly which has the following characteristics:

(1) The assembly completely isolates the eyes, nose, and mouth from the environment.

(2) The respiratory and eye compartments are continuously ventilated with a blown supply of clean gas that contains no NBC agents above the acceptable threshold limits.

(3) The pressures in the respiratory and eye compartments are greater than that of the environment.

a. General requirements. The protective assembly should be comfortable to wear and should produce minimal interference with the ability of the wearer to perform the activities essential to the operational task, both in flight and on the ground. It shall provide intercommunication, noise attenuation and protection against solar glare, hypoxia, thermal stress, bird strike, wind blast and impact. The assembly should provide a drinking capability, should be compatible with ejection systems and sequencing, and should provide for emergency oxygen use. The NBC assembly should be compatible with the use of corrective lenses and with flash blindness protective devices. Following accidental entry into water, the NBC protective assembly should not compromise survival. When applicable, the change of respirator suspension equipment should not be required for mission-to-mission change between chemical defense respirator assemblies and normal-issue oxygen masks.

b. Degree of protection. The protective assembly should envelop the entire head and neck so that it prevents contaminants in liquid particulate form from contacting the skin. The assembly should provide, under all operational conditions, a protection factor of at least 10^4 for both the respiratory tract and the eyes. The assembly should also provide limited protection (a protection factor of at least 10^3) for a period of at least 30 minutes in the event of a failure of the blown supply of chemically clean gas to the respiratory tract and eyes.

TABLE XVII. MBU-13/P mask, CRU-80/P filter pack and CRU-73/A regulator in normal mode.

Peak Flow Rate liter/min.	Inspiration Pressure inches-wg	Expiration Pressure inches-wg	Pressure Swing inches-wg
20	- 1.1	0.4	1.5
60	- 3.6	0.6	4.2
90	- 5.4	0.8	6.2
120	- 7.8	1.9	9.7
160	-12.7	3.2	15.9
190	-16.4	5.0	21.4

TABLE XVIII. MBU-13/P mask, CRU-80/P filter pack and CRU-73/A regulator in 100 percent mode.

Peak Flow Rate liter/min.	Inspiration Pressure inches-wg	Expiration Pressure inches-wg	Pressure Swing inches-wg
20	- 1.4	0.5	1.9
60	- 4.0	1.0	5.0
90	- 6.2	1.2	7.4
120	- 8.0	2.0	10.0
160	-12.9	3.8	16.7
190	-16.8	5.0	21.8

TABLE XIX. Pressure swing comparison data.

Peak Flow Rate liter/min.	Mask Only inches-wg	Mask/Regulator Normal Mode inches-wg	Mask/Regulator 100% mode
30	1.6	2.2	2.0
60	2.9	4.9	4.3
90	4.4	6.8	7.0
120	6.0	9.9	10.1
160	8.4	15.8	15.9
200	11.1	23.6	23.9

c. Conditions of use. The protective assembly should meet the respiratory performance requirements during and after the following conditions of use:

(1) Continuous wear for a period of up to six hours of flight or ground use.

(2) On the ground and on the flight decks of ships, both in areas of collective protection and in the open.

(3) Ground standby in aircraft and in flight up to aircraft altitudes of either 8000 ft (2440 m) (oxygen not used) or at least 40,000 ft (12,200 m) (in aircraft with fitted oxygen supply systems).

(4) At temperatures between -26°C and +55°C with wind speeds of up to 7.5 meters per sec (15 knots) for the full six hour period of wear, and for at least 30 minutes at temperatures between -40°C and -26°C with wind speeds of up to 7.5 meters per second (15 knots).

(5) At accelerations of up to +7 Gz for a period of at least 30 seconds and +9 Gz for a period of at least 15 seconds.

a. Weight, size and materials. The protective assembly should be as small and as lightweight as possible. The weight should be distributed evenly over the head so that the center of gravity of the complete assembly when worn is as close as possible to that of the bare head. The protective assembly will be sized so that it fits at least 95 percent of the aircrew population, with custom-fitting made available for the remaining aircrew. Those parts of the assembly which come into contact with the skin of the head and neck should be made of material(s) which do not irritate or contaminate the skin. The assembly should be flame resistant to the maximum extent feasible.

b. Donning and doffing. The wearer should be able to don and doff the protective assembly without contaminating the skin, eyes or respiratory tract with toxic agents in liquid or particulate form, and without any form of contaminant gaining access to the eyes or respiratory tract.

c. Respiratory performance. The respiratory components of the protective assembly should meet the following:

(1) Seal of the respiratory compartment. The leakage between the skin of the face and the respiratory compartment of the assembly should be such that:

(a) The inboard leakage into the respiratory compartment does not exceed 0.1 percent of the pulmonary ventilation when the mean pressure in the compartment is 1 kPa (4.0 in. wg) less than that of the environment; and

(b) The outboard leakage is less than 0.5 liter (ATPD) per minute when the mean pressure in the compartment is 1 kPa (4.0 in. wg) greater than that of the environment.

If the assembly includes an oronasal mask, the wearer should be able to adjust the tension of the mask on his face both on the ground and in flight, without impairing the protection provided by the assembly.

(2) Valve system. The valve system fitted to the respiratory compartment should ensure that flow of gas through the compartment is unidirectional and that gas only flows into the compartment during inspiration.

(3) Composition of the inspired gas. The gas delivered by the protective assembly on the ground and in aircraft not fitted with oxygen supplies should be filtered air. The assembly should provide supplemental oxygen in aircraft fitted with oxygen supply systems. The partial pressure of oxygen in the inspired (tracheal) gas when the pressure cabin is intact should not be less than 122 mm Hg. In future high performance combat aircraft, the inspired gas should contain at least 40 percent nitrogen at cabin altitudes between ground level and 20,000 ft (6100 m).

(4) Added respiratory dead space. The effective respiratory dead space of the respirator should not be greater than 200 ml body temperature and pressure, saturated (BTPS).

(5) Safety pressure. With the blown air supply operating, the pressures in respiratory and eye compartments should be greater than that of the environment at inspiratory flows of up to at least 1.4 liters ambient temperature and pressure, dry (ATPD) per second.

(6) Emergency oxygen. The assembly should allow for the use of emergency oxygen during inflight and ejection operations. An adequate flow of oxygen should be maintained to the mask for the time period necessary for descent to safe altitude.

(7) Impedance to respiration. The protective assembly should be capable of meeting peak inspiratory and expiratory flows of up to 2.8 liters (ATPD) per second. The assembly should impose the minimum of impedance to respiration. The impedance to respiration imposed at ground level and at any altitude up to 40,000 feet should not exceed the values given in table XX.

a. Equalization of pressure in middle ears and sinuses. A protective assembly which is to be used at altitudes greater than 1000 feet (300 m) above ground level should provide means for the wearer to occlude his nostrils in order to perform the Frenzel and/or Valsalva maneuvers, introducing air into the middle ears and paranasal sinuses during descent from altitude.

b. Vision. The protective assembly shall produce minimal interference with vision. The optical characteristics of the visor should meet the requirements of *MIL-V-43511A*. The visor should be free from misting and/or icing under all the environmental conditions expected. The limitations imposed by the assembly of the fixed binocular field of view shall be no greater than those imposed by the current aircrew protective helmet and oronasal mask. The assembly should also produce minimal restriction of head movement within the confines of the cockpit.

Filter-blower performance.

In new designs, consider the following factors for filter-blower performance:

a. Background. NBC protective headgear consists of a head enclosure in which pressure is maintained above that of the environment to prevent the entry of contaminants. This enclosure may be divided, in some systems, into an eye compartment and a respiratory compartment. Maintain a slight positive pressure within the eye compartment at all times by supplying uncontaminated gas. Systems employing demand breathing regulators need not maintain a positive pressure in the components that deliver gas to the respiratory tract. To obtain uncontaminated air, ambient air may be drawn through suitable NBC filters (containing a particulate filter and a vapor filter) with an electrically powered fan which delivers the filtered air to the respirator at the desired pressure. Oxygen free of contaminants may be obtained by:

(1) Ensuring that the contaminants do not gain access to the oxygen during production, transport, charging of the aircraft store and subsequent delivery to the respirator; and/or

(2) Placing a suitable NBC filter in the breathing gas line.

TABLE XX. Suggested values for the maximum impedance to respiration imposed by NBC protective assemblies at all altitudes from ground level to 40,000 feet.

Peak inspiratory and expiratory flow (liter/min (ATPD))	Respiratory Compartment Pressures (kPa (in. wg))	
	Maximum swing*	Maximum expriatory value (relative to ambient)
	Normal operating mode	
30	0.5 (2.0)	+0.88 (+3.5)
108	1.0 (4.0)	+1.0 (+4.0)
150	1.75 (7.0)	+1.25 (+5.0)
	Following failure of forced ventilation	
30	0.75 (3.0)	+0.88 (+3.5)
108	1.88 (7.5)	+1.12 (+4.5)

*Swing of pressure is the difference between minimum and maximum pressures during respiratory cycle.

The filter-blower system used to produce uncontaminated air can be either portable or permanently mounted in the aircraft cockpit. Newer or retrofitted aircraft that have On-Board Oxygen Generating Systems could use oxygen enriched air through the concentrator as an air source for demist and hood ventilation. This may require a slightly larger beds on the concentrator to handle the extra volume or oxygen enriched air. Additionally, the zeolites used in the bed should be investigated and tested as necessary to ensure that they will effectively filter the chemical and biological agents. 13X type zeolites have been demonstrated to effectively filter chemical agents. The electrical power for the blower may be obtained from a portable source or from the aircraft supply system. The power source may be combined with the filters and blower to form a single portable unit. Portable filter-blower units can be used to supply the aircrew respirator both when the wearer is on the ground outside the aircraft and in certain applications when the wearer is within the aircraft.

a. General requirements. Ensure that a filter-blower system designed to deliver uncontaminated air for aircrew NBC protection performs to satisfy the following criteria:

(1) A protection factor (ratio of the level of contaminants outside the headgear to the level inside the eye and respiratory compartments) of at least 10^4 is maintained by the delivery of uncontaminated gas and an adequate positive pressure is maintained under all conditions of use.

(2) The resistance to breathing when the blower is operating is low and does not become excessive when the blower fails.

(3) The flow of filtered air prevents misting of the internal surface of the optical area of the headgear over the range of environmental conditions likely to be met in use.

a. Specific performance requirements. The quality of the air and the pressures at which it is delivered by the filter-blower system should meet the following minimum standards as defined at the coupling by which the supply system is connected to the headgear.

(1) Protection factor. The concentration of any toxic chemical warfare agent in the air delivered by the system at flows of up to 2.5 liters (ATPD) per second should not exceed 1 x 10^{-4} that in the ambient air.

(2) Delivery pressure-blower operating. When the blower is operating, the pressure at which filtered air is delivered by the system should be such as to provide the above protection factor. For filter-blower systems providing inspiratory air, the pressure at which filtered air is delivered by the system in relation to the flow demanded from it should be within the limits given in *table XX* at ground level.

(3) Delivery pressure-blower inoperative. The suction required to draw a flow of 1.6 liters per second (ATPD) of air from the system when the blower is inoperative is not to exceed 1.0 kPa (4.0 in. wg).

a. Coupling. The air supply from the filter-blower system is to be delivered to the crew member through a flexible hose fitted with a coupling which will form a gas-tight connection to the air inlet of the headgear.

High g protection provisions. High g protection equipment shall be provided that meets physiological, environmental and operational requirements. The high g protection equipment shall meet the following minimum requirements _____.

The high g induced loss of consciousness is a major USAF concern as more than one aircraft accident has been attributed to this effect. The effects of high g's can be very fatiguing to crew members trying to breathe. The M-1 maneuver or straining maneuver complimented with the lower torso g suit has been used very successfully for years for high g protection. With the advent of higher performance aircraft like the F-16, high rates of g onset have more quickly caused g induced loss of consciousness. Figure 4 illustrates the effect of higher g onset rate on g tolerance. The system configuration is dependent upon the type of g compensated breathing regulator used. Figures 4a and 4b show schematically, configurations for an aircraft panel mounted and man mounted regulator systems.

TBD

FIGURE 3. Effect of g-onset rate on $\pm g_z$ tolerance.

Past g tolerance work has concentrated mainly on improvements to the g valve to increase its rate of inflation of the anti-g suit, the incorporation of new g-suit connectors that will only pull apart with a linear pull, and improvements to the g protection training program. This effort has enhanced the g protection and reliability to a small extent, but a large step forward has been taken in the mid-1980s with a new g protection concept called pressure breathing for g's (pbg's). A pbg system provides protection by increasing intrathoracic pressure in the lungs

according to the pressure schedule as shown on figure 5. A chest counter pressure garment, working in conjunction with a lower g suit, is used to counter the intrathoracic pressure and inflates to the same pressure as in the mask. The crew member forcibly exhales rather than straining to inhale. A mask tensioning device is also used so that high mask pressures may be delivered and maintained during the pbg phase of operation but does not impair pilot performance when the crew member flies routinely. The high mask pressures are only provided during the high g situations. Flight testing has shown that the pbg system has not only increased g tolerance, but has reduced fatigue and allowed the crew member to fly more efficiently in a high g environment for longer periods of time. Figure 6 shows the effect of assisted pbg on g endurance.

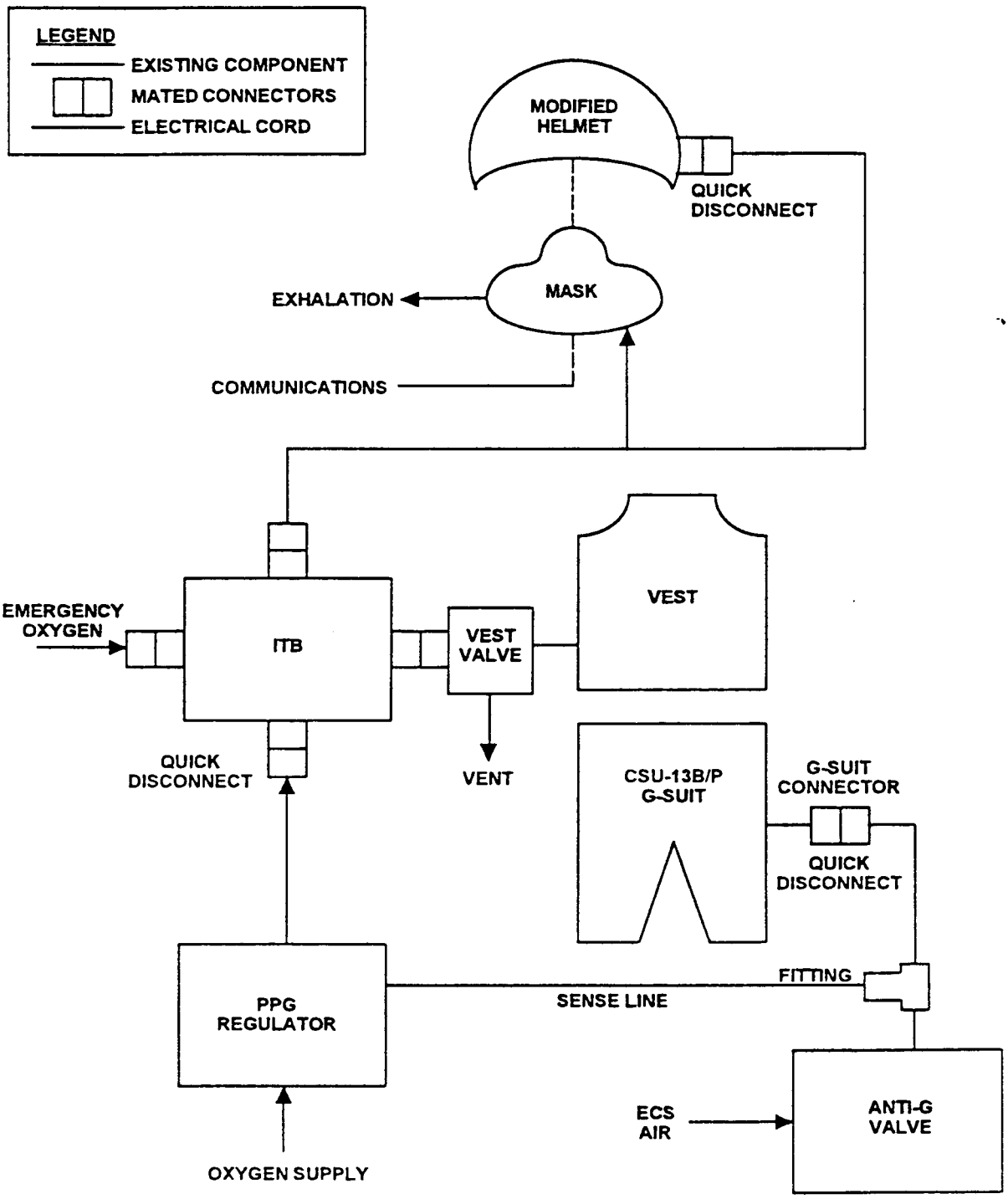


FIGURE 4. USAF COMBAT EDGE aircraft mounted regulator system schematic.

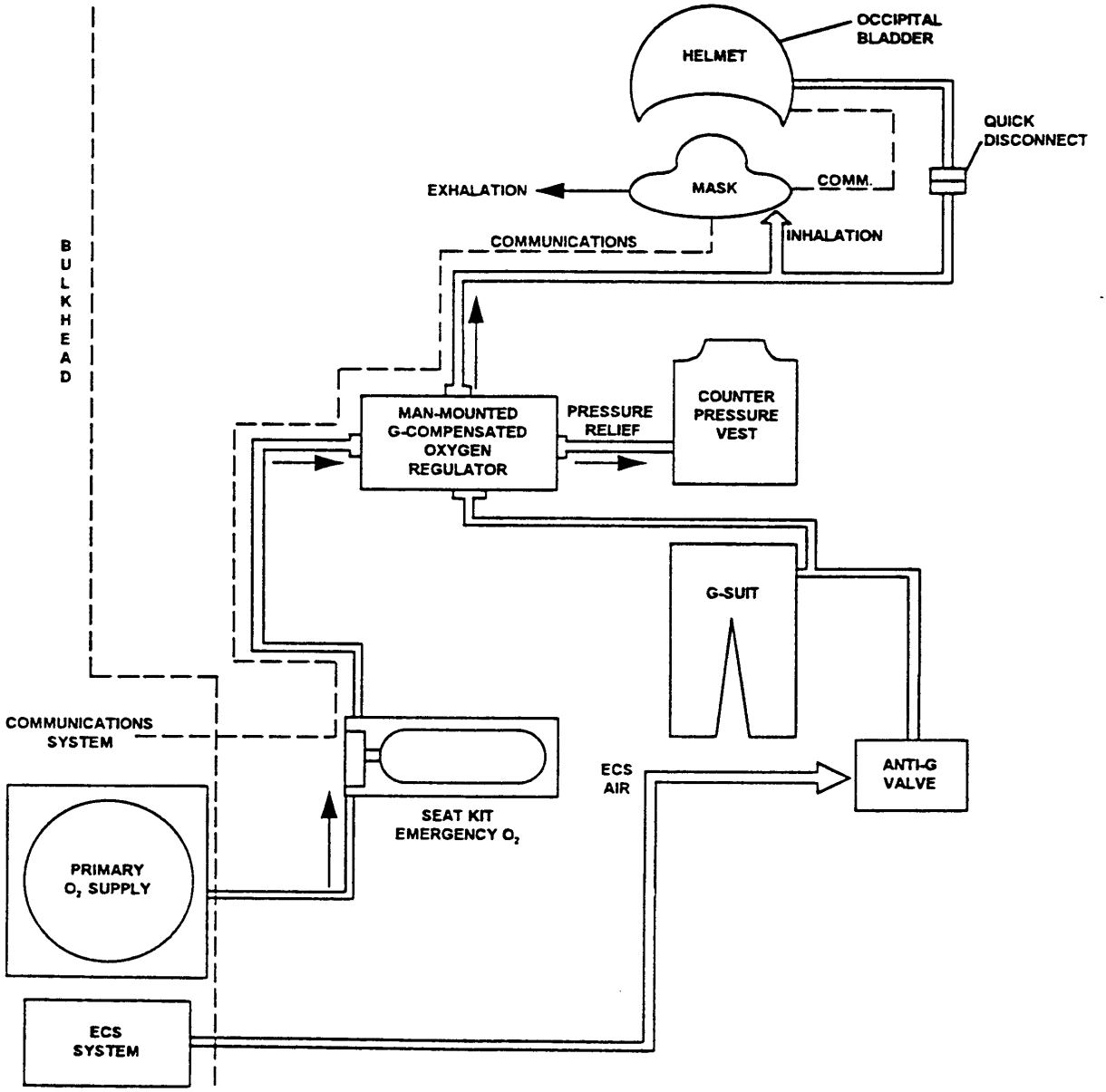


FIGURE 5. Navy COMBAT EDGE man-mounted regulator system schematic.

TBD

FIGURE 6. Pressure breathing for g's (pbg) as a function of $+g_z$ loading.

TBD

FIGURE 7. Effect of assisted pbg on g endurance.

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.

a. If during an emergency decompression (normally a mission abort situation) a mission is required to continue, continuous flow mask assemblies are sufficient unless the aircraft must remain above 15,000 ft pressure altitude. Under the latter circumstances pressure demand oxygen is required. Ensure the pressure demand oxygen is correctly regulated to the cabin pressure altitude and effectively supplies oxygen to leak-proof oronasal masks.

b. If the tolerance on the upper limit of the cabin pressure altitude from the environmental control system frequently exceeds 10,000 feet under normal operational conditions, the system should be set 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 *AFI 11-206.*

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

d. The flight time at these higher altitudes may vary up to 10 hours or more, depending on the available aircraft oxygen supply 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 two hours if used properly and if supply is sufficient providing the cabin altitude does not exceed 25,000 feet. Use of continuous flow equipment at altitudes in excess of 25,000 feet for more than 15 to 30 minutes is not recommended. Decompression sickness and hypoxia are likely to occur. If it is necessary to support the mission specialists for longer time periods above 25,000 feet, then pressure demand oxygen equipment is required.

e. Determine the maximum number of mission specialists and, if applicable, other crew members who obtain oxygen from a common supply source. If the aircraft mission can be aborted in any expected situation in the event of a decompression, a continuous-flow oxygen

system is sufficient and is necessary only for a minimum of 30 minutes. If the mission must continue at pressure altitudes above 10,000 feet for longer than two to three hours, or above 25,000 feet for periods in excess of 15 to 30 minutes, then pressure-demand regulated oxygen delivery components must be provided for crew and mission specialists. Pressure-demand regulated oxygen should be available to the flight crew. 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. The specified values for pressure and flow rates dictate many of the oxygen system design requirements. For example, the maximum flow rate possible from the CRU-73/A pressure-demand regulator is 135 liters 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 ten people on continuous-flow oxygen delivery equipment or more than two to three crew members on pressure-demand regulation, a 300-450 psi pressure range is necessary in the distribution plumbing. This ensures that under high demand conditions the pressure in the plumbing will not drop below 50 psi—the minimum pressure at which the CRU-73/A 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 liters per minute for short time periods and approximately 12-13 liters/min for normal conditions (no physical exertion). Continuous flow equipment should provide a minimum of 4.5 liters/minute/person of breathing gas. Increased flow rates may be required for persons under stress or exertion. A typical upper limit has been 12 liters/min/person.

REQUIREMENT LESSONS LEARNED (3.10.2.1)

Crew breathing system. Note that current operational limits interpret that 100 percent oxygen must be used in the situation designated O (oxygen must be used) in table I. This is physiologically the correct procedure as very little oxygen would be delivered to the crew member with the regulator in normal setting at an 8000 foot cabin altitude.

Any crew member not on 100 percent oxygen for at least 20 minutes prior to a cabin decompression at altitudes above 41,000 feet will be subject to loss of consciousness. For years commercial airline pilots have operated with one pilot on 100 percent oxygen when flight above 41,000 feet is planned. Once the pilots association tried to do away with this FAA regulation, but safety concerns over ruled this attempt.

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

The MBU-5/P has a nylon cord, while MBU-7/P had 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.

Early oxygen masks incorporated re breathing features that consisted of a bag in which 100 percent oxygen continuously flowed and which some fraction of expired gases from the crew member also entered. This combination of 100 percent oxygen and expired gas would be inhaled on the next breathing cycle. These types of breathing devices are no longer considered satisfactory for use by USAF crew members because they cannot deliver precisely controlled ratios of oxygen concentration, and they are not compatible with pressure breathing features required for higher altitudes.

Continuous flow systems are considered unsuitable for use by flight crew members who must breathe oxygen in excess of two hours. Actually, continuous flow systems are only considered suitable for passenger usage for emergency descent.

Based on past experience with ejected crew members drowning in sea water, tactical operational commands have established a need to preclude unconscious and/or incapacitated crew members from drowning. Three critical subsystems are required for an anti-drown capability: automatic release of the parachute canopy, automatic inflation of a life preserver ensuring that the head is held out of the water, and automatic oxygen mask anti-drown protection. Water activated oxygen mask removal has been more effective in the past than an anti-suffocation/anti-drown valve modification to the oxygen mask and/or the harness mounted connector. However, a mask that is effectively designed and sealed so that water is prevented from entering it when it remains on may be more favorable than mask removal because it would prevent the crew member from choking on water that might splash into the face.

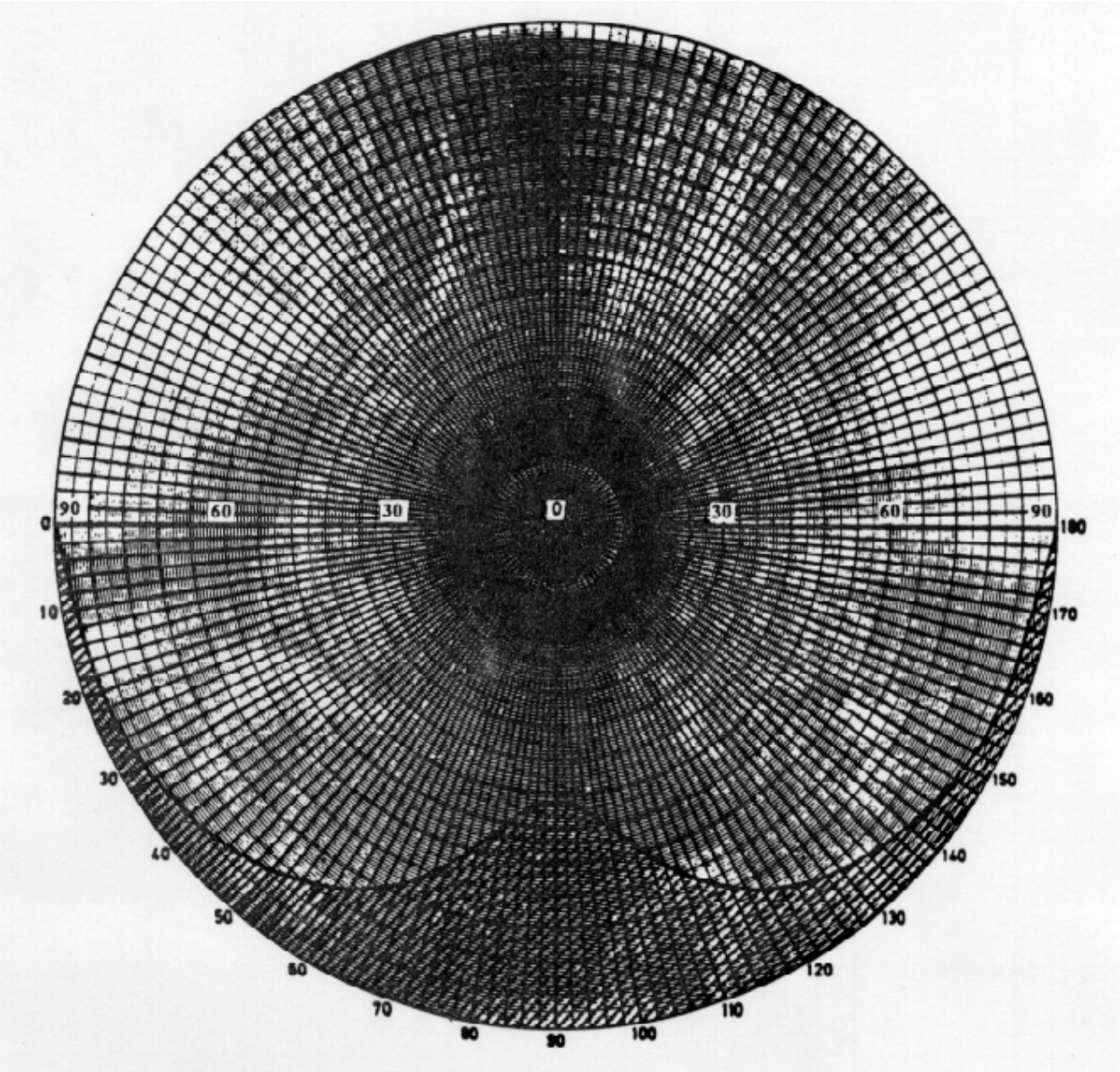


FIGURE 8. Perimetric chart defining maximum acceptable restriction of binocular vision (cross hatched area is maximum acceptable loss).

Crew regulator breathing equipment. For a four-man crew on a combat mission, high demand flow has been determined from flight test data to be approximately 40 liters normal temperature and pressure, dry (NTPD)/minute/man. Experience with fighter aircraft operations has shown that crew member inspiration flow rates up to 80 liters NTPD/minute/man have been recorded. The primary reason for these very high rates of inspiration in fighter aircraft are the acceleration forces of flight imposed on the crew member in a heavy workload situation.

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 $+G_Z$ maneuver (this applies to aircraft capable of high $+G_Z$ maneuvers in excess of +3 G_Z), he must grunt and strain his body to keep from blacking out. The pilot is trying to keep his blood from pooling to his legs by contracting his muscles. 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 used in M-1 and L-1 maneuvers. Peak flows in excess of 200-300 lpm have been recorded in these situations. It should be noted that inspiration flow rates up 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 crew members, and 85-100 lpm is under consideration for bomber crew members. 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 pilot survival. The time interval or bandwidth of these flow rates will be very short (two 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.

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. However, the concentration ratios of oxygen-to-air were not precise, and in many cases, the crew members 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. Another problem was that slight-positive pressure and increased positive pressure breathing were not provided. Therefore, this design resulted in increased incidents of hypoxia at higher altitudes. Pressure demand regulators as specified herein have significantly reduced these incidents.

Above 28,000 feet cabin pressure altitude, breathing 100 percent oxygen without additional pressure is not sufficient for efficient body performance (see AFP 160-5, pages 4-11 through 4-14). Positive pressure breathing is required and is accomplished by use of an oxygen system that delivers 93-100 percent oxygen at greater than ambient pressures. Most USAF crew member oxygen regulators are designed to provide positive pressures and 93-100 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 5000 feet pressure altitude. Mask pressures greater than 30 mm Hg cannot be tolerated for long periods of time without causing undesirable physiological effects. Also, it is extremely difficult to provide a seal between the perimeter of the conventional oxygen mask and the face to hold positive pressures in excess of 25 mm Hg without leaking. Therefore, 20 to 25 mm Hg has been established as an upper limit on positive pressure until newer and better face mask designs and mask tensioning devices allow greater pressures. Some existing design criteria are

given below:

a. The CRU-73/A regulator provides a positive pressure of 11 inches (plus or minus 5) of water gage at the outlet of the regulator, and not the mask cavity, to allow the crew member to test the mask fit. This regulator delivers a pressure in the range of 3 to 4 inches of water gage at 10 lpm and not less than 2 inches of water gage at 8 lpm.

b. Past regulator and mask combination designs for chemical defense have incorporated pressure-demand breathing. Pressure-demand regulated breathing equipment may have negative pressure inside the delivery components under inspiration. This increases the possibility for contaminated cockpit air to be drawn into the oxygen delivery components on crew member inhalation. Slight positive pressure breathing modes should be considered in new designs to minimize the possibility of breathing contaminated air.

Removal and replacement of multiple regulators is difficult because the regulator cannot be isolated from the supply equipment. Manual supply shutoff has been proposed on some aircraft systems to reduce maintenance time. Past experience has shown that two types of valves can minimize this problem: A line valve for the flight crew and the aft compartment personnel may be provided to shut off either distribution supply lines. It must be marked clearly and recessed as a safety control and be readily accessible by aircraft occupants while in flight. A good safeguard is to provide a manual shutoff control for each supply source that is safety wired in the “ON" position with control positions clearly discernible. This not only enables any one supply source in a multiple system (gaseous or LOX) to be removed keeping the oxygen system operational, but also the regulator may be isolated from supply for its removal and replacement without the need for depleting supply or purging the system again.

Experience with oxygen regulator failures that use aneroid assemblies shows they should be designed so that if the aneroid fails, the regulator is placed in the 100 percent oxygen mode. An aneroid usually fails as the result of a vacuum loss from small nicks or other physical damage.

Existing USAF regulators have a mechanism which, as a result of improper repair, could cause the regulator to deliver diluted oxygen when in the 100 percent mode. A component may be improperly placed or may simply fail. Regulators should be designed so that failure of a component or mechanism does not place the regulator in dilution mode when the 100 percent oxygen mode is selected.

During USAF experience chest mounted regulators supported only by crew restraint harnesses are frequently damaged or abused by crew or maintenance personnel. On one aircraft type which has a chest mounted regulator, when the crew members move the harness to egress, the regulator hangs loose and is easily banged against the seat rail or stepped on by crew or maintenance personnel. The regulator is very delicate and is easily damaged or knocked out of calibration. A clip was installed on the side of the seat headrest on which the crew member could mount the regulator as he departed the cockpit. The mounting is rarely used, however, and the regulator is still frequently damaged. The average life expectancy of a regulator of this type is eleven months. In new aircraft, the regulator mounting locations shall be determined by mission requirements. USAF regulator designs shall be prioritized as (1) aircraft panel mounted, (2) seat mounted, (3) man mounted. There are advantages and disadvantages to either design approach but this priority is best overall.

Chest mounted regulators have been successfully used by the U.S. Navy for may years. The

CRU-79/P chest mounted regulator provides 100 percent oxygen with safety pressure and pressure breathing. this regulator weighs less than 5 ounces. These regulators have been inexpensive compared to aircraft panel mounted type regulators and some models have endured several years with only minor aneroid adjustments. However, as other capabilities are considered for addition to the regulator (i.e., air dilution, G-compensation, and chemical/biological protection, etc.) the size and weight may increase enough to warrant a more practical location on the seat or aircraft.

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

To reduce oxygen waste and servicing from a logistics standpoint, it is often desirable either to remove the passenger LOX converter or to use a converter with a small LOX capacity. The reason for this is that many USAF transport aircraft with passenger accommodations spend the majority of the time transporting cargo rather than passengers. Therefore, a small crew member 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 their oxygen supply. A separate crew member oxygen supply source precludes these problems.

It has been found to be very beneficial to have a secondary means of pressure relief on LOX converters, especially those that are removed and serviced outside of the aircraft. A number of LOX converters have exploded due to moisture freezing in the relief valve and rendering each one inoperable.

Problems are being encountered with the plumbing installations in most aircraft. In aircraft ground tests, the lines are pressurized and leaks develop. To minimize such problems, the designer may elect to use a lubricant to accomplish a leak-proof closure of all connections. Many times an improper lubricant has been used, which 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, which then had to be disassembled, cleaned, and reassembled. This type of installation problem has been encountered quite often. Only a grease lubricant in accordance with *MIL-G-27617* is allowed for use in military aircraft oxygen system installations.

Periodically pressure vessels in the 2500 to 6000 psig range are considered for use in aircraft oxygen supply systems. They are not considered acceptable at this time because of the extreme fire and explosion hazards associated with pressure reducing valves at the valve head, the destructive energy that can be released from such vessels if penetrated, and the hazards associated in servicing such equipment. Existing military gaseous servicing carts use 2000 psig bottles. New, higher pressure servicing capabilities would have to be provided.

Operational problems have occurred with the use of zeolite filled canisters on MSOGS concentrators. Excessive moisture or water has penetrated the zeolite causing zeolite

degradation and excessive heat buildup. The maximum heat of adsorption of 5A and 13X type zeolites (typically used for oxygen generation) is 1800 BTU per pound of water. If the moisture has time to deactivate the zeolite because of improperly designed pressure swings, the zeolites will be ineffective for oxygen separation. Also, excessive water will cause a temperature rise within the canister. If not properly designed to dissipate heat, the concentrator temperatures can become excessive. Experience has shown these temperatures may exceed 400°F resulting in concentrator damage. Moisture and water can also degrade the clay binder, an inert substance that holds the zeolite granules together. This has resulted in a dusting which contaminates oxygen delivery components with very fine particles. Aircraft vibration and the oxygen concentrator pressure swings have a tendency to accelerate these dusting effects. Some dusting is a natural process, but effective canister loading mechanisms which allow for some loss of zeolite, minimizing moisture contamination and eliminating water contamination, and vibration damping are methods shown to significantly reduce the dusting process.

Dusting problems on a past USAF bomber has resulted in significant maintenance problems and excess support cost for the Molecular Sieve Oxygen Generation System for oxygen generation. MSOGS concentrations were being replace every 150 to 450 flight hours for overhaul. A new design uses an immobilization process. One year flight demonstration on two aircraft and MSOGS concentrators returned for over haul for other purposes has shown the new design is a significant improvement. Expected life times of the zeolite canisters are 2000 to 4000 flight hours.

The dusting of the MSOGS canisters also caused significant down times for aircraft to clean out the tubing and replace contaminated components. Many thousands of dollars were wasted also in cleaning the aircraft. Initially, Isopropyl Alcohol was used to flush out the lines, but several fires resulted and now CFC-113 is being used. By pass fittings also had to be locally constructed to take the component out of the cleaning fluid flush.

Onboard Oxygen Generation Systems (OBOGS) are more cost effective and safer than liquid oxygen (LOX) systems for supplying aviators breathing oxygen (ABO). Reference: AFALC/PTL, Wright-Patterson AFB OH, Abstract of Lessons Learned, 1 January 1987.

A low pressure aircraft oxygen system (fills to 450 psig) was filled from high pressure with an improper supply hose and valve. Even though the low pressure supply hose has a relief valve to preclude over pressurization, improper supply hoses are occasionally used. The loss of two aircraft has made it evident that pressure relief on the aircraft is required on low pressure oxygen systems filled from high pressure carts. The relief valve should be near the filler valve so that it vents outside the aircraft; visual and/or aural indication should be provided when over pressurization occurs; and the relief should be capable of handling flow rates that preclude over pressurization of the aircraft oxygen system.

When multiple LOX converter installations are provided on aircraft, a separate LOX fill-build-up and vent valves component must be provided for each converter. Experience has shown that LOX will flow to the path of least resistance and fill that converter. This one converter can be topped off (or filled) but the other converter(s) will be only partially filled. The LOX will flow through the full converters vent valve and not to the other converters.

A USAF fighter aircraft was destroyed by fire because the chafing and arcing of electric generator power lead was near an oxygen supply line. The fire burned through the oxygen line

and the oxygen gas fed a fire which became more intense causing the aircraft's destruction. Oxygen supply and distribution plumbing should not be located near potential fire sources such as electrical generating equipment and power lines.

Breakage of oxygen supply lines to breathing regulators in the aft cargo compartment has occurred on some USAF transport aircraft because of excessive fuselage vibration. When this occurs on an aircraft with a LOX system, a high flow rate develops pulling LOX from the converter(s) and it sprays LOX into the cargo compartment. This could seriously injure a person if it contacted his skin. It is also a severe fire and explosion hazard. Steel braid flex line should be used at the regulator inlet and/or vibration isolators on the plumbing mounting.

Nuclear, biological, and chemical (NBC) protection. In the mid 1980's a chemical defense ensemble was developed for USAF fighter aircraft called Tactical Aircrew Eye/Respiratory System (TEARS). The program reached Developmental Test and Evaluation when a problem was encountered. The fighter aircraft using the equipment ran out of LOX supply before completing the mission. The ensemble used oxygen gas from the breathing system to demist and ventilate the hood ensemble. LOX converters were weighed before and after the missions and oxygen consumption analyes were accomplished. This all showed that the amount of LOX supply was insufficient to support breathing, demist and ventilitation. The program was halted and another type of concept now called AERP using a blower with a filter pack was developed and put into operation.

High g protection provisions. TBD

Mission specialist oxygen system. TBD

4.10.2.1 Crew breathing system verification.

Analyses, demonstrations, inspections, and tests are essential in checking for a properly designed crew breathing oxygen system. The verification of the aircraft crew breathing oxygen system shall consist of _____. If a contained oxygen supply is proposed, then analysis must be accomplished by the Preliminary Design Review to ensure sufficient amount of oxygen supply is provided to meet mission requirements. If an On Board Oxygen Generating System is proposed, then analysis and inspections must be performed by the Critical Design Review to ensure that the system will deliver sustained and peak flow rates for the crew. Additionally, analysis and inspections must be completed by the Test Readiness Review to ensure that the system will not be degraded by water ingestion, high or low temperature extremes, and electrical power considerations. Demonstrations and testing will be proposed by the Test Readiness Review and completed by the Functional Configuration Audit to confirm the OBOGS will be reliable. All controls and displays shall be inspected for satisfactory design and proposed for demonstration at the Test Readiness Review.

VERIFICATION RATIONALE (4.10.2.1)

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

Crew mounted breathing equipment. Verification of the crew mounted breathing equipment

is necessary to ensure that all components function properly and meet all the physiological requirements of the crew members in the expected operational environment.

Crew regulator breathing equipment. Verification of the crew member regulator equipment is necessary to ensure that it will properly function in the expected operational environment and meet all the physiological requirements of the crew members.

Crew oxygen supply equipment. The crew oxygen supply equipment must be checked for proper functioning so that the physiological needs of the crew are provided for all expected operations.

Nuclear, biological, and chemical (NBC) protection. Verification of the aircraft mounted and personal mounted NBC protection equipment is necessary to ensure that all components properly function in the expected operational environments and protect the personnel from toxic NBC agents.

High g protection provisions. Verification of the high G protection equipment is necessary to ensure that a satisfactory level of protection is provided against high G levels and high G onset rates. Also, the safety of this equipment must be determined.

Mission specialist oxygen system. 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 (4.10.2.1)

Crew breathing system. The verification of the crew breathing system shall consist of _____.

The verification of the crew oxygen system should consist of analyses, inspections, demonstrations, and tests as necessary to ensure that all requirements have been met. Some recommended methods of verification that have been used 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 oxygen is delivered at physiologically compatible concentrations, flow rates, pressures, and temperatures, and that contaminant-free oxygen or breathing gas is delivered to each person within the operational envelope of the aircraft. The cabin 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 manual or seat ejection, should be analyzed. The variables involved in the fluid dynamics of the oxygen system plumbing and components are great. Many physiological requirements are specified in terms of oxygen concentrations, flow rates, pressures, temperatures, and air composition or purity. Therefore, these variables need to be considered for final installations.

d. The oxygen system, as installed on the aircraft, should be fully operational and all individual components should have demonstrated meeting 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. 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 usually highest. Less efficient operation may be encountered at higher altitudes due to 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. Crew members 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. Crew members 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 prebriefing and then with prebriefing.

g. The oxygen system should be instrumented as necessary and used by flight personnel in flight tests to ensure that the equipment operates as specified and is functional with all crew members 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.

Safety of Flight Certification: Prior to the first aircraft flight the oxygen systems must be evaluated and tested as appropriate to determine that the equipment is safe for flight. The Molecular Sieve Oxygen Generating System called MSOGS or On Board Oxygen Generating System called OBOGS are the most concern. The reason is that the proper operation of the OBOGS is a strong function of altitude, temperature and personal breathing demand flow rates. To ensure the MSOGS or OBOGS are safe for flight the following questions and issues should be resolved to the satisfaction of the development and government activities involved.

1. What analysis or testing will be done to demonstrate that the oxygen system will be able to provide physiologically acceptable performance under all conditions of:

- aircrew workload
- aircraft altitude/temperature/airspeed
- degradation of the system over time
- cabin pressurized and unpressurized

2. What analysis or testing will be done to ensure that sufficient oxygen pressure is provided to the regulator and sufficient oxygen flow to the aircrew under all possible flight

conditions

3. What analysis or testing will be done to ensure that the breathing gas has a sufficient percentage of oxygen at all aircraft altitudes for both a pressurized and unpressurized cabin

4. What analysis or testing will be done to ensure that during rapid decompression, such as during ejection at altitude, the pressure in the oxygen system will be relieved in a manner that will not over pressurize the aircrew's lungs and cause permanent injury

5. What analysis or testing will be done to ensure that during rapid decompression, such as during ejection at altitude, thermal shock to the oxygen system components will not adversely impact system performance

6. What analysis or testing will be done to ensure that the aircrew will have sufficient oxygen for the duration of all possible ejection scenarios

7. What analysis or testing will be done to ensure that in the event of an emergency loss of the MSOGS, breathing gas will be provided until the aircrew is able to fly to a safe altitude of 10,000 feet

8. What analysis or testing will be done regarding the incorporation of a backup to the primary MSOGS system in the event of system failure

9. What analysis or testing will be done regarding the incorporation of a backup to the primary MSOGS in the event of system failure

10. What analysis or testing will be done to ensure that noise level generated by the oxygen system does not interfere with crew duties

11. What analysis or testing will be done to ensure that inhalation and exhalation breathing resistance of the oxygen system do not place excessive breathing workload on the aircrew

12. What analysis or testing will be conducted on the reliability of the MSOGS oxygen concentrator

13. What analysis or testing will be done on the compressor and environmental control system failure modes and the impact on MSOGS What emergency procedures will be required

14. What analysis or testing will be done one the electrical power systems failure modes and the impact on MSOGS What emergency procedures will be required

15. What provisions will be made to prevent damage to the MSOGS during ground maintenance of other systems

16. What analysis or testing will be done to ensure that the MSOGS is readily accessible and maintainable

17. What analysis or testing will be used to verify that particles of metal, bugs, dirt, dust in the breathing oxygen flow will not be hazardous to the aircrew

18. What analysis or testing will be done to ensure that the smell of adhesives and elastomer materials used in the oxygen system will not make the aircrew sick or affect aircrew performance

19. What pressure relief capability will the oxygen system have to prevent oxygen mask pressures from causing damage to the lungs and sinuses of the aircrew in the event of an oxygen regulator failure

20. What analysis or testing will be done to ensure that the temperature of the breathing gas is within safe limits for all possible flight condition

21. What toxicological analysis or testing will be done to ensure that contaminants such as jet fuel and carbon monoxide are not concentrated by the MSOGS and provided to the aircrew at unsafe levels

22. What analysis or testing will be done to ensure there are no oxygen leaks and that none will develop in flight Oxygen leaks can cause loss of pressure precluding safe delivery of oxygen to the aircrew. Leaks can promote combustion in many sections of the aircraft.

23. What nontoxic, odor-free, non-ozone-depleting cleaning methods will be used to ensure the oxygen system is properly cleaned to breathing standards

24. What analysis or testing will be done to ensure that residue from cleaning substances do not exceed breathing standards

25. What analysis or testing will be done to ensure materials selected are oxygen compatible and that fire and combustion risks are minimized

26. What analysis or testing will be done to ensure that elastomers selected will not degrade when used in a high oxygen content environment

27. What analysis or testing will be done to ensure that dissimilar metals do not corrode in the presence of oxygen or salt spray creating a fire or failure hazard

28. What analysis or testing will be done on the performance of MSOGS during engine flameout, flat spin, idle descent, VSTOL, etc., flight modes

29. What analysis or testing will be done to ensure that the concentrator exhaust or venting cannot be blocked due to ice, dirt, rodents or birds

30. What analysis or testing will be done to ensure that MSOGS will continue to function in the event of a loss of cabin pressure due to ECS failure or cockpit seal failure

31. What analysis or testing will be done to ensure that liquids from other aircraft systems such as fuel, hydraulic fluid and avionics coolants will not enter the MSOGS in the event of a leak in adjacent systems

32. What analysis or testing will be done to ensure that unconscious aircrew will not suffocate in the event of MSOGS failure or during ejection scenarios

33. What hazard analysis of the MSOGS will be conducted to ensure that a single point failure of any component will not be hazardous to the aircrew

34. What environmental analysis and testing will be conducted to ensure that MSOGS functions and is not hazardous under environmental extremes generally expected for military equipment

35. What analysis or testing will be done to ensure that solid/liquid/vapor phase moisture in the MSOGS inlet air, will not damage the MSOGS during spin-up, spin-down and operation of the engines Slugs of water in the supply system can significantly deactivate the zeolites in an MSOGS.

36. What analysis or testing will be done to ensure that the MSOGS does not put an excessive flow demand on the ECS system leading to overheating or freezing of other aircraft components

37. What analysis or testing will be done to ensure that vibration and acceleration loads expected at the location of the concentrator will not impact performance of the concentrator or damage vibration isolator mounts In some programs, if the vibration scenario is unknown, but expected to be excessive it may be prudent to leave space for isolator mounts if not included in the concentrator design package.

38. What analysis or testing will be done to ensure that liquid removed by the MSOGS concentrator does not cause corrosion of supporting structures in the concentrator bay

39. What analysis or testing will be done to ensure that EMI fields (from inside and outside the aircraft) do not effect the function of the electronics controlling the MSOGS and/or the electronics warning the aircrew in the event of MSOGS failure

40. What system safety analysis of other systems physically adjacent to the critical components of the MSOGS will be conducted

41. What Ready For Issue (RFI) procedures will be conducted prior to installation of each critical MSOGS components

42. What testing of critical MSOGS components will be done at scheduled intervals during flight testing

43. What system level testing will be conducted on the aircraft MSOGS prior to first flight

44. What system level testing will be conducted on the aircraft MSOGS at scheduled intervals during flight testing

45. What Built-In-Test (BIT) capability will the MSOGS have for the aircrew to perform inflight or preflight

46. What analysis or testing will be done to ensure that the BIT has no single point failures

47. What analysis or testing will be done to ensure that the aircrew can disconnect quickly from the oxygen system for emergency egress and during man-seat separation

When all these questions have been dealt with and satisfactorily answers provided prior to first flight then the MSOGS would be certified safe to fly.

Crew mounted breathing equipment. The verification of the crew mounted breathing equipment shall consist of _____.

Verification of the crew mounted breathing equipment should consist of analyses, inspections, demonstrations and tests as necessary to ensure that all performance requirements have been met. Standard laboratory and altitude chamber testing criteria have been developed for this

equipment and are given here for verification of future designs.

a. Background.

(1) Delivery of physiologically adequate breathing gas is essential to optimal performance of aircrew members. Combined stresses such as altitude, acceleration, workload, temperature and psychological stress may impose a wide range of demands on the breathing gas delivery system. The oxygen delivery system must satisfy the user's physiological requirements under these diverse conditions. The information in this section is intended to establish standards regarding methods for developmental test and evaluation of breathing gas delivery equipment.

(2) The oxygen delivery system is defined as the operational configuration of all components from the aircraft oxygen supply to the user; these include the oxygen source and its supply line, the oxygen regulator, and the hose and face mask. Man-rating of oxygen delivery equipment should be accomplished prior to inflight test and evaluation by systematic investigation of performance characteristics. Oxygen delivery system performance should be evaluated under simulated operational conditions using mechanically imposed gas flows and human breathing tests. Performance evaluation of the oxygen delivery system is accomplished in three phases: test of the integrated system under constant (static) flow conditions; test of the system components under cyclic (dynamic) flow conditions; and human subject breathing tests.

a. Test and evaluation criteria. Developmental test and evaluation of oxygen delivery equipment must ensure that the system:

(1) Meets respiratory demands without imposing excessive resistance to breathing.

(2) Prevents significant hypoxia while the cabin is pressurized without inducing acceleration atelectasis (lung collapse) or delayed otitic barotrauma (middle ear block).

(3) Prevents significant hypoxia following decompression of the pressurized cabin up to the maximum cabin altitude which can occur in flight.

(4) Prevents the pressure generated by trapped gas on rapid decompression from exceeding acceptable physiological limits.

(5) Permit, when required, admixture of cabin air with the gas from the aircraft oxygen store or onboard generation system.

(6) Provides, when required, safety pressure in the mask cavity to prevent inboard leakage of environmental air.

(7) Does not produce significant oscillations of pressure within the mask cavity.

(8) Provides pressure breathing automatically when the cabin altitude exceeds that altitude at which pressure breathing is needed for safe operation. which in the USAF is 30,000 feet and, when manually selected, at ground level (press-to-test facility). See Figure 10a for the USAF pressure breathing schedule on the CRU-73/A breathing regulator. The Navy requires automatic pressure breathing for 100 percent oxygen breathing systems when the cabin altitude exceeds 34,000 feet. For an On-Board Oxygen Generating System (OBOGS) automatic pressure breathing begins at approximaately 32,000 feet to compensate for reduced oxygen percentages.

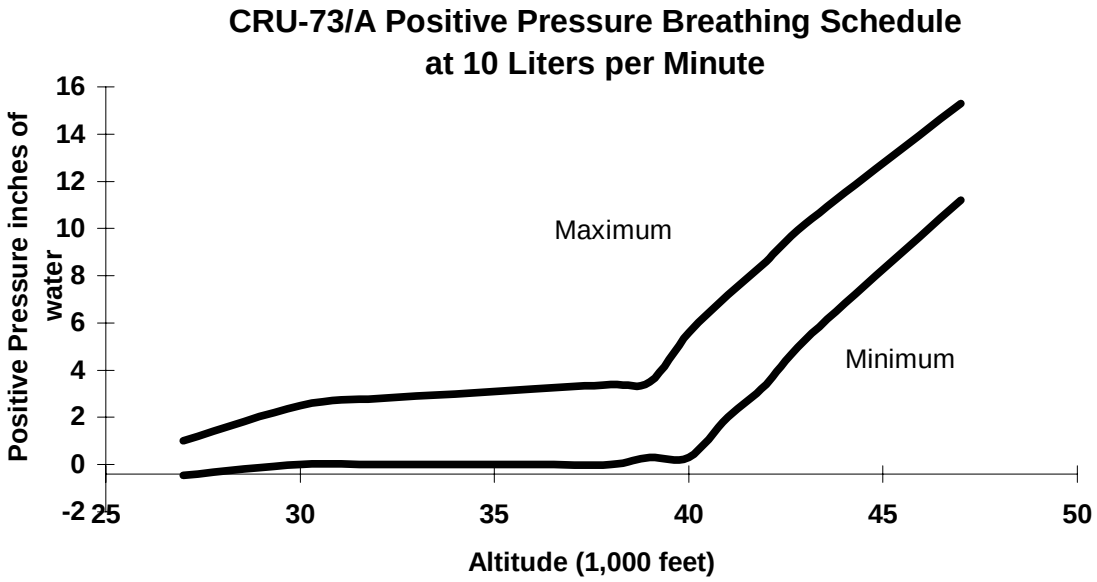


FIGURE 9a. Pressure breathing schedule of common USAF panel mounted regulator

a. Test assembly. The items required to perform tests are outlined below:

(1) An altitude chamber or suitable enclosure capable of attaining pressure altitudes up to the system's maximum, and which is capable of maintaining those pressure altitudes determined by the USAF to be within acceptable tolerances.

(2) An oxygen source which is able to provide the gas at pressures and flows which permit normal and emergency operation of the regulator without producing significant effects on either the line pressure or flow.

(3) A vacuum source to impose constant flows on the regulator as required.

(4) A cyclic flow pump to simulate respiratory flows. The pump must have a wide range of variable stroke volumes and frequencies to permit ventilation extremes to be attained. The pump must be capable of operation at all test altitudes. The test assembly used for cyclic flow testing should simulate the resistance characteristics of the human respiratory system.

(5) A device on which to seal the face mask, such as a mannequin head or other device suitable to form-fit the face mask without leakage.

(6) A device suitable for continuous measurement of inspiratory and expiratory flows.

(7) Rapid response oxygen and carbon dioxide analyzers for continuous measurement of breathing gas. Analyzers should have minimal sampling volume requirements.

(8) Pressure transducers which operate in the appropriate ranges for regulator suction pressures and mask cavity breathing pressures under all conditions. The transducers and recording system should have a frequency response that is flat (+1.5 dB) in the range of 0 to 20 Hz. For flow stability testing, the transducers and recording system should be sensitive to 25 Pa (0.1 inches water) within a frequency range of 0 to 60 Hz ($\pm$1.5 dB).

a. Constant flow test procedures.

(1) The man mounted equipment shall be tested with the regulator at constant flows which include the full range anticipated in use as well as the extremes of performance of the system. The oxygen inlet pressure shall be set to the nominal, minimum and maximum pressures of the supply system with which the regulator is to be used. The following will be monitored at the regulator outlet: suction and positive pressures, oxygen concentration and leakage. Testing should be performed at selected altitude intervals from ground level to an appropriate operational altitude in both 100 percent and normal dilution regulator settings.

(2) At ground level, the regulator will be tested for inward and outward leakage with the oxygen supply valve closed; outward leakage will be tested with the oxygen supply valve open and the appropriate inlet pressure; and relief valve outflow will be measured by applying appropriate back pressure at the regulator outlet.

a. Cyclic flow test procedures

(1) An idealized respiratory flow will be imposed on the oxygen delivery system. Responses of the oxygen delivery system should be monitored continuously. Variables to be monitored include pressure, oxygen concentration, flow at the mask, and altitude. Inboard system leakage will be evaluated.

(2) Sinusoidal or other idealized flow profiles will be imposed with a range of peak flows, respiratory frequencies and minute ventilations which span the extremes of actual use. Such flows will be imposed by means of a breathing simulator or mechanical pump with variable volume and frequency control. Ventilation, respiratory frequency and tidal volume imposed by the breathing simulator should range at least between suggested minimum and maximum presented in table XXI.

TABLE XXI._Breathing simulator suggested ranges*

	Range of settings	
	Minimum	Maximum
Ventilation (liter/sec (liter/min))	0.07 (4.0)	1.00 (50)
Peak Flow (liter/sec (liter/min))	0.20 (12.5)	3.30 (200)
Rate of Flow Change (liter/sec/sec)	0.60	20.00
Frequency (breaths/min)	5.00	60.00
Tidal Volume (liters)	0.50	2.50

*Reference Air Standardization Coordinating Committee *AIR STD 61/10B*, “Developmental Test and Evaluation of Aircraft Oxygen Delivery Systems," 18 Aug 1982.

(1) Peak flow tests may require frequency or volume settings on the breathing simulator outside the normal physiological range. Should the breathing simulator not be capable of attaining peak inspiratory flows of 3.3 liters per second (200 liters per minute) with the mask cavity pressures within acceptable limits, with a rate of change up to 20 liters per second per second, within the suggested range of frequency and tidal volume given in table XXI, additional tests will be performed to assess system performance during peak flows up to 3.3 liters per second (200 liters per minute).

(2) Tests should be performed at ground level and at selected altitudes progressively incremented to include the maximum cabin altitude which can occur following rapid decompression. Other combinations of cyclic flow may be used where deemed necessary. Both 100 percent and normal dilution regulator modes will be examined.

a. Human interface evaluation. Human breathing tests will be accomplished with subjects at rest and performing light, moderate and heavy work. Workloads may be imposed by bicycle ergometry, treadmill exercise or other suitable means. Tests will be performed at ground level and at selected altitudes progressively incremented to simulate appropriate flight profiles. Guidelines for workloads are given in table XXII. The oxygen inlet pressure shall be set to the nominal and extreme pressures of the supply system. Both 100 percent and normal dilution regulator modes will be examined. System performance will also be evaluated at appropriate temperature extremes. Additional tests will be performed during exposure to sustained acceleration where appropriate. Whole body vibration tests are also desirable. Pressure in the mask cavity will be monitored throughout human breathing tests and the effects of speech and head movement will be assessed. Inspiratory and expiratory flows will be monitored continuously. Inspired and end tidal concentrations of oxygen and carbon dioxide in the mask cavity will be monitored.

b. Pressure breathing evaluation. Determining the mean pressure in the mask cavity during pressure breathing is critical to evaluation of the oxygen delivery system. For this reason performance evaluation of positive pressure breathing must be accomplished by subjecting the system to human respiratory flow patterns at altitudes up to the maximum altitude. The maximum altitude is held for a period of up to one minute during which ventilation is varied between the extremes. Inspiratory flow is monitored and the mean mask cavity pressure over each complete respiratory cycle is calculated and correlated with each inspiratory peak flow measurement. System performance should be checked in both the 100 percent and normal dilution regulator settings.

c. Flow stability tests. Flow stability of the breathing gas delivered to the user depends on the particular respiratory flow pattern imposed on the delivery system, the impedance characteristics of the specific system components and hardware, and the impedance of the user's respiratory tract.

TABLE XXII. Workloads*

Condition	Ventilation		Peak Flow Range Range		Respiratory Frequency (Breaths/min)	
	(liter/sec)	(liter/min)	(liter/sec)	(liter/min)	minimum	maximum
Rest	0.12	(7)	0.33-1.17	(20-70)	6	25
Light Work	0.42	(25)	1.17-1.83	(70-110)	12	35
Moderate Work	0.75	(45)	1.83-2.83	(110-170)	15	45
Heavy Work**	1.00	(60)	2.83-	(170-)	18	45

*Reference *ASCC AIR STD 61/10B*.

**Heavy workloads are optional. All flows are measured at ATPD.

Determination of flow stability therefore requires duplication of the oxygen delivery system's operational configuration and the use of a number of different human subjects. It is essential

that the monitoring instrumentation not cause any change in the impedance of the system. Tests should be performed at ground level and at altitudes up to the maximum anticipated altitude of system use. Tests should be repeated with human subjects at rest and performing light exercise both with and without speech. Flow stability is assessed by measuring pressure oscillations in the mask cavity.

a. Rapid decompression tests. Evaluate the delivery system in unmanned tests to determine trapped gas pressure and oxygen partial pressure in the face mask following rapid decompression to an appropriate altitude. The system will be supplied with the nominal oxygen inlet pressure and the face mask will be attached to a mannequin head or other suitable device and sealed against leaks. Tests will be performed under no flow and cyclic flow conditions to ensure that trapped gas pressures and the time course of recovery of oxygen partial pressure are within physiologically acceptable limits.

Crew regulator breathing equipment. The verification of the crew member regulator equipment shall consist of _____.

The verification of the crew member regulator equipment should consist of analyses, inspections, demonstrations and tests as necessary to ensure that all performance requirements have been met. Standard laboratory and altitude chamber testing criteria have been developed to test the performance of this equipment and should be used in combination with all other features of the breathing system downstream of the regulator output that are expected to be used with this regulator.

Crew oxygen supply equipment. Verification of the crew oxygen supply equipment shall consist of _____.

Verification of the crew oxygen supply equipment shall consist of analyses, inspections, demonstrations and tests as necessary to ensure the proper operation of all oxygen supply equipment.

Nuclear, biological and chemical (NBC) protection provisions. The verification of the NBC protection assemblies shall consist of _____.

The verification of the NBC protective assemblies used in aircraft should consist of analyses, inspections, demonstrations, and tests as necessary to ensure that all requirements have been met. Those verification methods discussed in 4.10.2.1 are also applicable to NBC breathing equipment as the equipment must also provide altitude protection in most USAF aircraft. When the equipment need only be quick donned in the threat environment, altitude protection may not be required. Simulant and agent testing are necessary to ensure that the equipment does not allow inward leakage during all expected phases of operation.

High g protection provisions. The verification of the high G protection equipment shall consist of _____.

The verification of the high G protection equipment should consist of analyses, inspections, demonstrations, and tests as necessary to ensure that all requirements have been met. Those verification methods discussed in 4.2.2.1.1, 4.2.2.1.2, 4.2.2.1.3, and 4.2.2.1.4 are also applicable to PBG equipment, as this equipment must also provide altitude protection in military aircraft. Centrifuge and flight testing are essential to determine that this equipment provides the required high G protection. Comfort and sizing to different sizes of crew members are also

important considerations.

Mission specialist oxygen system. The verification of the mission specialist's oxygen system shall consist of _____.

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 4.10.2.1, Lessons Learned.

VERIFICATION LESSONS LEARNED (4.10.2.1)

Crew breathing system. TBD

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

Crew regulator breathing equipment. Past standards have not identified crew member 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. This has resulted in many different flow rate requirements from one system development to the next. Information has been provided to standardize these flow rates.

Past designs of oxygen equipment established peak flow rates in the vicinity of 100 to 150 liters per minute. Further work has adjusted these values for fighter and attack aircraft oxygen equipment design requirements to instantaneous peak flow rates delivered to the lungs in excess of 200 liters per minute. The peak flow rates are a function of the time interval in which they are measured. In the past, gas flow measurement devices have not had sufficiently quick response to measure these rapid flow rates as they occurred. More than one measurement should be taken in a one-second time interval. Peak flow rates measured in flight tests have not exceeded 60 to 80 liters per minutes although analyses and laboratory tests have shown that crew members may demand greater flow rates.

Crew oxygen supply equipment. Operational flights on a new MSOGS have shown that an outlet filter on the concentrator is necessary to preclude dust particles from entering the oxygen delivery equipment. The filter must be compatible with high concentrations of oxygen gas, stop particles with high efficiency down to six microns, and have a low pressure drop. Tests have also shown that some particles may be as small as 0.1 micron, so verifications may call for filtering capability to this particle size. This should be evaluated as a function of the system design.

In flight experience with an early molecular sieve oxygen generating system (MSOGS) revealed the following problem areas:

a. The MSOGS water extraction system should be able to dispose of the water/moisture in

the bleed air at a high efficiency rate.

b. The MSOGS should be tested against vibration and vibration with water/moisture for some appropriate time period which would be representative of its service life. Qualification testing by similarity should be avoided.

c. Residues upstream from the MSOGS (i.e., from bleed air lines) should be minimized to prevent the drain lines of the water extraction system from clogging.

d. The mechanism used for maintaining the preload on the MSOGS canisters should be capable of adapting to movements of the zeolite.

e. A filter should be installed downstream of the MSOGS to catch any unforeseen particulate. The filter color should be such that the particulate would be easily visible.

f. Past experience has shown that an MSOGS or OBOGS on an aircraft should include an oxygen monitor to measure oxygen partial pressures at all times, and to provide a warning signal when the oxygen partial pressure falls below minimum physiologically acceptable limits. See figure 10a for an example of these limits as used on past Navy aircraft OBOGS. Figure 10b shows models of the polarographic and solid state oxygen monitors.

g. Some type of tracking mechanism should be contained within each unit for the number of service hours.

h. Aircraft systems containing liquid should be incapable of backing up through the MSOGS drain lines and into the MSOGS canisters (i.e., no common drains or reservoirs).

i. The valve which releases the back-up oxygen supply should be tested to avoid leakage and closing problems.

j. Periodic maintenance checks should be established for the outlet filter.

k. The maintenance concept should provide for full organic capability at depot level. The inlet and outlet filters should be identified as LRUs and stocked appropriately. Field level replacement of other items should be considered.

Reply to USAF Aircraft On-Board Oxygen Generating System (OBOGS) Operational Utility Evaluation or Test Results from the F-16 OBOGS Flight Testing.

1. Additional development efforts for OBOGS should also address environmental control system (ECS) reliability, single point failure of the OBOGS and cabin pressurization system, an expanded BOS, and a completely closed breathing system capability. The difference with the existing liquid oxygen (LOX) system and the OBOGS is the single point failure concern. For example, if the engine or ECS fail on an OBOGS equipped aircraft, pressurized air will not be provided to the concentrator. The result is that oxygen will not be available to the crew member. Since the LOX system is totally independent, oxygen will still be available. The solution will be to make the OBOGS continue to operate even in the event that some ECS components failure. The worst case scenarios would be that oxygen must be available in the event of some failures in the ECS when flying over the ocean and delivering weapons in combat. If the engine fails, only descent oxygen for up to ten minutes needs to be available. If the engine is restarted, the OBOGS will continue to operate. The OBOGS has need for electrical power and ECS

pressurized air so there must be some degree of reliability and redundancy. For example, electrical power should be available from the emergency BUS and pressurized air should be available from another more reliable source of air such as upstream of the less reliable components of the ECS.

OBOGS has strengths to support the combat mission over LOX system. These strengths mean it is worthwhile to continue to support activity to find more operationally suitable OBOGS. Measures need to be taken to improve the reliability of the OBOGS. Not to be overlooked, are the strengths of the OBOGS. Consider a wing of military aircraft.

The enemy could knock out all your LOX supplies with one bomb reducing the mission capability of an entire group of aircraft. With OBOGS you are taking a chance on only one aircraft at a time. Overall, I think your chances are better with a wing of OBOGS equipped aircraft on completing most bombing missions.

In a hostile environment with a wing of OBOGS equipped aircraft, you do not need to service LOX thus improving your capability to turn around missions. Furthermore, the turn around time can be faster. LOX is supposed to stabilize at least 60 minutes before reusing the LOX converter for another mission. The pilot could go sooner, but he/she takes a chance that the LOX converter will not properly function. OBOGS is ready to go always.

LOX could be a hazard to the aircraft if shot with small arm's fire, promoting fire and possible loss of the aircraft. If no high pressure gaseous oxygen supply is included with the OBOGS, the OBOGS may malfunction if shot but this will not cause a fire or explosion on the aircraft. For this reason an improved combination bailout and backup oxygen supply on the ejection seat is the best approach. A source of high pressure backup oxygen in addition to the bailout supply is not as desirable.

The Mean Time to Replace LOX components is about 500 to 550 hours on the F-15 and F-16 aircraft. OBOGS Mean Time Between Failure that operationally is the same thing has been demonstrated at more than 2000 hours once the bugs are eliminated. That means more chance of having an operational oxygen system in all combat situations.

Nuclear, biological or chemical (NBC) agent threat could be introduced in the combat. OBOGS zeolites have been proven and demonstrated by test to effectively remove the six most common chemical agents to the breathing gas. The chemical agents are considered the worst case and simulant testing confirms the capability of the OBOGS to provide safe breathing gas. Nuclear dust and biological agents are larger than chemical agent molecules and would also be trapped by the zeolites. If LOX must be serviced in an NBC threat environment, the chance of introducing the agent into the LOX supply is considered a great risk. Decontamination of the LOX fittings is mandatory and the maintenance person must wear bulky protective clothing. No test data is available to show that this type of operation will be completely safe and effectively remove agents from the LOX supply.

Overall when considering all these factors, the chance of having an operational oxygen system in combat is greater with OBOGS than LOX.

Conclusions

1. OBOGS has strengths to support the combat mission over LOX system. These strengths mean it is worthwhile to continue to support activity to find more operationally suitable OBOGS. In the development of any new OBOGS design, it is important to keep the OBOGS design inherently simple and low cost.

2. Even if an independent source of oxygen supply is provided for ECS failure problems, how much oxygen is enough. When flying over the ocean, several hours of oxygen may not be enough. The best option is to provide some backup capability in the electrical power and ECS so that the breathing system may continue to function indefinitely, but at reduced capability.

3. Still yet another issue is the loss of pressure and air supply interrupts in the environmental control system (ECS). Provided the time period is not in excess of a few minutes this interrupt could be handled with a plenum that is at the same pressure as the OBOGS concentrator outlet. Concepts that would increase the pressure will once again increase system weight, volume, fire and explosion hazards and costs the same as with the separate high pressure backup oxygen equipment. System reliability may also be reduced.

4. It is desirable to reduce weight, volume, fire and explosion hazards and logistics requirements. The combination bailout and backup supply is considered the most desirable. It is much simpler and possibly less costly concept overall to implement. The times when both backup and bailout oxygen systems are needed in operation are considered remote and non life threatening if not provided.

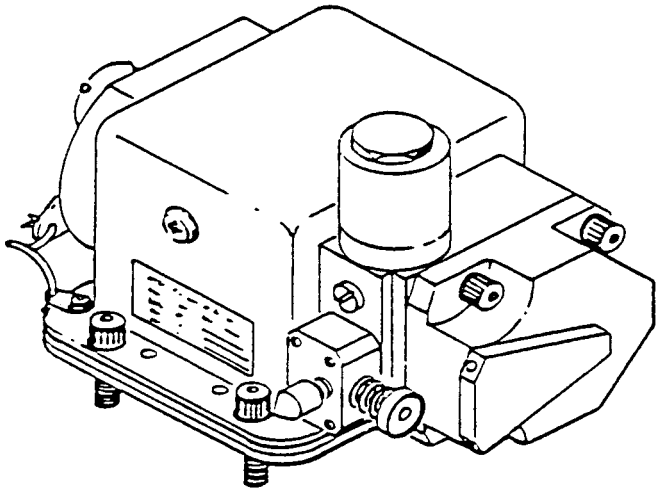
5. Another issue that has been discussed at length has been the need to have the backup oxygen supply activated automatically. The pilot will be busy with other aircraft systems and may forget to activate the oxygen supply. This could result in the crew member's loss of consciousness and leading to his or her death. Training and familiarization with the bailout oxygen systems may be more important to keep the design inherently simple as possible. Automatic supply activation will probably be too complex and costly in the long run.

Recommendations

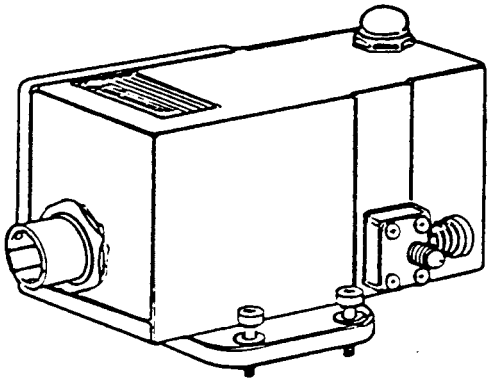
1. Measures need to be taken to improve the reliability of the OBOGS. Adding a high pressure backup system will not be sufficient. The OBOGS has need for electrical power and ECS pressurized air so there must be some degree of reliability and redundancy. For example, electrical power should be available from the emergency BUS and pressurized air should be available from another more reliable source of air such as upstream of less reliable components of the ECS. Other design concepts need to be investigated.

For any new OBOGS design concept proposed and Failure Analysis for single point failure relative to real peacetime and combat missions needs to be thoroughly evaluated.

OBOGS OXYGEN MONITOR



Polarographic Alarm Oxygen Monitor
CRU-91/A



Solid State Oxygen Monitor
CRU-99/A

FIGURE 10a and b. OBOGS polarographic and solid state oxygen monitors.

Nuclear, biological and chemical (NBC) protection. Reference McDonald, Gloria; Austin, Mary; and Beier, William, MSGT; “Aircrew Eye/Respiratory Protection (AERP) Program Development Test and Evaluation (DT&E), KC-135A/MBU-19/P Chemical Protective Hood/Mask Assembly Evaluation” Technical Report MSD-TR-89-73, December 1989. This report documents some lessons learned from the test objectives. Test objectives and conclusions were similar for other aircraft installation concerns.

1. (Objective 1) The aircrew members’ ability to operate the KC-135A while wearing the MBU-19/P was satisfactory. However, various concerns including excessive breathing resistance, heat stress, restricted mobility, perspiration buildup, and vision restrictions were raised.

2. (Objective 2) Only 50 percent of the aircrew members could perform a one-handed valsalva, which would normally result in an unsatisfactory rating. Two-handed valsalva will increase the percentage of the aircrew who can perform a valsalva. In a multi-position aircraft this method will not degrade mission performance. When this is coupled with the inability to perform a valsalva in the MBU-13/P, the overall ability to perform a valsalva (one-handed or two-handed) with the MBU-19/P on the KC-135 aircraft was satisfactory.

3. (Objective 3) The aircrew members’ ability to communicate while wearing the MBU-19/P was satisfactory. However, two areas of concern were raised. The first area is that the intercom and the radio hook into the MBU-19/P through the same connection. This can cause problems during the refueling portion of the mission. The second area was that the ground communication unit stopped operating at too low a sound level.

4. (Objective 4) The MBU-19/P’s integration with the current life support systems was rated satisfactory. The only area of concern was the excessive breathing resistance when hooked into the KC-135A oxygen regulator.

5. (Objective 5) The ability of the test aircrew to perform emergency ground egress and emergency doff procedures was satisfactory.

6. (Objective 6) Evaluate the integration of the AERP system MBU-19/P with flash blindness equipment on Strategic Air Command (SAC) (now the Bomber Group in Air Combat Command) aircraft. No evaluation was reported except see Objective 7..

7. (Objective 7) The MBU-19/P’s integration with helmet mounted displays was rated satisfactory. However, there was not a true helmet-mount display on the KC-135/A helmet but rather a permanent bracket for flashblindness goggles.

8. (Objective 8) The evaluation of the aircrew members’ visual capability while wearing the MBU-19/P was rated satisfactory. Although all ratings were satisfactory, various concerns were raised including fogging, sweat residue reducing the clarity of view, and some reduction in the field of view.

9. (Objective 9) Mission accomplishment while wearing the MBU-19/P was rated satisfactory. However, various concerns were raised including excessive breathing resistance, possibility of mixing up the oxygen and blower hoses during hookup, minor fogging, some loss of field of view, additional time to accomplish tasks, and possible interference between intercom and radio communications.

10. (Objective 10) -The MBU-19/P was rated satisfactory in the areas of comfort and fit.

However, various concerns affecting comfort and fit were raised. These included sweat buildup, poor design of straps to attach the system to an aircrew member, heat stress, and restriction of movement.

11. (Objective 11) The ability of the aircrew member to drink fluids while wearing the MBU-19/P was satisfactory.

12. (Objective 12) The anti-fogging capability of the MBU-19/P was satisfactory.

13. (Objective 13) No EMI/EMC problems were caused by the MBU-19/P.

14. (Objective 14) The observed Sortie Effectiveness Rate (SER) = Sorties without failure (22) divided by Number of sorties (26) = 0.85 percent. The observed Mean Time Between Maintenance (MTBM) = Operating time (81.8 hours) dividing by Number of maintenance actions (4) = 20.5 hours. The observed Mean Man-Hours to Repair (MMR) is inconclusive because the contractor performed all the maintenance. The 81.8 hours of operating time was insufficient to demonstrate the required Mean Time Between Failures (MTBF) of 750 hours. That observed was MTBF = Operating time (81.8 hours) divided by Number of failures (4) = 20.5 hours.

TABLE XXIII._Flow characteristics of filter-blower systems.

(liter/min (ATPD))				(kPa (in. wg))	
12	+0.5	(2.0)	to	+1.0	(4.0)
60	+0.25	(1.0)	to	+0.75	(3.0)

High g protection provisions. TBD

Mission specialist oxygen systems. TBD

3.10.2.2 Other oxygen subsystems.

Other oxygen subsystem(s) may be required to complement the primary aircraft oxygen system. These subsystems shall have duration and physiological performance requirements consistent with the operational scenarios in which they are used. The capabilities and features of the oxygen subsystem(s) may be: High altitude ejection, Aircraft backup oxygen supply, Automatic activation and deployment features, Oxygen controls and displays, recharging provisions, Compatibility with other systems, Respiratory performance, Adverse environments and/or _____. Emergency oxygen assemblies may consist of: Bailout/emergency oxygen supply, Walk-around oxygen assemblies, Aircraft fire fighter portable assembly, Helicopter Emergency Egress Device (HEED), and/or _____.

REQUIREMENT RATIONALE (3.10.2.2)

Crew breathing controls and displays.

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

b. Intercommunication microphones and headsets open to all crew members provide ease of communication that is essential to complete tasks in an emergency situation such as a rapid cabin decompression.

c. A means for the crew member to check for the proper functioning of lighted indicators while in flight is required to ensure bulbs have not burned out and lighted displays are illuminated for the proper situation. The crew member must also be able to check the proper functioning of indicators and instruments such as pressure gages (see *figure 3*).

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 that the appropriate crew member receives his warning in time to take corrective action.

Paratroop controls and displays.

a. Controls and displays are essential for the proper operation of the oxygen system. For example, in a gaseous or liquid oxygen system a display of the amount of supply is essential to determine when the supply must be replenished . Leaks in the distribution system accelerate the loss of oxygen supply so these displays offer a method whereby the crew may determine if this is a problem which needs corrected. Oxygen information and controls should be provided at the appropriate crew member's station.

b. In the event of an emergency decompression, the crew member responsible for the passenger compartment oxygen system and all passengers must be assured that the system is functioning properly. The emergency oxygen “ON" light(s) would indicate to this crew member that oxygen is flowing to the passenger mask assemblies. Flow indicators may be beneficial for each passenger mask assembly.

c. Even though automatic dispensing of supplemental oxygen may be provided in the design of the oxygen distribution system, manual on and off controls are recommended for all oxygen going to the distribution system. An audible warning is used to signal paratroop personnel to begin donning of oxygen masks. This warning may activate automatically from this control or manually from a control nearby. A silencing device for the audible warning is necessary to prevent the alarm from disrupting communications and interfering with required procedures after the emergency.

d. Crew members must be able to check the proper functioning of all oxygen controls and signals while in flight. 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 to avoid waste of oxygen when not all of the available seating is used.

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

Mission controls and displays.

a. The designated controls and display features are required to enable aircraft personnel to monitor and use the oxygen equipment. For example, in the event of emergency decompression, the crew member responsible for the aircraft oxygen system must be aware of the quantity of gaseous or liquid oxygen available. This enables the crew member to determine the amount of oxygen supply remaining to plan alternate aircraft missions. It also allows the crew member 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 crew member, 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 crew member responsible for any passengers using aircraft oxygen supply must be able to determine 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 oxygen system is not functioning properly and an alternate oxygen outlet 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 is provided to enable the crew member 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. Therefore it is essential that crew members 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 locations and the method of presentation for these types of displays should ensure the aircraft passengers and crew members occupying the passenger compartment receive warnings in time to take the appropriate corrective actions.

Aeromedical controls and displays.

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. Warning indication for low level or loss of supply is necessary to alert crew members to a potentially hazardous situation while in flight.

b. In an emergency decompression, the crew member responsible for the oxygen system must 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, each passenger should have some kind of flow indication at the mask assembly to determine availability of oxygen.

c. When the cabin pressure altitude reaches 10,000 to 12,000 feet or higher, a cabin decompression has occurred. It may be a slow or rapid decompression. The passengers have no way of determining how much time they have to don oxygen masks. 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. A guarded manual override emergency oxygen and mask activation control should be provided as a backup means of delivering emergency oxygen in case the automatic oxygen delivery function fails.

f. Functional compatibility requirements ensure 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 locations and the method of presentation for the displays indicating emergency or impending dangerous conditions should be specified to the extent that appropriate aeromedical crew members and passengers will receive warning in time to don oxygen before loss of consciousness.

Passenger controls and displays.

a. The crew member responsible for the passenger oxygen system must be informed of the oxygen supply status. This enables the flight crew to prepare for an emergency in which passengers will need supplemental oxygen. In the event the quantity indicator malfunctions or the display is overlooked, a low-level-of-supply warning indication is needed.

b. Providing oxygen “ON" information at every passenger station may not be practical, but warning signs and/or lights should be visible to all in the cabin. Emergency oxygen “ON" information is useful to the crew members who monitor the oxygen system to ensure that oxygen is available to all passengers.

c. A control to manually activate oxygen to the passenger mask assemblies must be provided in case the automatic activation subsystem fails. Because undue continuation of the alarm will distract further operations, a means to manually silence this alarm is also required.

d. Test controls are supplied to check for proper operation of instruments and indicator lamps.

Fire fighter controls and displays.

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. An indication of the amount of supply available in the supply source is required to determine whether it should be replaced or recharged for a new mission (as applicable).

Pressure suit controls and displays. To properly operate the pressure suit ensemble, proper controls and displays are essential.

Emergency oxygen system.

a. An emergency oxygen subsystem is required for crew members or personal life support to provide the ability to breathe following ejection from maximum aircraft altitude until the seat descends below 10,000 feet.

b. Emergency oxygen supply will also be required to provide life support for the crew member(s) or personnel for non-ejection situations and a loss of the primary aircraft oxygen supply when supplemental oxygen is necessary. Emergency oxygen supply may also be necessary to support the crew member(s) for smoke and fumes in the cockpit or cabin. This requirement does not comply that a single source of oxygen supply is required for ejection and non-ejection emergency situations.

c. Means of automatic and manual activation of the emergency oxygen subsystem and deployment features must be provided to allow the crew member(s) and/or passengers to breathe when required. U.S. Navy systems shall also provide a means to turn off the emergency oxygen supply. New U.S. Air Force emergency oxygen subsystems should consider the means to turn off the emergency oxygen supply if pressure demand breathing is provided.

d. An oxygen quantity display is needed to enable the aircraft occupant and/or ground maintenance personnel to determine when to replenish supply (if applicable) or replace it. If replenishment of supply is appropriate, a device must be provided to facilitate this, such as a filler valve.

e. The emergency oxygen subsystem must be physically and functionally compatible with other aircraft systems such as the primary aircraft oxygen system, the ejection system, the crew station layout, controls and displays. This minimizes any adverse impact to other systems and ensures that it is compatible with the crew member(s).

f. The demand and/or pressure breathing respiratory characteristics of the oxygen supply regulator or delivery features must meet the minimum physiological requirements of the crew member(s) to ensure their survival in all emergency situations.

g. The emergency oxygen system must function in the adverse environments of crew member ejection, rapid cockpit decompression and/or failure of the primary aircraft oxygen supply.

Manual bailout/emergency oxygen supply.

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. All assemblies are comprised of basic components regardless of the type of design used. Physiologically compatible breathing pressures must be delivered to the parachute jumper, crew member, 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 is 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 that the crew member wear his parachute pack and survival kit while seated (a non-ejection-seat system) on the aircraft. This aircraft may fly at altitudes above 10,000 feet where oxygen is required.

e. Controls and displays indicate that oxygen is available or flowing. 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 is required to be rechargeable so it may be reused when supply is expended.

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. Therefore, the free fall and parachute inflation altitude ranges must be specified. Additionally, the delivery flow rates and pressures must be physiologically compatible with an emergency decompression.

Walk-around oxygen assemblies.

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

b. To preclude hypoxia the dispensing equipment must have adequate means of regulation and dispensing components.

c. A sufficient number of assemblies must be provided to ensure that all onboard personnel have oxygen readily available to them in the event of decompression. The minimum number of walk-around assemblies required on the aircraft should be specified.

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

e. Existing low pressure oxygen assemblies provide only 7 to 15 minutes of oxygen supply. The supply for this type of portable assembly should be designed so that replenishment is possible from aircraft outlets. Outlets should be provided at convenient locations throughout the aircraft so a crew member may move about to replenish his supply when necessary.

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

g. It may be advantageous to use the low pressure type walk-around assemblies so they may be recharged on the aircraft, since the high pressure portable oxygen assemblies cannot be thus recharged. If high pressure 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.

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

i. 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.

Aircraft fire fighter portable assembly.

a. Fire fighting breathing assemblies are required in all aircraft in which there is space to move about. The oxygen supplied in a pressure-breathing mode keeps smoke and toxic fumes from the wearer's eyes and respiratory tract. A flexible breathing hose provided with a quick disconnect to the regulator enables the personnel who use the equipment to easily change mask assemblies. The breathing hose must be long enough to enable a person to carry the entire assembly while fire fighting 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 adequate design. A means of affixing the breathing device and eye and respiratory protection to the face must be provided. (See *figure 1*.)

If the oxygen delivery hose incorporates the same connector assembly as that used on crew member oxygen masks to connect to the aircraft supply from the breathing regulators, integral communication equipment is required. This enables the crew member 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 compatible with the aircraft communication intercom system.

Personnel need face protection to shield their eyes from smoke and fumes, but they also require a large, clear vision field to enable them to see in a smoke filled environment to locate and fight fires.

c. The minimum number of fire fighter assemblies should be specified for different locations in the aircraft to ensure the interior design satisfactorily accommodates these assemblies. Support brackets or another means to secure the assemblies is required 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 from a chemical generator should be called out, if this type is used.

f. A minimum amount of supply must be specified; otherwise, an inadequate quantity may

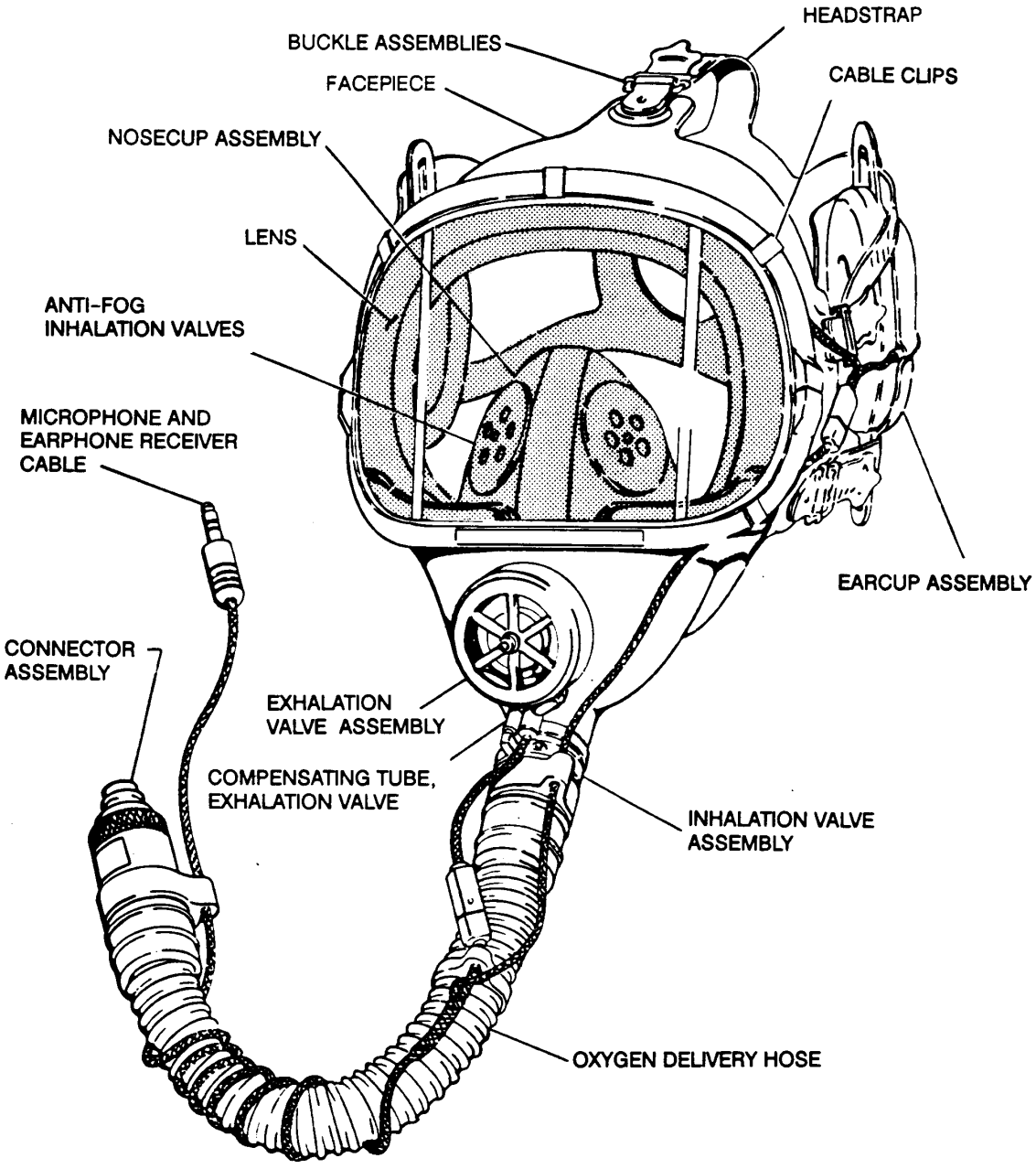


FIGURE 11. Typical fire fighter's smoke mask assembly components.

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.

Aircraft pressure suit provisions.

REQUIREMENT GUIDANCE (3.10.2.2)

Crew breathing controls and displays.

Each crew member shall have breathing system controls and displays that provide all essential information and necessary control functions. In designing the breathing system controls and displays, consider the following:

a. Information content and control functions.

b. Intercommunication capability.

c. Test controls.

d. Functional compatibility with oxygen system.

e. Emergency system controls and display.

a. Visual flow information such as a blinker assembly may be provided to indicate that the crew member 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 3*). Also, visual flow information consisting of a pressure gage to indicate the pressure of oxygen at the inlet of the regulator assembly may be provided. This confirms to the crew member that oxygen delivery equipment is functioning properly and that the crew member 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 that the crew member may determine during preflight checks that a sufficient supply of oxygen is available for the planned mission. In flight, the crew member may determine the approximate time available for use of oxygen at higher altitudes. Post flight, a crew member may indicate to the ground support crew that a supply of oxygen is required (see *figure 3*). The minimum essential number of controls needed for the proper operation of the crew oxygen system in all flight operation situations should be provided. Controls to consider are an “ON/OFF" oxygen delivery control, an air dilution or normal functioning mode control, a “93-100 percent oxygen" control, an emergency control that allows the crew member to select positive pressure breathing of 93-100 percent oxygen, and a control for manual selection of backup oxygen supply in the event of a failure of the primary oxygen system. *Appendix B* contains further information.

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), the crew member need not wear oxygen equipment at all times. In this case, emergency quick-donning assemblies that should be donned within five seconds optimum but at most 15 seconds are usually provided in the event of a rapid cabin decompression (defined as three seconds or less). In such an emergency, the crew members will be preoccupied with activation of many flight-essential controls and must be in contact with all other crew members. This requires that emergency quick-donning assemblies

incorporate hot mikes open to all crew members and headsets.

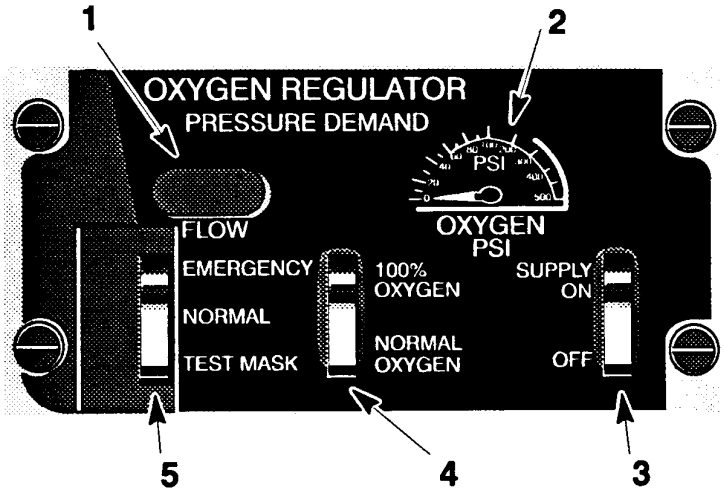
c. These controls are essential in all aircraft that do not incorporate built-in automatic test equipment. Without the proper functioning of all oxygen equipment controls and displays the crew member could not know the status of his oxygen supply, delivery capability, and proper functioning of all components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

d. All electrical and pressure range characteristics of the controls and displays should be specified in the designer's version of the applicable specification. The RFP 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 crew member'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 document, *MIL-STD-1776*, for additional guidance.

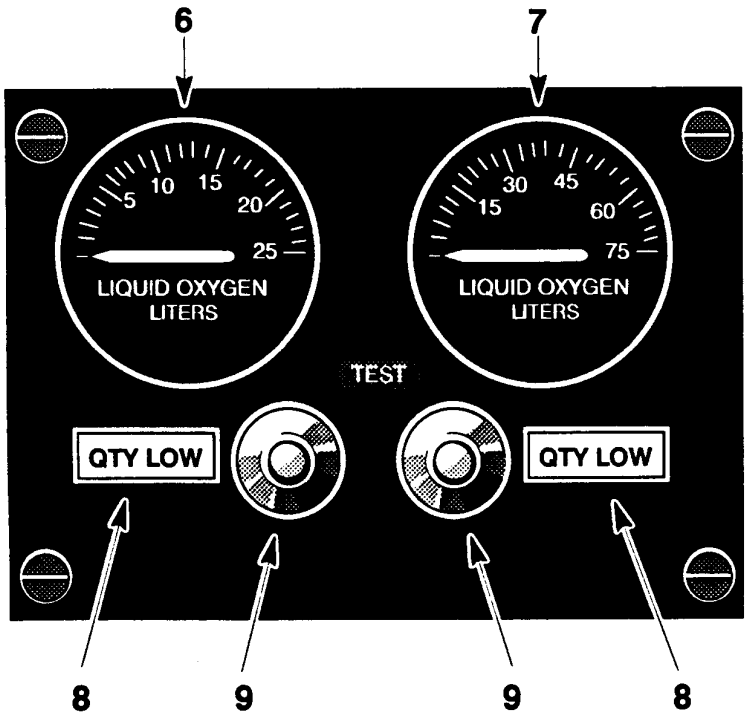
The low quantity or pressure warning is an indication to the pilot(s) that a malfunction or oxygen leak is providing a lower supply than planned. For crew members that have not followed preflight check it indicates that a situation is pending which will require descent to 10,000 feet pressure altitude (see *figure 3*).

