INTERNATIONAL

AEROSPACE RECOMMENDED PRACTICE

ARP1398™	REV. A
Issued 1989-02 Revised 2000-11 Reaffirmed 2021-08 Superseding ARP1398	

Testing of Oxygen Equipment

RATIONALE

ARP1398A has been reaffirmed to comply with the SAE five-year review policy.

FOREWORD

Changes in this revision are format/editorial only.

1. SCOPE:

This ARP delineates requirements for system cleanliness, test gas supply system, test stand design, environmental chamber definition, instrumentation, dynamic test equipment and testing procedures.

1.1 Purpose:

The purpose of this SAE Aerospace Recommended Practice (ARP) is to establish or outline, or both, methods and procedures for use in testing oxygen equipment.

2. REFERENCE DOCUMENTS:

(Use current issue)

2.1 SAE Publications:

Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096

AIR822	Oxygen Systems for General Aviation
AIR825	Oxygen Equipment for Aircraft
ARP1109	Dynamic Testing System for Oxygen Breathing Equipment
AIR1176	Oxygen System and Component Cleaning and Packaging
AS8010	Aviators Breathing Oxygen Purity Standard

2.2 Other Publications:

MIL-STD-17B-2	Mechanical Symbols for Aeronautical, Aerospacecraft and Spacecraft Use
MIL-STD-167	Mechanical Vibrations of Shipboard Equipment
MIL-STD-810	Environmental Test Methods for Aerospace & Ground Equipment
MIL-E-4970	Environmental Testing, Ground Support Equipment, General Specification for
MIL-E-8189	Electronic Equipment, Guided Missiles, General Specification for
MIL-O-27210	Oxygen, Aviator's Breathing, Liquid and Gas
MIL-P-27401	Nitrogen Gas
BB-N-411	Nitrogen Gas
AFSC P 80-6	Laboratory Capabilities Pamphlet

AMERICAN NATIONAL STANDARDS INSTITUTE, INC.

S1.1 (1960 Issue)	Acoustical Terminology (including Mechanical Shock and Vibration)
NFPA 99	Health Care Facilities 1987, Standards for

3. GENERAL REQUIREMENTS:

3.1 System Cleanliness:

System and component cleaning and packaging should be accomplished as specified in AIR1176.

3.2 Lubrication:

3.2.1 Tape Type, Antiseize: Polytetrafluoroethylene tape conforming to MIL-T-27730A may be used as the antiseize lubricant only on pipe thread fittings and straight thread fittings for permanent type joints. It shall not be used on sleeve or flares of tubing connections.

3.2.1.1 Tape Application: The tape should be applied to the male threads, beginning with the second thread, by wrapping in the direction of the thread spiral and overlapping the end of the tape. When a joint is disassembled, the previously applied tape shall be removed and replaced with new tape on subsequent reassembly.

3.2.2 Compound Type, Antiseize: Only antiseize lubricant conforming to MIL-G-27617C (KRYTOX) shall be used on all joints that the tape type antiseize is not permitted, and may be used on joints that tape type antiseize is approved. Do not apply compound to the first two threads of tapered pipe threads. Do not apply compound to the nose section of AN fittings or flared section of matching tube.

CAUTION:

1. Lubricants such as Krytox must not be used with aluminum and light alloys under high shear. A serious explosion could result even with the absence of oxygen.

2. Due to the critical nature of cleanliness, lubricants should be used carefully and sparingly when working with oxygen systems and components.

3. Be certain that lubricants coming in direct contact with oxygen are compatible for oxygen service.

3.3 Test Gas:

The gas used in testing the unit shall be oxygen conforming to specification MIL-O-27210, AS8010, or water pumped nitrogen conforming to specification MIL-P-27401 (Type I), or nitrogen per BB-N-411, or air having the following purity levels:

Moisture:	Dew point of -70 °F (-57 °C) or lower
Hydrocarbons:	3 ppm maximum
Particles:	No greater than 25 μm in size

The concentration of particles in the 0.5-10 μm range shall not exceed 1000 particles per cubic foot and the concentration of particles in the 10-25 μm range shall not exceed 25 particles per cubic foot.

If nitrogen or air is used, calibration curves shall be determined for correcting flow data. These calibration curves shall be determined on the test setup by using oxygen and either nitrogen or air. The gases used during calibration shall conform to the above specifications. The correction factors determined by using the calibration curves shall then be applied to the subsequent test data.

3.4 Test Stand Design for Sea Level Ambient Temperature Testing:

3.4.1 General Layouts:

3.4.1.1 Test Stand Drawing Layouts: A pictorial drawing of the test stand face, and another of the backside (plumbing side) shall be provided. The backside pictorial drawing will depict the plumbing detail (that is, tubing-runs) as simple straight lines with right angle bends. This will prevent a format that is too cluttered or confusing.

Each valve and instrument shall have connection numbers inscribed near the fitting(s). An additional drawing titled “plumbing chart” shall be provided showing a dimensional layout of tubing or pipe runs, specifying the tubing to be used, their sizes and bend radii, and the plumbing chart shall show in tabular form, which connections are joined together.

Example:

Plumbing Chart

The connector numbers listed together below are to be connected with indicated tubing:

#2 to #4 – 1/4 in (6 mm O.D.) x 0.035 (0.89 mm) Wall Copper Tubing
#12 to VAC Source – 1/2 in (12 mm O.D.) PVC Tubing of suitable wall thickness
#36 to 02 Pressure Source – 3/4 in (18 mm O.D.) SS Tubing of suitable wall thickness

A schematic drawing of the plumbing layout shall be provided. If required, an electrical schematic shall also be included.

Schematic drawings shall utilize oxygen and electrical symbols from AIR822, AIR825B and MIL-STD-17B-2.

3.4.1.2 Manuals: A manual shall be provided containing a description of the test stand, operating instructions, maintenance, calibration and troubleshooting information.

3.4.1.2.1 Document Storage: Test stand storage provisions shall be made to accommodate the test stand manuals, calibration charts, procedures and schematic diagrams. A copy shall be stored with the test stand.

3.4.1.3 Instrument Layout: Test stand instrumentation shall be positioned at eye level. Consideration shall be given as to whether the operator is normally standing or seated. Instrumentation shall be as closely grouped together as space and plumbing allows. Parallax resulting from placement of instrument scales at excessive angle(s) to the operator’s eyes, shall be avoided.

3.4.1.4 Instrument Test Conditions: Each instrument shall be clearly and permanently labeled as to percentage of accuracy, the calibration date, the calibration medium and standard conditions. Example: Accuracy = 0.5% full scale, oxygen at 760 mm Hg (101.3 kPa) and 70 °F (21 °C). Each instrument shall bear a limited use marking to ensure accuracy and require proper recalibration. This marking should include the certification/calibration date and the expiration date. The instrument must not be used beyond the expiration date until recalibration is accomplished.

3.4.1.4.1 A mercury barometer and thermometer should be on or near the test stand to determine actual test conditions.

3.4.1.5 Instrument Mounting: Instruments such as manometers, draft gages, flowmeters, etc., shall be mounted level and square on the test stand so as to minimize instrument error. A test stand leveling instrument shall be permanently mounted. Means of adjusting the test stand to level position shall also be provided. The test stand shall have adequate support and sufficiently rigid construction so it will not be damaged during transport and cannot inadvertently move out of plumb by forces exerted by the operator or by attached hoses or equipment.

3.4.1.6 Protective Devices: All instruments, chambers and rig plumbing must be adequately protected against overload by means of check valves, relief valves, or quick-acting shut-off valves, or quick-acting manometer bypass valves, or both. All manometers shall also be equipped with traps and zeroing devices. Instruments requiring protection from "adiabatic compression" shall be protected.

If the test stand uses oxygen, it may be desirable to use blowers or other ventilation means to prevent oxygen concentrations from accumulating inside of cabinets.

3.4.1.7 Controls: Test stand controls shall be centrally located to the operator and shall be clearly and permanently marked as to their function or control number, or both. Control numbers shall be preceded by a letter (or letters) and numbers as follows:

V4- = Valve 4-Way
V2- = Valve 2-Way
V3- = Valve 3-Way
R- = Regulator
RV- = Regulator Vacuum
SW- = Switch
CV- = Check Valve
SV- = Solenoid Valve
CN- = Connector
SWP- = Switch, Pump
VR- = Valve, Relief
VB- = Valve, Bleed
VN- = Valve, Needle
VF- = Valve Filler Recharge
VV- = Valve Vent
PR- = Pressure Reducer
BD- = Burst Disk

Example: 4-Way Control Valve #6 will be marked "V4-6".

3.4.1.7 (Continued):

Marking: Test stand regulators or bleed valves shall be permanently and clearly marked and identified. Test stand valves shall be clearly and permanently marked with positions such as “on-off”, etc. Test stand components shall be clearly and permanently marked “Oxygen Pressure”, “Vacuum Supply”, etc.

High pressure valves or controls shall be so marked.

The test stand operating manual shall identify each control. As an option to the above, and if the actuation of a single valve or switch accomplishes complete test, that valve or switch may be marked on the face of the test stand with the name of that test. Example – “Suction Leakage”.

3.4.1.8 External Inputs: External inputs to the test stand such as electric power, oxygen, nitrogen or air, etc., shall be permanently and clearly labeled or tagged at the point of inlet to the test stand with both the name and grade of the gas or input, plus the minimum and maximum allowable pressure (lbf/in^2 (gage) or kPa), voltage, and special or unconventional connections such as left-hand thread, etc.

Gaseous input connectors and fittings should be standard CGA (Compressed Gas Association) type for each particular gas.

3.4.2 Hardware:

3.4.2.1 Test Chambers: Test fixtures, connectors and chambers are identified as the chamber or fixture into or onto which the unit to be tested is housed, positioned or attached to during the test procedures.

3.4.2.1.1 Care shall be taken in the design of test chambers to assure that sufficient pressure is applied to adequately seal the chamber and not distort the item to be tested (especially pneumatically closed chambers). Connectors and ports shall be of sufficient size so as not to affect the test results, and not so large as to greatly increase dead air space.

3.4.2.1.2 Design consideration is required to prevent gas flows from becoming nonlinear because of excessively acute turns resulting in induced resistance to flow and erroneous test results.

3.4.2.1.3 Pressure taps (or piezometers) shall be located as close to the test item as possible. Upon completion of the chamber, fixture or test connectors, trial tests shall be conducted using a dummy test item to determine that final test results are not unduly affected by too small test connectors, acutely angular flows, and pressure taps or piezometer location in relation to the test item.

3.4.2.1.4 The test chamber surfaces shall be suitably protected from corrosion by plating or by use of corrosion resistant finishes.

3.4.2.1.5 Plumbing: Stainless steel, copper or copper alloys (suitably protected or plated against corrosion) are preferable; seamless aluminum is acceptable for gas pressures below 500 lbf/in^2 (gage) (3450 kPa); PVC tubing is acceptable for pressures below 200 lbf/in^2 (gage) (1380 kPa) for air, nitrogen or oxygen.

Stainless steel or copper alloy fittings may be brazed-on nipples or regular flared or flareless fittings. Aluminum tubing shall utilize regular flared fittings with coupling sleeve.

3.4.2.1.6 Fittings: Forged, cast and machined fittings such as elbows and tees for stainless steel, copper or aluminum tubing shall be welded or brazed. For low pressures below 200 lbf/in^2 (gage) (1380 kPa) soldering is acceptable if all traces of flux are removed. Matching or interfacing dissimilar metals together shall be avoided.

3.4.2.1.7 Tubing bends (radii) shall be as large and sweeping as practicable (see 3.4.2.1.2).

3.4.2.1.8 Routing: In the interest of minimizing dead air space, the tubing need not be square or parallel to the test stand sides. Rather, it may go directly from point to point (that is, direct from valve to manometer to test chamber) regardless of the resultant tubing angle(s) to the test stand. However, neatness of appearance and minimum stress in misaligned tubing should be considered. Ease of servicing shall be considered in the plumbing layout.

3.4.2.2 Valves: Valves of all major types may be used. A partial list includes:

a. Poppet
b. Rotor
c. Ball
d. Needle
e. Plate-Seat
f. Gate

Each valve shall be of a type suitable for its intended use. (For example, a needle valve for fine adjustment.)

3.4.2.3 Regulators: Regulators shall be clearly and permanently marked as to type (demand, vacuum, pressure demand manual, etc.), MIL-Spec number, and functional positions (that is, increase pressure, decrease pressure, etc.), and pressure range.

3.4.2.4 Vacuum Systems:

3.4.2.4.1 Accumulator or Reservoir: A vacuum accumulator of sufficient volume shall be utilized to prevent excessive fluctuations in vacuum negative pressures. Usually, a preset vacuum regulator shall be positioned between the accumulator and the vacuum source (pump) to maintain a constant negative pressure to the accumulator. Naturally, a vacuum pump of sufficient capacity to maintain constant negative pressure in the accumulator is required. Use of an ejector system is recommended for evacuating oxygen rich atmospheres.

3.4.2.5 Filters: The test stand shall include necessary filters insuring that all test supply gases or fluids, or both, are filtered upstream of all valving, metering, measuring or control devices. Vacuum bleed valves shall also utilize filters on the upstream side to prevent contamination from entering the test stand system.

3.4.2.6 Breathing Machines: For information and recommended practices on breathing machines, see ARP1109.

3.4.2.7 Other Hardware Items:

3.4.2.7.1 Standard Hardware Items: Standard hardware items such as nuts, bolts, screws, washers, clamp terminal connectors, switches, etc., shall be MS or AN wherever they are suitable for the intended purpose. Commercial utility hardware components may be utilized provided they are suitable for the intended purpose. Such commercial utility hardware components may be utilized provided they are suitably protected by plating, etc., and possess all other suitable properties.

3.4.2.7.2 Materials: The materials used in the construction of an oxygen test stand shall be of high quality, compatible with oxygen, entirely suitable for the intended purpose. Whenever plastics are used, they shall be suitable for the intended purpose.