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



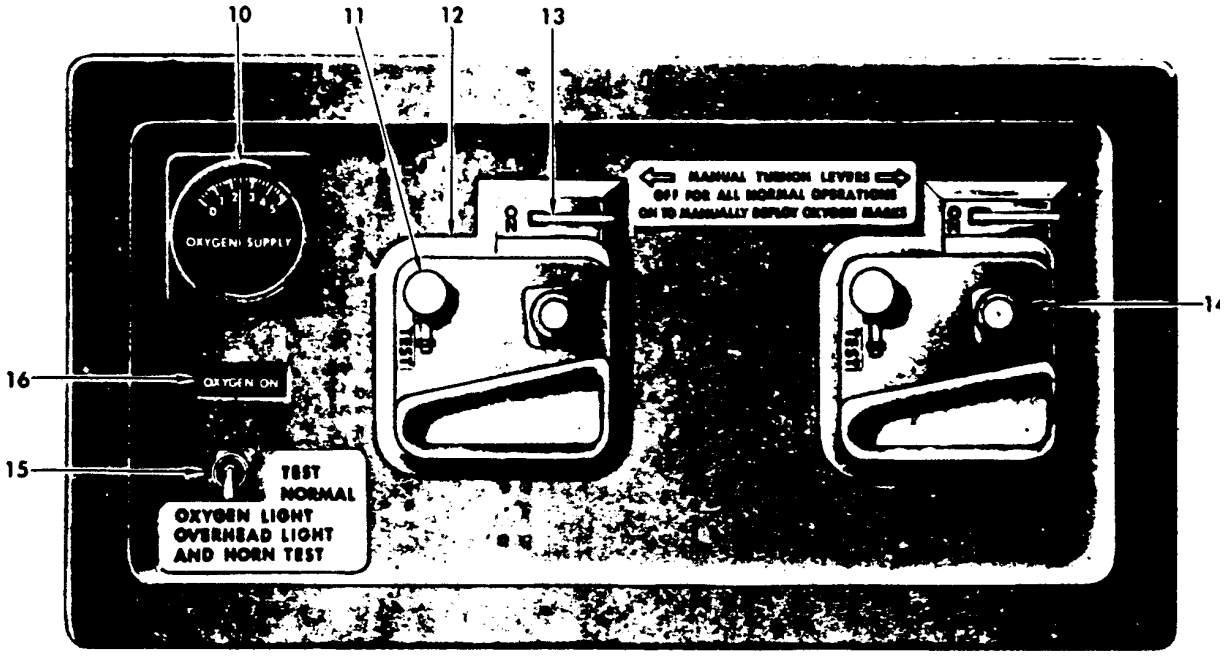
CREW OXYGEN REGULATOR PANEL

PILOT'S OVERHEAD PANEL



FLIGHT ENGINEER'S
OXYGEN SYSTEM PANEL
FOR 25 LITER AND 75 LITER
CONVERTERS

FIGURE 12. Typical example of control and display installation for passenger and crew on C-5A aircraft.



F

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 INDICATOR
14. REGULATOR ON-OFF INDICATOR
15. TEST SWITCH
16. OXYGEN ON LIGHT
17. OXYGEN MASK STORAGE CONTAINER
17. MASK HOSE
19. HEAD STRAP
20. OXYGEN MASK
21. LANYARD
22. CONTAINER DOOR

FIGURE 13a. Typical example of control and display installation for passenger and crew on C-5A aircraft. - Contd

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 that is readily accessible in flight shall be provided for each row of seats. This control shall have the following features ___(e)___. 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)___.

a. On transport type aircraft that incorporate supplemental oxygen for the troop compartment, the load master should be responsible for the troop compartment oxygen system. If there is no load master on the aircraft, the pilot is 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 is essential to provide emergency oxygen “ON" light(s) at the load master crew station to enable the crew member 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 load master should control manual oxygen activation. If there is no load master, 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 these controls should be placed in the branch lines of the distribution plumbing.

f. All electrical and pressure range characteristics of the controls and displays should be specified in the designer's version of the applicable specification. The request for proposal (RFP) developed by the procuring activity may not contain this detailed information because this level of detail cannot easily be specified without stating 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 conditions. Refer to *MIL-STD-1800, MIL-STD-1801* and to other human factors design handbooks for design guidance. Refer to *MIL-STD-1776* for criteria on control and display arrangements.

Mission 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).

a. An oxygen supply quantity indicator should be available to the pilot, and copilot if applicable, as well as to any other crew member responsible for oxygen systems (such as a load master). LOX quantity information should be displayed in liters 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 needed for proper operation of breathing regulators. If an on-board oxygen generation system (OBOGS) is 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 crew members, 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 may also indicate 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 alternative in the event of a malfunction is to connect a portable bottle to a recharger outlet and breathe from this position.

c. An override control is an essential backup device to enable oxygen to be dispensed at the discretion of the pilots or a flight steward at any time. 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. Because these audible warnings can be distracting and may impair flight duties after the warnings have been conveyed, a separate warning silence control is needed.

d. Test controls usually consist of spring-loaded push buttons 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 enunciator or caution light panel, the test

control(s) should be located adjacent to the lighted displays, indicators, and instruments.

e. All electrical and pressure range characteristics of the controls and displays should be specified in the designer's version of the applicable specification. The RFP 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 view able 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 view able locations. Refer to *MIL-STD-1800* and *MIL-STD-1801* for criteria and human factors design, and to *MIL-STD-1776* for control and display arrangements.

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)___.

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 one for the entire system).

b. The emergency oxygen “ON" information should, as a minimum, consist of a warning light at the pilot's station. If another crew member 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 Klaxon horn or similar device 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" should immediately illuminate 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 crew station of the crew member responsible for the oxygen systems. A manual override control is essential in case the automatic oxygen activation feature fails. All electrical and pressure range characteristics of the controls and displays should be specified in the designer's version of the applicable specification. The RFP 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.

f. All gauges must have a scale which indicates the pressure range of concern and quantity of LOX as appropriate to the supply type and size used. Appropriate electrical characteristics need to be determined and specified. Indicators must activate at the correct level of supply or failure of concern.

g. Emergencies that might require the use of oxygen are usually indicated using back-lighted 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.

Passenger controls and displays. On aircraft in which the general passenger oxygen subsystem is 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 or an adjacent control. A separate audible-warning silencer control shall be provided. Test controls shall be provided to check for proper functioning of all lighted displays, indicators, and instruments ___(d)___.

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 inlitres with low-level-of-supply warning given at 10 percent of the supply (see *figure* in *3.2.2.1.3*).In a gaseous system, the quantity indication applies to gas pressure in the supply container with low-level-of-supply warning given at 30-50 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 crew member, such as a loadmaster or flight engineer, who is responsible for monitoring the oxygen supply (see *figure* in *3.2.2.1.3*). 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 functioning properly. Provide lighted signs to alert passengers to don oxygen masks.

c. The manual activation 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)*. This control is a manual override to the automatic oxygen delivery. The 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. Provide a control to energize all indicator lamps, including caution, advisory, and warning legend lights and bull's-eye lights (see *figure* in *3.2.2.1.3*). This allows the crew member to check for proper functioning of the light bulb or illumination source, as applicable. The crew member 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.

Fire fighter 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.

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 pressure within the supply vessel. The gage should have a red zone which indicates an overpressure situation. A manual vent should be included to release pressure to a safe level. A chemical generator supply source should provide status information to indicate that the charged cartridge(s) are included. Consult *MIL-STD-1800* for human factors information on the proper design and operation of the control and display functions.

Pressure suit controls and displays. Manual override control of the pressure 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)____ crew members 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) ___.

To avoid duplication infomation on pressure suit ensembles has been move to MIL-HDBK-1776-4. Refer to this document for additional details.

Emergency oxygen system. An emergency oxygen subsystem may be required to complement the primary aircraft oxygen subsystem. The capabilities and features of the emergency oxygen subsystem should be as follows:

a. High altitude ejection.
b. Aircraft backup emergency oxygen supply.
c. Activation and deployment features.
d. Oxygen quantity display and recharging provisions.
e. Compatibility with other systems.
f. Respiratory performance.
g. Adverse environments.

Issues on Emergency and Backup Oxygen Supply for OBOGS equipped aircraft are addressed below.

Requirements for Supplemental Oxygen

There are requirements for other sources of oxygen other than the oxygen supplied from OBOGS aircraft. Another source of oxygen supply is needed for the following conditions when the aircraft is operating above 10,000 feet:

- Bailout from the aircraft.

- Loss of bleed air source to the OBOGS from Environmental Control System (ECS) failure or interrupt.

- Loss of bleed air source to the OBOGS from loss of engine(s).

- Loss of electrical supply that powers the OBOGS.

- Failure of OBOGS concentrator to properly operate.

- Decompression. In the past it was thought that a 100 percent oxygen supply was necessary in the event of a decompression. Studies have shown that provided the altitude does not exceed about 47,000 feet 93 per cent oxygen supplied from the OBOGS will be sufficient. Adjustments to the breathing regulator are necessary.

The Old USAF Bailout Bottle.

Past methods of meeting these supplemental oxygen requirements have been through the use of a bailout high pressure source of oxygen supply mounted on the seat, parachute pack or in the survival kit. The USAF mounts the bailout bottle on the seat on aircraft equipped with ACES ejection seats. There have been instructions in Technical Orders to use the bailout oxygen also as emergency oxygen in the event of failure of the primary oxygen supply. It has even been recommended that this oxygen supply will suffice as supplemental oxygen when

smoke and fumes in the cabin are present. This will not work as the bailout bottle on most USAF aircraft is manifolded through the CRU-60/P chest mounted connector or a similar manifolded connector such as on COMBAT EDGE equipped aircraft. The oxygen is continuously supplied and excess oxygen pressure is vented at the bottom of the manifold. This two-way valve also allows ambient air in should there not be sufficient volume of oxygen supply to the crew member. Approximately 10 minutes of supplemental oxygen supply is available if ambient air is allowed to supplement the continuous flow of oxygen supply provided. The crew member must be continually descending so that the proper ratio of oxygen supply is available. The bottom line is that the existing bailout oxygen supply has its limitations as a source of supplemental oxygen supply that would be needed for emergency oxygen in the event of failure of the primary oxygen supply. The existing bailout oxygen supply also will not be satisfactory in the event of smoke and fumes in the cabin and the loss of the primary oxygen supply. This does not happen very often, but several incidents are known on LOX equipped aircraft.

OBOGS Equipped Aircraft Bailout Oxygen Requirements May Differ.

In the past it has been desired that bailout oxygen supply also be available even after a non ejection event requiring supplemental oxygen other that OBOGS. For example, engines are lost and the OBOGS will not function. Supplemental oxygen is used. Engines are restarted and later ejection from the aircraft is necessary. If above 10,000 or 14,000 feet, it is still desired to have the bailout oxygen supply to support the crew member's breathing. While the crew member would not die, even if he had no oxygen, he or she could lose consciousness. That could be dangerous if a state of consciousness is necessary to survive for landing in water or a combat area. Then people logically conclude that another source of oxygen supply normally called backup oxygen is required. This has been provided on past aircraft in several ways. High pressure vessels have been provided that must be replenished from ground servicing. Examples are the B-1B, B-2, F-14 and F-18. Designers began to think that replenishing the oxygen supply from the ground was a logistics burden as well as an increased fire hazard. For that reason efforts were put into a backup oxygen supply replenished from the OBOGS concentrator. The YA-7F program used a concentrator mounted plenum and another low pressure cylinder remotely located that was filled from the OBOGS concentrator during normal operation. Since the source of pressure air enriched with oxygen was low, the amount of oxygen supply was too limited for the volume and weight of equipment needed. Next, the F-15E program decided to expand the concept with the use of an air pressure driven pump to pressurize the backup air enriched with oxygen supply. This method was very good as the logistics burden required from ground servicing and the fire hazards were virtually eliminated. The only new problem was that this concentrator device became heavier and more expensive. Designers then decided that for OBOGS to be competitive with LOX it has to be less expensive on a life cycle cost basis and comparable in weight and size. Now the trend is to develop a small, inexpensive and lightweight OBOGS concentrator. The need for backup oxygen again reared its ugly head.

Time to Reevaluate Bailout and Backup Oxygen Requirements on OBOGS Equipped Aircraft

I believe it is time once again to examine all the issues involving the emergency and backup oxygen supply. We need to determine the probability of the situations occurring requiring another source of oxygen supply other than the OBOGS concentrator. We also need to

reconsider the desirability of continuing with the existing bailout bottle design which has been around with some slight improvements since the 1940's. In its day it was a good design as we can see it has survived until this day on modern high technology jet fighter and bomber aircraft. I believe the time has come for an improved bailout oxygen supply. Since it has been desired to use the existing bailout bottle as a source of emergency oxygen supply for more than bailout, the new design should meet these needs. That means that pressure demand regulated oxygen supply is more desirable than the continuous oxygen supply. What about the need for bailout oxygen even after the bailout bottle is expended when used as emergency oxygen. Having both situations occurring in combat is a possibility, but ejection experiences show that higher altitude ejections do not occur too frequently. There is a good possibility that the pilot will not necessarily need bailout oxygen for the greatest majority of ejections. Even if he did eject at higher altitudes, loss of consciousness would be the only concern. We must also consider that in many ejections wind blast tears away the mask and the helmet. If this happens oxygen is not available to the crew member. In view of this, we should look at the pros and cons of a combination bailout and backup oxygen supply versus two separate sources of supply.

Pros of combination bailout and backup oxygen supply.

- The fire and explosion threat from servicing and operation are reduced as there is only one system. This is a most important issue as past accident records and analyses show that there are twice as many fires and explosions on gaseous oxygen equipment as with LOX equipped aircraft. See the figure below. Small arm's fire could also cause a fire or explosion. While pressure vessels are non shatterable, excess pressure waves and heat release could easily develop into a fire. See paragraph 3.5.1 herein for important information on hazards analysis and contamination investigation of primarily on gaseous oxygen systems. Of special concern has been the need generated for filtering any gaseous oxygen serviced into a fill valve. Also new fill valve designs are needed to reduce fire and explosion accidents.

- Weight and volume requirements are reduced overall on the aircraft.

- The logistics requirements are reduced as there are fewer items to support and service.

- The cost will probably be reduced overall from purchasing and maintaining only one item.

- A pressure demand regulated supply of breathing oxygen will enhance the chances of survival of the crew member for a landing in water or combat.

- A pressure-demand regulated supply of breathing oxygen will provide a longer duration of oxygen as less oxygen is wasted as with continuous flow of oxygen. A large supply is desired that has a 50 versus the existing 22 cubic inch bottle. No dilution is provided with the regulated bailout bottle.

- The crew has less equipment to monitor and be concerned about thus reducing workload on the pilot.

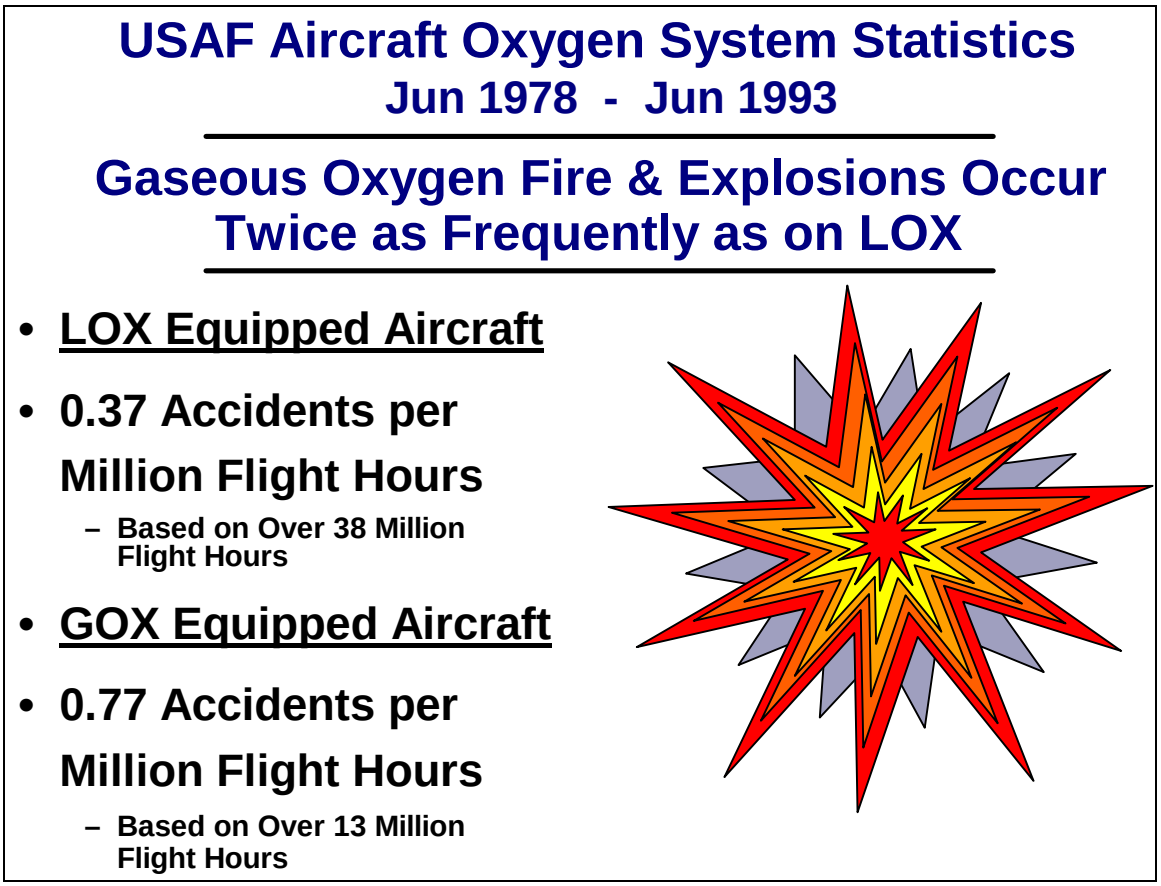


FIGURE 14. Comparison of safety of gaseous oxygen systems with liquid oxygen systems on USAF aircraft.

Cons of combination bailout and backup oxygen supply.

- New design is required for automatic supply of backup oxygen if desired. Manual activation is already available.

- There are difficulties with shutting off the oxygen supply for bailout reuse. If capability provided, leakage problems will probably develop.

- User acceptance that this arrangement will sufficiently meet his needs for breathing in all situations. We should remember that the LOX system has no backup oxygen supply. Only the bailout bottle on the seat is provided. LOX system failures have resulted from clogged LOX converter valves. Usually the pilot pulls the green ring initiating the bailout bottle and descends.

Issues on past aircraft designs

a. The emergency oxygen subsystem should provide high altitude ejection capability compatible with current and planned ejection systems. An analysis should be performed to determine the minimum oxygen supply needed for ejection and descent to a safe breathing

altitude. Currently, this maximum operation altitude is 50,000 feet without a full pressure suit, but advanced aircraft designs are considering the need for altitude protection up to 60,000 to 70,000 feet without a full pressure suit. In these designs a partial pressure suit will be incorporated. Currently, these types of partial pressure suits use a chest counter pressure garment to equalize respiratory and ambient pressures. Also, special breathing masks with mask tensioning devices are provided to enable effective breathing while under elevated pressures. Consider that the bailout oxygen system may either provide 100 percent of the supplemental oxygen or may use some ambient air for diluted oxygen supply to the crew member(s). The oxygen consumption calculations should address which design feature is incorporated as more oxygen supply is needed when 100 percent oxygen is provided. Consider also that emergency oxygen supply may be needed from the maximum altitude of the aircraft down to a safe ejection altitude.

b. Analyze the nonejection emergency situations in which the emergency oxygen subsystem supply is required. Some of these situations are a failure of the primary aircraft oxygen system, rapid decompression, contaminated oxygen supply such as a strong odor in the breathing gas, and smoke and fumes in the cockpit or cabin environment. For example, if a LOX system is the primary supply, the LOX may be contaminated and the breathing gas provided would be noxious and unsuitable for breathing. A component of the primary oxygen system such as the concentrator or generator of a molecular sieve oxygen generating system (MSOGS) may fail, oxygen pressure and supply may be lost from a plumbing leak, or the breathing regulator may malfunction. Damage may also cause a decompression of the cockpit and a failure of the oxygen system. In the event of either type of failure, if the aircraft is above 10,000 feet pressure altitude, supplemental oxygen is required for descent to a lower altitude where supplemental oxygen is not required. An analysis for each type of emergency situation is necessary to determine the amount of oxygen supply needed. The worst case or longest time period supplemental oxygen is needed should be used. Adding some extra supply for a safety margin is advised. Currently, 10 to 15 minutes of oxygen supply for these conditions is considered a practical compromise for protection. Note also that the emergency oxygen supply for ejection seat bailout may be a separate source than the backup oxygen supply for the failure of a MSOGS concentrator because an ejection may still be required even after activation and breathing for the backup oxygen supply.

In transport aircraft, impaired crew member egress has been attributed to smoke and toxic fumes, making apparent the need for improved protective equipment. The FAA has implemented ruling requiring that protective breathing units be installed on commercial aircraft for protection of crew members so that they may better assist passengers in safely egressing in an emergency. SAE AS 8047 was implemented in November 1987 to specify minimum performance requirements for crew member protective breathing equipment. If an emergency escape breathing device is desired for application to military transport aircraft, commercial equipment that meets this standard should be used. If there are additional military requirements, a new device may need to be developed, but the minimum requirements of SAE AS 8047 still apply.

c. Activation and deployment features must also be provided so that supply will be available throughout the dynamic environment of ejection and can be activated as required

while the crew member is in the aircraft. For ejection, the oxygen supply must be activated automatically and supply be immediately available when the ejection is initiated. In this way, oxygen is provided even if the crew member is unable to activate it. Oxygen must be available from the maximum altitude of the aircraft, down to a safe ejection altitude and then to a safe breathing altitude; therefore, placement of the supply source is critical. The current USAF approach is to mount a high pressure oxygen supply on the left side of the seat for ejection. This is feasible since the crew member stays with the seat with a drogue chute that slows it for descent to a safe breathing altitude where the parachute is deployed and the crew member separates from the seat. The supply hose is routed to the right side of the seat and it incorporates an in-line quick disconnect for seat-man separation. Currently, MSOGS designs incorporate an oxygen supply separate from the emergency oxygen cylinder for failure of the oxygen concentrator and this has separate control and display functions.

A manual control device is needed in the event of a failure of the automatic deployment feature. The control device for manual activation of the oxygen supply has been a green sphere or a green ring that is located within easy access. The minimum diameter of the green sphere (called a green apple) has been $1^1/_2$ inches. The green ring was used on the ACES ejection seat. Any ring used should accommodate a crew member's index and middle fingers (2 inches) with an arctic glove. Past activation forces have been in the range of 12 to 20 pounds. Newer designs may require reduced activation force to accommodate female pilots.

The Navy emergency oxygen system is contained in the seat survival kit for ejection seat equipped aircraft. Upon ejection and seat separation the seat survival kit remains with the crew member during parachute descent. Oxygen delivery is provided automatically during the ejection sequence.

d. If applicable, provide oxygen quantity display and recharging provisions for replenishment of supply.

The display feature should indicate the quantity of oxygen available. It should also incorporate a means to indicate when the level of supply is below acceptable safety margins and must be replenished. The display should be in a readily accessible location so that a maintenance person and the flight crew member(s) making a preflight check may determine if the supply is sufficient for the intended mission. Maintenance personnel or crew members should not have to disconnect any mounting provisions to make readings. If the backup oxygen supply source is not in a readily accessible location, such as in equipment bays, so that a display mounted to it could not be read, then the display should be remotely located in the aircraft cockpit or flight deck.

Provisions to replenish supply should be incorporated either on the device or remotely located to the aircraft exterior, the latter being the less favorable approach. If the device incorporates a cartridge for new supply, such as for a chemical generator, it should be easy to replace it without the use of special tools. If the device is a high pressure (1800-2150 psig) vessel, it should incorporate features similar to the existing system so that it may be refilled from existing support equipment.

e. The crew member emergency oxygen subsystem must be compatible with other aircraft systems to preclude any adverse effect to these subsystems and operate effectively

throughout ejection. The emergency oxygen supply source or an auxiliary source must be available to the crew member when he ejects. Ejections up to the operational altitude of the aircraft (50,000 to 60,000 feet) are possible even though the majority of aircraft ejections occur in the lower altitudes. Whether the crew member is in the ejection seat or under a deployed parachute, he will need emergency oxygen supply down to a safe breathing altitude (typically 10,000 to 14,000 feet). This means the emergency oxygen supply equipment should be readily available during emergency deployment and descent operations. The emergency oxygen subsystem also should not interfere with crew member mission performance while seated in the cockpit or on the flight deck. The oxygen hose length and stiffness should be optimized so as not to impede the aircrew's normal cockpit tasks. Communication lines should not be an integral part of the hose. Separation of the hose and communication line allows for the replacement if one is damaged, while allowing the other to stay in service. The emergency oxygen supply hose should also tie into the primary oxygen delivery hoses and valves in such a way that when used, the supply does not go back to the regulator or that the regulator supply does not move into the emergency oxygen supply line. The CRU-60/P harness mounted connector incorporates special check valves, disconnect fittings, and a two-way valve to restrict flow, but not stop it.

f. The supply regulation mechanism should have satisfactory respiratory performance throughout its intended operational environment. Ensure a partial pressure of oxygen is maintained in the lungs equivalent to a safe breathing condition that will keep the crew member conscious. With existing equipment, this equates to an altitude of about 5000 feet. The altitude should not exceed 10,000 feet when considering a large number of crew members. Many people can maintain consciousness up to 14,000 for up to 15 minutes; however, some people cannot. Either a slight positive pressure or a demand breathing regulator mechanism may be provided. The latter mechanism may conserve supply but the size and weight of the assembly required increases. Since the crew member will breathe more heavily and rapidly in an emergency situation, the emergency device must provide 95-100 percent oxygen or a mixture of this with ambient air to supplement the crew member's entire tidal volume (breath). Consider also that the crew member will descent from a higher altitude to the ground or sea level. The regulator must adjust oxygen delivery requirements with altitude. The supply source should provide sufficient oxygen for the crew member in an aircraft emergency descent from its ceiling, or for free fall following ejection from the maximum altitude to the preset aneroid pressure. For high altitude protection, the emergency oxygen system must be capable of delivering 93-100 percent oxygen within 0.5 seconds and begin providing oxygen for pressure breathing at 39,000 feet cabin altitude. Provide at least 5 in. wg supplied at 40,000 ft varying linearly with 37.5 in. wg supplied at 53,000 ft. Careful consideration must be given to higher altitudes as higher mask pressures required will exceed the physiological characteristics of the crew member. This will require chest counter pressure garments and mask tension devices to sustain the oxygen pressure in the lungs.

g. Design the emergency oxygen supply to operate satisfactorily in normal missions or during emergency ejection from the aircraft. The equipment must meet performance requirements in adverse environments including temperature and pressure extremes, cockpit decompressions, 600 KEAS on seat ejection, induced G forces, and the ejection forces expected. Man-mounted oxygen regulator systems shall not produce hazardous

conditions (excessive breathing pressures, water ingestion, etc.) during in water and under water emergency operations.

Past supply valves (flow controllers) 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 device (a cartridge with wire mesh), the delivery hose and into the crew member's mask until the oxygen supply source is exhausted.

Currently, the 22 cubic inch high pressure bailout bottle has a pressure gage that has a simple scale which reads 0, 1800, and 2500 psig. The scale is a red bar 0 to 1800 psig and is labeled REFILL. Beyond 1800 psig is the label FULL and the scale is a black bar. The bottle is typically filled from 1800 to 2150 psig, and whenever the pressure falls below 1800 psig it is refilled. The gage is labeled OXYGEN in black letters and USE NO OIL in red letters.

The filler valve to which the ground servicing connection is made in recharging the system is a check filler valve *MS22035* or line valve AN 6012 with a cone fitting such as AN 780-3. A dust cap and retaining chain in accordance with *USAF Drawing 55B3878* should be provided with the filler valve to preclude dust and contamination which could result in a fire or explosion on servicing the oxygen supply.

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 crew member to breathe with minimal fatigue from altitudes of ___(h)___ feet to ___(h)___ feet.

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 crew member and mission specialist required to be away from his position or station for extended time periods. Crew members 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 is beneficial to provide 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 currently used as a bailout assembly supply source.

Another possible supply source is a chemical oxygen-generating device. In designing the oxygen regulation device for correct flow and delivery pressures, consider that it must provide oxygen at a sufficient rate of flow to support a person who is undergoing physiological exertion resulting in high stress. Include flexible hose(s) in the design of the manual bailout bottle to allow satisfactory operation by the person wearing the assembly, ensuring that it does not require the user to hold bulk and weight near the face. The supply delivered to the face mask should 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. For crew members and mission specialists who must reach oxygen in the event of a decompression, provide a means to carry the assembly such as a shoulder strap. Refer to MIL-P-87141 for information on personal parachutes to ensure the compatibility of the installation of the oxygen equipment with parachute deployment.

d. Provide a storage location for the oxygen assemblies that is out of the way of other operations but convenient enough that the assemblies may be easily distributed for each mission when needed. The assemblies shall be retained so that the forces of flight do not break them or damage other aircraft components.

Provide a portable manual bailout oxygen assembly that is readily accessible to the crew member(s). If the aircraft mission requires that the pilots descend below 10,000 feet before crew members parachute, then aircraft integral oxygen may be used in this descent in the event of an emergency decompression. These factors regarding planned missions should be worked out in the conceptual phase 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 should be consulted to determine the type of refill valve that is compatible with their equipment. Information on military standard valves is in Appendix B herein.

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 falls in the ambient since 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, the delivery pressure should initially provide at least 60 to 100 mm Hg 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 50,000 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.

Walk-around oxygen assemblies. Portable, replenishable, supplementary oxygen assemblies shall be provided to allow crew members to move about in the aircraft when it is unpressurized at altitudes above 10,000 feet ___(a)___. The walk-around oxygen assemblies shall have oxygen regulation features of ___(b)___, flexible hose to a breathing mask with a means for inhalation and exhalation, and a means for replenishing the supply. The assemblies shall be located as follows: ___(c)___ on the flight deck, one in each lavatory, and ___(c)___ in the cabin or cargo compartment. Support brackets shall be provided for storage of each assembly on the aircraft 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)___. Assemblies of the low pressure type shall be designed to refill from the standard USAF recharging outlet to the pressure range of 300 to 500 psi and provide pressure relief at 500 psi ___(g)___. High pressure type assemblies shall be serviceable from military ground equipment to fill to a pressure of ___(h)___ psi and provide pressure relief at ___(h)___ psi. 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 crew member to breathe with minimal fatigue from continuous use at 20,000 to 25,000 feet pressure altitude ___(j)___.

a. Provide walk-around oxygen assemblies on all aircraft that fly above 10,000 feet pressure altitude unpressurized 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 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

favorable type of walk-around assemblies are rechargeable and a means should be provided in the assemblies to accomplish this. See paragraph 3.5.1 herein for important information on hazards analysis and contamination investigation of primarily on gaseous oxygen systems. Of special concern has been the need generated for filtering any gaseous oxygen serviced into a fill valve. Also new fill valve designs are needed to reduce fire and explosion accidents.

A pressure-demand breathing regulator that functions in accordance with the pressure altitude is the most favorable assembly. This may consist of a diluter-demand, slight positive pressure, and increased positive pressure breathing modes. Two successively less favorable means of regulation include a rebreather reservoir and a continuous flow type assembly. For a pressure demand system, a larger diameter convoluted hose is necessary, but for other systems smaller diameter hoses perform satisfactorily.

c. Unless otherwise specified by the using command, a minimum of one assembly for every two crew members should be provided. 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, two masks are generally provided in the lavatory, as untrained passengers may have difficulty using portable walk-around assemblies. Provide three to nine walk-around assemblies in the cabin compartment, depending on the mission and aircraft configuration.

d. A favorable mounting location for the pilot assembly is directly aft and to the outboard side of the seats. This precludes 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, the recharging outlets should be available throughout the aircraft to enable crew members 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 crew member 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 crew members with stations. A recharging outlet should be provided in each lavatory that has a 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 is needed to manually initiate and shut off oxygen supply. Chemical oxygen sources usually cannot be shut off once

oxygen supply is initiated. Manual controls for various breathing modes are advantageous 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 550 psi but normally fill to only 300-450 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 greater than 30 minutes is provided. High pressure portable oxygen assemblies currently in use fill to 1800 to 2150 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 chemical oxygen generators are selected for some of the portable assemblies, features should be included consisting of: a replaceable chemical generator cartridge; 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 surveillance aircraft, crew members and passengers use extended oxygen supply in the 15,000 to 25,000 cabin pressure altitude range. In many situations, these persons use a portable oxygen supply to move about the aircraft or because no aircraft oxygen regulator outlet is available. For example, a loadmaster works in a depressurized cargo compartment, moving about to inspect airdrop equipment while the aft door and ramp open.

Aircraft fire fighter portable assembly. Provide at least ____(a)____ fire fighter 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 fire fighter 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 crew member 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 fire fighter such that the breathing gas mixture does not exceed the threshold limits as specified by (g) for noxious gases and airborne particles.

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 type regulator minimizes the entry of noxious gases into the delivery hose and face mask. An adequate length of delivery hose is needed to enable the fire fighter to swing his body around in fire fighting. The hose should incorporate a disconnect filling to receive a standard crew pressure-demand mask and hose.

b. A new breathing mask design should provide as good a face seal as current crew member 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. A face shield should 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 fire fighting 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, consider the following: 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. 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. On aircraft that have compartmental zones for passengers, cargo, and/or equipment (such as avionics equipment bays that can be accessed in flight), fire fighting assemblies should be available in each compartment. 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 advisable to check the logistics and maintenance locations at the USAF bases for which the equipment is intended if the assemblies must be recharged from ground support equipment. See *3.2.2.9* for more information.

e. Detailed information for design concerns for a chemical generator of oxygen supply is given in *3.2.2.9*.

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. Oxygen containers that supply 20-30 minutes of breathing should be rechargeable from aircraft outlets. Most aircraft that use fire fighting units are of the transport or bomber type and usually have a cabin pressure altitude of 8000 feet or less.

However, if the aircraft should fly higher in an emergency, a fire could occur along with a cabin decompression. In this event, the protective equipment is also the breathing equipment for 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 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 selecting the threshold limits, 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.

Helicopter Emergency Egress Device (HEED). The HEED shall be a compact, light weight, self contained underwater apparatus consisting of _____. The HEED shall be capable of safely withstanding and operating in the following storage and mission environments: _____. The HEED shall be designed to provide _____ minutes of emergency breathing air required for a safe egress of a submerged aircraft at a depth of _____ feet, and a water temperature of _____ degrees. A safety relief device shall be incorporated within the system to prevent over pressurization. The system or part of the system while in the mouth during breathing shall permit freedom of movement of the head and shall not create any hazards to emergency egress, (not including the hazards inherent in using SCUBA). Additionally, the HEED shall be easy to locate and acquire by the aircrew member in the dark and when disoriented. The system shall be capable of being stowed in _____, and at the same time be comfortable for up to _____ hours of wear. Additionally, the system shall be compatible with the 3-point, 4-point and 5-point aircrew restraint systems, at the following applicable crew stations: _____. The overall weight of the HEED shall not exceed _____. The HEED shall contain a filter with the following characteristics: _____.

TBD

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 in-flight 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 crew member 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)___.

a. In aircraft required to fly missions above 50,000 feet pressure altitude in excess of a few minutes, a means of providing counterpressure to crew members' lungs is necessary in the event of an emergency decompression. Full pressure suit assemblies should be used for extended exposure to ambient cockpit/cabin altitudes above 25,000 feet.

b. To avoid duplication infomation on pressure suit ensembles has been move to JSSG-2010-9. Refer to this document for additional details.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.

REQUIREMENT LESSONS LEARNED (3.10.2.2)

Crew breathing controls and displays. Experience has shown the primary control and display problem to be accessibility to the crew member. Another problem was the crew members' misinterpreting the control position. For example, on the CRU-68/A and CRU-73/A type panel-mounted regulators, an “ON/OFF" switch is provided to initiate oxygen supply to the crew member's hose and mask. The design incorporates an over center cam that has a tendency to stick in the center position. Lubricating the cam would introduce fire hazards. The crew member may also misinterpret the switch position as oxygen “ON" when it is really “OFF."

The best design practice for sensing low supply and providing a warning to the crew member(s) for LOX converters is to illuminate a yellow caution light when the 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 proposed to be increased up to 50 percent on modern fighter aircraft. A low supply caution light that illuminates in excess of 50 percent oxygen supply will cause display illumination too frequently to be useful, resulting more in a distraction than a caution to crew member(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 primary 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 from leak. The secondary purpose is to remind the pilot to alert maintenance to refill the LOX converter.

If each LOX converter is not equipped with its own quantity indicating gage, then excessive maintenance man-hours will be used servicing units that do not require servicing. Even if a total oxygen quantity gage is used, individual indicators, low-level warning indicators and press-to-test controls for each LOX converter must be provided.

Paratroop controls and displays. Many past troop transport aircraft did not have a load master crew station. 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 load

master had to walk about the cabin to determine the status of this oxygen system. This is now considered an unfavorable 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 man-hours will be utilized servicing units that do not require servicing.

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.

In a past USAF transport aircraft program the contractor believed that a flow indicator could only be a sensor that sensed oxygen flow in the line it was intended. This device had great difficultly properly functioning at lower flow rates. Past flow indicator lights have used pressure sensor(s) in the plumbing downstream of the altitude compensating regulator(s) more successfully.

Mission controls and displays. TBD

Aeromedical controls and displays. TBD

Passenger controls and displays. TBD

Fire fighter controls and displays. TBD

Pressure suit controls and displays. To avoid duplication infomation on pressure suit ensembles has been move to MIL-HDBK-1776-4. Refer to this document for additional details.

Emergency oxygen system. Experience has shown that crew members may lose consciousness on or before seat ejection in the emergency. Windblast is another deterrent to breathing. For these reasons, the means of breathing regulation is critical in ensuring that oxygen is usable by the crew member even under loss of consciousness or windblast. This will enhance the probability of his or her survival.

There have been several problems with past emergency oxygen subsystem designs. Oxygen corrosion or oxygenization on some break-off type nipples lowered the breaking strength enough to allow inadvertent supply activations. The material chosen for the nipple should maintain a stable breaking shear strength in an oxygen-rich environment. Other problems have also occurred with the cable from the manual activation handle to the nipple. The pull-through cable could stick or freeze in a cold environment. Pins and mounting brackets would then resist activation.

In an aircraft accident, the crew member was unable to breathe because the aircraft primary oxygen system or LOX converter was lost in a fire that also destroyed the canopy removal equipment. They were both in the same aircraft compartment or equipment bay. The crew member attempted to use the bailout oxygen supply, but was not able to breathe as the equipment will only properly function if the chest mounted connector is disconnected from the oxygen supply hose. At lower altitudes not enough oxygen supply flow and pressure was available from the existing bailout oxygen equipment. The problem was that smoke and fumes would enter the crew member's breathing air if the chest mounted connector (CRU-60/P) would be disconnected. In the past, this type of equipment was only designed for altitude protection

during emergency descent. Later testing showed that this equipment will not satisfactorily meet crew member ventilation rates unless additional ambient air is available to supplement the emergency oxygen supply which provides 11 lpm initially and only 6 lpm after three minutes. Ventilation rates in excess of 15 lpm are required to physiologically support a crew member's breathing rates in an emergency situation. For existing aircraft, this lack of breathing protection in a smoke and fumes environment was dealt with by including a note in the aircraft pilot technical order handbooks. For new designs, breathing protection for a smoke and fumes environment is necessary as is altitude protection.

Manual bailout/emergency oxygen supply. Manual bailout oxygen assemblies are used on some USAF aircraft by crew members and mission specialists to enable them to walk about the aircraft cabin. A high pressure bailout bottle was provided in a canvas carrying pouch with a shoulder sling to enable the crew members 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.

Walk-around oxygen assemblies. 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. In the event the crew member's oxygen supply is damaged in combat, the crew members would need a backup oxygen supply. 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.

Early versions of portable oxygen assemblies incorporated continuous-flow supply regulation. These were very difficult to use because not enough immediate supply of oxygen would be available for rapid inhalation. Crew members could hyperventilate or experience hypoxia. Diluter-demand was a later version of the regulation of pressurized oxygen, but experience showed this was not completely satisfactory as smoke and noxious fumes could contaminate the breathing air. Modern versions of regulation close off the air dilution intake and incorporate pressure-demand breathing. One hundred percent oxygen is normally provided, and when at high altitudes or under physical exertion the crew member may select increased positive-pressure breathing. On aircraft integral regulators, these functions are normally automatic but can also be manually selected.

On a USAF aircraft that had up to 20 to 30 mission specialists, 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 sometimes struck crew members and/or fell to the aircraft floor. 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. 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 exposed an inefficiency in the location of recharger outlets on past USAF

transport aircraft used for high altitude airdrops of cargo and personnel. An efficient design is to have each portable cylinder adjacent to a recharger outlet, because 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 can plug 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, making the adjacent recharger outlets easy to find. This design approach reduces confusion and workload for the loadmaster. Presently, recharger flex line and outlets are difficult to find because they are not color-coded and warning labels are not placed nearby. Labeling of isolated recharger outlets is advised on future designs.

Experience from operational and logistics considerations has shown that the low pressure (300 to 450 psi) oxygen cylinder is the most desirable. High pressure cylinders have been used in the past, but these are potentially more hazardous should the valve break. Also, this type of cylinder 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 the aircraft without special support equipment. Although the low pressure cylinders are bulkier, they have more advantages in use and they weigh much less.

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. In light of these disadvantages, the US Air Force logistics commands have decided to phase out, where possible, the high pressure walk-around oxygen assemblies and the associated recharging stations.

A portable oxygen bottle in a USAF aircraft was mounted in retaining straps near the aircraft headliner. The MA-1 bottle worked loose of its straps and fell to the floor. The straps were not found to be defective, other than being of a poor design for an overhead mounting. Apparently, the straps do not prevent the bottle from moving upward during flight. They are also difficult to install and retrieve in those types of installations. Rigid metal brackets used on other USAF aircraft are a better design approach.

USAF military transport aircraft use portable oxygen devices called passenger oxygen kits (POK) for emergency decompression. These are essentially 22 cubic inch bailout bottles with a continuous passenger commercial-type oxygen mask and accumulator bag attached. An incident occurred in 1985 during a cold weather flight in which the aircraft experienced a decompression. Seven out of 23 POKs failed to properly deploy. This has been attributed to cold weather exposure (-15°F) during preflight and the tight packaging used to store the masks. The plastic accumulator bags ruptured from this exposure. Future designs should consider cold weather storage and packaging procedures.

During a boom operator's preflight check, he noticed that one of the portable oxygen bottles

had dropped to 100 psi. He proceeded to fill the oxygen bottle using a recharging outlet hose. As he did so, some of the air in the bottle leaked out. He noticed a strong odor like that of paint thinner or glue. He notified the aircraft commander, and in an inspection of all the bottles on-board, more contaminated bottles were found. Maintenance was contacted and the containers were replaced. An investigation indicated the contaminant was methyl ethyl ketone (MEK) which was introduced during cleaning. This illustrates that effective cleaning procedures are necessary to ensure that only pure aviator's oxygen gas is in the portable oxygen bottles.

A USAF aircraft without a breathing regulator added an extra crew member by using an oxygen recharger outlet. A portable walk-around oxygen bottle was hooked up to the filler valve at the aircraft oxygen recharger hose. Then an extra 6 to 8 foot oxygen hose was attached at the end of the portable oxygen bottle where the mask hose is normally connected and the other end was attached to the crew member's CRU-60/P harness mounted connector. The altitude sensor knob was placed in the normal position and the portable oxygen bottle served the function of a new breathing regulator. This practice caused a flash fire as the crew attempted after several unsuccessful attempts to connect the bottle to the recharger outlet. Another negative consequence is that the outlet fitting became worn. This outlet is only meant to be used for filling the walk-around bottle; leaving the unrestrained bottle attached to the recharger outlet is a hazard.

Aircraft fire fighter portable assembly. TBD

Helicopter emergency egress device (HEED). TBD

Aircraft pressure suit provisions. To avoid duplication infomation on pressure suit ensembles has been move to JSSG-2010-9. Refer to this document for additional details.

4.10.2.2 Other oxygen subsystem(s).

Analyses, demonstrations, inspections, and tests are essential in checking for a properly designed oxygen subsystem. The verification of the oxygen subsystem(s) shall consist of _____. Analysis shall be completed on the proposed subsystems to ensure they meet mission requirements and support all possible emergency scenarios. Inspections, Demonstrations and Tests shall be completed by the Test Readiness Review to ensure the subsystem(s) meet normal and emergency needs for flight testing. All controls and displays shall be inspected for satisfactory design and proposed for demonstration at the Test Readiness Review.

VERIFICATION RATIONALE (4.10.2.2)

Crew breathing controls and displays.

Paratroop controls and displays. 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.

Mission specialist controls and displays. 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 be able to detect and understand all displays.

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

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

Fire fighter controls and displays. Verification of the aircraft fire fighter'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.

Pressure suit controls and displays. 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 crew members who use them.

Emergency oxygen system. Verification of the emergency oxygen subsystem equipment is necessary to ensure that all components function properly in the expected operational environment and meet the physiological requirements of the crew members who will use the equipment.

Manual bailout/emergency oxygen supply. 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.

Walk-around oxygen assemblies. 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.

Aircraft fire fighter portable assembly.

Helicopter emergency egress device (HEED). Verification of the aircraft fire fighter 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.

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

VERIFICATION GUIDANCE (4.10.2.2)

Crew breathing controls and displays. 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 crew members in the expected operational environment. Some effective methods of verification are as follows:

a. The suitability of controls and displays is checked by outlining operational scenarios in which they may 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 crew member should be able to ascertain the control positions to determine which modes he has selected.

c. The quick-donning mask assembly intercom microphone and headset may be checked for suitability by personal 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.

Paratroop controls and displays. The verification of the paratroop oxygen system controls and displays shall consist of _____.

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.

Mission specialist controls and displays. The verification of the mission specialists' oxygen system controls and displays shall consist of _____.

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

Aeromedical controls and displays. The verification of the aeromedical oxygen system controls and displays shall consist of _____.

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.

Passenger controls and displays. The verification of the passenger oxygen system controls and displays shall consist of _____.

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.

Fire fighter controls and displays.

The verification of the aircraft fire fighter's portable assembly controls and displays shall consist of _____.

The verification of the aircraft fire fighters portable assembly controls and displays should consist of analyses, inspections, demonstrations, and tests as necessary to ensure that all requirements have been met.

Pressure suit controls and displays. The verification of the aircraft pressure suit controls and displays shall consist of _____.

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.

Emergency oxygen system. The verification of the emergency oxygen subsystem shall consist of _____,

The verification of the emergency 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.

Manual bailout/emergency oxygen supply. The verification of the manual bailout oxygen shall consist of _____.

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.

Walk-around oxygen assemblies. The verification of the walk-around oxygen assemblies shall consist of _____.

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.

Aircraft fire fighter portable assembly.

The verification of the aircraft fire fighter portable assemblies shall consist of _____.

The verification of the aircraft fire fighter 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.

Helicopter emergency egress device (HEED). The verification of the HEED shall consist of _____.

TBD

Aircraft pressure suit provisions. The verification of the aircraft pressure suit provisions shall consist of _____.

To avoid duplication infomation on pressure suit ensembles has been move to JSSG-2010-9. Refer to this document for additional details. 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 show that thesuit provides adequate altitude protection, that it is adequately comfortable, and that heating/cooling needs are satisfied.

VERIFICATION LESSONS LEARNED (4.10.2.2)

Crew breathing controls and displays. A fighter aircraft on-board oxygen generating system (OBOGS) flight test program, which used a molecular sieve oxygen generating system (MSOGS), uncovered numerous difficulties with the oxygen control and display arrangement that needed correction. One problem involved a selector control that was improperly labeled with functions not necessarily consistent with the labeling. Also, the selector control was not functionally located 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.

Paratroop controls and displays. TBD

Mission controls and displays. TBD

Aeromedical controls and displays. TBD

Passenger controls and displays. TBD

Fire fighter controls and displays. TBD

Pressure suit controls and displays. TBD

Emergency oxygen system. TBD

Manual bailout/emergency oxygen supply. TBD

Walk-around oxygen assemblies. TBD

Aircraft fire fighter portable assembly. TBD

Helicopter emergency egress device (HEED). TBD

Aircraft pressure suit provisions. To avoid duplication infomation on pressure suit ensembles has been moved to JSSP-2010-9. Refer to this document for additional details.

3.10.2.3 Passenger oxygen systems.

Oxygen equipment shall be provided for passenger(s) altitude and respiratory protection. The passenger breathing system shall meet servicing, duration, production, breathing dynamics, altitude protection, contamination protection, and NBC protection to meet the mission need of the passengers. The following types of passenger oxygen equipment may apply: General passenger oxygen, Paratroop oxygen system, Aeromedical oxygen system, Quick conversion aeromedical evacuation, Therapeutic oxygen, Aeromedical emergency descent oxygen, HALO/HAHO oxygen subsystem, and/or _____.

REQUIREMENT RATIONALE (3.10.2.3)

General passenger oxygen system.

a. In aircraft that fly above 10,000 feet cabin pressure altitude, supplemental oxygen is necessary for all general passengers. (General passengers are aircraft occupants who are transported from one location to another; mission completion is not required.) In the event of an emergency decompression oxygen will be provided until the aircraft descends to a pressure altitude of 10,000 feet where supplemental oxygen is not required.

b. Oxygen delivery flow rates and pressures compatible with the passenger's physiological needs must be specified to ensure that all oxygen system components are functionally compatible.

c. Passengers must be warned immediately of an impending emergency situation in which they will need to don oxygen masks and breathe oxygen to preclude hypoxia.

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 them.

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. The aircraft designer or the oxygen subsystem contractor must properly install supplemental oxygen dispensing equipment to ensure that the masks may be donned quickly so that 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 passengers who are provided smoke protection breathing equipment.

Paratroop oxygen system.

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

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 crew member 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. The time-to-don requirement guarantees an operationally effective design and helps ensure that the designer locates oxygen mask assemblies that are readily accessible and that untangle easily for use. 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 above 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 supply shut-off ensures that oxygen is not wasted.

e. Permanently installed oxygen system components are favorable for the paratroop side-wall seating on troop transport aircraft. To ensure that the designer includes all detail and components in the design, each component necessary to the aircraft oxygen system design must be called out.

f. Oxygen system components for centerline seats are provided in the form of a removable kit to facilitate cargo-carrying configurations in this area of the aircraft. Oxygen requirements for centerline seats are the same as for outboard side-facing seats. The gear worn by paratroop personnel greatly encumbers their movement; therefore it is important that oxygen plumbing does not restrict troop movement within the aircraft.

g. The space within the passenger compartment dedicated to allow unrestricted on- and off-loading and tie down of cargo (the design cargo volume) must not have permanent oxygen installations.

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 *Appendix B*.

h. 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.

i. If many passengers are to be supplied by the oxygen system, there must be 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.

Aeromedical oxygen system.

a. The aircraft oxygen system must be designed to accommodate the maximum number of each passenger configuration the aircraft is capable of carrying.

b. The oxygen supply source is sized to accommodate the maximum expected aeromedical configuration for therapeutic purposes.

c. The operational pressure range is specified to ensure it is compatible with existing oxygen components.

Quick conversion aeromedical evauation.

a. Many USAF transport and passenger aircraft have multi-mission capabilities; this sometimes includes an aeromedical configuration for emergency situations. Such aircraft carry some litters and seats designed to be stowed away, with the capability for rapid conversion to an emergency aeromedical configuration. Oxygen is a necessary complement to the

aeromedical kit configuration.

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).

Therapeutic oxygen.

a. Any therapeutic outlets provided must 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. Part 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 liters/minute/respirator/outlet (greater than 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 ruptured oxygen line would pose a fire and explosion hazard.

d. Therapeutic and respirator operational readiness is essential while patients are on the aircraft, both on the ground and in flight, to ensure the designer does not rely upon the operation of some subsystem of the aircraft that may not be available while on the ground.

Emergency decent oxygen.

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

b. An alarm signals the aeromedical crew to immediately ensure all patients and personnel don oxygen equipment. Lighting enables the persons to locate and don oxygen equipment.

c. The essential components and operation of the passenger emergency oxygen breathing system must be stated. The designer must know the type of masks needed, 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 specifying the exact locations. *AFI 11-206* 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 used to signal all passengers to don oxygen masks as rapidly as possible and breathe supplemental oxygen.

e. A maximum acceptable altitude to activate oxygen to the mask assemblies and to dispense the mask assemblies automatically (if applicable) is stated because this value varies with the type of aircraft.

Aeromecial oxygen subsystem components.

a. Each component known to be necessary to the aircraft oxygen system is called out to ensure that the designer includes all detail and components in the design. In the RFP, care should be taken to not have design solutions that tell the proposing activity which design to use (i.e., gaseous versus liquid oxygen versus on-board oxygen generating system supply).

b. A means to shut off oxygen in segments of the plumbing is necessary to preclude fire hazards and minimize loss of oxygen from leaks.

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. The mask assemblies are carried in protective stowage containers to prevent damage.

d. The oxygen supply source 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. Interconnecting supply sources through one-way flow check valves allows all outlets to receive oxygen from all supply sources. This, in turn, allows greater flow rates, and in the event one of the sources leaks oxygen, the other sources will not leak.

HALO/HAHO oxygen subsystem.

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

b. The primary locations to place the HALO/HAHO oxygen outlets should be stated. 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/HAHO jumpers' mobility is restricted by equipment, outlets must be readily accessible.

c. It is necessary to specify performance requirements for the outlet so it is compatible with the man-mounted prebreathing equipment.

d. Dust and contaminants should be kept out of the oxygen lines to prevent health hazards to the HALO/HAHO jumpers. Additionally, a build-up of dust and contaminants could preclude valve closure at the outlet, allowing leakage.

e. The HALO/HAHO oxygen supply shall be from the passenger oxygen supply, not from the crew member supply. The crew must have adequate oxygen supply after the HALO/HAHO jumpers have left the aircraft. Manual shut-off is necessary to reduce leaks and associated hazards that could occur if these lines were pressurized. In multimission aircraft, the HALO/HAHO outlets may be used only for a small fraction of the missions. On an aircraft whose main mission is HALO/HAHO flights, the manual shutoff control would assist in maintenance actions.

f. While positive pressure breathing can be more fatiguing than demand breathing, the former method's design 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 denitrification of the HALO/HAHO 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. Specifying a maximum time period for prebreathing will facilitate subjective testing.

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 adjusts the flow rates and pressures to the HALO/HAHO 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/HAHO equipment used by the paratroop personnel. Since these paratroop passengers must prebreathe, the oxygen delivery mode will be pressure breathing.

REQUIREMENT GUIDANCE (3.10.2.3)

General passenger oxygen. In the event of either an unplanned decompression of the normally pressurized aircraft cabin, 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. In the event the cabin pressure altitude exceeds 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.

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 on-board the aircraft as are crew members. Other types of passengers are aeromedical patients, medical attendants, HALO/HAHO 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. Refer to *SAE AIR 825B* and *TSO-C64*.

b. Based on the partial pressure difference of oxygen within the lungs and on the pressure in the aircraft cabin, the flow rates in *table I* must be supplied (as a minimum) to each passenger. Higher flow rates would be required if less than 100 percent oxygen is used, as with some On-Board Oxygen Generating Systems (OBOGS).

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. Specifying the nature of the alarm may be necessary to maintain consistency with the using command's procedures. Types of

alarms are Klaxon horns and whoopers. The alarm must be loud enough to be heard over the aircraft engine noise and aerodynamic noise while in flight. At night the lights may be out when the emergency occurs and sufficient time will not be available for a crew member to locate and turn on all the lighting. Therefore, automatic full-bright illumination of the cabin lighting is essential to enable passengers to quickly find the oxygen mask assemblies.

d. Other subsystem components that are essential to the oxygen system should be added to this requirement.

e. Chemical oxygen generators may be mounted on the seats within passenger reach. Another portable oxygen supply is a LOX converter or pressurized oxygen bottles which may be carried onboard as portable equipment and the plumbing temporarily routed to a passenger.

TABLE XXIV._Minimum general passenger oxygen flow rates.

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.

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 15 seconds is used as a rule of thumb. For smaller aircraft and aircraft that cruise above 50,000 feet cabin pressure altitude, only 6-7 seconds is allowed.

g. The rule of thumb for oxygen supply time using 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. The required supply time may be satisfactorily provided by portable units. A supply exceeding 30 minutes may be desirable on jet aircraft having long range, overseas missions.

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).

a. In most transport and military passenger aircraft, an 8000 to 10,000 foot cabin altitude is normal, and a 12,500 foot cabin pressure is the absolute ceiling at which the ECS maintains the aircraft under normal operational conditions. If the cabin pressure altitude exceeds 12,500 feet, failure of the ECS or cabin decompression has occurred. Parachute packs and other gear required for combat and survival greatly encumber and restrict a paratrooper's mobility. Therefore, these personnel require 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 used to remind crew and passengers to don oxygen equipment. In no case should the alarm be set above 14,500 feet which is the absolute highest ceiling above which passenger can preclude hypoxia without supplemental oxygen.

b. If the aircraft carries more than 20 paratroops, dispensing of oxygen masks and release of the oxygen supply should be automatic. The time available for the load master to assist paratroops in donning oxygen masks would not be sufficient for large numbers of personnel. Automatic dispensing of the oxygen mask with oxygen immediately available is the most desirable arrangement for all aircraft. The requirement for smoke protection will impact breathing equipment design, deployment, and operation. For example, air dilution is not possible from ambient cabin air that would be smoke filled. Smoke and fumes protection inflight and during emergency egress is a desirable goal.

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. In any aircraft that may experience a decompression above 35,000 feet, the time to don oxygen masks and breathe should not exceed 5 seconds. For larger aircraft, a greater time period may be available between dispensing and donning of masks and breathing oxygen. For smaller aircraft (such as a business jet), at 35,000 feet, decompression occurs so quickly that 15 seconds should be used as an absolute maximum, while 5 seconds is the recommended donning time. As an aside, the goal for the flight crew for all aircraft should be 5 seconds.

d. In past transport aircraft, the rule of thumb for the cabin altitude for automatic dispensing

of oxygen and mask assemblies is normally in a range of 12,500 to 14.500 feet. The oxygen should shut off again at 8,000 to 10,000 feet or lower cabin pressure altitude, except those systems supplied by solid-state chemical oxygen generators. The lower altitude limits apply to smaller aircraft; the upper limits 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 required for the installation of gaseous oxygen and LOX systems. If the 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 aisle ways is not restricted. Also, consider that connection/disconnection points permanently mounted onboard the aircraft should be protected from contamination from cargo when in the cargo configuration. That means that protction from mud, oil, water, etc. must be provided.

g. Any permanent equipment and plumbing should be located 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. Some components and plumbing may need to be stowable onboard the aircraft when removed from the design cargo volume. This should only apply to components needed for seat kits mounted within the design cargo volume when in the full paratroop configuration.

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. In many transport aircraft designs, the configuration varies 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 are 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 would quickly descend to about 10,000 feet. There the crew would do a safety check. Next, the pilot would ascend to a higher altitude to conserve fuel. Typically, the aircraft would fly at 20,000 to 25,000 feet pressure altitude with the passengers breathing supplemental oxygen. Flight 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. However existing USAF transport designs accommodate time periods up to 10 hours. For general passengers, the normal required usage is 20-30 minutes for descent. The average flow rate may be determined from *table I*.

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

Gas Volume =

174 liters/hr x 6 hrs x 100 paratroops

= 104,400 liters

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

j. If the oxygen system supplies more than ten people on continuous-flow oxygen delivery equipment or more than two to three crew members 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

TABLE XXV._Minimum oxygen supply requirement for each passenger on continuous flow equipment.

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

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 II*.

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 minutes desired and-30 minutes required. The occupants would be in danger of hypoxia and decompression sickness.

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.

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 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. Consider 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. 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.

Example: A 12-hour mission is flown to an austere airfield to transport 40 litter and 50 ambulatory patients. For normal breathing and no leakage, each therapeutic oxygen outlet provides a minimum of 6 lpm. If respirators are provided, use an average rate of 20 lpm. On emergency oxygen, the flow rate is about 3 lpm to physiologically support the passengers at about 25,000 feet cabin altitude.

40 litters x 6 lpm x 720 min = 172,800 liters

Emergency oxygen is used for one-half the mission as a worst case.

50 ambulatory patients x 3 lpm x 360 min = 54,000

Total = 226,800 liters

A single 75-liter LOX converter will supply 60,900 gaseous liters of oxygen. This means three to four 75-liter LOX converters would be required. However, as a compromise only two 75-liter LOX converters or less 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 therapeutic oxygen.

20 litters x 6 lpm x 720 min = 86,400

70 (litter + ambulatory patients) x 3 lpm x 360 min

= 75,600

= 162,000 liters Total

This compares favorably with the use of two to three 75-liter 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. This applies only to overseas missions in which flight must continue until reaching a landing site.

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 liters/hour (two therapeutic oxygen masks). Some outlets should accommodate flow rates up to 2400 liters/hour to support two respirators or 4800 liters/hour to support four respirators. It is also possible to provide outlets that supply up to 1500 liters/hour. This would support four litters in each tier (4 x 6 lpm x 60 min = 1440 liters/hour) or one respirator (20 lpm x 60 min = 1200 liters/hour). The arrangement design should be coordinated with the aeromedical requirements command at Scott AFB.

c. If the oxygen system is needed to support a small number of patients, 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. If a greater number of patients need oxygen, 300-450 psi delivery system is required to ensure that the pressure does not drop below 50 psi under the worst-case demand-flow rate.

Quick conversion aeromedical evacuation. This system consists of the aeromedical kit which may be either carried on-board the aircraft at all times to allow quick conversion in flight to aeromedical evacuation or may be stowed in another facility. 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 at (c) with features consisting of (c) .

a. Generally, the number of litters/seats used for this type of mission is about 12 for larger transport aircraft, six to eight for medium size aircraft, and one to four for small aircraft. However, this is dependent on the stowage space available, the weight of the kit, and the number of litters/seats 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. If the oxygen kit is plumbed into aircraft cabin wall(s) or bulkhead, it should not restrict passage of medical attendants through aisle ways 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.

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 ____(b)____ 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)____.

a. The therapeutic outlets should be similar to those provided on the C-9A aeromedical aircraft (see *figure 1*) or hospital type outlets used in medical facilities (see *figure 8*). 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, 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.

Another option is a portable therapeutic liquid oxygen unit developed in 1987 by the USAF for aeromedical applications on aircraft that do not include installations of these types of oxygen equipment. This liquid oxygen converter type CRU-87/U less the accessory kit weighs 80 pounds. The accessory kit contains three flow control valves, three 500 milliliter humidifier bottles with adapters and three 25 foot hose assemblies. It weighs 50 pounds which means the weight of the entire assembly is 130 pounds. The complete system includes an accessory kit, a GCU-24A/A 10 liter liquid oxygen converter, two heat exchangers in series, supply pressure gage, liquid quantity gage and three supply quick disconnects. The digit system quantity gage has momentary test and operate modes. Gaseous oxygen is delivered at 0 to 45 liters per minute at 50 5 psig supply pressure. Power for the quantity indicator is provided by the self-contained nine volt batteries. Adjustable tie down straps that secure the unit in place are provided.

b. The respirator outlets should be of the same physical type and configuration as therapeutic outlets. The primary difference is respirator outlets have plumbing that allows a greater oxygen flow-in rate. 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.

Providing separate outlets for therapeutic and respirator equipment would be inefficient. For example, different connectors would be necessary to ensure the lines are not improperly connected. In turn, two types of oxygen lines would be required. The number of each type to carry on the aircraft for different types of missions would be dubious. In the event that only one respirator type outlet is provided, either the patient requiring this device would have to be moved to it or a long line routed from the outlet to the patient would be required.

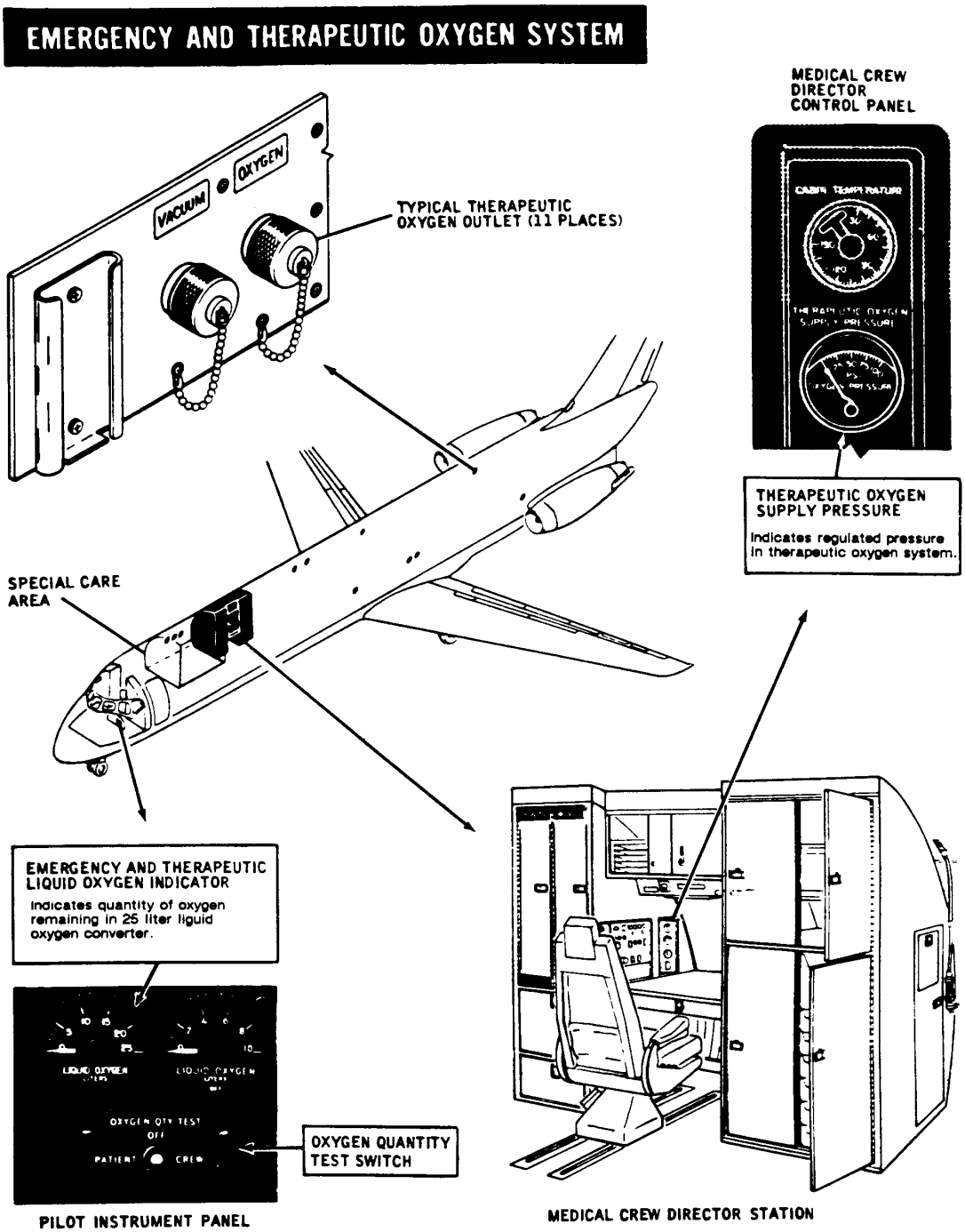


FIGURE 15_C-9A aircraft therapeutic oxygen outlet panel

c. Therapeutic and respirator outlets in aircraft with permanent litter and seat installations are most efficiently placed 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 aisle ways 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. A beneficial design approach is to route the plumbing overhead which has been an effective approach on the C-141 aircraft. Another concern is that these outlets should not be subject to damage from equipment and personnel movement.

d. The therapeutic oxygen system must be usable while the aircraft is on the ground and in flight. It is necessary to view the aircraft as sitting on the ramp, engines off, and power down. Patients are being loaded for transport or taken off the aircraft for treatment at a medical facility. 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.

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.

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 poses a definite risk.

b. The audible alarm should be easily heard under all expected flight noise conditions, including 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 so 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 necessary to enable all passengers to see masks, straps, and controls that must be handled to breathe the oxygen.

c. Oxygen supply should be initiated within a range of 10,000 to 15,000 feet depending on the aircraft and its mission. Either specify the exact type of oxygen mask or state that continuous-flow type is desired. Pressure-demand types of masks are usually provided for flight crew members. The face mask, inhalation/exhalation valves, reservoir bag, and activation lanyard are required components of any mask assembly. Automatic dispensing of these components is the most favorable but this may be more costly. Manual donning may be

acceptable if the mask assemblies are readily accessible. Because so many factors must be considered when determining the design and location of emergency oxygen equipment, specifying the locations is impractical. For example, installing oxygen bottles on passenger seat backs could be a hazard if passengers in the seats behind may be thrown forward and could strike their heads on the 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. The military type oxygen system should activate 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.

f. Portable MA-1 walk around oxygen bottles connected to MBU-5P/12P masks are provided for aeromedical evacuation crew members.

The Federal Aviation Administration requirement is 15,000 feet; most USAF transport aircraft dispense oxygen at about 12,500 feet; the DC-9 hospital aircraft dispenses oxygen automatically in a range of 11,000 to 15,000 feet (see *figure 2*). Shutting off the oxygen supply precludes fire hazards after the aircraft is at 10,000 feet or lower cabin pressure altitude.

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)___.

a. The components mentioned in the requirement are generally required for the installation of all gaseous oxygen and LOX systems. If the particular oxygen system to be used on a specific aircraft requires other components, these should also be specified. An on-board oxygen generating system supply source is not currently used for aeromedical aircraft 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 recommended method of releasing passenger oxygen masks from stowage containers is a spring-loaded door that opens when a surge of oxygen pressure is sensed by the assembly regulator inlet valve in the mask assembly. Electrical latching mechanisms may be less reliable and, if provided, must be activated from the emergency electrical

supply. 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.

d. The recommended location for the oxygen supply sources is in 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 favorable location for the supply source.

e. In all multiple supply installations, one-way flow check valves must 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.

HALO/HAHO oxygen subsystem. A minimum of ___(a)___ outlets shall be provided for high altitude low opening (HALO) and high altitude high opening (HAHO) parachute jumpers. This applies to a HALO/HAHO 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/HAHO oxygen subsystem shall consist of plumbing distribution with only HALO/HAHO 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/HAHO jumpers from sea level to ___(f)___ feet that allows nonfatiguing breathing from ____(f)____ minutes for prebreathing to a minimum of ___(f)____ minutes to complete the mission. The response of all regulators provided shall accommodate a rapid decompression of ___(g)___ seconds without adverse effects to the paratroops breathing from the HALO/HAHO outlets. Each HALO/HAHO oxygen outlet shall accommodate flow rates of (h)___ litres/hour/outlet and shall operate within a pressure range of ___(h)___ psi.

a. The HALO/HAHO parachute jumpers jump in groups varying in number depending on the mission. Provide the maximum number of outlets to accommodate the mission with the greatest number of jumpers.

b. One design approach is to integrate the HALO/HAHO 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/HAHO 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/HAHO jumpers' procedures and should not require complex multiple disconnect and connect procedures.

c. Each HALO/HAHO jumper will have only about 10 to 20 minutes of oxygen supply provided from the bailout bottle. The HALO/HAHO jumper must have an in-line regulator to reduce the higher pressure oxygen from the aircraft supply to appropriate breathing pressures. The jumpers also need a connector that adapts to the aircraft oxygen supply as well as the bailout bottle oxygen supply after disconnecting from the aircraft supply.

d. The outlet should be a self-sealing type to stop oxygen flow when the HALO/HAHO 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/HAHO distribution plumbing may not be compatible with the HALO/HAHO prebreathing equipment. As such, the HALO/HAHO oxygen plumbing lines may require separate lines.

f. The ceiling on this equipment will be 50,000 feet pressure altitude. A minimum of 30 minutes and a maximum of 75 minutes should be allowed for prebreathing to denitrify a jumper's body (see *Air Mobility Command Operating Instructions* for further guidance on HALO/HAHO airdrops. Note that this information was previously contained in *Military Airlift Command (MAC) Regulations 55-2, 55-130,* and *55-141*). To ensure that the jumper does not breathe nitrogen, pressure breathing equipment should be provided. Prebreathing with pressure breathing equipment can cause extreme fatigue in the jumpers if using an improperly designed regulator. A properly designed regulator that minimizes fatigue from pressure delivery is therefore essential. The amount of time paratroops can prebreathe is limited by the fatigue encountered from breathing on the regulation equipment. A 5000 foot pressure altitude is the ceiling above which dark eye adaptation is degraded; therefore, it is desirable to maintain an equivalent alveoli partial pressure in the lungs of 5000 feet or lower so the HALO/HAHO jumper may have night vision.

g. The Government engineer or contractor should determine a time period of decompression when the internal pressurized volume of the aircraft and the area of the opening through which the cabin air escapes are known. (See *table XXVII* in *appendix B*.) An explosive decompression occurs when a large window or cargo ramp or door opens in flight. The regulator should have a response time not to exceed 1-5 seconds for the normal decompression and should not adversely affect the HALO/HAHO jumpers in the event of an explosive decompression.

h. The paratroop personnel shall prebreathe 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 a larger number of jumpers, the upstream plumbing delivery pressure should be high enough to ensure adequate flow is provided at all HALO/HAHO outlets. Provide flexible supply hoses that have disconnect features to miniature regulators which distribute 70 psi 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 is lower than this, but in the event the aircraft flies to this altitude, a safety margin should be incorporated into the design.

REQUIREMENTS LESSONS LEARNED (3.102.3)

General passenger oxygen. Chemical oxygen generators, such as chlorate 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 theory. Any surfaces the user may touch should have a maximum temperature limit within human tolerance for pain at the defined altitudes.

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. (Reference AFALC/PTL, Wright-Patterson AFB, OH. *Abstract of Lessons Learned*, 1 Jan 1984. LL# 0055)

Passenger oxygen system. 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.

A USAF transport aircraft has cloth pouches that contain the mask assembly located adjacent to self-sealing outlets. In an emergency decompression, the load master 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. In some situations this can be hazardous. It may take the load master a long time to access the supply manifold. If paratroop personnel are fully equipped with backpacks, duffle bags, and full harness, it is extremely difficult to accomplish the required procedure. If the aircraft undergoes rapid decompression (less than one minute), paratroop personnel could lose consciousness.

The oxygen mask assemblies on another USAF transport aircraft were originally 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 repackaging of the mask assemblies in the passenger compartment required many man hours, and the wear and tear on the mask assemblies required more frequent replacement. This posed the risk that if a mask assembly dispensed in a decompression when it was necessary for survival, it may not be usable because of damage from repackaging. The reservoir bag tears easily and is

necessary for proper use of the mask assembly. The automatic dispensing altitude was moved to about 12,500 feet to preclude these problems.

TABLE XXVI. Expected oxygen flow rates on continuous equipment.

Cabin altitude	Flow rate (lpm)		
(feet)	(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

In a transport aircraft source selection, the aircraft manufacturer did not submit sufficient information in his proposed specification to ensure that all essential subsystem components would be included in the proposed designs. This risked the possibility of incomplete design. 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 this type of misunderstanding and others, a list of general components that make up the system is desirable.

Of the 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 on the aircraft even when not in use.

Paratroop oxygen system. TBD

Aeromedical oxygen system. TBD

Quick conversion aeromedical evauation. TBD

Therapeutic oxygen. 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 artificially maintain respiration to keep the patient alive. 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.

In some early transport aircraft, very little oxygen supply integral to the aircraft was available for passenger use. The supply provided was primarily for flight crew member use. Some early transport models had oxygen supply in high pressure vessels. This supply was limited and supported passengers primarily for emergency descent. These aircraft were powered by propellers and did not need to reach higher altitudes to fly efficiently as do jet aircraft. 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: *SAM–TR–73–57*. See *3.2.2.2* for lessons learned in the design approach for the proper routing of oxygen plumbing.

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 carried onto aeromedical/airlift aircraft required oxygen immediately to survive. The aircraft might be on the ramp for hours before takeoff. It would have been impractical 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 were not allowed to leave the aircraft. Some patients still needed oxygen during these stops.

Emergency decent oxygen. A contemporary transport aircraft aeromedical mission calls for a 5000, 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 5000 foot cabin pressure altitude would be planned when carrying patients in critical condition.

This transport 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 load master (or responsible crew member) 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.

TBD

FIGURE 16._Emergency oxygen installations in USAF C-9A aircraft from continuous-flow regulation.

Aeromecial oxygen subsystem components. Experience has shown that all valves used in a liquid oxygen system should be cryogenic to preclude their freezing open in emergencies.

HALO/HAHO oxygen subsystem. All earlier types of prebreathing equipment for HALO/HAHO 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 easily tangled and the jumpers were required to gather around the unit because the delivery hose lengths were limited to 8 to 12 feet. The oxygen supply provided by this unit is limited, and therefore the loiter or standoff time of the aircraft was limited once the HALO/HAHO jumpers initiated prebreathing. New designs need to be improved.

An aircraft was climbing in preparation for a high altitude high opening (HAHO) airdrop of paratroopers. Equipment and personnel checks were accomplished at 20,000 feet. About four minutes from the drop, the paratroopers stood up to prepare for the jump. At this time, one of them inadvertently disconnected from the paratroop oxygen console. About three minutes later, he lost consciousness and slumped to the floor. The aerospace physiological observers on-board immediately administered oxygen to the unconscious paratrooper and the pilot initiated an emergency descent. The paratrooper regained consciousness as the aircraft descended through 16,800 feet. This experience illustrates the importance of properly designed hoses and connectors that preclude inadvertent disconnects. (Reference the *MAC Flyer*, Aug 1987.)

General passenger oxygen.

VERIFICATION RATIONALE (4.10.2.3)

Passenger oxygen system.

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

Aeromedical oxygen system. 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.

Quick conversion aeromedical evacuation. 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.

Therapeutic oxygen. 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.

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

Aeromedical oxygen subsystem components. 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.

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

General passenger oxygen. Verification of the passenger oxygen system 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 (4.10.2.3)

Passenger oxygen system verification. Analyses, demonstrations, inspections, and tests are essential in checking for a properly designed passenger oxygen system(s). The verification of the passenger breathing oxygen system(s) shall consist of _____. The type of oxygen supply shall be defined by the Preliminary Design Review. Analyze shall be completed by the Preliminary Design Review to ensure sufficient oxygen supply will be provided to meet mission requirements. Demonstration of the time limits and suitability of methods of dispensing oxygen supply shall be proposed at the Test Readiness Review and completed during ground and/or flight testing as appropriate. All controls and displays shall be inspected for satisfactory design and proposed for demonstration at the Test Readiness Review.

Paratroop oxygen systems verification. The verification of the paratroop oxygen system shall consist of _____.

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:

Transport and tanker aircraft that have multi-mission roles, such as passenger and aeromedical missions, require kits which are easily installed and disengaged for ground storage when not in use. These arrangements will include oxygen subsystems. 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.

Aeromedical oxygen system. The verification of the aeromedical oxygen system shall consist of _____.

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

Quick conversion aeromedical. The verification of quick- conversion aeromedical evacuation shall consist of _____.

The verification of the quick conversion aeromedical evacuation kit 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.

Therapeutic oxygen. The verification of therapeutic oxygen shall consist of _____.

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*. Past experience has shown that an actual demonstration of the therapeutic equipment and configurations is very worthwhile to determine the problem areas which need to be corrected before the design is finalized.

Emergency decent oxygen. The verification of emergency descent oxygen shall consist of _____.

The verification of the aeromedical emergency descent 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 are discussed in *4.2.2.1*.

Aeromedical oxygen subsystem components. The verification of aeromedical oxygen subsystem components shall consist of _____.

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*.

HALO/HAHO oxygen subsystems. The verification of the HALO/HAHO oxygen subsystem shall consist of _____.

The verification of the HALO/HAHO 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*.

General passenger oxygen. The verification of the passenger oxygen system shall consist of _____.

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 (4.10.2.3)

Passenger oxygen system verification.

Paratroop oxygen systems verification. TBD

Aeromedical oxygen system. TBD

Quick conversion aeromedical. TBD

Therapeutic oxygen. TBD

Emergency decent oxygen. Experience has shown that a demonstration of a full percentile range of passengers donning the equipment needs to be accomplished to ensure all persons can reach the masks.

Aeromedical oxygen subsystem components. TBD

HALO/HAHO oxygen subsystems. TBD

General passenger oxygen. TBD

3.10.3 Oxygen systems design considerations.

The oxygen system design shall consider requirements for structural integrity, accessibility, maintainability, serviceability, logistics support, training, quality assurance, survivability, safety, supportability, reliability, human engineering, international standardization, hazards analysis and contamination investigation, contamination and cleaning concerns and _____. Design trade studies, mockups and _____ may be used to develop an effective oxygen system.

REQUIREMENT RATIONALE (3.10.3)

Oxygen subsystem integrity. The effectiveness of any military force depends on the operational readiness of its weapon systems. Major factors which affect the readiness of an aircraft are the reliability and maintainability (R&M) of its subsystems. The oxygen system is an essential life support subsystem. As such the R&M factors are critical to the integrity of this hardware and software. To improve the R&M and to increase readiness and minimize life cycle costs, the capabilities, conditions and operational limitations of the oxygen equipment must be established. Potential problems must be identified early in the life cycle to minimize their impact on the operational force. From these analyses a preventive maintenance program may be established which provides for the orderly scheduling of inspections and replacement or repair of life limited components of the oxygen subsystem. In some cases an integrity program for a small development effort may be considered excessive relative to the cost of the program. Integrity program development costs may be high, but a life cycle cost study may confirm its advantages.

Accessibility, maintainability, and seviceability design considerations.

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 due to elevated internal oxygen gas pressures. This is especially important when the oxygen supply is limited.

c. Oxygen breathing masks and delivery hoses 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.

d. All existing oxygen systems have expendable supply sources that require periodic

replenishment and maintenance. Even proposed on-board oxygen generating systems have filters and a molecular sieve canister that require periodic inspection and replacement. Filters will require more frequent replacement that the molecular sieve canisters. Past experience has shown the properly designed molecular sieve canisters require replacement every 2000 to 4000 flight hours. It is essential that quick and easy service and replacement capability be provided in the oxygen system design.

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

Survivability and safety design considerations.

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. Warning indications, labeling, and markings are recommended for future designs.

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

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

e. Pressurized 93 to 100 percent oxygen poses significant risk of fire and explosion hazards if an improper design or materials are used.

Hazards analysis and contamination investigation. An aircraft will be proposed to have a liquid oxygen supply, a high or low pressure oxygen supply system or an On Board Oxygen Generating system such as Molecular Sieve Oxygen Generating System (MSOGS). If an MSOGS is provided, it may have a low or high pressure backup oxygen subsystem to supplement crew member breathing gas in the event of emergency decompression or a failure of the MSOGS. If an ejection seat is provided, the crew may also have a high pressure emergency oxygen supply for ejection. From previous investigations on other USAF aircraft with liquid, high and low pressure oxygen equipment, design problems, improper materials and contamination were potential fire and explosion hazards. A proposed new or modified aircraft could also have similar safety-of-flight concerns. Investigations have shown these hazards as universal problems with liquid, low and high pressure oxygen equipment. Accident records in the Air Force show that the highest risks are associated with high pressure oxygen equipment.

Contamination. It shall not be contaminated by cleaning chemicals; nuclear, biological and chemical (NBC, USAF terminology) or chemical, biological, radiological (CBR, Navy terminology) warfare agents; and inert or noninert physical substances that are included in the design of the oxygen system.

Human engineering. 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, the equipment must be configured such that maintenance personnel are able to service it easily and efficiently.

International standardization provisions. International agreements ensure compatible ground support for USAF military aircraft operating in other countries. Additionally, internationally standardized aircraft equipment and associated ground support enhances eligibility for US trade of military aircraft to other countries. In turn, repair and maintenance are more easily facilitated.

Design trade studies. In many cases controversial and questionable areas of design are encountered that are not easily resolved without some initial study and analysis into the options available to the designer.

Mock-up requirements. Equipment mock-ups 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 can be discovered and resolved early. Various types of mock-ups provide this insight. A Data Item Description may be necessary to obtain data on the mockup.

Supportability. TBD

Cleaning. TBD

REQUIREMENT GUIDANCE (3.10.3)

Oxygen subsystem integrity. If an oxygen subsystem integrity plan is proposed by the Government as part of contractor design requirements, the contractor should establish refined integrity requirements for each subsystem to create an integrity program. Integrity requirements and milestones should be derived from experience and lessons learned. An integrity program should address service life, usage, functional performance, environments, loads, durability, damage tolerance, strength, vibration/dynamic response, thermal induced fatigue, flight and ground load induced fatigue, reliability, maintenance and integrity scheduling, and management. Proper interfacing with the airframe, escape, crew station, avionics, propulsion, and environmental control systems must be considered. The contractor must translate integrity into design criteria to be used for material selection, functional sizing, and overall design and qualification of the equipment hardware, software, and installation. Design criteria must also address producibility in the sense of fully preserving the design integrity and reliability of the oxygen system. No manufacturing process, prefabrication or assembly procedure, past selection criteria or acceptance process, or any other factory operation due in part or in whole to equipment or human error will degrade the “designed-in" integrity of the product. The objective is to ensure that criteria which reflect the planned usage of the oxygen subsystem are applied to the design so that specific functional performance, manufacturing, operational and maintenance/support requirements will be met. The task of developing criteria must begin in the earliest stages of the program such as the concept exploration phase (if applicable) and finalized in the early part of Full-Scale Development (FSD). Requirements for a failure-free operating period (FFOP) must be established relative to the design service life. Under ideal situations they would be equal. Early criteria of a general arbitrary nature may be required in some cases, particularly when it is difficult or too early in the development phase to understand and predict specific requirements.The contractor must establish integrity program milestones consistent with the Systems Engineering Master Schedule (SEMS). All final selected design criteria will be reviewed at predetermined events on the schedule and are subject to Air Force

approval. It is essential that Air Force engineering be involved in the review process for the establishment of integrity design criteria. Consider having the contractor prepare a design criteria report for each milestone that is updated as the program progresses and a final report for each milestone that is updated as the program progresses and a final report at the critical design review or later validation control events.

Air Force engineering will identify the desired FFOP, the service life, and the expected usage of the oxygen equipment for individual subsystems and components. The contractor should use this data in his integrity program.

Trade Studies - A realistic service life of many components must be achieved through a designed-in FFOP followed by a scheduled preventive maintenance program, if applicable. In the beginning phases of an oxygen subsystem program, the contractor should conduct trade studies to determine FFOP for individual components and evaluate the impact of alternate maintenance operating periods on cost, weight, performance, and logistics.

The results of the trade studies are used to define preferred design service lives for specific components as well as to define the required in-service maintenance to achieve schedule milestones and integrity requirements agreed upon between the Air Force and the contractor.

Integrity concepts for the preferred design service life of each component should be established as early as possible in the development program so these may be incorporated into subcontractor and vendor specifications. Establishing designed-in periodic scheduled preventive maintenance at intervals less than the specified subsystem service life must be evaluated against the Air Force logistics organization's capability to support this concept. Trade-offs should be accomplished since support equipment may need development and/or the cost, manpower, and training requirements may prove to be excessive. In any case, the Air Force's capability to support the planned preventive maintenance concept must be realistic and feasible.

Trade study results agreed upon between the Air Force and the contractor must be reflected in the final design criteria and the overall integrity Master Plan. Air Force guidance is available in *MIL-STD-1798*, *AFGS-87249*, and *MIL-A-87244*.

Critical Parts Analysis and Classification - The oxygen subsystem provides necessary physiological support to crew/passengers under normal and emergency flight situations. As such, the contractor must identify and classify essential hardware as safety-of-flight, mission essential, etc. This is done by conducting a failure modes and effects evaluation for the oxygen subsystem design. As a part of this evaluation, the contractor should consider the effect of hardware failure of the supporting and/or surrounding airframe and subsystems. This should also include a crash safety analysis. The contractor must also evaluate the effect of a software/firmware failure to the oxygen subsystem. This includes software/firmware in other subsystems that interface with the oxygen subsystem such as built-in-test. The objective of this assessment is to identify potential pitfalls to the oxygen subsystems and interfacing subsystems such that risks to the on-board personnel are minimized. The critical parts evaluation must be updated periodically throughout the program by the contractor to account for changes from design and software/firmware validation.

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)___ 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)___.

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. The designer should include additional requirements and expand the specification in this area should more information be available from lessons learned or experience. Additional information is available in Sections V through IX of *TO 15X-1-1*.

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 crew members, 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)___. The oxygen system design and all materials (metals, soft goods, etc.) used in the design of any oxygen system shall be evaluated by an appropriate analysis ___(e)___ so that the design may be as safe as possible from any fire and explosion hazards. These materials shall be deemed the most appropriate for the system design. Toxic materials or materials which produce toxic or corrosive by-products shall not be used in the oxygen system.

a. Survivability requirements should be applied to the oxygen system design on aircraft expected to fly in a threat environment. This applies to fighters, fighter bombers, attack, bomber, tactical transport, and surveillance aircraft. Major components of the oxygen system should not show any evidence of shattering, and the mounting provisions should withstand all forces encountered by the gunfire test. Fill the component with the LOX or gas at the nominal pressure expected to be used during normal operation while in flight and on the runway. Fire upon the component from a distance of approximately 50 yards with a

tumbling 50-caliber armor-piercing incendiary projectile. The bullet should 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 survivability test has been accomplished on past components. Ensure any other method used to test survivability 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 extreme temperatures. The maximum temperature limit for all oxygen system components is 260°F (123.3°C). 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, ensure that any possibility of overpressurization (500 psig is normally the maximum limit) does not exist.

For LOX converter selection and aircraft installation, consider the impact of other aircraft subsystems, such as fuel or hydraulics, on the LOX. LOX chemically reacts by fire and/or explosion with most hydrocarbon materials. If two or more converters are necessary, they should be separated as much as possible to minimize combat vulnerability. It is especially important to provide a supply source for the crew members on the flight deck separate from that supply source for other aircraft occupants. Supply lines may be manifolded such that the crew members on the flight deck may draw supply from other sources for the other aircraft occupants. The manifolding schemes and one-way flow check valve locations should be designed 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 is to keep total length to a minimum. This decreases combat vulnerability and reduces the chances for leaks. Plumbing installation should 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 should be separated as much as possible (not less than 12 inches) by space or physical barrier. Mount all tubing so 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. Provide holding clips near portable recharger outlet connections to prevent damage to the flexible lines and self-sealing outlets. The tubing, where passing through or supported by the aircraft structure, should have adequate protection against chafing by the use of flexible grommets or clips. No tubing should 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 fillbuildup vent such that it drains overboard at the bottom of the aircraft within sight of the filler box and not closer than 25 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. Crew members, passengers, and maintenance personnel will then be able to accomplish all necessary operations on the oxygen system with a minimum of mistakes.

c. Cleanliness 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. Specify special situations or unique aircraft design constraints which impose additional survivability and/or safety design considerations.

e. A rigorous analysis which examines the oxygen system design an materials used must be accomplished. Refer to the following paragraphs 3.5.1 and 4.5.1 for information on the hazards analysis. Where necessary, the design and/or materials used should be changed to reduce the hazard. Toxic materials or materials which produce toxic or corrosive by-products shall not be used in the oxygen system. Refer to US Government document SD-14 for a listing of know toxic materials.

Hazards analysis and contamination investigation. A _____ review of the proposed oxygen system and included components shall be conducted at _____ milestones in the program or project to ensure that no unacceptable risks are in the design, operation and maintenance of the aircraft oxygen system.

Initially, the concern is that the equipment may have design or materials problems. In other words, the design and materials contribute to ignition in an oxygen environment. Later, the concern is that proper precautions are taken minimize oxygen equipment hazards and contamination by procedure. Experience has shown that little attention has been focused on designs to minimize oxygen hazards and on a materials selection process from the oxygen compatibility standpoint. The design approach and materials selection has usually been based

on the aircraft manufacturer's and associated vendor's historical experience. For example, should the oxygen components (for example, valves, regulators, and plumbing) already be used on an existing aircraft oxygen system that would be sufficient justification to continue its use on another oxygen system without questioning potential hazards. Also, there is a strong desire to minimize costs and manufacturing fabrication problems. These goals are not necessarily consistent with the design of a safe, nonhazardous oxygen system.

A suitable detailed hazards assessment of the design and operation of the equipment has only been accomplished on a few military and commercial oxygen equipment components and configurations. This does not necessarily mean that a hazard exists with this equipment. But, it is prudent that in the procurement of oxygen systems a hazards analysis and contamination assessment be accomplished. Since oxygen hazards can be a system and/or a component problem, designs which use existing oxygen equipment should still be examined in detail. Also, if proper measures are not taken for servicing this oxygen equipment or replenishment of supply, contamination will be a prevalent problem. Contamination is not only a fire and explosion hazard, but it may also prevent or degrade proper oxygen equipment operation. Additionally, it has been found that servicing pressurized oxygen equipment too rapidly frequently contributes to accidents from the compression heating effects.

The aircraft program Statement of Work (SOW) should require a hazards analyses be performed on the oxygen system and components. Additionally, the Statement of Work (SOW) should require a contamination investigation later on in flight test evaluation and operations. This is necessary to determine whether a clean, safe oxygen system will be available in the operational environment. To ensure that the primary aircraft contractor corrects all problems under the contract the proper information must be included in the contract. Additionally, to ensure that the analyses and contamination investigation are competent, appropriate information must be included within the Request for Proposal (RFP) and the bidders proposals. It would be pertinent that the bidders provide the proper information in the Statement of Work, specification and data items delivered to the procurement activity.

A "quick look" preliminary hazards analysis be should be provided by the bidders in the proposals at the time of the Source Selection since these hazards are so strongly related to the design configuration and the materials from which it is made. This will assist in an early evaluation for a safe and effective oxygen system design. A more detailed hazards analysis and contamination investigation should be provided later in the program, after contract award.

Areas which need examination are system problems that contribute to higher risks, metals and nonmetals materials compatibility issues and proper component design. While it is feasible that the aircraft contractor, associate contractors and vendors could perform a hazards analysis, it is more desirable that an independent organization which has expertise in this field be contacted to do an independent study. We recommend that this independent organization be requested to perform a hazards analyses on the aircraft oxygen system prior to a final decision to install this oxygen system on the aircraft. One recognized suitable independent organization is NASA JSC White Sands Test Facility, Las Cruces, NM, USA. The Crew Systems Branch, ASC/ENFC, Wright-Patterson Air Force Base, OH, USA can also do some hazards analysis and be an advisor for hazards analysis and contamination assessments for military equipment procurements. This investigation should examine this equipment at the component and system level and also consider the hazards from an oxygen systems operation and maintenance

viewpoint. An overview of the issues of concern is discussed in Appendix D.

Training and guidance has been provided over the past few years to many aircraft contractor and oxygen equipment vendor managers and design engineers. Also included in the verification paragraph 4.5.1 and Appendix D is an outline describing reference information that is available in this technical area.

It should also be pointed out that these issues concerning oxygen system and equipment hazards are not well known or understood by many who are involved in the aircraft design and development process, therefore supplemental information and guidance is considered essential.

RECOMMENDED TASKS TO BE PERFORMED:

The aircraft contractor should ensure that the independent organization which does the hazards analyses and contamination investigation furnish the necessary personnel, facilities, material supplies and data to perform the following tasks:

Hazards Analyses: A "quick look" hazards analysis may be conducted by contacting the organization which will accomplish the investigations and providing to them information such as drawings, test reports, materials lists, and historical data. This organization bidding the proposal may then provide a "quick look" hazards summary for the organization evaluating the proposals to use for the source selection.

Later, after contract award, a more detailed hazards analysis on the pressurized oxygen system and equipment should be accomplished. The system / equipment design, materials and operation of the components must be examined in complete detail. It is essential that actual hardware and associated drawings be made available. The primary aircraft contractor should provide hardware and information to the organization which does the hazards analysis. Also, so that materials compatibility issues may be examined, all appropriate parts and materials must be identified. Often vendors have proprietary and/or patent rights on this hardware. It may be necessary to take appropriate safeguards to ensure that all organizations involved in the hazards analyses protect the rights of the vendors and suppliers of this equipment.

The purpose of obtaining this equipment is that teardown inspections and evaluation of the component designs is essential for a proper analysis. Fabrication and assembly problems may be discovered that are not necessarily design related. It is not expected that this equipment will be destroyed or consumed in the investigation. After the investigation, the equipment may be returned to the vendor for cleaning and reassembly.

The purpose of this analysis is to identify any potential hazards in a qualitative manner. Any moderate to severe hazards identified should be explained in sufficient detail so that any necessary changes may be determined by the primary aircraft contractor and the USAF. Recommendations provided should include options for consideration of design, fabrication, assembly and/or operational changes.

Contamination Assessment: Components of the aircraft oxygen system and equipment could be examined after some period time of flight operations. For example, this examination could occur near the end of flight testing or operations. It is desirable not to wait too long or it would be more difficult and costly to make any necessary design and/or procedural changes. On the

other hand, it is desired to wait some amount of time so that a contamination buildup will be found somewhat representative of possible contamination that could occur on the operational aircraft. An effective contamination assessment is only possible if the oxygen system components are taken from the aircraft and examined in a proper laboratory facility. It is also necessary to examine tubing and inlet/outlet fittings on the aircraft oxygen system that are not removed. If excessive contamination is found on equipment left on the aircraft, it will be necessary to clean the oxygen system at the aircraft prior to installing clean replacement parts. If the flight testing must continue, spare parts must be made available and used to replace the components which have been removed.

These components should be examined by a competent independent organization such as the same one which does the hazards analysis. NASA JSC White Sands Test Facility, Las Cruces, NM, USA is one independent organization that is a recognized authority in this technical area. For proper shipment these components should be properly packaged so that no contamination other than that which may already be within the equipment while installed on the aircraft shall be introduced. The equipment should be disassembled in a proper clean environment and examined for contamination. Any contamination identified should be recorded by appropriate documentation and photographs. Visual examinations are the primary method whereby contaminaton is evaluated. Visual examinations which may be enhanced by various techniques such as magnification and blacklighting may be used to discriminate hydrocarbon or halogen type contamination from other types. A nonvolatile residue analysis may also be accomplished which includes a particle size and weight distribution count on each component. An assessment of the contamination found should be provided which identifies the level of problem and/or hazard, if any.

It may be found that proper measures are needed to control contamination during operations. For example, it may be necessary to add filters to the aircraft or support equipment. Other equipment or procedural changes may also be needed to keep the oxygen system from excessive contamination.

Meetings and Reviews: Technical interchange meetings are desirable to hold to assess the problem areas and determine methods to correct any medium to high risk problem areas discovered. For military programs, military technical representatives shall participate in the briefing(s) by the organization which does the hazards analysis. Other meetings may be held as necessary. Later, the evaluating organizations / persons shall participate in the technical interchange meetings summarizing the results of the contamination assessment. ASD/ENFC may be consulted as an independent basis to advise on plans and recommendations.

Documentation: Prior to beginning any work, test and evaluation plans should be provided for review and comment. It is essential that acknowledgement for test and evaluation plans be provided by the bidders at the Source Selection which includes plans for the hazards analyses and contamination investigation. Also a preliminary "quick look" hazards analysis could be provided by the bidders at the source selection. Later, after contract award, a more detailed preliminary hazards report could be provided to the evaluators and contracting authority for review and comments. For a thorough investigation and analysis, an independent organization should review all plans and results and advise the contracting organization. The final hazards report shall be provided which includes pictures, investigation results, findings and recommendations.

Office of Prime Responsibility. The office of prime responsibility for review and comment of USAF aircraft oxygen systems hazards analyses and contamination assessments is the Crew Systems Branch, ASD/ENFC, Wright-Patterson Air Force Base, Ohio, USA 45433.

Contamination. The oxygen system shall not allow _____ contamination to reach the breathing gases.

Contamination by cleaning chemicals. The oxygen system may contain improperly cleaned components or not all cleaning components may be removed from the equipment. Odors and cleaning compounds shall be removed from the system such it is gives off no noxious odors and presents no hazard to the crew and passengers (if applicable).

Contamination by nuclear, biological and chemical warfare agents. The oxygen system shall be designed such that it does not allow nuclear, biological and chemical warfare agents downstream of the concentrator in the breathing gas. The procuring activity should specify the specific threats that must be considered. The primary nuclear contamination concern is radioactive dust. The primary biological concern is single cell diseases, viruses, toxins and microtoxins which are nearly always destroyed by elevated inlet temperatures and can also be filtered. The primary chemical agents threats that have been tested in the past with OBOGS zeolites are GB (sarin), GD (soman) and HD (distilled mustard). Should testing be required, the agents and simulants that need to be tested shall be specified by the procuring activity. The system shall be adequately designed to defeat this specified contamination. Any oxygen supply person equipment such as breathing regulators and hoses shall be hardened so that any agents cannot adsorb or penetrate the containment material and enter into the breathing gas.

Contamination by physical inert or noninert substances. In the breathing gas supplied to the crew member, the oxygen system shall preclude contamination by physical inert or noninert substances that may be toxic to the crew and passengers (if applicable) or degrade the operation of the aircraft. Examples of contamination that is not allowed is zeolite dust, coolant fluids, filter materials and mechanical particles.

Contamination by toxic materials. It is also possible that toxic materials such as lead or cadnimum may be included within the design of the oxygen system. A special reference to preclude these materials may be desirable.

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

Most design criteria that should be applied are contained in *MIL–STD–1800* and *MIL–STD–1472*. One should look through the standard and determine the requirements that apply. Should additional design guidance be desired, other sources of information should be quoted. A good source is *AFSC Design Handbook 1-3* and the list of reference books given in the Appendix, “Guidance Documents" of *MIL-STD-1472*.

International standardization provisions. The international agreements shall apply to the oxygen system design. Provisions for international standardization are as follows: _____.

The following list of international agreements is given here for reference. These documents are not intended to be referenced to implement requirements in a specification. In most cases, government furnished equipment (GFE) for oxygen systems have incorporated design

provisions to meet international agreements. For newly designed equipment, investigate the necessary design provisions applicable from these agreements. Trade studies or programmatics may conclude that these international agreements will not be implemented for a particular program. When designs are selected which do not comply with the international agreement, a reservation to the agreement must betaken per *AFR 73-6*. Where feasible, these treaties should be included as a part of design requirements.

NORTH ATLANTIC TREATY ORGANIZATION (NATO) AGREEMENTS

STANAG 3053GGS Breathing Oxygen Characteristics, Supply Pressure and Hoses

STANAG 3054GGS Characteristics of Compressed Air for Technical Purposes, Supply Pressure and Hoses

STANAG 3056 Marking of Airborne and Ground Gas and Liquified Containers

STANAG 3198AMD Functional Requirements of Aircraft Oxygen Equipment and Pressure Suits

STANAG 3296GGS Aircraft Gaseous Oxygen Replenishment Couplings

STANAG 3341AI Emergency Control Colour Schemes

STANAG 3370AI Aircrew Station Warning, Cautionary and Advisory Signals

STANAG 3499GGS Characteristics of Supply Equipment for Liquid Oxygen

STANAG 3545GGS Characteristics of Breathable Liquid Oxygen

STANAG 3546GGS Characteristics of Liquid Nitrogen

STANAG 3547GGS Characteristics of Replenishment Equipment for Liquid Nitrogen

STANAG 3568GGS Aircraft Gaseous Systems Replenishment Connections

STANAG 3611 Characteristics of Compressed Breathing Air

STANAG 3624GGS Characteristics of Oil-Free Compressed Nitrogen, Supply Pressure, and Hoses

STANAG 3647AI Nomenclature in Aircrew Stations

STANAG 3688GGS Characteristics of Breathable Oxygen Supplied by Chemical Solid Generators

STANAG 3705AI Principles of Presentation of Information in Aircrew Stations

STANAG 3806GGS Aircraft Gaseous Air/Nitrogen Systems Replenishment Connectors

STANAG 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*

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

The government model specification and statement of work should require that the proposing contractors provide equipment and testing to accomplish trade studies prior to submittal of source selection proposals. 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.

Mock-up requirements. .Mock-ups shall be constructed of _____. The goal is to determine _____.

Varying degrees of mock-up 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 mock-up constructed of the actual materials and similar materials is most useful. This might apply to a proposed regulator design. Mock-ups are also useful in determining proper location of portable equipment, and usability and accessibility 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 mock-ups should also be included in the statement of work.

Supportability. The oxygen system shall be supported in the following manner: _____.

TBD

Cleaning. The oxygen system shall be cleaned to the a level of _____. The oxygen system shall be cleaned ultilizing the following method: _____.

TBD

REQUIREMENT LESSONS LEARNED (3.10.3)

Oxygen subsystem integrity. Background on critical parts R&M of the equipment is not always easy to obtain. In many cases, this information may be obtained from the detailed military specification of existing oxygen equipment which is similar to proposed new designs. See Appendix B for documentation references on existing equipment.

An assessment of the R&M of existing military LOX systems in operation has shown a MTBF of 50-100 hours for transport aircraft and 150-250 hours for single place aircraft. This range is

accounted for depending on the time period the sample is taken and the aircraft type.

Accessibility, maintainability, and serviceability design considerations. LOX converters and associated servicing connections on some proposed aircraft designs have been located out of reach (too high) for the persons using this equipment. Oxygen servicing capability is severely compromised in such cases. There are many 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 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.

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.

Past LOX converter explosions indicate that better maintenance procedures are needed to preclude this hazard. For example, in 1986 an oxygen leak in the cockpit was detected by specialist personnel working on the aircraft. Environmental control system personnel were dispatched to troubleshoot the problem. They disconnected the LOX converter, found a loose B-nut, tightened it, connected the converter, leak checked again, disconnected the converter's supply and vent lines, and left the aircraft. The still-disconnected converter exploded six hours later causing extensive damage. The maintenance personnel had failed to check the line pressure of the oxygen supply. Foreign objects such as ice, dirt, rust, or oil probably blocked the pressure relief valve and possibly the build-up-and-vent valve. The converter built up excess pressure. If the pressure were in excess of that normally expected (125 psig for low pressure systems and 500 psig for high pressure systems), maintenance personnel should have recognized a malfunctioned converter, vented excess pressure at the regulator outlet(s), and removed it placing a vent tool on it to relieve all converter pressure. After all LOX had been

vented, it should have been sent to the depot for overhaul. If no pressure shows on the pressure indicator, a potential explosion exists and the vent tool should be placed on the converter immediately since excess pressure cannot be vented at the regulator.

At a USAF military aircraft base in July 1987, a partially expended bottle of welder's oxygen was discovered installed on a gaseous oxygen unit GC-01. It was believed that one or more aircraft emergency oxygen supply bottles were serviced with welder's oxygen instead of the more pure aviator's oxygen. No documentation could be found to place where or when the improper oxygen was issued or used. Investigations showed there are no warnings in the guidance for checking that proper bottles are installed, and that there is a widespread lack of awareness concerning the difference between the markings of the different oxygen bottles. Normally, an AFTO 134 form is filled out, but this was missing. To avoid this mistake in the future, ensure the proper markings are on purchased oxygen bottles, proper procedures are established to handle this, and personnel are trained to use the correct equipment to support USAF aircraft.

Survivability and safety design considerations. 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 in which 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 Contract 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, 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 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.

An existing USAF aircraft uses a curtain to separate the oxygen supply from hydraulic lines in a lower equipment bay. Additional maintenance manhours are required to access the oxygen equipment through the curtain which must be removed. This curtain is also a safety hazard as it can absorb combustible materials that may readily ignite in the presence of oxygen gas. Future aircraft installation should not use curtains, but should use metal barriers or space, to isolate LOX from other equipment with potentially combustible sources.

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 can also drive up the logistics support cost of the oxygen system. On a USAF aircraft, the inflight refueling manifold coupling assembly cracked allowing fuel to leak into the

LOX converter compartment through leak paths that were inadvertently designed into the airframe. This deficiency causes hazardous conditions to flight personnel and equipment. Sealing off all potential leak paths will have a beneficial impact on safety and survivability in that the hazard of fuel or any combustible material entering the LOX compartment will be removed.

Composite oxygen cylinders—Composite oxygen cylinders with aluminum liners shall not be used on aircraft with a gunfire threat and should be used only with much caution on other types of aircraft. Fragmentation resistance testing conducted by the Navy has revealed a problem with the use of composite oxygen cylinders with aluminum liners on military aircraft. Gunfire testing resulted in a significantly larger blast overpressure than that experienced with steel cylinders of the same size without a composite overwrap. When penetrated, the heat released ignites the aluminum liner adding more energy than that contained by the pressurized gas. The superior strength from the construction of the cylinder with the glass or Kevlar overwrap contains this energy allowing it to build to very high proportions until it is released through the openings caused by the projectile and the burning aluminum. Gunfire tests have shown that the blast over pressure of a composite aluminum lined cylinder pressurized with 100 percent oxygen was 5 times greater than that of a comparable size steel cylinder pressurized with 100 percent oxygen. Plans to test similiarly designed composite cylinders with low carbon steel liners were never completed. These cylinders may show promise, but must be gunfire tested first before the military may accept them.

Compisite cylinders with aluminum liners and aluminum cylinders are banned from use on military aircraft. Composite cylinders with liners other than aluminum should be tested before using to ensure that no significant blast over pressure will result in the event of failure. The following are other suggested types of testing recommended for composite cylinders, in addition to existing tests for steel cylinders. The first is a drop test. If the cylinder is considered serviceable after dropping it, it should be cycled with 100 percent oxygen gas and checked for failure. A second test is to assess included contamination in the cylinder during pressure cycling with 100 percent oxygen gas. The interior of the cylinder and its valve should be inspected for evidence of burning or pitting that would indicate metal ignition. If this has occurred, the cylinder should be rejected. A third test would be to rapidly break off the neck of the bottle to ensure no significant blast over pressure or liner burning results. Cylinders proposed for use on aircraft without a gunfire threat should still be gunfire tested, because a significant blast over pressure may occur upon failure of the cylinder. Testing will ensure the cylinder failure will not cause loss of the aircraft or of any on-board personnel.

The pressure reducer and/or regulator used on the cylinder should also be analyzed to ensure that it is of a material and design which minimizes the risk of fire and/or explosion. Experience has shown that most fires and explosions begin because of faulty valve design or improper application of an existing valve into a system. For example, quick opening valves are hazardous with high pressures. On opening the valve, the heat of the compression can easily raise the temperature above the combustion of metals commonly used in this application. Also, if soft goods are used in proximity with oxygen service, they could ignite, initiating a kindling chain reaction and igniting the metal.

FAA certification of a tanker aircraft—FAA certification in conjunction with development testing should be critically reviewed in developing future weapons systems. The FAA is only interested in vehicle airworthiness, not mission accomplishment. FAA certification can result in redundant

testing that is wasteful of resources. The FAA certification of aircraft requires additional flight test time compared to military testing. The FAA has very little experience in the conduct of the mission of the aircraft. For example, the FAA requires an aircraft experiencing cabin depressurization to descend to 10,000 feet. The oxygen systems in FAA-certified aircraft are designed to meet this requirement. The USAF, on the other hand, may continue the mission in a depressurized aircraft at altitudes up to 25,000 feet. Oxygen equipment designed for FAA requirements may not meet USAF mission requirements. The fact that an aircraft is FAA certified in no way ensures that the aircraft will be capable of completing its assigned military mission(s). (Reference Lessons Learned report *AFFTC 80-24*.)

Hazards analysis and contaimination investigation. High Pressure Gaseous Oxygen Equipment - Engineering investigations of past fire and explosion accidents attributed to oxygen equipment have revealed that high pressure gaseous oxygen equipment to be the primary contributor to the problem. High pressure in this case means pressures more than 25 psig. All system components including the piece parts are of concern. We realize that in the past with military oxygen breathing equipment pressures up to 500 psig are considered low pressure, but from the standpoint of fire and explosion hazards, low pressure is only up to 25 psig. A Department of Defense Safety Alert was issued by the Navy concerning testing of aluminum lined composite over wrapped 1800 to 2150 psig cylinders. Fragmentation testing (gun fire tests with oxygen gas included) showed a significant release of fire and over pressure much more than that of standard steel cylinders. Aluminum cylinders are no longer considered safe for use in military aircraft. This test pointed out that the concern with the use of aluminum cylinders (in this case composite) is not only with gunfire causing explosive failure, but that any ignition mechanism within the cylinder or pressure regulation at the outlet may propagate to the cylinder for an explosion failure.

Filtering the source of oxygen in filling the oxygen bottle is desirable since there is steel in the filler valve housing. It is recommended that the filter on the servicing side be 10 or 11 micron sintered brass or bronze (not steel). There is concern with a filler valve has a housing combustile housing such as aluminum or steel. Past experience with the old type Schrader filler valve still in widespread usage has show numerous problem areas that contribute to a fire. The USAF and Navy have had numerous accidents with the old type Schrader filler valve with the valve core. (Reference: GIDEP SAFE ALERT G7-S-91-01, titled, "Valves, Core, High Pressure Oxygen" and Amendment to same alert issued 15 October 1991, and GIDEP SAFE ALERT G7-S-94-03, titled, "Valves, Core, High Pressure and Housing Valves, Oxygen Filler" issued May 1994, both by Dennis W. Schroll Crew Systems Branch, Wright-Patterson Air Force Base, OH.) Review of several accidents with these Schrader filler valves shows that the most probable cause of a fire is a particle from the servicing side striking the filler valve housing and igniting the steel housing first, then the surrounding material. Other undesirable features of the filler valve which also can contribute to a fire, such as a high cracking pressure, all which resulted in the decision that a new type of safer design was needed. It should be pointed out, however, that the number of valves in use being serviced in comparison to the number of known fires is quite a large number. Even though the past experience has shown the potential for the fire is present, the risk from any one servicing is not high if precautions are taken to minimize hazards. If a servicing filter cannot be found and the adapter fabricated, then several things are recommended. The person(s) servicing should release the oxygen gas very slowly only from a regulated supply, not directly from the high pressure bottle. At the time of servicing

the person(s) should be at a distance or shielded from the filler valve location so if a fire does occur no one will be injured. The filler valve housing and filter should be made from metals that are not combustible in the 100 percent oxygen and higher temperatures. The materials of choice are metallic monel housing and sintered brass inlet filter or equivalent.

We strongly recommend the removal of any wire mesh screen at the entry of the bottle into the pressure regulator and the use of an adequate standpipe or anti siphon tube. The screen will hold particles generated from the use of the pressure reducer and from servicing. The particles will accumulate and stick to the screen. Even if the assembly is mounted upside down on the seat for use as a bailout bottle, aircraft maneuvers and removal and replacement of the assembly for replenishment of oxygen supply will allow particles to travel and stick to the screen. On supply activation these particles would be launched at high velocities into the valve body possibly igniting. If the valve body is aluminum the possibility of ignition is too high. It would be better to filter the oxygen at the filler valve inlet and let any particles that did get into the reducer would move into the cylinder and be contained within by a standpipe or anti siphon tube. Also, past test data by NASA shows that wire mesh screens are the most easily ignited metal configuration known in pressurized oxygen. Ensure that an adequate standpipe is used. Any holes in the standpipe that are too close to the bottle neck may allow entry of particles into the reducer on supply activation. A minimum of about one inch is considered desirable for the hole to be located from the interior bottle neck.

Past experience has shown that high pressure equipment is assembled in an adequate clean room. A 10,000 Class clean room to achieve high level of cleanliness is desirable. NASA has previously stated that high pressure oxygen equipment of this type which has an aluminum valve body and not so oxygen compatible non metals should be cleaned and assembled to a 50A Level. It is desirable that high pressure equipment be cleaned and assembled to as close to a 50A level which is possible such as on a laminar flow bench in the clean room.

Past experience has shown that improved assembly procedures are needed to eliminate excess RTV (thread locking compound), lubricant, any other nonmetals and metal particles generated during assembly. Precautions need to be taken to keep excess thread lubricant and locking compound from oozing out into the valve seeing oxygen service. There is also concern about metal particles being generated on the assembly of the pressure gage, filler valve, pressure relief valve and the supply line. Past experience with screwing steel hardware into aluminum valve bodies has shown that aluminum feathers and particles are generated. New and improved methods of ensuring this excess and any metal particles generating on assembly will be removed and controlled as much as possible. To minimize particle generation when screwing their aluminum valve or pressure regulator into a steel bottle, Teflon tape should be used with pipe threads and an oxygen compatible lubricant or thread lock around straignt threads. The new procedures also require removal of excess lubricant and RTV.

Several fires on high pressure regulators or pressure reducers have caused a great concern over the use of safe regulators and valves. In any new program that intends to use high pressure gaseous oxygen equipment, attention must be given to the use of properly designed equipment whether it uses existing equipment or is a new design. Presently, this is best accomplished by including an oxygen equipment Hazards Analysis in the development phase using Appendix D and ASTM G63, G88, G93, and G94 as guidance. Selection and evaluation of oxygen compatible designs and materials are very important in keeping risks to an

acceptable level. Should a high pressure gaseous oxygen system be proposed, experiences have shown there is a good possibility of fire and explosion from an unacceptable level of risks. Primary contributors of past accidents are thought to be compression heating (moving higher pressure gas to a lower pressure location), particle impact (primarily aluminum and steel particles), hydrocarbon contamination, and the use improper and/or excessive non metals or elastomerics at critical locations. This does not rule out the likelihood of other ignition sources.

The use of existing commercial or military aircraft oxygen equipment, no matter how long in use, does not guarantee a safe oxygen system. Past hazard analyses have shown that many hazards are inherent in existing oxygen equipment. Oxygen systems critical components should be investigated to the piece part level to determine design, materials and recommended operational and maintenance practices. Oxygen system critical components are defined as components and plumbing likely to contribute to an oxygen fed fire such as (but not limited to) pressure vessels, pressure reducers, regulators, manifolds, filler valves and check valves. Of special concern is gaseous oxygen supply equipment that is intended to be frequently serviced. This significantly increases risks as the chances for contamination and ignition sources are greatly increased.

Contamination. TBD

Human engineering. TBD

International standardization provisions. TBD

Design trade studies. The most important and most controversial issue is the means of oxygen supply. The three most common supply sources 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 trade-offs 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.

Mock-up requirements. TBD An approach and test plan in the use of any mock-ups assures they have been constructed for useful purposes. Should test and verification not be accomplished on the mock-ups, they could also be useful for sales and demonstration tools.

Supportability. TBD

Cleaning. TBD

4.10.3 Verification of oxygen systems design considerations.

Analyses, demonstrations, inspections, and tests are essential in checking for a properly designed oxygen system. The verification of oxygen systems design considerations shall consist of _____. Design considerations specified shall be provided at the Preliminary and Critical Design Reviews. Inspections and Tests shall be proposed at the Test Readiness Review to validate specified design considerations. Tests may be required to validate all

Hazards Analysis so that a safe design will be provided.

VERIFICATION RATIONALE (4.10.3)

Oxygen subsystem integrity. Verification of the oxygen system integrity is essential in providing a reliable and dependable operational capability under all operational and environmental envelopes.

Accessibility, maintainability, and serviceability design considerations. 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.

Survivability and safety design considerations. 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.

Hazards analysis and contamination investigation. Some component designs may never have been validated even after years of use. Some new aircraft oxygen system may be a new arrangement. The entire system and components must be examined for critical issues that are thought by a team of experts to have the most risk. It may be desired to run worst case cycling tests to exercise the system or components to ensure that a fire will not occur. Also, if test data is not available for some material under consideration that is used in what is thought to be high risk locations, it may be desirable to run tests to rank the untested material. This will determine if the material or better or worse than what was orginally proposed.

Contamination. The safety of the crew and any passengers should be provided by insuring that no contaminaion or toxic materials are in the breathing gas.

Human engineering. 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.

International standardization provisions. Verification of the international standardization provisions of the oxygen system design and equipment shall be essential to ensure that all required provisions have been accomplished.

Design trade studies. Trade studies are verified so the information may be available for future reference in the follow-on development effort or similar work.

Mock-up requirements. The verification of oxygen system mock-up design(s) and goals shall consist of _____.

Request preliminary test plans from the proposing contractors prior to the expenditure of government funds on mock-ups and models which are usually quite expensive. On the other hand, the use of mock-ups may be more economical when total development costs are considered, since required changes discovered later in development are usually 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.

Supportability. TBD

Cleaning. TBD

VERIFICATION GUIDANCE (4.10.3)

Oxygen subsystem integrity. The establishment of an integrity program must be verified by inspection, analyses, demonstrations, and tests and approved by the appropriate Air Force personnel. Integrity program elements include establishing design criteria, design service life and usage, trade studies, critical parts and classification, material/process selection and characterization, durability and damage tolerance control plans, corrosion prevention and control, load analyses, design stress/environmental spectra development, performance and functional sizing analysis, thermal/environmental analysis, stress/strength analyses, durability analysis, damage tolerance analyses, vibration/dynamics/acoustics analyses, materials characterization tests, functional qualification tests, strength tests, durability tests, vibration dynamics, acoustics testing, damage tolerance testing, maintainability/repairability demonstrations, quality assurance during production, and any other verification deemed necessary to validate the integrity of the oxygen subsystem. See the appropriate integrity Mil-Prime specification for further guidance.

Reliability tests. The verification of the oxygen system hardware and software integrity shall consist of _____.

Accessibility, maintainability, and serviceability design considerations. The verification of accessibility, maintainability and serviceability shall consist of _____.

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

Survivability and safety design consideration tests. The verification of survivability and safety shall consist of _____.

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.

Should any designs or materials be used which have not been previeously evaluated and/or tested, it would be desirable to conduct tests to evaluate the design(s) and rank the materials in terms of susceptibility to fire and explosion.

Hazards analysis tests. The oxygen system and components hazards analysis may be checked by _____ testing. Some tests may be system oriented while others will be to check the components.

The oxygen hazards analysis team should assist in the development of the testing needed to ensure the equipment will be safe. Past methods of testing are identified in:

American Society for Testing and Materials (ASTM) documents:

ASTM G72 "Standard Test Method for Autogenous Ignition Temperature of Liquids and Solids in a High-Pressure Oxygen-Enriched Environment"

Autoignition Temperatures of Plastics and Elastomers are determined and ranked. Lubricants and thread compounds are ranked.

ASTM G74 "Standard Test Method for Ignition Sensitivity of Materials to Gaseous Fluid Impact"

The pneumatic impact test has long been used to screen nonmetallic materials for oxygen service. This method has also been used to rank batches or lots of particular materials. (Reference: Moffett, G. E., Pedley, Schmidt, Williams, Hirsch and Benz; *"Ignition on Nonmetallic Materials by Impact of High-Pressure Oxygen,"* Flammability and Sensitivity of Materials in Oxygen-Enriched Atmosphere: Third Volume, ASTM STP 986, D. W. Schroll, Editor, ASTM, Philadelphia, 1988, pp. 218-232.)

The gaseous oxygen pneumatic impact test was used to evaluate the suitability of nonmetallic materials for use in high-pressure oxygen systems. Because of the high variability of the test data, it was recommended that new methods be developed for evaluating the suitability of materials for use in high-pressure oxygen systems. (Reference: Schmidt, Moffett, Pedley, and Linley, *"Ignition of Nonmetallic Materials by Impact of High-Pressure Oxygen II: Evaluation of Repeatability of Pneumatic Impact Test,"* Symposium on Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres: Fourth Volume, ASTM STP 1040, Stoltzfus, Benz and Stradling, Editors, ASTM, Philadelphia, 1989.)

ASTM D2512 "Standard Test Method for Compatibility of Materials with Liquid Oxygen (Impact Sensitivity Threshold and Pass-Fail Method)"

Many materials will ignite or initiate high energy reactions when in contact with gaseous oxygen or liquid oxygen if subjected to stimuli such as a mechanical impact, adiabatic compression (pneumatic impact), or an electrical discharge in the form of a spark. Such materials must therefore be characterized as to compatibility with liquid and gaseous oxygen to define the degree of hazard with their use. Generally, materials are more sensitive to mechanical impact in gaseous oxygen than in liquid oxygen, and impact sensitivity is known to increase with increasing pressure. Thus, the evaluation of the sensitivity of materials in gaseous oxygen is required to supplement liquid oxygen impact test data. The most suitable materials identified were Teflon TFE for gaskets and seals, Type III grease as given by MIL-G-27617 (Krytox 240AC grease is one of these) as a lubricant, and the fluorocarbon elastomers where a rubber is absolutely necessary. Experience with the design of military oxygen breathing equipment has shown that Fluorocarbon elastomers don’t seal well at cold temperatures down to -40 to -65 ^{0}F necessary for military equipment. Silicone rubber is safe and effective especially for low temperature applications. (Reference: Bryan, C. J. *"NASA Mechanical Impact Testing in High-Pressure Oxygen,"* Flammability and Sensitivity of Materials in Oxygen-Enriched Atmosphere, ASTM STP 812, B. L. Werley, Editor, ASTM, Philadelphia, 1983, pp. 9-42.)

Open-cup and pressurized mechanical impact tests were conducted at White Sands Test Facility on Al-Li alloys (2090, 8090, and WL049) and Al alloy 2219 in various tempers. Pressure drop height (potential energy), and environment (gaseous versus liquid oxygen) were variable in the test program. (Reference: Simon, McColskey, Reed, and Gracia-Salcedo,

"Reaction Sensitivities of Al-Li Alloys and Alloy 2219 in Mechanical-Impact Tests," Flammability and Sensitivity of Materials in Oxygen: Enriched Atmospheres: Fifth Volume, ASTM SP 1111, Joel M. Stoltzfus and Kenneth McIlroy, Editors, ASTM, Philadelphia, 1991.)

ASTM G86 "Standard Test Method for Determining Ignition Sensitivity of Materials to Mechanical Impact in Pressurized Oxygen Environments"

ASTM D2863 "Standard Test Method for Measuring the Minimum Oxygen Concentration to Support Candle-Like Combustion of Plastics (Oxygen Index)"

The oxygen index of a material, described in ASTM's Measuring the Minimum Oxygen Concentration to Support Candle-Like Combustion of Plastics (Oxygen Index) (D 2863), is the percentage concentration of oxygen in a mixture of oxygen and nitrogen that will maintain equiliibium burning conditions. It is a numerical measure that can be accurately reproduced with inexpensive test equipment and simple procedures, and it has been used as one criteion for determining the acceptability of materials for use in oxygen-enriched atmospheres. This paper discusses the advantages and the shortcomings of the oxygen index, comparing test results to data from heat-of-combustion and auto-ignition temperature tests. (Reference: Ikeda, G. K., *"Oxygen Index Tests to Evaluate the Suitability of a Given Material for Oxygen Service,"* Flammability and Sensitivity of Materials in Oxygen-Enriched Atmosphere, ASTM STP 812, B. L. Werley, Editor, ASTM, Philadelphia, 1983, pp. 56-67.

Past arguments supporting the oxygen index (OI) test for the evaluation of materials for oxygen service are reaffirmed. The OIs of solid fuels are compared to gaseous fuel flammability limits. The influence of the nonstandard diluents, sulfur hexafluoride, carbon dioxide, helium, and argon on the OI of poly(methylmethacrylate) is reviewed. New categories for the reporting of OI results are proposed. OI data for 79 materials are reported. A generalized "nitrous oxide index" is used to draw analogies between materials in N_2O service and materials in oxygen service. (Reference: Werley, B. L., *"As Oxygen Index Update,"* Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres: Third Volume, ASTM STP 986, D. W. Schroll, Editor, ASTM, Philadelphia, 1988, pp. 248-261.)

The oxygen index is established by ASTM as a standard measurement for the comparison of the flammability of plastics in Measuring the Minimum Oxygen Concentration to Support Candle-Like Combustion of Plastics (D 2863). The index is measured at atmospheric pressure. Measurements of oxygen index and burnign rate at absolute pressures to 2 MPa (20 atmospheres) have been made at 25 oC for six materials: polytetrafluoroethylene, Viton, neoprene, nylon, glass-filled nylon, and polymethylmethacrylate. The oxygen index was found to decrease with increasing pressure but to be independent of Reynolds number up to 1500. At the oxygen index, the burning rate was found to be independent of pressure. The data are correlated by a model that defines the oxygen index as a p oint of constant oxygen diffusion rate. It is concluded that with the exception of nylon, the ranking of materials for oxygen service at elevated pressures by their atmospheric pressure oxygen index is not changed. The index for nylon ranks it on the high side becasue, at lower pressures, hot liquid is lost from the test specimen and does not burn. (Reference: Benning, M. A., *"Measurement of Oxygen Index at Elevated Pressures,"* Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres, ASTM STP 812, B. L. Werley, Editor, ASTM, 1983, pp. 68-83.) See also, (Reference: Benning, Zabrenski, and Le *"The Flammability of Aluminum Alloys and Aluminum*

Bronzes as Measured by Pressurized Oxygen Index," Flammability and Sensitivity of Materials in Oxygen-Enriched Atmoshere, ASTM STP 986, D. W. Schroll, Editor, ASTM, Philadelphia, 1988, pp. 54-71.)

(Not Standardized) "Promoted Combustion Test: Test Methods to Determine the Minimum Oxygen Pressure Required to Support Self-Sustained Combustion (Threshold Pressure)"

See the following references:

Steinberg, Rucker and Beeson, *"Promoted Combustion of Nine Structural Metals in High-Pressure Gaseous Oxygen; A Comparison of Ranking Methods,"* Symposium on Flammability and Sensitivity of Materials in Oxygen-Enriched Atmosphere: Fourth Volume, ASTM STP 1040, Stoltzfus, Benz and Stradling, Editors, ASTM, Philadelphia, 1989.

Sircar, Stoltzfus and Gunaji, *The Relative Ignitability and Flammability of Lead-Tin Binary Alloy in Oxygen,"* Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres: Fifth Volume, ASTM STP 1111, Stoltzfus and McIlroy, Editors, ASTM, Philadelphia, 1991.

Stoltzfus, Lowrie and Gunaji, *"Burn Propagation Behavior of Wire Mesh Made From Several Alloys,"* Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres: Fifth Volume, ASTM STP 1111, Stoltzfus and McIlroy, Editors, ASTM, Philadelphia, 1991.

Sato, J. and Hirano, T., *"Behavior of Fire Spreading Along High-Temperature Mild Steel and Aluminum Cylinders in Oxygen,"* Flammability and Sensitivity of Materials in Oxygen-Enriched Atmoshpere: Second Volume, ASTM STP 910, M. A. Benning, Editor, ASTM, Philadelphia, 1986, pp. 118-134.

Sato, J., *"Fire Spread Rates along Cylindrical Metal Rods in High Pressure Oxygen,"* Symposium on Flammability and Sensitivity of Materials in Oxygen-Enriched Atmosphere: Fourth Volume, ASTM STP 1040, Stoltzfus, Benz and Stradling, Editors, ASTM, Philadelphia, 1989.

Stoltzfus, Homa, Williams and Benz, *"ASTM Committee G-4 Metals Flammability Test Program: Data and Discussion,"* Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres: Third Volume, ASTM STP 986, D. W. Schroll, Editor, ASTM, Philadelphia, 1988, pp. 28-53.

McIlroy, Zawierucha and Drnevich, *"Promoted Ignition Behavior of Engineering Alloys in High-Pressure Oxygen"*, Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres: Third Volume, ASTM STP 986, D. W. Schroll, Editor, ASTM, Philadelphia, 1988, pp. 85-104.

McIlroy, K. and Zawierucha, R., *"The Effects of Testing Methodology on the Promoted Ignition-Combustion Behavior of Carbon Steel and 316L Stainless Steel in Oxygen Gas Mixtures,"* Symposium on Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres: Fourth Volume, ASTM STP 1040, Stoltzfus, Benz and Stradling, Editors, ASTM, Philadelphia, 1989.

Zawieruch, R. and McIlroy, K., *"Promoted Ignition - Combustion behavior of Selected Engineering Alloys in Oxygen Gas Mixtures,"* Symposium on Flammability and Sensitivity of Materials in Oxygen-Enriched Atmosphere: Fourth Volume, ASTM STP 1040, Stoltzfus, Benz and Stradling, Editors, ASTM, Philadelphia, 1989.

Zabrenski, Werley and Slusser, *"Pressurized Flammability Limits of Metals,"* Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres: Fourthh Volume, ASTM STP 1040, Stoftzfus, Benz and Stradling, Editors, ASTM, Philadelphia, 1989.

Zawierucha, McIlroy, and Mazzarella, *"Promoted Ignition-Combustion Behavior of Selected Hastelloy in Oxygen GAs Mixtures,"* Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres: Fifth Volume, ASTM STP 1111, Stoltzfus and McIlroy, Editors, ASTM, Philadelphia, 1991.

(Not Standardized) "Patricle Impact Test: Test Method to Determine the Particle Impact Ignition Sensitivity of Materials in Gaseous Oxygen (GOX)"

Benz, Williams and Armstrong, *"Ignition of Metals and Alloys by High-Velocity Particles,"* Flammability and Sensitivity of Materials in Oxygen-Enriched Atmosphere: Second Volume, ASTM STP 910, M. A. Benning, Editor, ASTM, Philadelphia, 1986, pp. 16-37.

Stolzfus, Homa, Williams and Benz, *"ASTM Committee G-4 Metals Flammability Test Program: Data and Discussion,"* Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres: Third Volume, ASTM STP 986, D. W. Schroll, Editor, ASTM, Philadelphia, 1988, pp. 28-53.

Williams, Benz and McIlroy, *"Ignition of Steel Alloy by Impact of Low-Velocity Iron/Inert Particles in Gaseous Oxygen,"* Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres: Third Volume, ASTM STP 986, D. W. Schroll, Editor, ASTM, Philadelphia, pp. 72-84.

(Not Standardized) "Frictional Ignition Test: Test Method to Determine the Frictional Ignition Threshold for Materials in GOX and LOX"

The ignition of metals and alloy have been investigated by rotating the end of a hollow cylinder against an identical stationery cylinder on a common axis (frictional heating) in gaseous oxygen. A rankin criterion that measures the resistance of metals and alloys to ignition is discussed. It consists of the power per unit area required for ignition conveniently expressed as the product of contact pressure and average linear velocity . Data are presented that demonstrate that materials that are high in nickel and c opper require greater pressure and average linear velocity products for ignition (more resistant to ignition) than materials that are high in iron. Aluminum and titanium alloys are shown to require the lowest pressure and average linear velocity products ignition. (Reference: Benz and Stoltzfus, *"Ignition of Metals and Alloys in Gaseous Oxygen by Frictional Heating,"* Flammability and Sensitivity of Materials in Oxygen-Enriched Atmosphere: Second Volume, ASTM STP 910, M. A. Benning, Editor, ASTM, Philadelphia, 1986, pp. 38-58.

ASTM D4809 "Standard Test Method for Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter (Intermediate Precision Method)"

Lowrie, R., *"Heat of Combustion and Oxygen Compatibility,"* Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres, ASTM STP 812, B. L. Werley, Editor, ASTM, Philadelphia, 1983, pp. 84-86.

Contamination. The oxygen system shall examined and tested for _____ contamination by the following methods _____.

Upon completion of the oxygen equipment assembly on the aircraft, methods in accordance with accepted practices shall be used to determine that the breathing gas is free of cleaning compounds. Subjective sniff tests shall be used and instrumentation may be used (depending on what cleaning compounds have been used) to determine absence of cleaning compounds. Later on, during and at the completion of flight testing, it should be determined that the tubing downstream of the concentrator is free from zeolite dust (if applicable) and other contamination. Wipe testing and visual inspections with bore scoping are methods to check tubing interiors.

Impurities in the inlet air supply to the concentrator and the breathing gas supply should be measured by mass spectrographic analysis or by the following methods. These methods of measuring the maximum allowable concentration of other contaminants are implemented from NATO STANAG 3367.

Carbon dioxide and carbon monoxide. Non-dispersive infrared detection shall be used in accordance with national standards.

Total hydrocarbons. Flame Ionization Detector (FID) shall be used in accordance with national standards, using propane as a reference.

Nitrogen oxides. Chemoluminescence detection shall be used with a converter.

Acrolein. Methods outlined by NIOSH shall be used or equivalent.

Total aldehydes. Wet chemical photometric methods using 3-methyl-2-benzothiazolone hydrazone hydrochloride (MBTH) as a detection agent shall be used.

Engine generated oil particles. Sample shall be taken isokinetically on a carbon free glassfiber filter. The filter is used for burning off the oil in a combustion tube followed by non-dispersive infrared detection of the carbon dioxide produced. Depending on the carbon content of the oil, the amount of oil can be calculated.

Chemical agent testing. During the development of the oxygen system, it may be deemed necessary to conduct live chemical agent testing or testing with simulants. The procuring activity shall specify when this is required and what agents and or simulants shall be used. An inspection of component designs and supporting analyses will verify any equipment hardening provided.

TABLE XXVII. Product mixture contaminants.

Gas contaminant	Maximum level 2/
Carbon dioxide	20 3/
Carbon monoxide	10 3/
Oxides of Nitrogen	0.1 3/
Total Hydrocarbons:	50 3/
Total gaseous impurities (excluding moisture) 1/	0.5 percent by volume
Acrolein	0.01 3/
Total Aldehydes	0.05 3/
Refrigerants (Freons) or Solvents (halogenated)	2

Oil and particular matter	0.5 mg/m^3 3/
Ethanol	500
Hydrogen peroxide	0.5
Aviation fuels	125
Methyl bromide	10
Ozone	0.05
Methyl Alcohol	100
Oil and Particulate Matter	0.5 mg/m^3
Water vapor	0.2 mg/liter at NTP

1/ Gases, other than those noted in table, may be present, provided no physiological hazard is created.

2/ Parts per million by volume, unless otherwise specified.

3/ These maximum allowable concentration of contaminants are implemented from NATO STANAG 3367 (see 6.6)

TABLE XXVIII. Contaminated input air mixture.

Gas contaminant	Minimum level 1/
Carbon dioxide	5,000.0 2/
Carbon monoxide	50.0 2/
Total Hydrocarbons	250.0 2/
Total Aldehydes	1.0 2/
Nitrogen oxides	5 2/
Acrolein	0.1 2/
Water and moisture (15 oC and 760 mm Hg)	200 mg/m^3 2/ No liquid water into concentrator zeolites.
Sub-micron particles	not more 0.5 mg/m^3 Nickel not exceeding 0.5 mg/m^3 Cobalt not more than 0.1 mg/m^3 2/
Ethanol	1,000
Hydrogen peroxide	1
Methyl alcohol	200
Methyl bromide	20
Ozone	0.05

1/ Parts per million by volume, unless otherwise specified.

2/ These maximum allowable concentration of contaminants are implemented from NATO STANAG 3367 (see 6.6)

Human engineering verification. The verification of human engineering shall consist of _____.

This may be accomplished by developing a long, detailed checklist from *MIL–STD–1472* and *MIL–STD–1800* 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 of international standardization provisions. The verification of international standardization provisions shall consist of _____.

Applicable verifications are covered by inspection of the proposed specifications against the requirements of the stated international agreements to ensure the requirements are included.

Verifying design trade studies. The verification of design trade studies shall consist of _____.

Require the contractors to publish results of trade studies in report format which includes facts of the studies, conclusions, and recommendations.

Verification of mock-up requirements. The verification of oxygen system mock-up design(s) and goals shall consist of _____.

TBD

Supportability verification. Supportablity features shall be demonstrated and validated by: _____,

TBD

Cleaning. The oxygen system shall be cleaned to the a level of _____. The oxygen system shall be cleaned ultilizing the following method: _____.

TBD

VERIFICATION LESSONS LEARNED (4.10.3)

Oxygen subsystem integrity. 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 advisable to validate R&M values for oxygen equipment by both laboratory and flight testing.

Accessibility, maintainability, and serviceability design considerations. TBD

Survivability and safety design considerations. In 1989-90 the Navy gunfire-tested composite oxygen cylinders that had aluminum liners to determine if the cylinders would fragment into more than two pieces. This is the standard gunfire test in *MIL-C-7905*. While the cylinders did not fragment, there was a significant blast overpressure which damaged the test facility. The Navy decided the cylinder did not meet the intent of the test which is to fail with minimal damage to the aircraft. They are developing a new test procedure.

Hazards analysis and contamination investigation. TBD

Human engineering. TBD

International standardization provisions. TBD

Design trade studies. TBD

Mock-up requirements. TBD

Supportability. TBD

Cleaning. TBD

3.10.4 Integration 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. The oxygen system components and plumbing shall be installed to minimize fire hazards. All oxygen controls and displays, hoses, masks, and equipment mounted on the personnel shall be installed such that an effective interface that maximizes mission effectiveness has been provided between personnel using the equipment and the oxygen equipment itself. Where the oxygen system must be integrated with other aircraft components or subsystems, the operation and design of the oxygen system shall not be degraded. Other aircraft subsystems shall be effectively integrated with oxygen systems such that the following properties and limits are met: _____.

REQUIREMENT RATIONALE (3.10.4)

This requirement ensures the oxygen system is designed such that total aircraft performance and capability are not compromised and hazards are minimized. Effective interface with aircraft occupants is an important consideration so crew members and passengers may properly use the oxygen equipment and successfully perform other essential flight duties and operations. 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 subsystem designers to assess the impact of this change to their designs and equipment.

REQUIREMENT GUIDANCE (3.10.4)

It is necessary to include interface requirements to the specification for the design and installation of the aircraft oxygen subsystem. The properties and limits depend on which other aircraft subsystems are interfaced. Interface requirements are sometimes not called out in the government model specification in the RFP because a design solution would be required. 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 contaminant 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 (3.10.4)

In an oxygen system design for a trainer aircraft, the contractor had proposed an OBOGS. 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 in which 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. The throttle setting and altitude conditions were found to result in concentrator output breathing gas with oxygen concentration levels below those considered physiologically acceptable for the given altitudes. This may be corrected by either initiating supplementary oxygen or increasing throttle settings.

4.10.4 Integration requirements verification.

Analyses, demonstrations, inspections, and tests are essential in checking for a proper integration of the oxygen system(s) with aircraft systems and personnel. The verification of the aircraft subsystems and personnel integration requirements shall consist of _____. Integration areas of concern shall by resolved by the Critical Design Review. Inspections and Demonstrations shall be proposed at the Test Readiness Reviews to validate all integration concerns.

VERIFICATION RATIONALE (4.10.4)

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 (4.10.4)

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 (4.10.4)

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 nonavailability of space through bulkhead structural members.

3.11 Emergency Egress (see JSSG-2010-11)**.**

3.12 Deployable Aerodynamic Decelerator (DAD) System (see JSSG-2010-12)**.**

3.13 Survival, Search, and Rescue (SSAR) (see JSSG-2010-13)**.**

3.14 Aircraft Windshield/Canopy Systems and Transparent Enclosures (see JSSG-2010-14)**.**

4. VERIFICATION (WITH REQUIREMENTS)

5. DEFINITIONS AND ABBREVIATIONS

5.1 Acronyms used in this handbook.

The acronyms, abbreviations, and symbols used in this handbook are defined as follows:

(Not applicable at this time.)

5.2 Subject term (key word) listing.

aeromedical oxygen

aircraft oxygen

breathing assembly

breathing, crew

breathing equipment

breathing gas

breathing regulator

breathing system

chemical generation oxygen

emergency oxygen

gaseous oxygen

physiological protection

6. NOTES

(This section contains information of a general or explanatory nature that may be helpful, but is not mandatory.)

6.1 Intended use.

This handbook is intended to be used for guidance in the development of an individual subsystem-level aircraft oxygen specification.

APPENDIX A

PHYSIOLOGICAL HANDBOOK

A.1 SCOPE

A.1.1 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.

A.1.1.1 Goals.

The design goal for oxygen systems is to minimize impairment of normal breathing. The work of breathing represents only a small fraction of the total energy expenditure of the body. Any additional load imposed upon the automatic physiological mechanics of breathing by the oxygen equipment will disturb normal breathing patterns. It may also cause discomfort and fatigue of the muscles involved in breathing.

A.2 APPLICABLE DOCUMENTS

Government documents.

Specifications.

MILITARY SPECIFICATIONS

(Unless otherwise indicated, copies of federal and military specifications are available from the Standardization Documents Order Desk, Bldg 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.)

Other Government publications.

(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.)

Non-Government publications and references.

(Non-Government publications are normally available from the organizations that prepare or distribute the documents. These documents may also be available in or through libraries or other informational services.)

A.3 EFFECTS OF DECREASED PARTIAL PRESSURE OF OXYGEN ON RESPIRATORY PHYSIOLOGY

A.3.1 INTRODUCTION

It is generally recognized that the most serious danger for the aircrew member is the decreased partial pressure of oxygen encountered at low barometric pressures. Without the proper use of oxygen equipment and cabin pressurization, hypoxia can quickly lead to incapacitation or death, depending on the altitude. At least 75 hypoxic fatalities are known to have occurred in the European Theater during World War II aboard aircraft flying at high altitude.

Human tolerance to hypoxia has not changed since it was first described, but the altitude capability and performance of aircraft are constantly changing the requirements for adequate protective equipment and strict oxygen discipline. These factors have all continued to increase in importance as humans fly higher and faster. Even hypoxic episodes that lead only to mental confusion or temporary unconsciousness may result in the loss of the aircraft and its occupants.

TABLE A-I. Chemical composition of the atmosphere (dry) at sea level.

Constituent	Molecular Weight	Percent by Volume
Nitrogen (N_2)	28.016	78.09
Oxygen(O_2)	32.000	20.95
Argon (A)	39.944	0.93
Carbon dioxide (CO_2)	44.010	0.03
Neon (Ne)	20.183	1.8X10-3
Helium (He)	4.003	5.24X10-4
Krypton (Kr)	83.7	1.0X10-4
Hydrogen (H_2)	2.016	5.0X10-5
Xenon (Xe)	131.3	8.0X10-6
Radon (Rn)	222.	6.0X10-18
Dry Air	28.966	100.00

Pressure

One of the characteristics of the gaseous form of matter is that it has neither a definite shape or volume, but will instead expand in an attempt to completely fill, with uniform density, any vessel in which it is contained. The earth retains its gaseous envelope by the influence of gravity. The effect of gravity on the gaseous atmosphere results in an envelope which has a constantly decreasing density related to increasing distance from the earth's surface. Another way of expressing the change in density with increasing altitude is to consider the weight of the atmosphere at any given point. The weight of a column of the atmosphere with a cross sectional area of one square inch under standard sea level conditions is 14.7 pounds. This

atmospheric weight, or pressure, will support a column of mercury in an evacuated tube to a height of 760 millimeters or 29.92 inches, or a column of sea water of 33 feet. In aerospace physiology the unit most often used for atmospheric pressure is millimeters of mercury (mmHg).

Since atmospheric pressure in flight is commonly described in feet above sea level, a standard or reference plane is required. The standard which has been employed for the longest period of time is the 1965 United States Standard Atmosphere Table. The U.S. Standard Atmosphere is based on the

following assumptions:

a. Temperature decreases linearly with increase in altitude until the isothermal layer begins (35,332 feet under standard conditions).

b. The temperature of the isotherm layer is constant at -55^{o}C

(-67^{o}F).

c. Air is dry.

d. Air is a perfect gas.

e. Gravity is constant at all altitudes.

Some physical properties of the United States Standard Atmosphere are given in Table 2-2. At sea level, the standard pressure and temperature are 760 mmHg (29.92 in.) and 15^{o}C (59^{o}F).

Temperature

Heat is a result of the sun's radiation. This radiation (primarily visible and ultraviolet light) passes through the atmosphere without an appreciable warming effect on the air, but it does heat the surface of the earth. The intermediate layers of air are then heated by convection.

In as much as warm air is less dense than cold air, it rises. If a mass of rising air does not gain or loss heat, as during a rapid ascent, then the mass of air expands adiabatically; that is, without loss or gain of heat.

In adiabatic expansion, part of the moisture of the rising mass of air is precipitated in the form of clouds which will prevent excessive loss of heat from the earth through radiation. Repeated cycles of these physical phenomena is commonly known as "weather" which produces the relatively constant temperature. The water content of the air is so low that a balance exists between absorption of heat radiated from the earth and radiation from the atmosphere to outer space.

Temperature Lapse Rate. Temperature lapse rate can best be defined as a standard temperature change produced by warmed air masses that, as they rise from the surface of the earth, they expand, lose pressure, and cool. This phenomenon produces a heat loss rate of 2 degrees C (3.6^{o}F) with each 1,000 feet of altitude. The heat loss will continue until the rising air mass reaches an altitude where it stabilizes with the surrounding atmosphere. The temperature will then maintain a constant -55^{o}C. Variations in temperature do occur due to locality.

Temperature Inversion Caused by Radiation. Nocturnal air is relatively still; under this condition the earth loses heat through radiation. When the temperature of the atmosphere surrounding the earth falls below that at higher altitudes, a temperature inversion occurs. In winter, for example, surface temperatures at night have been recorded at -40^{o}C, while over the same area at 8,000 feet, a -5^{o}C has been recorded.

Temperature Inversion Caused by Turbulence. Turbulence inversions occur when a rapidly rising air mass expands and cools more rapidly than the temperature decrease with altitude. This causes an air mass at a given altitude to become colder than the surrounding air, resulting in a temperature inversion due to turbulence.

TABLE A-II. Barometric pressure and temeprature changes with geometric altitude.

(US Standard Atmosphere, 1962.)
(1 torr = 1 mm Hg)

	Pressure			Temperature	
Alt (Feet)	Torr	in.Hg	PSIA	^{o}F	^{o}C
Sea Level	760.00	29.92	14.70	59.0	15.0
500	746.37	29.38	14.43	57.2	14.0
1000	732.93	28.86	14.17	55.4	13.0
1500	719.70	28.33	13.92	53.7	12.0
2000	706.66	27.82	13.66	51.9	11.0
2500	693.81	27.32	13.42	50.1	10.0
3000	681.15	26.82	13.17	48.3	9.1
3500	668.69	26.33	12.93	46.5	8.1
4000	656.40	25.84	12.69	44.7	7.1
4500	644.30	25.37	12.46	43.0	6.1
5000	632.38	24.90	12.23	41.2	5.1
5500	620.65	24.43	12.00	39.4	4.1
6000	609.09	23.98	11.78	37.6	3.1
6500	597.70	23.53	11.56	35.8	2.1
7000	586.49	23.09	11.34	34.0	0 1
7500	576.46	22.66	11.13	32.3	0.1
8000	564.58	22.23	10.92	30.5	0.8
8500	553.88	21.81	10.71	28.7	-1.8
9000	543.34	21.39	10.51	26.9	-2.8
9500	532.97	20.98	10.31	25.1	-3.8
10000	522.75	20.58	10.11	23.4	-4.8
10500	512.70	20.19	9.91	21.6	-5.8
11000	502.80	19.80	9.72	19.8	-6.8
11500	493.06	19.41	9.53	18.0	-7.8
12000	483.48	19.03	9.35	16.2	-8.8
12500	474.04	18.66	9.17	14.5	-9.8
13000	464.76	18.30	8.99	12.7	-10.7
13500	455.62	17.94	8.81	10.9	-1.7
14000	446.63	17.58	8.64	9.1	-2.7
14500	437.79	17.24	8.47	7.3	-13.7
15000	429.08	16.89	8.30	5.5	-14.7
16500	420.52	16.56	8.13	3.8	-16.7
16000	412.10	16.22	7.97	2.0	-16.7

16500	403.82	15.90	7.81	0.2	-17.7
17000	395.67	15.58	7.65	-1.6	-18.7
17500	387.65	15.26	7.50	-3.4	-19.6

TABLE A-II. (CONTINUED)

Pressure Alt(Feet)	Torr	in.Hg	PSIA	Temperature °F	°C
18000	379.77	14.95	7.34	-5.1	-20.6
18500	372.02	14.65	7.19	-6.9	-21.6
19000	364.40	14.35	7.05	-8.7	-22.6
19500	356.90	14.05	6.90	-10.5	-23.6
20000	349.53	13.76	6.76	-12.3	-24.6
20500	342.29	13.48	6.62	-14.0	-25.6
21000	335.17	13.20	6.48	-15.8	-26.6
21500	328.16	12.92	6.35	-17.6	-27.6
22000	321.28	12.65	6.21	-19.4	-28.5
22500	314.51	12.38	6.08	-21.2	-29.5
23000	307.86	12.12	5.96	-22.9	-30.5
23500	301.33	11.86	5.83	-24.7	-31.5
24000	294.91	11.61	5.70	-26.5	-32.5
24500	288.60	11.36	5.58	-28.3	-33.5
25000	282.40	11.12	5.46	-30.0	-34.5
25500	276.31	10.88	5.34	-31.8	-35.5
26000	270.32	10.64	5.23	-33.6	-36.4
26500	264.44	10.41	5.11	-35.4	-37.4
27000	258.67	10.18	5.00	-37.2	-38.4
27500	253.00	9.96	4.89	-38.9	-39.4
28000	247.43	9.74	4.78	-40.7	-40.4
28500	241.96	9.53	4.68	-42.5	-41.4
29000	236.59	9.31	4.57	-44.3	-42.4
29500	231.31	9.11	4.47	-46.1	-43.4
30000	266.13	8.90	4.37	-47.8	-44.4
30500	221.05	8.70	4.27	-49.6	-45.3
31000	216.06	8.51	4.18	-51.4	-46.3
31500	211.16	8.31	4.08	-53.2	-47.3
32000	206.35	8.12	3.99	-54.9	-48.3
32500	201.63	7.94	3.90	-56.7	-49.3
33000	197.00	7.76	3.81	-58.5	-50.3
33500	192.46	7.58	3.72	-60.3	-51.3
34000	188.00	7.40	3.64	-62.1	-52.3
34500	183.62	7.23	3.55	-63.8	-53.2
35000	179.33	7.06	3.47	-65.6	-54.2
36000	170.99	6.73	3.31	-69.2	-56.2
37000	163.00	6.42	3.15	-69.7	-56.5
38000	155.37	6.12	3.00	-69.7	-56.5
39000	148.11	5.83	2.86	-69.7	-56.5

TABLE A-II.(CONTINUED)

Pressure				Temperature	
Alt(Feet)	Torr	in.Hg	PSIA	^{o}F	^{o}C
40000	141.18	5.56	2.73	-69.7	-56.5
41000	134.58	5.30	2.60	-69.7	-56.5
42000	128.29	5.05	2.48	-69.7	-56.5
43000	122.30	4.81	2.36	-69.7	-56.5
44000	116.58	4.59	2.25	-69.7	-56.5
45000	111.13	4.38	2.15	-69.7	-56.5
46000	105.94	4.17	2.05	-69.7	-56.5
47000	100.99	3.98	1.95	-69.7	-56.5
48000	96.27	3.79	1.86	-69.7	-56.5
49000	91.77	3.61	1.77	-69.7	-56.5
50000	87.49	3.44	1.69	-69.7	-56.5
51000	83.40	3.28	1.61	-69.7	-56.5
52000	79.51	3.13	1.54	-69.7	-56.5
53000	75.79	2.98	1.47	-69.7	-56.5
54000	72.25	2.84	1.40	-69.7	-56.5
55000	68.88	2.71	1.33	-69.7	-56.5
56000	65.67	2.59	1.27	-69.7	-56.5
57000	62.60	2.46	1.21	-69.7	-56.5
58000	59.68	2.35	1.15	-69.7	-56.5
59000	56.89	2.24	1.10	-69.7	-56.5
60000	54.24	2.14	1.05	-69.7	-56.5
61000	51.71	2.04	1.00	-69.7	-56.5
62000	49.30	1.94	9.53^{-1}	-69.7	-56.5
63000	47.00	1.85	9.09	-69.7	-56.5
64000	44.80	1.76	8.66	-69.7	-56.5
65000	42.71	1.68	8.26	-69.7	-56.5
66000	40.72	1.60	7.87	-69.6	-56.4
67000	38.82	1.53	7.51	-69.1	-56.1
68000	37.02	1.46	7.16	-68.5	-55.8
69000	35.30	1.39	6.83	-68.0	-55.5
70000	33.66	1.33	6.51	-67.4	-55.2
71000	32.10	1.26	6.21	-66.9	-54.9
72000	30.62	1.21	5.92	-66.3	-54.6
73000	29.20	1.15	5.65^{-1}	-65.8	-54.3
74000	27.86	1.10	5.39	-65.2	-54.0
75000	26.57	1.05	5.14	-64.7	-53.7
76000	25.53	9.98^{-1}	4.90	-64.2	-53.4
77000	24.19	9.52	4.68	-63.6	-53.1
78000	23.08	9.09	4.46	-63.1	-52.8
79000	22.02	8.67	4.26	-62.5	-52.5

TABLE A-II.(CONTINUED)

Pressure				Temperature	
Alt(Feet)	Torr	in.Hg	PSIA	^{o}F	^{o}C
80000	21.01	8.27	4.06	-62.0	-52.2
81000	20.05	7.90	3.88	-61.4	-51.9

82000	19.14	7.54	3.70	-60.9	-51.6
83000	18.27	7.19	3.53	-60.3	-51.3
84000	17.44	6.87	3.37	-59.8	-51.0
85000	16.65	6.55	3.22	-59.3	-50.7
86000	15.89	6.26	3.07	-58.7	-50.4
87000	15.17	5.97	2.93	-58.2	-50.1
88000	14.49	5.70	2.80	-57.6	-49.8
89000	13.83	5.45	2.67	-57.1	-49.5
90000	13.21	5.20	2.55	-56.5	-49.2
91000	12.61	4.97	2.44	-56.0	-48.9
92000	12.05	4.74	2.33	-5.4	-48.6
93000	11.51	4.53	2.22	-54.9	-48.3
94000	10.99	4.33	2.13	-54.4	-48.0
95000	10.50	4.13	2.03	-53.8	-47.7
96000	10.03	3.95	1.94	-53.3	-47.4
97000	9.58	3.77	1.85	-52.7	-47.1
98000	9.15	3.60	1.77	-52.2	-46.8
99000	8.75	3.44	1.69	-51.6	-46.5
100000	8.36	3.29^{-1}	1.62^{-1}	-51.1	-46.2
101000	7.99	3.14	1.54	-50.6	-45.9
102000	7.63	3.01	1.48	-50.0	-45.6
103000	7.29	2.87	1.41	-49.5	-45.3
104000	6.97	2.75	1.35	-48.9	-45.0
105000	6.66	2.62	1.29	-48.4	-44.7
106000	6.37	2.51	1.23	-45.8	-43.1
107000	6.09	2.40	1.18	-45.8	-43.2
108000	5.82	2.29	1.13	-44.3	-42.4
109000	5.57	2.19	1.08	-42.8	-41.6
110000	5.33	2.10	1.03	-41.3	-40.7
120000	3.45	1.36	6.67^{-2}	-26.1	-32.3
130000	2.27	8.92^{-2}	4.38	-10.9	-23.8
140000	1.51	5.95	2.92	+4.3	-15.4
150000	1.02	4.02	1.97	+19.4	-7.0
160000	6.97^{-1}	2.75	1.35	+27.5	-2.5
170000	4.78	1.88	9.23^{-3}	+27.5	-2.5
180000	3.26	1.28	6.31	+18.9	-7.3
190000	2.21	8.70^{-3}	4.27	+8.1	-13.3

TABLE 2-2.(CONTINUED)

	Pressure			Temperature	
Alt(Feet)	Torr	In.Hg	PSIA	^{o}F	^{o}C
200000	1.48	5.85	2.87	-2.7	-19.3
210000	9.85^{-2}	3.88	1.91	-22.0	-30.0
220000	6.41	2.52	1.24	-43.5	-41.9
230000	4.08	1.60	7.88^{-4}	-64.9	-53.9
240000	2.53	9.95^{-4}	4.89	-86.4	-65.8
250000	1.53	6.01	2.95	-107.8	-77.7
260000	8.92^{-3}	3.51	1.73	-129.3	-89.6
270000	5.09	2.00	9.85^{-5}	-134.5	-92.5

280000	2.90^{-3}	1.14^{-4}	5.62^{-5}	-134.5	-92.5
290000	1.66	6.52^{-5}	3.20	-134.5	-92.5
300000	9.49^{-4}	3.74	1.84	-126.8	-88.2
350000	8.52^{-5}	3.35^{-6}	1.65^{-6}	-24.5	-31.4
400000	1.60	6.30^{-7}	3.10	233.9	112.2
450000	6.31^{-6}	2.48	1.22	734.1	390.1
500000	3.50	1.38	6.78^{-8}	1203.8	651.0
600000	1.50	5.92^{-8}	2.91	1647.2	897.3
700000	7.42^{-7}	2.92	1.44	1835.7	1002.1
800000	3.95	1.56	7.64^{-9}	1964.3	1073.5
900000	2.22	8.74^{-9}	4.29	2053.4	1123.0
1000000	1.30	5.13	2.52	2124.6	1162.5
1100000	7.92^{-8}	3.12	1.53	2160.3	1182.4
1200000	4.96	1.95	9.59^{-10}	2189.3	1198.5
1300000	3.19	1.25	6.16	2214.6	1212.5
1400000	2.10	8.25^{-10}	4.05	2217.2	1214.0
1500000	1.40	5.52	2.71	2221.2	1216.2
1600000	9.55^{-9}	3.76	1.85	2232.1	1222.3
1700000	6.61	2.60	1.28	2233.7	1223.1
1800000	4.62	1.82	8.93^{-11}	2232.9	1222.7
1900000	3.26	1.29	6.31	2241.4	1227.4
2000000	2.33	9.17^{-11}	4.50	2250.8	1232.7

A.3.2 Measurement of Altitude

Altitude is expressed in feet above some certain reference point. There are three types of altitude which must be understood.

Pressure Altitude. Altitude above the standard datum plane is called pressure altitude. The standard datum plane is at sea level when "standard conditions" exist; that is, 760 mmHg and +15^{o}C. Pressures shown on the U.S. Standard Atmosphere are pressure altitudes. The human body responds physiologically to pressure altitude.

True Altitude. True altitude is the altitude of an object above mean sea level (MSL). This is the altitude used most frequently in flying aircraft at altitudes below 18,000 feet in the United States. On a standard day the true altitude and pressure altitude are the same. Above 18,000 feet pressure altitudes are flown and referred to as Flight Levels (FL). For example, 25,000 feet is referred to as flight level 250 or FL 250.

Absolute Altitude. Absolute altitude is the distance from the aircraft or space vehicle to the ground directly below it. This altitude is sometimes referred to as tapeline altitude. This value will change as the terrain changes. Expressed as altitude above ground level (AGL), absolute altitude is used to indicate minimum aircraft altitude for ejection or bailout.

A.3.2.1 Physiological Divisions of the Atmosphere

The characteristics and divisions of the atmosphere discussed above describe the physical features of the atmosphere. In the aerospace environment, it is the human's relation to that environment which is of primary concern. It is useful, therefore, to consider physiological

responses at various levels of the atmosphere, and to divide the atmosphere into three physiological zones.

Physiological Zone. The region of the atmosphere to which humans are adapted physiologically extends from sea level to 10,000 feet. The oxygen level within this zone is sufficient to keep a normal, healthy person physiologically fit without the aid of special protective equipment. The changes in pressure encountered with rapid ascents or descents within this zone can produce ear or sinus difficulties.

Physiologically Deficient Zone. This zone extends from 10,000 feet to about 50,000 ft (FL 500). Because of reduced atmospheric pressure, this is the zone in which oxygen deficiency becomes an ever increasing problem. Supplemental oxygen is required when flying above 10,000 feet. Trapped gas in the intestinal tract and evolved gas problems occur within this zone. In addition, protection must be provided against decreasing temperature.

Space-Equivalent Zone. From a physiological viewpoint this 88 zone begins when 50,000 feet is reached since supplemental oxygen (100%), even when supplied under pressure, no longer protects one from the problem of hypoxia. The means of protecting a person above 50,000 feet are such that they will also offer protection in true space (i.e., pressure suits, sealed cabins); hence, the name of this zone is quite applicable. The only additional physiological problems occurring within this zone, which extends from 50,000 feet to 120 miles, are possible radiation effects and the boiling of body fluids in an unprotected individual. Boiling of body fluids will occur when the total barometric pressure is less than the vapor pressure of water at 37^{O}C (47 mmHg) which is reached at 63,500 feet.

A.3.3 PHYSIOLOGY OF RESPIRATION

A.3.3.1 Introduction

The chief purpose of the respiratory process is to supply the lungs and, subsequently, the blood and tissues with adequate oxygen and to eliminate the carbon dioxide that is generated by the metabolism of the body tissues. A homeostatic state is maintained in spite of a wide variety of conditions and activities. Respiration, in conjunction with the renal system, also plays a role in maintaining the acid-base balance of the body within narrow limits under normal environmental conditions. However, in chronic hypoxic environments, the kidney is the major factor in this regard, and is important in the process of altitude acclimatization.

Respiration may be divided into three general categories-namely, the ventilation phase, the transport phase, and the utilization phase. The ventilation phase involves the exchange of gases between the external or ambient atmosphere and the alveolar air, and between the alveolar air and the blood in the pulmonary capillaries. The transport phase depends on an adequate cardiovascular system and on blood constituents for transporting the respiratory gases in adequate quantities between the lungs and tissues. The utilization phase of respiration involves the exchange of gases between the cells of the body and the blood in the tissue capillaries.

A.3.3.2 Ventilation Phase of Respiration

The total volume of air in the lungs (total lung capacity) is subdivided as shown on figure 2-1. These subdivisions are important in the study of pulmonary function in health, in disease, and under abnormal environmental conditions such as pressure breathing. The end of a quiet expiration is the usual reference point when making quantitative measurements of these divisions.

At the end of quiet expiration, the elastic recoil force of the lung is approximately balanced by expansive tendency of the chest wall. It, therefore, is often called the equilibrium point. There are four primary lung volumes as shown in the related illustration. Combinations of two or more primary lung volumes are known as lung capacities. These sometimes reflect the functional compartments of the lung more accurately than do the lung volumes.

The definitions and average normal values, measured in the resting state and at BTPS (gas volume in the lung existing at body temperature and atmospheric pressure and completely saturated with water vapor at body temperature) for the primary lung volumes are as follows:

Tidal volume is the volume of air exchanged in one breath. The resting tidal volume is about 500 ml.

Figure A-1. Standardization of Terms Used in Respiratory Physiology.

Inspiratory reserve volume is rarely referred to since it is quite variable, depending on the amount of the tidal volume. It is the maximum amount of air that can be inspired at the end of a resting inspiration.

Expiratory reserve volume is the maximum amount of air that can be forcibly expired following a normal expiration. The average value is about 1200 ml.

Residual volume is the amount of air remaining in the lungs following a maximum expiratory effort. The average value is about 1200 ml, and constitutes 20 to 25 percent of the total lung capacity.

There are also four major lung capacities:

Total lung capacity is the sum of all four of the primary lung volumes and averages about 6000 ml. Inspiratory capacity is the maximum volume of air that can be inhaled from the end of a quiet expiration (the sum of the tidal volume and inspiratory reserve volume). The average value is about 3600 ml.

Vital capacity is the maximum amount of air that can be exhaled from the lungs following a maximum inspiration. The average value is about 4800 ml. It is the sum of the inspiratory reserve volume, tidal volume, and expiratory reserve volume.

Functional residual capacity is the amount of air remaining in the lungs following a normal tidal expiration.

Measurements of all lung volumes and capacities can be made with a spirometer or special helium dilution techniques. The values given for the lung volumes and capacities are

approximations only. The values are affected by the age, sex, height, and weight of the subject; more accurate values may be calculated for individual subjects by using regression formulas which take these variables into account. When regression formulas are used to predict the normal values, the results are often given as "percent of predicted normal."

Knowledge of pulmonary physiology has increased rapidly in recent years. A significant number of advances have resulted from research associated with aviation physiology. A brief summary of some important concepts follows. The major physiologic functions of the lungs can be grouped under three main headings; namely; ventilation, diffusion, and perfusion:

Ventilation may be defined as the mass movement of air in and out of the lungs, or the process by which alveolar air is periodically mixed with atmospheric air. Adequate ventilation depends upon the creation of a pressure gradient between the alveoli and the external atmosphere by the bellows action of the chest and diaphragm acting upon the lung. The patency of the airways, the integrity of the "respiratory center" in the medulla, the strength of the intercostal and abdominal muscles and the diaphragm, and the elastic characteristics of the lung and thorax systems are important factors in the maintenance of adequate ventilation. In addition, distribution of the inspired gases throughout the lung is of great importance.

The presence of bronchial secretions, bronchiolar narrowing, or masses occluding some of the airways will cause the alveoli to be unevenly ventilated. Some will be normally ventilated or hyperventilated, and others will be under ventilated. Uneven distribution of inspired air may cause the lung to function as a group of compartments, each ventilating at its own rate. For example, about 50 percent of normal people show relatively slow ventilation of a lung compartment equaling 10 to 50 percent of the functional residual capacity. In individuals with severe obstructive emphysema, as much as two-thirds of the functional residual capacity may receive only 10 percent of the total ventilation.

Diffusion of gases across the alveolar-capillary wall refers to the mechanism by which the respiratory gases are transferred from the alveolar air to the blood in the pulmonary capillaries and vice versa. Carbon dioxide diffuses across the alveolar wall about 20 times as rapidly as oxygen. However, the pressure gradient of oxygen across the alveolar membrane is normally about 10 times as great as the pressure gradient of CO_2. The presence of fibrosis, granuloma, edema or exudate in the alveoli or in the alveolar- capillary wall interferes markedly with the process of diffusion and may result in hypoxia or CO_2 retention, or both. Certain types of diffusion abnormalities, such as granulomatous involvement of the alveolar wall in pulmonary sarcoidosis, are referred to as "alveolar-capillary block syndromes."

In diseases leading to abnormalities of diffusion, oxygen diffusion is generally impaired earlier and to a greater degree than is CO_2 diffusion which is due chiefly to the much greater diffusibility of CO_2 across the alveolar- capillary membrane. Thus, by increasing the minute volume of ventilation, normally functioning areas of lung may compensate for CO^2 retention in diseased areas. On the other hand, for end-capillary blood in the pulmonary circulation to become adequately saturated with oxygen, the oxygen must diffuse across the alveolar membrane through the interstitial fluid and the capillary endothelium. Within the capillary, the dissolved oxygen must then diffuse through the plasma, the red blood cell membrane and the intracellular fluid within the red cell to combine with the hemoglobin. Thus, oxygen must diffuse from a gaseous state in the alveoli to a dissolved state within the alveolar membrane and the

pulmonary-capillary tissues and fluids. The solubility of a gas, as well as its partial pressure, greatly influences its diffusion characteristics. Carbon dioxide is about 25 times more soluble than oxygen in pulmonary tissues and fluids and, as indicated above, its capacity for diffusion is about 20 times greater than oxygen.

Perfusion of blood through the lung capillaries is not always uniform even in normal individuals. In various disease states, blood flow through the lung may vary greatly from one area to another. Uneven perfusion of the lungs with blood may become a very serious matter when combined with uneven ventilation of the lung. Some areas of lung may be well-ventilated but poorly perfused. These areas merely increase the dead space and do not contribute to gas exchange. Other areas may be well-perfused but poorly ventilated. These areas act virtually as right-to-left vascular shunts since the blood flowing through them retains its venous character.

Disturbances of ventilation-perfusion relationships may occur during flight when G forces act on the lung during acceleration, causing redistribution of the blood flow to the lungs. For example, during exposure to +Gz forces, the lower lobes would become somewhat engorged. During exposure to -Gz forces, the apical regions would become engorged. Other ventilation- perfusion disturbances can result from pressure breathing.

A.3.3.3 Composition of Respired Air

Dry atmospheric air contains 20.9 percent oxygen, 79.02 percent nitrogen, and 0.03 percent carbon dioxide by volume. Included with the nitrogen are small amounts of rare gases that apparently have no physiological significance. The relative percentage composition of dry atmospheric air does not vary appreciably with altitudes up to 80,000 feet or about 15 miles. Above these altitudes, the percentage of oxygen very gradually decreases and the percentage of the trace gas helium increases slightly because of their molecular weights and the influence of gravity. There are no significant variations with latitude (see Table 2-1).

Quantities of gas at various altitudes expressed in percentages of the atmosphere have little significance, for percentage represents the relative volume of a gas and not its molecular concentration. Since molecular concentration determines the availability of the gas to the body, the actual concentration of any gas is best expressed in terms of partial pressure. The partial pressures of the other gases may be similarly calculated. Table 2-2 summarizes the barometric pressure of the atmosphere at various altitudes.

A.3.3.4 Composition of Pulmonary Air

The atmospheric air that is drawn through the nasal passages into the trachea becomes saturated with water vapor. Furthermore, it mixes with the alveolar air. One must visualize in the alveoli an interface across which gaseous interchange occurs between the air previously present in the alveoli and that which has newly entered. The newly entered air "delivers" oxygen and "receives" carbon dioxide, whereas that already present in the alveoli "receives" oxygen and "yields" carbon dioxide. Therefore, expired air contains less oxygen and more carbon dioxide than does inspired air which normally is essentially free of carbon dioxide. Expired air does not give a true picture of the conditions that exist in the alveoli, since it is a mixture of air from the alveoli and from the dead space. The partial pressure of oxygen in the alveoli determines how much oxygen reaches the blood and tissues. The pressure of oxygen in the

trachea varies with the percentage of oxygen in the inspired air and the barometric pressure, and is given by the following equation:

(1) $P_{TO2} = F_{IO2} (P_B - 47)$, where

P_{TO2} = tracheal oxygen tension in mmHg

F_{IO2} = fraction of inspired oxygen (0.209 for air)

P_B = ambient barometric pressure in mmHg

47 = vapor tension of water in mmHg at 37^oC

The pressure of oxygen in the alveoli also varies with the carbon dioxide tension. The carbon dioxide tension will decrease as the individual begins to hyperventilate with the onset of hypoxia, but the range of variation is small as compared to the extensive changes in alveolar tension. The water vapor in the alveolar air remains constant. The equation for calculating the alveolar oxygen tension, when inspired carbon dioxide is essentially zero, is:

(2) $P_{AO2} = (P_B - 47) F_{IO2} - P_{ACO2} [F_{IO2} + (1 - F_{IO2})/R]$

or

(3) $P_{AO2} = P_{TO2} - P_{ACO2} [F_{IO2} + (1 - F_{IO2})/R]$

where

P_{AO2} = alveolar oxygen tension in mmHg

P_{ACO2} = alveolar carbon dioxide tension in mmHg

R = respiratory exchange ratio (carbon dioxide given off/oxygen taken up)

When R is unity, equations (2) and (3) reduce to:

(4) $P_{AO2} = (P_B - 47) F_{IO2} - P_{ACO2}$

When breathing 100 percent oxygen at any altitude P_{ACO2} is closely approximated by the following equation:

(5) $P_{AO2} = (P_B - 47) - P_{ACO2}$

since oxygen, carbon dioxide and water vapor are the only gases which, for all practical purposes, occupy lung volume. Assuming that nitrogen washed out from the tissues is insignificant compared to oxygen volume. The partial pressures of the gases in the alveoli at sea level and at various altitudes, when breathing air and when breathing 100 percent oxygen, are shown in Table 2-3 which provides a comparison of the equivalent altitudes at which the alveolar gas compositions are essentially the same.

When one is breathing pure oxygen at 33,700 feet, the partial pressure of oxygen in the alveoli is the same as the pressure at sea level when breathing air. Above 34,000 feet, the partial pressure of oxygen in the lungs begins to fall below the pressure at sea level, even though 100 percent oxygen is breathed. At altitudes greater than 40,000 feet, the partial pressure of oxygen decreases rapidly and falls below the limit that maintains the body in a physiologically safe condition.

For the unacclimatized human, an alveolar oxygen tension of less than 50 mmHg is considered as approaching a severe state of hypoxia and an oxygen tension of 30 mmHg is not adequate for supporting consciousness; thus, collapse is imminent. Theoretically, at a barometric pressure of 87 mmHg (50,000 feet), with a normal carbon dioxide tension in the lungs of 40 mmHg plus the water vapor tension of 47 mmHg, even when breathing pure oxygen, the alveolar oxygen tension is reduced to zero and approaches a true state of anoxia. At 63,000 feet where the barometric pressure is 47 mmHg, the lungs are completely filled with water vapor, theoretically, leaving no available room for other gases. Actually, under such a condition as this, not only is there the theoretical tendency for the body fluids and venous blood to boil, but offgassing of all dissolved gases in the venous blood, including oxygen, carbon dioxide, and nitrogen will proceed outward at a vigorous rate through the lungs. This offgassing process becomes most extreme under conditions of a vacuum, such as in space flight conditions where the ambient barometer pressure is essentially zero. The term ebullism has been suggested for this unusual boiling phenomenon and unique medical syndrome. The altitude where ebullism occurs, 63,000 feet, is called Armstrong's line.

TABLE A-III. TABLE OF PULMONARY GASES AT EQUIVALENT ALTITUDES WHEN BREATHING AIR OR PURE OXYGEN

TABLE A-IV. TABLE TRACHEAL PARTIAL PRESSURE (mmHg) OF OXYGEN, PRESSURE BREATHING 100 PERCENT OXYGEN.

Barometric Altitude	Tracheal P_{O2} Breathing Pressure 100% O_2	Tracheal P_O Using Standard	Using Standard

			Air Force Oxygen Equipment	Air Force Oxygen Equipment
40,000	141	94	4-8	98-102
43,000	122	75	11-14	86-89
45,000	111	64	15-18	79-81
48,000	96	49	23	72
50,000	87	40	30	70

At sea level, the combined pressure of P_{CO2} and water is 87 mmHg and occupies 87/760 or 11 percent of the lung volume; oxygen occupies 103/760 or 14 percent; and nitrogen 75 percent. At 18,000 feet, P_{CO2} equals 31 mmHg, P_{H2O} remains 47 mmHg, and barometric pressure is 380 mmHg. At this level (31 + 47)/380 or 21 percent of the lung volume is occupied by carbon dioxide and water vapor. Water vapor alone occupies about 50 percent of the lung volume at an altitude of 47,000 feet and, without hyperventilation at this altitude, less than 15 percent of the volume is available for oxygen.

Between 30,000 and 40,000 feet, the automatic pressure-demand oxygen regulators are designed to deliver 100 percent oxygen under a slight "safety" pressure (3 to 4 mmHg) to prevent inboard mask leakage. At altitudes above 40,000 feet, the positive pressure delivered to the mask increases with increasing altitude, as shown in Table 2-4.

It can be noted that, at 50,000 feet, a positive pressure of about 30 mmHg is transmitted to the mask, resulting in a tracheal P_{O2} of about 70 mmHg, provided there is no excessive mask leakage. This is equivalent to breathing oxygen at 44,000 feet or breathing air at 18,000 feet. In all of these cases a severe degree of hypoxia is being compounded still further at 50,000 feet 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 feet 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 feet.

A.3.3.5 Blood Transport of Oxygen

The oxygen which has diffused from the alveoli is transported by the blood by two different methods: a. as physically dissolved oxygen in the plasma and b. as oxygen chemically combined with the hemoglobin molecules.

Physically dissolved oxygen normally plays a small role in oxygen transport because of its low solubility in the plasma. The solubility coefficient for oxygen in aqueous solutions such as plasma at body temperature is 2.44 ml O_2 per 100 ml plasma per atmosphere (760 mmHg) O_2 pressure. Therefore, at the usual oxygen tension of 95 mmHg in arterial blood only 0.3 ml of oxygen will be dissolved in 100 ml of plasma.

Most of the oxygen is carried in the red blood cells (RBC) in combination with hemoglobin as oxyhemoglobin (HbO_2). Hemoglobin which is not combined with oxygen is called reduced hemoglobin (HHb). One gram of hemoglobin is capable of combining with 1.34 ml of oxygen. In a normal human who has a hemoglobin content of 15 grams per 100 ml, the blood is capable of carrying 20.1 volume percent of oxygen as oxyhemoglobin, in addition to the comparatively small amount dissolved in the plasma. Although hemoglobin is capable of combining with this

amount of oxygen, it does not normally do so because the partial pressure of oxygen in inspired air might not be high enough to result in complete saturation. The extent to which hemoglobin combines with oxygen is usually expressed as the percentage saturation, and is illustrated by the following formula:

Percent oxygen saturation = oxygen content X 100

oxygen capacity

A.3.3.6 Influence of the CO2 Partial Pressure

The carbon dioxide content of the blood exerts a significant influence upon the oxygen dissociation curve (the Bohr effect). An increase in CO_2 shifts the dissociation curve to the right, while a decrease results in a shift to the left. Bancroft demonstrated that this influence of CO_2 is chiefly a consequence of changes in pH and the similar changes can be produced by other acids. The influence of CO_2 on the curve is of considerable physiological significance. In the lung, as CO_2 is released, the curve is shifted to the left so that at a given partial pressure of oxygen, more oxygen combines with hemoglobin. In the systemic capillaries the curve is shifted to the right and, at a given partial pressure of oxygen, more oxygen is released from hemoglobin to diffuse into the tissues.

Figure A-2. Oxygen Dissociation Curves for Human Blood

A.3.3.7 Influence of Temperature

As temperature rises, the curve is shifted to the right. The physiologic value of this effect is realized during exercise wherein the temperature of the active muscles increases, resulting in an increased release of oxygen at any given oxygen partial pressure in the tissues. A decrease in temperature shifts the curve to the left permitting less oxygen to be released from hemoglobin at a given oxygen tension. This temperature effect may have clinical significance in that exposure to cold, especially of certain body regions, may decrease the oxygen supply to the involved tissues, a circumstance which would aggravate any impairment of circulation imposed by a local vascular disorder.

Under physiological conditions with a normal position of the oxyhemoglobin dissociation curve, the arterial blood partial pressure of oxygen is 95 mmHg, it contains about 20.0 volume percent 0_2, and the hemoglobin saturation is approximately 98 percent. At the capillaries, the partial pressure of oxygen in the tissues is less than the arterial partial pressure, resulting in removal first of plasma (dissolved) oxygen to tissue by simple diffusion down the pressure gradient. The loss of plasma oxygen reduces its partial pressure in the plasma; it is released from the hemoglobin since the association of oxygen with hemoglobin depends on the plasma partial pressure. From the hemoglobin, the oxygen diffuses into the plasma and then into the tissues until there is no longer a pressure gradient. The blood entering the pulmonary artery has a P_{O2}

of about 40 mmHg and O_2 content of 14-15 volume percent and is approximately 75 percent saturated. Therefore, there is a drop-off of 5 to 6 ml O_2 per 100 ml of blood from arterial to mixed venous blood.

The amount of oxygen extracted from the blood depends on the metabolic level of the particular tissue. The higher the metabolic rate, the lower the tissue oxygen partial pressure and consequently more oxygen will dissociate from hemoglobin. The effect is potentiated by the effects of pH and the partial pressure of carbon dioxide so that with a decrease in pH, at given tissue oxygen partial pressure more oxygen will dissociate from hemoglobin.

A.3.3.8 Transport of Carbon Dioxide (CO2)

Before the transportation of CO_2 is considered, a review of the fundamentals of acid-base chemistry will be presented. The relative acidity or alkalinity of the blood plays an important role in the maintenance of normal body activity, and the blood CO_2 content is a significant factor regulating the blood acid-base level.

A very small amount, about 5 percent, of the CO_2 presented to the blood is carried in simple solution. Most of the CO_2 is carried as the bicarbonate ion (70 percent) with the remainder (25 percent) in combination with protein (carbamino). Shifting the blood acid-base balance is pathologic in itself; it also changes the slope of the HbO_2 dissociation curve. An excess of bicarbonate would move the HbO_2 curve to the left (curve pH = 7.6 on figure 2-2) and increase the affinity of hemoglobin for oxygen. Conversely, an increase in the carbonic acid component, which results from an increase in the blood partial pressure of CO_2, favors the dissociation of oxygen from hemoglobin (curve pH = 7.2 on figure 2-2). This is a very desirable situation since body tissues are continually producing CO_2 and eliminating it into the bloodstream. It increases the blood CO_2 partial pressure at the capillary tissue level, thereby accelerating the dissociation of oxygen from the Hb and making more oxygen available for diffusion into the tissue.

The association of CO_2 with Hb to form $HbCO_2$ (carbamino hemoglobin) is another important factor influencing the dissociation of oxygen from Hb at the tissue level and making more oxygen available for diffusion into the tissue. A fraction of the CO_2 eliminated by the tissues enters the red blood cell and the following reaction takes place (to the right):

$$CO_2 + HbO_2 \text{ <- -> } HbCO_2 + O_2$$

At the lung level this reaction proceeds to the left. The oxygen diffusing into the blood stream from the alveoli accelerates the dissociation of CO_2 from hemoglobin, thereby enhancing the elimination of carbon dioxide into the lungs. This is called the Haldane effect.

A.3.3.9 Summary of Transport Phase

The relationship between the oxygen dissociation curve, arterial and venous oxygen saturation's, and equivalent altitudes in terms of the alveolar oxygen and carbon dioxide tensions is shown on figure 2-3 where the values from Table 2-3 have been used. The normal oxygen dissociation curve (pH 7.4) indicates the arterial and venous points under sea level

conditions and shows that from arterial (A) to venous blood (V), the saturation decreases to approximately 70 percent with a decrease in oxygen content of about 6 volumes percent. At 20,000 feet while breathing air, or at 45,000 feet while breathing oxygen, the dissociation curve shifts slightly to the left because of the hypoxic hyperventilation which decreases carbon dioxide and increases pH. Here, the arterial saturation (A') is about the same as for venous blood (V) under sea level conditions. To deliver six volumes percent of oxygen to the tissues, blood flow remaining constant, the blood saturation must decrease to almost 40 percent saturation (V') with an oxygen tension of not much more than 20 mmHg. By increasing the blood flow, for example, by doubling the cardiac output, the same quantity of oxygen can be delivered to the tissues with a net effect of decreasing the oxygen content by three volumes percent and raising the venous oxygen saturation and tension to about 55 percent and 26 mmHg, respectively. Both the cardiovascular and ventilatory responses to hypoxia are important compensatory adjustments.

Furthermore, Figure 2-3 shows that, at the critical hypoxia levels above 18,000 feet while breathing air, and at 44,000 feet while breathing oxygen, the arterial saturation points lie on the steep portion of the dissociation curve where the oxygen tensions are between 30 and 40 mmHg. It is in this region of the curve that even a small decrease in the barometric pressure can result in a striking decrease in the arterial oxygen saturation. This is particularly true when breathing pure oxygen above 44,000 feet; each mmHg change in the barometric pressure represents the same change in the oxygen tension, and a change of only 2 to 3 mmHg can be the difference between consciousness and unconsciousness. This same concept holds true when pressure breathing at these or higher altitudes (with a tight or leaky oxygen mask). Under these conditions, every mmHg of oxygen counts, and even a slight drop in the mask pressure will immediately cause the arterial oxygen saturation to slide sharply down the dissociation curve to a dangerously low level. It is interesting to compare this type of situation with a change in altitude from sea level to 10,000 feet while breathing air. In this case, a decrease of 40 mmHg in oxygen tension has only a slight effect on the arterial oxygen saturation which decreases to about 90 percent. This important characteristic permitting humans to function effectively in a fairly broad pressure environment is the very basis for the design of cabin pressurization systems which allow considerable latitude in the selection and control of pressure differentials for the cabin.

A.3.3.10 Gas Exchange in the Tissues

Within the body tissues there is a partial pressure of O_2 less than 30 mmHg and a partial pressure of CO_2 greater than 50 mmHg. The partial pressure of oxygen in the arterial blood is approximately 100 mmHg and the arterial partial pressure of carbon dioxide is approximately 40 mmHg. Because of these pressure differentials, O_2 diffuses across the capillary tissue junction from the blood to the tissues and CO_2 from the tissues to the blood. The mixed venous blood leaving the tissues has a partial pressure of O_2 of 40 mmHg and a partial pressure of CO_2 of 46 mmHg. The HbO_2 dissociation curve indicates that at a partial pressure of O_2 of 40 mmHg, Hb is approximately 75 percent saturated. Therefore, approximately 25 percent of the O_2 carried by Hb in arterial blood was delivered to the tissues. During conditions of severe exercise the venous HbO_2 saturation will drop to values much lower than 75 percent due to the increased oxygen requirements of the body tissues. In such cases of exercise, the increased tissue requirement for oxygen is accommodated for by respiratory and cardiac rates which

increase the minute volume of blood, and therefore, of O_2 presented to the tissues. In addition, greater amounts of O_2 will diffuse into the tissues from the blood because: a. accelerated tissue metabolism and O2 utilization lower the tissue oxygen partial pressure, creating a greater blood-to-tissue pressure differential and b. increased CO_2 formation in the tissues lowers the pH, shifting the oxygen dissociation curve to the right which, in turn, increases the release of oxygen from the hemoglobin.

Figure A-3. Oxygen Dissociation Curves. The figure demonstrates the normal dissociation curve (pH 7.4) and the points on the shifted dissociation curve at various equivalent altitudes, breathing air or oxygen. The volume percent scale is based on a blood oxygen capacity of 20 volumes percent (data from Table 2-3).

TABLE A-V. PHASES OF RESPIRATION	MIXED VENOUS BLOOD	ARTERIAL BLOOD
O2		
Content	14 vol%	19 vol%
Tension	36 mmHg	100 mmHg
Physical Sol	0.1 vol%	0.24 vol%
CO2		
Content	54 vol%	49 vol%
Tension	46 mmHg	40 mmHg
Physical Sol	3.0 vol%	2.5 vol%
Hemoglobin		
Content	15 gram%	15 gram%
Oxy Hgb	70 %	96%
Hgb	30%	4%

A.3.4 CONTROL OF RESPIRATION

A.3.4.1 Neural Control

Physiological Anatomy. The periodic and rhythmic characteristics of respiration are maintained by means of relatively well-defined nervous pathways between the lungs and respiratory muscles and the brain. The seat for this neural control of respiration is located in the medulla oblongata. Within the compact, definitely located segment of the medulla, is the respiratory center; two subcenters or aggregations of nerve cells may be distinguished. These are the inspiratory and expiratory centers. It is believed that the inspiratory center is located caudal to the expiratory center. In the pons are located specialized nerve cells which also influence respiratory activity. This higher center is sometimes referred to as the pneumotaxic center.

Innervating the lungs are branches of the vagus nerve. The fibers of the vagus nerve carry impulses from the lungs to the respiratory center. They enter the brain stem at the level of the medulla. The phrenic nerves, whose fibers originate from cells in third and fourth cervical segments of the spinal cord, propagate impulses form the respiratory center to the diaphragm.

The intercostal nerves carry nerve impulses form the respiratory center to the intercostal muscles via their respective spinal levels.

In addition to the vagus, there are other afferent nerves which influence respiratory activity. These nerves originate in the chemoreceptors of the aorta and carotid artery (see below), in the pneumotaxic center and in higher brain centers.

Physiology. The Hering-Breuer reflex is the classical explanation of the manner in which nervous control of respiration proceeds. This theory has received considerable discussion in texts and is the subject of much controversy. It will be presented here as the most clear-cut, schematic representation available of what actually takes place during the respiratory cycle. The student is cautioned against categorical acceptance of this explanation and is reminded that the Hering-Breuer Reflex is but one segment of the very diagrammatic discussion of the neural control of respiration presented.

Classically, inhalation is initiated by a discharge of the nervous impulses from the inspiratory center via the phrenic and intercostal nerves to the diaphragm and the rib cage. Inflation of the lungs follows, and the resulting distention of stretching the lung excites the vagal nerve endings; impulses are carried by the vagus to the expiratory center. The nerve cells of the expiratory center are excited and impulses are propagated to the nerve cells of the inspiratory center which inhibits the action of the inspiratory center and terminates the discharge of impulse down the phrenic and intercostal nerves. The result is a cessation of inhalation and the initiation of exhalation (Hering-Breuer Reflex). If the vagus nerves are severed, thereby eliminating vagus excitation of the expiratory center, the nerve cells of the inspiratory center will discharge impulses to the higher pneumotaxic center (simultaneously with the nervous discharge down the phrenic and intercostal nerves). The pneumotaxic center relays a series of impulses to the expiratory center. Inhibition of inhalation is accomplished in this case without the influence of the vagus.

Many contemporary authors and investigators consider the following account of the neural control of respiration more plausible and in accord with data obtained from animal experimentation. Under normal conditions of quiet breathing the respiratory movements are regulated by the periodic intrinsic activity of the medullary respiratory center. Inspiratory impulses are set up within the respiratory center. These impulses are propagated by the phrenic and intercostal nerves, thus resulting in inhalation. During the recovery phase of the respiratory center, the propagation of these impulses is minimized and exhalation ensues (it should be noted that there is no direct or positive inhibition of an "inspiratory" center as suggested by the first theory).

After exhalation the respiratory center is again "auto-excited" by circus or cyclic conductance of the impulse within the center; another volley is sent down the phrenic and intercostal nerves and inhalation is repeated. This intrinsic respiratory center activity accounts for the periodicity of respiration. It has been concluded from experimental brain sectioning with animals that the rhythm of respiration is superimposed on the respiratory center by higher centers in the brain. The role of the Hering-Breuer Reflex is limited here to one of tonically maintaining proper respiratory center excitability, i.e., insuring that the respiratory center's threshold is maintained within normal limits (analogous to the maintenance of continuous braking action on the movement of a vehicle so that it will not attain excessive speeds). The respiratory center might

therefore be considered autonomous. However, it is normally influenced by other centers, viz., higher centers (including the "pneumotaxic" center) as mentioned above, and impulses from the chemoreceptors (see below).

It should be noted that, if the respiratory center is depressed directly (by drugs or disturbance in the levels of blood constituents), its activity may be maintained voluntarily (cerebral influence) or by the driving force of other impulses arriving at the center.

A.3.4.2 Chemical Control of Respiration

Variation in the chemical and gas constituents of the blood will effectively alter the respiratory frequency. The most important single factor influencing respiration is the blood CO_2 level. Other factors influencing respiration are the acid-base balance and the O_2 level of the blood. The way in which each of these affects respiration will be considered.

CO_2 Level. It has been realized for quite some time that an increase in the blood CO_2 level will increase the rate and depth of respiration, and that a decrease in the blood CO_2 level will depress respiration. At sea level (and usually up to 10,000 feet) the alveolar partial pressure of CO_2 is relatively constant at 40 mmHg. Any alteration in the alveolar CO_2 tension is an indication of a corresponding change in the blood CO_2 level. Harmful effects are produced on the body if the alveolar partial pressure of CO_2 and, therefore, arterial CO_2 tensions vary from the normal level. If such changes should occur, respiratory rate is immediately altered to restore the proper balance. For example, an increase in alveolar partial pressure of CO_2 of approximately 3 mmHg results in a respiratory rate 2.5 times normal. Respiratory rate is increased in an attempt to eliminate excessive CO_2 and restore the normal level. If the CO_2 level drops, respiratory drive decreases.