3.4.2.7.3 Metals: All metals used in construction with the test stand shall be corrosion-resistant or shall be suitably protected to resist corrosion during the normal life of the equipment. Dissimilar metals in intimate contact shall be avoided.

3.5 Environmental Test Chambers:

Environmental chambers for the testing of oxygen equipment or systems to simulate the effects of high altitude and related ambient conditions as contemplated for civil aircraft applications are commercially available. Custom designed chambers for specific applications such as the physiological reaction of humans to environmental extremes are also available. The requirements of the National Fire Protection Association document NFPA 99-1984 must be considered during design, construction and operation of hyperbaric or hypobaric facilities which are man rated.

Although not limited to the following, the majority of equipment for civil aircraft use will be subjected to extremes of altitude, temperature and humidity.

3.5.1 Combination Test Chambers:

3.5.1.1 Environmental test chambers capable of multiple testing for altitude, temperature and humidity, or any combination thereof, may be utilized.

3.5.1.1.1 Chamber Volume: Chamber internal work volume may vary from as small as 1 ft^3 to as large as 250 ft^3 (0.028 to 7.08 m^3) with some custom built chambers even larger.

3.5.1.1.2 Chamber Materials: Internal chamber surfaces shall be constructed preferably of welded stainless steel for purposes of high strength, corrosion resistance, minimization of pressure and temperature loss, and for ease of cleanliness. Any use of wood construction is to be avoided.

3.5.1.1.3 Chamber Insulation: The chamber shall be fully insulated for low heat transfer and impermeability to moisture.

3.5.1.1.4 Chamber Strength: Structural integrity of the chamber utilized shall be verified for the altitude range desired when subjected to vacuum to prevent implosion.

3.5.1.1.5 Access Door: A full opening, full width access door provided with a thermal pane fracture-proof viewing window, along with internal illumination, is desirable. The access door shall be provided with a minimum of two peripheral door seals for vacuum and thermal insulation and with rugged, quick release door latches.

3.5.1.1.6 Access Ports: Adequate access ports for pressure and instrumentation lines to the test specimen should be located in the chamber side walls. All pressure or electrical line connectors shall be pressure tight.

3.5.1.1.7 Circulation Fans: Internal circulation fans with grid protection shall be available for air circulation and reduction of hot or cold spots. The fans shall be provided with externally located motors and on-off controls; a fan on-off door interlock switch is desirable.

3.5.1.1.8 Temperature Sensors: Unless otherwise specified, thermocouples or equivalent temperature sensors utilized to determine or control the specified chamber temperature shall be centrally located within the test chamber where possible or in the return air stream, and shall be baffled or otherwise protected against impingement of supply air and against radiation effects.

3.5.1.1.9 Altitude Indicator: An easy to view, externally mounted mercury manometer shall be utilized for direct indication of altitude within the chamber. Dual calibration in millimeters of mercury and altitude in feet is preferred.

3.5.1.1.10 Temperature Indicator: Various instruments are available for the measurement or recording of chamber internal temperatures. The device utilized shall be selected to provide sufficient accuracy, response, and range for the test being conducted. Devices available include liquid or bi-metal thermometers, thermowells with electronic readouts, analog or digital readouts with thermocouples or thermistors and strip chart recorders. Electronic readouts designed for use with thermocouples offer certain advantages such as: high accuracy, ability to attach sensors directly to item under test and multichannel capability. For additional information refer to 3.6.4.

3.5.1.1.11 Humidity Indicator: A Wheatstone bridge type hygrometer located externally on the chamber, with a varying resistance humidity sensor located within the chamber, may be used as a direct readout for relative humidity. Accuracy of ±1% in the range of 1 to 98% relative humidity is required. Correction factors for the variation in chamber temperature are usually necessary with this instrument.

Another method for measuring humidity is by the use of a dew point hygrometer. Since dew point is independent of temperature the control of chamber temperature is less critical, allowing more convenient indication.

A third method of measuring relative humidity within the chamber is the use of the conventional wet and dry bulb thermometers. While relatively accurate (±1 to ±4%), the direct readout types must be placed directly in the circulated airstream within the chamber, thereby, restricting viewing. By using charts prepared for this purpose, the relative humidity (percent of saturation) can be determined at any given temperature by viewing the difference in reading between the wet and dry bulbs. Remote control recorder indicators using wet and dry bulbs are also available.

3.5.1.1.12 Electrical Requirements: All electrical components and wiring shall comply with the national electrical code and OSHA requirements. No exposed wiring shall be allowed within the chamber.

3.5.1.2 Low Temperature: Two basic methods of cooling environmental test chambers are in current use. One approach is the injection of cold gases (CO_2 or N_2) taken from their liquid state. The more common method is the mechanical refrigeration type with compressor(s) similar in some respects to the household refrigerator.

Lower temperature, lower operating costs, faster cooling and pull-down with improved control accuracy, together with lower frost and ice buildup, are certain advantages normally associated with the mechanical type vs. the gas injection type.

Mechanical systems are available in single stage or cascade types where extreme low temperatures or rapid pull-down is required.

The gas injection type is normally cheaper to procure or construct, and due to less complexity, is usually considered more reliable in operation and startup after long periods of shutdown. These units are usually easier and less expensive to repair.

Liquid CO_2 or LN_2 are often used as boosters or as a backup cooling system for the primary mechanical refrigeration system.

A third method of cooling, the use of frozen CO_2 (dry ice), may be more difficult to control.

3.5.1.2.1 Low Temperature Range: The test chamber shall be capable of reducing the temperature of the internal volume to -100 °F (-73.3 °C) from an ambient temperature of 75 °F (23.9 °C).

3.5.1.2.2 Low Temperature Control Accuracy: After stabilization of the chamber internal temperature at any set point from ambient to -100 °F (-73.3 °C), the regulation system shall be capable of maintaining that temperature at the control sensor within ±2.5 °F (±1.4 °C). The temperature gradient across the cross sectional area occupied by the test item shall not exceed 0.5 °F (0.3 °C) per foot in any direction.

3.5.1.2.3 Temperature Pull-Down Rate: The chamber with the test specimen installed shall be capable of reducing the internal temperature from ambient to -100 °F (-73.3 °C) within a time period of 30 to 90 min.

Special thermal shock units are available for immediate temperature reduction.

3.5.1.3 High Temperature: Heating of the chamber shall be conducted by open wire staged heating elements for rapid response and close tolerance control. The heating element(s) shall be suitably protected from the working area by a baffle. Blowers shall be employed for proper heat convection and air flow. If the chamber is to be utilized for high oxygen concentrations, open-wire staged heating elements are potentially hazardous and radiant heating is then recommended.

3.5.1.3.1 High Temperature Range: The test chamber shall be capable of raising the internal volume to a temperature of 350 °F (177 °C) from an ambient temperature of 75 °F (23.9 °C).

3.5.1.3.2 High Temperature Control Accuracy: After stabilization of the chamber internal temperature at any set point from ambient to +350 °F (177 °C), the regulation system shall be capable of maintaining that temperature at the control sensor within ±2.5 °F (±1.4 °C). The temperature gradient across the cross sectional area occupied by the test item shall not exceed 0.5 °F (0.3 °C) per foot in any direction.