The site of CO_2 activity on the respiratory center has not been definitely localized. It is possible that CO_2 may directly excite the nerve cells of the respiratory center, or that CO_2 may excite certain specialized chemoreceptors (nerve endings sensitive to changes in blood gas and acid-base concentrations) in the brain stem (near the roots of the 9th and 10th cranial nerves), which in turn influence the respiratory center. In any event an increase in the CO_2 content of the blood and an increase of spinal fluid H+ ions perfusing the brain, will increase respiration; a decrease will slow it down. Inspired CO_2 in excess of 10 percent may reduce respiratory volume due to an anesthetic effect on the respiratory center.

The blood CO_2 level also has a lesser affect on the respiratory center through the peripheral chemoreceptors is in addition to the direct effect of CO_2 on the respiratory center (see below). An increase in blood CO_2 will thereby stimulate respiration reflexly.

Acid-Base Balance. Alteration of the blood pH will change the slope of the HbO_2 dissociation as indicated on figure 2-2. Blood pH is altered when the CO_2 concentration deviates from normal. When the CO_2 level is raised, there is an increase in the H_2CO_3 (acid) content in relation to the HCO_3- (base) and blood acidity rises. This increase in acidity affects the respiratory center directly, accelerating respiration. Similarly, respiration is depressed when there is a decrease in the blood CO_2 level, and therefore a decrease in blood acidity.

Oxygen level. The respiratory center is influenced reflexly by special nerve endings, and chemoreceptors, located in the aorta and the carotid artery. From these receptor cells nerve

fibers are sent to the medullary respiratory center. Discharge of impulse from the chemoreceptors is increased whenever the arterial O_2 partial pressure of is decreased. Significantly, this reflex drive of the O_2 respiratory center caused by an O_2 deficiency (hypoxia) is the most important factor for the maintenance of respiration during hypoxia. Depression of the blood O_2 level also directly depresses the respiratory center. However, the reflex drive of the chemoreceptors supersedes the central depression during periods of oxygen deficiency and exclusively maintains respiration.

TABLE A-6. SUMMARY OF CHEMICAL CONTROL OF RESPIRATION

Factor	Direct Effect on Respiratory Center	Reflex Effect on Respiratory Center through Chemoreceptors
CO_2 Level	Increased P_{CO2} stimulates respiratory center (when alv. P_{CO2} increases excessively. 60-70 mmHg, CO_2 becomes a depressant. Decreased P_{CO2} depresses respiratory center.	Increased P_{CO2} stimulates respiratory center reflexly.
Acid-Base Balance	Increased acidity due to increased P_{CO2} stimulates respiratory center. Decreased acidity due to decreased P_{CO2} depresses respiratory center. Increased acidity due to other metabolites stimulates respiratory center.	Increased acid stimulates respiratory center reflexly.
O_2 Level	Decrease P_{O2} depresses respiratory center reflexly (predominant drive in hypoxia).	Decreased P_{O2} stimulates

A.3.5 HYPOXIA

Hypoxia in aviation is a syndrome that is a usually acute and results from inadequate oxygenation of tissues secondary to a decreased partial pressure of oxygen in the inspired air.

Anoxia, meaning literally "without oxygen", is sometimes used synonymously with hypoxia, but it is more exact to use the term "hypoxia," for even in cases of acute altitude sickness the tissues are never entirely without oxygen.

A.3.5.1 Classification of Hypoxia

There are generally four different classifications of hypoxia which is defined as oxygen deficiency in the blood, cells, and tissues sufficient to impair function.

Hypoxic hypoxia. Hypoxia is caused by a decrease of the partial pressure of oxygen in the lungs, or by other conditions that reduce the diffusion of oxygen across the alveolar-pulmonary capillary membrane. Hypoxic hypoxia the most common type reported in flying. Specific causes

include:

a. Reduced atmospheric pressure that causes a reduced alveolar partial pressure of oxygen (P_{AO2}).

b. Reduced pulmonary ventilation from any cause.

c. Pneumonia (where the collection of fluid in the alveoli hinders oxygen diffusion across the alveolar-capillary membrane).

d. Obstruction of air passages by tumors or strangulation.

e. Admixture of fully oxygenated blood with venous blood reduces the PO_2 of arterial blood in systemic circulation.

The causes of admixture are arteriovenous shunts, thebesian veins, and congenital cardiovascular defects. As the arterial oxygen tension declines with altitude, cellular delivery of oxygen is reduced. As blood flows through a capillary, the PO_2 continually decreases. Oxygen is supplied to each cell by capillaries and, as oxygen diffuses farther from a capillary, the PO_2 may be reduced to such a low value (approximately 1 mmHg) that aerobic metabolism is inhibited. Where metabolism is reduced, cellular function is depressed, and a tissue unit without oxygen, referred to as a lethal corner, may develop. According to this model the lethal corner would appear first in the cells most distant from the venous end of a capillary.

Hypemic or anemic hypoxia. Hypemic or anemic hypoxia is caused by a reduction in the capacity of the blood to carry a sufficient amount of oxygen because of a decreased hemoglobin content. For example, 1 gram of hemoglobin normally carries 1.34 ml of oxygen, and a normal, healthy human has the capacity to transport 20 volume percent. If the same individual were wounded and the hemoglobin were reduced by one-half due to blood loss, then only 10 volume percent could be transported. In the latter instance there may be insufficient oxygen for the tissues although the blood is fully saturated with oxygen and no cyanosis is present. For cyanosis to occur, over 5 grams of reduced hemoglobin per 100 ml of blood must be present in the capillaries of the skin. Carbon monoxide, nitrates, sulfa drugs, etc., cause the same type of hypoxia by forming stable compounds with hemoglobin and reducing the amount of hemoglobin available to form oxyhemoglobin.

Histotoxic hypoxia. Histotoxic hypoxia ensues when the utilization of oxygen by the body tissues is hindered. Alcohol, narcotics and certain poisons such as cyanide interfere with the ability of the cells to make use of the oxygen available to them, although the supply is normal in all respects. During histotoxic hypoxia, the venous HbO_2 saturation is higher than normal because the oxygen is not being unloaded to the tissues since they are unable to metabolize the delivered oxygen.

Stagnant hypoxia. Stagnant hypoxia is due to a malfunction of the circulatory system which reduces blood flow through a tissue. While the oxygen-carrying capacity of the blood is adequate, there is an inadequate circulation of the blood. Such conditions as heart failure, arterial spasm, occlusion of a blood vessel, and the venous pooling encountered during positive G maneuvers and pressure breathing would predispose to stagnant hypoxia.

It is evident that all these forms of hypoxia may become problems in flight; but the most frequent and important type of hypoxia encountered in aviation is that caused by breathing air

with a low partial pressure of oxygen.

A.3.5.2 Factors Influencing Hypoxia

The appearance of the signs and the severity of the symptoms of acute hypoxic hypoxia depend on the following variables:

a. Altitude.

b. Rate of ascent.

c. Duration at altitude.

d. Ambient temperature.

e. Physical activity.

f. Individual factors:

1. Inherent tolerance.
2. Physical fitness.
3. Emotional state.
4. Acclimatization.

A high surrounding temperature and physical exertion favor the development of symptoms at lower altitudes. Physical fitness and acclimatization from residence at high altitude raise an individual's "ceiling", while apprehension and lack of adequate physiological compensation by the respiratory and circulatory systems lower it.

A.3.5.3 Stages of Hypoxia

For convenience, the symptomatology of hypoxia may be divided into stages related to the approximate pressure, the altitudes, and the oxygen saturations of the blood. As shown in table 2-6 the stages of hypoxia are:

Indifferent Stage. The only adverse effect is on dark adaptation, which is manifest at altitudes as low as 5,000 feet. It emphasizes the need for oxygen from the ground up during night flights especially in the case of fighter pilots. Electrocardiographic changes may occur at altitudes as low as 5,000 feet; there is also an increase in pulse rate and a slight increase in alveolar ventilation.

Compensatory Stage. Physiological compensations may provide some defense against hypoxia so that effects are latent unless the exposure is prolonged, or unless exercise is undertaken. Respiration may increase in depth or slightly in rate. Cardiac output increases.

Disturbance Stage. In this stage, the physiological compensations do not suffice to provide adequate oxygen for the tissues; latent oxygen want becomes manifest. Subjective symptoms may include fatigue, lassitude, somnolence, dizziness, headache, breathlessness, and euphoria. Occasionally there are no subjective sensations up to the time of unconsciousness. The effect on systems is:

a. Special Senses. Both the peripheral and central vision are impaired and visual acuity is diminished. Extraocular muscles are weak and uncoordinated, and the range of accommodation is decreased. Touch and pain are diminished or lost. Hearing is one of the last senses to be impaired or lost.

b. Mental Processes. Intellectual impairment is an early sign which makes it impossible for individuals to comprehend their own disability. Thinking is slow, and calculations are unreliable. Memory is faulty, particularly for events in the immediate past. Judgment is also poor. Reaction time is delayed.

c. Personality Traits. There may be a release of basic personality traits and emotions as with alcoholic intoxication. There may be euphoria, elation, pugnaciousness, overconfidence, or moroseness.

d. Psychomotor Functions. Muscular coordination is decreased, and delicate or fine muscular movements may be impossible resulting stammering, illegible handwriting, and poor coordination in aerobatics and in formation flying.

e. Hyperventilation Symptoms. (See section on hyperventilation).

Cyanosis. The color of the skin becomes bluish from the reduction of hemoglobin in the capillaries.

TABLE A-7. STAGES OF HYPOXIA

Stage	Altitude in Feet		Arterial O2
	Breathing Air	Breathing 100% O2	Saturation (%)
Indifferent	0 to 10,000	34,000 to 39,000	95 to 90
Compensatory	10,000 to 15,000	39,000 to 42,500	90 to 80
Disturbance	15,000 to 20,000	42,500 to 44,800	80 to 70
Critical	20,000 to 23,000	44,800 to 45,500	70 to 60

Critical Stage. This is the loss of consciousness stage. It may be the result of circulatory failure ("fainter") or a central nervous system failure ("nonfainter," unconsciousness with maintenance of blood pressure). The former is more common with prolonged hypoxia, the latter with acute hypoxia. With either type there may be convulsions and eventual failure of the respiratory center.

A.3.5.4 Time of Useful Consciousness

Time of useful consciousness (TUC) is the period of time from the interruption of the oxygen supply or exposure to an oxygen-poor environment, to the time when useful function is lost. The individual is no longer capable of taking proper corrective and protective action. It is not the time to total unconsciousness. Table 2-8 reflects various altitudes with the corresponding average TUC. These times have been established from observations over a period of years.

These TUCs are for an individual at rest. Any exercise will reduce the time considerably. For example, usually upon exposure to hypoxia at FL 250, an average individual has a TUC of 3 to 5 minutes. The same individual, after performing 10 deep knee bends, will have a TUC in the range of 1 to 1.5 minutes. Although the times in Table 2-8 are often called average TUCs, an average failure is meaningless to a person who has a shorter TUC. There are many individual variations, and there will be variations in the same person. At the higher altitudes, the TUC becomes very short. The danger of hypoxia at high altitude is evident, and the emphasis is on prevention rather than cure.

TABLE A-8. TIMES OF USEFUL CONSCIOUSNESS

Altitude	Time of Useful Consciousness
FL 180	20 to 30 Min
FL 220	10 Min
FL 250	3 to 5 Min
FL 280	2.5 to 3 Min
FL 300	1 to 2 Min
FL 350	0.5 to 1 Min
FL 400	1.5 to 20 Min
FL 430	9 to 12 Sec
FL 500 and above	9 to 12 Sec

A rapid decompression can reduce the TUC by up to 50 percent caused by the forced exhalation of the lungs during decompression and the extremely rapid rate of ascent. The TUC has also been called Effective Performance Time (EPT). It is defined as the amount of time an individual is able to perform flying duties efficiently in an environment of inadequate oxygen supply.

A.3.5.5 Symptoms of Hypoxia

The crew members' last line of defense against incapacitation from altitude hypoxia, regardless of its cause (mechanical failure of pressurization or other equipment, etc.), is to recognize their own symptoms of exposure to hypoxia. Chamber flights permit students to experience and identify their individual symptoms of hypoxia under safe and controlled conditions. Individuals will experience their own symptoms or combination of symptoms, which will vary with age, physical condition, temperature, and the degree of apprehension. Once experienced, these symptoms of hypoxia can be classified as either objective signs perceived by the observer, or subjective symptoms perceived by the subject. In some cases, a particular reaction may be noticed by both the subject and the observer.

Objective Signs. Although not all signs are recognized by the subject, they can often be recognized by a chamber observer. These signs include an increase in rate or depth (or both) of respiration, cyanosis, mental confusion, poor judgment, loss of muscle coordination, and unconsciousness. At times they may be noted by the subject and the observer. Behavioral changes, such as an exceptional feeling of well-being or belligerence, may be noticed by the

hypoxic individual and by the observer.

Subjective Symptoms. The warning signals most important to the aircrew member are those that can actually be sensed and identified. These symptoms are emphasized as a means to recognize hypoxia during demonstrations in the chamber or during aircraft flight. Subjective symptoms that have been reported are air hunger or oxygen want, a feeling of apprehension, headache, dizziness, fatigue, nausea, hot and cold flashes, blurred vision, tunnel vision, tingling, and numbness. Euphoria and belligerence might be noticed by the subject. Experiencing and remembering these symptoms in the hypobaric chamber should provide for the crew member a basis for recognizing hypoxia if it happens to the crew member in an aircraft.

Individual variation in the ability to withstand hypoxia is considerable and accounts for variations in "ceiling." A large part of the tolerance is based on the adequacy of physiological adjustments, especially in breathing. The immediate result of deeper breathing is an increase of partial pressure of oxygen in the lungs and increased alkalinity of the blood. The latter favors uptake of oxygen by the hemoglobin. At such extreme altitudes as 40,000 feet, where 100 percent oxygen must be breathed, the total pressure in the alveoli equals the sum of the partial pressures exerted by water vapor, carbon dioxide and oxygen. (The pressure of the water vapor is relatively constant, tending to correspond to a saturated state of 37^{O}C). Consequently, lowering of the partial pressure of carbon dioxide such as occurs in deep breathing will increase the partial pressure of oxygen in the lungs by an approximately equivalent amount.

Inexperienced personnel collapse more frequently at intermediate altitudes than do experienced individuals. The factors involved in such collapse are primarily psychogenic. The hyperventilation produced by hypoxia ordinarily lowers alveolar carbon dioxide enough to produce only minor symptoms such as dizziness, but it could have more serious effects. However, an individual who is apprehensive may hyperventilate to a greater extent and produce a degree of hypocapnia associated with more marked symptoms. Such hypocapnia, added to the splanchnic vasodilatation, which is a not-infrequent response to fear, may bring about collapse.

A.3.5.6 Prophylaxis and Treatment of Hypoxic Hypoxia

The treatment for hypoxia consists in giving 100 percent oxygen by inhalation. If respiration has ceased, artificial respiration along with simultaneous use of 100 percent oxygen is indicated. If peripheral circulatory failure persists, the type must be determined and treated accordingly.

Instruction in the proper use of United States Air Force oxygen equipment is imperative. The principal types of oxygen equipment are described and illustrated in a later section.

Recovery from hypoxia is rapid when sufficient oxygen is supplied. An individual on the threshold of unconsciousness may regain full faculties within 15 seconds after receiving an abundance of oxygen. Experience has shown that if a hypoxic patient breathes deeply of oxygen, a flash of dizziness may occasionally be experienced, but this phase passes immediately followed by complete restoration of normal function. Performance, however, can be impaired for one to two hours after severe hypoxia.

A.3.6 Pressure Breathing

Though most high performance aircraft are pressurized, there are times when cabin pressure is lost and the body is exposed to decreased barometric pressure. Above FL 400, gut gas expansion is prevalent, and problems may arise (see later under Cabin Depressurization). Decompression sickness is also possible, even if descent begins immediately upon declaring an inflight emergency.

Hypoxia, however, is the primary acute threat that is of concern and for which protective steps must be taken. To prevent the occurrence of hypoxia above FL 400 feet, some method of increasing the partial pressure of alveolar oxygen must be used. One method is positive pressure breathing (PPB) by using an oxygen system that delivers 100 percent oxygen at greater than ambient pressures. Special pressure breathing equipment is required.

PPB Requirement. PPB as a means of protection against the hypoxia associated with exposure above FL 400 feet is a well-established technique. Its delivery as an emergency procedure during acute, unintentional exposures to high altitude is routine in military air forces throughout the world. The technique has also been adopted for use by flight deck crews in civilian supersonic aircraft. Recently, the acronym "PBA" has come into common usage when describing pressure breathing for altitude protection in contradistinction to the newer technique of pressure breathing for acceleration (G) protection (PBG).

At altitudes above FL 400, 100% oxygen under continuous positive pressure must be delivered in order to prevent hypoxia. In order to maintain total pressure within the lungs at the minimum acceptable level, i.e., at 141 mmHg (FL 400 equivalent), the magnitude of PPB delivered must increase progressively with altitude. For example, at FL 450 where PB = 111 mmHg, P_{AO2} = 39 mmHg, P_{AH2O} = 47 mmHg, and P_{ACO2} = 25 mmHg, a positive pressure of 30 mmHg [141 - (39 + 47 + 25)] is required. Even higher levels of pressure breathing are needed as altitude further increases.

Pressure breathing is not without considerable physiologic penalties of its own, however, and at very high altitudes the level of pressure required to completely prevent hypoxia must be balanced against the potential disadvantages of the pressure. In other words, a compromise must be reached between the magnitude of pressure breathing which is physiologically tolerable and an acceptable degree of hypoxia. For example, a positive pressure of 30 mmHg may be regarded as adequate at FL 500 where PB = 87.3 mmHg. A total alveolar pressure of only 117.3 mmHg would exist in this circumstance.

Physiologic Effects of PPB. The physiologic effects of PPB have been extensively investigated and are well-documented in standard aviation medicine texts. Of primary importance are the effects on the respiratory system, the cardiovascular system, and the head and neck.

Respiratory Effects. In continuous PPB the act of breathing becomes more difficult at increasingly higher pressures. The normal phenomena of active inspiration and passive expiration must be changed to a passive inspiration and a very active expiration.

In clinical settings, intermittent PPB partially compensates for this change in breathing mechanics by using a regulator which delivers oxygen under pressure only during inspiration. Both inspiration and expiration become passive phenomena. This quite commonly leads to a symptomatic hyperventilation, which would be a major disadvantage of intermittent PPB if used

in operational flight.

The mean mask oxygen pressure must always be discussed when considering pressure breathing. Mean mask oxygen pressure refers to the average pressure of oxygen at the mask over one complete respiratory cycle. The highest pressure offers the best physiological protection against hypoxic hypoxia. Continuous PPB delivers a mask oxygen pressure nearly equivalent to the pressure delivered by the regulator. Intermittent PPB delivers only one-third to one-half the peak mask pressure. Therefore, the highest mean mask oxygen pressure is obtained with continuous positive pressure breathing.

The efficiency with which the continuous positive pressure can be accepted also depends on the subjective response. If a rapid inspiration is followed by a prolonged expiration, the mean mask oxygen pressure is somewhat higher. There is also an increase in the intrathoracic pressure. This pressure increase restricts the normal flow of blood through the lungs and results in an increased venous pressure.

If the breathing pattern is changed to a prolonged inspiration followed by a rapid expiration, the mean mask pressure of oxygen is slightly lowered but the average intrathoracic pressure is considerably reduced. This latter condition allows higher pressures of oxygen to be used without compromising lung blood flow. With pressures from 15-30 mmHg (8-15 inches H_2O pressure), pressure breathing can be continued for a limited period.

With pressures above 30 mmHg, it has been shown that, besides fatigue, other symptoms may occur. Subjects commonly complain of being over inflated, and a concurrent feeling of congestion occurs in the region of the frontal sinuses. At even higher pressures, pain may occur in the ears and in the posterior pharynx, as a result of over distension.

When attempts are made to pressure breathe at 60 mmHg pain in the posterior pharynx is commonly the cause for termination. At pressures between 60 and 100 mmHg there is a likelihood of parenchymal lung damage secondary to over expansion, unless counter pressure is applied.

PP. normally causes dissension of the chest and lungs. The latter are fully distended at a pressure of 20 mmHg and require support by chest counter pressure (CCP) garments when the pressure reaches 80-100 mmHg. Over distension can be prevented by training in the breathing technique. Nevertheless, there is a tendency for inspiratory reserve volume to fall and expiratory reserve volume to rise.

Pulmonary ventilation may increase by 50% when breathing at a pressure of 30 mmHg. There is also an exaggeration of the ventilation-perfusion (V/Q) mismatch normally seen in the upright lung. Consequently, a fall in total pulmonary blood flow causes a generalized under perfusion of the alveoli throughout the lung. Pulmonary artery pressure rises to a lesser degree than intrathoracic pressure. The result is a greater decrease in perfusion normally seen at the lung apices, i.e., there is an increase in alveolar dead-space. PPB also causes a fall in carbon dioxide tension as a result of true hyperventilation, although this can be minimized by training.

Cardiovascular Effects. The cardiovascular effects of PPB depend upon the magnitude of positive pressure and the time during which it is delivered. The initial effect is peripheral pooling of blood. The rise in intrapleural pressure, which equals the breathing pressure less lung elastic recoil, is transmitted to the great vessels and causes a rise in central venous pressure. Venous

return from the limbs to the chest is reduced and may stop almost completely, though cerebral and abdominal return is maintained. Peripheral vascular distension occurs and blood pools in the limbs until the peripheral venous pressure exceeds the elevated central venous pressure. This usually occurs 10-20 seconds after pressure breathing starts, and flow from the limbs is re-established.

The amount of peripheral blood pooling which occurs is directly related to the degree of PPB. For example, approximately 200 ml pools at a pressure of 30 mmHg, while about 400 ml pools at a pressure of 80 mmHg. This reduction in circulating blood volume occurs as a result not only of blood pooling, but also extravasation (leaking) when peripheral venous and capillary pressures rise.

PPB at a pressure of 30 mmHg for ten minutes causes extravasation of about 250 ml of circulating fluid into the tissues. A total decrease in effective blood volume that occurs is equivalent to a hemorrhage (about 450 ml). Extravasation and pooling eventually lead to circulatory collapse if pressure breathing continues and no additional protection is provided. Pooling and extravasation can be minimized by the application of lower limb counter pressure.

Cardiac output is usually maintained at an adequate level, although it may decrease by about 30% when pressure breathing at 30 mmHg. Circulatory collapse may occur when there is a loss of peripheral arteriolar tone. Before collapse occurs, tachycardia and a gradual fall in blood pressure usually precede profound bradycardia and a precipitate fall in blood pressure. Such a collapse is akin to a simple syncope of the sort associated with pain or hemorrhage, and has the same clinical features.

Effects on the Head and Neck. PPB may cause spasm of the eyelids as the lachrymal ducts are pressurized. Distension of the upper respiratory tract frequently causes difficulty with speech and swallowing, and is distinctly uncomfortable at pressures greater than 70 mmHg. A significant rise in intravascular pressure can produce conjunctival hemorrhage.

A.3.6.1 PPB and Counter Pressure Garments

PPB for Altitude Protection. It is as an attempt to minimize the potentially harmful physiologic effects of PPB that counter pressure (partial pressure) garments may be employed to support the chest, abdomen and limbs. This is otherwise known as Balanced, or Assisted PPB (APPB). The partial pressure assemblies become more elaborate the higher the altitude and PPB level to which the aircrew may be exposed. For example, a pressure-sealing oro-nasal mask without counter pressure garments is suitable for use at pressures up to 30 mmHg, and is well-tolerated without additional support. Yet, when it is used in conjunction with a partial pressure jerkin (PPJ), a maximum pressure of 60 mmHg can be tolerated. Furthermore, when it is combined with a G-suit, it allows 70 mmHg to be tolerated, although head and neck discomfort are very noticeable.

At even greater pressures up to 100 mmHg, severe head and neck discomfort dictates the need for a partial pressure helmet, together with a sleeved PPJ and G-suit. Such an assembly is needed to apply breathing pressure not only to the respiratory tract, but also counter pressure to the ears, the neck and the floor of the mouth. The effective upper limit for PPB for altitude protection is about 100 mmHg. If exposure is to occur to altitudes at which delivery of higher pressures is required, a pressure suit must be worn.

It is important to note that a direct pneumatic connection must link the chest counter pressure garment to the mask. Pressure must always be available in the former when the latter is receiving pressure. One must also understand that PPB for altitude protection is an emergency procedure only. The physiologic acceptability of such protection is predicated on the assumption that descent to a safer altitude must be initiated immediately after an emergency occurs.

PPB for Acceleration Protection. The proposed use of PPB as a routine technique for acceleration protection has necessarily prompted a review of the technicalities of the procedure. The use of an inflated G-suit in order to prevent peripheral pooling of blood is obviously required. Evidence from centrifuge studies and flight trials indicates that the additional use of chest counter pressure and automatic mask tensioning provides improved comfort and efficiency. Other studies have shown that the maximum breathing pressure required to achieve the desired improvement in G tolerance is 55 - 65 mmHg at +9 Gz.

The routine use of counter pressure however, has prompted a reconsideration of the design of the garment. Thus, for the Tactical Life Support System (TLSS) and its derivatives for Combat Edge and the ATF, current garments are considered heavy and bulky. Though they are acceptable for emergency use at very high altitude, these garments are being replaced by a vest which covers only the chest and upper back. For altitude protection, the loss of counter pressure over the abdomen and lower back is remedied by increasing the bladder coverage of the G-suit and by the application of increased pressure within the bladder at three or four times the breathing/CCP garment pressure. For G protection, conventional inflation of the G-suit with a larger abdominal bladder is determined by the characteristics of the anti-g valve.

A.3.6.2 High Altitude Limits and Protection

Therefore, to have flights of any duration above FL 400 it is necessary to pressurize the person either in a pressurized cabin or by means of a counter pressure suit. According to USAF flying regulations, it is not permissible to fly above FL 500 regardless of cabin altitude unless the subject is protected by a pressure suit. Further, unpressurized flight is not authorized at cabin altitudes above FL 250.

One big disadvantage of pressurized cabins is that a sudden loss of pressure, due to mechanical defects or damage by gunfire, may subject the pilot or crew to a rapid decompression above the critical altitude at which pure oxygen is sufficient to sustain life. Between FL 400 and FL 500, pressure breathing regulators supply enough pressure to the individual to remain conscious until an immediate emergency descent can be made.

Above FL 500, pressure breathing is of little value since it is impossible to tolerate the amount of positive pressure necessary to prevent severe hypoxia without counter pressure. It is for this reason that all individuals flying in aircraft above FL 500 are required to wear a counter pressure suit. These suits must inflate automatically in the event of a loss of cabin pressurization.

The likelihood of sudden exposure to "critical altitudes" necessitates familiarity with the use of oxygen equipment and current pressure suits, since even under the most favorable conditions, only 15 to 20 seconds may elapse between the time of the decompression and loss of consciousness. Figure 2-4 shows the times of consciousness with varying types of exposure at

high altitudes.

Pressure Suits. The protection given by oxygen regulators and oxygen masks is sufficient for the operational and emergency altitudes established for the various types of oxygen delivery systems. The limiting factor for sustained flight at, and above, FL 500 is primarily an individual's respiratory and circulatory physiology, rather than technology to develop oxygen regulators and masks. As the flight altitude is extended beyond FL 430, the necessity for breathing 100 percent oxygen at increasingly higher pressures becomes critical. The flyer cannot tolerate the elevated breathing pressures for an extended period of time, because the normal function of respiration and circulation become seriously impaired.

Figure A-4. Time of Consciousness with Varying Types of Exposure at High Altitude. A- TUC after rapid decompression on oxygen. B- TUC after turning off oxygen at altitude. C- TUC after rapid decompression on air.

The need for pressure suits, then, arises primarily because of the hypoxia threat. A plane may ascend to a high altitude above FL 500 and the aircrew needs backup protection for the pressurization system, or sustained flight at very high altitudes causes an excessively high cabin altitude because of limitations in pressure ratio and compression temperature (discussed later under Aircraft Pressurization).

Design Criteria. Pressure suits are designed to embody three primary considerations: protection, mobility, and comfort. The basic protection provided by a pressure suit is the prevention of hypoxia. High breathing pressures can be tolerated in a pressure suit because of the counterbalance effect of the pressure suit and helmet. Counter pressure may be achieved by using a pressure suit that applies a mechanical squeeze force on the flyer's body, or by surrounding the body with a pressurized gas envelope.

Some pressure suits are specially designed to guard against thermal extremes encountered in the flying or survival environments, while others may offer minimal protection. Pressure suits do not protect against decompression sickness or the effects of trapped gases in the body. Current pressure suit technology does not provide absolute or total protection without compromising the important design criteria of mobility and comfort.

The aircrew member whose mission demands sustained flight above FL 500 is relatively secure in the aircraft pressurized cabin, and receives breathing oxygen at a very slight positive pressure within a specially constructed helmet. The pressure suit is basically inactive, or depressurized, and the crew member can move the body, arms, and legs with comparative ease. If the cabin decompresses, the flyer is immediately subjected to all of the environmental stresses of the actual pressure altitude. However, the pressure suit assembly pressurizes almost instantaneously, and the crew member is again safe.

Freedom of movement is moderately or severely impaired by the pressurized suit assembly. The degree of mobility the flyer has depends upon the type of pressure suit assembly in use, and the pressure altitude to which it is exposed. Proper suit size, adequate sizing adjustments, and equipment familiarity through training are important factors that contribute to optimum mobility required to perform flight duties. Finite movements of the arms and gloved hands are

difficult, even for the experienced flyer. This is due to the rigidity or constraining force of the protection it must provide.

Comfort of the flyer is of primary importance when considering the design and use of any item of protective equipment. Pressure suit assemblies pose some special problems concerning thermal stress, body water balance, impaired circulation, fatigue, cramps, and general discomfort.

The earlier designs of pressure suit assemblies that applied mechanical counter pressure directly to the surface of the body were subjectively less restricting to movement, but caused superficial skin discomfort due to the pressure or pinching exerted by seams and adjustment lacings. When pressurized for long periods of time, these assemblies also reduced peripheral circulation of blood, caused tingling sensations on the body, and contributed to muscle cramps. Modifications have partially corrected these problems.

Pressure suits that cover the entire body in a virtually airtight enclosure cause an accumulation of body heat and profuse sweating unless some method of cooling is provided. Heat removal is generally accomplished by convection. Cooling air or oxygen is introduced into the suit assembly and then exhausted to the outside of the suit. Fluids for drinking are obtained by inserting tubes through a specially designed orifice in the helmet visor or shell, and thereby maintain body hydration.

Types of Pressure Suits. The two basic types of pressure suits are the partial pressure suit and full pressure suit. The former applies counter pressure directly to the body surface by means of mechanical squeeze, and the latter by surrounding the body with an envelope of air or oxygen.

Partial Pressure Suits. The development of this series of suits began in 1947, and they are called partial pressure suits because counter pressure is applied only to the legs, torso, arms, and hands. The helmet, which seals around the neck of the user, provides breathing oxygen and pneumatic counter pressure surrounding the entire head.

The partial pressure suit is virtually form-fitting and applies direct counter pressure when the aircraft cabin altitude exceeds FL 400. The variable squeeze effect is produced by means of inflatable capstans, which extend down the back and along the arms and legs. These tubes are attached to the suit by means of crossing tapes. The diameter of the capstan is approximately one- fifth the diameter of the area it protects. Therefore, the pressure introduced into the capstan must be five times the desired resultant pressure on the body. The objective is to supply the amount of counter pressure that will just balance the breathing pressure necessary to prevent hypoxia at a given altitude.

For example, if breathing pressure of 100 mmHg, or approximately 2 PSI, is required, it is balanced by a counter pressure of 2 PSI, obtained by applying a pressure of 10 PSI to the capstan. Capstan pressures and breathing oxygen are delivered to the suit by means of a dual function oxygen regulator located in the seat kit of the aircraft. Partial pressure suits are in limited use.

Full Pressure Suits. The first operational full pressure suit was produced for the U.S. Navy during the 1950's, and has been succeeded by a number of other specially designed models. The full pressure suit, helmet, and gloves surround the body with a pressurized gas envelope to provide counter pressure usually when the aircraft cabin altitude exceeds FL 350.

Since the flyer is completely within the suit assembly, counter pressure and oxygen breathing pressure are metered at a ratio of approximately 1:1. Most full pressure suits are unpressurized until the cabin altitude exceeds FL 350.

When the cabin altitude exceeds FL 350, a suit-mounted controller senses the decreasing pressure and automatically causes the suit to inflate to a given pressure which, when added to the ambient pressure at that altitude, equals about 3.4 psia (FL 350 equivalent). Therefore, a flyer wearing a full pressure suit is never exposed to a pressure altitude greater than FL 350, regardless of aircraft altitude.

High Altitude Reconnaissance Mission (HARM) Support. This support consists of specialized physiological training, life support training, survival continuation training, pressure suit maintenance, survival kit maintenance, preflight inspection of pressure suits, survival kits, and parachutes, aircrew integration into the pressure suit and cockpit, and recovery of the aircrew member. This specialized support is provided by Aerospace Physiologists (9166), rated Aerospace Physiologists (1495A), Aerospace Physiology Technicians (911X0), Life Support Specialists (122X0), Survival Instructor Specialists (P122X0), and some civilians. Administrative Specialists and Supply Specialists also provide key support.

Physiological Support Division (PSD). This is an organization composed of the specialty codes listed above which directly support day-to-day HARMs. The special life support requirements and physiological stresses encountered by these operational aircrew are addressed by special aerospace physiology training units. These units are called physiological support divisions.

PSD personnel ensure that aircrews are dressed, tested, and denitrogenated on 100 percent oxygen for 60 minutes prior to takeoff for U-2/TR-1 high flights. The equipment and supplies managed and cared for by PSD personnel consists of many different components. Some of these are simple and some are complex and require a considerable amount of training to care for and maintain. Maintenance of this equipment is the most labor intensive and time consuming portion of PSD operations.

The following is a listing of this life support equipment and supplies. The functions of these items are described, and are related to the day-to-day activities of physiological support operations.

Special Modified Underwear. Each U-2 and TR-1 aircrew member is supplied modified long cotton underwear, modified jockey briefs, thin nylon or cotton gloves and wool socks. The underwear modification consists of a hole cut out in the front of the bottoms to accompany a condom shaped urine collection device (UCD). The hole is surrounded by the soft part of velcro. This holds the UCD in place. If a UCD is not worn, then a patch is placed on the hole. This underwear is washed, dried, sorted and placed in the aircrew's locker by PSD personnel.

Urine Collection Device (UCD) for males. This is a neoprene rubber device that is cylindrical in shape, measuring about 8 inches long and 1.75 inches in diameter. The UCD has a cone shaped portion that is trimmed for size by the aircrew member to fit comfortably on the penis. It is then held in place by the modified underwear. There is a hole positioned on the top of the UCD to allow air from a slightly pressurized pressure suit to enter and then pass out the front of the UCD through a tube. It then passes through the pressure suit at the UCD valve and into a tube which leads to a urine collection tank or a urine collection sponge device. This piece

of personal equipment is washed and maintained by the aircrew member.

Full Pressure Suit Assembly. The full pressure assembly comes in twelve sizes and can be fine tuned in size through lace adjustments on the legs, arms, and torso. Each aircrew member is issued two pressure suit assemblies, called a S1030 or S1031, but only one helmet. This assembly has a comfort layer that is held in place by velcro and is periodically removed and washed. The fire retardant outer cover is a treated material called fypro. This cover is removed occasionally and washed. The aircrew's primary suit undergoes a 25 minute preflight check and the back-up suit is given a cursory inspection prior to each high flight. A periodic inspection is conducted every 120 days, 125 flight hours, or 20 donnings.

The inspection is extensive and takes about four hours to complete. Each suit is overhauled annually. This entails an extensive breakdown of the suit, an 8 PSI stress test, replacement of worn parts, and replacement of diaphragms. Re-calibrations of various functions of the dual oxygen regulator and suit pressure controller are also necessary. The overhaul of these two pieces of hardware is very delicate work and requires a highly trained and skilled PSD technician. Maintaining the neck ring can be quite time consuming due to the approximate 122 ball bearings and nylon spacers that have to be removed, cleaned, and re-inserted one at a time. The 36 month overhaul requires about eight man-hours to complete.

Pressure Suit Helmet. Each crew member is issued one helmet. Several additional helmets are maintained and periodically inspected to serve as back- ups in case the aircrew's helmet has a mechanical problem during the suit up. All the helmets are the same size. Sizing is accomplished by different thickness helmet liners. The helmet is a fairly complex portion of the pressure suit system that requires considerable maintenance. Individual items that require a fair amount of maintenance and care include the exhalation valve, the anti-suffocation valve, and the dual oxygen regulator which is located in the back of the helmet. Maintaining the correct adjustment of the bailor bar (visor lock down lever) is also critical. The visor must be kept scrupulously clean. The microphone and ear phones in the helmet liner are notorious sources of problems and must be carefully maintained and inspected.

Gloves. Each crew member is issued three pairs of gloves. Gloves used to be constructed by PSD personnel and took about 30 minutes to make each glove. Now the gloves come almost pre-constructed. Each glove takes an average of 10 minutes to make when several are built at one time.

The Torso Harness. Each aircrew member is issued two of these harnesses. This harness contains the support webbing and parachute koch fittings to attach the crew member to his 35 foot canopy parachute. It also contains the automatic personal flotation device. This harness also undergoes certain periodic inspections.

Boots and Spurs. Each crew member is issued a pair of insulated boots two sizes larger than normal. This enables the pressure suit bootie to inflate in the boot. A set of spurs is attached to the heel of the boot during the dressing process and secured by nylon straps and Velcro. This spur is then attached to a ball and cable device attached to the ejection seat to prevent leg flailing during bailout. These items take very little maintenance and are replaced when worn out.

Tube Food and Drinking Bottles. In order to provide nutrients to the aircrew during flight

without opening the visor, a feeding port is located to the right of center of the helmet. This feeding port is automatically closed when not in use. When food or drink is required, "tube food" with a feeding "pon tube" attached or a water bottle filled with various beverages, is inserted into the feeding port. The "tube food" comes in 10 different varieties. The specific manufacture date must be monitored to ensure freshness. The aircrew's food and drink requirements have to be coordinated prior to every flight. After flight the water bottles have to be washed and sterilized to be used again.

Survival Kit. The survival kit used in the, U-2 or TR-1 is unique. Two 2200 PSI 45 cubic inch oxygen cylinders are a part of the survival kit. These provide oxygen during bailout or when required to supplement a malfunctioning aircraft oxygen system. The cylinders provide about 30 minutes of oxygen if there is no significant leak in the suit. This survival kit requires a 10 minute preflight inspection prior to installation into the aircraft. The seat kit repack takes about 30 minutes. The kit is repacked and inspected every 120 days.

Parachute. The parachute used in the, U-2, and TR-1 has a 35 foot canopy. The parachute pack and harness are inspected daily by PSD personnel prior to being used on a flight. This inspection takes about 10 minutes. The parachute is installed and removed from the cockpit daily by PSD personnel. Parachute repack and repairs are accomplished by the local parachute shop.

71800 Tester. The large 900 pound oxygen regulator and pressure suit controller calibration and testing console is maintained and calibrated by specially trained PSD personnel. Each PSD has at least two of these tester/calibration devices.

LOX Cooler. The LOX cooler is used as a portable source of 100% breathing oxygen and a source of ventilation air. It weighs 35 pounds when full of the 2.5 liters of LOX. The LOX cooler is overhauled when required.

PSD Van. It is a standard Air Force one ton step van that is customized by the same company that makes the pressure suit hardware. The roof is raised and two ceiling mounted air conditioners are installed. Shelves and racks are installed to hold the liquid oxygen (LOX) coolers and other PSD equipment. Two lounge recliners are installed for aircrew use. The van is designed to minimize aircrew member fatigue prior to being integrated into the cockpit.

A.3.7 HYPERVENTILATION

Hyperventilation is a condition in which the respiratory ventilation is abnormally increased causing an excessive loss of CO_2 from the lungs and lowering the normal CO_2 tension of 40 mmHg. Consequently, the acid-base balance of the blood is disturbed. The blood becomes more alkaline, a condition known as alkalosis. The two important results of hyperventilation are, therefore, hypocapnia (decreased CO_2 concentration) and alkalosis.

Preliminary principles of hyperventilation:

a. Normal respiratory rate is between 12 and 20 cycles per minute (average is 16). You will recall that control of respiration is mediated reflexly through the chemoreceptors in the aorta and the carotid artery by arterial oxygen deficiency in conditions of hypoxia. Under normal conditions, the ventilation rate is controlled directly by the CO_2 and acid-base balance of the blood circulating through the respiratory center in the medulla.

b. In normal individuals the amount of CO_2 produced by the tissues and the amount of CO_2 eliminated from the lungs are in perfect balance. This balance is maintained mostly by the blood buffers, which resist any tendency to alter blood pH. It becomes obvious that excessive elimination of CO_2 can cause a much-too-rapid fall in H_2CO_3. The result is an elevation in blood pH.

c. The activity within each body cell is regulated by the acid-base balance therein. Where the proper balance is destroyed, cellular activity is diminished and the entire organism does not function properly. In severe cases, excessive amounts of acid or base may completely prevent the organism's function and cause death.

Acidosis. Acidosis can be produced by a number of factors. For example, acidosis will result from any disturbance causing an excessive production of acids or preventing their elimination. Acidosis resulting from excessive production of acid will be seen in uncontrolled diabetes or indulgence in diets high in organic acids. Acidosis from failure to eliminate CO_2 can be caused by obstruction of air passages, pulmonary diseases (asthma, pneumonia), or cardiac disease where there is insufficient blood pumped to the lungs.

Alkalosis. The usual way in which alkalosis develops is by excessive elimination of acid since, in most cases, ingestion of high alkali or excessive alkali in the bloodstream will be neutralized immediately and quickly eliminated. The most common cause of alkalosis is excessive CO_2 elimination from the lungs. The development of this alkalosis is seen relatively frequently in naive aircrew personnel during aircraft and chamber flights. It appears that one effect of alkalosis is on the neuromuscular system. Alkalosis also seems to interfere with normal oxygen utilization by the brain cells. The symptoms of these effects on cerebral tissue are euphoria (a feeling of well-being) and eventually unconsciousness. When alkalosis occurs, the low CO_2 content of the blood induces the respiratory center of the brain to inhibit breathing to retain CO_2 and the cerebral blood vessels to constrict, thus inhibiting blood flow and O_2 transport to the brain.

The events leading to unconsciousness from hyperventilation are as follows:

a. Increase in minute volume (inappropriate for metabolic needs) leading to:

1. Decrease in partial pressure of alveolar CO_2.

2. Decrease in partial pressure of arterial CO_2.

3. Increased blood pH.

4. Respiratory alkalosis.

b. Vasoconstriction of blood vessels supplying brain (opposite to the normal vasodilating effects elsewhere).

c. Pooling of the blood present in the brain at the moment.

d. Brain utilizes O2 available in the pooled blood.

1. O2 concentration here drops.

e. Unconsciousness (due to hypoxia of cerebral tissue).

The symptoms manifested by alkalosis are neuromuscular irritability, muscular spasms, tingling and numbness of the extremities and around the mouth, and a sense of euphoria. Most people also feel short of breath. It is evident that these symptoms are somewhat similar to those of hypoxia; consequently, confusion about hypoxia in the untrained person is understandable. Cyanosis is seen in many cases of hyperventilation at altitude. This cyanosis is not a result of hyperventilation itself, but is often associated with it because of concurrent hypoxia.

Mechanism of Hyperventilation. The symptoms of hyperventilation are the same as those encountered in alkalosis since hyperventilation will always result to some degree in alkalosis.

a. General. Normally, the amount of O_2 and CO_2 diffused through the capillary alveolar membrane in the lungs is regulated to promote a proper balance between these gases. When there is a normal increase in respiratory rate, as during exercise, there is an increase in the O_2 demand of the body and in the CO_2 production by the body; therefore, proper CO_2 balance is maintained. If the respiratory rate should increase without need for additional O_2, then excessive CO_2 is eliminated inasmuch as additional CO_2 is not being produced. If this imbalance should continue alkalosis results. Examples of the causes of this alkalosis are voluntary over breathing or, as in certain instances of anxiety and apprehension, involuntary over breathing. Involuntary over breathing is the most common cause of alkalosis in aircrew personnel and may result in a vicious cycle -- the effects of hyperventilation will produce anxiety and anxiety in turn aggravates hyperventilation.

b. At altitude the picture is slightly different. At altitudes above 10,000 feet O_2 tension in the lungs is reduced below minimum acceptable levels. This reduced O_2 tension sets up a reflex impulse to the respiratory center which in turn increases respiration to increase the amount of O_2 presented to the blood. With the increase O_2, more CO_2 is eliminated in proportion to the O_2 received and the blood becomes slightly alkaline. This is normal (a slight increase in blood pH, in fact, is beneficial to O_2 transport and delivery to the tissues). It becomes abnormal when continued for a long period of time, causing severe alkalosis. In untrained or apprehensive individuals, hyperventilation may occur without the presence of hypoxia. The knowledge of the dangers of altitudes, i.e., reduced O_2 pressures, may incite the individual to breathe faster. The effects of hyperventilation are soon mistaken for hypoxia and the individual aggravates the condition by breathing even faster. All observers on a chamber flight must be constantly alert for any sign of abnormal respiration, and be prepared to issue corrective instructions. It should be noted that in hyperventilation, hypoxia occurs only in the brain and nowhere else since there is a reflex vasodilation of all blood vessels except those in the brain; there is no oxygen deficiency. Hence, cyanosis will only be seen when hypoxia occurs concomitantly with hyperventilation. After unconsciousness, respiration is reduced sufficiently to increase the CO_2 tension and correct the alkalosis, but sufficient O_2 must be present to maintain life.

Summary of Hyperventilation Signs and Symptoms.

a. Neuromuscular. The increased sensitivity and irritability of neuromuscular tissue, due to an elevation in blood pH, gives rise to a superficial tingling of the extremities (this tingling is not limited to the extremities, but is usually encountered there). The tingling usually precedes muscular spasm (i.e., a fixation of the hand wherein the fingers are drawn back toward the wrist). In severe cases facial muscles will be tetanically contracted, and the face will give an appearance of being pulled downward. The most dire and dramatic reaction is the "stiffening" of

the entire body due to generalized muscular tetany. It is believed that a reduction in the partial pressure of alveolar CO_2 to 24-30 mmHg is the critical level for the onset of these symptoms.

b. Psychomotor. Deterioration of muscular control and coordinated activity is invariably seen during severe hyperventilation. Performance deterioration is encountered whenever the partial pressure of alveolar CO_2 is reduced below 25 mmHg. As the value falls below this level, performance deterioration becomes more marked.

A.3.7.1Treatment of Hyperventilation

Voluntary reduction in the rate or depth or both of respiration of the individual affected is the most effective method of treatment, when applicable. It is conceivable, however, that an extremely apprehensive person would not respond to directions to slow respiration.

It should be noted that the symptoms of hypoxia and hyperventilation are virtually indistinguishable. The individual must treat for both simultaneously. If either occurs, a decrease in the respiratory rate and breathing 100 percent O_2 will correct the condition. In the presence of hypoxia, if other disturbances coexist, or in more severe cases, it is imperative to return to ground level before more serious developments occur.

A.3.8 OXYGEN TOXICITY

Oxygen is vitally necessary for the flier to operate an aircraft safely and efficiently. This chapter has emphasized its importance. The indispensability of O_2 to maintain life at altitude is undisputed. However, excessive amounts of O_2, or excessively high O_2 partial pressures can prove fatal. Death will result from too much O_2, paradoxically enough, because of tissue hypoxia. The O_2 partial pressures utilized by USAF aircrew are never great enough to cause harm to the body. On the other hand, prolonged 100% oxygen breathing at sea level as in denitrogenation could lead to pulmonary oxygen toxicity. The harmful manifestations of elevated partial pressures of oxygen are directly related to two factors: a. level of elevation of partial pressure and b. duration of exposure. At altitude, because of decreasing ambient pressure, breathing even 100 percent oxygen produces alveolar O_2 partial pressures which generally do not produce damage. The type of oxygen toxicity significant in sea-level oxygen breathing is the Lorrain-Smith Effect (Pulmonary Oxygen Toxicity). This phenomenon, first recognized during treatment of decompression sickness in deep sea divers at a depth of 165 feet or 6 atmospheres absolute (ATA) using air, can occur at as low as 0.7-0.8 ATA (532 mmHg or 9,500 feet) breathing 100 percent O_2 for long periods.

The lung damage which can result consists of fluid accumulation and hemorrhage into the alveoli with a resulting pneumonia-like condition which can be fatal. Some people are much more likely to suffer damage than others, but it has been noted that most people develop symptoms and signs in about 20 hours breathing 100 percent oxygen at sea level.

Thus, it can be seen that breathing 100 percent O_2 for long duration even at low altitudes could theoretically cause damage.

A.3.8.1 Air Force Issues of Concern Regarding Utilization of 100 Percent Oxygen for Aircrews

Oxygen is a drug, and as such both its usefulness and its actual and potential side effects in pilots must be considered when it is used in a flying environment. In addition to there being a minimum concentration of oxygen compatible with life, there is also a maximum concentration compatible with normal cellular function. Excessive partial pressures of oxygen may result in deranged function in two general ways: (1) by replacement of the inert gas nitrogen in the ears and lungs; and (2) by direct chemical toxicity.

Because of nitrogen, the gas volume reservoirs in the lungs and other gas-containing spaces in the body (such as the middle ears) are normally maintained. That is, when communication between the internal gas reservoirs (lungs or middle ears) and the external environment is blocked, oxygen is rapidly absorbed from the reservoir and into the tissues. Nitrogen is absorbed slowly, because it is poorly soluble in body fluids. The continued presence of nitrogen thus helps to maintain the integrity of the body spaces.

If the oxygen concentration of the inspired gas is increased to 100 percent, the concentration of nitrogen in the lungs and middle ears is decreased essentially to zero within 30 minutes--the process of “Denitrogenation”. Following the breathing of supplemental oxygen at altitude, a delayed ear block can occur several hours after return to ground level. However, this is easily preventable if the aircrew member will just Valsalva several times in order to restore normal gas volume in the middle ear.

Acceleration atelectasis is another potential problem caused by the breathing of 100 percent oxygen with consequent denitrogenation. That is, should acceleration-induced apnea or complete airway occlusion occur and last for two minutes while at a cabin altitude of 25,000 feet, complete lung collapse is possible. However, it is questionable whether this is an important consideration in otherwise healthy individuals--particularly when considering the hazards of a chemical warfare environment.

The direct chemical toxicity of oxygen is manifested mainly in the lungs and the central nervous system. However, the toxic effects of oxygen on the central nervous system have been demonstrated only at pressures greater than approximately 2 atmospheres. Thus, central nervous considerations only become important during hyperbaric oxygen therapy, in diving, and in decompression treatment protocols.

In healthy man there seems to be a threshold of about 50 to 70 percent oxygen below which there is little evidence of acute oxygen damage to the lungs even with prolongs exposure. The evidence indicates that no measurable changes in pulmonary function or gas exchange occur in man during exposures to less than 350 to 380 mmHg (0.5 atmospheres) of oxygen. In addition, it seems apparent that despite wide variation in human susceptibility, there is little identifiable risk in the administration of pure oxygen a 1 atmosphere for 24 hours to healthy man.

Since the aircrew member will be exposed to reduced total barometric pressures (and thus to reduced partial pressures of oxygen) while flying in a fighter aircraft, the problem of acute oxygen toxicity to the lungs should be minimal. If the individual is healthy and follows prudent rules of living, the problems of delayed ear block and absorption atelectasis should also be minimal. In light of the potential hazards of the chemical warfare environment, it would be worthwhile to reconsider any ban on the prolonged use of 100 percent oxygen in fighter aircraft.

Aircrew exposure to 100 percent oxygen breathing gas should be limited to a maximum of 12 hours. Aircrew should be briefed on their potential to encounter acceleration atelectasis, delayed barotitis media, and pulmonary oxygen toxicity. This briefing should include descriptions of symptoms and treatments, plus any possible preventive measures applicable to the equipment under evaluation (for example, with a chemical defense ensemble, the ability to switch to breathing cabin air through a suitable chemical filter).

Except for emergencies, special mission activities, and limited training, undiluted oxygen should not be used during normal peacetime flying or in non-toxic warfare environments.

The following paragraphs summarize the symptoms and/or signs, etiology, prevention, and treatment of these three aeromedical problems.

Acceleration atelectasis

Acceleration atelectasis (aeroatelectasis) or alveolar collapse causes chest tightness, substernal discomfort or pain, dyspnea, and dry unproductive coughing. Exposure to +4.5 Gz while breathing pure oxygen may reduce a pilot's vital capacity by as much as 40 percent. Postflight chest radiographs show patches of consolidation in the lower lobes of the lungs. Wearing anti-G trousers worsens the condition. Being a smoker may increase susceptibility. Positive Gz exposure causes the lung to weigh more, generating an increased gradient of pleural pressure down the lung and a severe reduction in alveolar ventilation in the dependent portion of the lung. G-suit inflation increases the proportion of poorly ventilated or unventilated alveoli by restricting descent of the diaphragm. Although many alveoli are effectively unventilated, they remain fully perfused, creating a ventilation-perfusion imbalance. If these unventilated alveoli contain 100 percent oxygen, they will collapse as that oxygen transfers to the pulmonary circulation. Breathing at least 30 percent inert gas (nitrogen, argon) before and during G exposure significantly decreases the observed reduction in vital capacity, limits radiographic changes, and minimizes symptomatology. Inert gas is absorbed very slowly and can thereby keep the alveoli inflated. Acceleration atelectasis is a transient, non-progressive, spontaneously remitting condition. As soon as the patient is able to take a few deep breaths and/or cough vigorously, vital capacity usually returns to near normal and the discomfort and coughing subside. Thus atelectasis is basically a distraction or discomfort that may have some impact on mission performance. Naval aviators have chosen to tolerate this discomfort because of an overriding operational need to breathe 100 percent oxygen if they enter the water (dilution systems would allow water into the breathing hose). The effect on pulmonary function of repeated acceleration atelectasis over a long term has not been investigated.

Delayed otitic barotrauma

Delayed otitic barotrauma manifests as ear discomfort or pain and reduced auditory sensitivity some hours after breathing a high concentration of oxygen during hypobaric exposure. Typically, an aviator will experience a dullness of hearing and minor discomfort upon awakening the morning after breathing high oxygen content gas at altitude. The tympanic membrane may be retracted and hyperemic; in severe cases fluid may accumulate in the middle ear. After prolonged breathing of 100 percent oxygen, particularly if it is used during the descent portion of flight, the gas in the middle ear (and other ventilated body cavities) is likely to be nearly pure oxygen. The aviator may be completely successful in clearing his ears during descent, but a high partial pressure of oxygen remains in the middle ear upon return to ground level. The

pressure gradient between the oxygen in this cavity and that in the venous blood of the surrounding tissues results in direct absorption of the oxygen into the blood. As the gas is absorbed, pressure in the cavity decreases. During normal waking activity, swallowing and jaw movement generally allow pressure equalization of the middle ear with the environment, provided the eustachian tubes are not occluded. During sleep, however, infrequent swallowing and minimal head movement may permit the negative pressure to build, resulting in barotitis. Performing Valsalva maneuvers while breathing air during the last portion of descent and after landing, plus periodic post-flight Valsalvas, especially prior to retiring, will normally prevent delayed barotitis media or at least reduce the severity of symptoms. Treatment is the same as in acute otitic barotrauman: swallowing, chewing motions, nasal vaso-constrictors, and Valsalva maneuvers are usually ameliorative. In severe cases, ascent to altitude and slow descent performing Valsalva maneuvers while breathing air, or gentle politzerization may be necessary. Generally, delayed barotitis media is a mild, relatively benign affliction resolved by most aircrew without medical assistance. Because it occurs with some delay following flight, it does not directly affect mission performance. Long term effects of recurrent mild barotitis media apparently have not been documented.

Pulmonary oxygen toxicity

Pulmonary oxygen toxicity, usually a clinical therapeutic problem, causes substernal distress, dyspnea, and coughing. Vital capacity will be reduced and radiographic consolidation may be observed. The effect is related to high oxygen partial pressure in the lung over an extended time. Most patients develop symptoms after breathing pure oxygen at sea level pressure for 12-20 hours, although some highly susceptible individuals may react within 4 hours or at oxygen partial pressures as low as 0.6 atmosphere (equivalent to 13,000 feet altitude). Direct toxic action upon the alveolar wall is probably responsible, but the exact mechanism is not fully understood. The pathologic result is lung irritation, pulmonary edema, hemorrhage into alveoli, and a pneumonic syndrome. Severe untreated cases may be fatal. Preventive measures are limiting inspired oxygen concentration to 50 or 60 percent for extended periods, limiting exposure time on pure oxygen to a few hours, or interrupting oxygen breathing with intervals of air inhalation. Mild symptoms are relieved by breathing air for a few hours; severe cases require treatment of pulmonary edema. Flying personnel generally are not exposed to high partial pressure of oxygen long enough to cause toxicity.

The above aeromedical problems should not be ignored. Whenever possible, they should be prevented by sound engineering design of life support systems, based on the physiological requirements of the aircrew. Both the U.S. Navy and the Air Force, however, currently conduct a wide range of missions utilizing 100 percent oxygen due to other operational requirements that outweigh the relatively minor risks of oxygen usage. Historically, oxygen toxicity, delayed barotitis media, and acceleration atelectasis have not been significant problems. During chemical attack, aircrew eye/respiratory protection is of paramount importance. The threat of aircrew incapacitation or death due to toxic chemical exposure far exceeds the hazards of 100 percent oxygen usage. Therefore, from an aeromedical standpoint, 100 percent oxygen would be acceptable for demonstration, evaluation, and operational usage in chemical defense systems intended for toxic chemical environments. Limited training with such systems would also be acceptable. However, if system design requires 100 percent oxygen usage during normal peacetime flying activities or in wartime conditions where chemical attack is not

anticipated, the above medical considerations(principally acceleration atelectasis) constitute a strong argument against such systems.

Engineering and logistics consequences of 100 percent oxygen use may be just as important as medical considerations. Stored liquid or gaseous oxygen supplies on aircraft will be depleted approximately twice as fast in the 100 percent mode versus normal air dilution, assuming the gas is not used for ventilation purposes in addition to respiration. Any ventilation usage will drastically increase oxygen consumption. Mission duration could be limited by oxygen storage capacity, or additional airframe weight and volume may have to be devoted to oxygen storage. Higher oxygen consumption increases aircraft servicing requirements, which probably means increased maintenance (translate to reduced reliability and readiness), and adds to logistic demand for oxygen. These penalties may make the operational cost of such a system prohibitive. Newer On Board Oxygen Generating Systems provide a continuous amount of oxygen supply from an aircraft air source such as the engine bleed air.

A.3.9 AIRCRAFT PRESSURIZATION AND DECOMPRESSION

The most effective method for providing physiological protection from reduced barometric pressure is aircraft pressurization. Aircraft pressurization is accomplished by increasing the barometric pressure above ambient pressure within the crew and passenger compartments, thus, in effect, reducing the cabin altitude to safe levels. In a pressurized aircraft there is a greater pressure inside the cabin than outside, and the walls must be structurally reinforced and sealed to contain this pressure. Aircraft pressurization necessarily increases the engineering and maintenance costs of the aircraft and tends to reduce the performance characteristics due to the added weight and power considerations. The conventional method for increasing the pressure in aircraft cabins is to use the ambient air as a source of gas and force it into the cabin by means of a compressor. Cabin pressures and ventilation can be controlled by varying the amount of air forced into the cabin and the amount allowed to escape though adjustable outflow valves. Aircraft pressurization falls into two schedules, Isobaric and Differential.

A.3.9.1 Methods of Pressurization

Isobaric control refers to the condition where the cabin altitude is maintained constant, for example, 8,000 feet. The cabin remains at the 8,000- ft pressure level while the aircraft continues ascent to a lower barometric pressure.

Differential control refers to the system that, rather than maintaining a constant cabin altitude up to the aircraft's operational ceiling, automatic controls seek to prevent the cabin pressure from exceeding the outside pressure by a given amount. When an aircraft reaches the engineering design limit for the isobaric schedule, and can no longer sustain the difference in outside and inside pressure, then a constant pressure differential is maintained between the aircraft cabin and the outside altitude, for example, 5.00 pounds per square inch. Thus, a differential pressure from inside to outside remains constant and both cabin and flight altitude vary proportionally. The rate of pressure change, however, is less inside than outside.

Usually the isobaric control maintains the cabin at 8,000 feet until the aircraft passes through FL 230. At this point a 5.00 PSI differential is reached. As the aircraft continues to climb, the

cabin maintains this differential. The cabin altitude also climbs, but at a slower rate. For large aircraft, such as the C-5, the isobaric schedule begins at ground level and keeps the cabin at that altitude until a set pressure differential level is reached, usually a 8.6 PSI differential (PSID).

A.3.9.2 Limitations to Pressurization

Pressure Ratio Limitations. The ratio between the cabin pressure and the outside ambient pressure is expressed as the number of times that the rarified outside air must be compressed to maintain the desired cabin pressure. For example, an aircraft cabin maintained at an equivalent altitude of 3,048 m (10,000 ft) has a pressure ratio of 10:1, or 10, when flying at an altitude near FL 600. This means that the outside air must be compressed to a pressure that is 10 times greater in order to achieve the desired cabin altitude. Under the same conditions near FL 750, the pressure ratio is 10:0.05, or 20. It is in this range that cabin pressurization by mechanical compression becomes limited.

Compression Temperature Limitations. In addition, as the pressure ratio increases, the temperature of the compressed air also increases. Therefore, all compressed air must be cooled, necessitating an elaborate environmental control system. At FL 750, for example, with a pressure ratio of 20, the compressed air temperature is about 315.6 degrees C. At FL 1000 with a cabin maintained at 3,048 m (10,000 ft), the pressure ratio is more than 60 and the compressed air temperature increases to over 500 degrees C. This normally exceeds the heat exchange capacity of pressurization systems. Together with the pressure ratio limitations, compression temperature limitations require that aircraft which fly above FL 800 maintain higher than normal cabin pressures. This obviously means that additional efforts (denitrogenation and pressure suits) must be taken to prevent DCS and hypoxia.

A.3.9.3 Cabin Depressurization

The major causes of cabin pressure loss in recent incidences have been the failure of canopies, hatches, doors, and Plexiglas, and because of maintenance deficiencies, defective component parts, or human errors. During a decompression the effects on the body are primarily due to rate of pressure change and to the pressure differential to which the body is exposed. Decompression can be divided into two categories: Slow and rapid.

Factors Affecting the Decompression Rate. Decompressions exhibit a rate of pressure loss from the aircrew compartment which can be calculated when several specific parameters are known. Rates of pressure loss per unit time depend on the cabin volume, the size of the opening, and the relative pressure ratio from inside to outside.

a. Volume of the Pressurized Cabin. The larger the cabin, the slower 0"2 the decompression, with other factors remaining the same.

b. Size of the Opening. The larger the opening or defect in the cabin, the faster the decompression. The ratio between the volume of the cabin and the product of the cross sectional area of the opening and speed of sound at that altitude, are factors used to determine the rate (feet per minute) and time (usually in seconds) of a decompression.

c. Relative Pressure Ratio. The time of decompression is also dependent on the ratio of the

cabin pressure before the decompression to the cabin pressure after decompression. More specifically, it is the relative change in pressure loss (pressure inside minus pressure outside divided by the pressure inside) that determines the rate of decompression, not the absolute pressure difference between the inside and outside of the cabin. The larger the relative pressure ratio, the longer the decompression time. Thus, the volume of the cabin, the size of the opening, and the relative pressure ratio are the principal factors that govern the total time of a decompression used to calculate rate.

Factors Affecting the Severity of a Decompression. Two other factors are often mentioned as affecting the rate of decompression, but more appropriately should be considered as affecting its severity, and therefore, the threat to the aircrew. The first is flight altitude.

a. Flight Altitude. Generally, the higher the flight altitude, the greater will be the pressure ratio until the differential pressure setting is achieved, e.g., 5 PSID. It is true that the greater the relative pressure ratio, the longer will be the total time of decompression. Yet, the issue of greater consequence is time to onset of hypoxia, which is critically shortened at flight altitudes above 12200 m (40,000 ft). Severity of decompression, therefore, is critically determined by flight altitude.

b. Pressure Differential. The second factor critical to severity is the difference in the inside and outside pressures. Large pressure differentials always increase the severity of a decompression, but not necessarily the total time of the decompression. The difference in pressure from inside to outside is the pressure that must be released from the cabin, and is also the pressure that must be released from trapped gas areas of the body, particularly the lungs. The potential harm to the aircrew increases depending on the physical nature of the pressure loss. Flight altitude and pressure differential figure prominently in this hazard potential.

Slow Decompression. Cabin decompression, or failure of the cabin pressurization system, is not always sudden. It is possible that a slow leak may occur without the aircrew member detecting it. Hypoxia symptoms may be the first indications a crew member has that there is a loss in cabin pressure. The crew member may be incapacitated by hypoxia if the cabin is decompressed above 10,000 feet (3,048 meters). Therefore, it is important that the aircrew member make periodic checks of the cabin altimeter.

Rapid Decompression. When considering the possible physiologic effects of a rapid decompression, one must distinguish between what may occur during the decompression itself, such as having a crew member blown through an opening in the cabin, or having physiological injury occur, due to the expansion of gas in the lungs. There are also physiological consequences that can result after the decompression, such as acute hypoxia and decompression sickness.

a. Wind Blast Effects. The rapid decompression that follows the loss of a 022 window or door in a pressurized aircraft is accompanied by a forceful outward movement of air. Crew members caught in the path of the out reaching air may be blown from the aircraft; therefore, persons sitting close to windows in larger aircraft, or under the cockpit canopy in smaller aircraft, should have seat belts fastened during pressurized flight.

b. Mechanical Expansion of Gases.

1. Gastrointestinal Tract During Rapid Decompression. One of the potential dangers during a

rapid decompression is the expansion of gases within body cavities. The abdominal distress during rapid decompression is usually no more severe than that which might occur during slower decompression. Nevertheless, abdominal distention, when it does occur, may have several important effects. The diaphragm is displaced upward by the expansion of trapped gas in the stomach, which can retard respiratory movements. Distention of these abdominal organs may also stimulate the abdominal branches of the vagus nerve, resulting in cardiovascular depression, and if severe enough, cause a reduction in blood pressure, unconsciousness, and shock. Usually, abdominal distress can be relieved after a rapid decompression by the passage of excess gas.

2. The Lungs During Rapid Decompression. Because of the relatively large volume of air normally contained in the lungs, the delicate nature of the pulmonary tissue, and the intricate system of alveolar airways for ventilation, it is recognized that the lungs are potentially the most vulnerable part of the body during a rapid decompression. Whenever a rapid decompression is faster than the inherent capability of the lungs to decompress (vent), a transient positive pressure will temporarily build up in the lungs. If the escape of air from the lungs is blocked or seriously impeded during a sudden drop in the cabin pressure, it is possible for a dangerously high pressure to build up and to over distend the lungs and thorax. No serious injuries have resulted from rapid decompressions with open airways, even while wearing an oxygen mask, but disastrous, or fatal, consequences can result if the pulmonary passages are blocked, such as forceful breath-holding with the lungs full of air. Under this condition, when none of the air in the lungs can escape during a decompression, the lungs and thorax becomes over-expanded by the excessively high intrapulmonic pressure, causing actual tearing and rupture of the lung tissues and capillaries. The trapped air is forced through the lungs into the thoracic cage, and air can be injected directly into the general circulation by way of the ruptured blood vessels, with massive air bubbles moving throughout the body and lodging in vital organs such as the heart and brain.

The movement of these air bubbles is similar to the air embolism that can occur in SCUBA diving and submarine escape when an individual ascends from underwater to the surface with breath-holding. Because of lung construction, momentary breath-holding, such as swallowing or yawning, will not cause sufficient pressure in the lungs to exceed their tensile strength.

3. Decompression Sickness. Because of the rapid ascent to relatively high altitudes, the risk of decompression sickness is increased. Recognition and treatment of this entity remain the same as discussed elsewhere in this publication.

4. Hypoxia. While the immediate mechanical effects of rapid decompression on occupants of a pressurized cabin will seldom be incapacitating, the menace of subsequent hypoxia becomes more formidable with increasing altitudes. The time of consciousness after loss of cabin pressure is reduced due to offgassing of oxygen from venous blood to the lungs. Hypoxia is the most immediate problem following a decompression.

5. Physical Indications of a Rapid Decompression. The rapid decompression given in the hypobaric chamber is designed to train aircrew personnel to recognize some of the physical characteristics of a rapid decompression occurring in a pressurized aircraft. It is unfortunate that all physical characteristics found in an aircraft decompression cannot be duplicated in hypobaric chamber decompressions; however, periodic rapid decompressions better prepare

the aircrew member to recognize and react to an actual aircraft decompression.

(a) Explosive Noise. When two different air masses make contact, there is an explosive noise. It is because of this explosive noise that some people use the term explosive decompression to describe a rapid decompression.

(b) Flying Debris. The rapid rush of air from an aircraft cabin on decompression has such force that items not secured to the aircraft structure will be extracted out of the ruptured hole in the pressurized compartment. Items such as maps, charts, flight logs, and magazines will be blow out. Dirt and dust will affect vision for several seconds.

(c) Fogging. Air at any temperature and pressure has the capability of holding just so much water vapor. Sudden changes in temperature or pressure, or both, change the amount of water vapor the air can hold. In a rapid decompression, temperature and pressure are reduced with a subsequent reduction in water vapor holding capacity. The water vapor that cannot be held by the air appears in the compartment as fog. This fog may dissipate rapidly, as in most fighters, or not so rapidly, as in larger aircraft.

(d) Temperature. Cabin temperature during flight is generally maintained at a comfortable level; however, the ambient temperature gets colder as the aircraft flies higher. If a decompression occurs, temperature will be reduced rapidly. Chilling and frostbite may occur if proper protective clothing is not worn or available.

(e) Pressure. A rapid drop in pressure can be expected when a rapid decompression occurs. The earlier the aircrew member recognizes the physical characteristics of a decompression, the sooner the physiological hazards can be combated.

A.3.10 OXYGEN EQUIPMENT

In general, an oxygen system in an aircraft consist of containers for storing the oxygen, tubing to conduct the oxygen from the main supply to a metering device which controls the flow of oxygen, and a mask to direct the oxygen to the user's respiratory system.

A.3.10.1 Oxygen Storage Systems

Oxygen is carried in cylinders or converters mounted in the aircraft. The location of these containers depends on the type aircraft and maybe found in the wings or fuselage. There are three predominant types of oxygen storage systems in use in the USAF, and each is classified by the method in which the oxygen is contained in the aircraft.

Low Pressure System. In the USAF, low pressure oxygen is stored in yellow, lightweight, nonshatterable cylinders. These cylinders carry a maximum charge of 450 PSI and are normally filled to a pressure of 400 to 450 PSI. The low pressure system reduces the possibility of explosions, but limits the volume P42 of oxygen. This limited volume dictates immediate descent to altitudes not requiring supplemental oxygen anytime the pressure drops below 100 PSI.

High Pressure System. Some aircraft, especially commercial carriers, are equipped with high-pressure cylinders. Most tactical fighters, bombers and trainers are equipped with high pressure emergency systems. These cylinders are non-shatterable and can carry a maximum charge of

2150 PSI and are normally filled to a pressure of 1800 to 2000 PSI. The most distinguishing characteristics of these cylinders in the USAF are their bright green color and heavy weight. The chief advantages of the high pressure cylinder is that a large amount of oxygen can be stored in a relatively small space.

Liquid Oxygen System. Liquid oxygen (LOX) systems are the most widely used storage systems in military aircraft today. Low pressure gaseous systems are lightweight, but require considerable space. High pressure gaseous systems require less space, but are heavier. A LOX system saves on both space and weight, and thus has become the system of choice. A LOX converter is used to store the oxygen in a liquid state and convert it to gaseous oxygen as needed. The standard LOX converter is a double-wall vacuum insulated container. A LOX converter will expand each liter of liquid oxygen into 860 liters of gaseous oxygen. The expansion is controlled and the gaseous oxygen is maintained at a constant operational pressure. In multi-place aircraft such as bomber, cargo and aeromedical evacuation aircraft, the LOX converter is designed to produce an operational pressure of 300 PSI. In jet fighters and trainers the operational pressure is generally 70-90 PSI. Higher pressure is necessary in multi-place aircraft because of the greater number of crew members and the need to recharge portable oxygen assemblies.

A.3.10.2 Oxygen Delivery Systems

The oxygen delivery system receives oxygen from the storage system and delivers it to the user. The delivery system consists of a regulator which meters the amount of oxygen, and a mask which directs the oxygen to the user's respiratory system. There are three types of delivery systems currently used in the Air Force: the continuous flow, diluter demand, and pressure demand systems. Each system can be installed as a fixed, aircraft-mounted, or portable system.

Continuous Flow System. This system delivers a continuous flow of 100 percent oxygen to the user. Although continuous flow equipment has disappeared from the flight deck of military aircraft, it is still used in some general aviation aircraft and by passengers and non-flight control crew members on many military cargo aircraft. This system will supply an adequate amount of oxygen to the passenger who does not require as much oxygen as the crew members flying the aircraft. The operational altitude of this system is FL 250. Above FL 250, this system serves as emergency function to get the passenger down to a safe altitude.

On military transport aircraft, there are fixed mounted continuous flow oxygen regulators with distribution lines extending down each side of the passenger compartment, and oxygen masks which are attached to the distribution lines. The regulators are designed to supply oxygen to a large number of individuals simultaneously. There are numerous masks designed for use with a continuous flow system.

Pressure Demand System. This system consists of a pressure demand regulator and a pressure demand mask. Oxygen is delivered only during inhalation; that is, on demand. This system reduces the oxygen waste evident in a continuous flow system and provides a higher percentage of oxygen to the user because of better mask fit and efficiency. The regulator will deliver adequate oxygen to protect an individual at all altitudes up to FL 350. During inhalation, negative pressure closes a one-way exhaust valve in the regulator. There is dilution at all

altitudes up to FL 340. Above FL 340 the regulator delivers 100 percent oxygen.

The demand regulator is designed with an automix lever which can be set at "NORMAL OXYGEN" or "100 PERCENT OXYGEN." When in the "NORMAL OXYGEN" position, the user will receive a mixture of ambient air and oxygen up to FL 340, as described above. When placed in the "100 PERCENT OXYGEN" position, 100 percent oxygen will be provided at any altitude. A green oxygen supply lever is located on the right side of the regulator provides a means of manually supplying positive pressure for testing mask fit and for emergency use. The emergency setting directs a steady stream of 100 percent oxygen to the mask, making it operate as a continuous flow system regardless of altitude. The emergency setting is for use with suspected hypoxia, unconsciousness or serious leakage in the mask or delivery hose. Use of the emergency setting, however, depletes the oxygen supply in a relatively short time and causes difficulty exhaling when wearing the face mask.

Above FL 400 the oxygen saturation of the blood decreases to low levels even if 100 percent is breathed. Pressure demand oxygen systems have been developed to protect individuals exposed to altitudes in excess in FL 400 by presenting 100 percent oxygen under a continuous positive pressure to the oxygen mask. Since the lungs have a relatively low tolerance to high internal pressures, the effective range of the pressure demand equipment is limited. The operational ceiling for pressure demand equipment without counter pressure is FL 430 with an emergency ceiling of FL 500.

Pressure demand oxygen masks (there are several designs available) are, in principle, designed to hold pressure in excess of ambient pressure requiring two features which are not found in other type masks. A face seal forms a ring around the inside of the mask which serves as a pressure seal. A special inhalation/exhalation valve located on the floor of the mask is designed to allow oxygen to enter the mask on inhalation and sustain a continuous positive pressure until regulator pressure is overcome during exhalation.

With the pressure demand mask a connector assembly is used to attach the oxygen mask delivery tube to the regulator oxygen delivery hose. The connector assembly provides a means for quick disconnect from the aircraft oxygen supply during bailout or ejection. The most widely used connector is the CRU-60/P connector assembly. The connector is a three-way manifold block. It recesses by means of a dovetailed plate into a receiving bracket which is mounted on the parachute harness. Disconnection from the aircraft oxygen supply hose takes place at the lower intake port. The oxygen mask delivery tube remains attached to the parachute harness to prevent flailing. The emergency oxygen cylinder hose is attached to a swivel port on the side of the connector. The oxygen mask delivery tube attaches to the other port of the connector. The connector incorporates a disconnect warning device which offers a resistance to breathing during inhalation unless the inlet is properly inserted into the regulator oxygen delivery hose. When the emergency oxygen supply is activated during egress procedure, the resistance to inhalation is not experienced as long as oxygen is supplied. The CRU-60/P is designed to allow a straight pull during occupant-seat separation facilitated by the short flexible hose on the connector.

Emergency Oxygen Assembly. In the event the aircraft oxygen system should fail, or during high altitude egress, the emergency oxygen assembly provides an emergency source of oxygen to the flier. This assembly supplies a sufficient continuous flow of oxygen for aircraft

escape and parachute descent from a maximum altitude of FL 500. The system consists of a high pressure cylinder, a pressure gauge and a hose for attaching the cylinder to the connector assembly, CRU-60/P. Emergency oxygen is obtained by pulling the activation ball ("Green Apple"). There are provisions for housing this system in the parachute or in the seat kit. Activation of the seat kit system is usually automatic when the ejection seat separates from the aircraft, but certain aircraft, such as the A-7 and T-38, require manual activation.

Portable Oxygen Assemblies. Portable or "walk-around" oxygen assemblies are provided in multi-place aircraft which permit the safe movement of personnel within the aircraft. Most walk-around assemblies consist of low pressure cylinders and regulators which are comparable to the fixed system used in the aircraft. The duration of oxygen in a portable system will vary with the physiological need of the user, the pressure of the system, and the altitude where it is being used. There are continuous flow and pressure demand portable assemblies. One of the more commonly used portable assemblies is the MA-1 assemble. This assembly consists of a low pressure cylinder and a pressure demand regulator. The MA-1 is designed to provide 100 percent oxygen at ambient pressures up to FL 300. Above this altitude, positive pressure is obtained by manually setting the pressure control valve on the 30M or 42M or emergency position.

Solid State Oxygen System. A recent advance in USAF oxygen equipment is the chemical combination, solid state, oxygen system. This system was developed for use in aircraft such as the C-5 for emergency use by passengers. The system components are enclosed in a plastic canister. It consists of a continuous flow mask with lanyards connected to actuating pins and attached to the inner canister which houses a sodium chlorate candle. The system is activated by removing the mask and extending the lanyards far enough to release the actuating pins. A harmless amount of chlorine may be detected for about 12 seconds after activation. The candle burns at a maximum temperature of 1,100^{o}F. The oxygen supply generated depends on the size and burning time of the candle.

A.3.10.3 Oxygen Equipment Problems

Even though oxygen equipment is well designed and reliable, crew members can encounter oxygen equipment problems. Fortunately, the majority of these problems are minor and can be corrected with common sense and the equipment knowledge learned during training. There are two ways to approach oxygen equipment problems, through preventive maintenance and through on-the-spot corrective action. Some of the more common oxygen equipment problem areas will be discussed.

One of the most frequent errors committed by crew members is the failure to have their oxygen mask inspected by the Base Life Support Section. This inspection is required every 30 days and all flying personnel are responsible for compliance. The Life Support Section can correct major discrepancies such as broken or deteriorated parts. When using a pressure demand oxygen mask, the crew member may occasionally encounter difficulty exhaling. This difficulty is frequently caused by moisture collecting in the exhalation port of the oxygen mask valve. If it is found that the exhalation valve will not open when performing the initial oxygen equipment preflight check, the life support technician should be informed of the problem. The emergency oxygen assembly employs the continuous flow principle. The pressure demand mask was not designed to be used with a continuous flow system for normal operation. Thus, oxygen flows

continuously through the mask, opening the inhalation valve but closing the exhalation valve almost entirely, accounting for the difficulty in exhalation. Consequently, most of the gas will be exhaled around the mask face seal. This system, however, will supply sufficient oxygen for emergency use.

Occasionally a crew member may lose the rubber gasket located on the quick-disconnect of the mask-to-regulator connector (CRU-60/P), causing a serious leak, and could result in hypoxia. In addition to leakage, the quick disconnect could become permanently lodged in the regulator hose connector. Crew members should assure a gasket is in place before flying. Most aircraft are equipped with automatic pressure demand regulators (CRU/ or MD-1 Series). These regulators have proven to be very reliable.

Equipment Checklist. Aborted missions, hypoxia incidents, and deaths have occurred because crew members and passengers did not perform adequate or frequent checks of their oxygen equipment. The PRICE oxygen equipment checklist is designed to guide crew members and passengers in checking oxygen equipment prior to each flight and for frequent inflight checks. Each letter in the word "PRICE" represents an inspection point that must be checked. The following listed items should be checked by each member of the aircrew on every flight requiring the use of oxygen equipment. MAKE THESE CHECKS HABIT! Perform each check in the same order each time to prevent missing an item.

a. Pressure. Depends upon system being used.

1. Low Pressure Gaseous System - 400 to 450 PSI or 425 +25. Cylinders are color-coded yellow.

2. High Pressure Gaseous System - 1,800 to 2,000 PSI for fixed aircraft system. Cylinders are color-coded green. High pressure emergency cylinder pressure is 1,800 to 2,200 PSI.

3. Liquid Oxygen (LOX) System-generally, with 70 to 90 PSI, or in the case of multi-place aircraft, 300 PSI. In addition to checking the pressure gage on a LOX system, the quantity gage must be checked to determine if the converter has been filled with the adequate amount of LOX.

b. Regulator. Everything must be checked on the specific regulator being used. Checks for dents, cracks, legibility of printing, movement of knobs, dials and levers, presence of oil or grease, and broken gages. The automatic pressure breathing regulators are given the following check (check for good mask fit):

1. ON-OFF lever to the ON position.

2. Automix lever to the 100 PERCENT OXYGEN position.

3. Emergency - test mask ever to the EMERGENCY position.

4. Breath normally for a minimum of three cycles. The flow indicator should show alternately black and white.

5. Hold breath. The flow indicator should indicate black, or no flow. White indicates a leak somewhere in the system.

6. Automix lever to NORMAL position. Indicator should remain black. White in this case,

indicates a leak. You should hold your breath for this check.

7. Emergency - test mask lever to NORMAL position.

c. Indicator. The flow indicator shows gas is flowing through the regulator.

d. Connections. Connections should be checked in the following sequences:

1. Regulator hose to regulator connection - secure if exposed.

2. Regulator hose - check for signs of wear, damage, and missing parts.

3. Quick disconnect.

(a) Silver C-Ring - 12 to 20 pounds (5.4 to 9.1 kg) pull to disconnect.

(b) Breath restricting valve - check operation.

(c) White silicone gasket - provides airtight seal.

(d) Black silicone "O" ring.

(e) Short black hose of CRU-60/P - check clamps and general condition.

(f) Emergency assembly connector - secure.

(g) Hold-down plate where applicable - secure.

e. Emergency Assembly. The emergency assembly is usually packed in the parachute or seat and must be checked prior to fitting and wearing of the parachute.

1. Pressure gauge - 1800 to 2200 PSI.

2. Green ball handle - secure.

A.3.11 EFFECTS OF DECREASED PRESSURE: DECOMPRESSION SICKNESS

A.3.11.1 INTRODUCTION

Decompression sickness (DCS) is one of the least likely events to occur in flight, but the seriousness of any episode of DCS compensates for such a low probability of occurrence. Manifestations of DCS range from mild pain in a joint to blindness and even death. From one individual to the next, there is considerable variability in the onset and severity of symptoms. The difficulty in predicting individualized DCS under specific flight conditions requires the flight surgeon to be aware of its etiology and the factors contributing to its development.

DCS is an illness caused by reduced pressure on the body that results in formation of bubbles of an inert gas and specific related symptoms. An understanding of this fact with regard to nitrogen during wet diving has existed for many years.

As early as 1917, Yandell and Henderson predicted the possibility of DCS in aviators. In 1919, Herringer formulated the theory that the mechanisms involved in both altitude and diving DCS were identical. Within thirty years of the historic flights by the Wright brothers at Kitty Hawk, DCS was a recognized if unexplained problem of flying. Planes had ever-increasing flight performance, including the ability to fly higher. Consequently, altitudes were achieved that

resulted in “dysbarisms” not unlike caissons disease or diver’s bends. Only with the advent of pressurization systems in the late 1940’s was inflight DCS minimized. Curiously, however, it was not conquered.

Though the conditions required to produce DCS and some of the factors influencing bubble formation and growth are known, a complete etiology is impossible to describe. Reliable pressurization systems have been used for the past four decades, yet some missions still exist in which DCS remains a potential hazard. Aircraft may depressurize, exposing the aircrew to high cabin altitudes under these conditions. Depressurization is usually caused by a defect in the pressurization system or a breach in the aircraft pressure vessel. The aircrew are then quickly exposed to a reduced pressure which may cause DCS.

Very high altitude flights, e.g., above 15,240 meters (50,000 feet), allow cabin altitudes above the threshold altitude known to cause DCS. The high cabin altitude in these aircraft is not due to a defect in the pressurization system, however. Rather, the maximum pressure differential the aircraft can maintain is not sufficient to protect the crew member (see the cabin pressurization section of the previous chapter). Usually, crew members aboard these aircraft were pressure suits which, because of poor mobility when inflated, are pressurized only in the vent of a loss of cabin pressure.

Exposure to hazardous altitudes is not always accidental or unpreventable. Some missions require deliberate depressurization of the aircraft. The most common mission of this type is high altitude parachute drops in which the entire aircraft remains unpressurized. In this situation both the crew and the jumpers are exposed to hazardous altitudes.

Certain space operations also create the potential for DCS problems. For example, astronauts must wear pressure suits during extravehicular activity (EVA). The mobility of these suits is poor when they are pressurized to much more than about 4 PSI above ambient pressure. Therefore, suits are generally restricted to these lower pressures. An astronaut preparing for an EVA must undergo decompression from the Space Shuttle cabin pressure (sea level equivalent, or 14.7 PSI) to the suit pressure. Such decompression is often sufficient to cause DCS.

Some aircraft are not equipped with pressurization systems so the crew is always exposed to the ambient altitude. These aircraft are usually permitted to fly no higher than 7520 meters (25,000 feet), yet this altitude is known to have some risk of DCS. Additionally, altitude chamber training by design exposes students to law pressures. This training is a compromise between the need for realism and the definitive risk of DCS.

A.3.11.2 BRIEF HISTORY

Although the early literature is dominated by reports of DCS as a result of decompression from hyperbaria, the first citation of DCS induced in an animal describes an altitude exposure. Robert Boyle in 1670 noted a bubble in the eye of a snake he had exposed to decreased pressure. He surmised that bubbles could disrupt the flow of blood. From his hypo/hyperbaric chamber work, the “bubble theory” of DCS was provided by French Physiologist, Paul Bert in 1879. Early balloonists did not experience DCS because normally they were debilitated by hypoxia before DCS became a factor. Mountain climbers also did not experience DCS for the same reason. Modern mountain climbers are still not concerned with DCS, even when hypoxia

is prevented with supplemental oxygen, because of the slow rates of ascent.

Bridge building in the nineteenth century required compartments called caissons to be lowered into the water or mud of the river bed to permit the workers to excavate materials. the caisson was maintained at t pressure equal to the surrounding water to prevent inward leakage. When workers completed their work, they were decompressed to the surface. If the rate of decompression was too rapid the workers often suffered from “caissons disease”. In more modern times, use of diving equipment, both hard hat and SCUBA, has produced more cases of DCS than any other activity.

Humans and animals exposed to altitudes display symptoms similar to the symptoms of caisson workers and divers, even when they are provided supplemental oxygen. A diver on loads additional nitrogen the longer he stays at depth and the deeper the dive; thus, their risk of DCS occurs on ascent. Similarly the aviator is saturated with nitrogen at ground level and is at risk only on ascent to a higher altitude. Thus, when returning to the surface (ground level) the diver increases the probability of DCS, but the flyer decreases the probability.

Early aircraft had relatively low maximum altitudes, but the advent of supercharged, reciprocating and jet engines permitted higher altitude flight. World War II stimulated a great increase in DCS research because of the unacceptable DCS rate in the flying population. Crew members were screened for DCS by exercising at altitude to determine altitude screening susceptibility. This severe screening process caused some deaths, but is no longer used because of the high risk associated with DCS symptoms and the lack of test validity.

The greatest progress in DCS research was made with the discovery that breathing pure oxygen before decompression decreased the probability of DCS. DCS continues to be a hazard of flight, but the incidence is substantially p62 lower. Nevertheless, use of high pressure spacecraft and low pressure space suits has renewed the interest in DCS.

A.3.11.3 ETIOLOGY OF DCS

Theoretical Considerations. DCS occurs when a person is subjected to a sudden reduction in ambient pressure that causes inert gas bubbles to form and grow within body tissues and vascular spaces. The theoretical cause of DCS is the nucleation and growth of bubbles in the tissues. During decompression from any atmospheric pressure, some quantity of inert gas in the tissues diffuses into the blood, travels to the lungs, and leaves the body through expired air. The amount of inert gas which is dissolved in body tissues is in direct proportion to the inert gas partial pressure around the person prior to decompression. If the decompression exceeds some threshold, the body frequently cannot unload the inert gas through the respiratory system, and a state of super saturating exists. When super saturating occurs, some of the inert gas comes out of solution in the form of bubbles, and if enough bubbles develop, pathophysiologic mechanisms of DCS are manifested. Some knowledge of the factors involved in the formation and behavior of bubbles is important as a background to understanding the causes and rationale of treatment of DCS.

Bubble Nuclei. A gas bubble will form when the concentration of a dissolved gas is greater than can be maintained in solution. This condition is termed "super saturating". Spontaneous de novo bubble formation in a pure physical solution occurs at differential pressures between 100 and 1000 ATA (atmosphere absolute). Such magnitude of pressure change is not necessary to

create bubbles in humans. With physiological body fluids that are supersaturated with nitrogen, bubbles form because bubble nuclei already exist, a threshold pressure change occurs, and it occurs quickly. This is also true for flying.

The driving force for bubble nucleation processes is the difference between the dissolved gas partial pressure and the absolute pressure. By convention, whenever the difference is positive, the rate of bubble nucleation is positive and bubbles begin to form in supersaturated tissues.

Bubble nucleation occurs more rapidly at elevated temperatures and at liquid-surface interfaces, especially if these interfaces are hydrophobic. Gas nuclei tend to cling to hydrophobic surfaces, thus increasing their stability. The effects of surface tension are also reduced if a bubble forms in a surface irregularity. Here, a bubble can grow and seed off other bubbles from the original site into the surrounding fluid. Both hydrophobic surfaces and surface irregularities aid bubble formation by allowing the bubble to avoid some of the surface tension effects. In addition, bubble nuclei are thought to form at sites of negative hydrostatic pressure where conditions are more favorable for bubble formation.

The absolute hydrostatic pressure of the tissues is proportional to the external atmospheric pressure; however, the variation of hydrostatic pressure from tissue to tissue is a factor in determining the sites in which DCS symptoms might appear. Regions in which the hydrostatic pressure is above the average are less likely to give rise to symptom-producing bubbles than those regions in which the hydrostatic pressure is low. Intravascular bubbles are produced in areas of low pressure by turbulent blood flow found at points of vessel constriction or points of vessel bifurcation. Shearing forces also cause regions of low pressure. These forces can occur in both blood and tissue (muscle shear through exercise) and may be one of the causes of formation of intravascular and extravascular bubbles. Bubbles have been observed in veins, p62 arteries, lymph vessels and tissue spaces; however, doppler studies suggest that venous bubbles occur prior to arterial bubbles. Intra-arterial bubble formation apparently occurs only under circumstances of extremely serious or explosive decompresssion. Arterial blood pressure is normally 70-120 mm Hg greater than that of the surrounding tissues, making it more difficult for gas bubbles to form within the arteries. Exactly what each of the above compartmental regions contributes to the syndrome of DCS is difficult to postulate at this time.

There is generally less probability of super saturating and, therefore bubble formation, in the high pressure side of circulation than in the venous circulation. This is a consequence of several factors. First, the blood that leaves the lungs has a diminished nitrogen tension because of the diffusion offload that occurs at the capillary-alveolar interface. This necessarily must occur if a state of super saturating is in effect.

Second, as previously mentioned, the higher pressure of the arterial circulation itself may limit the degree of super saturating. Since total pressure is a combination of atmospheric and blood pressure, critical super saturating ratios are less likely to be exceeded on the arterial side.

Because of the decreased probability of super saturating on the arterial side, arterial bubbles are less likely to form. A more severe decompression generally would be required to produce arterial bubbles. The consequence of arterial bubbles, e.g., occlusion of blood flow to critical tissues such as brain, is obviously a significant hazard.

Super saturating. Pressure is the most important environmental factor affecting the physiology

of the diver or flyer. One concept must be remembered at all times. In order to cope with the changes in barometric pressure within the flying or diving environment, the pressure in the various body cavities and tissues must equalize with the ambient pressure. If pressure equalization is not attained, tissue inert gas pressures will exceed barometric pressures, leading to a condition of inert gas supersaturating and bubble formation. The body can tolerate a certain level of super saturating without causing inert gas to come out of solution to form bubbles; however, once the critical super saturating ratio is reached, bubbles develop.

Bubble formation per se, if not too extreme, may not result in symptoms of DCS. "Silent" bubbles have been shown to occur during many normal or asymptotic decompressions. Indeed, silent bubbles may be very prevalent in most flying and diving operations, and eventually disappear with no consequence to the body.

J. S. Haldane first described the concept of critical super saturating in 1906. He demonstrated that humans could be exposed to hyperbaric pressure and be subsequently decompressed without suffering DCS. The only condition was that the total pressure reduction not exceed more than 50 percent, i.e., pressure may not be changed by more than a 2:1 ratio from a deeper to a shallower depth.

There are apparently a number of critical super saturating ratios for the various tissue compartments in the body. As such, the Haldane 2-to-1 rule is no longer used in present day decompression schedules and the rule is not applicable to hypobarics. Various physiological and environmental factors can reduce the critical super saturating ratio below 2:1 and induce bubble formation and DCS onset.

Nitrogen is the primary gas involved in the development of DCS. Bubbles formed solely by the action of oxygen or carbon dioxide are unlikely because these gases have unique blood transport mechanisms, are rapidly consumed or excreted, and their concentrations are controlled by the respiratory and p62 circulatory systems. Nitrogen is neither consumed, excreted, bound to other molecules, nor actively controlled. The solubility of nitrogen in water is relatively low, but in some tissues such as fat, is relatively high. Nitrogen diffuses slowly from fat tissues to the blood.

The degree of nitrogen super saturating is expressed by the following relationship:

$$R = \frac{P_{N2}}{P_B}$$

R is the super saturating ratio, P_{N2} is the partial pressure (tension) of nitrogen in the tissues, and P_B is the total atmospheric pressure. Methods of preventing DCS depend on decreasing the value of this ratio, i.e., decreasing the tension of nitrogen in the tissues and/or increasing atmospheric pressure.

Bubble Theory. The initial condition leading to DCS is a reduction in the pressure applied to the body in a relatively short period of time. This reduction in pressure can result from ascent from

one altitude to a higher altitude, ascent from a depth of water to a shallower depth, or a combination of the two. In general, the manifestations of DCS caused by decompression from hyperbaria are the same as those seen by decompression to altitude. DCS may occur concurrently with hypoxia, but DCS is actually caused by the physical reduction in pressure rather than the lack of oxygen in the breathing gas. Thus, a crew member flying at a high cabin altitude, even with properly functioning oxygen equipment, is still susceptible to DCS.

In the lung, inspired gases dissolve in the blood and are transported to the body tissues. Over an extended time, the dissolved gases in the body, principally nitrogen, oxygen and carbon dioxide, have variable partial pressures between the various body tissue compartments, and diffusion occurs between these compartments. Nitrogen is metabolically inert and experiences no net diffusion between the various tissue compartments as long as the atmospheric pressure is constant. Since the dissolved nitrogen is in equilibrium with the gaseous nitrogen in the lung, the tissues are said to be saturated with nitrogen.

When the total pressure of the atmosphere is reduced, the partial pressures of nitrogen and oxygen in the alveoli are reduced. The driving force for diffusion, the partial pressure gradients, favors diffusion from the tissues, to the blood, and to the alveoli. Specifically, when the tissue tension of nitrogen exceeds the alveolar tension of nitrogen, a state of super saturating exists. In the lung this "excess gas" diffuses out of solution and is exhaled.

When the reduction in pressure is relatively slow, the gases remain dissolved while being transferred through the tissues and blood. If, however, the pressure reduction is relatively fast, the degree of super saturating may exceed a critical level, and bubbles may form in the tissues. Once a bubble is formed, any further decrease in pressure causes the bubble to grow (Boyle's Law). The formation of bubbles is the initial insult of DCS. This "bubble theory" has become widely accepted as a major component of the etiology of DCS.

The bubble theory is supported by two facts.

(1) The symptoms of DCS are usually preceded by the appearance of bubbles.

(2) Descent or repressurization in a hyperbaric chamber causes a reduction and elimination of bubbles and generally a resolution of symptoms. Bubbles associated with DCS have been found in virtually all tissues in the body. p62

Bubbles have been detected in various tissues with x-ray techniques, light microscopy, dissection, and with ultrasound systems. One indication of impending DCS is the appearance of venous bubbles as detected by an ultrasonic flow measurement system. Bubbles produce distinctive noises, chirps or pops, as they pass through the sonic field.

Although the formation of bubbles is accepted as a key step in DCS, the precise role of bubbles after they are formed is not known. At least three hypotheses seem plausible.

1. Bubbles in the circulation may occlude blood flow, causing ischemia.

2. Intravascular bubbles may cause activation of the clotting mechanism, including platelet activation and platelet adherence to the bubble surface. Furthermore, release of vasoactive agents may affect the contractile state of the microvessels. These factors may exacerbate any occluding effects of bubbles.

3. Expanding extravascular bubbles may impinge upon and distort sensory nerves, causing pain. These events may act simultaneously and synergistically, with each having variable importance depending on the tissue involved.

It would seem that vascular bubbles of any type would present a hazard. However, the first use of the ultrasonic bubble detector in 1968 indicated that "silent bubbles" are produced under decompression schedules shown to be safe. Silent bubbles are those found in the venous circulation that produce no overt symptoms of DCS. Although persons with DCS generally have venous bubbles, the presence of bubbles even in asymptomatic persons suggest that the lung has a high capacity to filter the free gas.

The possible long term effect of years of repeated exposure with the production of venous bubbles remains unknown, yet the presence of these bubbles may be associated with disease states such as bone necrosis. This disease, however, is far more common in divers than in persons exposed to hypobaric environments.

Super saturating and bubble formation are more likely with nitrogen, but other gases may diffuse into an existing bubble. The key role of nitrogen in DCS is supported by another observation. Decreasing total body nitrogen before decompression reduces DCS incidence. Breathing 100% oxygen establishes a diffusion gradient to offload nitrogen from the blood to the lungs. In turn, this establishes a gradient to offload nitrogen from the tissues to the blood. Denitrogenation with oxygen, also called "pre breathing", is the current prophylaxis for DCS. The longer the time spent in pre breathing, the lower is the body's residual nitrogen stores, and the lower the probability of DCS.

Denitrogenation. The rate of nitrogen off loading is not homogeneous throughout the body. That is, some tissues denitrogenate more slowly than others. The rate of washout depends on the biochemical makeup of the specific tissue and the degree of perfusion of that tissue. A specific tissue is said to have a "half-time". Half-time is the amount of time required to reduce the nitrogen content to one half of its beginning content. It is common to refer to "fast tissues" as those that denitrogenate rapidly, and to "slow tissues" as those that denitrogenate more slowly.

There is a continuous distribution of the various half-times for tissues in the body. However, discrete half-times such as 5, 10, 20, and 40 minutes, etc., have been used to simplify mathematical modeling. From empirical studies, it is apparent that some tissues are indeed very slow in eliminating nitrogen. Although the total body reservoir of nitrogen may be one liter or less, nitrogen can be detected in the exhaled gas even after 12 hours of oxygen breathing. DCS symptoms sometimes occur only after the subject has been at altitude for several hours. This suggests that, with regard to DCS p62 development, it is the slow tissues that are involved.

Pre breathing 100% oxygen for 30 minutes prior to initiating ascent to altitude significantly reduces the incidence of DCS for short exposures (10-30 minutes) to moderate altitudes (18,000 - 43,000 feet). This denitrogenation process eliminates nitrogen from the body tissues. In theory, the super- saturation ratio remains below a critical threshold for bubble formation because the value for P_{N2} has been reduced. However, a critical point about denitrogenation must be explained.

Denitrogenation eliminates nitrogen from various tissues at different rates. These rates are

dependent on the solubility of nitrogen in specific tissues but, more importantly, also on the circulatory perfusion of the tissues. Some gases are more soluble than others, and some liquids are better solvents than other liquids. For example, nitrogen is five times more soluble in fat than it is in water. Fat is poorly perfused, thus increasing denitrogenation requirements. Therefore, all body tissues come into equilibrium with each other and with respired gas at different times. With altitude exposure, the saturation ratio of certain tissues always remains within a safe range. This fact may partially explain why signs and symptoms of DCS occur only at characteristic locations in the body.

The volume of nitrogen exhaled during pre breathing follows an exponential process. Off loading is rapid earlier in pre breathing but the rate decreases with time. This denitrogenation function is complex and is actually a sum of the nitrogen leaving all the half-time tissues. The exponential character of the process is caused by the decreased partial pressure of nitrogen in the tissues. As time passes, the diffusion gradient decreases so less nitrogen per unit time is off loaded.

Denitrogenation is also effective in decreasing DCS symptoms even after their initial presentation. The high tension of oxygen encourages the diffusion of nitrogen from existing bubbles and minimizes further growth of existing bubbles. Denitrogenation is generally used as the first treatment for DCS. If conditions indicate, it is also used in conjunction with hyperbaria so that the bubbles are compressed in size; the primary impact of oxygen treatment is to improve oxygen flow to potentially ischemic tissues.

Bubble Growth. Growth of a bubble is influenced by a number of factors. One is gaseous composition. The pressure within a bubble is the sum of the partial pressures of all the gases present. DCS would appear irrespective of which gas had the largest partial pressure. It is only the prevalence of nitrogen in air and its physiologically inert nature that makes nitrogen the chief factor in the DCS of high altitude flight and diving.

When bubbles are produced upon decompression from air breathing hyperbaric conditions, gases other than nitrogen represent only a small percentage of the total gas composition of the bubble. The role of other gases may be significant in bubbles formed at altitude because they represent only a small percentage of the total gas composition of the bubble.

Once a bubble has formed and grown beyond the stage where surface tension tends to force it back into solution, its volume changes with the relative rates of diffusion of gas into and out of the bubble. This diffusion is influenced by a variety of physical and physiological factors. In terms of treatment of DCS, the most important of these is the difference in partial pressures between the bubble and the surrounding fluid. This can be expressed by the equation :

$P = t - P_{ab}$

p62

where:

P = the differential pressure, or tendency for gas to leave the liquid phase, in dynes/cm^2 (or mmHg).

t = total gas tension in the medium, in dynes/cm^2 (or mmHg).

P_{ab} = the absolute pressure (that is, the total barometric pressure on the body plus the hydrostatic pressure).

Within an artery at sea level, t = 760 mmHg. The absolute pressure, P_{ab}, is 760 + mean arterial blood pressure (100 mm Hg) = 860 mmHg. Therefore, P is:

$$P = 760 - (760 + 100)$$

$$P = -100 \text{ mmHg.}$$

Within a great vein at sea level, t= 706 mmHg, P_{O2}= 40, P_{CO2}= 46, P_{N2}= 573, and P_{H2O}= 47. Absolute pressure, P_{ab}, is 760 + mean venous pressure (which in this example is taken to be 0 mmHg). Therefore, P is:

$$P = 706 - (760 + 0),$$

$$P = - 54 \text{ mmHg.}$$

When the value of P is negative, there is no tendency toward bubble formation. If the value for P becomes zero or a positive value, bubble formation is more likely to occur.

By suddenly exposing someone to an altitude of 18,000 feet (380 mmHg), without time for equilibration at the new pressure, venous P would have a large positive value:

$$P = 706 - (380 + 0),$$

$$P = + 326 \text{ mmHg.}$$

As the hydrostatic pressure of the tissues decreases, the deformation pressure of the bubble exceeds a threshold value, causing tissue disruption and intensifying the severity of symptoms associated with DCS. If the hydrostatic pressure increases, the pains of DCS slowly disappear. Hydrostatic pressure is therefore considered to be a force opposing bubble formation and includes not only blood pressure and cerebrospinal fluid pressure but local tissue pressure (or turgor) which varies directly with blood flow.

Once a bubble is formed, its size will increase if the total pressure is decreased (Boyle's law

effect). For this reason, flying after an altitude chamber flight exposure is not recommended. During hyperbaric therapy, on the other hand, bubble size is reduced during compression. The surface tension of a bubble is inversely related to bubble size and opposes bubble growth. Thus, as total pressure is increased, the surface tension opposing bubble growth is also increased. Once a critically small bubble size is achieved, the surface tension is so great that the bubble can no longer exist. The bubble collapses, and its gases are reabsorbed.

A.3.11.4 BUBBLE EFFECTS ON THE BODY

Theoretically, regardless of their precise site of origin, bubbles have two major categories of effect in the body .

Mechanical Effects. Bubbles can be detected by Doppler techniques once p62 they reach a size of 40 to 50 microns, especially if there are many of them. However, it is important to remember that Doppler sounds also demonstrate "silent" bubbles, which are not synonymous with bends of DCS.

All tissues have structure, possess varying degrees of elasticity, and tend to resist deformation. A gaseous bubble growing in the tissues will displace and deform adjacent structures. When the deformation pressure exceeds a threshold value, nerve fibers or endings are stimulated. The intensity of stimulation and hence the severity of pain symptoms is directly proportional to the excess deformation pressure above the threshold value. In theory, growing bubbles may create sufficient mechanical pressure to block conduction in the nerve fibers in nerve trunks, spinal roots, and the central nervous system. The occasional paralysis and losses of sensation seen in subjects at reduced atmospheric pressures seem to support such a mechanism.

If the deformation pressure of the bubble becomes too great, the local tissues give way, tearing of limiting membranes will takes place, and destruction of formed elements occurs. The resulting tissue trauma may account for the post-exposure symptoms, from the smallest areas of tenderness and edema to the most grave neurologic disturbances.

Bubbles can mechanically obstruct vessels, leading to ischemia and possible circulatory collapse. A large volume of gas bubbles in the right side of the heart may interfere with cardiac contraction by forming an air lock. This could cause a massive infarction and death. If there is an excess number of bubbles, the pulmonary filtration system may become overloaded, causing pulmonary hypertension (chokes). This syndrome may further lead to right ventricular failure and circulatory collapse.

Bubble-Blood Surface Interface Effects. Bubble-blood surface activity indirectly provides the mechanism to release bound lipids, activate enzymes, and alter proteins that in turn promote the clumping of red cells and aggregation of platelets at the bubble surface. Although bubbles may conceivably appear first in the arterial or capillary areas, most of the current measurements relate to their movement within the venous systems. They are released freely into the veins, either due to their own growth or because of disruption by movement of the tissue or limb.

As venous bubbles produce platelet aggregation, there is a release of vasoactive substances such as serotonin and epinephrine, leading to vasoconstriction. Aggregation in the post-capillary vessels and small veins blocks capillary flow, causing tissue ischemia. The release of

platelet factor 3 accelerates clotting and creates further circulatory embarrassment. Blood viscosity increases with a concomitant rise in capillary flow resistance and capillary pressure. These effects, coupled with ischemia, lead to large shifts of fluid from the intravascular to the extravascular spaces. The volume loss decreases venous return and a further reduction in blood flow ensues. The resultant hemoconcentration increases the hematocrit and blood viscosity, and raises the fibrinogen concentration. These relationships generate a vicious cycle which can be reversed only when DCS is treated by hyperbaric and adjunct therapy.

A.3.11.5 CLINICAL MANIFESTATIONS OF DECOMPRESSION SICKNESS

Type DCS. Type I DCS includes joint pain (musculoskeletal, or "pain only" symptoms) and symptoms involving the skin (cutaneous symptoms) and lymphatics.

(1) Lymphatic Manifestations. Pitting edema is caused by blockage of the lymphatics by a bubble. It has been reported as a secondary finding in the p62 vicinity of a painful joint which may have been the presenting symptom. It occurs less commonly in the absence of other manifestations, such as edema of a hand, limb, or, rarely, the face. Though specific treatment is not necessary for this condition, hyperbaric therapy is advised to help relieve pain, decrease swelling, and possibly reduce more serious manifestations from developing later. It should be noted that peripheral swelling may disappear completely during recompression, but usually it takes days or weeks for swollen lymph nodes to subside after treatment.

(2) Cutaneous Manifestations. Skin symptoms (paresthesias) can result from extravascular or intravascular bubble formation in the skin. In the first instance, only when the size of an extravascular bubble is sufficient to mechanically stimulate sensory receptors will the modalities of touch, pressure and temperature be affected. Sensations that are described include pruritis (itching), formication (insects on the skin), mild stinging or pin pricks, hot or cold feelings that may or may not alternate in occurrence, and sometimes numbness. These skin symptoms are usually quite transient. Sensations of vibration and diffuse or localized pain are not typical of the paresthesias associated with skin DCS. Were this form of DCS allowed to progress without treatment, a crepitus sensation caused by subcutaneous emphysema could theoretically occur.

Concurrent with the localized nature of paresthesias is a characteristic flushed or mottled appearance of the skin that sometimes appears. Vasodilation of the affected area may likely be the result of an axon reflex, although intravascular bubble formation (causing stasis) is possible. Consequently, an irregular spatial arrangement of skin perfusion is observed.

Intravascular bubble formation in the skin circulation may produce some of the same skin manifestations. Due to interruption of the circulation, some skin areas may turn pale and eventually exhibit a mottled, cyanotic appearance, or marbling. Such marbling may be present in several diagnostic forms even including a histaminergic response, or rash, but in every instance is ultimately the result of bubble formation. Without bubble resolution endothelial damage may occur, resulting in localized edema. Edema may also occur if there is obstruction of the venous lymphatic drainage from the affected area.

The most common cutaneous manifestations of decompression sickness or pruritus and cutis marmorata (marbling). These manifestations range from being local and innocuous, to generalized and ominous, with a complete spectrum in between. Pruritus may occur with or without a punctate scarlatina form rash, and is most commonly seen during decompression

from deep, short, "dry" dives, i.e., chamber dives in which the skin is surrounded by chamber atmosphere rather than water. Some researchers postulate that this may be partly or wholly due to the atmospheric gas passing into the skin from the hyperbaric gas environment.

Pruritus is often a transient, presenting very soon after decompression, and is not considered a systemic manifestation of DCS. The condition is best described as a sensation of cutaneous prickling, as if a pin-point sized bubble were embedded in the skin. The ears, face, neck, arms, and upper torso are most commonly affected. Pruritus is generally self-limiting and begins to resolve shortly after decompression (from a dive) is complete.

Cutis marmorata (marbling) is caused by venous obstruction of the skin by bubbles or by vascular spasm in response to subcutaneous bubbles. This condition usually starts as intense itching around the shoulders, upper thorax, or upper abdomen. After a variable period of time, areas of erythema (redness) appear, ultimately giving way to patchy, dark bluish discoloration p62 of the skin (cyanotic marbling). The skin may feel thickened. In some cases the rash may be raised and blanches by direct pressure. Crepitus has not been observed.

Marbling is a bona fide form of DCS which should be treated by recompression. Therapy usually leads to complete resolution of signs and symptoms. Marbling is often a harbinger of more serious forms of DCS, since gas bubbles are present in both tissues and blood vessels.

Skin symptoms, when they occur, are not life-threatening. Though they do not always precede other DCS symptoms, skin manifestations can serve as a warning that similar bubbling has occurred elsewhere in the body. Hyperbaric treatment, or at least medical monitoring, is advised. If skin symptoms occur during flying, immediate descent is required and the crew member should see a flight surgeon.

(3) Musculoskeletal Manifestations. Pain in and around the joints or, less commonly, in large muscle masses, is called the bends. It is the most common manifestation of DCS. Often the pain is described as being "deep" and throbbing. With time the pain tends to radiate or extend along the limb. Severity ranges from barely perceptible to severe. There is a tendency for the person suffering from the bends to work the joint, attempting to ease the pain. This generally is not effective and often worsens the pain.

Bends pain, as with other DCS manifestations, generally worsens with time at altitude. Pain may decrease with descent, but in some cases the pain may begin and worsen after return to ground level. Unfortunately, the amelioration of pain occurring on descent has, at times, convinced the crew member to continue the mission or fail to report the incident after landing. Although bends is not commonly thought of as having the consequence of the more systemic forms of DCS, such as CNS disorders, the pain is often progressive and can lead to total debilitation. In severe cases, the pain effectively prevents movement, with obvious consequences to aircraft operations. Severe cases can lead to collapse, either directly by the effects of pain, or by other DCS manifestations that may occur at the same time. Furthermore, bends pain may not develop exclusive of other manifestations, but may be the most prevailing.

Although bends pain was originally attributed to evolved gas (bubbles) in the joints, this explanation most certainly is simplistic. Radiographs have indicated free gas may or may not be present in the joint when pain occurs. A more likely explanation involves free gas in the connective tissue in the area of the joints which may stimulate pain receptors. As indicated

above, bends pain is the most common manifestation of DCS.

Susceptibility of the joint area may be a consequence of the anatomy vis-a-vis circulation and constituency of connective tissue. The joints consist of relatively non-distensible tissue. Bubble formation may be more likely to impinge on sensory nerves contributing to the perception of pain. Additionally, perfusion of these areas is relatively poor, and this may preclude the removal of nitrogen via diffusion gradients established when blood flow is as good as in other tissues. Thus, a perfusion limitation may exist.

Type I DCS of this kind refers to "pain only" symptoms. Joint pain is by far the most common type, approximating 90% of all cases of DCS, but other types of pain may occur which do not involve joints. The shoulder is the most common site of joint pain, but the elbow, wrist. hand, hip, knee, and ankle may be involved. Often, when two joints are involved, they are adjoining ones, and frequently the localization is between joints, over the scapula, on tendon insertions, etc. Rarely is the involvement symmetrical. p62

Active and passive motion of the joint tends to aggravate the discomfort. The application of local pressure by means of a sphygmomanometer cuff may result in considerable relief and may be a rudimentary means of diagnosis. The characteristic pain of Type I DCS has been described as a deep pain, sometimes a dull ache, but rarely a sharp pain, with intensity ranging from an awareness (a "niggle") to an excruciating pain. When joint pain occurs, it is not uncommon to have aching pain in the muscles around the joint.

In altitude DCS, the pain may occur during the altitude exposure, on descent, shortly after descent, or, in some cases, only become manifested several hours after descent. In most cases, DCS occurring at altitude is relieved by descent because of the increase in barometric pressure. In some cases, pain symptoms relieved by returning to ground level recur at ground level. In these cases, as well as those cases where pain is not relieved by descent, hyperbaric oxygen therapy is the definitive form of treatment. Ordinarily, an aviator that is effectively treated for Type I DCS can be returned to flying duties in 72 hours.

A sharp, knife-like pain that shoots down an extremity or encircles the body trunk (radicular pain), vague thoracic or abdominal pain, or pain that moves from one area to another and is clearly related to a painful hip or shoulder joint, should be treated as arising from CNS involvement and treated as Type II symptoms. Pain may mask other, more significant symptoms, and therefore should not be treated with drugs in an effort to make the patient more comfortable. The pain may be the only way to localize the problem and monitor the progress of treatment.

Type II DCS. In the early stages, symptoms of Type II DCS may not be obvious and Type I symptoms may or may not be present at the same time. For this reason, symptoms must be looked for during post-flight after a decompression to high altitude, during a post-dive period, and treated before they become too severe. Type II DCS comprises serious symptoms or signs involving the central or peripheral nervous system, or the cardiopulmonary system. Any aviator experiencing Type II DCS requires waiver to return to flying duties.

(1) Pulmonary Manifestations. The chokes is a DCS disorder that is marked by sharp, substernal pain that increases in severity with inspiration. The affected person commonly has a feeling of suffocation with an obvious concurrent apprehension. The individual often is pale and

sweating and feels fatigued and faint. A dry, progressive cough is frequently present. Total collapse may occur in severe cases. Bubbles associated with chokes may be in the interstitium of the lung tissue or carried from peripheral tissues to the lung circulation.

Chokes is often confused with air embolism. Air embolism can be caused by a breach in the alveoli, permitting gases to enter the circulation. Holding one's breath while ascending in diving is the most common cause of air embolism, but it also may occur if the breath is held during a decompression to a higher altitude. Ascent and subsequent expansion of alveolar air can burst the alveoli.

Chokes, on the other hand, is caused by gases already in the circulation in gaseous form. An arterial embolism can cause immediate debilitation and death in a short time particularly if the embolus lodges in the central nervous system. True chokes, however, is primarily manifested in the lungs and has a longer course of progression.

Pulmonary manifestations of DCS are rare, accounting for less than 2 percent of all cases. The symptoms usually develop several hours after the exposure and are life threatening. The mechanism is most likely progressive p62 embolization of the pulmonary capillary bed by air bubbles formed in peripheral veins and carried to the lungs as gaseous pulmonary emboli. Reduced gas exchange and circulatory embarrassment can occur as a direct result of such embolization. The flooding of the systemic arterial circulation by bubbles forced through pulmonary shunts might be an indirect serious consequence of chokes.

The most specific early symptom of the chokes is a substernal pain made worse by deep inspiration. The triad of dry, nonproductive cough, dyspnea, and burning pain on inspiration must be differentiated from the burning inspiratory pain often felt after breathing dry oxygen for prolonged periods. Chokes that are allowed to continue without treatment result in marked dyspnea with shallow respiration, cyanosis, loss of consciousness, and circulatory collapse. Left untreated, death may follow. Immediate hyperbaric therapy is required.

(2) Neurological Manifestations. These manifestations appear to be associated with disturbances within the brain or the spinal cord. Because of the controlling function of the central nervous system, signs and symptoms may appear in virtually any area and system within the body.

Perhaps the most common neurological manifestation involves vision. Symptoms are commonly unilateral but may be bilateral. Although neurologic manifestations are rare, the consequences are serious. If untreated, symptoms often progress even after descent. Permanent defects have occurred in rare incidents and some deaths have been recorded.

Neurological DCS may be manifested by a wide range of signs and symptoms involving the central or peripheral nervous system. About 25 percent of all DCS cases include signs of neurologic involvement. In aviators, the brain is most commonly affected while lesions in divers often involve the spinal cord. Central nervous system involvement includes both the brain and spinal cord. When the spinal cord is involved, the lower thoracic or upper lumbar segments are most frequently affected, producing motor and sensory disturbances like paraplegia, monoplegia, paresis, paralysis, spasticity, loss of bladder and rectal control, muscular weakness, altered reflexes, and paresthesias (collectively from numbness, tingling, and decreased sensation to touch and pain). Some cases of spinal cord DCS begin with girdling

abdominal or thoracic pain, which precedes the onset of sensory and motor deficits. Within 30 minutes of onset, the entire clinical picture of a partial or complete transverse spinal cord lesion may be manifested.

Cerebral DCS is one of spotty sensory and motor signs and symptoms not attributable to a single brain locus. Visual disturbances are the most common manifestations from altitude exposure, including blurring, scotomas, tunnel vision, diplopia, and other field defects. Other manifestations frequently noted are headaches, spotty motor or sensory deficits, unilateral paresthesias, and a confused state. Seizure activity, dizziness, vertigo, nausea, vomiting, and unconsciousness may also occur.

When the cerebellum is involved, ataxia, tremor, nystagmus or a lack of coordination may be present. In some cases, extreme fatigue or personality changes ranging from emotional lability to a significant flattened affect are the presenting symptoms.

Inner ear or labyrinthine DCS ("staggers") is a common manifestation of central nervous system involvement. In these cases, either the cochlea or the vestibule, or both may be involved. The presenting symptoms, therefore, include tinnitus, deafness, vertigo, nausea, vomiting, and ataxia. Physical examination may reveal nystagmus. Involvement of either the hearing or the vestibular system may predominate. Inner ear DCS is a true emergency, and it must be treated immediately if permanent damage is to be avoided. Because the nutrient arteries supplying the inner ear are small, a rapid reduction in bubble size is important.

Peripheral nervous system involvement may include the cranial nerves, spinal nerves, and the autonomic nervous system with such motor and sensory disturbances as numbness, paresthesia, paresis, paralysis, and muscle weakness or twitching. Immediate hyperbaric therapy is required.

Permanent neurologic deficits result from spinal cord DCS and are most feared by divers. Even with proper and rapid treatment, approximately 15% of patients who have suffered spinal cord DCS show some degree of permanent neurologic deficit from minor sensory and motor losses to complete paraplegia.

(3) Circulatory Manifestations. Some authors attempt to segregate circulatory manifestations from other manifestations. More likely, circulatory manifestations occur concurrently with or are secondary to the other forms of DCS. The signs are usually circulatory shock. Although these effects may be secondary to other forms, direct effects of bubbles on the vasomotor areas of the CNS are a likely factor.

Generally, circulatory impairment is manifested as shock following the development of chokes, severe bends pain, or severe neurological impairment. Circulatory collapse without other symptoms preceding the development of shock has not been reported. Possible mechanisms of circulatory collapse include direct involvement of the vasomotor regulatory center or massive vessel endothelial damage by the bubbles, with subsequent loss of intravascular fluid. Hematocrits as high as 70% have been recorded in some cases.

Whatever the course, a hallmark of this grave sign is its refractiveness to fluid replacement. This is similar to the response commonly seen in a severe head injury that results in a central "sympathectomy." Treatment should consist of hyperbaric therapy and fluids, along with vasopressor agents. Failure to treat the patient within 6 to 24 hours after symptom onset can

result in death.

A.3.11.6 FACTORS AFFECTING DCS INCIDENCE AND SEVERITY

Certain physiological and environmental factors pertaining to both altitude and diver DCS are thought to increase the likelihood or severity of this syndrome. Most of these influence the blood supply to tissues and therefore, the speed of gas uptake or release. In general, analyses of these factors do not predict the probability that a person will suffer DCS, but are believed to indicate individual susceptibility in a large unselected group.

Altitude. Increasing the altitude contributes to an increased incidence of DCS. A higher altitude increases the degree of super saturating which increases the probability of bubble formation. Considerable debate surrounds the minimum, or threshold altitude for DCS. Recent evidence indicates DCS is possible as low as 13,000 feet, but it is rare unless an extended period of time is spent at the altitude. Although no discrete boundary exists, the most commonly cited minimum "bends altitude" is 25,000 feet. Based on decades of unpressurized flight in Air Force trainers to FL 250, this may be a reasonable supposition.

Indeed, relatively few cases occur below this altitude in routine flight, but the crew member must be warned of this potentially debilitating situation. Aircraft pressurization has substantially decreased DCS incidence because it effectively exposes the crew member to a lower physiologic altitude (cabin altitude). However, at some flight altitudes, e.g., greater than 40,000 feet, the cabin altitude may still be in the DCS danger area. More commonly, a loss p62 of pressurization because of a system failure may rapidly expose the crew member to an altitude equal to the ambient altitude.

A flyer whose body tissues are in equilibrium at sea level achieves a condition of super saturating during decompression to altitude, as during the loss of aircraft pressurization or simulated flights in an altitude chamber. The occurrence of DCS with altitude exposures of less than 18,000 feet is exceedingly rare unless there was a precipitating factor, such as recent exposure to compressed gas breathing (scuba diving) within 24 hours. During such conditions, DCS onset may occur at altitudes of 5,000 feet or less.

With increasing altitude and duration of exposure, the incidence of DCS also increases, as does the ratio of severe to mild cases. A second exposure to altitude to greater than 18,000 feet within 3 hours of a preceding flight greatly increases the chance of DCS occurring, even if the first exposure was asymptomatic. A recurrence of symptoms is almost certain if the first exposure is symptomatic. The aviator is protected from DCS by maintaining aircraft pressurization, and through the process of denitrogenation. At altitudes greater than 25,000 to 30,000 feet, the incidence of DCS (above 75%) does not increase as a function of altitude. However, the time at altitude before the first manifestation of DCS does decrease with increased altitude.

Time at Altitude. Increased time at altitude contributes to a greater incidence of DCS. It would appear that if one remains at altitude long enough, nitrogen stores would be depleted and the DCS probability would decrease. However, altitude exposure itself causes a decrease in the denitrogenation rate. More importantly, bubble formation and subsequent effects causing pain and incapacitation usually occur before the point when tissue nitrogen is reduced to the extent that bubbles can no longer form or grow. More likely, increased time at altitude permits growth

of bubbles that are otherwise innocuous at a smaller size. A rapid descent after a decompression and particularly after experiencing any manifestation of DCS is critical in minimizing the hazard of DCS. In most cases, descent and landing as soon as possible eliminates the pain of simple limb bends.

Rate of Ascent. A faster rate of ascent to altitude contributes to a greater incidence DCS. A slow ascent permits excess nitrogen to be transported in solution from the tissues to the lungs so a supersaturated state is less likely. Rate of ascent probably has been overemphasized in the past. Generally, a rapid decompression taking a few seconds has about the same incidence as a decompression taking a few minutes. If the decompression is slow (several hours), the risk decreases significantly.

Exercise. Exercise during decompression or immediately following the exposure speeds the elimination of nitrogen from some areas of the body and enhances bubble formation. The formation and growth of gas micronuclei and increased carbon dioxide production from exercising muscle, have been postulated to explain the increased incidence that is actually observed. Because carbon dioxide is a highly soluble gas, it can diffuse rapidly into a gas phase, aiding in the formation, stabilization, and growth of micronuclei, thus producing the onset of DCS. It has been found that even small increases in the fractional concentration of carbon dioxide in inspired gas can significantly increase the probability of DCS.

Exercise during altitude exposure increases DCS incidence. Other factors that may contribute to this effect include the sliding movement of one tissue against another, such as in joints and in muscles, which causes a shearing action to encourage bubble formation, and contracting skeletal muscles, which may cause areas of local blood cavitation and turbulence, encouraging bubble formation. For this reason, persons exposed to high altitude should minimize p62 exercise. Furthermore, if DCS does develop, any additional movement especially of the limb (in the case of bends) may worsen the condition.

Some studies have shown that exercise during the pre breathing period may decrease DCS incidence during the subsequent exposure. The suggested mechanism is that increased blood flow to the muscles accelerates nitrogen off loading. This factor remains unproven.

The effect of exercise after return to ground level following an altitude exposure remains unproven. Numerous anecdotal accounts, however, suggest that post flight exercise increases the probability of delayed DCS. Furthermore, post flight exercise-induced injury may be confused with or mask DCS pain. Finally, if asymptomatic bubbles caught in the lungs pass through to the arteries as cardiac output increases blood flow in the lungs, then very serious DCS symptoms may arise. For these reasons, persons exposed to high altitude should be discouraged from strenuous exercise immediately after exposure.

Body Fat. Earlier studies have emphasized that an increased proportion of body fat increases the probability of DCS. This theory was based on the fact that nitrogen is about five times more soluble in fat than in water and functions as a reservoir for the gas. Recent studies have not confirmed the correlation between body fat and DCS in persons who have met USAF weight standards, i.e., those persons not significantly different from average weight for a given height. However, early studies involving DCS-related deaths noted that in most cases the victim was either obese or grossly obese. Furthermore, in a recent (1987) flight-induced DCS death, the crew member was obese.

There is no scientific evidence to validate whether or not obesity increases the probability of diving DCS. However, when body fat, rather than body weight, is examined in relation to DCS, it is clear that obesity does increase the probability of DCS, especially after long, deep dives. The reason for this increased probability is that adipose tissue is slow to take up or eliminate inert gas because of its relatively poor blood supply and increased inert gas solubility.

Fat reservoirs, such as the abdomen and buttocks, typically are not the sites of DCS pain, although large volumes of nitrogen are likely to be contained there. Furthermore, fat depots are generally poorly perfused, further decreasing the effect of denitrogenation. Fat is poorly innervated with pain receptors and easily distensible. If bubbles in the fat are formed, they may not produce pain.

It should be noted that medical emergencies are difficult to manage and are generally more hazardous in an obese person. This may partially account for the increased mortality. In summary, the crew member slightly above average in body fat content but who meets current weight standards is not at a measurable increased risk.

Previous Injury. There are numerous accounts of bends pain occurring preferentially in areas that have been previously injured. No objective data are available for analysis to support this theory. However, injury may cause blood perfusion changes or deposition of scar tissue. It is possible that these changes decrease nitrogen washout rates and predispose bubble formation in these areas. In addition, flight often involves extended periods in cramped conditions. Pain not actually associated with bubble formation may mimic bends pain. Since diagnosis under these conditions is difficult, such pain must be carefully studied.

Injury. Recent local injury may predispose a diver to DCS at or near the site of the injury. Such DCS is manifested as localized pain. Although the mechanism which accounts for the predisposition is unclear, it has been p62 suggested that changes in local perfusion and an increase in gas micronuclei formation in the injured tissue may be responsible for this effect.

Age. Before the age of about 40 years, no correlation between age and DCS incidence is clearly demonstrated. After 40 years, DCS incidence increases with increased age. This increase occurs in both compressed air workers and aviators, with a three-fold increase in incidence between the 19-25 year old and 40-45 year old age groups. The mechanism underlying this phenomenon is not understood but may result from changes in circulation due to aging. Factors contributing to this effect might be an increased deposition of fat within connective tissues, and changes in capillary density and permeability.

Sex. A great deal of controversy exists regarding the possible differences in susceptibility to DCS between men and women. There is some information which suggests females are 2 to 3 times more prone to DCS than males exposed to similar diving conditions.

Blood Factors. Recent studies have indicated that persons with elevated serum cholesterol undergoing experimental altitude chamber flights have an increased incidence of DCS. Other blood factors, particularly those involved in clotting mechanisms, also may be related to DCS incidence. This information is valuable because these factors may serve as a predictor of those persons who are prone to form bubbles and develop DCS.

Temperature. No correlation exists between the frequency of DCS and the ambient temperature in the range of 21.1 ^{o}C, to 34.3 ^{o}C. However, at an ambient temperature of -23.3

^{o}C, the incidence of DCS is twice that at 21.1 ^{o}C, with a larger ratio of serious cases to mild cases. Temperature, then, is usually of little or no consequence to altitude-induced DCS.

Diving in cold water increases the probability of DCS. Inert gas uptake is actually reduced when working during a cold dive as compared to a warm water dive or a dive with a hot water suit. The diver begins the dive euthermic and exercise lessens the vasoconstriction that would otherwise occur in response to the cold. During decompression to the surface, the diver is less active, allowing sufficient time for hypothermia to develop and peripheral vasoconstriction to ensue. Inert gas elimination is greatly impeded and DCS follows.

Pre breathing at Altitude. Breathing 100% oxygen during ascent or at altitude, though it may have operational significance in order to hurry up the launch of aircraft, is not as effective in eliminating nitrogen as pre breathing at ground level for an equal time. As ambient pressure decreases, the tension of nitrogen in the tissues decreases. The number of molecules of nitrogen is still the same, but the partial pressure cannot remain the same because the total pressure is less. Although the volume of nitrogen dissolved in the periphery remains the same, the diffusion gradient (the difference between the tension of nitrogen in the alveoli and in the various tissues) decreases. Since the diffusion gradient, not the volume, determines the rate of denitrogenation, pre breathing at altitude is less effective. Nitrogen is off loaded more slowly and the probability of DCS increases.

Break in Pre breathing Schedule. It was once thought that if a person breathed air during pre breathing, the break in pre breathing could be compensated by extending the pre breathing period by an equal amount of time. Recent studies have shown this assumption to be false. Breaks in denitrogenation usually occur when there is an equipment failure, the oxygen regulator is accidentally reset to the NORMAL (less than 100%) oxygen setting, the mask is removed, or the mask fit is unacceptable.

Since denitrogenation is an exponential process, a great amount of the total body stores of nitrogen is off loaded early in the pre breathe period. The p62 partial pressure of nitrogen decreases rapidly, particularly in the fast tissues, during the early part of pre breathing. If pre breathing is interrupted with even short periods of air breathing, the diffusion gradient strongly favors nitrogen diffusion into the tissues. Since this on loading rate is faster than the off loading rate, an equal amount of time added to the pre breathe period does not return the tension of tissue nitrogen to a level equal to the tension had the pre breathe period not been interrupted.

Estimates have been made of the additional time that must be added to the total denitrogenation period to compensate for breaks in pre breathing. These formulas are not practical in the training arena. A good general rule to follow is, if the air breathing period exceeds a few breaths, it is best to restart from the beginning.

Furthermore, intravascular bubbles, even when occurring without symptoms, can decrease the nitrogen off loading rate. This may be due to the occlusive effects of the bubbles in both the pulmonary and systemic vasculature. The decrease in the denitrogenation rate is exacerbated. Finally, one should be aware that a poor mask fit can increase the probability of DCS. Even small inward leaks can decrease the diffusion gradient and diminish the effectiveness of pre breathing.

Repeated Exposure. There is controversy concerning the effects of repeated exposure, that is,

two or more altitude exposures in succession. It appears that exposures occurring in rapid succession within minutes or a few hours of the previous exposure increase the incidence of DCS during the subsequent exposure. This is presumably because some bubbles may remain from the previous exposure. Bubble growth is more likely under this condition. If the exposures occur on successive days, there is no increase in the incidence of DCS, but the time of first appearance of symptoms is decreased in the subsequent exposure.

Diving. Safe decompression limits vary with the time and the depth of the dive. A diver may exceed these safe limits either through missed decompression stops to the surface or through multiple ascents during a dive, thus enhancing the presence of venous gas bubbles. If a diver exposes himself to increased pressures within 24 hours of a previous dive, the residual nitrogen remaining within the tissues may increase the likelihood of DCS. Mild or insignificant cases may become worse.

If asymptomatic (silent) bubbles have been produced by diving, then subsequent diving even longer than 24 hours afterwards may precipitate DCS. It has been found that after the pains of DCS are produced and relieved by increasing the atmospheric pressure, they can recur almost immediately and at the same site after re ascent if the time spent at higher pressure is less than three hours. This definitely indicates the presence of extravascular bubbles or gas nuclei at specific sites in the tissues and demonstrates how slowly the extravascular bubbles are reabsorbed.

High Altitude Diving. Diving in mountain lakes and other bodies of water that exist at altitudes well above sea level creates special problems for the diver. Sea-level decompression tables become less safe as altitude increases. Several decompression methods for altitude diving have been proposed, but few have been human tested. Special decompression schedules have been provided to the Peterson AFB hyperbaric facility because of its elevation above 6000 feet.

Flying After Diving. SCUBA diving followed by altitude exposure vastly increases the incidence of DCS. Furthermore, the procedure decreases the minimum altitude at which DCS manifestations begin. This can be demonstrated even during flight on aircraft equipped with excellent pressurization systems such as commercial airlines, whose cabin altitudes are 1524 - 2438 meters p62 (5,000 to 8,000 feet).

Persons who have been diving usually have elevated nitrogen stores, i.e., are supersaturated, after return to the surface. This elevated tissue nitrogen predisposes the diver to bubble formation, especially in the slow tissues. In addition, subclinical bubbles may form during a dive, fail to resolve on return to the surface, and expand while ascending to altitude. Some special military operations limit the maximum cabin altitude of flight to be determined by the maximum depth and time at depth. In practice, however, this is difficult to control. The USAF policy for all except special operations is to forbid flight within 24 hours of a compressed air exposure.

Flying following diving potentiates bubble formation by theoretically increasing the super saturating ratio beyond the critical threshold, even after an uneventful decompression to sea level. There are enough cases of DCS to substantiate this theoretical consideration. Absolute limits for the interval between diving and flying based on specific hyper/hypobaric conditions have not been developed. Therefore, the present conservative approach of the Air Force is to specify 24 hours between any dive and subsequent altitude exposure. Recent Navy experience with divers using saturation tables has shown that DCS can result 4 days after surfacing if the

diver is exposed to altitude. Thus, for exceptional exposure dives, the 24-hour non flying rule is too short. Until more conclusive research is accomplished in this area, the 24-hour restriction appears to be a practical solution for Air Force aviators.

Individual Variability. There is great variability in individual susceptibility to DCS. Under the same conditions, persons develop DCS while others show no signs or symptoms. There is also variability within individuals, but this is smaller than the between-individual variability. There is a tendency for a person who develops DCS under given conditions to again develop DCS later under similar conditions. Individual susceptibility was the basis of the effort to screen "bends-prone" flyers during World War II. However, since the factors predisposing DCS are extremely complex, a single case of bends in an individual is not indicative of consistently recurring problems during future exposures. Individuals who suffer bends are often generally affected in the same area upon subsequent exposure. This suggests that there are specific anatomic factors predisposing DCS in those areas.

A.3.11.7 TREATMENT OF DCS

Initial Response to DCS Onset During Flight. Decompression sickness continues to occur during altitude chamber training exposures. Pre breathing before ascent significantly lowers the incidence of DCS, but many hours of denitrogenation are required for total protection. The same is true for operational flying. Whether or not unpressurized operations are planned or occur accidentally, the development of DCS symptoms must not be taken lightly. All cases of DCS should be treated as an emergency. If a trainee or crew member is suspected of developing DCS, the following procedures should be used.

1. Descend and use 100% oxygen from an aviators oxygen mask during the entire descent. The increased pressure on descent serves to compress existing bubbles. Oxygen serves to establish a diffusion gradient to further reduce the size of bubbles. Often the pain associated with DCS decreases or completely disappears on descent. Resolution of pain does not cancel the emergency.

2. Land (or return to ground level in a chamber) as soon as possible and remain on oxygen.

3. Get qualified medical help. Delayed DCS manifestations are possible p62 after return to ground level whether or not manifestations were present at altitude. In the case of altitude chamber induced DCS, students are no longer under the supervision of an aerospace physiologist after they depart the altitude chamber, thus, they should be instructed to be aware of the possibility of post flight symptoms.

Medical Management of DCS. The following procedures should be adhered to in all cases of DCS (Type I and Type II) persisting at ground level:

a. Place the patient in a supine position and immediately provide 100% oxygen by a tight fitting aviator's mask. The use of 100% oxygen enhances nitrogen elimination by increasing the diffusion gradient of nitrogen and relieves tissue hypoxia. Avoid using other hospital-type oxygen masks and nasal cannulas.

b. Intravenous fluids (normal saline, Ringer's lactate) should be used to restore intravascular volume since hemoconcentration can occur with loss of volume from the vascular compartment. An infusion rate of 250 cc/hour is recommended for the first few hours.

c. If no differential diagnosis can be made between serious DCS and arterial gas embolism, treat for arterial gas embolism. The incidence of gas embolism in aviators is rare. The absence of a rapid decompression exposure usually indicates that the symptoms are DCS related.

d. Do not ignore seemingly minor symptoms. They can quickly become major. If multiple symptoms occur, treat for the most serious condition. In order of increasing severity they are: Type I DCS, Type II DCS, and arterial gas embolism.

e. If a hyperbaric chamber is on site, the patient should be moved to the chamber and immediately treated on the proper hyperbaric treatment table. No observation period is warranted at ground level. The effectiveness of treatment decreases as the length of time between the onset of symptoms and the treatment increases.

f. If there is no on-site hyperbaric chamber, arrangements should be made for immediately transporting the patient to the nearest hyperbaric facility capable of administering proper treatment. The patient should be kept on 100 percent oxygen by aviators mask while awaiting and during transportation to the chamber. If the patient has bends pain only symptoms, and these clear completely without recurrence while awaiting transport, movement to be hyperbaric chamber can be canceled.

g. If bends pain is relieved while awaiting transport but symptoms recur, the patient should be transported and treated even if symptoms are relieved again after recurrence.

h. Any patient with symptoms or signs of neurological DCS, chokes, or neurocirculatory collapse (shock) should be immediately transported to the nearest chamber regardless of whether or not the symptoms persist.

i. Transportation must be at or near sea level pressure. Aircraft used for movement must possess this pressurization capability. (Any requirement to deviate from sea level pressures must be discussed with U.S. Air Force School of Aerospace Medicine (USAFSAM) hyperbaric physicians.)

j. The USAF Hyperbaric Center physician on call at USAFSAM (AUTOVON, daytime 240-3281, nights 240-3278) should be notified as quickly as possible concerning all known or suspected cases of DCS regardless of where they are to be treated or whether or not they are to be treated.

Patient Treatment for DCS. Once the diagnosis of DCS has been made, hyperbaric compression therapy is required. If the patient must be flown to the nearest recompression facility, the use of air transportation may prove life-saving. The patient should be transported at a cabin pressure as near as p62 possible to sea level. The use of a pressurized aircraft is ideal, but if a helicopter or other unpressurized aircraft must be used, a maximum flying altitude of 800 to 1000 feet should never be exceeded. If the patient is exposed to high altitude, bubbles in the tissues will expand and the medical condition will deteriorate rapidly.

If oxygen is available, it should be administered by a tight fitting mask and used continuously during flight. Whether DCS or air embolism is the cause for a patient's signs or symptoms, immediate use of hyperbaric therapy is in order. It is never acceptable to continue observation if the patient is improving. The use of oxygen at 1 ATA for such patients should be restricted to the period of initial observation and examination, the time required for transportation to a

hyperbaric chamber, and while the hyperbaric facility is being prepared for use. Oxygen at 1 ATA is not a substitute for hyperbaric therapy.

Adjuncts to Hyperbaric Therapy. In the treatment of DCS, there is no substitute for hyperbaric therapy. However, secondary development of blood sludging, increased platelet aggregation, hemoconcentration, reduced blood volume, and edema must be corrected with drug therapy. Compressing the bubbles that initiated the decompression sickness does not repair these secondary effects. Decisions to use such adjunctive measures as steroids, low-molecular-weight dextran, plasma, and plasma expanders must be made by the responsible team medical officer in view of the patient's condition and response to hyperbaric therapy. Patients may also have unrelated problems requiring therapy, such as trauma, burns, poisoning, or infections. The team medical officer must be prepared to give the patients medical therapy for these conditions while hyperbaric therapy is being administered.

A.3.12 EFFECTS OF ACCELERATION

A.3.12.1 INTRODUCTION

Aeromedical concern about the effects of acceleration has a long history. Concern was first stimulated during World War I when pilots complained of a loss of vision and consciousness during pullouts from dives in aerial combat. Interest in this area has continued until the present day, where the effects of sustained acceleration have become a major limiting factor in the operation of the newer generation fighter aircraft (F-15, F-16, F-18). Because of their high thrust-to-weight ratios and structural strength these aircraft are able to routinely fly in the 7 to 9 +Gz range for sustained periods. Future aircraft designs such as the advanced tactical fighter (ATF) will make it possible to fly in the 10 to 12 +Gz range if the human limitations to such operations can be overcome. This chapter will discuss the human responses to acceleration in terms of physiology, tolerance, illusions of orientation, motion sickness, and protective measures against the adverse effects of acceleration.

A.3.12.2 BASIC PRINCIPLES

A.3.12.2.1 Speed and Velocity

Speed is a scalar quantity which signifies rate of change of position (1). It is calculated as:

Speed = distance/time or $v = ds/dt$

where v is the average linear speed measured in meters per second (m/sec), feet per second (ft/sec), miles per hour (mph), or more commonly in the aviation community nautical miles per hour (knots); ds is the distance traveled; and dt is the time elapsed.

Velocity is measured in the same units as speed and is calculated the same way, but it has the additional property of implying direction as well. Thus velocity is a vector quantity. Any change in direction or speed requires an acceleration.

A.3.12.2.2 Acceleration

Acceleration is defined as the rate of change of velocity and it is a vector quantity (1). It is

calculated as:

$a = (v2-v1)/dt$

where a is acceleration in meters per second per second (m/sec^2) or feet per second per second (ft/sec^2) or knots per second (knots/sec); v2 is the final velocity; v1 is the initial velocity; and *d*t is the elapsed time.

A special case of acceleration is centripetal, radial, or curvilinear acceleration. This acceleration occurs when the direction of motion of the body or aircraft of interest is changing as in a turn or a pull-up into a climb. The acceleration acts along the radius of the circle that is described by the motion made by the aircraft. While this is not the only source of acceleration in the aviation environment, it is the predominant one (1). The acceleration produced by a turn at constant velocity can be calculated by:

$a = v^2/r$

where a is the acceleration measured in the units previously mentioned; v is the velocity of the aircraft in the turn, and r is the radius of the turn measured in the same units of distance as the velocity.

G values: The measurement of acceleration is often done in units of G. The previous calculations of acceleration can be converted to G units by dividing "a" by the acceleration experienced by a free falling object near the surface of the earth (the acceleration due to gravity). This value is 32.2 ft/sec^2 or 9.81 m/sec^2. This conversion results in a dimensionless number that is useful for comparing gravitational forces (1).

As acceleration and velocity are vector quantities, it is necessary to define ways of expressing direction as well as speed by using the x, y, and z axes as defined by international agreement. Table 4-1 and Figure 4-1 explain the precise scientific definitions of these axes. When talking about physiologic functions the inertial resultant axes are important. It is very important to understand these axes and what system an author uses in describing acceleration. Pilots refer to "positive G" when they mean +Gz and to "negative G" when they mean -Gz. However, physicists refer to "positive G" when they mean the airplane is accelerating in the -az direction. Another example is that accelerating forward in the +ax direction as in a takeoff one experiences being pushed back into the seat, and this is described as -Gx physiologically.

TABLE A-V. NOMENCLATURE SYSTEM DESCRIBING THE REACTION FORCES IN ACCELERATION (2).

A. Direction of Acceleration

Linear Motion	Aircraft Standard	Acceleration Description
Forward	+ax	Forward acceleration
Backward	-ax	Backward acceleration

Upward	-az	Headward acceleration
Downward	+az	Footward acceleration
To the right	+ay	Right lateral acceleration
To the left	-ay	Left lateral acceleration

B. Inertial Resultant of Body Acceleration

Linear Motion	Physiologic Descriptive	Physiologic Standard	Vernacular Descriptive
Forward	Transverse PA G, prone G, back to chest G	-Gx	Eyeballs-in
Backward	Transverse AP G, supine G, chest to back G	+Gx	Eyeballs-out
Upward	Positive G	+Gz	Eyeballs-down
Downward	Negative G	-Gz	Eyeballs-up
To right	Left lateral G	+Gy	Eyeballs-left
To left	Right lateral G	-Gy	Eyeballs-right

Figure A-4. Description of the Anatomical Axes.

A.3.13 BASIC PHYSIOLOGICAL EFFECTS OF ACCELERATION

The physiological effects of acceleration can be looked at from many perspectives. This section will take the systems approach. Different body systems will be looked at and the effects of acceleration on those systems will be discussed.

A.3.13.1 Cardiovascular System Effects

Numerous cardiovascular symptoms have been noted under G stress. These symptoms include grayout, blackout, loss of consciousness with accompanying seizures, convulsions, amnesia and confusion, cardiac dysrhythmias (tachycardia and bradycardia), heart blocks, and a stress cardiomyopathy.

The easiest way to understand many of the basic cardiovascular effects of G is to model the human circulation as a simple hydrostatic column. The important parameters then become the height of the column, the pressures within it, and the density of the fluid affected. For all practical purposes this model is a good representation of the body's response to rapid onset short duration +Gz stress.

Assuming this model, the hydrostatic pressure at any point in the circulation can be predicted using the following equation:

PH = h d G

where: PH is pressure in mm Hg; h is the height of the column in mm; d is the specific density of blood; and G is the accelerative force in Gs (3).

The hydrostatic column that is of the most interest is between the heart and the brain. The

brain is approximately 340 mm above the heart. The specific density of blood with respect to mercury is 1/13.6. Therefore, at 1 G there is hydrostatic pressure gradient (PH) of:

PH = 340 mm x (1/13.6) x 1 = 25 mm Hg.

If one assumes an average heart level systolic blood pressure (Pa) of 120 mm Hg, then the brain level blood pressure is 120 - 25 = 95 mm Hg. At 5 G the PH of 125 mm Hg will exceed the average Pa of 120 mm Hg and the lack of blood flow will cause unconsciousness. To understand the phenomenon of "blackout" all one has to do is remember that the average intraocular pressure is 20 mm Hg. This intraocular pressure is the pressure the retinal artery must overcome to supply blood to the retina. "Grayout" occurs as the retinal artery pressure in the periphery can no longer overcome the intraocular pressure and blood flow to the peripheral retina ceases. Blackout is explained by the complete lack of blood flow to the eye which causes it to cease to function before the brain does. Blackout will precede unconsciousness by about 0.8 +Gz (20 mm Hg/25 mm Hg).

The model just outlined does not adequately explain the cardiovascular response to gradual onset +Gz because the cardiovascular reflexes can compensate for the changes caused by +Gz stress. These reflexes will also play a role in the response to rapid onset G after 6 to 10 seconds of exposure. The reflexes which are mediated by the carotid and aortic arch baroreceptors result in increased sympathetic discharge and a resulting increase in cardiac rate, vasoconstriction and venoconstriction, and an increase in cardiac contractile forces.

An increase in heart rate has been one of the generally observed responses to +Gz. This response has been highly variable due to individual variation, psychological stress, and the amount of muscular straining being performed by the experimental subject. The amount of absolute increase in heart rate is affected by the maximum G level reached and the rate at which the G was applied. Occasionally, individuals have been observed to have a paradoxical bradycardia at high G levels. This finding is thought to be a sign of cardiac decompensation and is grounds for stopping a G exposure. The heart-rate response to G has not been shown to be predictive of G tolerance.

Cardiac output has been noted to transiently increase under +Gz. The measurement of cardiac output under increased G load is difficult. It has been shown that there is a decrease in venous return under high-G loads which decreases the preload to the heart. So, despite the increase in heart rate, most authors believe that cardiac output is at best maintained under high G and that it probably decreases.

The rhythm disturbances seen under +Gz have been of great aeromedical interest. There has been and continues to be debate on the significance of these observations. In asymptomatic and otherwise healthy individuals these dysrhythmias are probably benign. Three specific dysrhythmias cause particular concern because of their potential for sudden incapacitation. These dysrhythmias are sino-atrial (S-A) block, atrioventricular (AV) dissociation, and ventricular tachycardia. Table 4-2 summarizes a 3-year history of acceleration-related dysrhythmias observed in healthy subjects on the United States Air Force School of Aerospace Medicine (USAFSAM) centrifuge.

TABLE A-VI. THREE YEAR HISTORY OF ACCELERATION-RELATED DYSRHYTHMIAS AT USAFSAM.

Rank	Occurrences	Dysrhythmia Description
1	1566	Sinus arrhythmia (rate varying > 25 beats/min (bpm)_between beats)
2	1073	Premature ventricular contractions (PVCs)
3	768	Premature atrial contractions (PACs)
4	546	Sinus bradycardia (Rate < 60 bpm)
5	372	Ectopic atrial rhythm
6	272	Premature junctional contractions (PJCs)
7	171	PVCs with bigeminy/trigeminy
8	126	Multiform PVCs
9	104	AV dissociation
9	104	Paired PVCs

Based on the exposure of 544 different individuals exposed to 9831 +Gz runs (1).

Many of the foregoing observations on cardiovascular response to +Gz were based on observations of response to one time exposures to +Gz on the centrifuge. Recent research work has concentrated on the response to multiple +Gz exposures and the effects of fatigue on this response. Generally, heart- rate response is dependent on +Gz level, but it also appears to be related to the blood lactate level which is an indication of the amount of anaerobic work involved in resisting the effects of +Gz and the performance of the anti-G straining maneuver(AGSM) (4). This ability to perform anaerobic work may explain the observed effects of physical training regimens on aerial combat maneuvering G tolerance (5,6,7).

Respiratory Effects

The major physiologic effects of +Gz on pulmonary function can be summarized as: a. altered ventilation/perfusion ratios resulting in hypoxemia, b. airway closure, and c. atelectasis (1). There is also concern that exposures above 9 +Gz may result in pathophysiologic changes such as a compromise of chest wall mechanics, pulmonary edema, and disruption of the anatomical integrity of the lung (1).

Observations of pulmonary function during increased +Gz have shown an increased respiratory rate, an increased tidal volume (limited at the upper +Gz levels by the G force and the compression of the G-suit), and an increased physiologic dead space. As a result, the $PaCO_2$ changes very little with increasing +Gz but the PaO_2 progressively decreases with increasing G stress (1).

The hydrostatic theory, just explained would predict that at higher +Gz there would be less perfusion of the upper areas of the lung and that at higher -Gz there would be more. This theory has been nicely demonstrated in a study of perfusion scans of the lung at various Gz levels (8). Similar ventilation-perfusion (V/Q) inequalities would be expected from G exposure along the other axes and this has been observed (1,9).

Acceleration atelectasis is a collapse of alveoli in the dependent lung caused by absorption of

the alveolar gas. It has been associated with symptoms of cough, chest pain, and dyspnea. Acceleration atelectasis has been observed to be exacerbated by breathing 100 percent oxygen and by the use of the anti-G suit (10). It has been shown that the absorption atelectasis produced by +Gz exposure can be reduced progressively with the addition of an inert gas (N2) into the breathing mixture until it is almost entirely prevented with a mixture of 40 percent N2, by the use of unassisted positive pressure breathing (PPB) and by use of the anti-G straining maneuver (AGSM) (10). Acceleration atelectasis has been one of the reasons diluter demand regulators have been favored by the United States Air Force (USAF). The proposed use of onboard oxygen generating systems (OBOGS) or more appropriately molecular sieve oxygen generating systems (MSOGS) in new generation fighter aircraft which will provide 95 percent oxygen on a continuous basis has prompted concern that acceleration atelectasis may become an operational problem of some significance (10).

Central Nervous System Effects

The observed central nervous system (CNS) effects of acceleration are explainable by the effect of G on the cerebral circulation. The electroencephalogram (EEG) studies have not shown any cumulative or pathologic effects of +Gz stress up to +7 Gz (1).

Renal System Effects

Decreases in renal blood flow observed when humans stand upright and when they exercise make it reasonable to predict that +Gz stress would decrease renal blood flow. Although this prediction has not been investigated in man, animal models confirm this prediction (1). Oliguria has been noted in humans and increased levels of plasma renin have been measured at +2 and +2.5 Gz (1). Further work on this area may be useful as even small deficits of water and sodium balance have been associated with decreased +Gz tolerance.

Musculoskeletal Effects

Back, neck, and limb problems are the most frequently reported musculoskeletal problems. There are reported cases of intervertebral disk ruptures under high +Gz and many complaints of sore necks after centrifuge rides and flights in high-G aircraft. Permanent injury is rare enough to warrant a case report.

G Tolerance

The human tolerance to acceleration has been the subject of much research. This research has traditionally looked at the relaxed tolerance of subjects to single exposures of +Gz and the absolute level of +Gz the subject is able to withstand. This research has defined the limits of G tolerance in the z axis very well. The limits of G tolerance in the other axes are not so well defined. More recently there has been increasing interest in repeated exposures to multiple +Gz levels for varying time courses. The purpose of this research has been to define the other parameter in G tolerance, namely, that of duration tolerance. When discussing G tolerance it is important to understand the definitions of tolerance and the various endpoints that have been used by researchers in their experiments.

Early research in +Gz tolerance attempted to define the point of unconsciousness. As the understanding of the response to G became more refined, "blackout" or visual loss was used as the endpoint in human research. The modern concept defines +Gz tolerance in terms of the

rate of acceleration whether it be rapid (> 0.33 G/sec) onset or gradual onset, and the point at which there is peripheral light loss (PLL) or the point of central light loss (CLL).

Current research at USAFSAM uses three kinds of centrifuge runs to evaluate G tolerance. The gradual onset run (GOR) is conducted at 0.1 G/sec, the rapid onset run (ROR) at 1 G/sec, and very high onset G (VHOG) at 6 G/sec. The GOR evaluates the body's baroreceptor response to G, as the cardiovascular responses have time to be effective. The RORs and VHOGs are more representative of the types of G onset profiles that aircrew are likely to experience in the F-15 and F-16 generation of aircraft. This kind of research on normal unprotected subjects has resulted in the data found in Table 4-3 and is illustrated on figure 4-2.

TABLE A-VI. ROR G TOLERANCES OF 1000 SUBJECTS (1 G/SEC ONSET RATE).

Criterion	Mean Threshold (G units)	Standard Deviation (G units)	Range (G units)
Grayout or loss of peripheral vision	4.1	+/-0.7	2.2-7.1
Blackout	4.8	+/-0.8	2.7-7.8
Unconsciousness	5.4	+/-0.9	3.0-8.4

Figure A-5. G-Time Tolerance Curve.

As discussed in the section on cardiovascular effects, the simulated aerial combat maneuver (SACM) has been used to evaluate longer duration tolerance to +Gz stress and to evaluate the fatigue ability of G tolerance. This research has shown that the work of being at high +Gz is anaerobic and that understanding human performance and endurance at high +Gz is best related to isometric exercise physiology and to anaerobic metabolism (4).

G-induced Loss of Consciousness

G-induced loss of consciousness (GLOC) has become an issue of major research and operational interest. The USAFSAM definition of GLOC is "a state of altered perception wherein (one's) awareness of reality is absent as a result of sudden, critical reduction of cerebral blood circulation caused by increased G force"(12). The literature reports in the 1983-85 time frame, seven USAF class A mishaps have been officially attributed to GLOC (12). As this chapter was being written in early 1988 three more high profile accidents have been recently attributed to GLOC and these accidents have once again prompted calls for quick and effective measures to combat this operational threat.

The loss of aircraft and aircrew are, of course, a major concern, but every GLOC episode does not result in a loss of an aircraft. Surveys by the USAF and the U.S. Navy indicate that the pilot

population in the fighter- attack-trainer is reporting about a 12-14 percent incidence of GLOC (13). The work of Whinnery on the occurrence of amnesia in GLOC suggests that at least half of pilots will not recall an incident of GLOC so the incidence may be as high as 24 percent, with occurrence rates in aircraft such as the F-18 of 9.3 incidents per 10,000 flying hours (13,14). This is obviously an issue of major operational concern.

Research on the degree of incapacitation caused by GLOC has indicated that there is an average total incapacitation (unconsciousness) time of 15 seconds followed by a period of relative incapacitation (confusion and disorientation) of 12 to 15 seconds, resulting in a total time of incapacitation of between 24 and 37 seconds (14). Research is now focusing on ways to both prevent the GLOC episode and to shorten the periods of incapacitation.

Several protective strategies to increase G tolerance and to prevent GLOC have been explored. These strategies include centrifuge training, weight training, new G suits and G valves, altering the seat back angle in the aircraft, and the use of positive pressure breathing both assisted (with counter pressure) and unassisted.

Centrifuge training has been received with enthusiasm by all those who have undergone it. Most major North Atlantic Treaty Organization (NATO) air forces, including the USAF, either have centrifuge training programs in place or are developing them (15). These programs usually consist of one day of lectures on the physiology of G, a GOR run on the centrifuge, followed by several ROR to a maximum of 9 +Gz (15).

The work on new G valves for inflating G-suits has revolved around the need for faster inflation rates with high flow valves, variable inflation rates that match the G-onset profile and the use of "smart" microprocessor controlled systems that may pulse the pressure in the suit, to "milk" the venous return from the legs (16).

The first workable anti-G suit was developed by Franks in Canada during World War II (2). The suit was not acceptable operationally because it was water filled, but it laid the groundwork for what was to follow. The current USAF anti-G suit is the CSU 3-B/P which has calf, thigh, and abdominal air bladders that can be inflated to a maximum of 10.0 PSI. This suit must be individually fitted and provides about 1 +Gz of protection. Most of the protection seems to be provided by the abdominal pressure bladder or the combination of all the bladders as inflation of the leg bladders alone only provides 0.2 G increase in +Gz tolerance (1).

The use of reclined seats to increase G tolerance has only been partially incorporated into an operational fighter, the F-16, which has an inclined seat of about 30 degrees. Most research would suggest that there is no significant increase in G tolerance until the seat is inclined 45 degrees. Experimental work has shown great potential for this technique, but at present the practical problems of incorporating supinating seats into the cockpit have not been solved (17).

Positive pressure breathing with chest counter pressure has been shown to increase G tolerance only about 0.5 +Gz but it has had significant fatigue reduction effects (17). This technique, using 60 mm Hg of breathing pressure above ambient pressure, has been incorporated into the experimental tactical life support system (TLSS) which is a combination G-suit, chest counter- pressure jerkin, high pressure mask, and chemical defense ensemble. This suit is currently being developed at USAFSAM.

One other area of "GLOC protection" is the development of auto recovery systems. The

current generation of fly-by-wire aircraft can be flown by the mission computers without pilot input. If systems can be developed to correctly identify that a pilot has lost consciousness, the aircraft's computers can be programmed to recover the aircraft to straight and level flight. Problems with this concept at present are the unequivocal identification of loss of consciousness (LOC), the provision of appropriate pilot override capability and pilot acceptance of the machine doing the flying.

While the problem of GLOC has not been entirely solved, the technology to solve many of the problems and the training to use the technology are at hand.

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A.3.14 THE OTOLARYNGOLOGIC ASPECTS OF AEROSPACE MEDICINE

A.3.14.1 INTRODUCTION

Abnormalities in the ear, nose and throat (ENT) area can conveniently be divided into two areas, those conditions which are directly related to aerospace operations and those relatively common entities which affect aircrew along with the general population. Human beings are terrestrial creatures with sense organs that are well suited for surface living; however, when they venture above the surface of the earth (or below that portion which is aqueous) certain difficulties may be encountered. Those most directly related to flying are: a. the effects on air-containing body cavities from environments of changing barometric pressure and b. the functional inadequacy of the spatial orientation system under flight conditions.

Pathologic changes with rather definite symptoms can result from passing through an environment of decreasing barometric pressure (ascent) and also from exposure to one of increasing ambient pressure (descent). Historically, dysbarism was the general term used to denote all of the disturbances within the body which result from a change in barometric pressure, both increase and decrease, with the exception of hypoxia. However, current authorities prefer to classify the effects of exposure to changes in barometric pressure as either mechanical effects (expansion or contraction of gases trapped in body cavities) or decompression sickness (gases evolved from body fluids). The creation of relatively positive pressure in the middle ear space may cause alternobaric vertigo. The development of relatively negative pressure in the middle ear space or a paranasal sinus causes barotitis media or barosinusitis. Mechanical effects of trapped gases can produce symptoms in other areas of the body as well (e.g., abdominal pain).

The conditions which most commonly result from inadequacy of the human spatial orientation system to cope with the non physiological accelerations encountered in flight are spatial disorientation and airsickness. These are discussed in detail in another chapter.

Diseases of the ENT area which affect fliers and non-fliers alike may be acute or chronic, but the aeromedical implication is usually clear; i.e., the crew member must be grounded until the pathologic process has cleared and the involved part is functionally normal. Also, an acute condition (e.g., a viral upper respiratory infection) may make the crew member more vulnerable to those abnormalities which can complicate exposure to the flight environment. A primary consideration in assessing the aeromedical significance of any particular abnormality is whether or not it is capable of producing sudden incapacity which would jeopardize flight safety. In any

involvement with this potential, the likelihood of recurrence is the most pertinent consideration for the flight surgeon. By these criteria, the vertiginous entities are particularly important.

In this chapter, those otolaryngological abnormalities which are etiologically related to aerospace operations (barotitis, barosinusitis and alternobaric vertigo) and the most common and generally encountered vertiginous entities will be discussed. Also, a few general ENT problems frequently seen by the flight surgeon will be briefly discussed.

A.3.14.2 MECHANICAL EFFECTS OF BAROMETRIC PRESSURE CHANGES

A.3.14.2.1 General

The mechanism by which this type of barotrauma is produced is fairly simple. Boyle's law states that at any given temperature a given mass of gas varies in volume inversely with the pressure. The pressure of the atmosphere decreases with altitude on a curvilinear gradient. A container that is closed but capable of expanding will vary in size as it ascends or descends depending on the ambient pressure. When a rigid-walled cavity that cannot change in size is moved through an environment of decreasing pressure (ascent), a pressure differential will be created, with the pressure inside the cavity being greater relative to its environment. When this same cavity is moved through an environment of increasing pressure (descent), the pressure inside the cavity will be less or relatively negative. If such a cavity contains an opening through which these pressure changes can be equalized, there will be no pressure differential. However, if this opening becomes occluded there will be an increase in pressure within the cavity on ascent and a decrease in pressure (relative negative pressure) on descent. The rate of ascent or descent will determine the rate and extent to which a pressure differential develops. Symptoms may be produced by the relatively positive pressure which can develop in a gas-containing cavity during ascent or by the relatively negative pressure which can develop during descent. Experience has shown that more serious symptoms are much more likely to develop when a relatively negative pressure exists in a gas-containing cavity or space (e.g., ear block or sinus block on descent).

Altitude chamber reactions can be utilized to suggest the potential incidence of barotrauma in flight operations. Table 6-1 lists the distribution of altitude chamber reactions in the USAF for calendar years 1979-1982. Barotitis was the most common adverse reaction encountered, comprising almost two-thirds of all the reactions for each of the years. In this entity, symptoms result from relatively negative pressure (descent). The next most common condition, though only about one-fourth as frequent as an ear block, was abdominal gas pain (which results from trapped gas expanding during ascent). Barosinusitis was a close third; here symptoms result from relatively negative pressure. All other reactions are much more infrequent. So, roughly 75% of chamber reactions occur during descent.

TABLE A-VII. DISTRIBUTION OF ALTITUDE CHAMBER REACTIONS IN AIRCREW TRAINEES DURING CALENDAR YEARS 1979-1982.

Symptom	1979	1980	1981	1982
Totals	(72652)	(77424)	(77875)	(76401)
Aerotitis	3.477	3.347	3.217	3.226
Aerosinusitis	.776	.754	.697	.694

Abdominal gas pain	.245	.262	.243	.272
Bends	.051	.055	.067	.076
Barodontalgia	.063	.048	.051	.048
Neurological	.008	.008	.006	.004
Chokes	.000	.001	.001	.000

A.3.14.2.2 Barotitis

Barotitis media may be defined as an acute or chronic traumatic inflammation of the middle ear produced by a pressure differential (either positive or negative) between the air in the tympanic cavity and contiguous air spaces and that of the surrounding atmosphere. The classical description of barotitis media was published by Armstrong and Heim in 1937.

The anatomy of the middle ear is key to the pathophysiology of barotitis. The middle ear is a mucosa-lined bony cavity, with a thin, semi-elastic partition laterally (tympanic membrane), which communicates with the nasopharynx by way of the eustachian tube. All of the walls of this space are rigid except for the ear drum laterally; however, movement of the ear drum is also limited so that only minimal equalization of pressure can be effected. This averages only 100 to 300 feet of atmospheric pressure change. So, for all practical purposes, the middle ear cavity is a rigid-walled space. The posterior third of the eustachian tube is a bony channel which is always open; the anterior two-thirds is a membrano-cartilaginous structure which is normally closed and opens physiologically only with swallowing, yawning, or working the lower jaw (any action which causes the tensor and levator veli palatini muscles to contract). This one-way flutter valve action of the eustachian tube readily permits air under pressure in the tympanic cavity to pass into the nasopharynx. However, if the air pressure in the tympanic cavity is less than ambient pressure the eustachian tube will remain closed unless it is opened physiologically or by one of the non physiologic maneuvers (Valsalva or politzerization).

Ascent produces a relatively positive pressure inside the tympanic cavity as the pressure of the atmosphere decreases. This positive pressure is ordinarily passively equalized as the air can usually pass through the eustachian tube to the nasopharynx with ease. The pressure change is greater at lower altitudes because the air is more dense there; however, for practical purposes there is approximately 10-15 mm Hg pressure change for every 500 ft of altitude. This may be perceived by the individual as a mild fullness in the ear, mild decrease in hearing and minimal discomfort. Normally, 5 mm Hg positive pressure will force air out through the eustachian tube, relieving the symptoms or they can usually be readily relieved by swallowing. If even this positive pressure is not relieved, more severe symptomatology will result, the most impressive manifestation in most individuals being vertigo which will usually over-shadow any tinnitus or pain that may accompany it. This is alternobaric or pressure vertigo and it is discussed in more detail below.

On descent, however, a totally different situation exists. The eustachian tube acts as a flutter valve and remains closed unless actively opened by muscle action or high positive pressures. If the eustachian tube opens, any existing pressure differential is immediately equalized. If the tube does not open regularly during descent, a pressure differential will develop. If this pressure differential reaches 80-90 mm Hg, the eustachian tube muscles cannot overcome it and re-ascent, or a non physiologic maneuver, will be necessary to open the tube.

The most common cause for failure of the middle ear space to ventilate on changing from low to high atmospheric pressure is swelling of the nasopharyngeal end of the eustachian tube, usually due to an acute upper respiratory infection or allergy. Even minimal edema of the wall of the eustachian tube in the narrower portions of the lumen may produce sufficient constriction to cause blockage during descent.

Certain contributory etiologic considerations should be mentioned. Ignorance of the necessity for swallowing at frequent intervals during descent in aircraft is a significant factor. The ability to recognize the early pressure changes incident to beginning descent and then adjusting the interval between swallowing to meet the demands of the rate of descent comes only with flight experience. The rate of descent is also a significant factor. This has been recognized for many years by commercial airlines. There descent rates are usually quite gradual and generally under 400 ft per minute. Descent rates in military aircraft are usually greater, frequently several thousand feet per minute.

The use of oxygen during flight increases the likelihood of barotrauma. Oxygen as delivered from an aircraft's oxygen system is usually quite dry and may produce some irritation of the mucosa of the upper respiratory tract. Also, the absorption of oxygen by the mucous membranes contributes to the relative negative pressure in the various upper respiratory cavities, including the middle ear space. When oxygen absorption is the primary factor in the development of a pressure differential, the term "delayed barotitis media" is sometimes used. Personnel who fly in certain jet aircraft equipped with a system that delivers 100% oxygen from the beginning to the end of the flight are most prone to develop this type of ear block. However, this absorption of oxygen must be combined with the infrequency of swallowing during sleep in order to produce an ear block. Individuals who fly aircraft equipped with this type of oxygen system are aware of this possibility and will keep their ears ventilated following termination of a flight; however, if a flight is completed in the late evening hours or during the night and the individual retires a short time later, a significant pressure differential may develop during sleep due to the combined factors of oxygen absorption and infrequent swallowing. Once the pressure differential develops, the situation is exactly the same as that which occurred due to failure of ventilation of the eustachian tube on descent from altitude. It should be added that sleeping during letdown in an aircraft can lead to an ear block, again due to the infrequency of swallowing while asleep.

The pathological changes vary with the magnitude of the pressure differential between the tympanic cavity and the ambient air pressure and also with the length of time the pressure alteration acts upon the tissues before equalization takes place. For practical purposes, the differential results in the development of a partial vacuum in the middle ear space. This produces retraction of the tympanic membrane and engorgement of the blood vessels in the ear drum and middle ear mucosa. In mild degrees of barotrauma, the pathological changes may be limited to these. If the pressure differential is great enough and persists long enough a transudate will usually form. This is usually serious but may be serosanguinous or even hemorrhagic. Rarely, with the development of a severe pressure differential, the ear drum may rupture. The rupture usually occurs in the weakest area or in an area previously damaged by an earlier pathologic process. The formation of a transudate is a more frequent occurrence. Once the fluid accumulates in the middle ear space the pressure differential is relieved. This is eventually followed by auto- inflation with bubbling and resolution of the process when the

eustachian tube opens.

Symptoms can occur on ascent but are much more likely on descent. Subjective appreciation of the relatively negative pressure in the middle ear space varies with the degree of pressure differential between the tympanic cavity and ambient air pressure as well as the length of time the pressure differential has existed. In minimal barotitis, symptoms are usually limited to a sense of fullness in the ear, mild ear pain, low-pitched tinnitus and decreased hearing (conductive type). With this degree of involvement, symptoms usually disappear soon after ventilation is established. In moderate degrees of pressure differential, all symptoms are of increased intensity. If a transudate occurs the patient may notice sensations due to fluid movement as head position is changed or during the act of swallowing. In severe barotitis, the pain may develop quickly and be so severe that it will actually be incapacitating. The hearing loss will usually be more severe and the tinnitus greater. Vertigo may be experienced on descent with severe barotrauma; however, this is more likely to occur on ascent with the development of positive pressure in the middle ear space. If the tympanic membrane ruptures, pain and any other symptoms present usually quickly subside.

Clinical findings during ascent are related to the development of positive pressure in the middle ear space which will cause the ear drum to bulge outward. This is usually of brief duration and unlikely to be seen by a physician unless one is monitoring a flight. The clinical findings on descent vary with the degree of pressure change and the length of time the tubal blockage persists. Development of a relatively negative pressure in the middle ear space produces retraction of the ear drum with prominence of the short process of the malleus and fore-shortening of the long process. The vascular engorgement produces injection and hyperemia of the ear drum which is most marked peripherally and along the long process of the malleus. Hemorrhagic areas may be seen in the drum, again most likely along the long process of the malleus and in the drum periphery. These tiny hemorrhages also occur throughout the middle ear mucosa but usually cannot be visualized. The formation of a transudate may be manifested by a middle ear simply full of serous fluid or there may be an air-fluid interface in the form of a relatively straight line (which will shift with changes in head position) or bubbles may be seen. A hemorrhagic transudate may produce a classical hemotympanum. Perforation of the tympanic membrane may occur at any point; this will usually be the weakest area in the drum and may be at the site of an earlier perforation which resulted an atrophic scar.

A conductive-type hearing loss is the usual finding; it is generally mild unless there is hemorrhage into the tympanic cavity in which case it may be greater. Weber and Rinne tests are consistent with a conductive loss.

The diagnosis in most cases should not be difficult and is based primarily on a history of pain and hearing loss developing during or immediately following descent. Retraction of the tympanic membrane and hemorrhage into the substance of the drum as well as the presence of serosanguinous or sanguinous fluid in the middle ear space aid in diagnosis. The differential diagnosis should include serous otitis media, acute or chronic otitis media, external otitis, and myringitis bullosa. An adequate history of barotrauma as well as the characteristic drum findings should aid in differentiating barotitis media from the other entities.

Treatment depends on the point at which intervention is attempted. In- flight measures should consist of the performance of the Valsalva maneuver as soon as a feeling of fullness is noted in

either ear. If the individual has a topical nasal decongestant, the nose should be sprayed. This is best done by spraying each side initially and then applying a second spray a few minutes later after the initial one has had time to shrink the anterior mucosa. The second application has a much better chance of reaching the nasopharyngeal area and shrinking the tubal orifice. If the ear cannot be ventilated by the Valsalva maneuver, return to a higher altitude should be carried out if operational conditions will permit it. The ear should then be ventilated and gradual descent carried out while performing the Valsalva maneuver as frequently as required.

If the individual presents to the flight surgeon's office with a fully developed ear block, the initial treatment should be determined by the clinical findings. If there is not evidence of a transudate, an attempt should be made to ventilate the ear to relieve the pressure. Politzerization will usually be required since Valsalva will not be effective (or the individual would probably not have developed an ear block). Either the Politzer bag or a source of compressed air may be used. The nose should be well sprayed with a decongestant solution and maximum shrinkage of the mucosa obtained. For the bag method, the olive tip is placed in one nostril, the nose is compressed between the physician's fingers and the patient is then instructed to say "kick, kick, kick" while the bag is squeezed, thereby increasing the pressure in the nasopharyngeal cavity while the hypopharynx is closed, hopefully to the point where the eustachian tubes will be opened and the middle ear spaces ventilated. If the ear cannot be ventilated by the patient vocalizing, it may be repeated while having the patient swallow a small amount of water during the application of air pressure. If compressed air is used, the pressure is turned down to 4 to 5 PSI and a suitable empty spray bottle that will take a nasal tip (such as a DeVilbiss nebulizer) is utilized for delivering the air to the patient's nose. It may be necessary to increase the pressure gradually several times until air enters the middle ear; however, the pressure should not be greater than 5 to 6 PSI. If politzerization cannot be accomplished at this pressure level, further increase in pressure will very likely not result in success. It must be emphasized that successful inflation of the ear does not necessarily mean immediate resolution of the process. The degree of trauma to the eustachian tube determines this and, if there has been significant trauma to the eustachian tube, simply ventilating the ear will not be sufficient. The patient can be relied upon to verify that the middle ear has been inflated. If desired, another physician can apply the air to the nasal cavity and one can directly observe the ear drum for evidence of ventilation. It may be necessary to repeat the politzerization for a period of several days until eustachian tube adequacy is established.

If transudation into the middle ear space has occurred by the time the patient is first seen, no attempt should be made to ventilate the ear. The formation of fluid will relieve most of any pain and the patient's only complaint will be the feeling of fullness in the ear and the mild hearing loss. The patient should be started on conservative therapy consisting of topical and systemic decongestants. When the tube begins to open (as manifested by bubbles behind the ear drum) resolution of the process (3-7 days) may be hastened by the institution of the valsalva maneuver by the patient.

Hemotympanum should be managed conservatively. It should be understood that prolonged treatment may be necessary since considerable time may be required for blood to clear from the middle ear space. This may be as long as several weeks but usually 1-3 weeks.

Myringotomy is rarely indicated and should be avoided if at all possible. Probably the only absolute requirement for myringotomy would be an flier who absolutely had to return to flying

duties for compelling operational reasons during actual warfare. Myringotomy would not restore the eustachian tube to functional status but it would open the middle ear space and prevent the development of further ear symptoms.

Perforation of the tympanic membrane should be treated conservatively. The ear should simply be kept dry and the patient followed. If healing is not well under way by the end of 2 weeks, the patient should be referred to an otolaryngologist.

It cannot be over-emphasized that the management of barotitis is essentially conservative. It should be borne in mind that the mucous membrane of the upper respiratory tract is delicate and nothing should be done that could possibly add to the existing trauma. Catheterization of the eustachian tube orifice is not indicated. It should be obvious that this would only further traumatize the eustachian tube and probably prolong the healing process.

Regardless of the condition in which the patient presents for treatment, therapy must be continued until the process has completely subsided and the eustachian tube and middle ear are functionally normal. In the aircrew member, it is imperative that the individual be grounded for this period and not be returned to flying duties prematurely.

Recurrent barotitis media is essentially the problem of chronic eustachian tube obstruction which is usually secondary to pathology in the nose or the nasopharynx. The most common causes are hypertrophic lymphoid tissue in the nasopharynx, allergic rhinitis, and chronic sinusitis. Gerlach's tonsil (the lymphoid tissue deposited submucosally along the anterior two-thirds of the eustachian tube may be hyperplastic. Occasionally, deflection of the nasal septum may be a significant factor. Treatment should be directed at resolving the primary problem. This may be either surgical or medical.

60.2.3 External Barotitis

This refers to a relatively uncommon barotraumatic injury of the lining of the external ear canal due to creation of an airtight space by an object in the outer ear canal. Unperforated ear plugs (such as some of those used for protection against aircraft noise), tightly impacted cerumen, or any other foreign matter may entrap air in the external canal. During ascent the plug may simply be extruded, however, during descent, this entrapped air may become relatively negative with respect to the outside air pressure or that of the tympanic cavity. Due to this mechanical effect, the outer layer of epithelium of the tympanic membrane or that of the external canal wall may be sucked away from the underlying tissue to form hemorrhagic areas beneath the epithelium. If these areas become large enough, hemorrhagic bullae may be formed. Small subepithelial hemorrhages usually require no specific treatment. If large hemorrhagic bullae have formed, recovery will be more rapid if the blood is evacuated (with a syringe and needle or by means of a small incision).

No one should be subjected to barometric pressure changes if the external auditory canal is completely obstructed in any manner. Noise protectors, small ear phones and similar devices must not fit so tightly that pressure equalization cannot occur or else each one must be vented in some manner.

A.3.14.2.3 Barosinusitis

Barosinusitis is an acute or chronic inflammation of one or more of the nasal accessory sinuses

produced by the development of a pressure difference (usually negative) between the air in the sinus cavity and that of the surrounding atmosphere. The condition is characterized by pain in the affected region; this pain can develop suddenly and be so severe that the individual will be incapacitated.

The etiology results from a paranasal sinus being a rigid-walled cavity which, directly or indirectly, communicates with the nasal cavity or nasopharynx by way of an ostium. As shown in figure 6-1, during ascent the air in such a cavity will move out by way of the ostium until equilibrium is reached at altitude. During descent air will move back into the sinus cavity until equilibrium is again reached at the earth's surface. This normal movement of air out of and back into the sinus cavity is not perceived and no symptoms occur. Abnormal conditions may alter or even prevent this free flow of air from the sinus and produce symptoms and pathologic changes. The larger sinuses are more often involved than the smaller ones. Those having small caliber tubal structures as exits (such as the frontal sinus) are more likely to be involved than those with large openings. The frontal sinuses are most often involved with the maxillary sinuses second. Involvement of the ethmoid and sphenoid sinuses is possible but, from a practical standpoint unlikely.

Figure A-7. Barometric Adjustment Within the Sinus on Change of Altitude. On ascent, adjustment of sinus pressure is made by escape of air from the sinus. On descent, adjustment of sinus pressure is made by entry of air into the sinus.

As shown in figure A-8, obstruction of a sinus opening by redundant tissue or anatomical deformities can occur during ascent or descent. Even though obstruction of a sinus ostium can occur during ascent, it is much more likely to develop during descent. Abnormalities capable of blocking a sinus opening are more frequently intra-nasal than intra-sinal. Since the flow of air from a sinus cavity is outward during ascent, an edematous flap or small polyp will be pushed away and pressure equalized at altitude. During ascent, air can even bubble through thick secretions and permit equalization at altitude. However, on descent the relatively negative pressure inside the sinus pulls the flap or polyp or exudate into the ostium forming an airtight seal and producing a sinus block (figure A-9). If aspiration of mucopurulent material failed to produce a sinus block, it would contaminate the sinus cavity and could result in a purulent sinusitis.

Figure A-8. Occlusal Factors in Maxillary Antrum in Flight.

A. During ascent any valvular formation within the sinus cavity will prevent the exit of air from the sinus as the atmospheric pressure decreases. D. During descent and increases of atmospheric pressure, similar formations on the nasal side of the ostium will prevent the

entrance of air into the sinus. A. Ascent A 1. V-Developmental flap-valve formation of sinus mucous membrane. A 2. M-Swelling of the mucosa of sinus with flutter-valve effect. A 3. P-Mucosal polyps in sinus constituting a ball-valve. A 4. S-Effusion in sinus cavity acting as an exhaust-piston. D. Descent D 1. V-Developmental flap-valve formation of nasal mucous membrane with flutter-valve effect. D 3. P-Polyps presenting in nasal fossa and acting as a ball-valve. D 4. S-Effusion in sinus cavity with exhaust-piston effect. (Reproduced by the permission of Dickson, E.D., et al., Contributions to Aviation Otolaryngology, London, Headley Brothers, 1947).

Pathology results from the production of a relatively negative pressure inside a sinus results in a space-filling phenomena. The most common of these are swelling of the mucous membranes and transudation of fluid either into the cavity of the sinus or beneath the sinus mucosa. When sufficient space is filled to equalized the pressure differential. The valve mechanism is released and recovery begins. In mild and moderate degrees of sinus barotrauma vascular engorgement and generalized submucosal edema occur. With more severe trauma, mucosal detachment and submucosal hematoma may develop.

The symptoms of barosinusitis are generally proportional to its severity and are much more likely to occur on descent. These may vary from a mild feeling of fullness in or around the involved sinus to severe excruciating pain. This pain can develop very suddenly and be incapacitating. It is thought to be associated with stripping of the sinus mucosa in the formation of submucosal hematomata. There may be tenderness over the involved sinus. There also may be some bloody discharge from the nose. There is usually no fever at the onset of the condition; however, within a period of several hours, some temperature elevation may develop depending upon the extent of damage and the degree of associated infection.

TBD

Figure A-9. Frontal Sinus During Flight.

The diagnosis of sinus barotrauma must be differentiated from acute purulent sinusitis. A history of pain over one or more of the paranasal sinuses during or shortly after exposure to barometric pressure change usually simplifies the differentiation. In the more severe cases the patient usually describes the onset of pain as quite sudden and very severe. In the less severe cases, the pain may be described by the patient as having slowly developed after return to ground level. This exacerbation of symptomatology after return to ground level may be due to an increase in the relative negative pressure with the sinus following oxygen absorption from the air trapped in the sinus. Epistaxis occurring during or after exposure to barotrauma is strongly suggestive of sinus involvement.

X-rays are probably the most valuable diagnostic aid. The standard sinus series in most institutions consists of Caldwell, Water's, lateral, and submentovertex projections. The Water's projection accomplished in the lateral decubitus position may be very valuable in determining whether or not fluid is present in the sinus cavity. The usual findings are mucosal thickening which may be localized (as in a hematoma) or so generalized and severe that it simply produces an opaque sinus. An air-fluid level may also be demonstrated. These are nonspecific findings and must be correlated with the history. If hematoma is present it is usually found in

the frontal sinus and presents as an ovoid density varying from a few millimeters in diameter to practically complete occupancy of the sinus cavity. The hematoma may be single or multiple, unilateral or bilateral.

Treatment should begin at the first sign of barosinusitis and consists of returning to the altitude at which the block occurred, spraying the nose well with a decongestant solution, and then slowly descending to ground level. This may or may not be possible depending upon operational conditions. It is easy to see that this might not be feasible in a combat situation. If the patient is first seen at ground level, at some installations an altitude chamber might be available in which the individual could be returned to altitude. From a practical standpoint, this is rarely necessary and of questionable value in a fully developed case. Generally speaking, the transudate, whether it be serous or serosanguinous, will be sufficiently space filling to relieve the pressure differential thereby alleviating the pain and possibly releasing the flap or ball valve. Active treatment is usually limited to those procedures which will relieve persisting pain, promote drainage from the sinus cavity and offer protection against infection. Oral analgesics are usually sufficient. The patient's nasal mucosa should be thoroughly decongested with topical agents and the patient should be given a supply of the same along with a systemic decongestant. The application of heat, preferably in the form of a hot pack, is generally appreciated.

In most cases, barosinusitis can be managed conservatively and uneventful recovery is the rule. In the milder cases, the involvement is usually self- limited with resolution taking place in a few hours to a few days. In the more severe cases, the clinical course may run from a few days to a few weeks. Complete resorption of a submucosal hematoma may take several weeks. If the barotraumatized tissues do not become infected, recovery is more rapid. Should infection occur, a severe purulent sinusitis may result due to the lower resistance of the traumatized tissues and the excellent culture media afforded by the presence of the transudate. Any hemorrhage that occurs is usually self-limited.

It is imperative that the individual remain grounded until fully recovered and the nose and paranasal sinuses are functionally normal. The patient must not only be asymptomatic but any abnormality demonstrated radio graphically must have cleared. A chamber flight should always be required if there is any doubt as to whether or not the individual is fully recovered and ready for return to flying duties.

Prevention is the key in barotrauma. The most important preventive measure which can be emphasized by flight surgeons on a continuing basis is that individuals must not fly when they have an upper respiratory infection. This point cannot be over emphasized; experienced fliers are not immune to barotrauma.

Any significant intranasal condition which could affect the ventilation of the paranasal sinuses should be corrected. This could be uncontrolled nasal allergy, the presence of nasal polyps, a significant septal deviation or even chronic sinusitis.

A.3.14.3 Alternobaric Vertigo

Ordinarily, as emphasized in the discussion of barotitis, expanding air within the middle ear space readily escapes due to the action of the eustachian tube as a one-way valve favoring flow of air from the middle ear to the nasopharynx. However, if for any reason this ready release of

pressure does not occur and a significant positive pressure is produced in the middle ear cavity, symptoms may be produced, the most prominent and aeromedically significant one being vertigo.

The exact mechanism of production of the vertigo is not known but is has been postulated that unequal pressures between the ears results in differential stimulation of the vestibular system. The existence of positive pressure in the middle ear space is accepted and the resultant vertigo implies stimulation of the vestibular system, probably through an intact oval window. Jones (8) feels that sudden movement of the stapes causes stimulation of the vestibular end-organs. The increase in pressure due to failure of ventilation of the middle ear on ascent is gradual and, in most instances, this is not enough to produce vertigo. The addition of a sudden pressure increment by performance of a forceful Valsalva maneuver can be sufficient for vestibular stimulation. Minimal residual eustachian tube edema secondary to a resolving upper respiratory infection can make ventilation of the ears on ascent difficult and require a more forceful Valsalva maneuver than is usually necessary.

Alternobaric vertigo is probably a fairly common occurrence in pilots of high performance jet aircraft that are capable of a rapid rate of climb. The role that pressure change plays is corroborated by the higher incidence in divers since pressure changes are much greater in an aqueous medium. In 1957, Jones (8) reported an incidence of 10% in 190 pilots that he interviewed. In 1966, Lundgren and Malm (10) reported an incidence of 17% in 108 pilots that they surveyed. The understandable reluctance of pilots to report symptomatology of this type makes it reasonable to assume that this entity is more common than is generally realized.

The flier, usually in a high performance jet aircraft, usually relates the history of noting the sudden onset of typical vertigo following performance of a forceful Valsalva maneuver to relieve a feeling of fullness in one or both ears. This usually occurs on ascent, but has been described on descent following a particularly forceful Valsalva maneuver. The vertigo characteristically is of brief duration, ordinarily lasting from 10 to 60 seconds. The individual usually feels perfectly normal as soon as the vertigo clears.

The treatment of alternobaric vertigo is essentially prevention. This implies a continual process of education of aircrew in which the common nature and potential hazards of this condition are emphasized. The admonition "do not fly with a cold" cannot be overly emphasized. It is certainly safe to assume that the most common reason for having difficulty ventilating the middle ear is residual eustachian tube involvement from an acute upper respiratory infection, most likely a common cold. It is also wise to advise aircrew most likely to encounter this condition to clear their ears more frequently during climb-out and try to avoid the necessity for a very forceful Valsalva.

The aeromedical significance of alternobaric vertigo should be fairly obvious; it is capable of producing sudden incapacity in flight. The fact that it may be of brief duration is of little significance nor is it necessary to assume that it may occur at a critical time in flight. In the operation of high performance fighter-type jet aircraft, all aspects of flight are critical and a time period of several seconds is sufficient for an unsafe operational condition to develop. That alternobaric vertigo can occur and does so not uncommonly must be realized by aircrew and receive continual emphasis by flight surgeons.

A.3.15 NOISE, AUDIOMETRY, AND COMMUNICATION

A.3.15.1 INTRODUCTION

Sound is one of the physical attributes of the environment for which living beings have developed a special sense. Minute vibration in the air around us is more readily perceived than gross vibration of the ground we walk upon. As with the special senses of vision and smell, small inputs are amplified anatomically and neurologically so that our perception of the world comes to us almost as a form of filtered telemetry. This allows us to know about the things around us before they bump into us.

But the perception of sound is a two bladed sword. The richness and variety of vibration in the air molecules around us consists of huge spectra of both frequency and intensity. With acuteness of hearing comes the need to compensate for these wide variations and also a need to make some sense of the many vibrations.

In this chapter, the basic issues of noise and communication are discussed in relationship to the aerospace environment. Preservation of hearing through protection and engineering are discussed, and monitoring programs are described. A bibliography is attached to allow the flight surgeon to become more familiar with specific areas of interest.

A.3.16 AUDITORY SIGNALS AND NOISE

A.3.16.1 Sound, Noise, and Signal

Sound can be defined as the series of pressure changes which are almost always present in any fluid in nature. Since we are flight surgeons, we will limit ourselves to the fluid of mixed gasses called air. Since we are humans, we will limit the pressure changes to cyclic pressure changes with frequencies greater than 20 cycles per second (Hz) and less than about 20,000 cycles per second.

When sound conveys useful information in the form of a signal, the sound has value. Any other sound (i.e., no signal or worthless information) is noise. Sound as pleasure is outside the scope of this chapter, although it exists somewhere between signal and noise as an entity.

By our definition, static on a radio, the sound of air rushing over a canopy, engine sounds, and questions from a flight surgeon in the back are usually considered noise by pilots. These sounds MAY include some useful information, but frequently are not reliable signal sources.

The question may arise: why use auditory information in aircraft The answer, of course, is that the flight crew in charge of the aircraft's mission has to be aware of an enormous array of constantly changing information. Flight safety and mission completion require continuous navigational situation awareness; flight attitude, altitude, and speed parameters; aircraft systems performance; and monitoring of offensive and defensive weapons systems.

Visual and tactile channels are extensively utilized and are augmented with sophisticated systems such as the Heads Up Display of the fighter and the stick shaker of the transport. The other special senses such as smell and taste do not easily lend themselves to clear contrast or rapid information transfer. The only other special sense channel into the crew member’s

thought stream is acoustic in nature.

A.3.16.2 Types of Auditory Signal

Useful aural information in the cockpit is usually presented as 1) a communication signal, 2) an auditory display, or 3) speech synthesis technology.

Communication signals were the first refined auditory tools available to aviation. Although the only aural communication available in early biplanes was the mouthpiece calling tube, radios came into military use shortly after World War I. Communication was available air to air and also air to ground. Radio meant that no longer was the airman a solo knight of combat, now extensive command and control could be used to manage complicated mass bombing, transport, and escort missions. Later expansion of communication radio added mainly to the number of channels utilized at one time. It is now commonplace for aircrew to monitor up to four communication channels concurrently.

Auditory displays were also introduced into early aircraft. They are presentations of acoustic information through nonverbal means. These consist of alarms, beeps, buzzes, bells, whistles, tones, and warbles. Their presentation is at different intervals and at different frequencies, continuously or intermittently. These displays are unfortunately not standardized among aircraft types or classes. Even worse, many of them may be presented coincident to each other (up to 4 at a time is the standard), and simultaneous to other aural signals such as radio and intercom voice communication. The combination of all this acoustic information is a rich potpourri of essential, simultaneous information.

Concern for the pilot being able to remember the meaning of increasing numbers of aural warnings and alarms as expressed by bells and whistles has lead to the development of synthesized speech technology displays. The advantage of synthesized speech is that the intended meaning of the display is immediately obvious. The disadvantages of synthesized speech are numerous. On one hand, there is another voice to listen to. (Remember the 4 radio channels being monitored). A second problem is that voice messages must be heard for several seconds before their meaning is deciphered. Perhaps worst, since an infinite number of messages can be comprehended by the crew, a near infinite number of messages are sent by the engineers who design the central flight computer. This tendency has lead to the aircrew's favorite term for speech synthesis - BITCHING BETTY or HARASSING HAROLD.