3.5.1.3.3 Temperature Buildup Rate: The chamber, with the test specimen installed, shall be capable of increasing the temperature from ambient to +350 °F (177 °C) within a time period of 30 to 60 min. Special thermal shock chambers shall be employed where immediate temperature increase is required.

3.5.1.4 Altitude: Pressure evacuation of the internal volume of the test chamber shall be by means of adequate, oil free vacuum pumps with appropriate controls. The chamber shall be so constructed as to minimize inboard leakage to prevent excessive pump cycling.

3.5.1.4.1 Altitude Range: The internal volume of the chamber shall be capable of being reduced to a vacuum of 33.7 mm mercury (70 000 ft altitude).

3.5.1.4.2 Altitude Control Accuracy: After stabilization of the chamber internal volume at any set point from ground level to 70 000 ft (21 336 m), the vacuum control system shall be capable of maintaining that altitude within ±0.5%.

3.5.1.4.3 Altitude Control Rate: The internal volume of the test chamber shall be capable of reaching a simulated altitude of 50 000 ft (15 240 m) within 10 min. Special altitude shock chambers shall be employed where immediate altitude increase is required.

3.5.1.5 Humidity: A number of methods of controlling humidity within an environmental chamber are in use. The most widely used and probably the most effective type is the vapor-generating, immersion-heated water concept. A reservoir of water stored in a glass container is located externally of the chamber, isolating the water from internal chamber temperature effects. An immersion heater, controlled by the humidity control regulation system, heats the water on command until water vapor pressure is produced. The water vapor is forced through a copper tube into the circulated air stream within the chamber, thereby increasing chamber humidity.

3.5.1.5.1 Humidity Range: The chamber shall be capable of maintaining the internal volume at a relative humidity from 1 to 98%, with ambient temperatures from +35 °F (1.67 °C) to +185 °F (85.0 °C).

3.5.1.5.2 Humidity Control Accuracy: After stabilization of the chamber internal volume at any relative humidity within the temperature range allowed, the humidity control system shall be capable of maintaining the relative humidity within ±1%.

3.5.1.5.3 Humidity Control Rate: The time required for stabilization of the set point relative humidity is optional, but should be reasonable and compatible with the testing procedure.

3.5.2 Altitude Chambers - Hardware Type: Hardware chamber are defined as those designed primarily for production or experimental altitude testing of components.

3.5.2.1 Chamber Size: Small fixture type chambers may be specially machined from aluminum or steel barstock to accommodate the size of the item being tested. Allowance shall be made for interconnection of oxygen pressure lines to the test specimen. Sealing of the access hole may be achieved with O-ring type packings or gaskets. Wall thickness of the chamber and access closure shall be sufficient to prevent deformation or implosion under high vacuum. Larger chambers for altitude testing may be constructed of welded steel plate of adequate thickness to withstand the stresses involved under high vacuum.

3.5.2.2 Bell Jars: Commercially available bell jars may be utilized for vacuum testing. High-tempered glass jars can be utilized for pulling of relatively high vacuums. Clear, transparent, high-strength plastic jars in some cases are acceptable for vacuum use. In any case, the structural integrity of the bell jar should be verified before use as a vacuum device. Because these items are constructed of transparent materials, they are ideal for use where visual examination of the specimen under test is desired. A flat, noncorrosive, structurally sound plate shall be provided to close the open end of the bell jar. Sealing of the plate to the bell jar shall be accomplished with a relatively soft strip of neoprene or silicone rubber around the entire perimeter of the jar itself.

3.5.2.3 Pressure and Vacuum Lines: The test fixture shall be provided with inlet and outlet oxygen ports for the control of oxygen into and out of the specimen under test. Refer to 3.4.2.1 of this document for additional information regarding pressure hookups. Vacuum ports shall be provided for vacuum pull-down and for attachment of manometers or altitude gages. In the case of bell jars, all pressure and vacuum lines shall be plumbed into the bottom metal base plate.

3.5.3 Altitude Chamber, Man Rated: Man rated chambers are defined as those of sufficient internal size to properly house a group of individuals comfortably for observation and testing of the physiological reaction to high altitude. Such chambers are also in use by the Military and certain Federal agencies for indoctrination of flying personnel to the effects of high altitude. Due to the physical size and rarity of such units, they are entirely custom built to meet the user's requirements. Such units may be designed for a relatively slow rate of altitude climb or to simulate a high altitude pressurized aircraft rapid decompression. An interlock chamber of a controlled pressure differential with specified volume may be utilized for such rapid decompression testing. The chamber shall incorporate a full flow, deadweight type, pressure relief valve.

3.5.3.1 Chamber Volume (Size): The chamber size is predicated primarily on the number of individuals to be subjected to high altitude. Chamber sizes may range anywhere from 3 to 20 individuals, with larger sizes conceivable. The chamber preferably shall be rectangular, with adequate floor space for ease of movement of individuals and ease of emergency entry and exit. The compartment height shall be a minimum of 7 ft (2.13 m) from floor to ceiling. A lock compartment with separate altitude controls may be provided if necessary for control of rapid decompression or location of observers.

3.5.3.2 Basic Construction: The construction of the chamber shall be of the highest strength materials available commensurate with safety. The internal and external walls, floor, and ceiling shall be smooth and continuous. The highest design, construction, and reliability standards shall be employed to assure safe operation. A minimum safety factor of four shall be employed for all structural components, including doors, windows, floors, ceilings, walls, components, etc. All welding shall comply with applicable military or ASME codes. All structural materials shall be stress relieved after fabrication.

3.5.3.3 Windows: Observation windows shall be strategically located around the chamber and between main and lock compartments if utilized. In addition, each entry (exit) door shall be provided with a window. The windows shall be of double pane tempered safety glass. The outer panes shall be a minimum of 1 in (25.40 mm) thick. The inner pane shall consist of two pieces of 3/4 in (19 mm) thick tempered plate laminated together. The air space between inner and outer panes shall be so designed as to prevent the accumulation of moisture and fog during altitude transients.

3.5.3.4 Doors: Entrance and exit doors which swing outward from the internal chamber shall be provided. The number of doors provided is dependent upon the size of the chamber, and safety entrance and exit factors of medical personnel if so required. The minimum size door shall be 6 x 2-1/2 ft wide (1.82 x 0.876 m). Highly reliable, structurally sound, quick release locking devices shall be employed. The doors when closed shall adequately seal inboard leakage to the degree specified.

3.5.3.5 Air Conditioning: The chamber(s) shall be provided with an air conditioning system capable of maintaining an ambient temperature of 67 to 73 °F (20 to 23 °C) at ground level, with a relative humidity of not greater than 50%. The air conditioning system need not function under high altitude but internal ducting, etc., shall be capable of withstanding the high differential pressures encountered.

3.5.3.6 Illumination: Proper internal lighting shall be employed. The electrical system and lighting shall not be affected by altitude extremes. If rapid decompression is encountered, all lamps, ballasts, wiring, etc., shall be capable of withstanding extreme and rapid pressure changes. An emergency 24 V DC lighting system shall be provided.

3.5.3.7 Seating: All individuals shall be provided with a seat. Aircraft type structural seats, lounge chairs, benches, etc., are acceptable. The seats shall be adequately stable or fastened to the floor.

3.5.3.8 Oxygen Systems(s): Each individual or observer in main or interlock compartments shall be provided with an oxygen system predicated and determined by the type of tests involved. All equipment furnished shall comply with applicable FAA Standards. It is recommended that automatic pressure demand and manual pressure demand regulators, with immediate transfer capability, be available for each individual station when used at altitudes over 34 000 ft (10 363 m). Positive pressure at the higher altitudes is required to maintain acceptable partial pressure of oxygen in the blood stream. A typical range of positive pressure available from 34 000 to 40 000 ft is 0.13 in H_2O minimum to 3.6 in H_2O maximum.

Each individual station may be designed to employ numerous types of equipment. The safety stations shall employ quick-donning type masks.

3.5.3.9 Communications: The main chamber and lock chamber, if so used, shall be provided with a communication system designed so that each and every individual shall be able to communicate clearly. The system shall not be affected by spontaneous altitude variations. In addition, each oxygen outlet shall be provided with an individual microphone jack for communication.

3.5.3.10 Evacuation: Vacuum pump(s) utilized shall be of the size and type capable of evacuating the main chamber or lock chamber to the altitude vs. time required. In the event that rapid decompression is a requirement, the main and interlock chambers shall be so designed as to effect a rapid decompression within a specified period of time.

3.5.4 Control Systems: Environmental control systems are those devices capable of controlling, and in some cases recording, environmental extremes within the chamber.

3.5.4.1 Temperature Control Systems: Temperature sensitive probes are located within the chamber to sense and signal to the electronic controller temperature variations. The output of the controller shall be proportional to enable the refrigeration and heating equipment to be controlled in close response to sensing probe demand. Separate probes may be utilized for strip chart recorders or programmers.

3.5.4.2 Humidity Control Systems: See 3.4.1 through 3.4.1.5.2 for information regarding humidity control systems. Programming and recording of humidity conditions can be conducted with equipment available commercially.

3.5.4.3 Altitude Control Systems: Altitude pressure transducers with linear voltage outputs for input into electronic controllers may be utilized for automatic control of selected altitude. Vacuum regulators with holding reservoirs may be used for manual control.

3.5.5 Vacuum Reservoirs: For information on vacuum systems, refer to 3.3.2.4.

3.6 Instrumentation - General:

Instrumentation for testing oxygen equipment is commercially available. Selection of specific test equipment is dependent on the equipment function which is being monitored or qualification test which is being administered.

Since most civil aircraft oxygen equipment is subjected to extremes of altitude, temperature and humidity, the instrumentation sensors employed in testing must be operable under those same conditions.

Instrumentation considered here is categorized as follows:

a. Temperature
b. Flow
c. Pressure
d. Humidity

The parameters which are considered in the selection of test instrumentation include:

a. Compatibility with oxygen
b. Flow
c. Reproducibility
d. Range of sensitivity
e. Power or signal output

All instrumentation placed within a test chamber must be compatible with the environmental conditions encountered in the chamber. These are as follows:

Temperature: -100 to +350 °F (-75 to +175 °C)
Pressure: 1060 to 30 mm Hg absolute
Relative Humidity: 10 to 100%

3.6.1 Altitude Measurement: Measurements of altitude environments for testing of oxygen equipment range from sea level to 70 000 ft (21 366 m). Associated with the increase in altitude is a decrease in atmospheric pressure from 14.7 to 0.64 lbf/in^2 (absolute) (101.3 kPa to 4.4 kPa).

Altitude measurement may be accomplished by a pressure measurement and appropriate conversion from pressure to altitude. The pressure may be determined using manometers, aneroid devices or pressure transducers which are designed to indicate absolute pressure.

3.6.1.1 Manometers: Manometers used for absolute pressure measurements should be constructed of noncollapsible (glass) tubing with one end of the tubing closed and one end connected to the altitude-pressure environment through a reservoir column of mercury. These types of manometers are commercially available with accuracies of ±0.5 mm or better and are suitable for altitude-pressure measurements at ambient temperatures. Liquid-filled manometers should not generate contaminants and/or be inherently hazardous.

NOTE: Manometers filled with combustible fluids should not be used in contact with oxygen. Water is satisfactory above 32 °F (0 °C).

3.6.1.2 Altimeters: Altitude measurements of environments inclusive of temperature effects can be made using solid-state type devices. These devices are free of any liquids and normally employ pressure transducers for pressure sensing.

Readout can be direct or with remote analog or digital recording. The dynamic error band should be ±1.8% or better over the altitude-pressure range. The error introduced by temperature variations shall not exceed 0.03% per °C throughout the range of -55 to +75 °C (-67 to +167 °F) and the output signal resolution should be continuous.

3.6.1.3 Aneroid Gages: Gages used for altitude-pressure measurements are generally aneroid types. This type of gage uses a bourdon tube and diaphragm displacement for the altitude indication. They are commercially available with accuracies of ±1% with special calibrations available upon request.

These gages shall be 5 cm (2 in) minimum dial diameter with a 270 deg arc indicator. Compound gages shall not be used for altitude-pressure measurements.

NOTE: Bourdon tube gages should be made of beryllium to avoid corrosion.

3.6.2 Flowmeter System: A flowmeter system to be used for testing of oxygen equipment should be chosen considering the following:

a. Metered media (gaseous oxygen)
b. Media temperature
c. Media pressure
d. Oxygen system function
e. Materials of construction
f. Readout devices

3.6.2.1 Flowmeters, General: Flowmeters may be categorized in two basic classes: volumetric and mass. Volumetric flowmeters operate by a number of principles of which pressure drop through a laminar flow device, buoyant force displacement and velocity change are commonly used. Volumetric flowmeters can be used for gas flow if the pressure and temperature of the gas are known and constant.

Mass flowmeters are generally preferred where the pressure and temperature of the gas may change. These devices usually operate by thermal, acoustic or momentum change principles.

Monitoring instruments for oxygen flow shall be selected on the basis of maximum expected flow rate and allowable pressure drop through the flow metering element. Maximum allowable gas temperature through the sensor may be a consideration if a chemical oxygen source is being tested without cooling provisions.

Oxygen flow rates may be monitored mechanically or electrically. If flow variations with time are important, mechanical (wet or dry) flow totalizers should not be used where line pressure fluctuates. Electrical totalizers should have a meter readout plus provisions for integral or remote analog recorder or digital printout.

3.6.2.2 Flowmeters, Specific: Mass flowmeters or flowmeter systems, or both, should be used when a continuous measurement of flow rate is desired and operational conditions permit. They shall be capable of detecting flow rates of 0.5% of the measurement range for liquid flow and 0.1 SLPM for gas flow. They shall have an accuracy of ±0.5% and a response time of 0.1 s or better.

When testing oxygen generating equipment with an operating pressure of less than 20 lbf/in^2 (gage) (138 kPa), the resistance to flow through the flowmeter should not exceed 10 mm Hg (5 in H_2O).