A.3.16.3 Noise as a Human Factor

Since World War II, it has been more and more widely recognized that some aircraft accidents and incidents are due to people problems. In the beginning, this was simply described as "pilot error," and was thought of as an inexcusable and inexplicable dereliction of duty on the part of the aircrew. But as time passed, the problem was studied and found to consist of a number of "human factors." G-induced loss of consciousness, fatigue, channelized attention, hypoxia, and a number of other elements are well- recognized human factors in aircraft incidents. Noise is a human factor which affects aircrew in several ways.

Noise interferes with communication which may be necessary for flight safety. The 1977 accident at Tenerife in the Canary Islands was found in large part due to missed communication between the tower controller and the flight crews of two 747 aircraft on a foggy

airport runway. The radio link allowing communication was temporarily affected by simultaneous transmissions leading to a squeal on the frequency. Non-standard communication phrases also lead to the communication breakdown. Both of these problems are noise problems as per our definition.

Noise is one of the common causes of acute fatigue. Listening through static to more than one channel in the noisy environment of the typical cockpit or flight deck is one of the determinants of how soon a crew becomes so fatigued that the mission or safety is affected. The management of noise (see below: Noise Protection) leads to improved communication and decreased fatigue.

A.3.17 AEROSPACE SYSTEM NOISE

A.3.17.1 Acoustics - The Physics of Sound

Sound, as we have said, is the perceived result of small, cyclic barometric pressure changes. Sound waves travel through air at sea level at about 1000 feet per second, or about a mile in 5 seconds. Scientifically, sounds can be described in terms of duration, spectrum, and intensity.

The duration of a sound, for medical purposes, is either a very short duration sound known as impact sound or is continuous sound. Impact sound is the result of a single pressure wave passing the observer. This is usually the result of a percussive event such as the explosion of ordinance or the collision of one object with another. Continuous sounds are the result of objects vibrating or moving with a frequency audible to the human ear. Examples of continuous sounds would be the sound from an aircraft engine or the sound of a siren.

The spectrum of a sound refers to the frequency or mixture of frequencies of pressure change. Pure tones, as used in hearing testing, consist of a sine wave pressure change with a specified frequency of between 500 to 6000 hertz (cycles per second). Almost all sounds in the environment are inevitably more complex than single frequency pure tones. The complex pattern of resonant frequencies and other overtones is usually hard to adequately describe, but clinical use allows either analysis of the sound at specific frequencies or the averaging of multiple frequencies.

As stated above, the total audible frequency response of the ear is from 20 to 20,000 Hz. But the very high frequencies and the very low frequencies are poorly perceived. The best and most responsive frequencies lie between 500 to 6000 Hz, the frequency range of intermediate priced hi-fi equipment. The frequencies used in speech communication are between 500 and 2000 Hz. This is convenient, for as it will be seen, early hearing loss often occurs at frequencies well above 2000 Hz. Because the human ear perceives different frequencies to different extents, care must be used in weighing the importance of various frequencies in the overall description of noise.

Which leads us naturally to a discussion of the intensity or pressure level of sound. The intensity of sound is the amount of pressure change occurring. Commonly called loudness, the perceived intensity of a sound at a specific frequency varies in a non-linear manner with both the frequency and the intensity of the sound. That's to say that low frequency sounds (within the range of normal hearing) are perceived at lower intensities than actually present. This is especially true at low intensities. Specific weighting systems are discussed in the section on

measurement of sound, but the primary reason for weighting systems is decreased apparent acuity to low as opposed to medium frequency sound.

The human ear response to intensity at all frequencies is also non-linear in general. The doubling of sound pressure does not result in a sound perceived twice as loud. The perception of sound is more closely related to a geometric (logarithmic) curve.

For the convenience of audiologists and physicians, sound intensity (sound pressure level) measurement is quantified on a specific logarithmic curve known as the decibel scale. The unit of the scale is the dB (d for the latin deci, B in honor of Alexander Grahm Bell). Since the smallest amount of pressure change audible to an average person is .00002 Pascals (Newtons/square meter), this is arbitrarily assigned a value of 0 dB. Each tenfold increase in pressure is assigned 20 dB so that the scale has the following points:

Pascals	dB
.00002	0
.0002	20
.002	40
.02	60
.2	80
2	100
20	120
200	140

Using this scale, the normal threshold of hearing is 0 dB; face-to-face communication takes place at 60 to 70 dB; discomfort occurs at 115 dB; and pain is present at 130 dB.

Because of the geometric scale employed, dB arithmetic follows modified logarithmic rules. The combination (addition) of two 80 dB sound sources next to each other leads to a doubling of the sound pressure which is a 3 dB increase. Sound propagation follows the inverse square law, so doubling the distance from a sound source decreases it's intensity by a factor of 4 (a 6 dB decrease). A secondary feature of intensity attenuation is the relatively selective high frequency drop-off in comparison with low frequency transmission. A sound, like that of a jet engine, will transmit it's lower frequencies much further than its high frequencies. The same is true of any insulator to sound; high frequencies are much more attenuated than low frequencies.

A.3.17.2 Sound Pressure Measurement

Sound pressure (intensity) is measured with an instrument called a sound level meter. This is simply a microphone attached to an amplifier which then drives a read-out device. The electronic insides of the device may give the sound pressure at specific frequencies (useful in

engineering applications), or more commonly gives a weighted average of all frequencies.

Because of the variable response of the ear to different frequencies, weighted averages are utilized. Three different weighting systems are in common use (A, B, C). With the A weighted average, low frequency sounds are given little weight in the average. With C weighting, all frequencies are averaged almost equally. The B weighting system is an intermediate scheme. A weighting corresponds to the human response to low intensity sounds, C weighting approximates response to high intensity noise. A weighting is the standard for measurement for compliance with OSHA and USAF regulatory programs in the workplace.

Figure A-10. Frequency Response for A B C Weighting Characteristics

In addition to instantaneous measurement of sound pressure, noise dosimeters are available for the determination of time weighted sound pressure measurements. These devices are useful for determining the average and peak noise exposure that ground operation personnel and aircrew are exposed to. The apparatus is battery operated and lightweight, allowing portable use. Unfortunately, since recording dosimeters have only recently become available, exposure in many aerospace environments has not been documented.

A.3.17.3 Sources and Characteristics of Aerospace System Noise

Aircraft noise has different characteristics depending on whether the observer is on the ground during maintenance and ground operations or if the observer is on the flight deck during flight.

Ground operation noise is related to the power plant and it's associated appendages (props, fans, rotors), and to the tools used in starting auxiliary power units (APU) and maintaining (fork-lifts, etc.) the aircraft. Long gone are the days when jet engine mechanics carefully tweaked the engine by it's sound at full throttle, without ear protection. But maintenance personnel, crew chiefs, and runway personnel are all exposed to potentially damaging sound pressures. Typical auxiliary power units (APU) used in starting some aircraft produce about 110 dB, and the idle rpm sound of military aircraft at several exterior stations reaches 120 to 130 dB. Ear protection is needed as far away as 200 feet for most aircraft during taxi and run-up, when sound levels can be 100-120 dB.

Many communications during ground operations are accomplished with hand signals because of the environmental noise and it's tendency to mask auditory communication. However, during the ground operation of several aircraft, crew chiefs and other maintenance people need to talk with the flight crew by intercom. Attenuating insulation for the outside microphone as well as for the earphones are necessary for these circumstances. A potential danger is present when workers are functioning near intensely loud aircraft. Oftentimes, personnel are unable to hear alarms or danger signals. Visual alarm signals are likewise difficult to use when the job at hand is highly visual to begin with. Tactile warnings are not readily available, except as a tug or pull from a fellow worker.

Inflight noise (at more than .8 mach) on the flight deck or in the cockpit is surprisingly not

mainly due to the engine. The majority of noise is due to the boundary layer of air rushing over the canopy and fuselage. Secondary sources of noise are the cabin conditioner, communication radios, and finally the power plant. Inflight noise increases with airspeed and decreases with altitude. Larger aircraft with their lower typical speed and with better acoustic insulation tend to have lower interior sound pressures, but many still require hearing protection in crew positions. In fighter aircraft helmets are universal, but depending on the helmet and it's configuration, secondary hearing protection may still be needed. Helicopters have small amounts of boundary layer noise, but large amounts of power plant and rotor noise. Much of the noise in helicopters is in the lower frequencies not protected well by passive noise attenuation systems.

A.3.18 THE EFFECTS OF NOISE ON MAN

A.3.18.1 Communication Effects

The primary effect of noise in the aerospace environment is to mask communication. Other than in formation flight, or at work stations on the flight deck, acoustic communication by radio or intercom is the only form of communication available to the aviator. This leads to an importance of vocal communication found in few other occupational settings.

One of the predominant problems of communication in a high noise environment is the signal to noise gradient. Distorted reception, as is common in aviation radios, and background noise, naturally lead the crew member to turn the volume up, leading to amplification distortions. There are some circumstances in which distortions do not allow an acceptable signal to noise gradient.

Several factors in aviation communication have been designed to deal with the limited intelligibility of communications. One of the larger determinants in a pilot's reception of a radio message is the aviator's experience. Crew members learn what messages to expect, and which words are key to understanding the communication. The use of special alphabets and standard phrases in aviation makes information transfer safer and less fatiguing. For the same reasons, use of non-standard phrases can be dangerous. When a pilot tells the co-pilot to "cheer up," he or she better be sure that the crew is not expecting a command to bring the GEAR up.

Pilots who have a mild hearing deficit are traditionally tested in an inflight test of hearing. The FAA requires an examiner to fly with an individual and determine if that person is able to hear and comply with instructions from air controllers. The USAFSAM flight test of hearing is a set of words spoken by a flight surgeon examiner and heard by the crew member through the aircraft intercom system during flight. There is no limit placed on the crew member’s volume control, only accuracy is assessed. For details see SAM TR #73-29, Materials and Procedures for In-flight Assessment of Auditory Function in Aircrewmen.

Both acute and chronic fatigue decrease an aircrew member's skill at learned tasks, including radio communication. Noise in the airplane leads to increased fatigue, and what's more, the sounds coming out of the aviation radios constitute one of the principle sources of noise in the cockpit! In addition, fatigue leads to acceptance of lower standards of accuracy and performance. So while the crew member is straining over the radio to hear what the controller

just said, the individual is getting tired, and less able to hear the repeat message.

It is noted that for familiar sounds, the identity of the sound, it's apparent location in space, and it's movement can be determined. The same is not necessarily true for unfamiliar sounds. One avenue of ongoing research is the artificial placement of various radio messages and aural warnings in apparent space. The utility of placing communication radios up and to the left, navigation radios down and to the right, and missile warning warbles directly in front of the aviator or in some other arrangement makes for interesting research. At present, neither the basic advantage of lateralization or the best arrangement have been elucidated.

A.3.18.2 Noise Induced Injury

Noise is mechanically transmitted to the outer ear following the rules of wave propagation discussed in the section on acoustics. The outer ear acts as a collector of the air pressure changes, and transmits the pressure change to the middle ear by way of the tympanic membrane. The TM and the ossicles of the middle ear act as an impedance matching device, amplifying the air pressure change and effecting vibration of the fluid in the neurosensory cochlea of the inner ear. The cochlea, in turn, acts as a transducer of pressure signals into an electrically coded signal which can be transmitted to neural pathways and eventually to the cortex of the brain for interpretation.

Damage at any level in this chain leads to lessening of the individual's hearing ability. Tumors can affect the neurosensory tracts. Connective tissue diseases can cause fusion of the ossicles. Infection or Eustachian tube dysfunction can cause erosion of the middle ear. Pressure changes can rarely cause rupture of the fluid portion of the inner ear (round window fistula). Unfortunately, exposure to overly loud noise can also damage the hearing apparatus.

One kind of noise induced injury to hearing occurs when loud sounds damage the middle ear. Extreme impact sounds can rupture the TM, strain the muscles of the middle ear, or cause dislocation of the ossicular chain. Bleeding and scaring of the middle ear is also possible. These changes or other middle ear pathology may lead to a permanent conduction type hearing loss with the patient's hearing affected about equally at all frequencies. If one ear was affected by the impact (as when one ear is slapped in a childhood game), then the damage is limited to that ear.

By far the more common type of noise induced hearing deficit is the sensorineural type of loss. The usual picture in early noise induced loss is of high frequency injury. Exposure to loud sounds leads to a transient loss of hearing known as temporary threshold shift. Tinnitus is usually the first sign of noise induced hearing deficit, but may be ignored by the patient. Several hours or days after exposure, the temporary shift clears and the tinnitus is resolved. The accumulation of many incidents with temporary threshold shift may result in permanent threshold impairment.

Permanent threshold shift is typically bilateral and begins at 4000 Hz and then becomes present as damage worsens at 3000 and 6000 Hz. Without a formal monitoring system, this damage is seldom noticed until it begins to interfere with speech critical frequencies below 2000 Hz. By this time the hearing loss at 4000 Hz may approach a 40 to 60 dB deficit.

The differential diagnosis of noise induced sensorineural loss includes checking for hearing loss

due to pathology of the VIII nerve. In cochlear disease the phenomenon of recruitment tends to be present. That is, small increases in sound intensity above the audible threshold are perceived as large increments in the intensity of the sound. In proximal VIIIth nerve disease, on the other hand, threshold adaptation ensues. Threshold adaptation of up to 10 dB is considered normal, but disease of the VIIIth nerve leads to excessive adaptation on continued stimulation.

Distinguishing noise induced (i.e., employment related) hearing loss from other forms of hearing loss is important in the context of workers' compensation programs. One complication of such programs is determining the amount of hearing loss due to noise exposure at work as compared with that due to recreational noise exposure. Practically, compensation programs are geared to the conservative assumption that all hearing loss while in the employment of the USAF (if the worker is exposed to significant noise) is compensatable regardless of etiology. Theoretically, if hearing loss can be shown to be entirely due to noise exposure off the job, then the employer is not liable for compensation. This might exist if the worker had a steady second job as a rock musician, for instance. A second complication of the workers' compensation program is the presentation of fictitious hearing loss. Fortunately, malingering is fairly easy to establish by means of audiometry.

A.3.18.3 Other Effects of Noise

One universal problem which bothers nearly everyone at one time or another is speech interference due to noise. From 0 to 50 dB of background noise there is no interference with speech. 50 dB is about the level of background sound present in a classroom. At 79-80 dB, the level of noise in the cabin of a commercial airliner, normal conversation is not audible more than 5 feet away, and your neighbor's conversations across the aisle will not be audible to you. At 84 dB, communication at more than 3 feet requires shouting. This is the level of sound pressure in many factories, and sound levels above this require hearing protection. At sound levels above 90 dB speech is usually not possible.

Other effects are noted by people exposed to loud environmental noises. Many are annoyed by loud sounds and find themselves constantly irritated by situations requiring them to be in loud noise areas. Other people have interference with normal sleep and rest in the presence of even minimal noise. Such annoyance and sleep disturbance is listener dependent. People tend to get used to their environment and can even be annoyed at unusual quiet. Even more unusual are nausea and vertigo related to noise. This syndrome is poorly understood but tends toward only one of the two components in an afflicted patient.

A.3.18.4 REFERENCES

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Human Factors. London: Tri-Med, 1978: 525-57.

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Schubert ED. Hearing: It's Function and Dysfunction. New York: Springer- Verlag, 1980.

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A.3.19 OPHTHALMOLOY AND THE AEROSPACE ENVIRONMENT

A.3.19.1 GENERAL EFFECTS OF ALTITUDE

The temporary visual difficulties of the human organism at high altitudes are due to hypoxia, decompression, glare, empty visual fields, brightness, and the visual effects of light.

A.3.19.1.1 Visual Effects of Hypoxia

Hypoxia can cause several changes in vision. These visual disturbances, and the ophthalmoscopically visible changes in the blood vessels which accompany them, are described in this section.

The indifferent zone is the range from sea level to 10,000 feet, because ordinary daytime vision is not affected within this range. There is, however, a slight impairment of night vision, a fact which makes it imperative for night combat flyers to use oxygen from the ground up.

The zone of adaptation is the range from 10,000 to 16,000 feet, because even though visual functions are impaired, the flyer is able to carry out the mission. In this zone, the following changes occur, becoming more marked with increasing altitude:

a. the retinal vessels become dark and cyanotic
b. the diameter of the arterioles increase 10 to 20 percent
c. retinal blood volume increases up to four times
d. the retinal arteriolar pressure increases along with the systemic blood pressure
e. the intraocular pressure increases somewhat with the increase in blood volume
f. the pupil constricts
g. there is a loss (at 16,000 feet) of 40 percent in night vision ability
h. accommodation and convergence powers decrease
i. the ability to overcome heterophorias diminishes.

All these changes return to normal by either the administration of oxygen or the return to ground level. Up to 16,000 feet, these effects remain latent, in the sense that physiologic compensation enables the flyer to continue basic tasks, unless this altitude is maintained for long.

The zone of inadequate compensation is the region from 16,000 to 25,000 feet, because one, several, or all of the preceding changes becomes severe enough to produce interfering visual difficulties. Visual reaction time is slowed. Motor response to visual stimuli is sluggish; mental processes are all slowed. Heterophorias are no longer compensated by fusion and become heterotropias with resulting double vision. Accommodation is weakened and convergence lost, so that instruments become blurred and doubled.

Dilation of retinal vessels, with the accompanying pressure changes, continues to increase until circulatory collapse intervenes. Visual acuity is impaired by diplopia, loss of accommodation, and general retinal and cerebral malfunction, and night vision is seriously impaired. All these changes are reversed by the use of oxygen or by returning to sea level.

The zone of decompensation or zone of lethal altitude occurs above 25,000 feet. In this zone circulatory collapse occurs; there is a loss of both vision and consciousness. As result of the death of neurons from severe hypoxia and lack of circulation, the flyer may suffer permanent damage to the retina and brain.

APPENDIX B

EXISTING DESIGN AND INSTALLATION PRACTICESFOR MILITARY AIRCRAFT OXYGEN SYSTEMS

B.1 SCOPE

B.1.1 Scope and purpose.

The purpose of the information provided in this appendix is to give background information on design and installation practices for existing military aircraft oxygen systems. The majority of past and existing military oxygen systems have been gaseous oxygen (GOX) supply and liquid oxygen (LOX) supply systems. This appendix includes much detail on existing GOX and LOX military aircraft oxygen equipment and installation practices. Military specifications and standards are cited which contain valuable information on the equipment under discussion. These documents need not be cited as requirements for the oxygen system design and development program, but they should be used for background information when writing a new development specification. Also, all this equipment is not necessarily applicable to any one oxygen system. The designer may desire to incorporate existing equipment in his oxygen system. For that purpose, this appendix will provide useful information on the equipment, the associated military specifications and installation practices.

Exercise caution in recommending the use of and in using Government furnished equipment (GFE) as it may not be as readily available as anticipated. GFE is usually procured only in quantities necessary to maintain existing aircraft in the event of failure and destruction during normal service. This equipment is maintained in the military for repair and overhaul of the aircraft that require it. However, some of this equipment has been phased out of production and is not readily available for use in the development programs. Therefore, lead time should be allotted to assure delivery of this equipment for new or modified oxygen system development programs. One to two years of lead time is considered a relatively conservative estimate.

Although subsystems and equipment vary in detail from one aircraft to another, all oxygen systems consist of the following equipment categories: (1) oxygen supply equipment and applicable mounting provisions, (2) delivery components consisting of plumbing, valves, and fittings, and (3) crew and passenger equipment. Appendix B is divided into these equipment categories and includes the associated existing test procedures.

B.2 APPLICABLE DOCUMENTS

B.2.1 Government documents.

B.2.1.1 Specifications and standards.

SPECIFICATIONS

Federal

BB-A-1034 Compressed Air, Breathing

BB-N-411 Nitrogen, Technical

WW-T-700 Tube, Aluminum Alloy, Drawn, Seamless, 5052, General Specification for Military

MIL-V-5027 Valves, Check, Oxygen, High Pressure

MIL-B-5087 Bonding, Electrical, and Lightning Protection, for Aerospace Systems

MIL-W-5088 Wiring, Aerospace Vehicle

MIL-E-5400 Electronic Equipment, Aerospace, General Specification for

MIL-C-5886 Cylinder, Aircraft Oxygen, Low Pressure, Nonshatterable

MIL-R-6018 Regulator, Oxygen, Diluter Demand

MIL-G-6019 Gages, 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-M-7700 Manuals, Flight

MIL-P-7788

MIL-C-7905 Cylinders, Steel, Compressed Gas, Non-Shatterable

MIL-V-7908 Valves, Aircraft Low Pressure Oxygen Systems

MIL-A-8416 Adapter, Headset-Microphone MX-1646, General Specification for

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-S-8805/3 Switches, Push, 10 Amperes or Low Level, Dusttight

MIL-V-9050 Valves, Oxygen, Pressure Relief, Aircraft

MIL-V-9439 Valves, Oxygen Cylinder, High Pressure

MIL-M-9472 Microphone M-34-AIC

MIL-V-18318 Valve, Pressure Regulating, Oxygen System

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-M-19417 Mask Assemblies, Oxygen and Smoke, Full Face

MIL-C-19803 Converter, Liquid Oxygen, 10 Liter, GCU-24A/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 Mixtures

MIL-C-25021 Converter, Oxygen, Aircraft, Liquid to Gaseous, Type MA-1

MIL-R-25410 Regulators, Oxygen, Diluter-Demand, Automatic-Pressure Breathing

MIL-P-25508 Propellant, Oxygen

MIL-V-25513 Valve, Check, for 300 PSI Liquid Oxygen Converter Systems, Type MH-1

MIL-L-25567 Leak Detection Compound, Oxygen Systems (Metric)

MIL-I-25645 Indicator, Liquid Oxygen Quantity, Capacitance Type, General Specification for

MIL-C-25666 Converters, Liquid Oxygen, Capacitance Type Gaging, General Specification for

MIL-E-25670 Earphone Elements, General Specification for

MIL-C-25674 Converter, Liquid Oxygen, Type ME-3

MIL-C-25777 Converter, Liquid Oxygen, GCU-2A/A

MIL-C-25781 Converter, Liquid Oxygen GCU-3/A

MIL-V-25961 Valve, Fill-Buildup-Vent, Liquid Oxygen Converter, CRU-50/A

MIL-V-25962 Valve, Liquid Oxygen Drain

MIL-T-26069 Trailer, Oxygen Cylinder, AF-M32R-3, High and Low Pressure, 2 Wheel 8 Cylinder Capacity

MIL-C-25972 Converter, Liquid Oxygen GCU-11/A

MIL-C-25973 Converter, Liquid Oxygen, GCU-12A/A

MIL-C-25974 Converter, Liquid Oxygen GCU-10/A

MIL-T-26069 Trailer, Oxygen Cylinder AF/M32R-3, High and Low Pressure, 2 Wheel 8 Cylinder Capacity

MIL-H-26312 Headset-Microphone H-157/AIC

MIL-I-26376 Indicator, Liquid Oxygen Quantity GMU-11-A (CANCELLED)

MIL-I-26380 Indicator, Liquid Oxygen Quantity GMU-5A

MIL-I-26382 Indicator Set, Liquid Oxygen Quantity, A-A24J4 and A-A24J8

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-26542 Microphone, Dynamic, General Specification for

MIL-H-26626 Hose Assembly, Tetrafluoroethylene, Oxygen

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

MIL-M-27274 Mask, Oxygen MBU-5/P

MIL-C-27336 Converter, Liquid Oxygen, Type GCU-17/A

MIL-H-27467 Headset Electrical H-154/AIC General Specification for

MIL-A-27471 Adapter, Pressure-Reducer, In-Line CRU-43A/A

MIL-G-27617 Grease, Aircraft and Instrument, Fuel and Oxidizer Resistant

MIL-C-27652 Converter, Liquid Oxygen GCU-20/A

MIL-T-27730 Tape, Antiseize, Polytetrafluoroethylene, with Dispenser

MIL-C-29576 Cylinders, Steel, Compressed Gas, Welded

MIL-T-38170 Tank, Mobile Storage, Liquid Oxygen, TMU-27/M

MIL-C-38271 Connector, Oxygen Mask to Regulator, CRU-60/P

MIL-M-38800 Manual, Technical, Organizational Maintenance Instructions for Aircraft, Missiles, and Non-Munition Accessories

MIL-H-55582 Headset, Microphone Kit, MK-896

MIL-S-81018 Survival Kit Container, Aircraft Seat, with Oxygen, General Specification for

MIL-C-81302 Cleaning Compound, Solvent, Trichlorotrifluoroethane

MIL-I-81387 Indicators, Liquid Oxygen Quantity

MIL-I-81388 Indicator Repeaters, Liquid Oxygen Quantity

MIL-T-81533 Trichloroethane, 1,1,1 (Methyl Chloroform), Inhibited, Vapor Degreasing

MIL-R-81553 Regulator, Chest Mounted, 100 Percent Oxygen, Positive Pressure, CRU-79/P

MIL-H-81581 Hose Assemblies, Breathing Oxygen and Air, General Specification for

MIL-R-83178 Regulator, Oxygen, Diluter–Demand, Automatic– Pressure-Breathing, General Specification for

MIL-H-83511 Headset-Microphone and Headset-Electrical (Medium Noise Attenuation, Hearing Protective), General Specification for

MIL-H-83511/3 Headset, Electrical, H-158A/AIC

MIL-D-85520 Design and Installation of On-Board Oxygen Generating Systems in Aircraft, General Specification for

MIL-C-85521 Concentrator, Oxygen, GGU-7/A

MIL-M-85522 Monitor, Oxygen, CRU-91/A

MIL-R-85523 Regulator, Chest Mounted, Positive Pressure, CRU-82/P

MIL-M-87163 Mask, Oxygen, MBU-12/P

AFGS-87235 Emergency Escape, Aircraft

STANDARDS

Military

MIL-STD-17A Mechanical Symbols for Aeronautical, Aerospace–craft, and Spacecraft Use

MIL-STD-203 Aircrew Station Controls and Displays: Assignment, Location, and Actuation of, for Fixed Wing Aircraft

MIL-STD-411 Aircrew Station Signals

MIL-STD-889 Dissimilar Metals

MIL-STD-1247 Markings, Functions and Hazard Designations of Hose, Pipe, and Tube Lines
for Aircraft, Missile, and Space Systems

MIL-STD-1359 Cleaning Methods and Procedures for Breathing Oxygen Equipment

MIL-STD-1472 Human Engineering Design Criteria for Military Systems, Equipment and Facilities

MIL-STD-1776 Aircrew Station and Passenger Accommodations

MS 21211 Valves, Check, Aircraft Low Pressure Oxygen Systems

MS 21227 Cylinder, Oxygen, Low Pressure

MS 22001 Mask Assemblies, Oxygen, Pressure Breathing

MS 22012 Valve, High Pressure Oxygen Cylinder Automatic Opening

MS 22016 Connector, Oxygen Mask Hose, Type MC-3A

MS 22032 Recharger Assembly, Portable Oxygen

MS 22035 Valve, Check, Oxygen, High Pressure, Filler Connection

MS 22055 Hose Assemblies—Oxygen Breathing, Connector to Regulator

MS 22058 Connector, Oxygen Hose to Regulator

MS 22059 Oxygen System, Portable, 295 Cu In., High Pressure, Aircraft

MS 22061 Oxygen System, Portable, 96 Cu In., High Pressure, Aircraft

MS 22062 Regulator, Oxygen, Diluter Demand, Automatic, Pressure Breathing

MS 22068 Coupling Assemblies, Quick Disconnect, Aircraft Liquid Oxygen Systems

MS 24548 Hose Assembly—Tetrafluoroethylene, Oxygen

MS 26545 Cylinders, Steel, Compressed Gas, Non-Shatterable, Seamless, 2100 PSI

MS 27566 Cap, Fill, Buildup and Vent Valve

MS 27599 Regulator, Oxygen, Diluter, Demand

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 90338 Valve, High Pressure Oxygen Check, Flareless Ends

MS 90339-2 Hose Assembly, Oxygen Mask to Connector

MS 90339-3 Hose Assembly, Oxygen Mask to Connector

MS 90341 Mounting Bracket, Mating Portion for 5 and 10 Liter Liquid Oxygen Converters

MS 90457 Hose Assembly, Metal, Liquid Oxygen

(Unless otherwise indicated, copies of federal and military specifications, standards, and handbooks are available from the Standardization Documents Order Desk, Bldg. 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.)

B.2.2.2 Other Government documents, drawings, and publications

AIR FORCE - NAVY AERONAUTICAL STANDARDS

AN 780-3 Nipple, Union

AN 805 Nut, Union

AN 806 Plug—Flared Tube

AN 929-5 Cap Assembly, Pressure Seal Flared Tube Fitting

AN 6009 Coupling—Automatic Oxygen

AN 6010-1 Regulator—Automatic Continuous Flow Oxygen

AN 6011 Gage—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 6016 Valve—High Pressure Oxygen Check, Style C

AN 6017 Valve—High Pressure Oxygen Check, Style D

AN 6018 Valve—High Pressure Oxygen Check, Style E

AN 6021 Gage, Panel Mounting Low Pressure Oxygen

AN 6024-5 Valve, Filler Low Pressure Oxygen

AND 10089 Fitting End, Standard Dimensions for Cone Connection

AND 10104 Tubing, Steel, Corrosion-Resistant, Round, Standard Dimensions for

AIR FORCE DRAWINGS

44A25450 Sleeve, Oxygen Coupling

46A16236 Clip, Recharger Low Pressure Oxygen System

53C3794 Cylinder and Regulator, Breathing Oxygen, Portable

53D3970 Mask-Cylinder-Regulator, Oxygen, Portable, Aircraft Firefighters

55B3878 Dustcap—High Pressure Oxygen Filler Valve-Assembly

60D3570 Cylinder and Regulator, Breathing Oxygen, Portable A/U26S-3, Assembly of

66B818 Headset-microphone H-133C/AIC

66B819 Headset-microphone H-133C/AIC

66B857 H-136/AIC Earphone

AIR FORCE SYSTEMS COMMAND DESIGN HANDBOOKS

AFSC DH 2-2 Crew Stations and Passenger Accommodations

TECHNICAL ORDERS

TO 00-20-1 General Technical Order on Maintenance Management

TO 15X-1-1 Technical Manual, Maintenance Instructions, Oxygen Equipment

FEDERAL AVIATION REGULATIONS

FAR Part 25 Federal Aviation Regulation Airworthiness Standards: Transport Category Airplanes

(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.)

B.2.3 Non-Government publications

SAE AMS-4071 Aluminum Alloy Tubing, Hydraulic Seamless, Drawn, Round 2-5 Mg -0.25 Cr (5052-0) Annealed

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

(Applications for copies should be addressed to the Society of Automotive Engineers, Inc., 400 Commonwealth Drive, Warrendale PA 15096)

B.2.4 OXYGEN SUPPLY EQUIPMENT

B.2.4.1 Gaseous oxygen supply systems.

Gaseous aviator's breathing 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 liter at 760 mm Hg 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 become blocked, resulting in a lack of oxygen delivery to aircraft occupants or the destruction of the pressure vessel(s) from over pressure when pressure relief is precluded. Aviator's breathing oxygen is purer than “technical" oxygen or “medical" oxygen that is used at ground facilities to be compatible with aircraft operation. Moisture in the oxygen gas would be desirable from a physiological standpoint to prevent drying of the 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. In spacecraft and high altitude aircraft applications, Grade F oxygen per *MIL-P-25508* is used for fuel cells, but it may also be used for crew breathing in subsystems using a common storage for both functions. *MIL-D-8683* has been used to design low and high pressure gaseous oxygen systems for Army, Navy, and Air Force aircraft and provides details for equipment installation.

The gaseous oxygen supply capacity must be determined so that the intended mission of the aircraft is satisfied for all normal and emergency situations. The means of calculating these capacities are given in Appendix A. Usually all the pressure vessels (cylinders typically) are the same size to enhance ease of replacement and reduce the number of parts used on any one aircraft system. Sometimes, however, it is acceptable to use a different size pressure vessel for the flight crew system versus the passenger and/or non flight crew system because different considerations for oxygen supply exist for each. The required oxygen supply may be excessive and the number of pressure vessels may thus result in a weight penalty. When the number of pressure vessels becomes excessive and the associated weight penalty is too great, alternate storage means should be considered. Lightweight high strength metal alloys may be used for weight reduction, but they should meet the same design requirements as the heavier metal cylinders in *MIL-C-7905* for cylinders that are spun and *MIL-C-29576* for cylinders that are welded. **For new applications, wire-wrapped cylinders are not used by the Navy.**

Kevlar or fiberglass may be used to strengthen oxygen pressure vessels in newer designs to achieve vessel strength against higher pressures while minimizing weight. These are called composite cylinders. When Kevlar or fiberglass wrapping is used, the design should place a maximum limit on the stress in the filament winding so that stress-rupture life is maximized. For fiberglass, the fiber stress design limit should not exceed 35 percent as past experience has shown this to be a valid limit.

For U.S. Navy and Air Force use, composite oxygen cylinders with aluminum liners are not acceptable. This is especially critical for military aircraft with a gunfire threat and of grave concern on other types of aircraft. Fragmentation resistance testing conducted by the Navy has revealed a problem with the use of composite oxygen cylinders with aluminum liners on military aircraft. Gunfire testing resulted in a significantly larger blast over pressure than that

experienced with steel cylinders of the same size without a composite over wrap. When penetrated, the heat released ignites the aluminum liner adding more energy than that contained by the pressurized gas. The superior strength from the construction of the cylinder with the glass or Kevlar over wrap contains this energy allowing it to build to very high proportions until it is released through the openings caused by the projectile and the burning aluminum. Gunfire tests have shown that the blast over pressure of a composite aluminum lined cylinder pressurized with 100 percent oxygen was 5 times greater than that of a comparable size steel cylinder pressurized with 100 percent oxygen. See Appendix A, paragraphs 3.5, 3.5.1, 4.5 and 4.5.1 for addition detailed information on this topic.

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 or isolated as much as practicable to minimize combat vulnerability. Sufficient space is needed to replace cylinders and to perform maintenance on all parts.

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 to connect the external filling source does not exceed one man-minute and does not create a hazard for servicing personnel.

Typical gaseous oxygen systems for various types of aircraft and their general arrangement are shown in *figures 17* through *25*. The actual number, location and application of these components and plumbing should be determined by the aircraft characteristics, missions, and any additional requirements.

B.2.4.2 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 with 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 the primary aircraft oxygen supply. High pressure oxygen cylinders are typically filled to a pressure of 1800 to 2200 psigG.

In high pressure systems, military GFE high pressure oxygen cylinders conform to *MS 26545* and include an *MS 22012* automatic opening valve. If possible, the size of the cylinders is selected based on facilitating two cylinders, so that if one fails the other is available. Pressure-reduction valves are located as close to the cylinder as possible within the design constraints imposed on the oxygen system. *MIL-V-18318*, Type I may be used for 70 psig service and Type II may be used for 400 psig service.

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 heavy weight. High pressure oxygen cylinders should be a bright green color. 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 I*. Cylinder types are named according to the applicable standard.

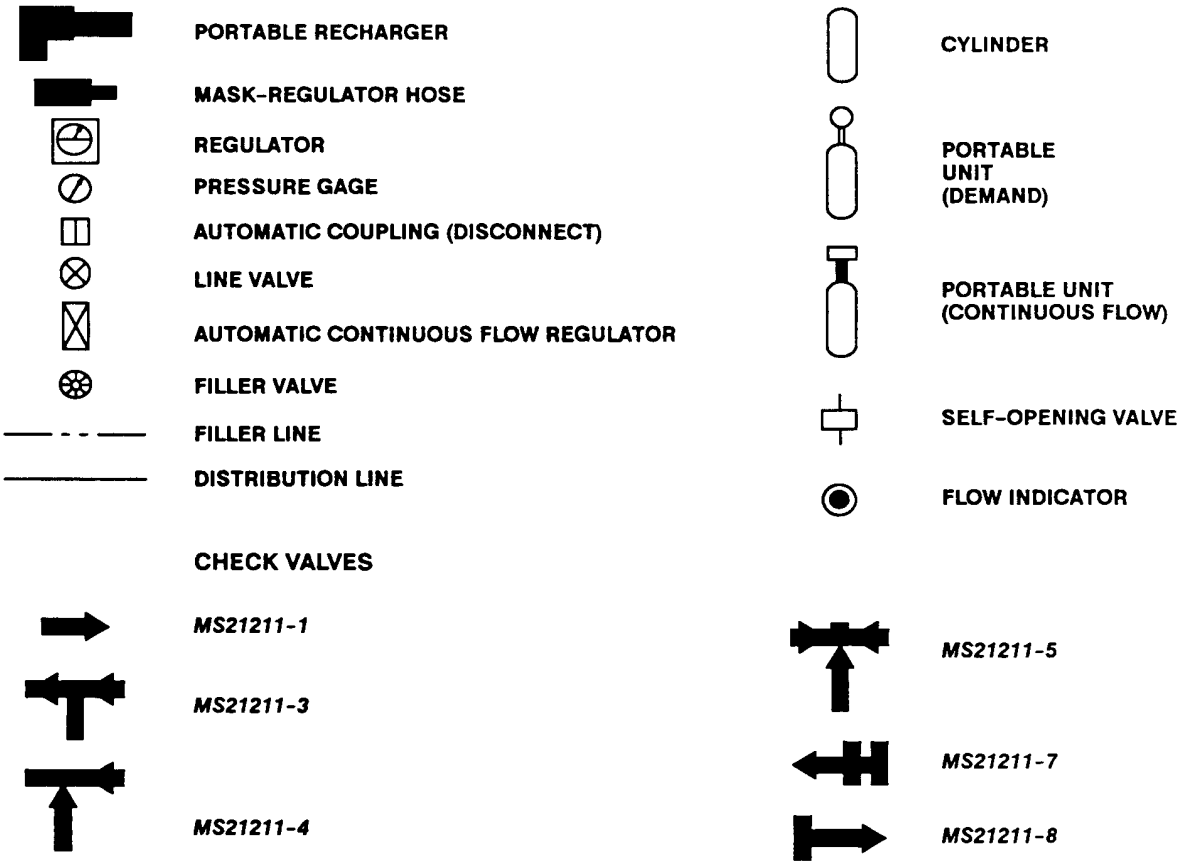
MS 26545 gives the government qualified non-shatterable high pressure cylinders dimensions and designations. An example of the designation used would be *MS 26545* A 2X0025W where *MS 26545* is the applicable part number, A is the thread type, 2 is the class definition, X is the usage code note, 0025 is the nominal capacity and W indicates wire wrapped (where applicable). At this time it has been proposed to delete the class definition from the code. *MIL-C-7905* is used to design high pressure cylinders for use in aircraft oxygen systems that are spun and *MIL-C-29576* is used for cylinders that are welded. The primary advantage of the high pressure cylinder is that a larger amount of oxygen may be stored in a smaller space as compared to the lower pressure cylinder.

The high pressure supply systems are designed similar to low pressure supply systems except that a pressure-reducing 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 for military aircraft is discouraged. A better design approach is to install pressure-reducing valves at the cylinder opening (reducing 1800 psig to 300-450 psig) with manual off and on control, a servicing port, and pressure relief on one regulator assembly. All oxygen distribution supply lines including manifolding should be downstream of these regulators. Oxygen system designs on commercial aircraft have used this design approach successfully.

B.2.4.3 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 psig and are normally filled to 400 to 450 psig from ground servicing containers. Portable walk-around containers, which are filled on-board the aircraft to the pressure in the supply lines, are also considered low pressure supply equipment. Should the aircraft have a low pressure supply system installed, the capability to replenish the portable walk-around container will be limited from 450 down to 50 psig depending on how much supply has been used. Although the volume of oxygen gas that may be stored is somewhat limited compared to the high pressure systems, the low pressure supply system does reduce the possibility of explosions. Unfortunately, many large, bulky containers are required to store any significant supply of oxygen.

Even though the gas is very dry, some moisture is always present. A system that drops below 50 psig must be filled within several hours to prevent condensation contamination. Should condensation occur, the supply containers would need to be purged to eliminate moisture that could cause malfunctions on later flights such as freezing of components at higher altitudes.



NOTE: The pressure gage and the indicator may be an integral part of the regulator

FIGURE 17. Gaseous oxygen symbols.

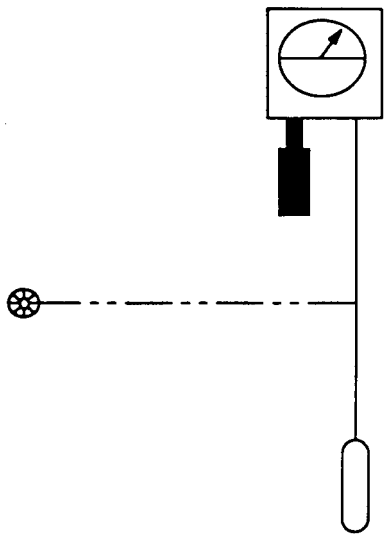


FIGURE 18. Typical one cylinder gaseous oxygen installation.

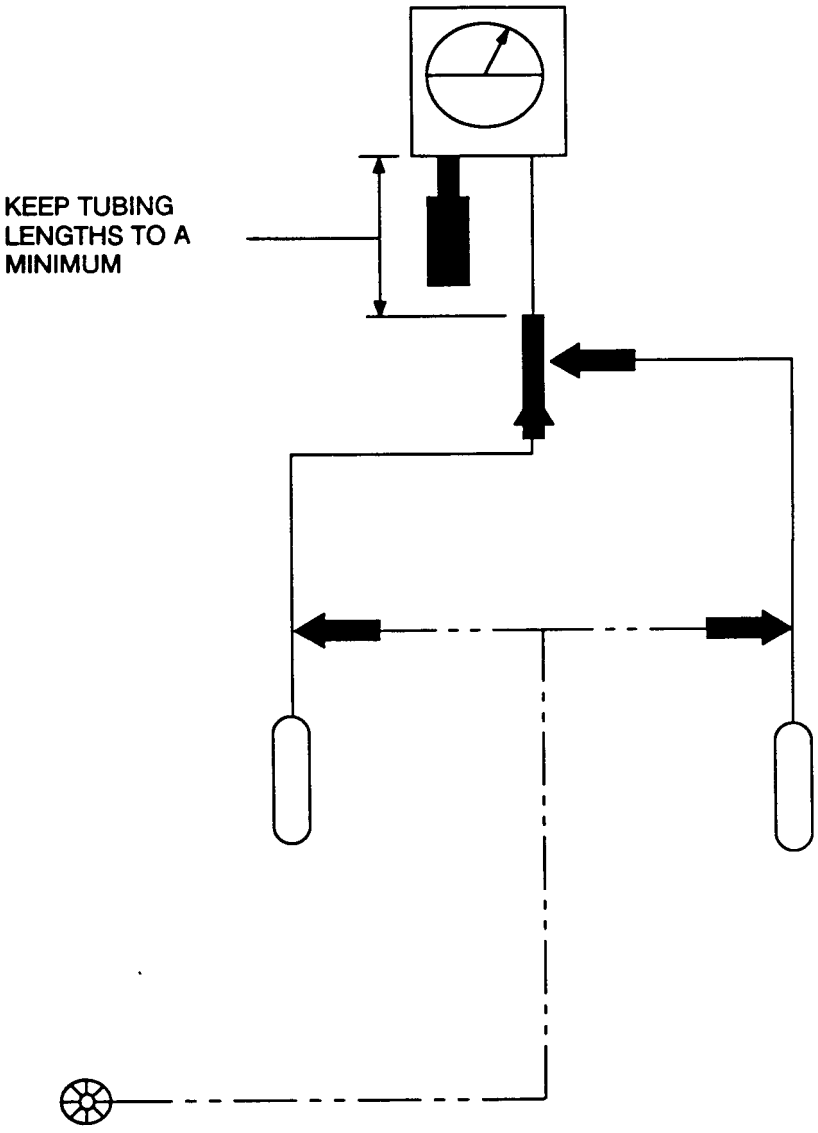
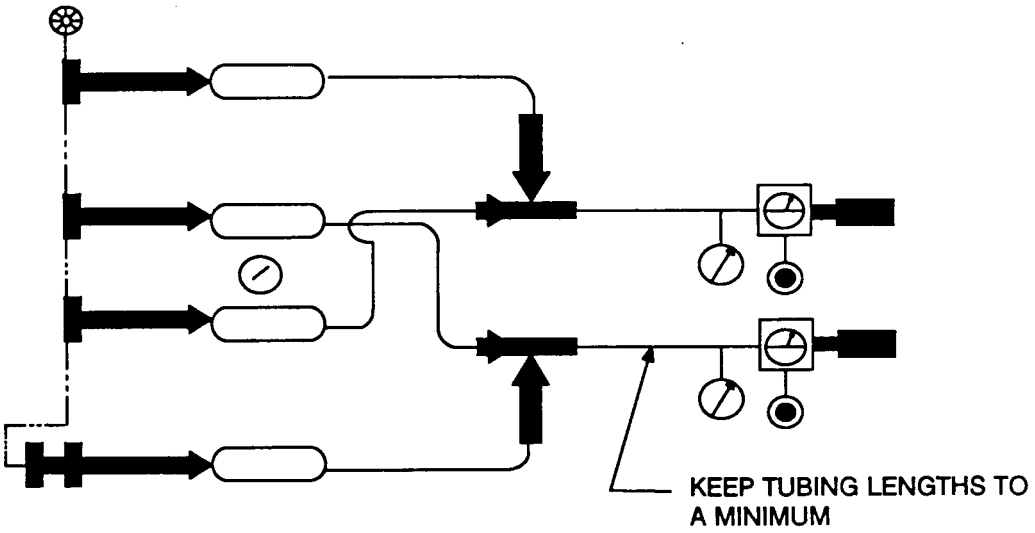
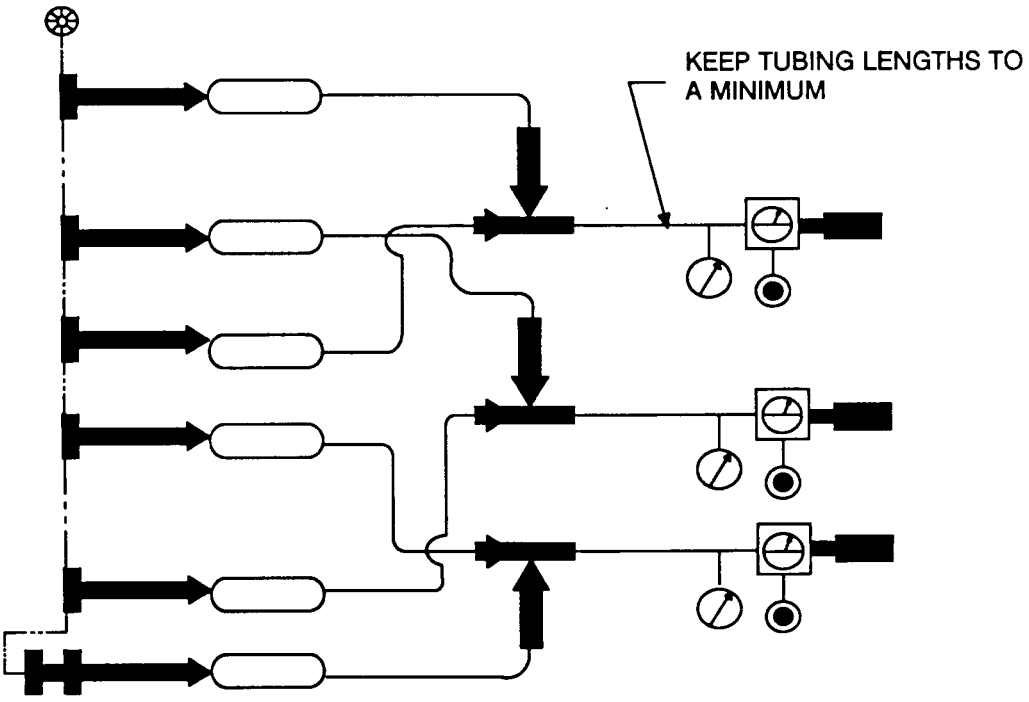


FIGURE 19. Typical two or more cylinder gaseous oxygen installation.



INSTALLATION IN DUAL PLACE AIRCRAFT



INSTALLATION IN THREE-PLACE AIRCRAFT

Note: Above illustrations show separation of cylinders to individual stations.

FIGURE 20. Typical gaseous oxygen systems in dual- and three-place aircraft.

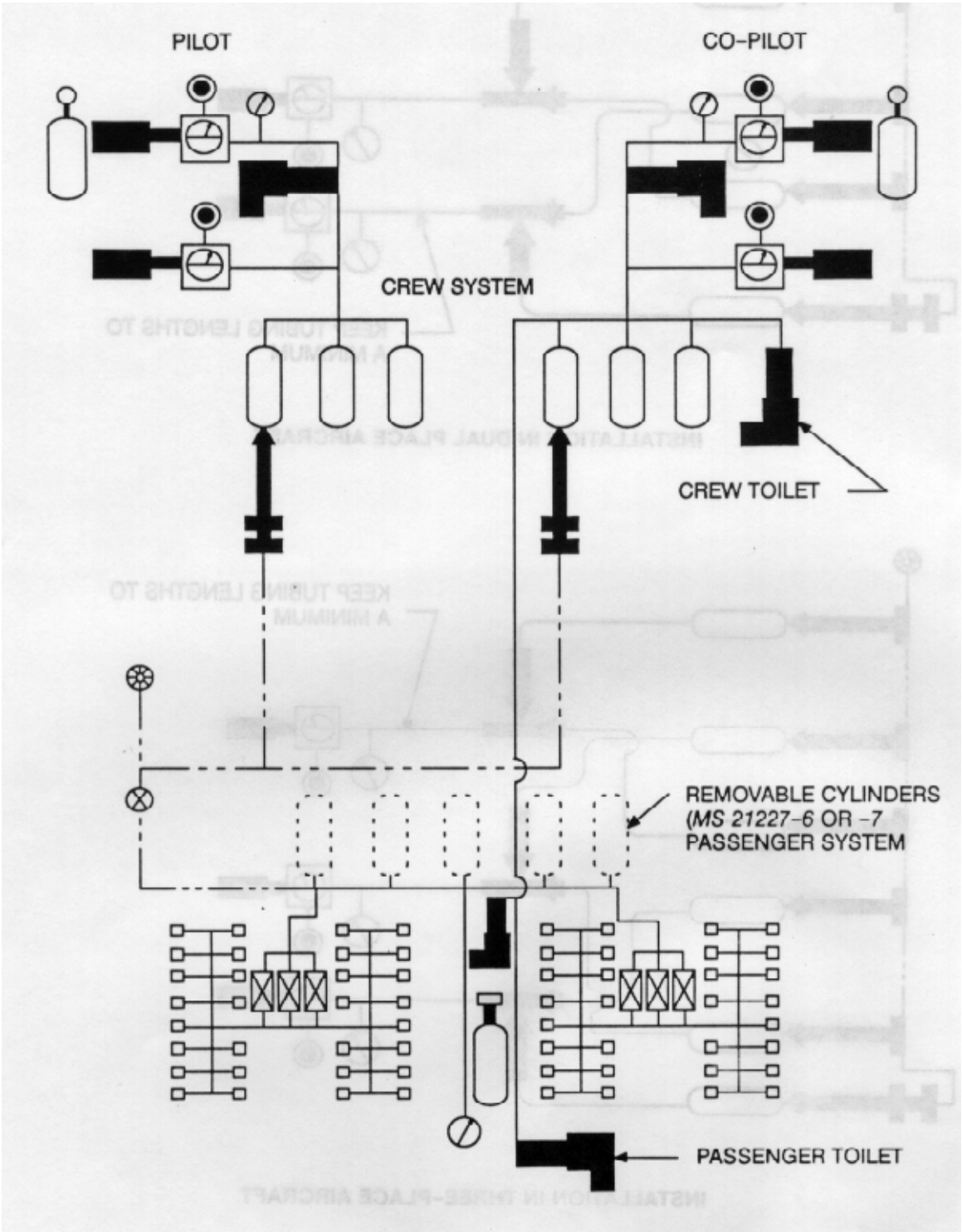


FIGURE 21. Typical gaseous oxygen systems in transport aircraft.

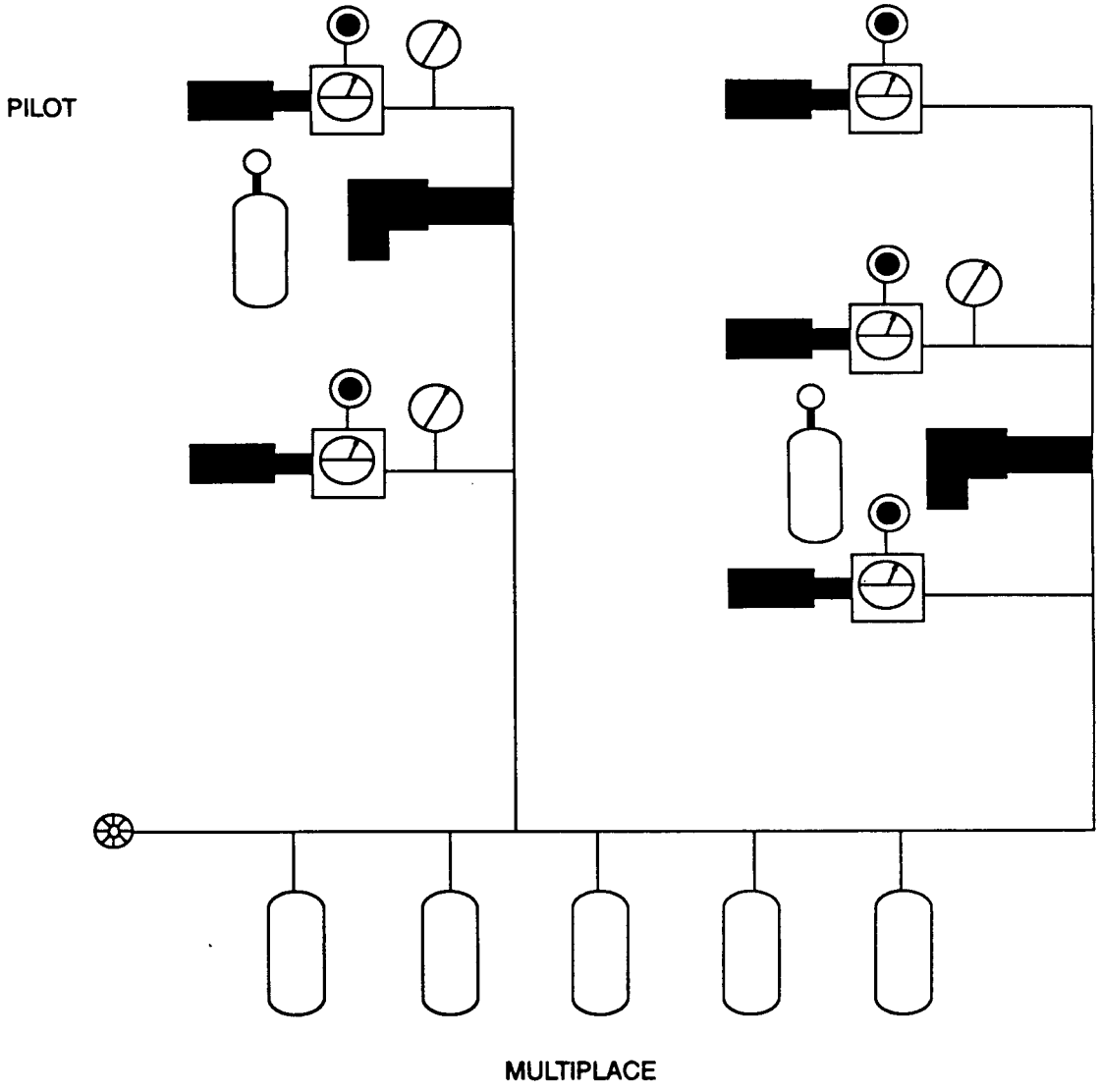
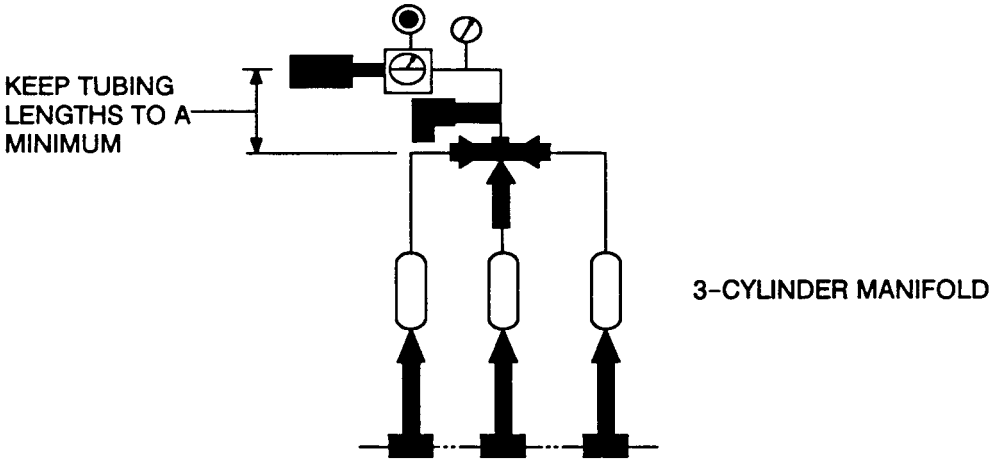
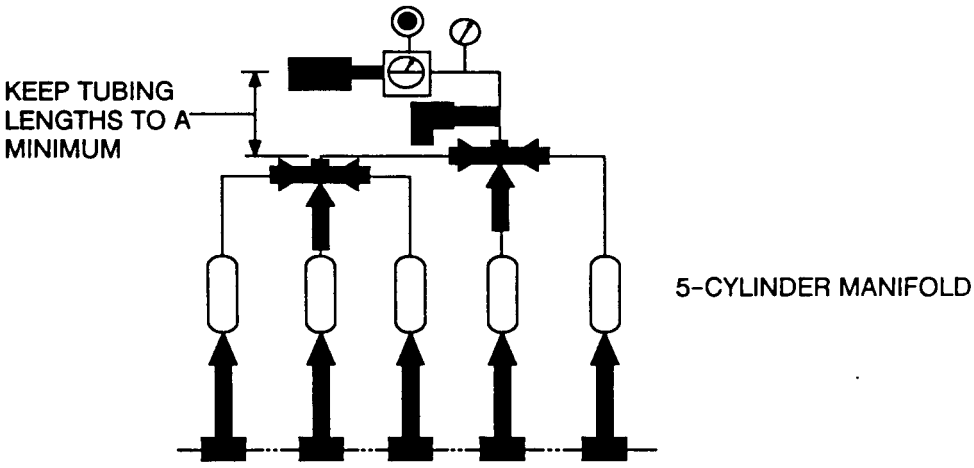


FIGURE 22. Typical gaseous oxygen installation in training aircraft.





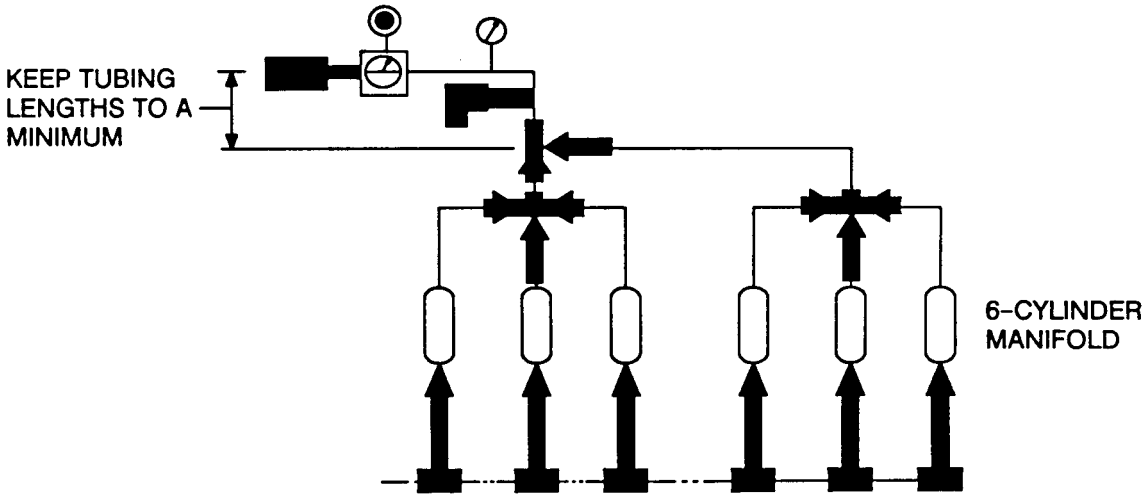


FIGURE 23. Typical individual manifold portion gaseous oxygen installation.

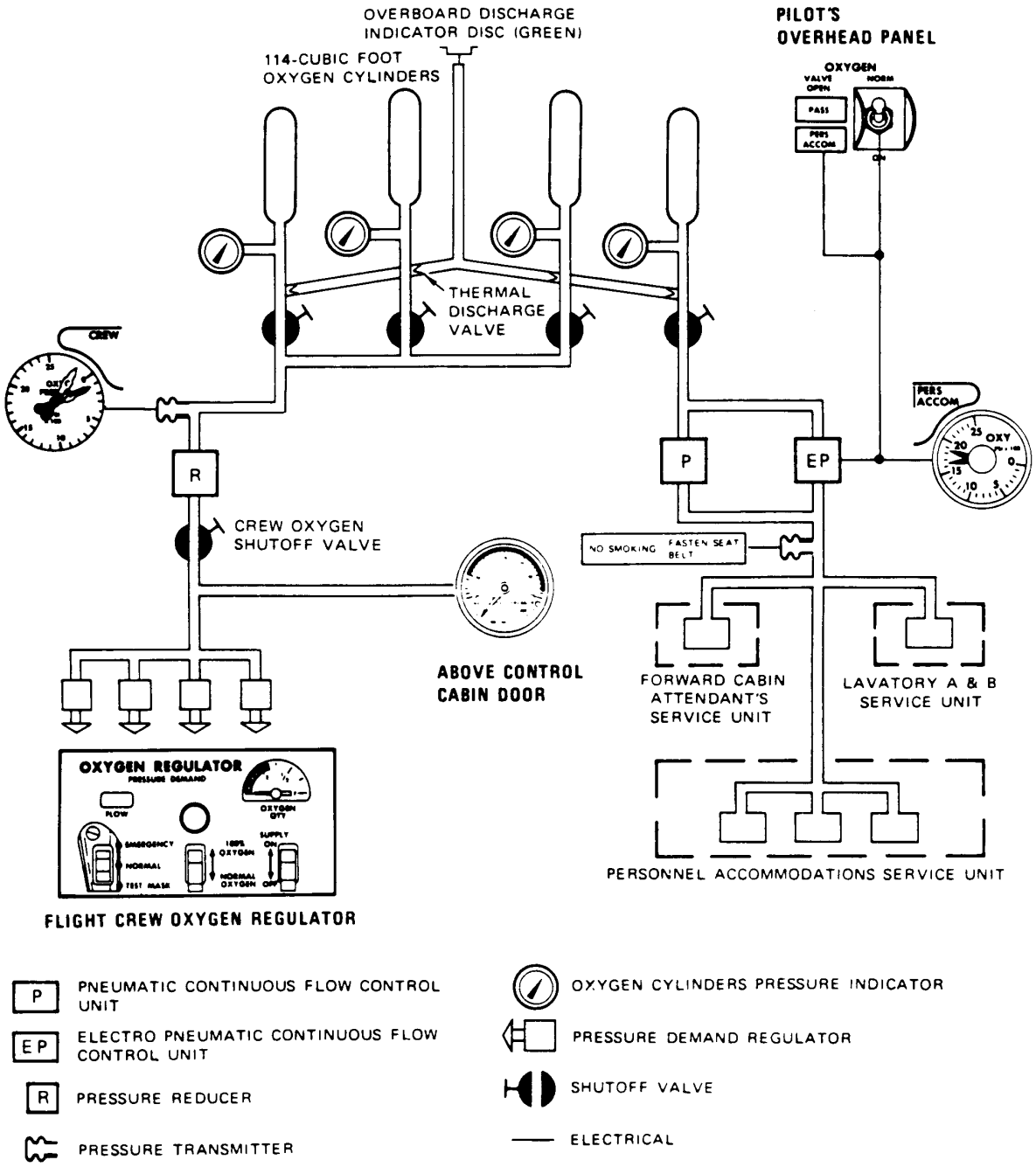


FIGURE 24._C-18A gaseous oxygen system– crew and personnel accommodations.

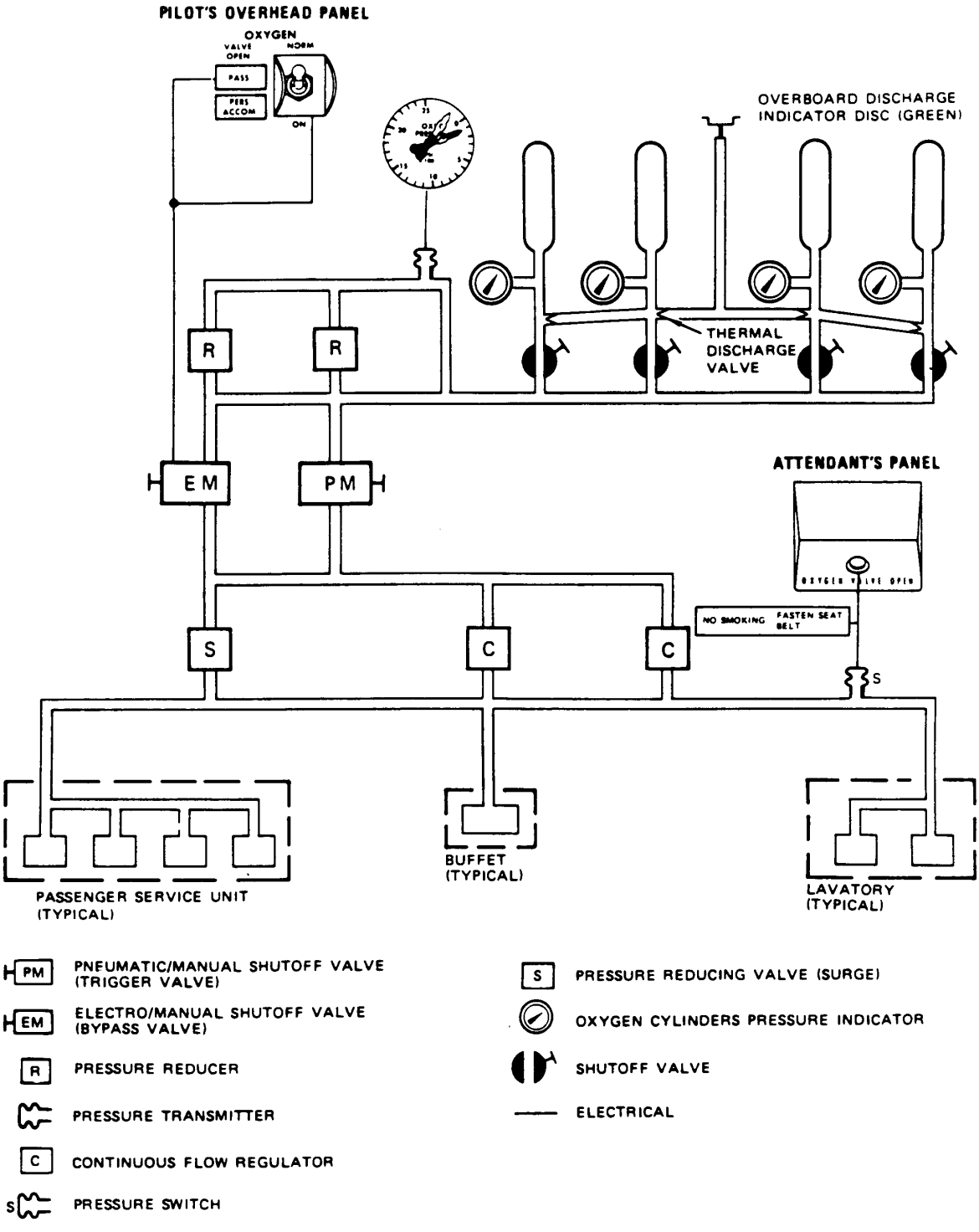


FIGURE 25._C-18A gaseous oxygen system– passenger configuration.

TABLE B-I. Characteristics of high pressure oxygen cylinders.

Cylinder Type	Internal volume m^3	Internal volume $in.^3$	Length mm	Length in.	Diameter mm	Diameter in.	Available oxygen 12.4 to 1.0 MPa (1800 to 100 psig) m^3	Available oxygen 12.4 to 1.0 MPa (1800 to 100 psig) 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	0.560	19.6
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

Shatterproof or nonshatterable cylinders resist shattering by gunfire when punctured at a pressure of 2.8 MPa (400 psig). 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 currently used in many aircraft and are distinguished by their yellow color. Identifying characteristics of the various types of low pressure supply containers and their available gas capacities are given in *table II*.

In low pressure systems, military GFE oxygen cylinders are designed according to *MIL-C-5886*. Existing cylinders are available according to *MS 21227*. The size of the cylinder usually is selected for individually manifolded systems so that each manifold has a minimum of two cylinders. In single place aircraft, two or more cylinders are desired for system redundancy.

B.2.4.4 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 26*. The system converts liquid oxygen to gaseous oxygen using a heat exchanger and needs no external source of power, as the ambient air warms 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. Installation guidance for single and multiple converters and stations is given in *figures 26* through *34*. Liquid oxygen vaporizes more rapidly from smaller converters because a more rapid heat transfer accompanies the high area-to-volume ratio. For this reason, converters with capacities of a minimum of five liters are used. For the same reason, installing a minimum number of converters on the aircraft is desirable. 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 psig or 300 to 450 psig to meet all design needs.

Greater demand is required on larger aircraft that must supply oxygen to many crew members and passengers. These types of aircraft use 300 psig systems to maintain maximum demand

by keeping the delivery pressures above 200 psig. Most existing breathing regulators will not properly function with input pressures of less than 50 psig. Also, when these aircraft incorporate portable refillable cylinders, a working pressure of at least 200 psig is desirable to recharge the supply of oxygen. On smaller aircraft that have only one or two crew members,

TABLE B-II. Characteristics of low pressure oxygen cylinders.

Type	Cylinder Drawing	Available oxygen (400 to 50 psig) 2.8 to 0.3 MPa		Internal volume		Length		Diameter	
		ft^3	m^3	$in.^3$	mm	in.	mm	in.	m^3
A-6	MS21227-1	0.004	0.108	280	368.3	14 1/2	146	5 3/4	3.8
B-3	-2	0.004	0.108	280	381.0	15	146	5 3/4	3.8
D-2	-3	0.008	0.195	500	596.9	23 1/2	146	5 3/4	6.9
F-1	-4	0.016	0.391	1,000	1,457.2	18	257.2	10 1/8	13.8
F-2	-5	0.016	0.391	1,000	1,130.3	44 1/2	146	5 3/4	13.8
G-1	-6	0.034	0.821	2,100	621.3	24 1/2	317.5	12 1/2	29.0
J-1	-7	0.294	8.022	18,000	1,250.9	49 1/4	622.3	24 1/2	248.0

such as fighters, a converter working pressure of 70 psig is adequate. See *table III* for a listing of many existing converters. See *Figure 26a* that shows an illustration of a typical liquid oxygen converter assembly.

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. For 1 liter (0.0353 cubic feet) of liquid oxygen 860 liters of gas will be produced at 70°F and sea level atmospheric pressure. To pressurize this oxygen gas, the new volume is determined by $V_2 = (P_1/P_2)V_1$ assuming a perfect gas with constant temperature. For example, if the supply pressure is 300 psig and 1 liter of liquid oxygen is vaporized to the reference sea level condition of 860 liters at 70°F, then the new volume of gas in the distribution system will be V_2 = (14.7 psigI) 860 liters = 42.14 liters of oxygen gas. One liter of liquid oxygen weighs 2.513 pounds when referenced to 14.7 psigG; therefore one may easily determine that 75 liters of liquid oxygen in a 75 liter converter weighs 188.475 pounds at ambient pressure. The liquid oxygen converter is a double-walled, insulated storage container with the necessary valves and tubing for vaporizing the liquid and warming the gas for use by crew members. 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.

The design quantity of oxygen is determined from Appendix A. After a mission analysis is accomplished for oxygen quantity requirements, the amount of liquid oxygen required may be determined from *table IV*. The design quantity is the liquid oxygen available 24 hours after servicing.

Design oxygen capacity - The maximum oxygen flow rates shall be determined by looking at the highest demand that may be expected in any mission increment. In a tactical aircraft, the maximum flow rates would be expected to occur in high G maneuvers in flight or with a pressure-demand type regulator in the emergency or safety pressure breathing mode at lower altitudes. Activity factors shall be determined and used for either case. In a transport aircraft, the highest demand flow rates would be expected to occur when all crew members select 100 percent emergency oxygen and the passenger oxygen regulator is at higher altitudes.

An activity factor of not less than 1.25 for not less than 15 minutes shall be used for all crew members. In either case, the converter shall be installed with a properly sized heat exchanger such that in all expected highest demand mission situations, liquid oxygen is not pulled too far downstream such that the temperature range at the outlet becomes too cold.

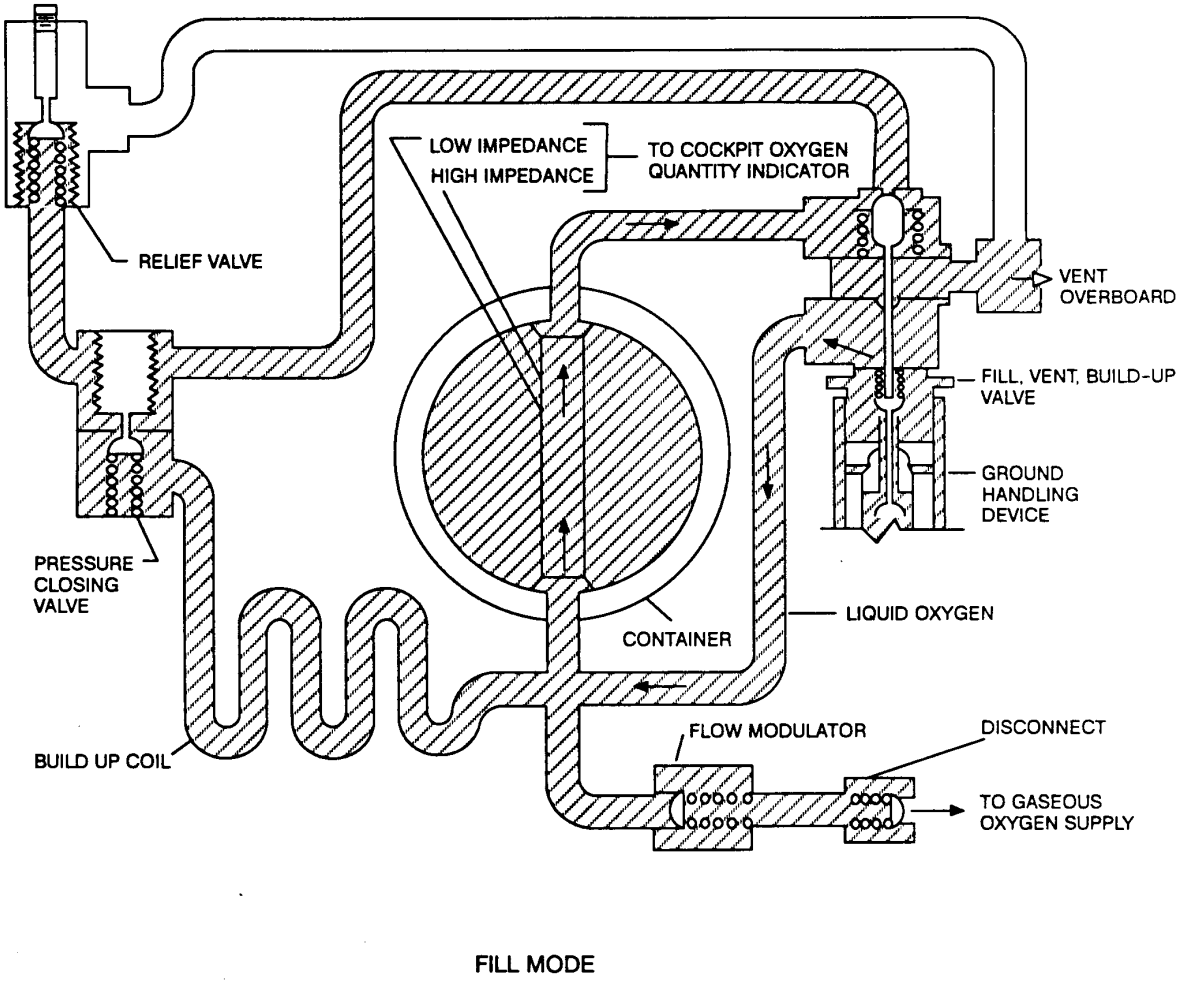


FIGURE 26. Liquid oxygen converter flow diagram.

FIGURE 26a. Liquid oxygen converter assembly, Type GCU-24/A.

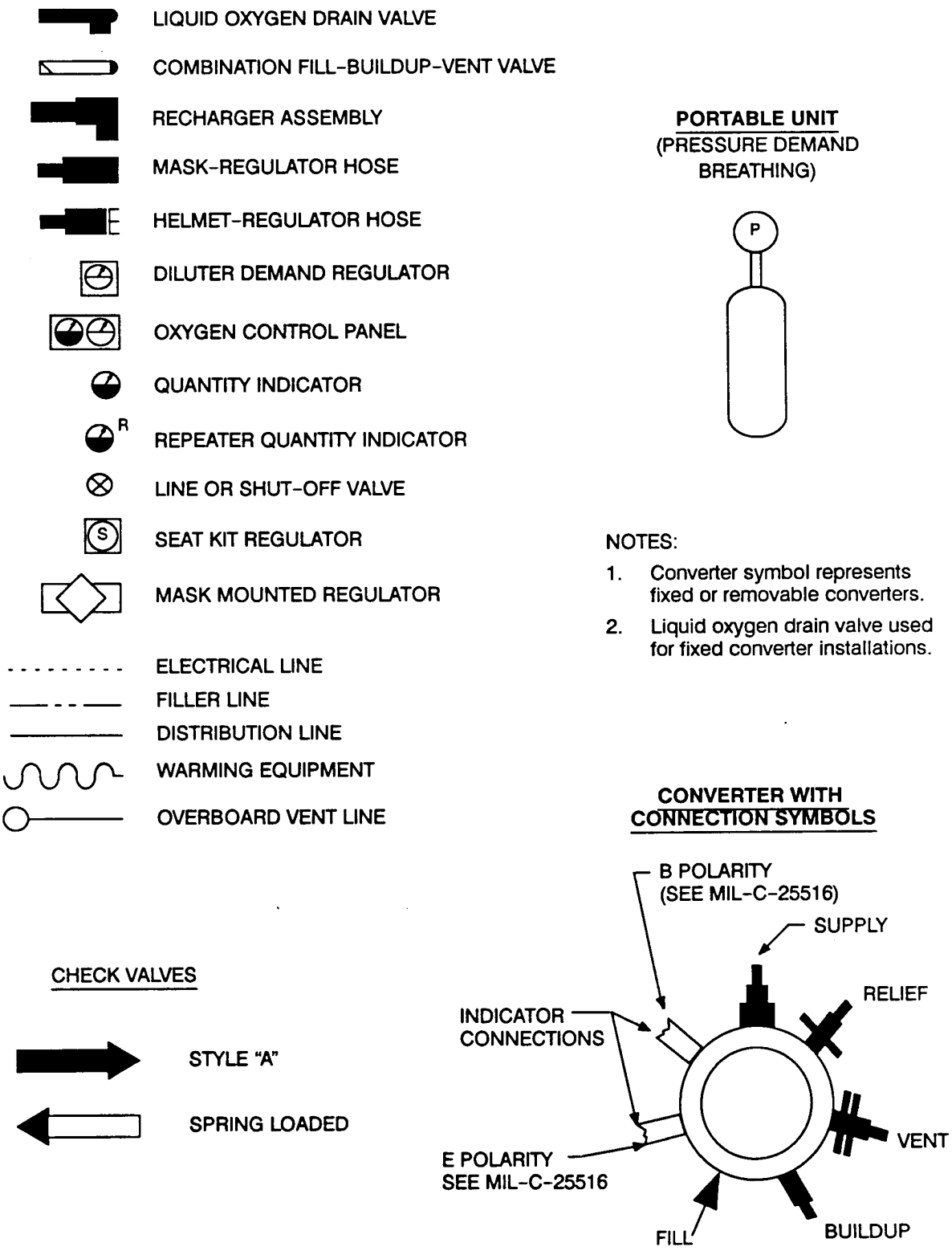


FIGURE 27. Liquid oxygen (LOX) symbols.

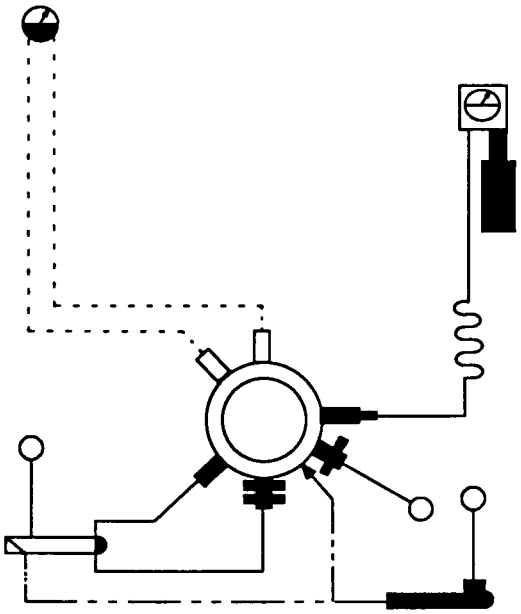


FIGURE 28. Typical installation single LOX converter in single

FIGURE 28. Typical installation single LOX converter in single place aircraft– fixed converter installation.

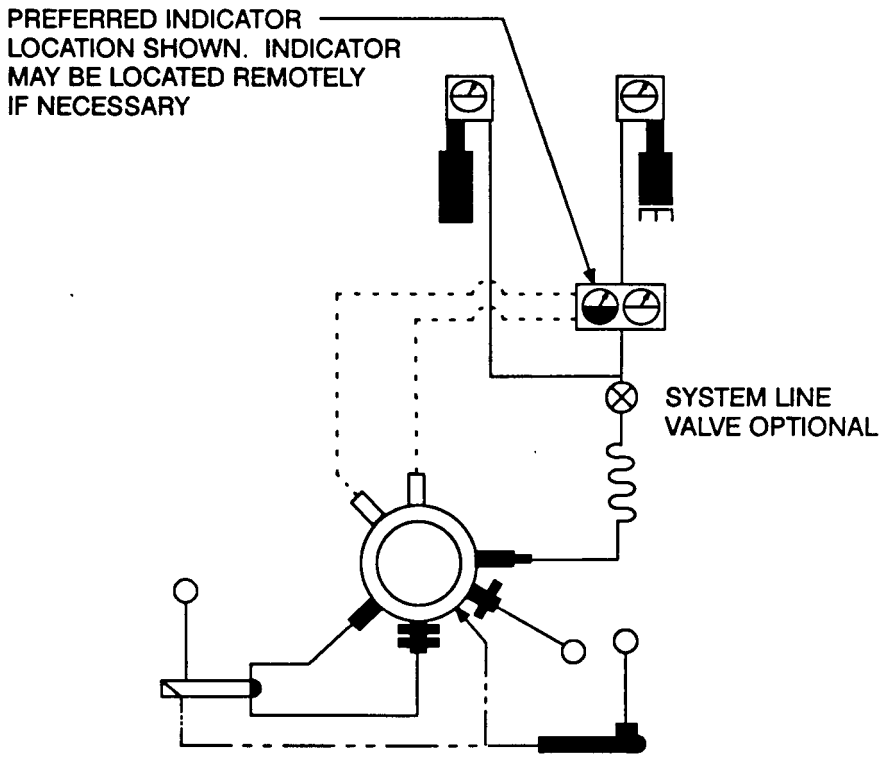


FIGURE 29. Single LOX converter with dual regulator– fixed converter installation.

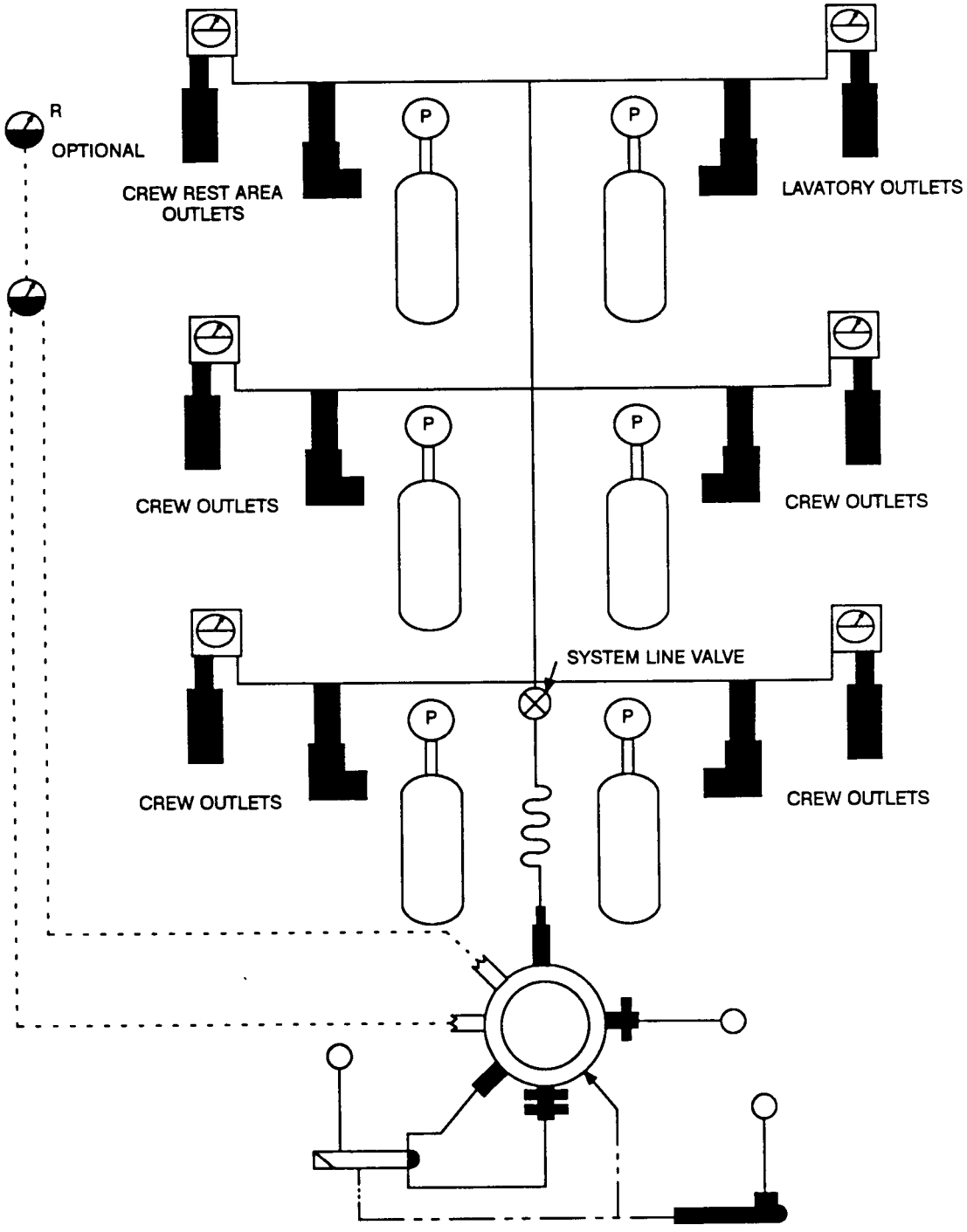


FIGURE 30. Typical installation of single LOX converter in a multiplace crew station– fixed converter installation.

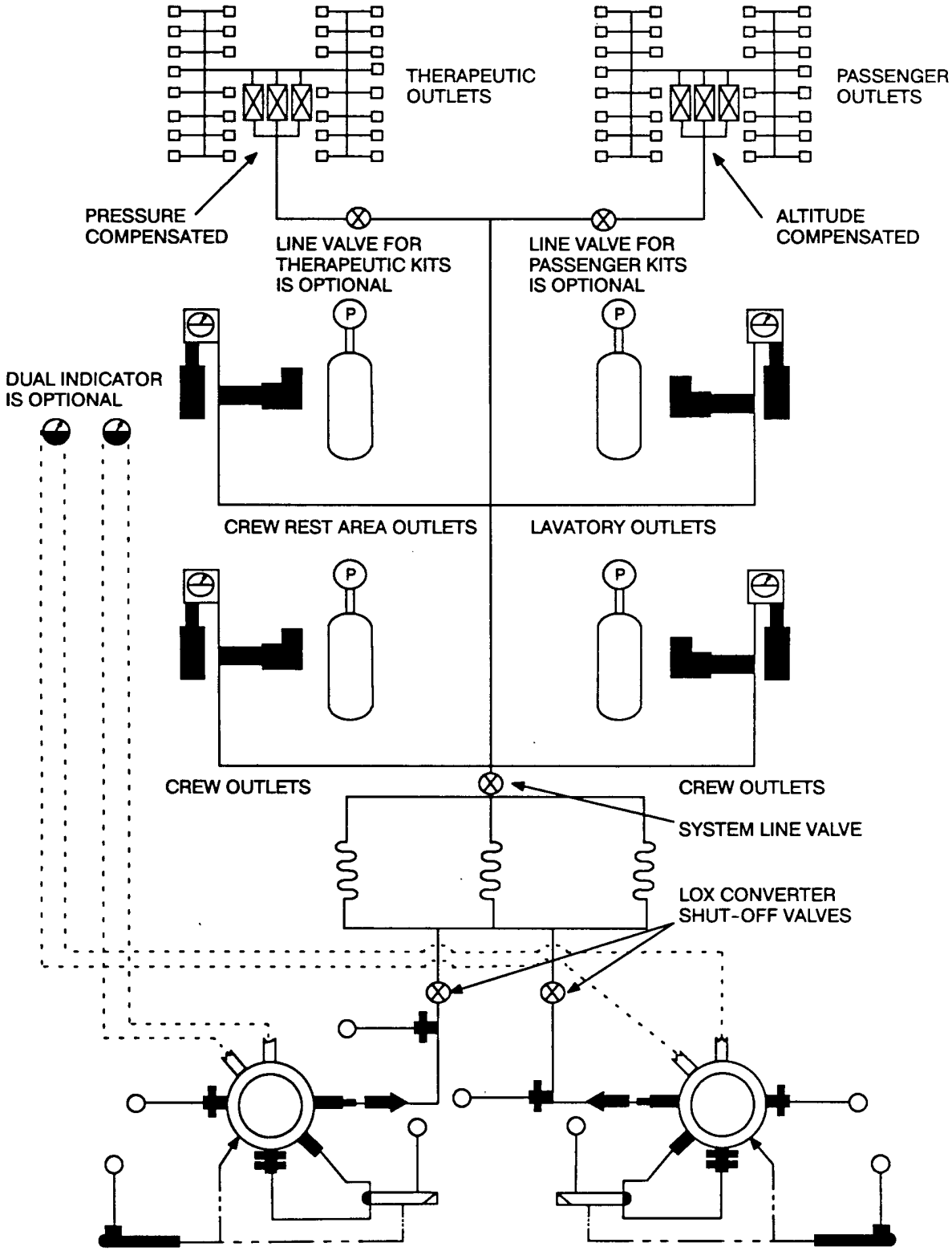


FIGURE 31. Typical installation with multiple LOX converters in a

multiplace crew station– converters mounted together; manifolded heat exchangers.

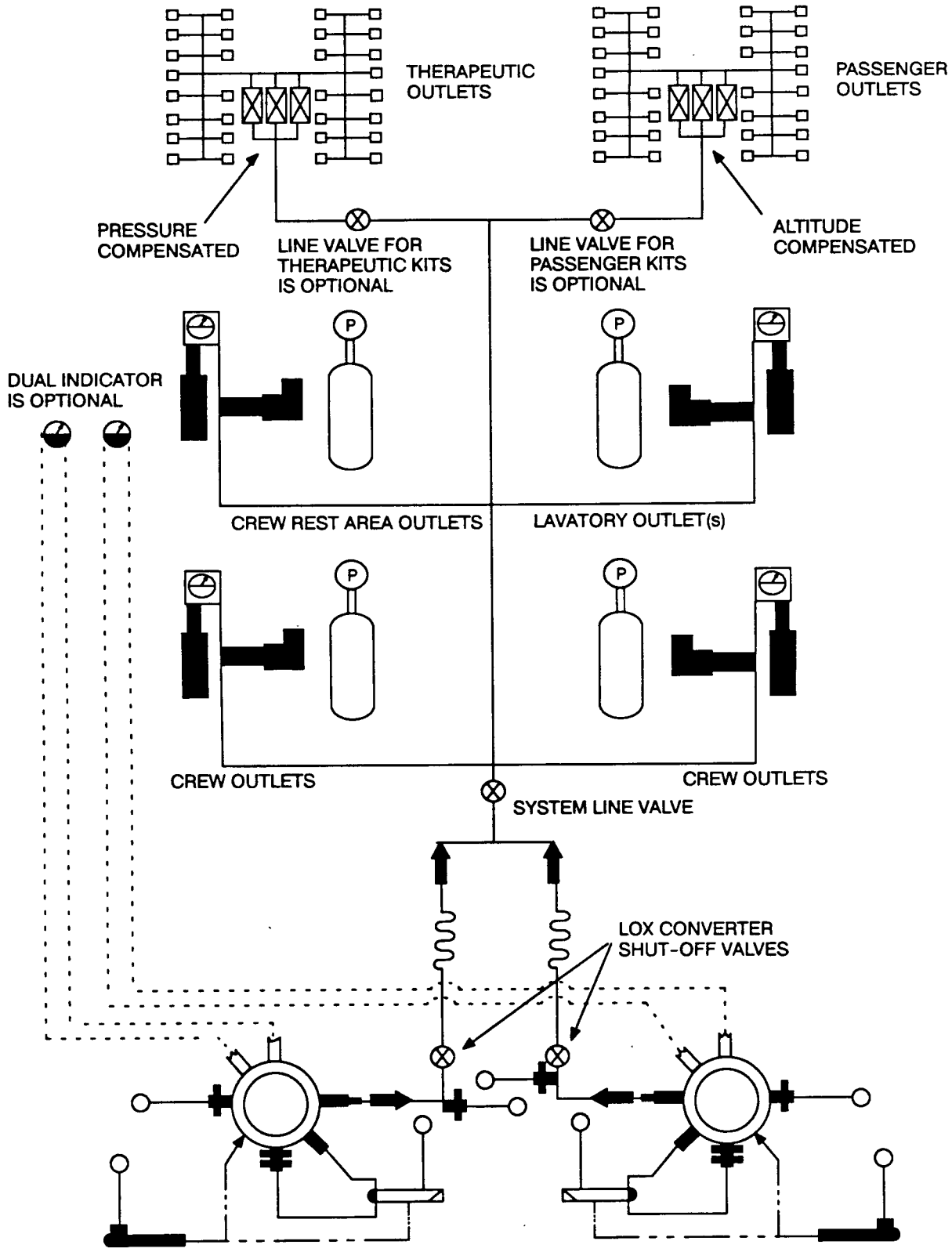


FIGURE 32. Typical installation with multiple LOX converters in multiplace crew stations– converters remotely located; each with own heat exchanger.