The use of flow rate indicating devices (rotameters) shall be permitted for flow rate measurements where the inlet pressure to the device is constant and known and a continuous resolution measurement is not required. Rotameters shall have an accuracy of ±2% full scale or better and a measurement range no greater than 150% of the operational flow rate range.

3.6.3 Pressure Measurement: Various types of pressure measurements may be required including:

a. Altitude chamber pressure
b. Differential pressure across a component or orifice
c. Oxygen supply or line pressure

Cursory pressure measurements may be made with manometers or simple mechanical-type indicators with suitable calibrations (altitude in cm, mm Hg, etc.). Precision monitoring of oxygen system performance should be executed with instruments employing strain gauges or other electrical pressure-sensing transducers. In addition to a direct-read-out meter, the instrument should be equipped with terminals for remote analog or digital recording.

3.6.3 (Continued):

For altitude transducers the dynamic error band should be ±1.8% or less over the entire range of 0 to 21 336 m (70 000 ft). The error introduced by the temperature variations should not exceed ±0.03%/°C (±0.015%/°F) from -55 to +75 °C (-67 to +167 °F). Proof pressure should be 20 lbf/in^2 (absolute) (130 kPa). Resolution should be continuous and life should be at least 25 000 full scale cycles or 20 years.

For differential pressure transducers the error band, that is, the maximum deviation of any pressure point from a straight line drawn between the end points, shall not exceed ±0.5% FSO. Zero shift with line pressure should be less than ±1% per 35 atm (500 lbf/in^2). Thermal span shift should be less than 0.01%/°C (0.005%/°F). Resolution should be continuous (infinite).

For oxygen line pressure measurements, the transducer selected should have a range maximum which exceeds the expected maximum line pressure by approximately 20% or more. Linearity and hysteresis shall be within 0.2% FSO; repeatability within 0.1% FSO, thermal sensitivity shift within 0.01%/°C (0.005%/°F). Resolution shall be continuous (infinite).

In all cases, if the instrument is located in a chamber in which it is exposed to salt spray, sand and dust, fungus, etc., it shall be qualified according to the requirements of MIL-STD-810.

Pressure measurements of high range 35 to 340 atm (500 to 5000 lbf/in^2 (gage)), intermediate range 4.5 to 35 atm (50 to 500 lbf/in^2 (gage)), low range 1 to 4.5 atm (0 to 50 lbf/in (gage)) and vacuum and section (0 to 760 mm Hg (0 to 14.7 lbf/in^2 (absolute)) may be required. Differential pressure measurements in the range of 0 to 37 mm Hg also may be required as part of test instrumentation.

3.6.3.1 High Pressure Range (35 to 340 atm) (500 to 5000 lbf/in^2 (gage)): Pressure measurements in the high range shall be performed using pressure transducers with a minimum overpressure rating of 150% of the operating range. Pressure transducers are available with a number of operating principles including: diaphragm differential transformer, diaphragm piezoresistance, potentiometric, diaphragm variable reluctance and diaphragm bonded strain gage. The pressure transducer selected shall have an accuracy of ±0.5% or better. Repeatability shall be within 0.1% and the thermal sensitivity shift shall not exceed 0.01%/°C (0.005%/°F). Linearity and hysteresis effects shall not exceed 0.2%.

Aneroid type pressure gages may be used for pressure indication where a continuous pressure measurement is not required. Pressure gages for high range indications shall have an accuracy of ±1.0% or better and a range of 200% of the working range. These gages shall have dials a minimum of 9 cm (3.5 in) diameter with a 270 deg arc indicator.

3.6.3.2 Intermediate Pressure Range (4.5 to 35 atm) (50 to 500 lbf/in^2 (gage)): Pressure measurement instrumentation for this range shall be and have the same functional characteristics as for the high pressure range. The diameter or dimension of aneroid type pressure gages, however, will be 5.1 cm (2 in) minimum

3.6.3.3 Low Pressure Range (1 to 4.5 atm) (0 to 50 lbf/in^2 (gage)): Pressure measurement instrumentation for this range shall be and have the same functional characteristics as for the intermediate pressure range.

3.6.3.4 Vacuum and Suction (0 to 760 mm Hg) (0 to 14.7 lbf/in^2 (absolute)): Measurement of vacuum or suction pressure shall be performed with either absolute pressure transducers, vacuum gages or manometers. The use of vacuum gages and manometers shall be restricted to static pressure measurements. Compound gages, those gages capable of vacuum and positive pressure measurement, shall not be used for vacuum or suction pressure measurements.

3.6.3.5 Differential Pressure (0 to 40 mm Hg) (0 to 20 in H_2O): Pressure differentials across orifice plates, fans, regulators, filters and other flow devices shall be measured using aneroid gages, manometers or transducers. The preferred instruments are aneroid gages and transducers, but manometers (using an oxygen-compatible liquid) may be used.

3.6.4 Temperature: The range of temperature measurement and devices for temperature measurement is wide and varied. The temperature range may extend from the boiling point of oxygen -183 °C (-297 °F) to greater than 800 °C (1472 °F).

Monitoring of test equipment shall include sensor(s), readout meter, and signal jack for stripchart recorder or digital printout. If a thermocouple sensor is used, then an electronic reference junction compensator is required. A means for calibration shall be provided.

The instrument used shall have a resolution capability of 0.5 °C (1 °F) or better and a response time of 2 seconds full scale. Range should be from -75 to +315 °C (-100 to +600 °F). For thermocouple sensors, type T (copper/constantan) may be used to cover this entire range. For thermistor sensors, two or three sensors are required. Low temperature thermistor units, with resistances of 100 to 1 kΩ at 25 °C (77 °F), are suitable for use in the -75 to +65 °C (-100 to +150 °F) range. Intermediate temperature thermistor units, with resistances of 2 to 75 kΩ at 25 °C (77 °F), are suitable for use in the 65 to 150 °C (150 to 300 °F) range. High temperature thermistor units, with resistances of 100 to 500 kΩ at 25 °C (77 °F), are suitable for use in the 150 to 315 °C (300 to 600 °F) range.

Temperature monitors employing other types of sensors may be used provided they have the response characteristics of thermocouple or thermistor instruments. The temperature monitor may be placed outside the test chamber.

3.6.4.1 Liquid Thermometers: Liquid filled thermometers may be used for static temperature measurements above -75 °C (-100 °F). These thermometers should be the capillary tube type with a dial indicator, which is compensated for ambient temperature changes. Since these devices are immersion types, their accuracy is affected by the installation and care must be used to assure proper temperature indication.

3.6.4.2 Thermocouples: Measurement of temperature, either static or transient, should be performed with ANSI thermocouples. Copper/constantan alloy thermocouples shall be used for temperature measurements in the range of -185 to +370 °C (-300 to +700 °F). Measurement of temperatures in excess of 370 °C (700 °F) shall be performed using chromel/alumel alloy thermocouples. The accuracy of thermocouples shall be ±2% or better with reference junction temperature compensation provided. The response characteristics shall be 0.5 s per 50 °C (90 °F) temperature change or better when immersed in water.

3.6.4.3 Bimetal Thermometers: Static temperature measurement within the range of -20 to +165 °C (-4 to +329 °F) may be performed using bimetal thermometers. Care should be exhibited, however, to assure proper immersion installation of the thermometer. The accuracy shall be ±1% of the scale range or better.

3.6.4.4 Resistance Temperature Devices: If direct static or slow transient temperature measurement at high level accuracy and sensitivity are required, thermistors or resistance thermometers can be used. Accuracies of ±0.01 °C (±0.02 °F) or better can be achieved although the range of measurement is less than that of thermocouples and the response time is typically above 5 s. Two or three different range thermistors can be employed to cover the entire temperature range of interest.

Resistance temperature devices also have the advantage of providing a high electrical output, compared to thermocouples, which enable a number of readouts, recorders, controllers and data-loggers to be used in conjunction with the temperature transducer.

3.6.5 Time: Time measurement devices for testing of oxygen equipment may range from a stop watch to a precision countertimer. The stop watch is sufficiently accurate for most functions such as flow or pressure initiation or termination. However, more sophisticated timing devices may be required for causal functions such a short cycle (<1 s) events including pressure relief and electronic hardware operation.

3.6.5.1 Electric Timers: Electric timers shall be used for time period measurements of 30 s or longer. The readout shall be digital in standard time units readable to 0.01 min or 0.5 s.

3.6.5.2 Stop Watches: Time periods of less than 30 s shall be determined by a stop watch. Stop watches may be either mechanically or electrically driven and be readable to within 0.1 s.

3.6.5.3 Electronic Timers: Time period measurements of less than 5 s shall be determined by electronic timer. These timers may be triggered by photocell, pressure signal or other rapid means to obtain sufficient accuracy of measurement.

3.6.6 Humidity Instrumentation: Humidity can be reported in four different forms; in terms of relative humidity, absolute humidity, dew point, and humidity ratio. Most available instruments report in terms of dew point or relative humidity.

The relative humidity instrument selected shall have the following specifications:

Range: 0 to 100% RH
Accuracy: ±2% RH, sensitivity 0.4% RH Linearized Scale
Automatic temperature compensation from -5 to 77 °C (20 to 170 °F)

Dew point instruments shall have the following specifications:

Range: -75 to 10 °C (-100 to 50 °F)
Accuracy: ±0.5 °C
Sensitivity: ±0.05 °C

In each case a recorder output shall be available.

3.6.7 Instrument Calibration Requirement:

3.6.7.1 General: The calibration system used for each item of measuring or test instrumentation shall provide adequate accuracy in the use of the instrumentation. Measurement standards used in the calibration system shall be calibrated using reference standards whose calibration is certified as being traceable to the National Bureau of Standards.

Primary standards shall be those measurement standards maintained by the National Bureau of Standards. Secondary standards need not be maintained by the NBS but shall be immediately subsequent to the primary standard within the standard hierarchy.

Standards that establish the basic accuracy of a particular calibration system shall be Reference standards. All other standards shall be Transfer standards

3.6.7.2 Calibration to Secondary Standards: Those measurement standards which establish the basic accuracy values of a calibration system (reference standards) shall be calibrated to secondary standards. Measuring or test instrumentation used for, or as part of, testing of oxygen equipment shall not require calibration to secondary standards.

3.6.7.3 Calibration to Primary Standards: Measurement standards or measuring or test instrumentation used for, or as part of, testing of oxygen equipment shall not require calibration to primary standards.

3.6.7.4 Proof of Calibration: Measurement standards or measuring or test instrumentation shall be supported by written calibration procedures establishing the method of calibration used to assure the accuracy of the instrumentation. These procedures may be standard practices or manufacturer's instructions provided that the practices or instructions are sufficient to assure the required degree of calibration.

Measurement standards and measuring or test instrumentation shall be labeled or coded to indicate the date of last calibration, the calibration procedure, by whom the calibration was performed and when the next calibration is due.

3.6.7.5 Calibration Frequency: Measuring or test instrumentation and measurement standards shall be calibrated at periodic intervals based on the degree of usage, stability and purpose. Calibration intervals for measuring and test instrumentation shall not exceed 6 months and may be shortened as required to assure continued accuracy. Measurement standards shall be calibrated at intervals not exceeding five years if these measurement standards have documented stability histories. Other measurement standards shall be calibrated at intervals not exceeding 2 years.

3.6.8 Gas Purity Measurement Instrumentation: The analysis of the oxygen and its contaminants can be included under the instrumentation of testing the oxygen equipment or can be treated as a separate procedure. It will be considered here as a separate item and can be used for checking oxygen cylinders that may be a part of the oxygen equipment. There are many types of analytical equipment commercially available and detailed procedures will not be given here.

3.6.8.1 Gases To Be Analyzed: The oxygen is the gas that is desired and nitrogen, carbon dioxide, carbon monoxide, chlorine, and hydrocarbons are definite contaminants. Water vapor is not a physiological contaminant but may be an operational contaminant at low temperature. Certain chlorinated gases can be present from cleaning procedures and must be considered as contaminants. These may also be found under the hydrocarbons. Oxygen can be analyzed fairly accurately or all contaminants can be analyzed accurately and subtracted from 100% to give the percentage of oxygen.

3.6.8.2 Types of Analytical Equipment: There are many types of analyzers and in several cases different gases can be determined by the same type of instrument. The Compressed Gas Association has manuals on various gases and together with the U.S. Pharmacopeia lists many methods of analysis. The accuracy, with which the contaminant is analyzed, must be consistent with the allowed contaminant level.

3.6.8.2.1 Oxygen Analyzers: Some of the methods of analysis of oxygen are paramagnetic, polarographic and volumetric or manometric gas absorption (Orsat type).

3.6.8.2.2 Nitrogen Analyzers: Nitrogen can be analyzed by gas chromatography, gas ionization, and mass spectroscopy.

3.6.8.2.3 Carbon Monoxide Analyzers: Carbon monoxide can be analyzed by infrared, gas chromatography, catalytic combustion, color reactive absorption tubes and mass spectroscopy.

3.6.8.2.4 Hydrocarbon Analyzers: Hydrocarbons can be analyzed by infrared, flame ionization, oxidation to carbon dioxide, gas chromatography and mass spectroscopy.

3.6.8.2.5 Water Vapor Analyzers: Water vapor can be determined by infrared, gas chromatography, electrolytic hygrometer, dew point, color reactive absorption tubes and mass spectroscopy.

3.6.8.2.6 Chlorine Analyzers: Chlorine can be analyzed by coulometric electrochemical analyzer, colorimetric analysis (for example, methyl orange method), iodometric titration, color reactive absorption tubes and mass spectroscopy.

3.6.8.2.7 Carbon Dioxide Analyzers: Carbon dioxide can be analyzed by non-dispensive infrared analyzer, gas chromatograph using thermal conductivity detector, color reactive absorption tubes, and mass spectroscopy.

3.6.8.2.8 Particulate Analysis: Particulate analysis can be measured by gravimetric membrane filtration procedures.

3.7 Dynamic Test Equipment:

3.7.1 Vibration Test: Of all the tests performed on systems and components, probably none is more important than that of vibration. This is evidenced by the fact that more failures occur in vibration testing than in any other environmental test. For this reason the fact that the subject is technically complex, the following text was excerpted from "Aerospace Fluid Components Designers Handbook".