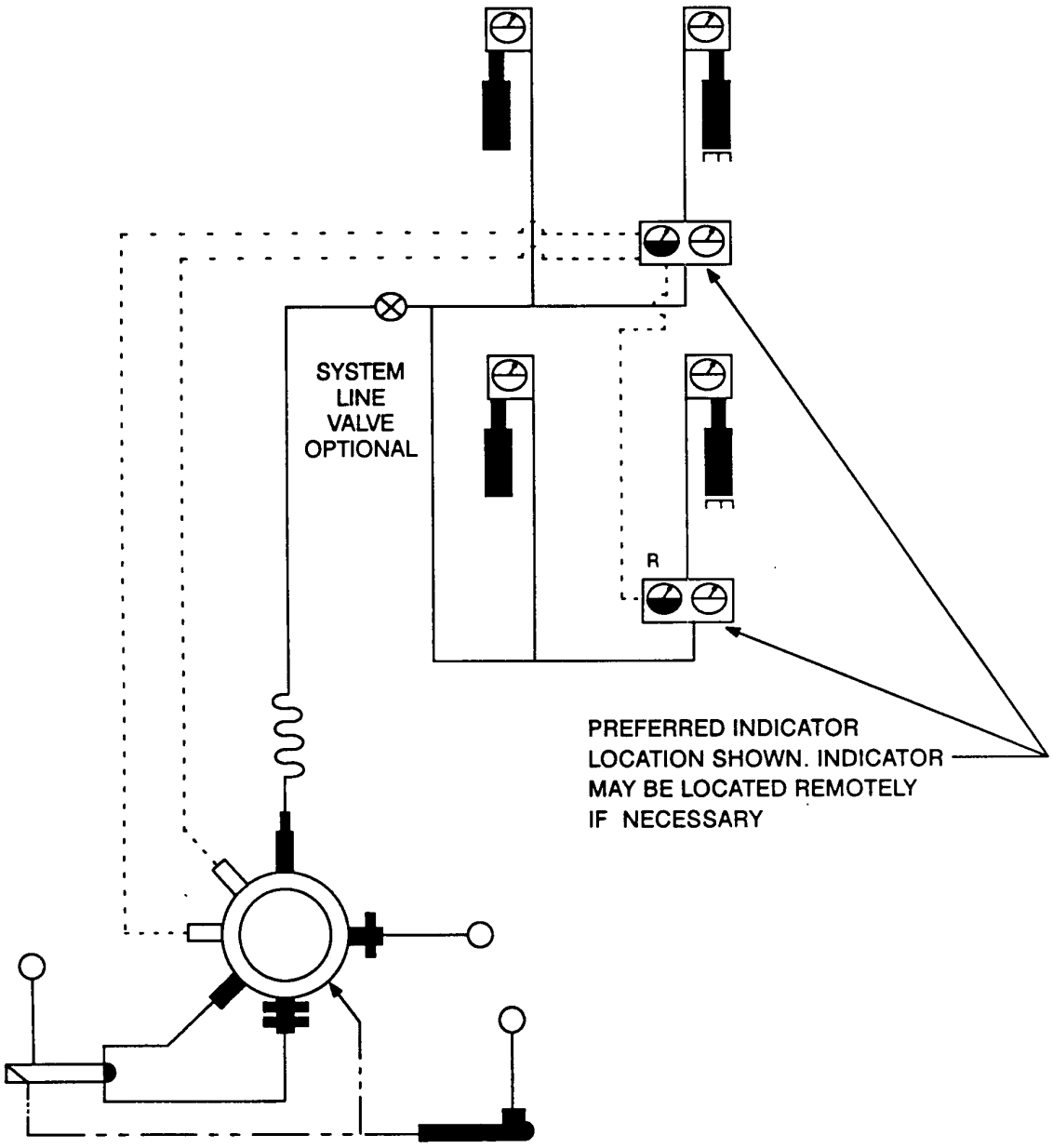
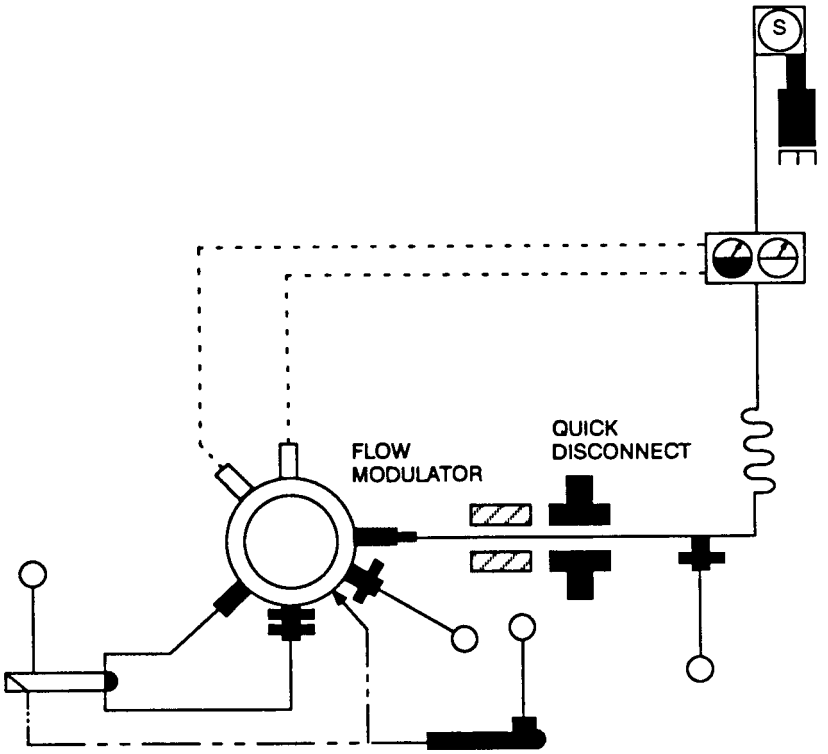


FIGURE 33. Single LOX converter with dual regulators in two-place crew stations– fixed converter installation.



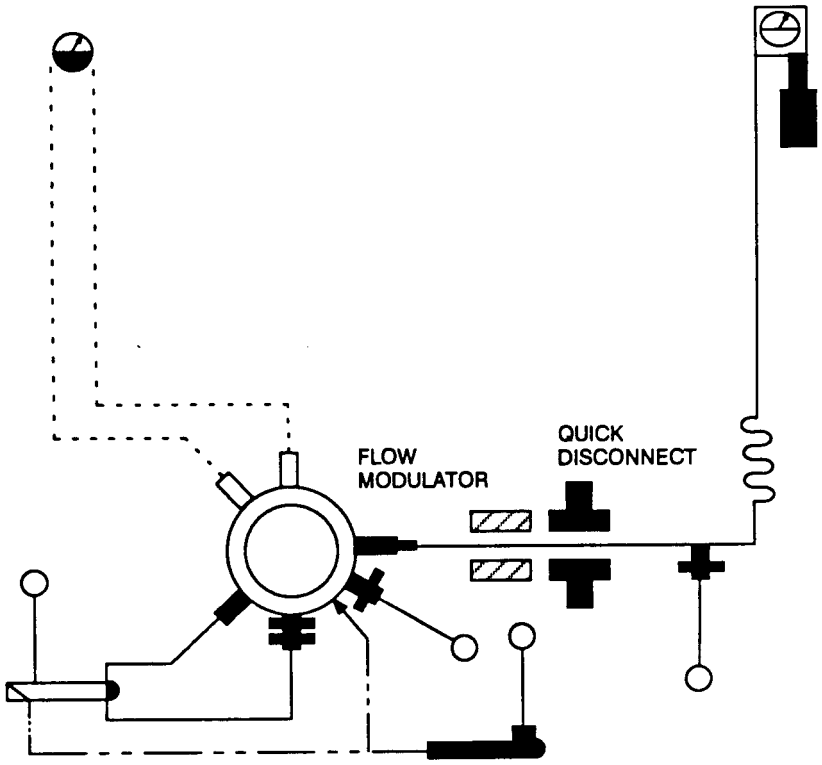


FIGURE 34. Single removable LOX converter with one or more regulator outlets— seat kit regulator or diluter demand regulator.

TABLE B-III. Military liquid oxygen converters and their operating characteristics.

Type	Specification	Maximum LOX Evaporation Capacity (liters)	Operating (nominal) Pressure (psig)	Delivery Rate of Gas (lpm)		Loss (lbs/24 hrs)
*MBA-5A	MIL-C-19328	5	70	-		3
GCU-12 A/A	MIL-C-25973	5	70	72+/-	10	2.5
*GCU-24 A/A	MIL-C-19803	10	70	120		3.75
GCU-2 A/A	MIL-C-25777	10	70	72		3
GCU-3/A	MIL-C-25781	10	70	72+/-	10	3
GCU-10/A	MIL-C-25974	10	300	80		3
GCU-11/A	MIL-C-25972	10	300	100		3
MA-1	MIL-C-25021		20	300	120	4
ME-3	MIL-C-25674		25	300	150	4
GCU-17/A	MIL-C-27336	25	300	150		4
GCU-20/A	MIL-C-27652	75	300	400		9

*NOTE: These LOX converters are designed with quick disconnect coupling assemblies, *MS 22068*, and mount on a quick release wedge plate mounting bracket, *MS 90341*.

LOX converters that are deleted:

Type A-2, This 8 liter, 300 psig LOX converter is no longer satisfactory for USAF use.

Type A-3, *MIL-C-7407* is inactive for new design; for replacement use *MIL-C-25973*, GCU-12/A.

GCU-13/A, *MIL-C-26340* is canceled; items are no longer satisfactory for USAF use.

GCU-14/A, *MIL-C-2638A* is canceled; items are no longer satisfactory for USAF use.

GCU-18/A, *MIL-C-27423* is canceled; this item is replaced by *MIL-C-19803*, 10 Liter, GCU-24/A LOX Converter.

GCU-21/A, *MIL-C-27886* is canceled; items are no longer satisfactory for USAF use.

TABLE B-IV. Liquid oxygen converter capacities.

Size of converter (Calibration pressure)		Minimum flow rate**		Theoretical liters of free gas (sea level and 70°F) (21.1°C) immediately after servicing		Design quantity at 70°F, 14.7 psigG (21.1°C, 101.3 kPa***	
liters		liters/hr	cu m/hr	liters	cu m	liters	cu m
5	(70 psig)	4,380	4.380	4300	4.300	3,273	3.273
10	(70 psig)	4,800	4.800	8600	8.600	7,316	7.316
10	(300 psig)*	6,000	6.000	8600	8.600	7,573	7.573
20	(300 psig)	7,200	7.200	17,200	17.200	15,831	15.831
25	(300 psig)	8,000	8.000	21,500	21.500	20,131	20.131
75	(300 psig)	24,000	24.000	64,500	64.500	61,420	61.420

* The exception is the 10 litter converter defined by *MIL-C-25974* which has a minimum flow rate of 4800 liters/hr.

** To determine the flow rate capabilities that may be provided that exceeds this minimum flow versus supply pressure, the converter manufacturer should be contacted.

*** Minimum amount of LOX converter supply available 24 hours after filling due to loss from evaporation and referenced to sea level ambient conditions.

Size and number of converters - Unless otherwise specified, all converters installed in an aircraft shall be of the same size and operating pressure. However, it is acceptable to provide different size converters for crew and passenger systems. The design quantity given in *table IV* is the amount of oxygen which can be expected to be available from each converter 24 hours after filling and this shall be used for design calculations. The converter(s) selected shall have the capability to develop the maximum flow rate as determined necessary in any increment of the mission. *Table IV* provides the minimum flow rate a converter must develop and still maintain a supply pressure at its calibration pressure.

If more than one converter is required to get the quantity of oxygen required, then two or more converters of the same size and working pressure should be selected. They should be manifolded together so that any aircraft outlet may get oxygen from any one of the converters. The only exception for different size converters would be if flight station crew members had a supply source independent from the passengers supply. For example, some transport aircraft use a 25 liter converter for flight station crew members and a 75 liter converter for passengers. A good practice consistent with current flight operations is a line of supply from both the flight crew station converter and the passenger converter for flight station crew members. This is a

good practice because many flights in a transport aircraft involve no passengers, so both converters are available for use by the flight crew. When passengers are carried, it would not be desirable that they use the flight crew oxygen supply, so passengers may only use the supply from the passenger converter. Installation schematics are given in *figures 27* through 34.

The crew members and passengers on-board the aircraft are positioned at various outlets throughout the aircraft. Since liquid oxygen is at a temperature of -297.4°F (-183.0°C), it must be brought up to an acceptable temperature for breathing when supplied to the crew and passengers. Also, as cold liquid and gaseous oxygen is brought from the converter through the heat exchanger(s) and distribution lines, frost will form on the plumbing from condensation. As some water will condense on the tubing and drop below, aircraft design provisions must take this into account so that the water does not corrode or damage aircraft electrical components or structure. The minimum length of tubing between the converter(s) and the first breathing outlet is given in *table V* and the length of supply tubing to the frost line is given in *table VI*.

TABLE B-V. Minimum length of tubing between converter and first station.

Flow rate		Length of 5/16 inch (7.94 mm) tubing, plain		Length of 1/2 inch (12.70 mm) tubing, plain		
Liters/min	cm^3/s	Feet	Meters	Feet	Meters	
20		333.3	20	6.10	11	3.35
40		666.6	40	12.19	22	6.71
60		1,000.0	60	18.29	34	10.36
100		1,666.6	100	30.5		
30.4857	17.39					
150		2,500.0	150	45.72	85	25.91
200		3,333.3			113	34.44
300		5,000.0			170	51.82
400		6,666.6			227	69.19

TABLE B-VI. Approximate length of supply tubing to frost line.

Flow rate		Length of 5/16 inch (7.94 mm) tubing, plain		Length of 1/2 inch (12.70 mm) tubing, plain		
Liters/min	cm^3/s	Feet	Meters	Feet	Meters	
20		333.3	12	3.66	6	1.83
40		666.6	24	7.31	12	3.66
60		1,000.0	36	10.97	18	5.49
100		1,666.6	60	18.29	29	8.84
150		2,500.0	90	27.43	43	13.11
200		3,333.0			58	17.68
300		5,000.0			87	26.52
400		6,666.6			116	35.36

When the system is being filled, the pressure build-up 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 servicing tank by means of an insulated, flexible hose. Pressure in the servicing tank forces liquid oxygen into the system.

B.2.4.5 On board oxygen generating system.

The on-board oxygen generating system (OBOGS) comprises of, as applicable, concentrator(s), monitor, emergency oxygen, back-up oxygen, air source, heat exchangers, oxygen supply plumbing, plenum(s) relief valves, check valves, quantity gauges, regulator, portable units, adapter, mask to regulator hoses, brackets, shut off valves and any other ancillary equipment required for a complete aircraft installation. The OBOGS must be compatible with each aircraft specific resources, such as engine bleed air and electrical power, in order to generate and provide sufficient oxygen to the crew throughout all normal flight and emergency conditions from sea level to 50,000 feet. The OBOGS must be compatible with various types of breathing regulating devices (100 percent, dilution, positive pressure, constant flow), oxygen masks, counter pressure garments, and full and partial pressure suits and helmets. The OBOGS also provides for an integrated back up emergency oxygen supply in the event of an OBOGS failure or loss of aircraft resources. System components shall be installed in such a manner so that they will be readily accessible to aircraft resources and personal equipment interfaces according to MIL-D-85520. The installation of components must be in areas that will be consistent with the environmental conditions the concentrator shall be accessible to permit use of aircraft installation and removal within a 15 minute time period. The oxygen equipment, tubing and fittings must be located as remotely as practicable from fuel, oil, hydraulic fluid, water injection, storage battery systems, exhaust stacks and manifold, electrical, radio and insulating materials. Insofar as practical, oxygen lines is not be grouped with lines carrying flammable fluids. Where necessary, deflector plates may be used to keep flammable fluids away from oxygen lines, fittings and pressurized equipment shall not be in line with the plane of rotation of a turbine or propeller such that the loss of a blade or propeller will penetrate the oxygen equipment. Components of the oxygen system are not installed where they will be subjected to temperatures in excess of that specified in the individual component specifications, and no part of the system is installed in an area which will be subjected to a temperature in excess of 160 ^{o}F. In order to minimize degradation of the concentrator due to heat, concentrator(s) are not be located near equipment that dissipates a high quantity of heat. Concentrators and associated pressurized supply equipment are also not be located near aircraft components that give off flammable fluids or gases unless physically isolated such that heat and flammable fluids or gases cannot enter the oxygen equipment. Other equipment components that may be located nearby, but not physically separated shall be qualified to an explosive atmosphere. Concentrators, associated plumbing and heat exchanger(s) are located and installed to withstand a crash loading, G level and pulse duration, applicable to that component and the aircraft for which it is intended. On aircraft such as transports where it is desired to provide maximum survivability of the oxygen system, the concentrators should be separated and check valves provided such that the loss of one concentrator does not result in the loss of the complete oxygen supply. If two or more concentrators are installed in the aircraft design for combat, they should be separated as much as practicable to minimize combat. At

this time there are no transport or multiple installations of OBOGS on military aircraft. Typical OBOGS layout schematics are shown on figure*s 34a through 34e* for aircraft utilizing engine bleed air as the input air for the concentrator. These figures represent general arrangements of the item the actual number, location and application of the OBOGS are determined by the aircraft characteristics. Military aircraft OBOGS installations have followed these general practices in so far as possible. When two or more concentrators are installed in an aircraft they are best manifolded for distribution. *Figure 34f* show a typical OBOGS installation with one concentrator. Unless otherwise specified, all concentrators installed in aircraft for crew use are of the same size. However, it is acceptable to provide different size concentrators for passengers than the crew. Concentrator size is governed by aircraft specs and location and for allowing sufficient clearance to perform maintenance functions. An emergency backup oxygen system is be incorporated to provide at least 200 liters at 14.7 psig, 70 ^{o}F to each crew station. It is integrated with the OBOGS to supply oxygen to the crew in the event of a concentrator failure or loss of aircraft resources. The backup system can be a pre pressurized source of one that obtains the oxygen directly from the concentrator and stored. Either type should be manually and automatically activated and shall be resettable. Interface with the OBOGS should be in such a manner that upon actuation of the backup system, flow from the OBOGS concentrator unit will close and only emergency oxygen shall be directed to the crew. Ejection seat type aircraft has an emergency oxygen system which is integrated with the OBOGS. This system is used primarily for in flight ejection and ground/underwater egress and is not a part of the backup oxygen system. The system is automatically actuated during the ejection or egress situation. It can also be manually actuated. The integration with the OBOGS must be such so that it does not interfere with the emergency sequence of events.

B.2.4.5.1 Major OBOGS system components.

Concentrator - Each OBOGS installation incorporates an oxygen concentrator. The concentrator processes input conditioned air to provide a moisture reduced, low contamination, oxygen enriched breathing gas to the crew within the limits specified in MIL-C-85521. Any exhaust gases produced as a result of the generation process is vented in such a manner to prevent compartment contamination or corrosion problems. Concentrator characteristics and tests performances are defined in MIL-C-85521. The concentrators are capable of being removed from the aircraft and replaced in less than 15 minutes. Access to all connections shall not create a hazard for maintenance personnel. Sufficient clearance must be available to allow for removal of all connections with standard hand tools. A simple concentrator design and configuration for Navy aircraft are shown on figure*s 34g and 34h*.

Concentrator controls and status displays - On/off control switches are provided to operate the concentrator and for selection of the backup oxygen in the event of a concentrator failure. Status displays giving warning signals to the crew of low pressure and high temperature conditions shall be provided. Automatic or manual shut off of the concentrator at extreme pressure and temperature is provided to prevent damage or improper operation of the concentrator.

Monitor - Each OBOGS installation incorporates a monitor to constantly measure the oxygen percentage or partial pressure of the enriched air from the concentrator and to relay this information to a warning device or signal to alert the crew that the oxygen concentration has

fallen below physiological acceptable limits. The only exception is the B-1B aircraft. A press-to-test or automatic control feature should be incorporated to enable the crew to check for proper monitor and signal operation. Monitor characteristics performance and tests are defined in MIL-M-85522.

Regulators - A breathing gas regulator is provided for each crew member that will be required to wear an oxygen mask. See the later section for details on regulators.

Panel mounted regulators - Most USAF regulators are panel mounted and include on/off, normal (air dilution)/100 percent, emergency (safety pressure), and test mask functions such as provided by the CRU-73 regulator in MIL-R-83178. Pressure breathing for G protection or higher altitude functions shall be provided should missions require this. An automatic diluter demand pressure breathing regulator such as the CRU-98/A, is installed at each permanent and temporary crew station in the aircraft. The pilot's panel mounted regulator is located in accordance with MIL-STD-203. The crew member's regulator should be in the crew members' field of vision so that they can readily read the regulator without turning their head and with minimum interference with their flight duties. The exception is the F-16 aircraft. The regulators should be located as close to the stations as is required to reach the regulator by normal extension of the crew member's arm. The regulators shall be located so that they cannot be damaged by movement of personnel around them and may be mounted vertically or horizontally. The regulator should be installed with flexible hose for both inlet and outlet ports, so that the regulator may be front serviced for both installation or removal.

Non panel mounted - Unless otherwise specified, for installations which utilize regulators without a manual shut-off valve incorporated in the regulator, a manual shut-off valve should be provided at each crew member's station. The valve should be installed in the line upstream of the individual regulator to prevent loss of oxygen when the regulator is not is use and for stopping flow from a defective quick disconnect or a damaged supply hose. Stowage provisions shall be made for chest mounted regulators to prevent damage or contamination during servicing or ingress/egress actions.

Applicable to the Navy - The design, construction and performance of the Navy chest mounted regulators have been defined by MIL-R-85523. The design, construction and performance of the COMBAT EDGE, Anti-G, regulator is defined MIL-R-XXXXX for the Navy performance requirements.

TBD

FIGURE 34a. Single concentrator, single engine, single place aircraft

TBD

FIGURE 34b. Single concentrator, single engine, dual place aircraft

TBD

FIGURE 34c. Single concentrator, twin engines, single place aircraft

TBD

FIGURE 34d. Single concentrator, twin engines, dual place aircraft

TBD

FIGURE 34e. Dual concentrator, twin engines, dual place aircraft

TBD

Note: On USAF aircraft OBOGS installations, a high pressure backup oxygen cylinder is not acceptable and the emergency oxygen will usually be seat mounted on the side of the seat versus in the suvival kit as on Navy aircraft.

TBD

FIGURE 34f. On Board Oxygen Generating System Typical Installation

TBD

FIGURE 34g. Simple OBOGS concentrator design schematic typical on Navy aircraft

TBD

FIGURE 34h. GGU-7/A and GGU-12/A oxygen concentrators

B.2.4.6 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 to be 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. 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. Cylinders are designed to be easily replaced by loosening the brackets and removing the fittings with which they are attached to the lines.

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 *MS 90341* quick-change mounting bracket. Converters of this type conforming to *MIL-C-19328* or *MIL-C-19803* should be provided. The removable converters should be capable of being removed from the aircraft and replaced in less than five minutes. The converter base should be within five degrees of horizontal when the aircraft is in normal cruise altitude. The converter may require an evaporator heat exchanger to adequately 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 and pressure closing valves are also included in the system and are usually located on the converter.

When passenger cylinders are removed, the line valve must be closed and a disconnect for the tubing from the fittings in the passenger cylinders is separated. The tubing is closed or sealed with plugs conforming to *AN 806* and the cylinder fittings may be covered with caps conforming to *AN 929*. 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* or 40.15 herein.

B.2.4.7 Systems utilizing oxygen delivery equipment.

Aircraft having flight ceilings over 10,000 feet (3048 meters) shall have oxygen supply and the necessary delivery and personal equipment to support the physiological needs of all aircraft occupants.

B.2.4.7.1 Fighter and attack aircraft supply.

These aircraft shall have an oxygen system of sufficient capacity to supply the entire crew for the total duration of any specified design mission. The oxygen supply system shall be sized to ensure mission completion in the event of loss of cabin pressure enroute to or at the combat zone. If applicable, the oxygen system shall be sized to include range extension due to auxiliary fuel stores and/or aerial refueling.

B.2.4.7.2 Bomber aircraft supply.

Bomber aircraft shall have an oxygen system of sufficient capacity to supply breathing oxygen to the entire crew for 75 percent of the duration of the longest specified design mission, or to the entire crew for the total time the cabin altitude is above 8,000 feet (2438 meters), whichever condition establishes the larger amount. The oxygen supply system shall be sized to ensure mission completion in the event of loss of cabin pressure enroute to or at the target. If applicable, the oxygen system shall be sized to include range extension due to auxiliary fuel stores and/or aerial refueling.

B.2.4.7.3 Transport aircraft supply.

Transport aircraft shall have an oxygen system of sufficient capacity to supply all of the primary crew members and all of the passengers with breathing oxygen whenever the cabin altitude exceeds 10,000 feet (3048 meters). In the event of loss of cabin pressure, the oxygen system shall provide the full primary aircrew with breathing oxygen for at least 50 percent of the design mission duration. The passenger oxygen supply shall be dispensed from a continuous flow system and shall have sufficient capacity to provide breathing oxygen to a full passenger load for 50 percent of the design mission duration or for a shorter period if so specified by the acquisition activity, but in no case for less than 15 minutes. When therapeutic oxygen capability is specified, a supplemental quantity shall be included within the passenger oxygen supply. Therapeutic oxygen usage shall be independent from passenger oxygen usage and the quantity shall be adequate for 100 percent of the design mission plus two hours to allow for patient loading and unloading.

B.2.4.7.4 Mission specialist and training aircraft supply.

Mission specialist and training aircraft shall have an oxygen system of sufficient capacity to supply the entire flight crew, mission specialist, trainees, and any passengers (if applicable) with breathing oxygen whenever the cabin altitude exceeds 10,000 feet (3,048 meters). The flight crew and mission specialist may need additional oxygen supply for extended flight at higher altitudes to continue the mission, inflight refueling, and night flight. The oxygen system shall support all aircraft occupants during depressurization at cabin altitudes and duration’s as specified by the acquisition activity.

B.2.4.7.5 Systems utilizing demand and pressure demand breathing equipment.

Aircraft having flight ceilings over 10,000 feet (3048 meters), but not over approximately 35,000 feet (7620 meters) of altitude and the capability of descending immediately to 10,000 feet (3048 meters) or below following a decompression shall use demand breathing equipment. USAF equipment shall incorporate air dilution where possible. Aircraft having flight altitude ceilings over 35,000 feet (7620 meters) and the capability of descending immediately to 10,000 feet (3048 meters) or below following a decompression shall use pressure-demand breathing equipment. The appropriate pressure breathing schedule shall be incorporated as necessary to provide altitude protection. The crew station equipment shall support the use of pressure breathing or pressure-demand oxygen masks, regulators, hoses and any other equipment as necessary to support this capability.

B.2.4.7.6 High altitude aircraft supply.

Aircraft having a sustained flight capability above 50,000 feet (15,240 meters), or the requirement to remain above 42,000 feet (12,801 meters) for a period over 5 minutes, but not equipped with emergency pressurization capsule provisions, shall be provided with an installed oxygen system designed to support high altitude pressure suits and helmets, or pressure breathing masks and counter pressure garments, as appropriate. The quantity shall be adequate to provide for 93-100 percent oxygen for the entire mission, including, if appropriate, a period of oxygen breathing at ground level prior to flight. In addition, provisions shall be made for the use of pressure breathing masks and counter pressure garments during flight operations if emergency descent is possible. If emergency descent is not possible for the required mission, then a full pressure suit capability shall be provided.

B.2.4.7.7 Systems utilizing capsules.

The pressurization requirements and the oxygen requirements shall be as specified in *AFGS-87235A* or *MIL-A-23121*, as applicable. The system to be installed shall be capable of meeting the specified mission profile.

B.2.4.8 Portable oxygen systems.

When crew mobility within the aircraft is required, as is normally the case in bomber and transport aircraft, portable oxygen systems shall be provided in a ratio not less than one system for two crew members. At least one portable oxygen system shall be provided in each compartment of the aircraft including lavatories. Smoke masks suitable for respiratory and eye protection shall be available for use by the pilot and any other critical crew members and be usable with the crew station oxygen regulator as well as with the portable systems. Portable oxygen systems shall be selected in accordance with the information as provided in the section on portable oxygen systems.

B.2.4.9 Emergency oxygen.

Aircraft equipped with a seat pan or back pack emergency oxygen supply, as specified in *MIL-0-27335* or *MIL-S-81018*, or an equivalent emergency oxygen supply, shall have such system completely independent of the aircraft oxygen supply system. Any emergency oxygen supply system will normally remain with the crew member during ejection from the aircraft and subsequent descent via parachute. When the emergency oxygen is attached to the seat, separation from the seat shall not occur above an altitude of 15,000 feet (4,571 meters).

B.2.4.10 Helicopter Oxygen System (HOS).

The Helicopter Oxygen System is a completely self-contained, portable oxygen system that requires no modifications to the aircraft. It can be installed and operational within 15 minutes witout the use of special tools or support equipment. Under normal conditions the console supplies one hundred percent breathing oxygen, simultaneously, to six people for one hour at altitudes fo 10,000 to 25,000 feet msl. Under the same condition, one person can be sustained with oxygen for approximately six hours. Oxygen is stored under high perssure (1800 psi) in two tandem-connected storage cylinders which can be recharged through the system filler

valve.

B.2.4.10 High Altitude Search and Rescue Helicopters. Oxygen systems for Army helicopters shall provide oxygen to all crew members for the operational range of the aircraft plus 30 minutes reserve.

B.2.5 OXYGEN SYSTEM DISTRIBUTION PLUMBING AND COMPONENTS

B.2.5.1 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. The check valves are installed in accordance with the applicable system schematic diagram.

B.2.5.1.1 High pressure system check valves.

High pressure system check valves for oxygen systems are specified by *MIL-V-5027*. Check valves conforming to *AN 6014* through *AN 6018* are military GFE and are designed for the *AND 10089* cone connections, while the *MS 90338* check valve is designed for flareless connections.

B.2.5.1.2 Low pressure system check valves.

Low pressure system check valves for oxygen systems are specified by *MIL-V-7908*. Check valves in accordance with *MS 21211* should be used.

B.2.5.1.3 Pressure system check valve installation.

Pressure system check valves are installed to effectively prevent additional loss of gaseous oxygen supply in the event that any one oxygen pressure vessel or plumbing line is destroyed by an aircraft emergency such as a fire or combat gunfire. Therefore, when more than one pressure vessel (or a cylinder, typically) is installed in the aircraft, each pressure vessel or the tubing to and from each source should be equipped with check valves.

A check valve should be installed where a line from a pressure vessel or group of vessels is connected to a main distribution line. For groups containing more than three pressure vessels, sufficient plumbing lines should lead from the pressure vessels to the main distribution plumbing line so that a single line of tubing runs from each of the subgroups of three pressure vessels or less. This design requirement does not apply to non combat or non critical-mission aircraft.

B.2.5.2 Pressure system 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. Line valves are desirable in crossover plumbing between LOX converter installations.

B.2.5.2.1 High pressure system line valves.

Line valves should not be used on high pressure systems except for filling purposes. *MIL-V-*

8612 is representative of line valve requirements for high pressure use.

B.2.5.2.2 Low pressure system line valves.

A low pressure system line valve conforming to *MIL-V-7529* is provided in transport aircraft between the passenger and crew oxygen systems so that the supply line may be closed and the passenger oxygen system may be removed. The valve should be installed in a location easily accessible to crew members during flight. The line valve should provide for the filling of the crew oxygen system alone or for filling the entire system as a whole. With this valve closed, only the cylinders for the crew would be filled when recharging. The line valve, when open, should also permit the use of the passenger oxygen supply by the crew.

B.2.5.2.3 Passenger oxygen supply removal.

When the passenger oxygen pressure vessel(s) (usually cylinders) is/are removed, the line valve should be closed and the tubing disconnected from the fittings on the passenger pressure vessel(s). The tubing and fittings should be temporarily closed to preclude contamination.

B.2.5.3 Pressure vessel filler valves.

B.2.5.3.1 High pressure vessel filler valves.

The filler valve to which the ground servicing connection is made in recharging the system uses a checking filler connection, *MS 22035*, or a line valve, *AN 6012*, with a cone fitting such as *AN 780-3*. A dust cap and retaining chain, in accordance with Drawing *55B3878*, is provided with the filler valve. All cylinders should be filled from a single filler valve.

B.2.5.3.2 Low pressure vessel filler valves.

Low pressure gaseous oxygen subsystems are provided with an *AN 6024-5* ground filler valve to which the ground servicing connection is made in recharging the system. Multiple gaseous oxygen cylinders are filled from a single filler valve.

B.2.5.3.3 Aircraft installation.

On most aircraft, the filler valve is located inside the fuselage within a closed box behind a special removable cover plate in the skin which has a dirt and oil-tight seal. The filler valve should not be located aft of and below any potential sources of hydrocarbon contamination. The filler valve should be readily accessible by a man standing on the ground outside the aircraft. Making connections for recharging with an oxygen servicing trailer conforming to *MIL-T-26069* and manipulating the valve with a heavily gloved hand should be possible. The cover plate should be designed for quick access and hinged from the leading edge of the plate so that in the event it is left open after ground maintenance or inadvertently opens while in flight, the wind blast will not tear it away from the aircraft, but moves it to the closed position. The location of the valve is marked by a sign stenciled on the exterior access door (see 40.11). The human engineering design practices of *MIL-STD-1472* provide access information.

B.2.5.4 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 psig) 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.

B.2.5.5 Pressure system relief valves.

B.2.5.5.1 High pressure system relief valves.

High pressure system relief valves are not currently in use on most military aircraft installations because the gaseous system ground servicing carts have a rupture disc, and the supply pressure on the ground carts does not exceed 2150 psig. This pressure is well within the safe limits for nearly all high pressure vessels that fill to pressures of 1800 to 2150 psig.

B.2.5.5.2 Low pressure system relief valves.

A low pressure system relief valve that opens for pressure relief at 500 +/- 25 psig should be provided on low pressure system gaseous aircraft oxygen systems to prevent over pressurization during ground servicing and maintenance. The relief valve should be tested to provide an indication of the suitability of the design. These tests should include leakage, pressure cycling and gas flow, low and high temperature, vibration and proof pressure. The valve should open at 500 +/- 25 psig with increasing pressure and fully close at an inlet pressure of not less than 425 psig with decreasing pressure. The relief valve should permit oxygen gas to flow at a rate of at least 220 standard cubic feet per minute and should not permit the system pressure to exceed 700 psig at that flow rate.

B.2.5.5.3 Pressure system relief valve installation.

The pressure relief valve should be installed such that gas is vented to the exterior for small aircraft installations or in safe regions for larger aircraft installations. Venting of oxygen gas should be near the filler valve, and an indication of over pressurization should be detectable by servicing personnel.

B.2.5.5.4 Pressure relief valve.

The pressure relief valve on the liquid oxygen converter shall be vented overboard, using $^{5}/_{16}$ in. (7.94 mm) minimum outside diameter tubing. The relief valve overboard vent may be the same as that used for the combination fill-buildup-vent valve. When removable converters are installed, a pressure relief valve in accordance with *MIL-V-9050*, Type V, shall be connected into the supply line downstream from the *MS 22068* coupling assembly that also vents overboard (see *figure 26*).

B.2.5.6 Check valves for LOX systems.

Check valves are installed conforming to the system schematic design. Installation of liquid

oxygen valves is effective in preventing additional loss of oxygen in the event that any one converter or line is destroyed by gunfire. Many check valves that are used in primary distribution lines conform to *MIL-V-7908*. Check valves are also incorporated into quick disconnects on LOX converters. In all multiple converter installations, check valves shall be installed where they are effective in preventing additional loss of oxygen in the event any one converter is installed in a multi-place aircraft, check valves, in accordance with *MIL-V-25513* or *MIL-V-7908*, depending on the operating pressure, may be installed in each of the auxiliary distribution lines to each station. Check valves that are designed in accordance with *MIL-V-7908* may be installed along the primary distribution lines to each station. All check valves installed shall be cryogenic check valves. Since these check valves are placed in the plumbing such that LOX may be trapped and over pressurization may result, a pressure relief valve must be provided to preclude over pressurization.

B.2.5.6.1 Valves for multiple converters with multiple crew stations.

When two or more liquid oxygen converters are installed in an aircraft, all converters shall be of the same size and have the same operating pressure with the exception of transport aircraft that divide oxygen supply between the flight crew and passengers then the converters may be different sizes. Multiple converters for the passengers shall still be the same size. Converters shall be manifolded for distribution. Converters shall be divided between each distribution or supply line such that any one converter will provide oxygen supply to all outlets with the exception of separate crew and passenger oxygen supply then the crew may have the passenger oxygen supply available but the passengers may not have the crew oxygen supply. On aircraft such as transports where it is desired to provide maximum survivability of the oxygen system, the converters shall be separated and check valves provided such that loss of one converter does not result in the loss of the complete oxygen supply. *Figure 31* shows an installation with two or more liquid oxygen converters that are mounted side-by-side and manifolded to two or more heat exchangers. *Figure 32* shows an installation with two or more liquid oxygen converters that when physically separated and provided with separate heat exchangers and distribution plumbing as shown will maximize survivability. To enhance safety and maintenance, a manual shut-off valve shall be provided on the supply line near each converter such that either converter may be isolated as necessary. If the shut-off valve is not accessible while in flight, it may be desirable to also provide remote activation from the flight deck. Additionally, line valve(s) shall be provided such that each entire distribution line may be isolated from the oxygen outlets, for conditions of non use and safety. The line valve(s) shall be readily operable from it's/their location(s) while in flight and each shall be clearly labeled near the valve(s) as to it's/their proper use. Both the manual shut-off and line valve shall withstand cryogenic liquid oxygen and both be operable when subjected to liquid oxygen.

B.2.5.6.2 Manual shut-off and line valve indication.

A means of indication shall be provided on any manual shut-off and line valve provided such that it is readily apparent to the flight crew whether the valve(s) is/are in “on" or “off" position. When provided, the valves shall be located and installed such that the proper markings and labeling are given as to function and type of control. Line valve(s) shall be easily accessible while in flight but not located as to be easily subject to damage. Line valves shall be marked as emergency or safety devices.

Most past commercial and military transport aircraft have incorporated manual shut-off valves and line valves with multiple converter and gas cylinder installations. Manual shut-off valves enable the maintainer to isolate one LOX converter from another for replacement of any one converter so that the entire LOX system will no need to be cleaned and purged. Manual shut-off valves are located near each converter and are therefore cryogenic valves. Additionally, under certain mission scenarios, it may be desired to use only one converter or some number less than that installed on the aircraft. The manual shut-off valve enables the maintainer to shut-down any number of LOX converters he wishes too, and use the remaining LOX converters. The manual shut-off valve may also be used as a safety device like the line valve and remotely activated from the flight deck. Often the design is such that the manual shut-off valve cannot be reached while in flight. As a desirable safety feature, the shut-off valve shall have the capability to also manually shut it off. As a back-up safety control a line valve shall also be provided. The line valve enables the maintainer to shut-down the oxygen gas pressure in the distribution line when the aircraft is not in use, thus reducing the associated hazards and possible leaks. Line valves are located downstream of the heat exchangers and depending on their distance from cold oxygen liquid or gas they may be cryogenic or non cryogenic valves. Past line valve designs have been manually operated and were located near the flight deck. Newer designs show an advantage to the use of cryogenic capability as a failed regulator or downstream plumbing can still pull liquid oxygen from the converter even if remotely located. Line valves will also minimize the amount of oxygen outlets that are pressurized with oxygen gas from the main distributions line (s). Many existing USAF transport aircraft incorporate line valves for safety reasons.

B.2.5.7 LOX fill-buildup-vent valves.

Each permanently installed liquid oxygen converter is 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 psig) and 2.1 MPa (300 psig). One combination fill-buildup-vent valve should not be used to fill more than one converter, otherwise, the LOX will flow through the path of least resistance and only completely fill one converter, making it impossible to top off the other converter(s).

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 and to permit the ground crew to manually exert an engagement or disengagement torque.

The distance from the fill section of the combination fill-buildup-vent valve to a permanently installed LOX converter is kept as short as possible. The fill line is usually no longer than ten feet. A good practice has been to insulate fill lines to prevent frosting and sweating if they pass over equipment which would be harmed by water dripping from the lines. Another practice is the addition of drip pans under these lines that drain the water overboard.

A vent line is located downstream from the combination fill-buildup-vent valve to drain LOX and vent cold oxygen gas overboard from the aircraft. The overboard vent is located within sight of the fill valve compartment, but not closer than 24 in. measured along the fuselage. The LOX flow from the overboard vent may be directed away from the filling valve to prevent a hazard for

servicing personnel. LOX is not allowed to impinge on the aircraft. Similar to the fill lines, insulation or drip pans could be used on vent lines to prevent harm to equipment from dripping water. 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 at the outlet of the liquid oxygen drain valve by an end fitting conforming to *MS 33656*, which is located near the filler valve. The fitting has a cap that conforms to *AN 929-5* with a suitable chain permanently attached.

B.2.5.8 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. Under conditions of high demand and subsequent supply shut-off, LOX will vent overboard through this valve. Therefore, the valve is located such that aircraft components will not be damaged. Also, the valves used must withstand cryogenic temperatures. When removable converters are installed, a pressure relief valve in accordance with *MIL-V-9050*, Type V, is connected to the supply line downstream from the *MS 22068* coupling assembly.

B.2.5.9 Converter disconnects.

The disconnects for removable LOX converters conform to *MIL-C-21049* and are in accordance with *MS 22068-7* and *MS 22068-8*. The plumbing openings are either self-sealing outlets or have contaminant protection covers. If the supply line is required to be uncoupled for maintenance purposes, the quick disconnect is in accordance with *MS 22068-1* or *MS 22068-2*.

B.2.5.10 Hose for LOX systems.

On removable converters, metal hose assemblies are used conforming to *MIL-H-22343* and the applicable part number, *MS 90457*. This hose is flexible at temperatures down to -297°F (-183°C) but, since it contains a metal bellows, is somewhat vulnerable to fatigue failure if subjected to repeated severe flexing. These flexible supply lines are $^{5}/_{16}$ in. (7.94 mm) equivalent inside diameter and the flexible vent lines are $^{1}/_{2}$ in. (12.7 mm) equivalent inside diameter. The bend radius is not less than that specified in the flexibility test of *MIL-H-22343*. If relative motion between two connections is encountered, a metal hose is installed so that torsion (twisting) will not occur under any condition of operation. Loosening of connection fittings should not occur. Clamp-type flexible tubing installations are not used. The supply and vent lines contain metal hoses of sufficient length to provide 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. This flexible hose usually conforms to *MIL-H-26626* and the applicable part number, *MS 24548*. This hose is flexible at temperatures down to -65°F (54°C); therefore, disconnecting and manipulating the hose should be delayed until a few minutes after the flow of LOX has ceased.

B.2.5.11 Pressure and LOX system plumbing.

Note that references to metric equivalents of plumbing sizes which are manufactured by English standards do not mean that these plumbing components can be used in metric systems. The tubing diameters should conform as much as possible to existing Government inventory tubing.

B.2.5.11.1 High pressure system tubing.

All tubing for high pressure gaseous systems should be seamless steel (preferably stainless), corrosion resistant (304), and annealed, conforming to *MIL-T-8506*. The outside diameter of the tubing should be at least $^{3}/_{16}$ in. (4.76 mm), and the wall thickness should be at least 0.035 in. (0.89 mm). Larger tubing diameters are used when necessary to assure adequate flow capacity.

B.2.5.11.2 Low pressure system tubing.

Tubing for low pressure systems may be an aluminum alloy conforming to *SAE AMS 4071* or steel as discussed in 40.11.1. The aluminum alloy tubing should have a nominal outside diameter of $^{5}/_{16}$ in. (7.9 mm), and a wall thickness of 0.035 in. (0.89 mm). An anodic film conforming to *MIL-A-8625* or an alodine coating should be used when a protective coating is required on aluminum alloy tubing. In those portions of systems where high flows will occur, $^{3}/_{8}$ or $^{1}/_{2}$ in. (9.52 or 12.70 mm) outside diameter tubing should be used as necessary to limit the pressure drop to within acceptable levels for proper operation of the delivery equipment.

B.2.5.11.3 Tubing for LOX systems.

LOX system tubing is an aluminum alloy conforming to *WW-T-700/4* or *AMS 4071*, or corrosion resistant annealed steel (304), conforming to *MIL-T-8506*. The minimum outside diameter of tubing used for oxygen supply lines is $^{5}/_{16}$ in. (7.94 mm). Tubing for fill and vent lines have minimum outside diameters of $^{3}/_{8}$ in. and $^{1}/_{2}$ in. (9.53 mm and 12.7 mm), respectively. All aluminum tubing has a wall thickness of 0.035 in. (0.889 mm), while corrosion resistant steel tubing conforms to *AND 10104* and has a wall thickness of 0.020, 0.028 or 0.035 in. (0.508, 0.711 or 0.889 mm) as necessary in the application. All tubing should be electrically bonded in accordance with *MIL-B-5087*.

B.2.5.11.4 LOX system evaporation and warming tubing.

If the converter does not include warming coils or a heat exchanger, the aircraft must include a heat exchanger or a minimum length of tubing, indicated in *table V*, between the converter and the first crew station for the indicated flow rate. *Table VI* indicates the approximate length of supply tubing along which frost and condensation can be expected for the indicated flow rate. When other equipment might be affected by condensation, the supply tubing is provided with drip shields or other suitable means of protection. For flows greater than 100 liters per minute (1 666.6 cu. cm/s), pressure losses in $^{5}/_{16}$ in. (7.94 mm) tubing may be excessive and more than one supply tube or a larger size tube may be required. The design flow quantity is supplied to the oxygen dispensing regulators at a temperature within +10, -20°F (+5.5, -11°C) of the cabin ambient temperature and at a pressure not less than 55 psig (379.2 kPa).

It should also be noted here that many past LOX subsystem designers have used a rule-of-

thumb that the oxygen velocity in the tubing not exceed Mach Number 0.3, otherwise, the heat addition will cause choked flow. Usually the tubing diameters will be made larger to compensate.

B.2.5.11.5 LOX system tubing flaring and bending.

Aluminum alloy tubing of $^{5}/_{16}$ in. and $^{3}/_{8}$ in. (7.94 mm and 9.53 mm) outside diameters should be double flared to conform with *MS 33583*. Aluminum alloy tubing of $^{1}/_{2}$ in. (12.7 mm) outside diameter and all sizes of corrosion resistant steel tubing may be single flared to conform with *MS 33584*. As an alternative, corrosion resistant steel tubing may be welded, brazed or swaged using methods and quality controls that produce leak proof joints, providing that no undue degradation of tubing strength, corrosion resistance, or fatigue life occurs. Tubing systems having these permanent type joints should be designed for ease of fabrication, inspection, and installation in the aircraft. The system layout provides for rapid in-service repair and component replacement. Tubing bends should be uniform, without kinks, and fit the span between fittings without tension. The minimum bend radius to tube center lines should be in accordance with *MS 33611*.

B.2.5.11.6 Oxygen tubing coupling sleeve.

To enhance the strength of the tubing where it is flared, a coupling sleeve is used. This coupling sleeve also provides a better bearing surface to torque down the coupling nut against the cone end fitting. The oxygen coupling sleeve for flared tubing should be in accordance with USAF Drawing *44A25450 or MS 20819*. Coupling sleeves have been used extensively on past military aircraft oxygen subsystem installations.

B.2.5.11.7 Oxygen system tubing routing and mounting.

In routing the tubing, keep the total length including all branch lines to a minimum to minimize weight and possible leakage locations. Allow for expansion, contraction, vibration, and component replacement. In all installations of two or more pressure vessels where check valves are used, the tubing lengths in the portion of the system between the regulator and the nearest check valve in the distribution line should be minimal. To further reduce the vulnerability from emergency fires and combat gunfire, the tubing lengths between the check valve and pressure vessels should be separated or isolated as much as possible, but not less than 12 in. (305 mm). All tubing should be mounted to prevent vibration and chafing. This may be accomplished by using oxygen-compatible rubberized or cushion clips installed at no greater than 20 in. (508 mm) intervals for $^{5}/_{16}$ in. (7.94 mm) tubing and 15 in. (381 mm) intervals for $^{3}/_{16}$ in. (4.76 mm) tubing and as close to the bends as possible. The tubing, where passing through or supported by the aircraft structure, should have adequate protection against chafing through the use of flexible grommets. Clips are provided near portable recharger connections. The tubing should not strike against the aircraft during vibration and shock encountered during normal use of the aircraft. All tubing should be electrically bonded in accordance with *MIL-B-5087*.

B.2.5.11.8 Pressure and LOX system fittings.

All fittings should be compatible in strength and dimensions, as well as being compatible with

oxygen gas, in accordance with applicable standards. Unless suitably protected against electrolytic corrosion, dissimilar metals as defined in *MIL-STD-889* should not be used in intimate contact with each other. Anti-seize tape conforming to *MIL-T-27730* is used on all male pipe thread fittings but not 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. The end $1^{1}/_{2}$ to 2 threads should not be wrapped. Compounds are not used on tapered pipe threads that are not approved for use with 95-100 percent oxygen. Presently, only greases qualified to *MIL-G-27617* are applied sparingly on oxygen fittings and only if necessary.

B.2.5.11.9 Pressure and LOX system torque of joints.

Tightening of flared tube, straight thread and pipe connections shall be accomplished in accordance with the best commercial practices and instructions as cited herein. Flared tube connections shall be tightened with torque wrenches; the torque used shall be within the limits as specified in *table VII*. The torque limits specified in *table VII* also apply to double flared AMS 4071 aluminum tubing or *MIL-T-8506* corrosion-resistant annealed tubing. Straight thread fittings which seat on an end fitting to prevent leakage shall be finger tightened until seated. Tighten until firmly seated, and leak test. If leakage persists, tighten slightly more until leakage is stopped. 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 to allow closure of the joint with less torque and to facilitate 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). On pipe threads wrap *MIL-T-27730* anti-seize tape on the threads leaving the end $1^{1}/_{2}$ to 2 threads exposed, tighten the coupling nut by finger until tight. Tighten by wrench another $^{1}/_{4}$ to $^{1}/_{2}$ turn and leak test. If there is a leak, tighten another $^{1}/_{4}$ to $^{1}/_{2}$ turn and leak test again. If leakage persists, the part may be defective and should be replaced (or try tightening very carefully until leakage is stopped).

B.2.5.11.10 Oxygen system clearance requirements.

Oxygen lines, fittings and equipment should be installed above and at least 6 in. away from fuel, oil, and hydraulic systems to avoid contamination. Deflector plates may be used, where necessary, to keep hydraulic fluids away from oxygen lines, fittings, and equipment. Open ends of cleaned and dried tubing are to be plugged with impermeable caps at all times, except during attachment or detachment of parts. The oxygen system and flexible moving parts of the aircraft should have a clearance of at least 2 in. (50.8 mm). The oxygen system and rigid parts of the aircraft, except at clamp areas, should have at least $^{1}/_{2}$ in. (12.7 mm) clearance. The oxygen

TABLE B-VII. Torque requirements for flared tube connections.

Tubing O. D..		Torque			
		Aluminum		Steel	
Inch	mm*	In..-lbs	N-m	In.-lbs	N-m
3/16	4.69	50-70	5.65- 7.91		
5/16	7.94	100-125	11.30-14.12	170-200	19.21-22.60
3/8	9.53	200-250	22.60-28.25	270-300	30.50-33.90
1/2	12.70	300-400	33.90-45.19	450-500	50.84-56.49

* Metric equivalents of tubing manufactured to English standards.

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system tubing, fittings, and equipment should be separated at least 6 in. (152.3 mm) from all electrical wiring, heat conduits, and heat emitting equipment in the aircraft. Insulation may be provided on the hot ducts, conduits, or equipment to prevent heating of the oxygen system. To assure adequate glove clearance around valves and disconnects, at least a 3 in. (76.2 mm) diameter circle around the vent and supply disconnects and a 5 in. (127 mm) diameter circle around the filler valve for permanent installations should be used. The centers of the circular clearance areas coincide with the longitudinal axes of the valves.

B.2.5.12 Aircraft gaseous and liquid oxygen system marking requirements.

All tubing should have markings in accordance with *MIL-STD-1247*. As a minimum, this includes a green band to identify the line as containing oxygen. The aircraft shall be permanently and legibly marked in the locations of the oxygen system components specified below, using black letters on a white background with a minimum letter height of $^{1}/_{4}$ in. (6.35 mm).

B.2.5.12.1 High pressure systems.

a. On the outside surface of the filler valve box cover:

1800 psig, 12.4 Mpa **HIGH PRESSURE OXYGEN** **FILLER VALVE** **CAUTION** **SERVICE A SLOW RATE TO AVOID EXCESS HEATING AND POSSIBLE FIRE**

b. Visible on a plate mounted on a wall inside the recess near the filler valve:

HIGH PRESSURE OXYGEN **FILL TO RATED PRESSURE**

B.2.6 2150 psig

DO NOT EXCEED RATED PRESSURE **CAUTION** **KEEP CLEAN, DRY, AND FREE OF ALL OILS**

B.2.6.1 Low pressure systems.

a. On the outside of the filler valve box cover plate:

B.2.7 psig, 3.12 MPa
LOW PRESSURE OXYGEN

b. Visible on a plate mounted on a wall inside the recess near the filler valve:

LOW PRESSURE OXYGEN **FILL TO 475 psig** **CAUTION** **KEEP CLEAN, DRY, AND FREE OF ALL OILS**

c. In a readily visible location in the aircraft near the valve:

OXYGEN LINE VALVE **(OPEN FOR FILLING PASSENGER SYSTEM)** **CLOSE FOR FILLING CREW SYSTEM ONLY** **CLOSE WHEN PASSENGER CYLINDERS** **ARE REMOVED**

d. Visible on a plate mounted on a wall inside the filler valve box recess:

SEE OXYGEN VALVE LOCATED **OPEN TO FILL PASSENGER SYSTEM** **IN ADDITION TO CREW SYSTEM** **CLOSE TO FILL CREW SYSTEM ONLY** **CLOSE WHEN PASSENGER CYLINDERS** **ARE REMOVED**

e. In a readily visible location in the aircraft near each automatic coupling or near each coupling manifold:

PASSENGER OXYGEN

f. On the face of the portable unit brackets in a clearly visible location:

PORTABLE OXYGEN LOCATION **REFILL BEFORE REPLACING**

g. On a suitable, clean, dry box or compartment, as defined in 3.6.4.2.1:

(QUANTITY) PLUGS, AN 806D5 **(QUANTITY) CAPS, AN 929-5** **FOR PLUGGING OPEN ENDS WHEN** **PASSENGER CYLINDERS ARE REMOVED** **CAUTION** **KEEP CLEAN, DRY, AND FREE FROM OIL.**

B.2.7.1 LOX systems.

a. Adjacent to the overboard vent opening:

CAUTION— LIQUID OXYGEN VENT

b. On outside surface of filler box cover plate:

LIQUID OXYGEN (BREATHING) ACCESS

c. On underside surface of filler box cover plate:

CAUTION **KEEP CLEAN, DRY, AND FREE OF ALL OILS**

d. Adjacent to liquid oxygen drain valve location:

DO NOT OPEN DRAIN VALVE UNTIL DRAIN HOSE AND DRAIN TANK ARE CONNECTED

e. Adjacent to recharger location:

PORTABLE OXYGEN RECHARGER

f. Adjacent to filling station:

Aircraft are marked in accordance with *MS 33739*.

B.2.8 Lubricants in gaseous oxygen and LOX 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 on oxygen component seals. 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. When approved lubricants are used sparingly on seals and straight threads when assembly difficulty is encountered, the specified torque limits may no longer apply. Threads may strip at the recommended torque limits.

B.2.9 Gaseous oxygen and LOX system cleanliness.

Maintenance procedures are implemented to ensure that the completed installation is free of oil, grease, fuels, water, dust, dirt, objectionable odors, and any other foreign matter (both internal and external) prior to introducing oxygen in the system. The internal surface area of all components of the aircraft system should not exceed a maximum nonvolatile residue of 3.0 milligrams per square foot. Cleanliness and cleaning facilities requirements have in the past been discribed in MIL-STD-1359. Future cleaning requirements and facilities are discribed in SAE ARP-1176. Many other cleanliness criteria are given in the individual equipment TO's. For example, purging procedures for LOX converters are given in USAF TO 15X-1-1. Requirements for contractor cleaning operations and facilities have in the past been given in MIL-STD 1359, this will now be in SAE ARP-1176. This information has been coordinated by the U.S. Army, Navy, Air Force and Industry in the Oxygen Standardization Coordinating Group. The goal in the government has been to do away with Ozone Depleting Substance (ODS)for all applications. The military is reducing the use of ODS's for cleaning oxygen equipment. However, in the best interests of safety in removing combustible substances from oxygen equipment, some ODS's will need to be used. It is anticipated that the use of these ODS's will be gradually reducing until eliminated where possible. It is the intent of the government to NEVER require the contractor or industry to use an ODS, but that the contractor may use an ODS is local rules permit this and proper disposal and handling rules and regulations for that locality are met. The goal will be for the contractor to show cleanliness of 3.0 milligrams per square foot by a test method.

B.2.9.1 Oxygen Equipment Cleaning Details.

The oxygen distribution system or components of the oxygen system shall be degreased,

cleaned, and purged in accordance with the military best practices. These practices should have also been accepted by the health and environmental agencies of the Government and approved by the procuring activity.

Public Law 101-189, Section 356 requires the Department of Defense to reduce the unnecessary release of ozone layer depleting chemicals (OLDC's or commonly called ODC's) into the atmosphere, In addition, the production, importation and use of Class I ODC's are now banned. The Environmental Protection Agency has granted accross the board waivers to use ODC's. In the USAF, waivers are required to use Class I ODC's. Effort has been underway in the Department of Defense since 1991 to find suitable substitute degreasing and cleaning fluids.

The primary purpose of cleaning fluids and degreasers for oxygen equipment is to remove hydrocarbon deposits from manufacturing, storage and use that may cause a malfunction or fire. A malfunction may occur if these deposits clog small openings necessary for the proper operation of an oxygen system. Metallic particles (primarily aluminum and steels) can promote combustion within an oxygen system when flow velocities become excessive causing the particle to impinge on metal surfaces. A fire can occur if equipment is contaminated with substances that readily ignite in the presence of high concentrations of pressurized oxygen. Degreasers and cleaning fluids must be completely removed from the equipment and the system because even trace amounts of the chemicals could be toxic or cause noxious fumes to be emitted from an aircraft breathing system.

Investigations to find suitable replacements cleaning chemicals for Ozone Depleting Chemicals (ODC's) or Ozone Depleting Substances (ODS's) that are being phased out, have not found a suitable "drop in" replacement for CFC-113 and other toxic and ODC solvents used in the past for cleaning oxygen equipment. In the future, aqueous cleaning will be in more widespread use for cleaning gaseous and liquid oxygen equipment. Aqueous cleaning chemicals and methods as mentioned herein should eventually replace existing solvent and vapor degreasing cleaning such as used to clean tubing and piece parts. Equipment and cleaning procedures will have to be changed. For example, ultrasonic and circulating tanks and pressure spray equipment will replace vapor degreasing equipment. Aqueous cleaning effectiveness is specific to the type of equipment being cleaned and the desired cleanliness. Each organization should consider using the general pre cleaning and final cleaning chemicals and methods provided in the attached instructions and tailor this to their own operation(s). Any toxic or fire and explosion hazards with aqueous based cleaning chemicals are minimal if proper procedures are followed for rinsing of any residue left behind. There is a potential to damage materials, especially aluminum, if either the chemicals are not diluted and rinsed sufficiently with clean demineralized water to preclude the caustic reaction.

Areas of concern for cleaning oxygen equipment where aqueous cleaning is not suitable are wipe solvents and cleaning precision oxygen equipment such as "closed ended" gauges and test sets. Wipe solvents and cleaning precision equipment, especially gauges, will require a non aqueous cleaning chemical. Non Volatile Residue (NVR) checks can be done on the aqueous cleaner rinse water, but a solvent may be required in special situations. HCFC-141b defined by the Commercial Item Description A-A-504.25 solvent may be used until an effective non ODC solvent is found. This HCFC will be phased out in January 2003. Great caution must be exercised in the use of any cleaner for high pressure oxygen equipment especially where

pressures exceed 500 psig. For these cleaning situations, a refined liquid form (99.9 per cent pure) of HCFC-141b meeting A-A-504.25 is the preferred choice for cleaning.

All oxygen equipment Technical Orders (TO's) and NAVAIR Aviation Crew System Manuals, 13.1.6 series, which contain ODC's will soon be modified eliminate or reduce the use of ODC's.

B.2.9.2 Oxygen Equipment Cleaning Future Considerations.

The following recommended replacement cleaning chemicals and procedures for oxygen equipment cleaning in the future are discussed in the following paragraphs. The military assumes no responsibility for any persons or organizations which may chose to use the following chemicals and procedures for cleaning oxygen equipment. This information is provided based on extensive investigations in the military but is not in widespread use at this time. Refer to MIL-STD-1330D or later revisions for details on cleaning with Navy Oxygen Cleaner (NOC).

Cleaning Separate Parts (Piece Part Cleaning) including Tubing

Parts that will contact either gaseous oxygen, liquid oxygen or a vacuum must be cleaned separately where possible. Gaseous oxygen components include tubing, valves, cylinders and regulators. Liquid oxygen components include the vent line installation, heat exchanger assembly, liquid level gauge assembly, pressure gauge and line, fill line components, service line components, service hose, pressure relief and drain assemblies, and pressure buildup valve.

Pre Cleaning Only:

Pre cleaning is accomplished until no soil or buildup is visible. Several choices are available for pre cleaning. Navy Oxygen Cleaner (NOC) or MIL-C-87937, Type II cleaning chemicals are available. Each chemical must be diluted and mixed by the activity which is responsible for cleaning the oxygen equipment in the proportions as given below.

Navy Oxygen Cleaner (NOC) diluted to 50% NOC and 50% demineralized water with 0.1 to 0.5 ounces per gallon of nonionic liquid detergent, MIL-D-16791, Type I.

Stock numbers for 100% NOC

NSN 6850-01-389-3880 55 gallon drum

NSN 6850-01-389-3859 5 gallon container

Instructions - NOC can be mixed with nonionic liquid detergent, MIL-D-16791, Type I to prepare an alkaline detergent that will function adequately as a component pre-cleaner. Prepare the alkaline detergent as follows: add 0.1 to 0.5 ounces of nonionic liquid detergent to each gallon of NOC diluted to 50 percent demineralized water. Use the alkaline detergent at temperatures less than or equal to 140 ^{o}F. At higher temperatures, the solution will become turbid as the cloud point (solubility point) of the detergent is reached. Additionally, the alkaline detergent will foam, and any spilled solution will dry very slowly, The detergent being essentially a water soluble oil, inhibits the evaporation of the overall solution. The results of silicone soil removal with these alkaline detergent solutions are given in Table 2 of Reference 2. NOC mixed with nonionic liquid detergent SHALL NOT BE USED AS A FINAL CLEANER FOR OXYGEN COMPONENT, PIPE LINE OR TUBING CLEANING.

For aqueous cleaning dilute to 90 percent clean demineralized water to 10 percent MIL-C-87937, Type II Cleaning Chemical. For spot cleaning, the chemical may be used in increased concentrations up to full strength with lint free cloth or non abrasive brush. This cleaning solution is considered environmentally safe for disposal. Ensure that local rules and restrictions are followed.

Stock numbers for MIL-C-87937, Type II Cleaning Compound.

NSN 6850-01-390-7827	1 gallon container
NSN 6850-01-390-7828	bulk material
NSN 6850-01-339-5227	5 gallon container
NSN 6850-01-339-5228	55 gallon drum

WARNING - Operator should insure that adequate ventilation or breathing air is available when using these cleaning chemicals in confined spaces. When establishing a cleaning operation in a facility, it is best to review the Material Safety Data Sheets (MSDS) for supplemental safety information and precautions.

WARNING - Material may have a tendency to form excessive suds in ultrasonic tanks and several rinses with clean demineralized water may be needed to remove all traces of the chemical.

WARNING - These chemicals are relatively benign, but ensure that local rules and restrictions are following when disposing.

Final Cleaning:

Parts that are cleaned by immersion or pressure spray such as heat exchanger assembly and tubing, clean with NOC. If parts contain aluminum or easily damaged components use NOC diluted to 50% demineralized water. Most desirable to final clean when possible in a covered ultrasonic tank or parts washers heated to 140-160 ^{O}F for 5 to 15 minutes. If part is too large or cannot be place in ultrasonic tank, use heated pressure spray with part on a clean hard surface such that residue is drained away from the part(s) being cleaned. In either case, immediately rinse with demineralized water to avoid deposits that cannot be easily removed.

Flushing of tubing with NOC shall be performed at flush rates equivalent to 3-6 feet per second fluid velocity. Perform a Shake Test on the NOC to determine if all pre cleaner is absent. Fill a sample container half-full with NOC, cap and vigorously shake for 15 seconds, and let stand for 5 minutes. No foam or visible oil should be present. If foam or oil is present, replace the NOC with fresh solution and repeat the final clean step. Perform a pH check on the final rinse water to determine if all NOC is absent. Rinse until pH of the rinse is less than 8 measured with litmus paper or a pH meter.

WARNING - See above.

WARNING - Avoid the use of Tri-Sodium Phosphate (TSP) or other phosphate containing cleaners such as BRULIN 815GD or TURCO 3878 LF-NC as pre-cleaners when using 100 percent NOC as the final cleaner for components. Phosphate containing cleaners can leave a

phosphate surface residue which in contact with 100 percent NOC can result in the formation of a precipitate in the NOC or insoluble deposits on the item being cleaned. No precipitate or deposits have been observed when using NOC diluted 25-50 percent with demineralized water.

Alternate cleaning chemicals to NOC:

Pre cleaning only. Alkaline cleaning per FED P-C-437, Type I may be used as an alternative cleaner if NOC is not available. Primarily used for steam cleaning. Contains MIL-D-16791 detergent and should not be used on oxygen equipment without a final cleaning and/or rinsing. More caution should be exercised when using alkaline cleaners not to damage components being cleaned.

Pre cleaning and final cleaning. Detergent FED O-S-642, Sodium Phosphate, Triassic, Anhydrous; Dodecahydrate; and Monohydrate; Technical may be used as an alternative cleaner if NOC is not available. TSP is a general purpose cleaner and may be used anywhere parts are not damaged. More caution should be exercised when using alkaline cleaners not to damage components being cleaned.

WARNING - Do not exceed a 5 percent solution with clean demineralized water. Rinse immediately as chemicals precipitate on surface of material being cleaned. Check for the absence of pre cleaner by the method described above. Agitation and a temperature of 160 ^{O}F are needed for proper cleaning. At lower temperatures, TSP may precipitate out of solution, as well as onto cold parts introduced into a heated bath of TSP.

WARNING - Do not use with aluminum, bronze or brass parts without checking to see that the concentration of less that 5 percent does not damage the component or leave an unacceptable surface discoloration. Concentrations less than 5 percent may be checked for reaction with the metal being cleaning. TSP is known to severely corrode aluminum if concentrations are excessive.

WARNING - Phosphates are damaging to dispose in the environment. Ensure that local rules and restrictions are following when disposing.

Pre cleaning and final cleaning. Brulin 815GD and Brulin 1990 have not be qualified to military specifications, but have been tested and evaluated by industry to be excellent cleaners. While these aqueous cleaners may be a little more expensive than the other choices mentioned herein, they are excellent degreasers to use in cleaning metal components like oxygen tubing. They may be used in recirculating tanks, ultrasonic tanks and pressure spray washers.

Brulin 815GD FSN 6850-01-392-8430,

55 gallon drum

Brulin 1990 FSN 6850-00-K28-8910,

55 gallon drum, (currently this is a temporary federal stock number and Brulin Corp. is pursuing getting a more permanent stock number assigned to this product).

Point of contact is John Kirk, Brulin Corp., Indiana, phone (317) 923-3211x3260.

WARNING - Follow the same precautions as mentioned above for NOC.

Cleaning Interior Surface of Large LOX Storage Tanks

In larger storage tanks for liquid oxygen, access must be gained so that the aqueous cleaner may be sprayed at the tank walls. In liquid oxygen transfer carts, solution may be added to inner tank and agitated by moving cart back and forth. Ensure that the solution may be adequately drained without damaging any drain components. Ensure that rinsing the aqueous cleaning solution is accomplished immediately.

Pre cleaning

MIL-C-87937, Type II Cleaning Compound. Use as discussed above. Rinse immediately with clean demineralized water to avoid surface deposits that cannot be easily removed. Spraying from pressure nozzles and heating the water to 120 ^{O}F promotes more effective cleaning and rinsing. Non abrasive brushes and mops may be used provided no hydrocarbon material is left behind or is allowed to become trapped in drain lines.

Final cleaning

When aqueous cleaning, use only clean demineralized water. Spraying from pressure nozzles and heating the water to at least 120 ^{O}F promotes more effective cleaning and rinsing. Use Shake Test as discussed above to determine if all pre cleaner is absent from a sample of the final wash after the final clean and last rinse. If organic contamination is present do another rinse with clean demineralized water.

B.2.10 Wipe Solvent and Gauge Cleaning

In components with inaccessible locations that cannot be broken down to fewer components or water cannot be introduced because of physical limitations or possible damage, an alternate method of cleaning is needed. Clean by spraying a liquid form of HCFC-141b. Use only in small amounts spraying on a lint free cloth and wiping the surface or by spraying and allowing to evaporate with oil type contamination to minimize use since HCFC-141b is a Class II ODC. In inaccessible parts of oxygen components, hot gas purging is effective in removing the contamination after spraying HCFC-141b. Use only hot nitrogen as air and oxygen can promote combustion when mixed with HCFC-141b solvent vapors.

When a liquid form of solvent to replace CFC-113 is needed as a wipe solvent to pre clean gauges from a syringe and do NVR tests, use a pure refined form of HCFC-141b.

When using as a wipe solvent, HCFC-141b solvent can be difficult to use because of its very low boiling point and very high evaporation rate. The cleaning potential is reported to be similar to but less than CFC-113. To address that concern, a special formulation HCFC-141b FSN 7930-01-398-0987 is available from a spray can. This special formulation contains Isopropanol (commonly called Isopropyl Alcohol and IPA) to slow the evaporation rate and is a pure form with low amounts of Non-Volatile Residue (NVR). The NVR is 25 PPM. This high NVR will probably fail most oxygen NVR tests so if a lower NVR is needed use the above discussed pure refined form of HCFC-141b. Each of these solvents is recommended as the interim replacement for CFC-113 for wipe solvent cleaning.

HCFC-141b Ozone Depleting Potential is only a about 1/10th that of CFC-113 and is recommended for use in small quantities for aircraft maintenance and support until 30

December 2003. Ethane, 1,1-Dicloro-1Fluoroethane (called HCFC-141b, R-141b and Forane (R) 141b) in liquid form is not currently known to be covered by any specification. The chemical is economical to purchase in large quantities, but only pure refined forms of HCFC-141b with low NVR should be used to clean oxygen equipment with the exception of a wipe solvent as discussed above. The goal is to minimize the use of this chemical as it is an ODC.

HCFC-225 Ozone Depleting Potential is even less that HCFC-141b and it has been recommended by the Environmental Protection Agency for use in small quantities for aircraft maintenance and support until 30 December 2030. Toxicology testing needs to be accomplished before the military recommends this solvent for use. It is possible this could be accomplished in several years or by 1997. This chemical is more expensive to purchase than HCFC-141b, and only pure refined forms should be used to clean oxygen equipment with the exception of a wipe solvent as discussed above. The goal is also to minimize the use of this chemical as it is an ODC.

Wipe Solvent Cleaning

For wipe cleaning oxygen components, such as remove a small spot or area, spraying HCFC-141b, FSN 7930-01-398-0987 (PN 04016) may be used where a NVR of 25 PPM is allowed. Wipe contamination free after it has dissolved with a clean lint free cloth. Where a lower NVR is needed, use only pure refined forms of HCFC-141b. In cases where the over spray could result potentially damaging surrounding components or equipment, spray the clean lint free cloth first, then wipe the oxygen component. Ensure that any HCFC-141b used does not contact plastic surfaces or damage will occur.

Pre Cleaning "Closed Ended" Gauges

MIL-C-87937, Type II Cleaning Compound diluted with demineralized water may be used with a lint free cloth or a non abrasive brush to clean buildup of soils and greases away from the outside surfaces of a gauge installation. Rinse the surfaces with demineralized water before it's removal.

After removal, the interior of gauges should be pre cleaned with a pure refined form of HCFC-141b by injecting the chemical through a syringe into the tubes from the gauges that see oxygen service and allowing to air dry. If the gauge costs is less than $100 it will be more economical to discard the gauge and use a new gauge rather than cleaning it. Gauges which cost more than $100 should be pre cleaned and sent to the appropriate organization for cleaning and calibration. The activity that installs the gauge should ensure that the expiration date of one year after installation is attached to the gauge with a label so it will be known when to replace the gauge. If equipment is currently available that used CFC-113, replace cleaning chemical with a pure refined liquid form of HCFC-141b. When equipment is available, purge with nitrogen gas heated to 120-160 ^{O}F.

Final Cleaning "Closed Ended" Gauges

Gauges can be final cleaned with only pure refined form of HCFC-141b may be used with existing equipment which uses the chemical in a closed system. Gauges should be packaged and shipped to installations which have been used in the past. Purge only with clean filtered nitrogen gas heated to 120-160 ^{O}F.

WARNING - Proper precautions must be followed not to breathe vapor, mist or gas of HCFC-141b. The respiratory toxicity limit of HCFC-141b is 500 PPM. Care must be taken in the use of this solvent in confined spaces as this is very toxic to breathe. Ventilation must be provided to preclude injury or death.

WARNING - Also, HCFC-141b is very caustic to certain plastics. HCFC-141b is compatible with glass. Ensure that no spray or over spray comes in contact with the gauge face clear covering if plastic and if not sure whether glass or plastic.

WARNING - Only small amounts of these solvents should be used. Use aqueous cleaning methods whenever possible. When establishing a cleaning operation in a facility, it is best to review the Material Safety Data Sheets (MSDS) for supplemental safety information and precautions.

WARNING - When injecting HCFC-141b into a gauge, combustible gases will exit the gauge. Ensure that no sparks or flames are in the immediate vicinity which could ignite the gas. Non refined forms of this chemical solvent leaves behind more non-volatile residue than is desired and this may also be reactive with oxygen. For these reasons a refined form of this solvent is desired for use on oxygen equipment. Test data currently available from NASA shows that HCFC-141b. However, the vendor reports a flammable limit in air at 7.4 to 15.5 per cent and an auto ignition temperature (AIT) of 1022^{O}F in air. Thermal decomposition due to exposure to heat above 800^{O}F also releases irritating, toxic and corrosive gases.

WARNING - These solvents are damaging to dispose in the environment. Ensure that local rules and restrictions are following when disposing.

B.2.10.1 Alcohol Cleaning Considerations

. The U.S. Navy and Air Force has banned the used of any alcohol including Isopropyl Alcohol (IPA) for cleaning surfaces of equipment that see oxygen service. Should anyone desire to use alcohol for cleaning these surfaces then best practices are that commercial and military grades of alcohol with Non-Volatile Residue (NVR) of greater than 10 PPM may be used to clean exterior surfaces only of oxygen equipment provided special precautions are taken to avoid contact with any surfaces that may contain liquid or gaseous oxygen. Should any cleaning of components with alcohol that have surfaces which contact oxygen be done, extreme precautions must be taken to dry and purge the components to ensure removal of all the residue left behind which contains hydrocarbons and is extremely dangerous in contact with liquid and gaseous oxygen. It may be desirable to bake components in ovens to ensure of complete drying. Do not bake non metals.

Isopropanol (commonly called Isopropyl Alcohol and IPA) is cited as a deicer and degreasing chemical in a number of military Technical Orders to clean and degrease military aircraft oxygen equipment. This is not a desirable solvent for use on oxygen equipment. Federal Specification TT-I-735 (Grade A is a general solvent and Grade B is an anti-icing fluid) is used to procure this chemical.

WARNING - Laboratory tests by the Navy and NASA shows that methyl and isopropyl alcohol are poor solvents and does not effectively dissolve greases and contaminates commonly found on oxygen equipment. Not only will a combustible hydrocarbon residue be left behind, but also

the combustible contaminates intended to be cleaned. This increases the risk of a fire and explosion. Also, Non-Volatile Residue (NVR) hydrocarbon compounds are left behind (reference Government Industry Exchange Program (GIDEP) Safe Alert No. H6-S-93-01, dated 14 April 1993 for a discussion of an IPA accident.) Even in minute amounts spontaneous combustion will occur with oxygen.

WARNING - Isopropyl Alcohol evaporates slowly with colder temperatures. This will leave a sludge behind that will take a long time to evaporate. To counter this problem, a wipe cloth is recommended, but the effectiveness of this method is questionable. Isopropyl can be used as a cleaning chemical in the shop, but its effectiveness outside is very questionable. In the shop a hot gas purge or baking in ovens should be used to remove any residue. This is not usually practical to do outside or at the aircraft.

WARNING - Isopropyl Alcohol is also used as a deicer during the servicing of liquid oxygen at an aircraft. Precautions are necessary to remove any sludge and keep it out of the liquid oxygen. This cleaning chemical should be used only with special precaution on oxygen equipment to carefully remove any residue and not contaminate any surfaces that may come in contact with oxygen.

WARNING - IPA is extremely flammable with a flash point of 56 ^{o}F. Also, IPA in comparison to CFC-113 dries very slowly, and standard commercial and military grades of IPA will have an excessive amount of Non-Volatile Residue (NVR). This will be left behind on the surface posing a fire and explosion hazard. Grades of IPA with a low amount of NVR (less than 10 PPM) is desired.

WARNING - IPA should be used with caution in confined spaces. Its vapors are toxic with a Threshold Limit Value (TLV) of 400 PPM. Ensure adequate ventilation is provided or respiratory protection is necessary.

WARNING - Caution should be exercised when using IPA to clean non-metallic materials. Rubber and plastic such as Teflon absorb solvents such as IPA requiring careful drying procedures to prevent off-gassing flammable and toxic materials. Permanent damage to the materials may result. Ensure that IPA is compatible with the non-metallic material before its use is authorized.

B.2.10.2 Cleaning Oxygen Tubing.

Most past methods of cleaning tubing including oxygen tubing have been to use solvents to vapor degrease and liquid degrease by continuous fluid circulation. 1,1,1 Trichloroethane (common name is TCA or Methyl Chloroform), specification O-T-620, Type I is used for a general purpose solvent and Type II is used for vapor degreasing metals has been most effective to vapor degrease oxygen tubing. Other solvents that have been used to liquid degrease such as CFC-113 are discussed below. After cleaning any oxygen tubing, the ends should be capped with non shredding caps to prevent any entry of contamination.

B.2.10.3 Information on Cleaning Chemicals

Existing chemicals used for oxygen cleaning are given below. These ODS's and non ODS's have risk in there use and should only be used after all environmental, safety and health factors

have been considered. The reference below to ODS's does not require the use of any of these substances, but is provided for background information only since many of the below chemicals are being used. It should be noted that cleaning methods and solvent chemicals can pose serious toxic, fire and explosion hazards. The following information is forwarded concerning the risks with the use of these chemicals.

a. Trichlorotrifluoroethane (CFC-113 or Freon 113) specification MIL-C-81302, Type I is the safest solvent that can be used on oxygen equipment and is the only approved solvent chemical. This solvent is approved for use for most all applications. Precautions must be taken because this solvent will damage many elastomerics or soft goods. When cleaning oxygen equipment, alcohol can leave behind 20 times and Dry Cleaning Fluid can leave behind 100 times the non volatile residue than Freon 113 which leaves a maximum of 1 PPM hydrocarbons. Since CFC-113 is an ODC, the USAF and Navy plan to implement aqueous processes for component cleaning of oxygen equipment in the shop and clean room. However, on-going studies have not yet identified a cleaning agent (solvent or otherwise) acceptable to replace Freon 113 as a wipe solvent, oxygen gauge cleaner or cleanliness verification fluid. The USAF and Navy currently plan to recommend the continued use of Freon 113 as a wipe solvent, instrument cleaner, and cleanliness verification fluid. Care must be taken in the use of this solvent in confined spaces. Ventilation must be provided to preclude injury or death. The respiratory toxicity TLV limit is 1000 PPM and there is no reaction with oxygen.

b. 1,1,1 Trichloroethane (common name is TCA or Methyl Chloroform), specification O-T-620, Type I is used for a general purpose solvent and Type II is used for vapor degreasing metals. This is considered the second safest solvent to use in cleaning oxygen equipment. Specification MIL-T-81533 is also cited in many Technical Orders to clean oxygen equipment. Since this is an Ozone Depleting Chemical (ODC), a waiver must be applied for and approved to use this. This chemical is not, however, recommended as investigations have found that a sticky oily residue has separated out from the fluid and this is considered hazardous to use on oxygen equipment and is no longer recommended for use. This is only available from storage and will not be produced any more. This chemical reacts with oxygen so it must be used with precautions in cleaning any oxygen equipment. Its toxicity limit is lower than CFC-113 so it is more dangerous to breathe. Since it leaves behind excessive non-volatile residue, it must be used with precautions and a final rinse with CFC-113 is desirable. Care must be taken in the use of this solvent in confined spaces. Ventilation is absolutely required to preclude injury or death. The respiratory toxicity TLV limit is 350 PPM and there is reaction with oxygen. The ignition temperature is however very high at 998^{O}F. If diving equipment is under consideration, it should be known that NAVSEA prohibits the use of this solvent in contact with all diving equipment. The reason is that the chemical decomposes in contact with alkaline CO_2 removal equipment forming highly toxic and flammable dichloroacetlyene.

c. Trichloroethylene, Oxygen Compatible, (commonly called TCE) specification MIL-T-27602 was used and specification O-T-634 is now used (Type I is a general purpose solvent and Type II is used for vapor degreasing) is cited in many Technical Orders to flush oil and grease from oxygen system tubing. This chemical is reportedly used by some aircraft organizations. If this chemical is under consideration for use with diving equipment, it should be known that NAVSEA prohibits use of the solvent in contact with all diving equipment because the solvent decomposes in contact with alkaline CO_2 removal equipment forming highly toxic

and flammable dichloroacetlyene. If this cleaning chemical is used to clean oxygen equipment, great precautions must be followed to preclude breathing toxic fumes. Care must be taken in the use of this solvent in confined spaces as this is very toxic to breathe. Ventilation must be provided to preclude injury or death. The respiratory toxicity TLV limit is 50 PPM and there is a reaction with oxygen. The ignition temperature is however very high at 770^{O}F.

d. Perchloroethylene (common name is PERK, PCE, Dry Cleaning Fluid) has been used. It is purchased by specification O-T-236, (Grade A is another type of dry cleaning fluid and Grade B is a vapor degreasing solvent). It is an extremely good solvent. It is not a fire hazard unless it has been stabilized with an organic solvent. This would increase the flammability of the chemical with oxygen. It has a slow evaporation rate and leaves behind an excessive non-volatile residue. Of primary concern is that it is classified as a suspected human carcinogen. This chemical is also extremely toxic to breathe and any residue left behind could contaminate the breathing gas. This cleaning chemical should be used only with special precautions on oxygen equipment. Care must be taken in the use of this solvent in confined spaces. Ventilation is absolutely required to preclude injury or death. The respiratory toxicity TLV limit is very low at 25 PPM and there is no reaction with oxygen. The chemical is also toxic to the skin and a short term exposure limit of 150 PPM is established. Skin protection should be provided.

e. Dichloromethane (commonly called Methylene Chloride) specification ASTM D4701 is a good solvent. This is not a desirable solvent for use on oxygen equipment. It leaves behind excessive non-volatile residue and reacts with oxygen. It is also a suspected human carcinogen. Since its toxicity level is under debate as not safe to breathe, its use for cleaning oxygen equipment is not recommended. This cleaning chemical should be used only with special precautions on oxygen equipment. Care must be taken in the use of this solvent in confined spaces. Ventilation is absolutely required to preclude injury or death. The respiratory toxicity TLV limit is 500 PPM and there is reaction with oxygen. OSHA has recommended reducing the exposure limit to 25 PPM since the solvent is being reclassified as a suspected human carcinogen. The ignition temperature is not known.

f. Dry Cleaning Fluid or Stoddard Solvent P-D-680, Type II evaporates very slowly (high boiling point of 350^{O}F) and has a high NVR and should be prohibited from use on oxygen equipment. This chemical leaves an excessive amount of residue. This is not a desirable solvent for use on oxygen equipment. This is an extremely dangerous chemical to use for many reasons, and it should not be used. The respiratory toxicity TLV limit is 500 PPM and there is reaction with oxygen. The flash point is 140^{O}F.

g. Isopropanol (commonly called Isopropyl Alcohol and PI) is cited as a deicer and degreasing chemical in a number of Technical Orders to clean and degrease military aircraft oxygen equipment. This is not a desirable solvent for use on oxygen equipment. Federal Specification TT-I-735 (Grade A is a general solvent and Grade B is an anti-icing fluid) is used to procure this chemical. Laboratory tests by NASA show that IPA is a poor solvent and does not effectively dissolve greases and contaminates commonly found on oxygen equipment. Not only will a combustible hydrocarbon residue be left behind, but also the combustible contaminates intended to be cleaned. This increases the risk of a fire and explosion. Also, Non-Volatile Residue (NVR) hydrocarbon compounds are left behind (reference Government Industry Exchange Program (GIDEP) Safe Alert No. H6-S-93-01, dated 14 April 1993 for a discussion of an IPA accident.) Even in minute amounts spontaneous combustion will occur

with oxygen. Isopropyl Alcohol will not evaporate much with colder temperatures. This will leave a sludge behind that will take a long time to evaporate. To counter this problem, a wipe cloth is recommended, but the effectiveness of this method is questionable. Isopropyl can be used as a cleaning chemical in the shop, but its effectiveness outside is very questionable. In the shop a hot gas purge should be used to remove any residue. This is not usually practical to do outside or at the aircraft. Isopropyl Alcohol is also used as a deicer during the servicing of liquid oxygen at an aircraft. Precautions are necessary to remove any sludge and keep it out of the liquid oxygen. This cleaning chemical should be used only with special precaution on oxygen equipment to carefully remove any residue and not contaminate any surfaces that may come in contact with oxygen. The respiratory toxicity TLV limit is 400 PPM and there is a reaction with oxygen. This chemical easily ignites as the flash point is only 56^{O}F. Because of the flammability concern, this material should not be used to clean oxygen equipment.

h. Denatured Alcohol is Ethyl Alcohol that has been rendered unusable for human consumption by the addition of odorous and/or obnoxious constituents. This is not a desirable solvent for use on oxygen equipment. MIL-STD-1201B addresses different formulations of Denatured Alcohol with various combinations of the following denaturants: Isopropyl Alcohol, Methyl Isobutyl Ketone, Methyl Alcohol, Ethyl Acetate, Gasoline, Kerosene and rubber hydrocarbon solvent. The non-volatile residue of Denatured Alcohol will be greater than Ethyl Alcohol. The flammability of Denatured Alcohol will be similar to Ethyl Alcohol, while the toxicity will generally be greater than Ethyl Alcohol. This chemical leaves behind an excessive amount of hydrocarbon residue. The respiratory toxicity TLV limit is 1000 PPM and there is reaction with oxygen. The flash point is very low at 57^{O}F. Because of the flammability concern, this material is not considered suitable for use to clean oxygen equipment.

i. DS-104 or DS-108 by Dynamold is approved by the F-16 System Program Office as a wipe solvent on aircraft exterior surfaces for aircraft manufacture. DS-104 is composed of Propylene Glycol Methyl Ether Acetate, Isoparaffins, and Butyl Acetate. The material is flammable with a flash point of 105^{O}F. The material is a personal toxic hazard with a Threshold Limit Value (TLV) of 150 PPM. Because of the flammable hazard and toxic concern this is not safe for use on oxygen equipment.

j. Ethane, 1,1-Dicloro-1Fluoroethane (called HCFC-141B, R-141B and Forane (R) 141B) is not currently known to be covered by any specification. Use of this chemical for cleaning precision equipment such as oxygen by vapor degreasing and cold metal immersion has been banned by the federal government in any form. Only limited applications are under consideration 31 December 2003. Military agencies are anticipating authorizing the use of HCFC-141B. Proper precautions must be followed not to breathe vapor, mist or gas. There are possible flammable vapors and the chemical should not be used near heat, flames or sparks. The solvent leaves behind excessive non-volatile residue and is believed to be reactive with oxygen. For these reasons, this is not a desirable solvent for use on oxygen equipment. No test data is currently available specifying the flammability of the solvent with oxygen. However, the vendor reports a flammable limit in air at 7.4 to 15.5 per cent and an Autoignition temperature of 1022^{O}F in air. Thermal decomposition due to exposure to heat above 800^{O}F releases irritating, toxic and corrosive gases. The solvent can be difficult to use because of its very low boiling point and very high evaporation rate. The cleaning potential is reported to be similar to CFC-113. The respiratory toxicity TLV limit is 500 PPM.

Elastomeric materials are special concerns when using solvents. Exercise caution when cleaning Teflon and other elastomeric materials. These materials absorb solvent during the cleaning process. The subsequent drying process may not remove all solvent. Any remaining solvent will slowly evaporate during use presenting a possible fire and toxicity hazard. A recent oxygen fire was traced to a Teflon lined hose cleaned with Isopropyl Alcohol. Past personnel injury has also been traced to life support hoses cleaned with highly toxic solvents such as Trichloroethylene.

Another issue that must be considered is the use of aqueous methods of cleaning. Nonionic or Distilled Water, Mild Detergents and Mild Soaps are non toxic to breathe and generally safe to clean with. Some detergents and soaps, however, leave behind hydrocarbon residues. Use of these cleaners for oxygen equipment is highly specific to equipment configuration, cleaning method and location. As such careful consideration must be followed when using either of these aqueous cleaners. Use only Nonionic or Distilled Water (no known document) to clean pressurized oxygen equipment where contact with oxygen is likely. Hot Nonionic Water with a lint free cloth is best. Mild Detergents from specification MIL-D-16791 or equivalent and Mild Soaps from specification P-S-1792, Type II, Class I, II, or equivalent (P-S-600 was the specification) may be used for general purpose cleaning of oxygen equipment providing there is a final rinse with Nonionic or Distilled Water or CFC-113. This is necessary to remove any residue that may be left behind. Either cleaner may be used to clean exterior surfaces of tubing and fittings, but the use of hot Nonionic Water with a clean lint free cloth is the best choice. Care must be taken not to leave any residue behind that may contact oxygen causing a fire and explosion hazard. Mild Detergent per MIL-D-16791 should be mixed at no greater than 0.5 ounces per gallon of water, and used at no greater than 125^{o}F. The solubility of Mild Detergent per MIL-D-16791 in water decreases as the quantity added per gallon of water and temperature increases. At high concentrations and temperatures, the detergent will deposit on the equipment being cleaned. There is no known toxic hazard on breathing either of these cleaners when used in confined spaces. Neither of these cleaners must be used such that it is allowed to accumulate or collect within oxygen equipment. Water can freeze and result in oxygen equipment malfunction. Problems with corrosion are also likely. Also, detergents and soaps can cause excessive suds when too much agitation is applied.

References

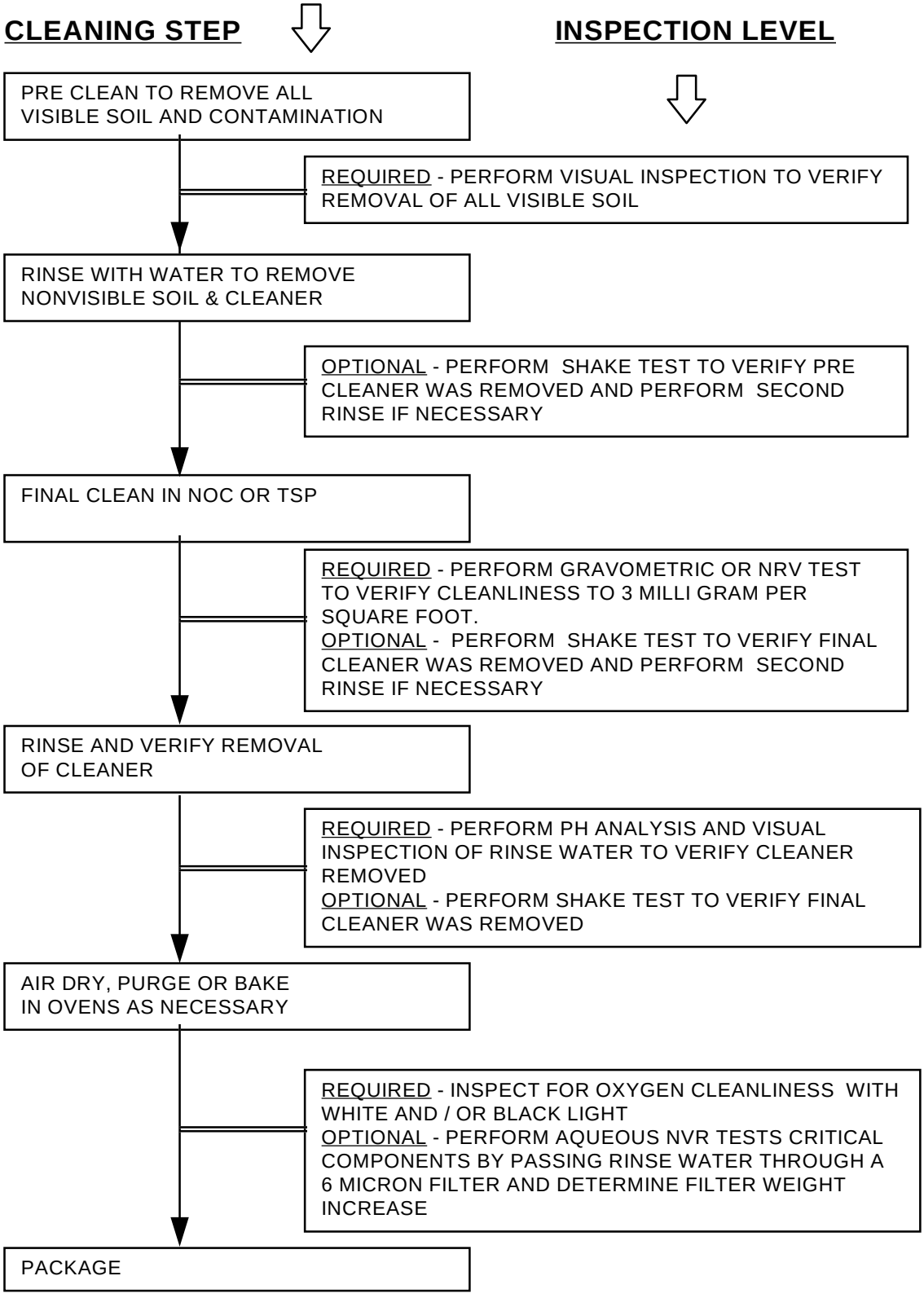
Additional information is available in these references to supplement cleaning processes herein:

"NAVSEA Report On: Aqueous Oxygen Cleaning Products and Processes," by Neil Antin, 24 March 1994, Naval Sea Systems Command, 2531 Jefferson Davis Highway, Arlington, VA 22242-5160. Phone (703) 602-5552x205.

"NAVSEA Report On: Aqueous Oxygen Cleaning Products and Processes, (Supplement To The NAVSEA Report On Aqueous Oxygen Cleaning Products and Processes Dated 24 March 1994)" by Neil Antin, , 7 April 1995, Naval Sea Systems Command, 2531 Jefferson Davis Highway, Arlington, VA 22242-5160. Phone (703) 602-5552x205.

“Investigative Report on the Evaluation of Solvent Alternatives to Trichlorotrifluoroethane (CFC-113) for Cleaning of Gauges and Precision Instruments, Phase I,” WSTF-IR-95-0048, 30 January 1995, National Aeronautics And Space Administration (NASA), Lyndon B. Johnson Space Center, White Sands Test Facility, P. O. Drawer MM 88004, Phone (505) 524-5011.

Aqueous Oxygen Component Cleaning Process Flow Chart



B.2.10.4 Aircraft oxygen system filters.

When deemed appropriate, a flight line replaceable filter may be provided in the oxygen system to effectively minimize the accumulation of contaminants in certain critical components. The type, size and location of filter(s) should be determined by the contractor. If two or more different filters are used, they should be distinguished as such to preclude their improper installation. All filters used in oxygen service must be oxygen compatible to preclude adverse effects.

B.2.10.5 LOX Converter Closures.

If the aircraft LOX converter is located such that lines are required to be disconnected during aircraft maintenance checks or overhaul, suitable closures are provided for each exposed connection to prevent materials which are incompatible with oxygen from entering the system. Caps which introduce moisture and tapes that leave adhesive deposits should not be used for these purposes. The closures should remain with the aircraft at all times and shall be stored, when not in use, in close proximity to the connections and in such a manner as not to become contaminated. All openings of lines, fittings, valves, and regulators should be kept securely capped until closed within the installation.

B.2.10.6 Purging.

The oxygen system must be capable of being purged to remove any contaminants. If the oxygen system has been left open to atmospheric conditions for a period of time, or is opened for repairs, the system should be purged with hot, dry nitrogen conforming to *BB-N-411*, Type I, Class 1, Grade B or hot, dry air conforming to *BB-A-1034*, Grade A or C provided the oxygen supply (pressurized oxygen or the LOX converter assembly) has been isolated or not installed. The temperature at the inlet to the system should not exceed 250°F (121.1°C) during hot purging. The final purge should be accomplished with hot, dry oxygen, conforming to *MIL-O-27210*, Type I. The purging temperatures selected should be a trade–off between the increased risks associated with hot oxygen gas and equipment components and the time interval necessary to complete the purging. Current USAF TOs *and NAVAIR Aviation Crew System Manuals, 13.1.6*. for purging practices on LOX aircraft and ground support equipment and installations should be consulted. The purging procedure should meet the following requirements.

B.2.10.7 Oxygen distribution system purging.

The aircraft oxygen distribution system should be purged separately from the liquid oxygen converter by establishing a flow from each oxygen station of at least five liters per minute (83.5 cu.cm/s) for a period at least 30 minutes. In large aircraft, it may be necessary to divide the system, as determined by feeder lines, and purge each separately. Depending on the type of converter and its installation in the aircraft, purging procedures and times will vary. Refer to *USAF TO 15X-1-1 and NAVAIR Aviation Crew System Manuals, 13.1.6* for detailed information. The latest version of the KMU-78/E purging heater should be used.

B.2.10.8 LOX converter purging.

LOX converters of 5 and 8 liters capacity should be purged 45 to 60 minutes when the container is at ambient temperature for 20 to 30 minutes and it is within 6 hours after LOX draining. LOX converters of 10 to 75 liters capacity should be purged 60 to 90 minutes when the container is at ambient temperature 45 to 60 minutes and it is within 6 hours after draining. Should the drain time exceed 6 hours then the purge time must be increased to a minimum of 70 minutes for the 5 and 8 liter converters, a minimum of 90 minutes for the 10 liter converter, and a minimum of 120 minutes for the 20 to 75 liter converters. Detailed methods and procedures for purging are given in *USAF TO 15X-1-1 and NAVAIR Aviation Crew System Manuals, 13.1.6*. It is essential this publication be referred to for the proper procedures to follow when establishing detailed methods and procedures for purging LOX converters.

B.2.10.9 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 and regulators mounted on shock-mounted panels to permit easy maintenance. An adequate length of line should be available to connect tubing and flexible hoses.

B.2.11 Oxygen system survivability.

The oxygen equipment, tubing and fittings shall be located as remotely as practicable from fuel, oil, hydraulic fluid, water injection, storage battery systems, exhaust stacks and manifolds, electrical, radio and insulating materials. Insofar as practicable, oxygen lines shall not be grouped with lines carrying flammable fluids. Where necessary, deflector plates shall be used to keep flammable fluids away from oxygen lines, fittings and equipment. Converters shall not be in line with the plane of rotation of a turbine or propeller. Components of the oxygen system shall not be installed where they will be subjected to temperatures in excess of that specified in the individual component specifications, and no part of the system shall be installed in an area which will be subjected to a temperature of 260 degrees F (123.3 degrees C) or greater. In order to minimize loss due to heat, liquid oxygen converters shall not be located near equipment that dissipates a high quantity of heat. Liquid oxygen converters and associated fill and build-up and vent lines shall not be located near aircraft components that give off flammable fluids or gases unless physically isolated such that heat and flammable fluids and gases cannot enter the converter area. Other equipment components that may be located nearby, but not physically separated shall be qualified to an explosive atmosphere. All components, including converters filled with LOX, shall be installed to withstand a crash loading, G level, and pulse duration applicable to that component and the aircraft for which it is intended.

B.2.12 Servicing aircraft LOX converters.

The characteristics of supply equipment for servicing liquid oxygen converters are desired to be interchangeable from one organization and country to another as possible. The ensures

aircraft LOX converters can be serviced in many bases and countries. NATO STANAG 3499 is implemented by this document to promote this goal. The aim of this agreement is to ensure minimum acceptable characteristics of charging connectors used in replenishment of aircraft liquid oxygen systems, thereby increasing the effectiveness of aircraft cross-servicing.

B.2.13 CREW AND PASSENGER OXYGEN EQUIPMENT

B.2.13.1 Oxygen regulator installation.

B.2.13.1.1 Panel mounted regulators.

When panel mounted regulators are used, automatic diluter demand, pressure breathing regulators as specified by *MIL-R-83178* and *MS 27599* or *MIL-R- 25410* and *MS 22062* are installed at all permanent and temporary crew stations in the aircraft. Newer molecular sieve oxygen generating systems (MSOGS) use different breathing regulators, but their performance should equal or exceed that of the CRU-73/A as specified in *MIL-R-83178*. In continuous-flow systems, 2 to 4 regulators are used with for passenger stations, and their mounting locations are not critical, as the passengers will breathe at remote outlets.

The crew panel-mounted regulators are located in accordance with *MIL-STD-1776*. The crew member'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 crew member's arm. The regulators are designed and located so that accidental actuation of the toggles by surrounding personnel is minimized. The regulators are mounted vertically on the forward panel or horizontally on the console. Installation of the panel-mounted breathing regulator with flexible hoses for inlet and outlet ports is a good design practice, allowing the regulator to be front serviced for both installation or removal.

In single-pilot and tandem-pilot aircraft, the oxygen regulator, pressure gage, 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 gages, and flow indicators 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 dilution air entering the oxygen regulator, as instances of oil vapors entering a crew member's oxygen subsystem have occurred. The regulator is also 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 USAir Force and Navy policy requires checking and/or replacement of the regulators at scheduled intervals in fighter and trainer aircraft. All regulators should receive a leakage and flow test in accordance with the applicable documentation prior to installation in the aircraft. The test should be conducted not more than 30 days before installation of the regulator. Organizational level checks may be performed with portable test sets on the CRU-73/A regulator whenever a regulator problem is encountered by the crew member 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.

B.2.13.1.2 Non-panel mounted regulators.

Some special considerations require chest- or seat-mounted breathing regulators in lieu of panel mounted regulators. The performance of these regulators should also equal or exceed that in *MIL-R-83178*. Installation of the non-panel mounted regulators should be specified and reviewed by the procuring activity. Stowage provisions should be made for any chest-mounted regulators to prevent damage or contamination during servicing or ingress-egress actions.

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 and to stop flow from a defective quick disconnect or a damaged supply hose.

B.2.13.2 Oxygen breathing regulator types.

Three oxygen delivery systems are 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 crew member 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 in use for passengers and noncritical crew members who do not have control of the aircraft or its mission.

B.2.13.2.1 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 crew members. The operational altitude of this system is sea level to 25,000 feet. Above this altitude, the regulators serve an emergency function to support the passenger down to the normal operating altitude of this equipment. However, the typical procedure is to descend to 10,000 feet or lower. 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 to add sufficient gas volume to his lungs (tidal volume) for breathing, which dilutes his oxygen intake.

The continuous flow regulator delivers oxygen to the crew member's or passenger's mask at a continuous rate of flow. Flow may be controlled either manually or automatically. This is usually 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 the military types of continuous-flow regulators:

a. Types A-8, A-8A, A-9 and A-9A. These regulators include a pressure gage, 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 feet. A-9 and A-9A regulators are limited at a back pressure up to 500 psig.

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. This multi-outlet regulator accommodates up to 15 persons. These regulators are installed in banks of two to four, plumbed in parallel as a safety precaution in the event one fails. This is necessary because failure may occur with no visual indication to aircraft occupants. This regulator will not deliver oxygen unless the mask bayonet connector is plugged into one of the line outlets. This regulator operates within an inlet pressure range of 50 to 500 psig. No manual control is necessary nor is any provided with this regulator. Various models of the Type A-11 regulator are summarized in *table VIII*.

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 first stage is back loaded from the final outlet pressure to maintain a constant pressure drop across the second stages, which operate in parallel. This regulator operates on an inlet pressure range of 75 to 400 psig, from sea level to 41,000 feet, provides an outlet flow from 0 to 527 liters per minute (lpm) as a function of altitude and provides a corresponding outlet pressure up to 55 psig dependent on altitude and flow rate.

d. Type part number 26651-3. This continuous-flow oxygen regulator operates from an inlet pressure range of 200 to 315 psig 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. Other automatic, continuous-flow, regulators have one major disadvantage: During an emergency, there is no way to provide an additional flow of oxygen. The manual override feature on the type CRU-5/P regulator has eliminated this problem, however. This regulator includes a pressure gage and a 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 *AN 6010*. The *AN 6010-1* 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 with no manual controls, no flow indicator, and no pressure gage. However, a pressure gage 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.

g. Airox VIII Regulator Type Device (Army). The Airox chest mounted regulator type device is an oxygen metering and air inlet valve assembly. Regulated constant flow oxygen enters the Airox valve through the flow indicator and filter and is metered by the valve, and

passes to the outlet port for delivery to the users mask. During exhalation, back pressure shuts off oxygen at the Airox valve inlet, thus conserving oxygen. Resumption of breathing restores normal flow through the valve. The oxygen supply may be supplemented with ambient air which enters the valve through the ambient air inlet port.

TABLE B-VIII. Type A-11 regulators.

Type	Inlet pressure range—psig	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
Series 1000-on	50-500	sea level-30,000	48
ALAR A-2000	35-2200	sea level-30,000	48

B.2.13.2.2 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 at altitudes up to 28,000 to 34,000 feet depending on the regulator. 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, which 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 28,000 to 34,000 feet depending on the regulator 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) or the 100 percent oxygen mode depending on the needs of the crew member. 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 crew member when the oxygen is flowing to his mask. This flow indication is useful as the crew member has an indirect indication of hose or mask leaks if it fails to function.

The following paragraphs cover the types of diluter demand regulators that are or have been used on military aircraft:

a. Types A-12, A-12A, *AN 6004-1*, 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 and a higher altitude than that provided by continuous flow regulators is desired. The regulator has a control for normal oxygen (air dilution) or 100 percent oxygen. An emergency valve is also provided.

b. Types 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 types MBU-5/P or MBU-12/P, 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 psig. Types 2857–A1, 2857–A1A, 2858–A1A, 2858– A1B, 2858-B1B and 2858-C1B are very similar.

c. Types 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 psig and at altitudes up to 50,000 feet.

B.2.13.2.3 Pressure demand regulators.

With the diluter demand equipment discussed in the previous paragraphs, a crew member can ascend to about 35,000 feet with an oxygen intake adequate for any reasonable activity. However, between 35,000 and 40,000 feet (because of the declining pressure of the oxygen in the lungs), reduction in the oxygen load of the blood increases the risk of hypoxia. Above 40,000 feet, as the oxygen load of the blood continues to fall with decreasing atmospheric pressure, the symptoms and dangers of hypoxia become more severe. With a leak-tight system, 40,000 feet is considered the absolute ceiling for the diluter demand regulator. Two ways of obtaining oxygen above 40,000 feet are: (1) a pressurized cabin which maintains a relatively high pressure both outside and inside the crew member's body and (2) the positive-pressure diluter demand oxygen regulator which supplies oxygen to the crew member'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 more than a few minutes unless it is an emergency situation, and then the altitude should be reduced to 25,000 feet as soon as possible. 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. Various types of positive pressure diluter demand regulators are available and are used in aircraft having an operational ceiling above 35,000 feet.

B.2.13.3 USAF pressure demand regulators.

The following covers the pressure demand types of breathing regulators in use in the USAF:

a. Type CRU-73/A. This pressure demand, panel-mounted regulator is the primary oxygen regulator in most modern USAF fighter and transport aircraft. This oxygen breathing regulator is designed according to *MIL-R-83178* and *MS 27599* (see *figure 35*). The regulator is designed to automatically provide the proper ratio of oxygen as altitude is increased. Also automatically provided are the proper outlet pressures and flow rates to meet pressure breathing requirements. The primary feature of this regulator is that it was designed to permit flight line checks of proper operation of air dilution, flow-suction, and pressure-breathing characteristics for all altitudes up to 50,000 feet. The regulator incorporates two test ports that are connected to a portable test set. When vacuum simulating altitude is applied to the pressure breathing port, the regulator should deliver the proper pressure at the outlet. When a pressure-measuring device is attached at the air inlet test port, it should be possible to check proper valve operation by applying vacuum at the regulator outlet.

Some of the primary features of this regulator are:

(1) Emergency and test pressure modes. When the emergency mode is selected, positive pressure is provided at the regulator outlet. The test position is spring loaded so that this mode is deactivated when let go. In these modes the regulator will deliver 3 in. to 4 in. of water pressure at 10 lpm.

(2) Oxygen supply mode. This control enables 100 percent oxygen from the aircraft oxygen supply. The control is detented such that it cannot stop at any intermediate positions to prevent the crew member from thinking that it is on when it is not.

(3) Air dilution control. In the normal position, oxygen is diluted with intake cabin air to fractional equivalents of oxygen that increase with altitude to meet minimum physiological demands. This control can also select 100 percent oxygen.

(4) Flow indicator. This indicator gives visual indication of flow from the regulator. Flow rates that exceed 4 lpm at sea level or 8 lpm at 35,000 feet at the regulator outlet will be indicated.

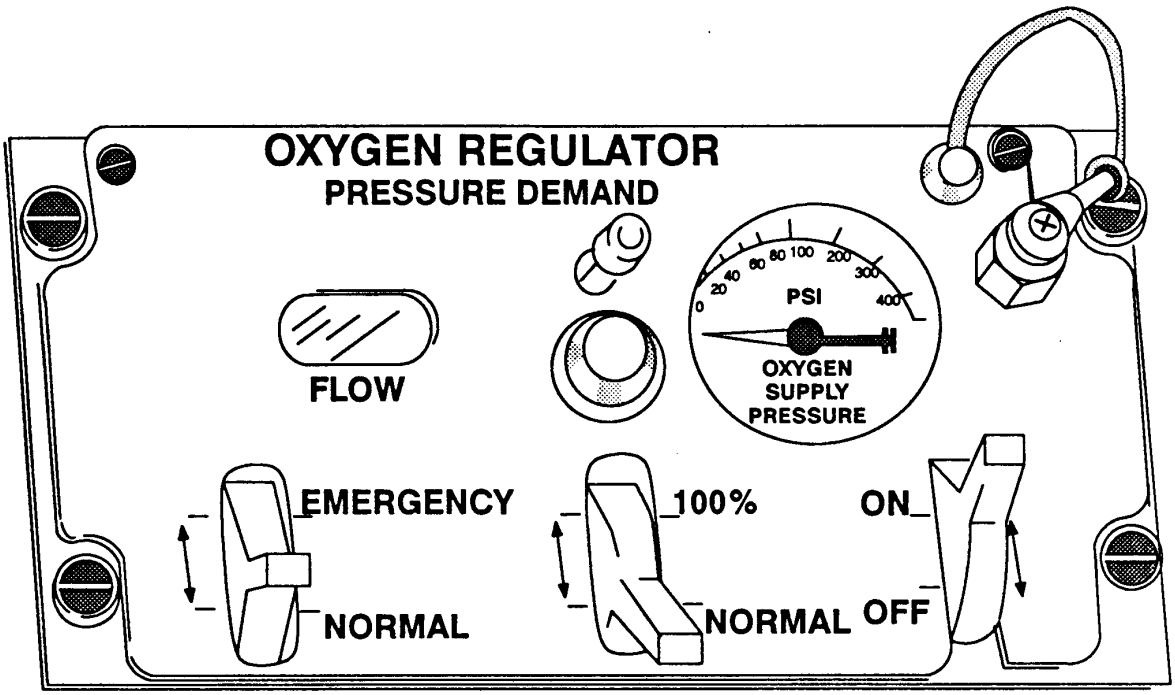


FIGURE 35. CRU-73/A typical panel-mounted pressure demand oxygen regulator.

(5) Pressure gage. This gage displays the regulator inlet line pressure and is calibrated up to 500 psig so that it is functional for low pressure (50 to 120 psig) and high pressure (50 to 500 psig) LOX systems.

(6) Relief valve. This valve will vent excess pressure of the regulator outlet supply so that the operator will not be injured. The flow is vented at 45 lpm at 2 in. of mercury.

(7) Orientation. The regulator is designed so that it will function at any orientation including face-up, face-down, face-aft, and face-inboard.

(8) Lighting. The regulator includes an edge lighted control panel per MIL-P-7788 which is viewable in a darkened environment.

b. Type CRU-66/A. This barometric-demand oxygen regulator is designed to be chest mounted on the crew member with a wedge-plate mounting on the restraint harness. A variation of this regulator is used by the two crew members 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 psig 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 in. of water is supplied on demand from sea level to approximately 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.

c. Other USAF pressure demand regulators. Other USAF pressure demand regulators that are currently in use, but not recommended for use in future USAF aircraft, are given in *table IX*. An exception is the portable walkaround regulators which may be used in that application.

B.2.13.3.1 US Navy CRU-79/P regulators.

The CRU-79/P miniature chest mounted regulator is used in U.S. Navy fighter and attack aircraft equipped with LOX supply systems (see *figures 36 and 36a*). This miniature oxygen breathing regulator is designed to regulate 100 percent positive pressure oxygen to the crew member during flight. Refer to *MIL-R-81553* for complete design requirements. This unit operates from an inlet pressure of 40 to 120 psig, delivers an oxygen flow rate up to 100 lpm, and is operational up to an altitude of 50,000 feet. The safety pressure feature automatically maintains a positive pressure in the mask of 1.0 in. to 3.7 in. 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 in. 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. All models of the CRU-79/P regulators are given in *table X*.

B.2.13.3.2 U.S. Navy CRU-82/P, CRU-88/P and CRU-103/P chest mounted regulators

The CRU-82/P, and CRU-88/P chest mounted regulators, *figure 36b*, are used in U.S. Navy tactical aircraft equipped with and On board Oxygen Generating System (OBOGS). These regulators are designed to regulate 100 percent of the OBOGS product gas to the crew members. The regulators operate with an inlet pressure of 5 to 120 psig, delivers the oxygen enriched breathing gas at rates up to 100 lpm at all altitudes up to 50,000 feet. The safety pressure feature automatically maintains a positive pressure in the oxygen mask of 0.05 to 2.50 inches of water at all altitudes up to 32,000 feet. The pressure breathing feature maintains a positive pressure in the oxygen mask of up to 20.0 inches of water at altitudes between 34,000 feet and 50,000 feet with the positive pressure increasing in proportion to the altitude. These regulators are also compatible with aircraft LOX supply systems.

The CRU-103/P chest mounted regulator, *figure 36c*, is a component of the Navy COMBAT EDGE (NCE) System. It is used in U.S. Navy tactical aircraft to provide the crew with assisted positive pressure for enhanced protection against the hazards of high positive acceleration (+Gz) forces. The regulator can be used with either an OBOGS or a LOX system and regulates the product gas from these systems to the crew member. The regulator operates with an inlet pressure of 5 to 120 psig, delivers the breathing gas at rates up to 240 lpm at all altitudes up to 50.000 feet. The safety pressure feature automatically maintains a positive pressure in the oxygen mask of 0.50 to 4.50 inches of water at altitudes up to 34,000 feet. The pressure breathing feature maintains a positive pressure in the oxygen mask of up to 20.0 inches of

water at altitudes between 34,000 feet and 50.000 feet with the positive pressure increasing in proportion to the altitude. During positive pressure for G (PBG), the regulator contains a pressure proportioning valve that receives pressure signals from the G valve outlet. Regulator performance requirements for PBG is shown in figure 36d. Requirements for these regulator models are given in *Table XLVIIa.*

B.2.13.3.3 U.S. Navy panel mounted regulators.

The U.S. Navy also uses panel mounted regulators similar to the USAF CRU-73/A regulator. Requirements for these regulators are governed by MIL-R-25410. See *figure 35a* and U.S. Navy panel mounted regulators are given in *table XLVII*.

TBD

FIGURE 35a. U.S. Navy aircraft panel mounted oxygen regulators.

B.2.14 USAF oxygen regulator development considerations.

Numerous complex factors must be considered in the design and development of a new oxygen breathing regulator. Included are 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 crew members or passengers. Many past regulator designs have functioned from an inlet pressure of 50 psig minimum to 500 psig maximum where the nominal delivery pressure is 70-120 psig. A pressure-reducing inlet valve is provided to be compatible with 300-500 psig systems. These inlet pressure ranges of operation are compatible with low and high pressure LOX system converters and pressurized oxygen supply systems. However, the new molecular sieve on-board oxygen generation system (MSOGS or 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 engine bleed air. Smaller fighter and trainer aircraft may provide a range of 5-70 psig with the nominal being 30-60 psig. This means that lower and wider ranges of inlet pressure variations must be accommodated in MSOGS breathing regulators. Another difference is that the MSOGS regulator may not provide the air dilution function. In an MSOGS, a component called a monitor senses the partial pressure of oxygen in the delivery air and may sense the cabin pressure altitude. In an MSOGS 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 MSOGS regulators to function at higher pressures to be compatible with LOX and gaseous oxygen supply systems.

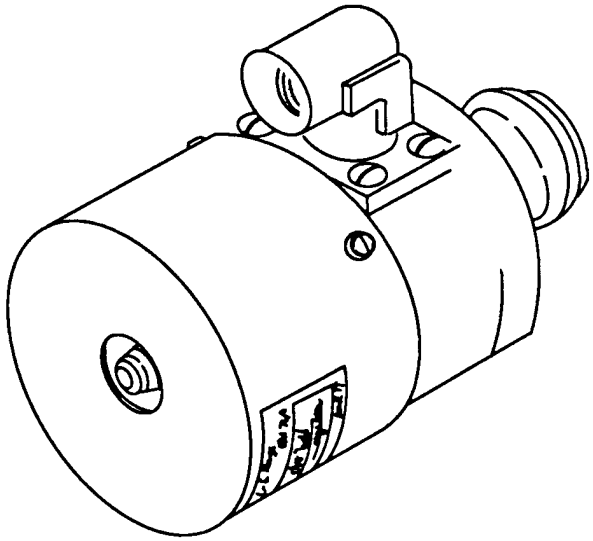
Regulator location is critical. Most past USAF oxygen regulators are panel mounted with the exception of the F-111 aircraft that incorporate chest-mounted regulators and B-1B aircraft that incorporate seat-mounted regulators. The using commands have given unfavorable feedback concerning the chest-mounted regulators, as they are considered personal equipment to be checked out and accounted for by each crew member. Like helmets and masks, a separate item must be provided for each crew member. Therefore, more regulators must be provided than in panel- and seat-mounted designs, and the chest-mounted regulator is more likely to be

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, instrument or the regulator) or be thrown over the shoulder (possibly damaging the regulator, mask or helmet).

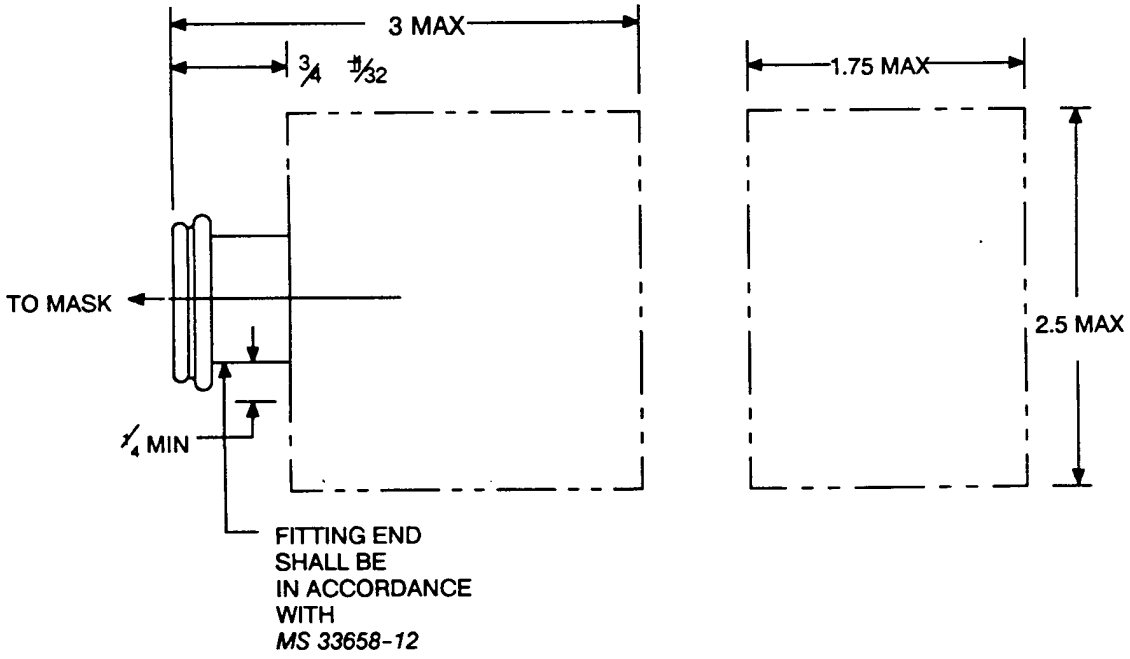
TABLE B-IX. USAF pressure demand regulators currently in use.

Regulator or Part Number	Pressure Breathing Altitude Range	Inlet Pressure Range psig	Design Features
A-13	Manually Selectable	100 - 500	Used with A-4 or D-2 cylinders to be an air-craft portable assembly
2885-5C-A1	39,000 - 50,000 ft	50 - 500	Automatic air dilution
CRU-69 A/A, CRU-69A	up to 50,000 ft	50 - 500	Automatic air dilution
ARO F425500-1, F4255000-3 and F2400-12	up to 70,000 ft	50 - 80	Provides flow rates up to 90 lpm
CRU-68 A/A, CRU-68/A CRU-73/A	43,000 - 50,000 ft	50 - 500	USAF panel mounted regulators
29270-10A-A1, 68B850059-1003	43,000 - 50,000 ft	50 - 500	Interchangeable with CRU-68/A
A-21	Manually Selectable up to 45,000 ft	50 - 500	Used on portable units, MIL-R-7605
D-2, D-2A	39,000 - 50,000 ft	50 - 500	Older panel mounted regulator
2881-5C-A1	39,000 - 50,000 ft	50 - 500	Similar to D-2 unit
MB-2	32,000 - 48,000 ft	50 - 500	Similar to D-2 unit
CRU-44A, CRU-21A, CRU-34/A	43,000 - 50,000 ft	50 - 500	Older panel mounted regulators
CRU-47/A, 29258-A1 CRU-49/A, CRU-48/A, CRU-52/A			Very similar to

29258-A1	up to 75,000 ft	50 - 140	High altitude regulator



ENVELOPE DIMENSIONS IN INCHES



NOTES:

1. ANPT shall be in accordance with *MIL-P-7105*
2. Regulator shall include a 1/8 - 27 ANPT inlet fitting for 40-120 psig oxygen.
3. Envelope dimensions include all hose connecting parts.

FIGURE 36. US Navy CRU-79/P chest-mounted regulator.

TBD

FIGURE 36a. CRU-82/P chest mounted regulators.

TBD

FIGURE 36b. CRU-88/P chest mounted regulator

TBD

FIGURE 36c. Navy COMBAT EDGE (NCE) CRU-103/P G-compensated breathing regulator.

TBD

FIGURE 36d. Navy COMBAT EDGE (NCE) CRU-103/P oxygen regulator PBG performance requirements

TABLE B-XLVI. U.S. Navy CRU-79/P miniature chest mounted oxygen breathing regulators.

Regulator Type or Part Number	Pressure Breathing Features	Inlet Pressure Range (psig)	Design Features
900-002-025-05	32,000 to 50,000 feet	40 to 120	Weighs less than 5 ounces. Provides up to 100 lpm, 100 percent oxygen. Includes safety pressure.
3260024-0101	32,000 to 50,000 feet	40 to 120	
900-002-025-07	35,000 to 50,000 feet	40 to 120	

Control settings on chest-mounted regulators are more difficult to determine because of vision and orientation problems. Chest-mounted regulators add weight to the crew member which is fatiguing in normal operation and, in many cases, unbearable in high-G combat maneuvers. The weight of the regulator is multiplied by seven to nine G's in this case. For example, a 1-pound chest-mounted regulator could weigh seven to nine pounds and bear down on the chest. This hinders the crew member's flight and combat operations. For these reasons, the using commands have decided not to accept any more chest-mounted regulator designs for non chemical defense use.

Seat-mounted regulators are another option, but there are problems with this type mounting as well. 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 determine because of vision and orientation.

Panel-mounted regulators avoid 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.

TABLE B-XLVII. U.S. Navy panel-mounted regulators in use.

Type	Part Number	Pressure Breathing Altitude Range	Inlet Pressure Range (psig)	Design Features
CRU-96/A	TBD	30,000 to 50,000 feet	50 to 2,000	Diluter Demand Automatic Pressure Breathing MIL-R-25410
CRU-97/A	TBD	30,000 to 50,000 feet	50 to 500	
CRU-101/A	TBD	30,000 to 50,000 feet	50 to 2,000	Night Vision Imaging System Compatible to MIL-L-85762
CRU-102/A	TBD	30,000 to 50,000 feet	50 to 500	

TABLE B-XLVIIa. U.S. Navy OBOGS CRU-82/P, CRU-88/P, CRU-103/P chest mounted oxygen breathing regulators.

Regulator Type or Part Number	Pressure Breathing Features	Inlet Pressure Range (psig)	Design Features
CRU-82/P 3260014-0401	32,000 to 50,000 feet 0.5 to 20 inches water	5 to 120	Weight 9.5 ounces Provides 100 lpm 100 percent oxygen enriched breathing gas OBOGS and LOX systems compatible
CRU-88/P 2900W000-001	32,000 to 50,000 feet 0.5 to 20 inches water	5 to 120	Weight 9.5 ounces Provides 100 lpm 100 percent oxygen enriched breathing gas OBOGS and LOX systems compatible
CRU 103/P F241-2300-1	Pressure breathing for altitude (PBA) 32,000 to 50,000 feet 0.5 to 20 inches water Pressure Breathing for G (PBG) 4.0 to 9.0 G's 0.5 to 28.8 inches water	5 to 120	Weight 12.0 ounces Provides 240 lpm, 100 percent oxygen enriched breathing gas OBOGS and LOX systems compatible Provides acceleration counter pressures up to 9.0 G's

B.2.15 Oxygen mask assemblies.

Oxygen masks are either a part of the personal equipment of the crew or 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 communication, helmet retention, and face protection. Two types of masks are presently used in the Air Force: the pressure demand and the continuous flow. The pressure demand type is mandatory for high altitude flights, and the continuous flow mask can be used satisfactorily at lower altitudes but is primarily used by passengers for safe emergency descent of a depressurized aircraft. In pressure suit garments for flight above 50,000 feet, oronasal masks are not usually provided, but breathing gas is provided through valves to a helmet assembly which totally encloses the crew member's head. This incorporates air dilution from the regulator to provide increased pressures to the entire head. Anti-fogging of the clear visor and air conditioning of the entire suit volume is also provided.

B.2.15.1 Pressure demand mask assemblies.

This assembly consists of the mask face piece; inhalation and exhalation breathing valve assemblies; communications microphone, electrical line, and quick disconnects; and a flexible low pressure delivery hose. The delivery hose interfaces to a harness mounted connector device like the CRU-60/P that incorporates a quick disconnect for seat ejection or oxygen system failure, and an integral two-way valve that provides a warning if disconnected and air intake for decreasing oxygen supply. This harness mounted device has another connector for the emergency oxygen. See *figure 37* for an illustration of all these components. The oxygen hose may also connect to a small chest-mounted regulator on other designs such as those presently used in the Navy.

A pressure demand oxygen mask is designed to hold pressure in excess of ambient pressure. This requires two features. First the face seal forms a ring around the inside of the mask, which serves as a pressure seal. Second, a special combination inhalation-exhalation valve or separate inhalation and exhalation valves located at the bottom of the mask are designed to allow oxygen to enter the mask on inhalation and sustain a positive pressure until the regulator outlet pressure is overcome during exhalation.

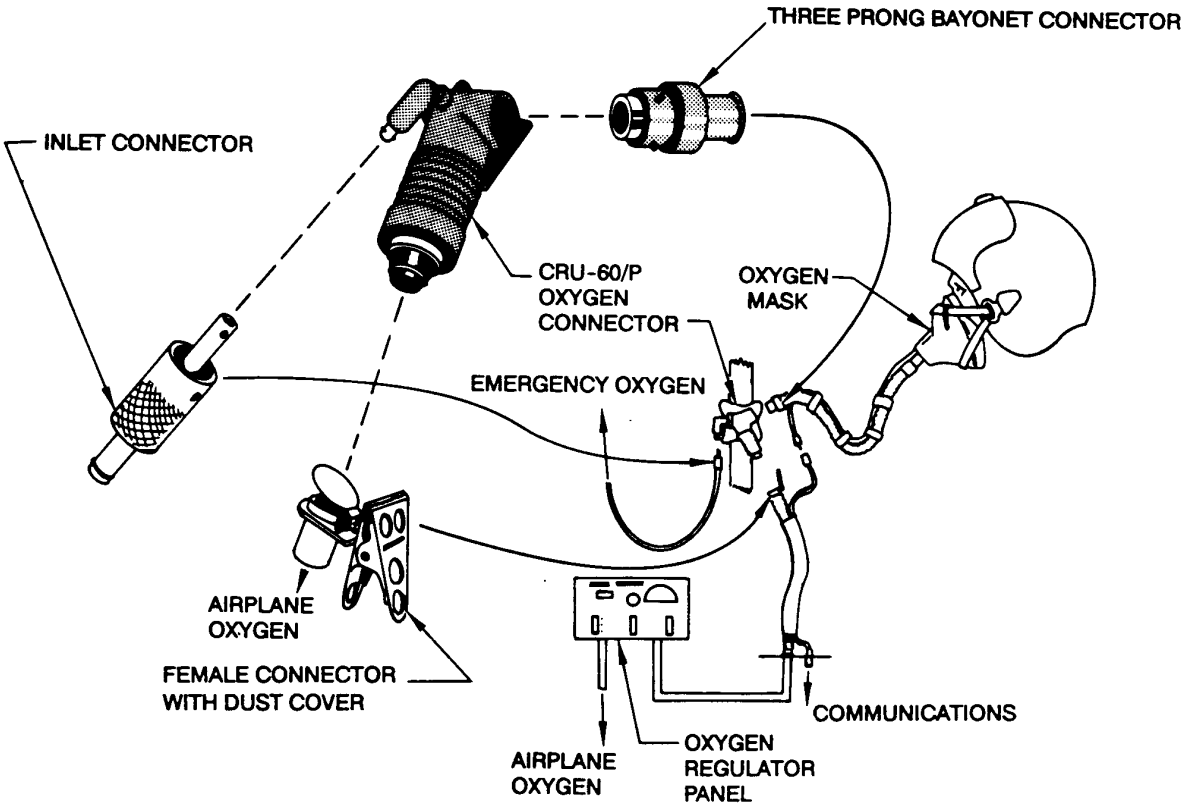


FIGURE 37. CRU-60/P oxygen connector arrangement.

B.2.15.1.1 MBU-5/P pressure demand oxygen mask.

The MBU-5/P mask has been the standard USAF pressure-breathing oxygen mask (see *figure 38*), but its use in aircraft is being phased out and replaced by the MBU-12/P mask. The main components of the MBU-5/P are the face form, hard-shell body, combination inhalation-exhalation valve, harness strap assembly and retention devices, and the oxygen delivery tube assembly. The mask is lightweight with a face piece molded of silicone rubber for comfort and maximum service life. The hard-shell is a semi rigid plastic material and the 17.5 in. (44.5 cm) delivery hose is silicone rubber. 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 high impedance M-100/AIC microphone is used with, 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 retain positive pressure and 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 harness mounted connector

for use with emergency assembly.

The mask is manufactured in four sizes: short narrow, regular narrow, long narrow, and regular wide. It can be used with the CRU-8/P or CRU-70/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. Detailed information on the MBU-5/P mask is contained in *MIL-M-27274*.

B.2.15.1.2 MBU-10/P pressure demand oxygen mask.

The MBU-10/P quick-don oxygen mask is a pressure demand oxygen mask which uses the MBU-5/P mask assembly held in a quick don suspension assembly to facilitate its rapid donning. The device enable a crew member without a helmet to rapidly don a oxygen mask in the event of an emergency decompression. These are most often used on transport type and special mission aircraft with a cabin pressurization schedule that does not allow a cabin to routinely go above 8,000 feet and the crew member is in a shirt sleeve environment. The USAF is phasing out this mask and replacing it with the quick-don mask assembly, part no 358-1506V. This mask is still being used by the US Navy.

B.2.15.1.3 MBU-12/P pressure demand oxygen mask.

This mask (see *figure 39*) was designed as an improvement and replacement for the MBU-5/P crew member 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 were 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 face piece molded to a plastic hard-shell. This mask is becoming the standard equipment in USAF fighter and attack aircraft. The mask is also used extensively by the Navy and the Army. Further design information is included in *MIL-M-87163*.

B.2.15.4.1.4 MBU-20/P Oxygen Mask Assembly

The oxygen mask is part of the Combined Advanced Technology Designed G Ensemble (COMBAT EDGE) system and is required for Pressure Breathing for G (PBG). The oxygen mask contains separate inhalation and exhalation valves. The inhalation and exhalation valves are interconnected by a compensation tube. The compensation tube senses inhalation pressure and a portion is directed to the underside of the exhalation plate. This compensating pressure keeps the exhalation valve shut during inhalation. The exhalation portion of the valve is constructed so that a portion of the exhaled gas is vented through the compensation tube over the inhalation valve to keep it closed during exhalation. The pressure required for this is 1 mm Hg greater than the pressure of the oxygen being delivered from the regulator. Mask connection to the flyers helmet is accomplished using offset bayonet connectors that will interface with the current helmet receivers. A bladder supply hose connects the mask

assembly to the helmet bladder. The mask contains an M-169A microphone. Communication interfaces with the helmet and with the aircraft intercommunication system are the same as the current communications system configuration.

The mask is manufactured in four sizes: short narrow, regular narrow, regular wide, and large wide. In the USAF the mask is used with the CRU-94/P Integrated Terminal Block (ITB). In the Navy the MBU-20/P mask is also used with the CRU-103/P chest mounted, G-compensated oxygen reulator in the Navy COMBAT EDGE. The mask is also planned to replace the Navy MBU-12/P oxygen mask series and will be integrated with other Navy chest m ounted oxygen regulators types CRU-79/P, CRU-82/P and CRU-88/P.

The oxygen hose contains a nylon anti-stretch cord which prevents elongation during ejection. A three-prong push, turn and lock bayonet adapter connects the delivery tube to the ITB.

The ITB serves as the central interface for breathing gas hose, vest hose and emergency oxygen hose. It also has a pressure relief valve which provides system over-pressure protection for the aircrew member when the COMBAT EDGE counter pressure vest is not being worn or has been inadvertently disconnected. This will prevent the aircrew member from receiving excessive PBG when not wearing the vest, even if the CRU-93/A regulator selector switch is inadvertently left in the PBG position. The ITB provides a man/aircraft interface separation point during ground egress or ejection and is categorized as man side equipment, although it is stored in the aircraft. A dovetail fitting is used for attachment of the ITB to the torso harness. The ITB also contains a split ring quick disconnect with a disconnect warning device which warns that the crew member is disconnected from the oxygen source.

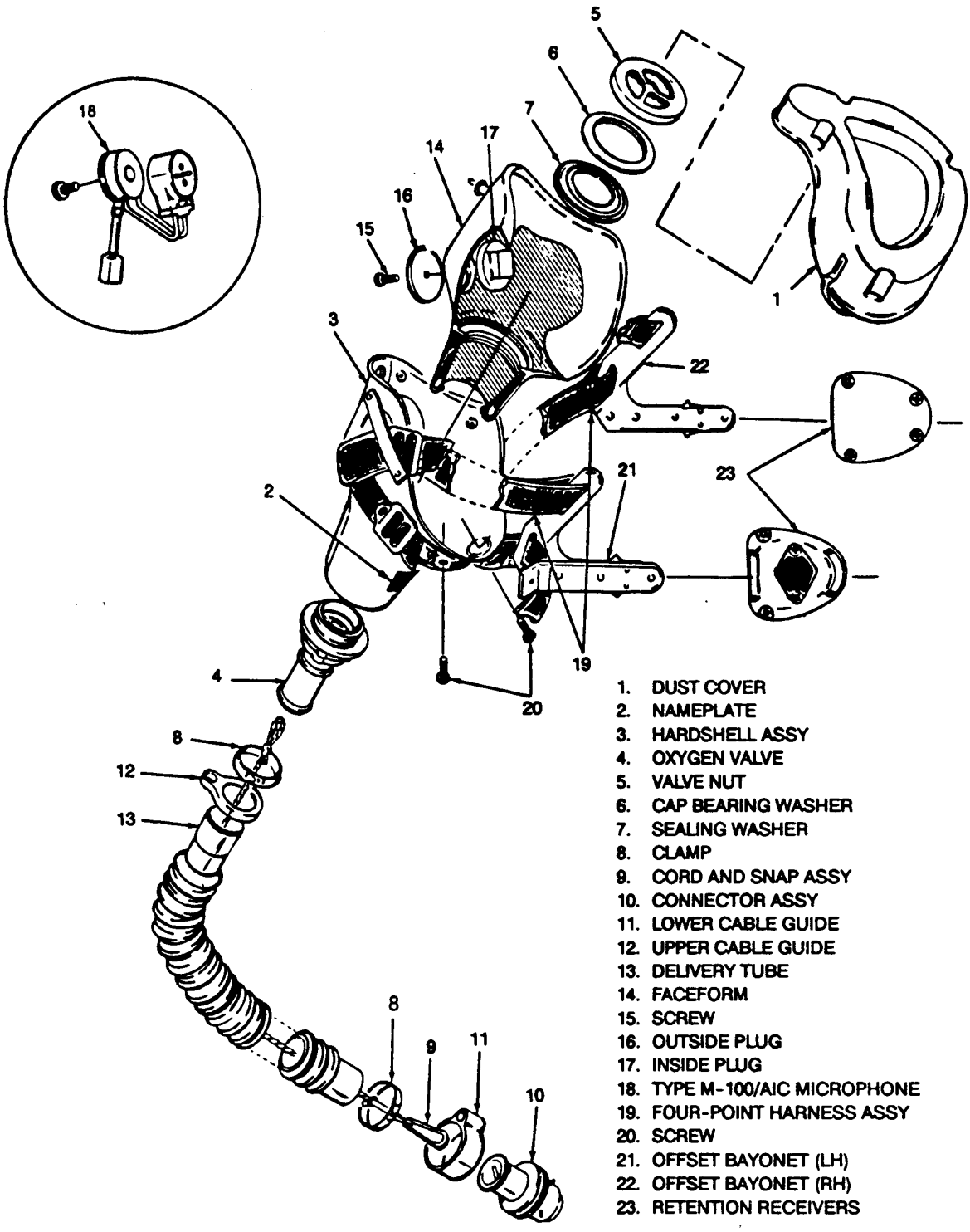


FIGURE 38. Type MBU-5/P oxygen mask assembly.

B.2.15.4.1.5 Quick-don mask 358-1506V.

The quick-don mask assembly, part no 358-1506V, is the new quick-don mask assembly used by the Air Mobility Command (AMC). This mask assembly is a variation of the commercial mask certified to FAA TSO C-78 and is used on large commercial jet aircraft which cruise at higher altitudes. This mask was procured due to the concern of smoke and fumes in the cabin. This mask is made with a needle valve at the top which will insert into eye goggles to allow pressurized oxygen to flush smoke from the crew member's eyes. The goggles, part number 322-70, are donned separately from the mask. Tests have shown this mask to be a considerable improvement over the older military smoke goggles as the time to don is considerably reduced. This assembly can be used for altitude protection only or smoke and fumes protection unlike earlier equipment which required independent oxygen masks and smoke masks and goggles. Also used with this mask are the quick release holding strap, 358-643C, and the dust cover, 00-5989.

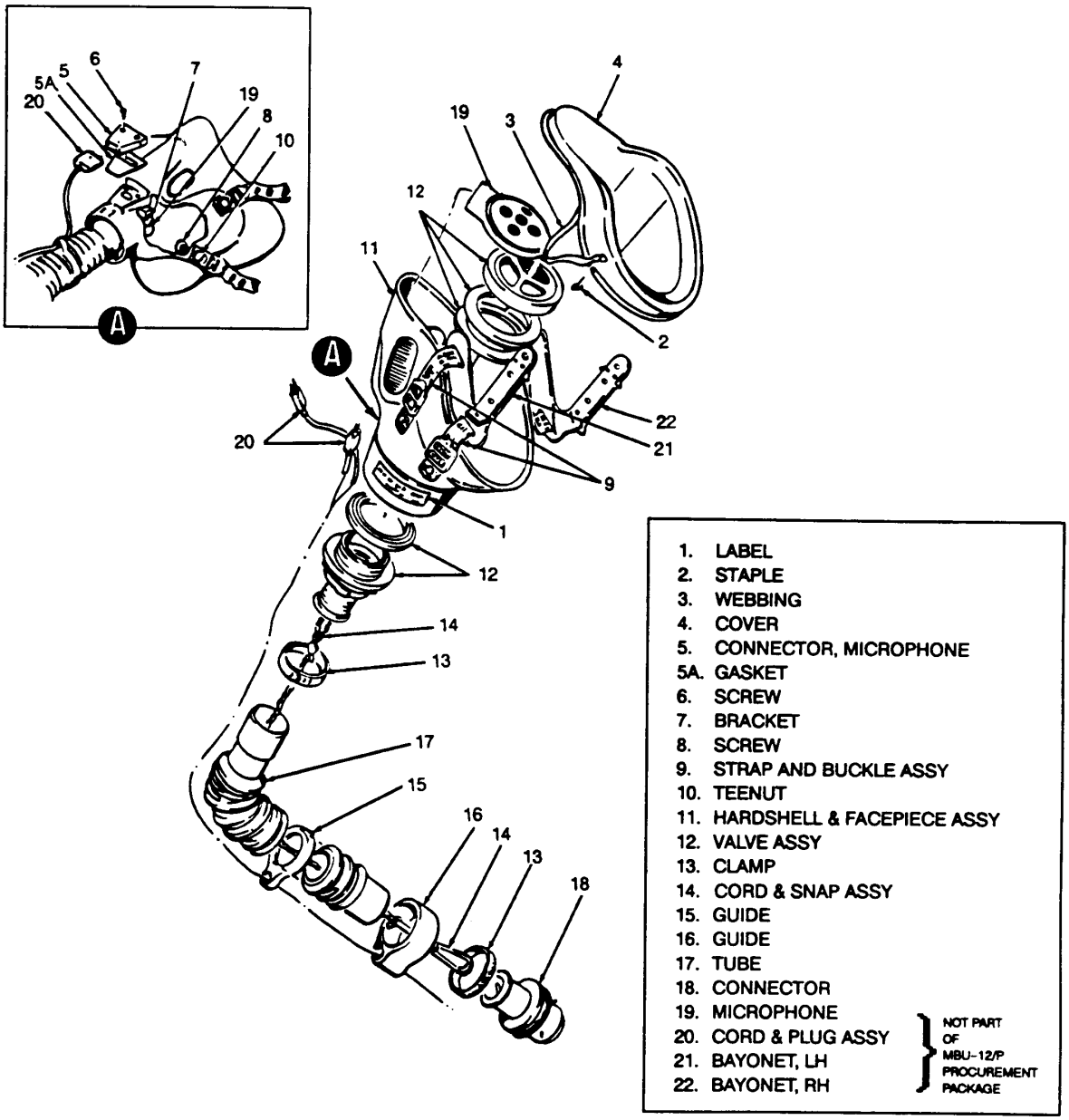


FIGURE 39. MBU-12/P pressure demand oxygen mask.

B.2.1.5.5 Breathing hose assembly.

When using a pressure demand mask, a delivery tube which passes oxygen from the regulator to the mask is needed. With larger hoses in use in the USAF and Navy transport aircraft, a spring clip or retainer strap is available to attach the tube to the crew member's clothing or to the aircraft structure when not in use. This feature takes the weight of the delivery tube off the

oxygen mask. The delivery tube may be stowed by attaching the spring clip to the cloth tab provided or to the aircraft structure at the flight station. On aircraft equipped with ejection seats, the delivery tube is routed through the automatic separation of the oxygen hose and other personal leads when the ejection seat is fired so that the disconnection force is not applied to the crew member. *Figure 40* shows a typical oxygen hose assembly and related personal services for an ejection seat-equipped aircraft. Stations supplied by *AN 6010-1A* 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 should be avoided, 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 hoses which are ozone-resistant and suitable for use with air or breathing oxygen are in *MIL-H-26385* and *MIL-H-81581*. The *MIL-H-26385* hose is a low pressure type without convolutes and is stiffer and more rigid than the *MIL-H-81581* type. Its use is encouraged where possible. When routing and stowage requirements necessitate a more flexible breathing hose, the *MIL-H-81581/5* hose is recommended. In USAF applications, the *MS 22055* or equivalent hardware is used at the end fittings to be compatible with existing equipment. *MIL-H-81581* covers many types of high and low pressure oxygen hoses primarily used by the Navy.

B.2.15.6 Personal leads disconnects and oxygen equipment connectors.

When using a pressure demand mask, the personal leads automatic disconnects provide the best operation during ejection. The disconnects separate with a pull of at least 12 lbf (53 N) but less than 22 lbf (97 N). Personal leads are routed for minimum interference with crew duties.

When using a pressure demand mask, the combination harness-mounted connector (CRU-60/P) is used 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 and 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 crew member. 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*, *MS 22055*, and *MS 22058*.

The CRU-43A/A (*MIL-A-27471*) model oxygen equipment connector adapts the high altitude seat-kit oxygen systems to a standard pressure-breathing oxygen mask such as the MBU-5/P or MBU-12/P. These adapters include a pressure-reduction mechanism to change the helmet pressure delivered by the seat-kit regulator to a pressure which is compatible with the MBU-5/P oxygen mask. The flow capacity is insufficient for prolonged use above 30,000 ft (9,144 m), so that an immediate descent to 30,000 ft (9,144 m) or below is mandatory if cabin pressure is lost while using these adapters. Further information on the CRU-43 A/A is contained in *MIL-A-27471*.

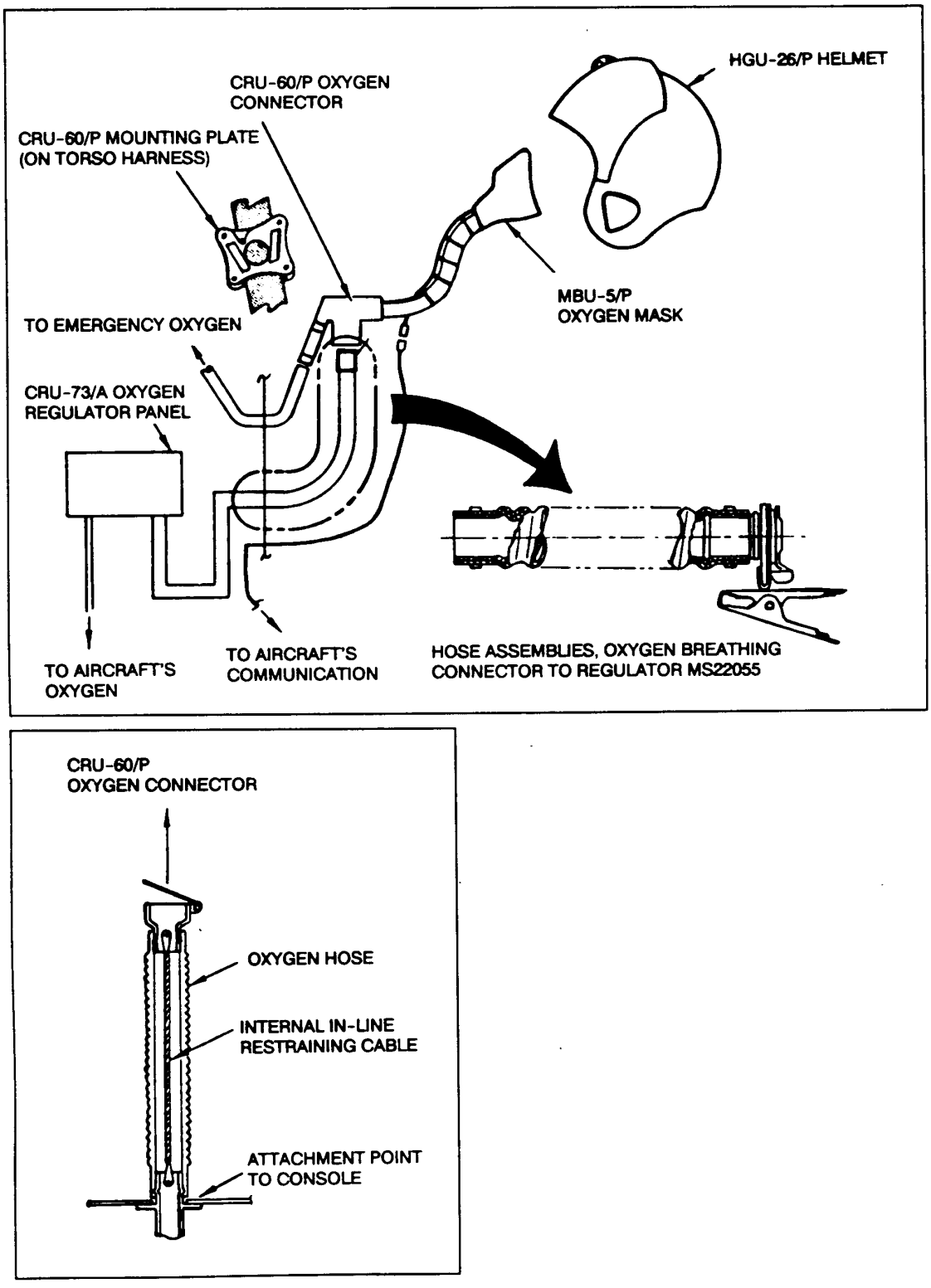


FIGURE 40. Typical oxygen hose assembly with hose cutaway shown at left.

B.2.15.7 Continuous flow mask assemblies.

This mask assembly is the recommended passenger continuous-flow equipment (see *figure 41*). 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 (not to be confused with a rebreather bag) which is attached to the face piece of the mask. When fully inflated, the bag contains about $^{1}/_{2}$ liter (pint) of oxygen (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 face piece admits atmospheric air. This enhances the partial pressure of the alveolar by increasing the volume of gas in the lungs. However, because the valve will admit smoke to the lungs in a smoke-filled cabin situation, this mask assembly is not a suitable smoke protection breathing assembly. 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.

It should be remembered that this mask, when attached to an aircraft breathing system, receives decreasing oxygen flow from the aircraft regulator at lower altitudes until no oxygen flow is received at about 10,000 feet or lower. More and more cabin air must complement the lungs' tidal volume at lower altitudes. This is physiologically sound assuming a smokeless environment and conserves aircraft oxygen supply. As such, the weight of oxygen supply may be minimized.

a. The oxygen mask stowage unit is located 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. Instructions for donning and using these units must be readily available.

c. A retaining strap for holding the mask in place is provided.

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 Part 25*).

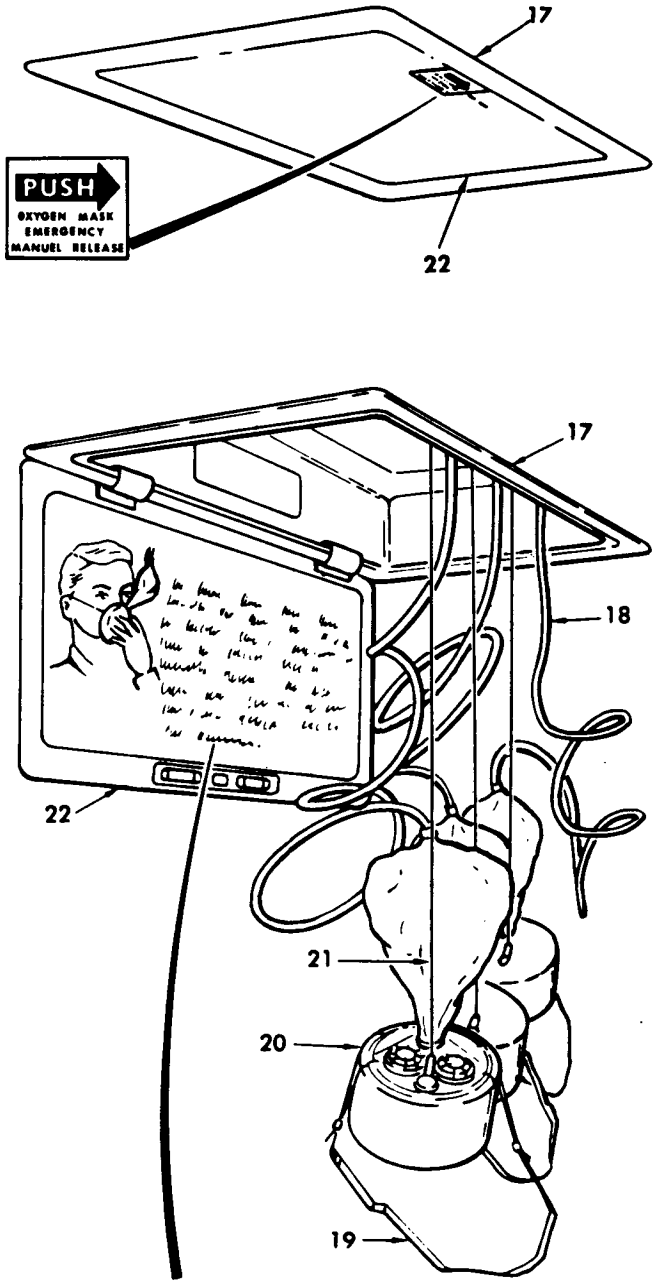
f. Deployment of the mask should not be obstructed by surrounding or adjacent equipment.

g. The oxygen outlets for passengers in transport aircraft may have automatic couplings in accordance with *AN 6009* or a commercial equivalent. One automatic coupling for each passenger station on the aircraft should be provided and located in a readily accessible location so it will be possible to connect the mask easily while in flight. The coupling should be mounted flush with the aircraft interior lining not more than 42 in. away from the passenger when in his seat sitting erect or reclined. The couplings are usually installed so that the outlets point downward no more than 90 degrees off the vertical. Temporary passenger stations, such as lavatories, should also have automatic couplings that are connected to the passenger manifolded oxygen supply.

h. Commercial continuous flow oxygen masks of this type are designed and certified to FAA TSO C-64.

B.2.15.7.1 Quick donning emergency oxygen masks.

Also for application in passenger, aeromedical, and troop aircraft, commercial oxygen mask assemblies may be used for manual donning. The supply source may be a chemical oxygen generator, a LOX converter, or a 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 should be used to hold the mask assembly to protect it from dust, humidity, sunlight, and personal abuse. Locating the supply above or in front of the passenger is more desirable than locating it 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-restraining strap, and suitable oxygen flow rates are provided for these masks. Presently, the continuous flow mask assemblies are widely used on USAF transport aircraft with the 22 $in.^3$ bailout assembly. This bailout bottle stores oxygen gas at 2150 psig and the flow controller initiates oxygen flow at about 11 liters per minute and decreases rapidly to lower flow rates in seven minutes. These are called passenger oxygen kit (POK) assemblies.



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 41. Commercial-type continuous flow passenger oxygen mask assembly shown in a typical over head storage container installation.

B.2.15.7.2 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. A mask is provided for each crew member in case of fire, smoke, or fumes within the cockpit. The mask is stored in an easily accessible place in the headrest area (see *AFGS-87235A*).

B.2.15.7.3 Aeromedical passenger and patient mask assemblies.

Oxygen masks for passengers and transported hospital patients are either permanently installed or carry-on disposable which are normally not part of the personal equipment. The commercial type continuous flow oxygen mask is the passenger mask which is commonly used. Oxygen masks used to provide emergency oxygen to patients and medical crew deploy automatically. Provisions are made for maintaining proper oxygen mask placement for incapacitated patients' walk-around oxygen assemblies and the medical crew. The aeromedical oxygen requirements for patients and medical crews are also covered in *AFSC DH 2-2*, DN 6A4.

B.2.15.8 High-altitude breathing assemblies.

Survival at altitudes above 50,000 feet requires that an artificial pressure environment compatible with human existence be provided. Pressure garments have been developed to protect crew members in the event of exposure at high altitude, either through loss of cabin pressurization or during 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. 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 above 50,000 feet altitude is required. Also, they are used for missions over 25,000 feet, as in the case of a cabin depressurization where it would be impossible to immediately descend to a point at which cabin pressure could be maintained at or below 25,000 feet.

B.2.15.8.1 Breathing mask assembly development considerations.

The development of any new mask assembly, crew or passenger, involves many important design considerations. 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. Many factors must be considered in the selection of materials for the assembly. Materials must be of a type, grade, and quality which experience and/or tests have shown to be suitable for the intended purpose. Materials must not be used which contaminate oxygen nor should they 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, storage deformation, shatter, skin reactions and environmental extremes. *SAE AS 8026* contains important design detail considerations and additional references.

Materials which contact 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 crew member masks and special consideration for passenger masks and firefighter's full face masks which are designed to fit all potential users with one size. Anthropometric survey information is available for male and female military and commercial personnel. With good and proper fit of the face piece, leakage should be minimized, and the capability of the mask to provide respiratory protection should be enhanced. For fighter aircraft mask design, the center of gravity of the mask should be as close to the face as possible without adversely compromising design considerations to ensure a good face seal even under high G maneuvers. Should the mask be designed to function with positive pressure breathing for increased G protection, the mask internal volume should be minimized to preclude the mask parting from the face with high internal pressures. A mask tensioning device to minimize mask leakage and a counter pressure garment to counter the high pressures of gas in the lungs are desirable. For commercial and transport mask designs, special consideration is necessary for enabling the user to quickly don the assembly. New transport type quick donning masks incorporate eye goggles in combination with an out flow valve that provides oxygen gas pressure to the goggles to keep smoke and fumes from the eyes. Inhalation and exhalation breathing resistance in the mask should be minimized. Inhalation, exhalation, and pressure swings should be baselined against the MBU-12/P and MBU-13/P for chemical defense type masks. The breathing resistance should be no worse than these masks, and every attempt should be made to improve these masks.

B.2.15.9 Portable oxygen system.

Many situations require a short duration of oxygen supply when crew members and/or passengers are not able to use the main aircraft oxygen supply. One situation is when the crew member must move about an aircraft cabin that is decompressed (at an altitude above 10,000 feet) or is smoke-filled. Another situation is when extra personnel are on the aircraft and access to the aircraft oxygen supply is limited because all outlets are in use by other crew and passengers. The extra personnel may breathe from a portable oxygen system. Portable oxygen supply is also needed in situations in which the crew and/or passengers must eject or parachute from the aircraft.

B.2.15.9.1 Portable oxygen system, high pressure type.

When a portable oxygen breathing system is required, but refilling during use is not contemplated, the oxygen assembly is usually selected in accordance with *MS 22059*, *MS 22061* or USAF Drawing *60D3570*. High pressure portable assemblies store oxygen gas at about 1800 psig to 2150 psig 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 on-board recharge or refill capability. An advantage is the extended time of supply that may be provided (as much as 2-3 hours). Commercially available assemblies may be provided if all essential features are included.

B.2.15.9.2 Portable oxygen system, low pressure type.

In transport-type aircraft where extended flight is required in the 10,000 to 25,000 feet altitude range while the aircraft is not pressurized, low pressure portable walk-around assemblies that fill up to the 300-400 psig 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 crew members 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 (*MS 22032*), usually available at each flight station and latrine, consists of a flexible hose (*MS 24548*) with a standard *AN 6024-5* 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, the flow meter is set to read at least 5,000 feet above the indicated altitude. After use, the regulator valve is turned off. The *SAE AS 1046* contains general design information on portable oxygen equipment.

The most commonly used portable low pressure assembly in the USAF now is designed according to USAF Drawing *53C3794* and consists of an A-21 (*MIL-R-7605*) regulator and an *MS 21227-1* metal cylinder. The A-21 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 five minutes at sea level. It does not have a diluter valve.

When a portable oxygen breathing system is required along with refilling during flight, the oxygen assembly shall be in accordance with Drawing *53C3794* for crew use with their pressure breathing oxygen masks, or in accordance with Drawing *53D3970* if the full face pressure breathing smoke mask is to be included. Each assembly shall be secured in a bracket in accordance with Drawing *44B24627* which will retain the assembly under flight conditions and provide for rapid removal for use. The secured assembly shall be convenient to the crew duty stations and to each toilet. Recharging hoses in accordance with *MS 22032* shall be accessible from crew duty stations and toilets and have the filler valve end secured by a clip conforming to Drawing *46AI6236* in a vertical, valve down position.

B.2.15.9.3 Aircraft firefighter portable system.

These assemblies may be either low or high pressure type. The low pressure type typically used consists of an A-21 regulator and an *MS 21227-1* cylinder per USAF Drawing *53D3970*. The high pressure type is not commonly used in USAF aircraft, but may be acceptable provided all essential features are included. These units may be heavier and cannot be recharged on board the aircraft. Also, each 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. The USAF full face smoke mask is shown in USAF

Drawing *53D3970*. The US Navy full face smoke mask is in accordance with *MIL-M-19417*. Type I is a mask assembly with hose assembly (*MS 90339-3*) and connector (*MS 22016*). Type II is a mask assembly with hose assembly (*MS 90339-2*) and connector (USAF Drawing *55B3509*).

B.2.15.9.4 Chemical oxygen generator portable system.

The chemical oxygen portable assembly has been available for many years in commercial aircraft, but has had limited use in military aircraft. The main disadvantage of this assembly is that a continuous mode of breathing is provided rather than pressure demand. During 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 perform satisfactorily in this situation. However, new design concepts incorporate plenum chambers that allow a larger volume of oxygen to be inspired on inhalation and the plenum to be filled on exhalation. These assemblies are small and reasonably lightweight. With the advent of smoke protection designs, chemical oxygen generator portable assemblies are finding wider application and acceptance in military aircraft oxygen systems. A small, lightweight chemical generator is used in conjunction with a flexible smoke hood that is clear in the front for visibility. When donned and activated, the chemical generator is located at the back of the neck.

B.2.15.9.5 Emergency egress portable oxygen system.

A seat pan, backpack, or seat-mounted emergency oxygen supply is provided for ejection seat equipped aircraft. The oxygen supply activates automatically upon high altitude seat ejection to support the crew member as required at altitudes above 10,000 feet. Navy aircraft require an oxygen supply that will enable the crew member egress under water from a crashed aircraft; therefore, the oxygen is supplied through a closed system. USAF designs have not incorporated such closed systems. A harness mounted connector (CRU-60/P or similar device) allows additional ambient air supply to supplement and extend the oxygen supply. The position and configuration of the emergency oxygen supply is determined by the type of ejection seat configuration. In non-ejection seat bomber and transport aircraft, an emergency escape capability by parachuting may be provided. Most electronic surveillance type aircraft provide this capability with bailout chutes through the aircraft floor and fuselage. Emergency oxygen supply is necessary for bailout above 10,000 feet. Emergency oxygen supply is also provided for high altitude troops that parachute from transport aircraft. In these cases, the emergency oxygen supply is mounted to the parachute backpack or harness. For special forces high altitude parachuting, sometimes it is mounted to the man's clothing.

B.2.15.10 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, such as flow indicator and malfunction information, is useful. Also, controls are needed depending on the situation to select the proper operation of the breathing regulator.

B.2.1.5.10.1 Oxygen quantity information for LOX supply.

LOX quantity indicators show in liters the amount of liquid oxygen in a converter. The normal loss or loss by puncture of a converter will be indicated directly by its quantity gage. The indicator(s) may differ in type according to liquid oxygen capacity and operating pressure of the converter. In a multiplace aircraft, a quantity indicator should be installed at the pilot's or co-pilot's station for level of supply of each converter to permit monitoring of the total aircraft oxygen supply. Repeater indicators may be provided at the station of the crew member responsible for oxygen. Some aircraft installations will have quantity indicators only at the flight engineer's station, but a mission analysis should be accomplished to ensure these indicators are not needed at the pilot's and/or copilot's station. In most installations the indicators are within normal vision of the crew member. Liquid oxygen quantity indicators are designed to conform to *MIL-I-25645* or *MIL-I-81387*, as applicable. Liquid oxygen quantity indicator repeaters are provided in accordance with *MIL-I-25645* or *MIL-I-81388*, 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 as discussed in *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 connected 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, and the readout is in liters 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*. 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 insertion of the dummy converter produces an “empty" reading on the indicators 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 and 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. In past installations, low-level caution lights have been provided adjacent to the quantity indicators. When illuminated, the light indicates that the oxygen quantity indicator has sensed that the quantity of liquid oxygen in the converter is low, usually at and below 10 percent of full scale.

Additionally, the low pressure warning light should be activated when the converter system pressure drops to 42 2 psig (290 14 kPa). For each station in a 70 psig (483 kPa) oxygen

system, the pressure sensor shall be located downstream of the on-off valve. If an oxygen regulator in accordance with *MIL-R-83178* is used, the pressure sensor shall be located upstream of the regulator. The momentary drop in supply line pressure upon inhalation should not activate the low pressure warning.

f. Press-to-test. A press-to-test switch in accordance with *MIL-S-8805/3* should be located near each liquid oxygen quantity indicator. This switch should allow the indicator to be functionally checked.

g. Quantity indicator installation. The installation wiring of the indicator is defined by its detailed 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, quantity indication is provided to show the quantity of each liquid oxygen converter aboard the aircraft. Each indicator is located to be readily visible to the pilot. One or more liquid oxygen converters may be provided.

(2) On side-by-side pilot (two-place) aircraft, quantity indication is provided to show the quantity of each liquid oxygen converter aboard the aircraft. Each indicator is located to be readily visible to both crew members. One or more liquid oxygen converters may be provided.

(3) On tandem-pilot (two-place) aircraft, an indicator set, consisting of master and repeater indicators, is provided to show the quantity of each liquid oxygen converter aboard the aircraft. Each indicator is located to be readily visible to each crew member. One or more liquid oxygen converters may be provided.

(4) On bomber, cargo, or transport aircraft, quantity indication is provided to show the quantity of each liquid oxygen converter aboard the aircraft. Each indicator is located to be readily visible to the copilot or systems engineer. One or more liquid oxygen converters may be provided.

Total quantity indicators - For US Navy application, a total quantity indicator shall be installed at the pilot's or copilot's station of the aircraft in which more than one converter is installed. This will permit monitoring of the total aircraft oxygen supply. Repeater indicators shall be provided in all isolated flight compartments within normal vision of one crew member. Liquid oxygen quantity indicators shall be in accordance with *MIL-I-81387* or *MIL-I-25645*, as applicable. Liquid oxygen quantity indicator repeaters shall be in accordance with *MIL-I-81388* or *MIL-I-25645*, as applicable.

Separate quantity indication - For USAF application, at least one quantity indication shall be provided for each converter installed on the aircraft. The procuring activity shall determine the most effective means of liquid quantity indication. This may be accomplished by the use of a separate indicator for each liquid oxygen converter or by the use of one indicator with a switch to select the indication of each converter. The indicator shall be correlated and labeled with the liquid oxygen converter that it applies to so that it may be easily determined which converter the indicator is used with. The quantity indicator (s) shall be installed at the crew station of the crew member(s) designated as responsible for the oxygen system (i.e., pilot, copilot, flight engineer, loadmaster.) Repeater indicators may also be provided in isolated flight compartments. If they are provided at other crew stations they shall be within visual range and readable by that crew member while seated. Other crew stations on large transport aircraft may be the flight engineer,

loadmaster, the head nurse or the flight steward station. Liquid oxygen quantity indicators shall be in accordance with *MIL-I-81387* or *MIL-I-25645*, as applicable. Liquid oxygen quantity indicator repeaters shall be in accordance with *MIL-I-81388* or *MIL-I-25645*, as applicable.

Since multiple LOX converter installations are not filled from a single filler valve, the person servicing the LOX converter needs to know which LOX converter to service. If only a total quantity indicator is provided, he will not know which converter to service. This can be critical in an environment where the turn-around time is limited. Normally, all other aircraft subsystems cannot be maintained while servicing LOX. In addition, there is no design standard nor existing LOX converter total quantity indicator available. Past USAF aircraft with multiple LOX converter installations using only total LOX quantity indicators, have been maintenance problems as numerous connections to LOX filler valves for converters already nearly full would require a disconnect and another connection to one of the other converters for filling. This not only increases the maintenance burden, but increases the risk of injury and/or a fire/explosion. On large transport aircraft sometimes there will be other crew members who need to monitor the aircraft oxygen system. Requirements are provided for these situations.

h. Gauging system requirements. The gauging system, when installed in the aircraft, indicates the amount of liquid oxygen in the converter within an accuracy of 2 percent of indication and 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*. All electrical components shall be protected from electromagnetic interference (EMI) and aircraft voltage power surges. 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 is provided between the indicator connectors so that they can be readily disconnected by servicing personnel. Storage for the aircraft connectors is provided when the converter is removed.

B.2.1.5.10.2 Pressure information requirements.

The following pressure information is provided on military aircraft.

a. Gages. Pressure gages are provided for low and high pressure oxygen systems. The pressure gages should indicate actual pressure in the subsystem. Pressure gages are installed at each permanent and temporary crew station in the aircraft only when non-panel-mounted regulators are installed. A pressure gage is also provided for the passenger oxygen system to be readily visible by a responsible crew member. In subsystems with 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. A puncture in one or more cylinders protected by check valves will not appreciably change the pressure reading as long as one intact cylinder remains connected to the manifold. However, the supply duration obviously will be reduced. The *AN 6021* (*MIL-G-6019*) pressure gage is used to indicate pressure in low pressure cylinders. This gage is usually installed at flight stations. The *AN 6011* pressure gages indicate oxygen pressure in high pressure cylinders installed in aircraft. A 500 psig gage is also incorporated in the panel face of the oxygen regulator (CRU-73/A).

b. 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 0.001 MPa (50 2 psig). 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-STD-411* has more details.

B.2.15.10.3 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 the quantity of oxygen flow or whether 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 into the panel face of the oxygen regulator (CRU-73/A). Flow information may be used to indicate to a crew member that the breathing regulator is functioning properly and that all appropriate connections are made. The lower sensitivity threshold should be incorporated in the indicator design so that a proper flow from the regulator may be indicated for breathing.

B.2.15.10.4 Chemical generator emergency oxygen supply indicators.

In the design of chemical generator emergency oxygen supply units, a visual means that does not require disassembly of the emergency oxygen supply or removal of the housing cap is provided for determining that the device has been ignited, used or expended. Temperature–sensitive paint or temperature-sensitive decals are two methods which may be used.

B.2.15.10.5 Breathing mode control.

These types of breathing mode controls are usually provided:

a. Air dilution. Air dilution control is provided for crew member oxygen regulation to reduce oxygen waste for flight at lower altitudes and to preclude the adverse effects to the crew member'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 such that with decreasing amounts of dilution air admitted into the mixing chamber of the regulator increasing percentages of oxygen occur in the inspired gas 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. Therefore, this mixing is accomplished automatically. On the CRU-73/A regulator, this control function is labeled “NORMAL OXYGEN."

b. One hundred percent oxygen. A control is normally provided for manual selection of 100 percent oxygen. This option is required for 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. If the air used for air-dilution breathing gas in chemical defense MSOGS breathing delivery components is filtered, 100 percent oxygen is not required. However, it would still be desirable to allow the operator to select 100 percent slight positive-pressure breathing to ensure the crew member has adequate physiological protection during combat

maneuvers and in the event of hypoxia symptoms. On the CRU-73/A regulator, this control function is labeled “100% OXYGEN."

c. Test mask. A control is provided for 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. On the CRU-73/A regulator, this control function is labeled “TEST MASK."

d. Emergency oxygen. Conditions may arise in flight where increased positive pressure breathing is required to reduce or eliminate the effects of hypoxia. For this situation, increased pressures of 100 percent oxygen are needed. On the CRU-73/A regulator, this control function is labeled “EMERGENCY."

B.2.15.11 Communication equipment, personal mounted.

Personal mounted communication equipment must be compatible with personal mounted oxygen equipment. On fighter aircraft, the microphone is within the mask assembly, the headset is in the helmet, and the communication cords and plugs are routed along the oxygen hose. Good communication equipment permits effective coordination between crew members of one fighter aircraft to another; among crew members of transport aircraft; among crew members in aircraft formation; and between aircraft and traffic control stations or essential ground observers. Because of distances between crew positions, the separation of positions by equipment or aircraft structures, the noise level, and the use of oxygen masks or protective helmets, direct speech is impossible in most situations. Further communication problems result from low ambient pressures in unpressurized or partially pressurized aircraft flying at high altitudes. At these conditions, the human voice, earphones, and loud speakers become less effective at propagating sound to the human ear. Also, microphones become less sensitive at certain frequencies as the ambient pressure is reduced.

Personal mounted headsets and microphones must be compatible with existing types of voice communication equipment. The following are standard USAF communications equipment:

a. HF radio (2 to 29,999 MHz) is normally used for voice communications over medium distances.

b. VHF radio (30 to 75,999 MHz) is used in USAF aircraft for voice-FM communication facilities over line-of-sight distances.

c. VHF radio (117.775 to 149.975 MHz) is used exclusively in commercial aircraft and in some USAF aircraft for line-of-sight communications.

d. UHF radio (225 to 399.99 MHz) is standard equipment used in all USAF aircraft for line-of-sight communications.

e. Intercom equipment is used to maintain contact with crew members in nearby aircraft, to communicate in transport type aircraft, and to provide information to passengers.

The following sections give detailed information on the individual components of the communications equipment including headsets, microphones, headset-microphones, cables and disconnects, and loudspeakers. *Figure 42* shows how the equipment is configured.

B.2.15.11.1 Headsets.

Headsets are used when any of the following conditions exist:

a. Ambient noise levels are so high that ear-protective devices are required to protect the ears of the listener.

b. Different listeners must receive different messages.

c. Reverberation interferes with loudspeaker listening.

d. The listener must wear special equipment such as an oxygen mask and protective helmet.

e. The available electrical power is inadequate to operate a loudspeaker.

f. Ambient noise interferes with transmission intelligibility.

Performance, comfort, and durability are prime considerations in the selection of headsets. Frequency response and noise attenuation are important characteristics. The frequency response characteristic must be smooth and broad enough to cover the range of frequencies desired in the system. Because the cushions or sockets that hold the earphones influence the frequency response and affect the fidelity, earphone sensitivity, noise attenuation characteristics of the cushion, and comfort combinations must be considered to provide the best signal to noise ratio. However, sensitivity and comfort are not inherently compatible. The sensitivity of an earphone depends, in part, on the size of the cavity formed by the earphone and cushion about the ear. The smaller this cavity, the higher the sound pressure produced for a given power. A large, lightweight ear cushion is desirable to achieve comfort, but it is less effective in ambient noise attenuation. A compromise between performance and comfort must be made in accordance with each application. *Table XII* summarizes available earphones and headsets.

B.1.15.11.2 Microphones.

A microphone which has high sensitivity to acoustic speech signals, good transduction of the acoustic speech signal into an electric signal, and a good noise-canceling characteristic should be selected. Many microphones have desirable frequency-response characteristics, but few have the capability to discriminate between the talker's speech signal and the ambient noise levels. Therefore, selection of a microphone will depend on each application. For aircraft which require use of oxygen masks throughout the mission, the selection is normally limited to a microphone which can be incorporated into the mask. The microphone selection should be based on the inventory summarized in *table XIII*.

B.2.15.11.3 Headset-microphones.

For the shirt sleeve environment found in transport aircraft, trainers, and tankers not equipped with ejection seats and not requiring the use of oxygen masks except for emergency conditions, the microphone is normally attached to the crew member's helmet or is part of a headset-microphone assembly. The microphone is mounted on an adjustable boom which attaches to the left side of the helmet or headset. This arrangement provides hand-free communication in aircraft at altitudes not requiring an oxygen mask. The headset-microphone should be selected from those listed in *table XIV*.

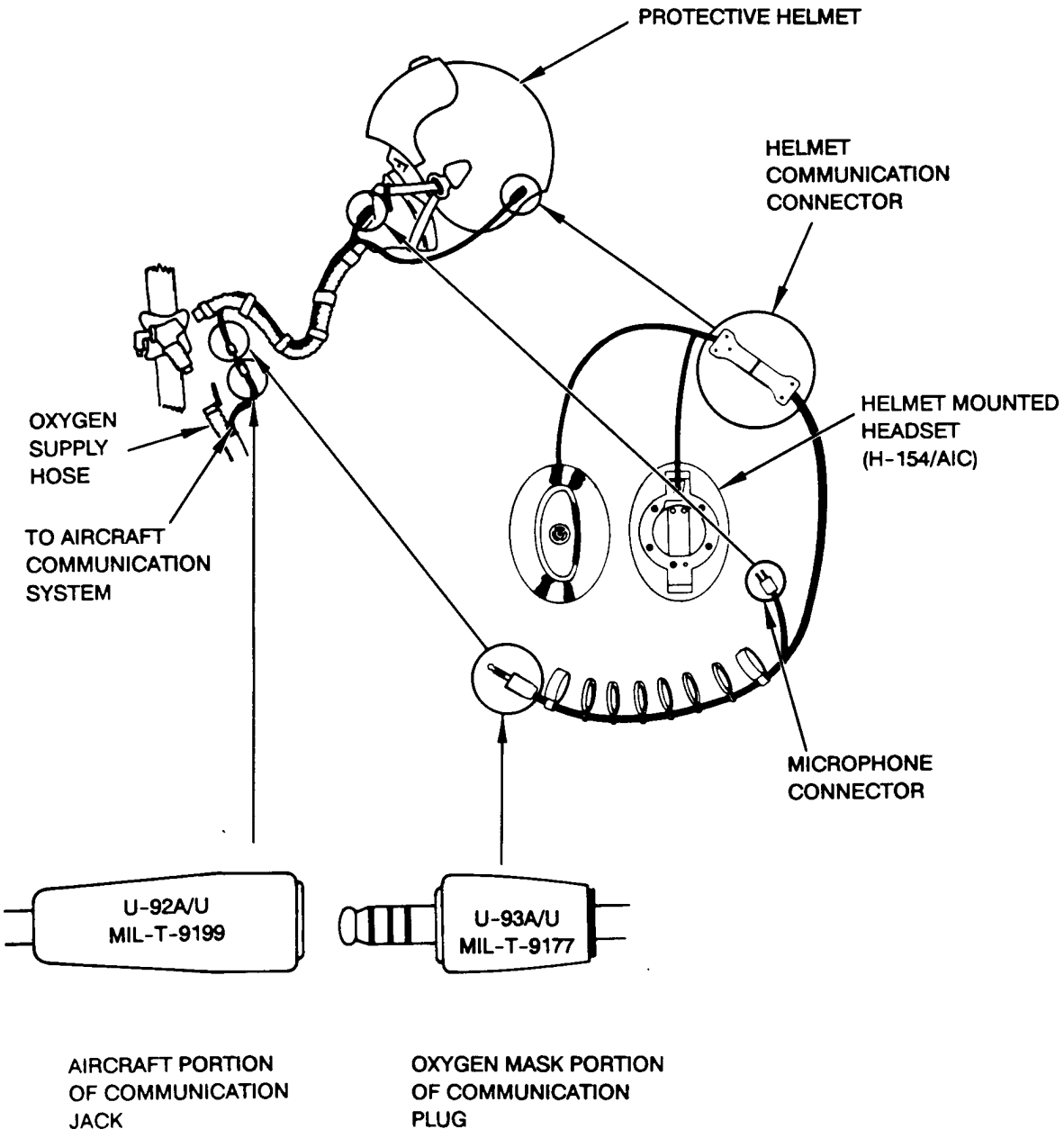


FIGURE 42. Individual component of the crew member's communication equipment.

TABLE XII. Earphones and headsets.

NAME AND TYPE	SPECIFICATION OR DRAWING	CHARACTERISTICS	APPLICATION	REMARKS
Earphone H-136/AIC	66B857	Moving coil, high output, 22.5 ohms impedance	H-133C/AIC	High sensitivity earphone used in headset by aircrew for ground-level maintenance and checkout
Earphone H-143/AIC	MIL-E-25670	Lightweight, moving coil, 19 ohms impedance, 105 dB sensitivity	H-154/AIC H-157/AIC H-158/AIC H-256/AIC	Used by aircrew in military aircraft in various headband and helmet headsets; used with AN/AIC-10 and AN/AIC-18.
Headset, Electrical H-154/AIC	MIL-H-27467	Helmet headset type, two earshells with H-143/AIC earphone in parallel, 10 ohms impedance	HGU-2A/P helmet	Used with flying helmet worn by aircrew in high performance aircraft and with oxygen mask microphone; used with AN/AIC-10 and AN/AIC-18.
Headset, Electrical pressurized H-158/AIC	MIL-H-26541	Two earphones on headband, earphone elements H-143/AIC in parallel, 10 ohms impedance		Used by aircrew at low altitudes or in cabins; used with AN/AIC-10.

B.2.15.11.4 Cables and disconnects.

Proper interfacing between the crew member's personal communication equipment and the communication system of the aircraft is a primary problem. The problem areas are usually associated with the personal service quick disconnects required during ejection in aircraft with ejection seats. Cable guides are used to attach the communication cable from the earphones and microphone to the oxygen delivery tube. The matching U-92A/U communication jack for the U-93A/U plug on the communication cable, the associated twisted, four-conductor, shielded pair cables, and the other hardware are provided to connect to the personal services control panel from this quick release point. See MIL-C-9177 for information on these communication jack and plug (U-92A/U and U-93A/U). This communication cable is integrated into an assembly with the oxygen hose and emergency oxygen hose. This self-contained assembly results in minimum snagging during routine use by the crew members. Care should be taken in routing these communication lines to provide strain relief on the cable at various cable interfaces. The

communication cable must automatically separate at the communication jack during pilot ejection from the aircraft and during ground egress. Proper cable routing and positioning of the jacks will ensure that the connection disconnects on seat ejection. 8 2 lbf (35.6 8.9 N) has been used successfully.

TABLE XIII. Microphones

NAME AND TYPE	SPECIFICATION OR DRAWING	CHARACTERISTICS	APPLICATION	REMARKS
Microphone M-34/AIC	MIL-M-9472	Hand held, noise moving coil	Hand held	Used with AN/AIC-10. canceling
Microphone M26542/1-01	MIL-M-26542/1	New design headset assembly	Transport aircraft	Used with boom, CX-4434/U cord assembly and U-173/U plug assembly.
Microphone M-87/AIC M26542/2-01, -02, -03	MIL-M-26542/2	Noise canceling moving coil	Oxygen mask or helmet	Used with AN/AIC-10. altitude
Microphone M-100/AIC	MIL-M-26542/3	Uses M-101 element and MT-2189 mounting bracket.	Used with oxygen mask.	Used with AN/AIC-10 and AN/AIC-18.
Microphone M-101/AIC	MIL-M-26542/4	Dynamic, moving coil noise canceling	M-100/AIC M-102/AIC M-103/AIC H-133/AIC	Used in various mountings in oxygen mask microphone; used with AN/AIC-10 and AN/AIC-18.
Microphone M-102/AIC	MIL-M-26542/5	Dynamic with M-101 element and MT-2190 mounting bracket	Used with oxygen mask.	Used with AN/AIC-10 and AN/AIC-18.
Microphone M-103/AIC	MIL-M-26542/6	M-101 element, MT-2191 mounting bracket	Used with oxygen mask.	Used with AN/AIC-10 and AN/AIC-18.
Microphone M-94 B/A	MIL-M-26542/7	Weighs 1.5 oz.	Used with oxygen mask.	Used with U-173/U plug.
Microphone M-116( )/G	MIL-M-26542/8	Dynamic, moving coil, noise canceling		Used with JJ-055 plug assembly, microphone low weight—18 grams.
Microphone	MIL-M-26542/9 M-133/U	Dynamic, moving coil, noise canceling	Transport aircraft	Used with boom, P/N M22442/36-5 cord assembly and U-173/U plug assembly.
Microphone M-138/G	MIL-M-26542/10	Moving coil, noise canceling.	On headset assembly	Used with boom, M22442/38-1 cord assembly and U-173/U plug assembly.
Microphone M26542/11-01	MIL-M-26542/11	Dynamic, headband-type headset	Transport aircraft	Used with boom, M22442/36-3 cord assembly and U-173/U plug assembly.

Microphone M-169/AIC	MIL-M-26542/12	Dynamic (5 ohms), noise canceling	MBU-12/P oxygen mask	Used with AN/AIC-1( ) and AN/AIC-8.

TABLE XIV. Headset-microphones and adapter

NAME AND TYPE	SPECIFICATION OR DRAWING	CHARACTERISTICS	APPLICATION REMARKS
Headset-microphone H-133C/AIC	66B818 66B819	Headset, ear protector type equipped with microphone M-101/AIC and earphone H-136/AIC	Designed for use by ground crew during maintenance and warm-up in high noise environment of jet aircraft; used with AN/AIC-10 and AN/AIC-18.
Headset-microphone H-157/AIC	MIL-H-26312	Headset-electrical H-158/AIC and microphone M-87/AIC on boom	Used by aircrew at low altitudes or in pressurized cabins; used with AN/AIC-10.
Headset-microphone H-256/AIC	Roanwell Corp. spec 3691 dwg 108110	Helmet type, microphone 108500, earphones H-143/AIC connected in parallel, 10 ohms impedance	Used in hard hat by aircrew of high altitude cargo and passenger aircraft; designed for use with quick-don oxygen mask; used with AN/AIC-10 and AN/AIC-18.
Headset-microphone MK-896( )/AIC	MIL-H-55582	Helmet type microphone M-87, earphone H-143, 10 ohms	Used in protective flying helmet by helicopter crew used with AN/AIC-10.
Adapter, headset-microphone MX-1646( )/AIC	MIL-A-8416	Adapter-amplifier input is 8 ohms, 600 ohms output; Earphones-microphone input is 4 microvolts, output is 500 millivolts.	Adapts low impedance dynamic headsets and microphones to equipment designed for use with 600-ohm headsets and carbon microphones; used with AN/AIC-10.

B.2.15.11.5 Loudspeakers.

Loudspeakers are used as part of the communication system when:

a. Ambient noise levels are relatively low and special protective equipment is not worn.

b. Headset cables are impractical because listeners must move around.

c. The message is intended for a large number of listeners.

d. Emergency, warning, or alerting signals must be received by personnel not wearing headsets.

When installing the equipment, the signal strength, sensitivity, bandwidth, and distance must provide an adequate signal-to-noise ratio at the listener's ears. Also, reverberation and echoes caused by reflection off the aircraft structure should be considered.

B.2.16 EXISTING TEST PROCEDURES

B.2.16.1 Existing ground test procedures.

B.2.16.1.1 Test conditions.

Oxygen gas used in testing the oxygen system components conforms to *MIL-O-27210*, Type I (Gaseous) and the oxygen used in filling a LOX system conforms to *MIL-O-27210*, Type II (Liquid). Tests are usually conducted at the local ambient temperature and barometric pressure which are recorded at the time of test and inspection. This should be calibrated to the normalized conditions (NTP): 29.92 in. of mercury (101.2 kPa) and 70°F (21.1°C). Test instruments should be calibrated or adjusted according to their required usage in conducting individual tests.

B.2.16.1.2 Transfer equipment and servicing capability test.

When gaseous servicing is needed for test purposes, a gaseous oxygen trailer conforming to *MIL-T-26069* is used. A liquid oxygen storage tank conforming to *MIL-T-38170*, or another suitable military liquid oxygen servicing trailer, is used to service liquid oxygen systems. Transfer equipment hoses and connectors should be demonstrated to be capable of mating with the fittings provided for filling.

B.2.16.1.3 Visual examination.

The total aircraft installed oxygen system is examined to determine that it conforms to the applicable installation specification and drawings.

B.2.16.1.4 Leakage test.

The completed aircraft installed gaseous or liquid oxygen system including heat exchanger(s), distribution plumbing, valves, all breathing regulator connections and any other plumbing components are subjected to a gaseous oxygen pressure equal to the complete range of its operating pressure. If a removable LOX converter is installed, it is excluded from the test. With

any included pressure relief valves, the pressure is increased to its setting at which relief of pressure should occur to determine it properly functions. While this test pressure is maintained, all fittings and connections are examined for leaks by application of a leak test compound conforming to *MIL-L-25567*. The system should not show any evidence of leaks. Care is taken to remove all traces of the leak test compound from the system after the test has been performed.

B.2.16.1.5 Functional tests.

A gaseous oxygen system is serviced to its operational pressure; a liquid oxygen system is permitted to build up to the designed operating pressure after filling. All regulator control and display functions should be checked, as well as quantity and pressure gages, and the low-level warning indicator.

B.2.16.1.7 Pressure decay test.

The complete system is charged with gaseous oxygen to the system operating pressure range. Removable converters (if installed) may be removed for this test. After the system pressure has been stabilized for 5 minutes, oxygen pressure (typically 70 psig for a low pressure LOX system and 300 psig for a high pressure LOX system), time, and distribution line temperature(s) are recorded. These parameters are recorded again after one-half hour and should not show a pressure decay for the entire system greater than 12 psig (82.74 pa) with a 5 liter converter, 6 psig (41.37 kPa) with a 10 liter converter, 3 psig (20.68 kPa) with a 25 liter converter, and 2.5 psig (17.24 kPa) with a 75 liter converter. If multiple converters are used, the pressure decay should be for the largest converter used and should not exceed the stated pressure decay even if more than one converter is used. The completed aircraft gaseous oxygen system should not have a pressure decay from a fully charged pressure greater than one-half percent per hour after four hours but less than 12 hours after servicing. Oxygen pressure, temperature, and times are recorded.

B.2.16.1.8 LOX evaporation loss test.

The completed aircraft LOX system is filled with liquid oxygen and the mating assembly is disconnected from the combination fill-buildup-vent valve. One hour after filling the system, a wax pencil may be used to mark the positions of pointers on glass faces of liquid oxygen quantity indicators. Twenty-four hours after marking the indicators, readings are taken from the indicators and the loss by evaporation is determined. Evaporation should be within the maximum limit of 1.3 liters loss from a 5 liter converter, 1.6 liters loss from a 10 liter converter, 2.0 liters loss from a 25 liter converter, and 3.0 liters loss from a 75 liter converter.

B.2.16.1.9 Electrical continuity test.

The liquid oxygen quantity indicator leads are disconnected from the LOX converter. A precision variable capacitor, capable of providing stable and precise electrical capacitance equivalents of empty and full liquid oxygen converters, are connected to the leads disconnected from the converter. With the capacitor set to provide zero quantity indication, power is applied to the indicator, and the capacitance input is recorded. The capacitor is then set to provide full scale quantity indication and the capacitance input is recorded again. The capacitance inputs

are to be within the limits specified in *table XV*.

If two or more converters are installed in an aircraft, the above test is conducted at each converter with the capacitor connected to the leads disconnected from one converter, as described above. All other oxygen quantity indicator leads in the system are disconnected from the converters and connected to the appropriate dummy converter.

TABLE XV. Indicator system capacitance.

Converter's Capacity (liters)	Converter Capacitance (pf) Empty	(pf) Full	(pf)
5	63.5 ± 0.4	92.5	± 0.4
10	123.5 ± 0.7	181.5	± 0.7
20	247.5 ± 1.4	363.0	± 1.4
25	303.5 ± 1.8	448.4	± 1.8
75	910.5 ± 5.4	1,345.5 ± 5.4	

B.2.17 Existing flight test procedures.

Aircraft flight tests using the newly installed or modified oxygen system are desirable. These tests determine the proper functioning of all oxygen equipment in the aircraft by actual crew use and functional measurements. Often the suitability of the proper arrangement of oxygen equipment items is determined by accessibility and convenience to all crew members during their flight duties. Upon completion of the flight tests, leakage and function tests are desirable. Leakage tests and functional tests should be accomplished as part of periodic maintenance; thus, the initial post flight testing may be an invaluable aid to determine technical order maintenance procedures.

B.2.17.1 Pilot's flight handbook technical order information.

Typically in an oxygen subsystem development program, schematic drawings and operating duration tables need to be developed for use in the pilot's and/or crew member's operational technical order.

B.2.17.1.1 Schematic drawing.

A schematic drawing of the oxygen system is needed for use in the pilot’s flight handbook in conformance with *MIL-M-7700* and in the maintenance manual in conformance to *MIL-M-38800*. The drawing should include a plan view of the aircraft and items which are given a symbol in *MIL-STD-17A*, Part 2. The drawing should also include the symbol key, where applicable, listing the type number of the items. Each converter on the drawing should be numbered to correspond with a readily visible number placed by each converter in the aircraft.

B.2.17.1.2 Pilot's flight operating duration tables.

Duration tables needed for the pilot's flight handbook, conforming to *MIL-M-7700*, should be provided. A conversion factor of 1 liter liquid oxygen equal to 860 liters of gaseous oxygen at 70°F (21.1°C) and 14.7 psig is used in the oxygen duration tables.

B.2.17.2.2 Flight test procedures needs for newly developed LOX systems.

Past experience has shown considerable problems in properly designs heat exchanging capability for newly developed LOX equipped aircraft. This is especially true for new designs such as COMBAT EDGE that increase oxygen flow tremendously over past designs and larger aircraft that have many crew members with pressure demand type regulators. The need exists for improved methods of calculating heat exchanger requirements with computer models and for additionally test data on new heat exchangers under consideration. After the best efforts have been expended to determine the properly sized heat exchanger another test method needs to be developed to measure on the ground and inflight if the heat exchanger will be adequate under conditions of high flows. The need also exists to locate a flow control device that may be installed just before the first outlet to dial in the high flows determined appropriate for the design and measure oxygen gas temperatures. It is desirable that the temperatures not be too cold at the first outlet. Methods to measure temperatures need to be established.

B.2.18 Maintenance handbook tech order information.

The proper maintenance procedures should be documented so that the aircraft oxygen system can be properly maintained. Procedures for normal versus trouble shooting maintenance actions should be determined. Often installation schematics are very useful and should be included.

CONCLUDING MATERIAL

Custodians:

Army - AV

Navy - AS

Air Force - 11

Review activities:

Air Force - 82, 99

Preparing activity:

Air Force - 11

(Project No. 15GP-0013-10)

STANDARDIZATION DOCUMENT IMPROVEMENT PROPOSAL

INSTRUCTIONS

1. The preparing activity must complete blocks 1, 2, 3, and 8. In block 1, both the document number and revision letter should be given.
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I RECOMMEND A CHANGE:	1. DOCUMENT NUMBER JSSG-2010-10	2. DOCUMENT DATE (YYMMDD) 981030

3. DOCUMENT TITLE
Crew Systems Oxygen Systems Handbook

4. NATURE OF CHANGE (Identify paragraph number and include proposed rewrite, if possible. Attach extra sheets as needed.)

5. REASON FOR RECOMMENDATION

6. SUBMITTER

a. NAME (Last, Middle Initial)	b. ORGANIZATION	
c. ADDRESS (include Zip Code)	d. TELEPHONE (Include Area Code (1) Commercial (2) AUTOVON *(If applicable)*	e. DATE SUBMITTED *(YYMMDD)*

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