3.7.1.1 Specifications: The following specifications are widely used in military vibration testing:

a. MIL-STD-810 Military Standard "Environmental Test Methods"
b. MIL-STD-167, "Mechanical Vibrations of Shipboard Equipment"
c. MIL-E-8189, "Electronic Equipment, Guided Missiles, General Specifications for"
d. MIL-E-4970, "Environmental Testing, Ground Support Equipment, General Specification for"
e. AFSC Manual 80-6

3.7.1.2 Vibration Levels: The appropriate level of vibration to be used for testing a particular part is often unknown. Other uncertainties are the type of vibration to be used: sine, random, acoustic, or a combination of all three; and the axes through which the specimen is to be tested. If the specified levels are too low (a rare occurrence), the part may fail prematurely on the vehicle. If the levels are too high, an unnecessary design penalty is imposed upon the product.

Vibration levels are determined in several ways, each having advantages and disadvantages. A description of the procedures for determining these levels is as follows:

a. Environmental Prediction: In the case of a component being supplied for a vehicle not yet built, the vibration levels to be expected must be predicted based on the general design of the structure and information available from similar vehicles. A large degree of uncertainty as to the validity of the levels must necessarily be present when this procedure is used.

b. Data Acquisition: In this procedure, actual data are acquired from an existing vehicle. If the vehicle is an airplane, the data acquisition is relatively inexpensive and can be quite reliable, as the instrumentation can be carried and monitored on-board. In the case of the space vehicle, the problem is more complex because the amount of data that can be acquired is limited by factors such as the weight that can be carried and the relatively short launch duration.

c. Extrapolation of Data: If the vehicle to be built is similar to a previous vehicle, vibration levels may be inferred from data taken on the previously tested vehicle. These data will tend to be more accurate than data calculated for a new vehicle but are still subject to severe limitations in accuracy.

d. Zoning: Information from any of the above procedures may be used to (arbitrarily) designate zones within a vehicle. In this procedure, every piece of equipment in a given zone is considered to be subject to the same level of vibration.

It is apparent that the range of uncertainty associated with a specified level in any given vibration test specification may be quite large. The specification writer should consider the uncertainties in the various methods of setting test levels and should make every effort to ensure that they are realistic. The design and test engineer should be aware that the values established by any specification may be in error when applied to a particular component or system. With this awareness, a requirement that is unrealistic may be detected, reevaluated, and modified.

3.7.1.3 Types of Vibration Tests: 3.7.1.3.1Development Tests: Development tests are conducted on components to obtain basic data regarding the design. These tests are often more informal than qualification or acceptance tests as the usual instrumentation and inspection constraints do not apply. In many cases, the component can be mounted to a simple fixture, and its action observed under arbitrarily selected levels of vibration. A strobe light, which may be made to flash in synchronization with the vibrator, is a useful tool for observing the action of the component. If vibration equipment is available in-house, many tests may be run in a matter of minutes and involve only the test engineer and perhaps the vibration machine operator, as contrasted with the formal test, which may involve considerable time because of the requirements for fixture design, fixture checkout, instrumentation, witnesses, etc.

3.7.1.3.2 Design Verification Test (DVT): A design verification test is conducted on the component to verify the design of the completed unit. In this test the unit is subjected to the complete vibration requirements as noted in the specification. This test may be more severe than in the qualification test of the specification. In some instances, after a component has successfully completed a rigorous DVT, the qualification test requirements may be greatly reduced based on the information obtained during the DVT. One reason for the severe DVT is that a failure occurring in DVT may be corrected with fewer reporting and contractual implications than a failure that occurs in a qualification test.

3.7.1.3.3 Acceptance Testing: Vibration tests are often specified as part of the acceptance test for a component. The vibration levels are usually set much lower than the levels used in qualification testing. The purpose of the test is to discover any discrepancy that may have occurred in manufacture, such as a cold solder joint or a bad weld. High quality electric relays are often subjected to low level vibration testing as a routine manufacturing procedure.

3.7.1.4 Types of Equipment:

3.7.1.4.1 Mechanical Vibrators: Motor-driven mechanical vibrators use a scotch yoke, simple crank, or similar mechanism to impart reciprocating motion to a table or to a specimen. The acceleration level and frequency inputs can be varied by changing displacement or the rotational speed of the motor or both. With proper controls, they may be programmed to vary the inputs. These vibrators are relatively inexpensive and are used in testing small components, for which the requirements of frequency and acceleration are not too exacting.

3.7.1.4.2 Simple Shakers: Electromagnetic shakers normally used in industry for such tasks as vibrating paper stock, IBM cards, or other materials may be used to good advantage where it is not required to meet stringent MIL Spec requirements. With a 60 cps input the device produces a clean, pure half cycle. Machines are available that will produce accelerations from 1 g to about 100 g and the level is normally controlled by a simple rheostat on the machine. If more precise g levels are desired, a Variac controlling the power line voltage may be used. These machines are ideally suited for performing tests before submitting a specimen to the much more expensive electrodynamic vibration programs.

3.7.1.4.3 Electrodynamic Vibrators: The most common vibrator in use in the aerospace industry is the electrodynamic vibrator, which consists of a coil moving in direct proportion to an input voltage. These vibrators have a force output ranging from 2 to 35 000 lb. They may be programmed to produce a sinusoidal waveform, random vibration, or to duplicate any pattern from a magnetic tape.

3.7.1.4.4 Electrohydraulic Shakers: The electrohydraulic shaker (or hydrashaker) consists of a hydraulically-driven piston or actuator controlled by a servovalve, which receives a signal from a recorded tape. This type of shaker is useful where very high force-pound outputs are required and where the frequency does not exceed approximately 500 cps. The force output of these shakers is about 100 000 lb.

3.7.1.4.5 Acoustic Vibrators - Noise Generators: There are three types of facilities in general use for conducting acoustical tests. These are progressive wave tubes, standing wave tubes, and reverberant wave chambers. Progressive waves, standing waves, and diffused fields will exist as a function of frequency range of these facilities.

a. Progressive Wave Tube: A free progressive wave in a medium free of boundary defects propagates with the velocity of sound. In a progressive wave tube, the acoustic source is coupled to a suitable test section by an acoustic horn. Reflections are avoided by a termination placed at the end of the test section.

b. Standing Wave Tube: A standing wave tube is a device containing a periodic wave having a fixed distribution in space, which is the result of interference of progressive waves of the same frequency and kind. The standing wave tube is terminated by a hard or semi-hard reflecting surface, which causes waves characterized by the existence of pressure nodes or parietal nodes and anti-nodes fixed in space.

c. Reverberant Wave Chamber: A reverberant wave chamber is an enclosure containing a diffused sound field, in which the time average of the mean-square sound pressure is everywhere the same, and the flow of energy in all directions is assumed to be equal.

While acoustic testing is becoming increasingly important, it still must be regarded as a specialized field limited to large prime contractors, governmental agencies, and private laboratories. Information on this test can be found in MIL-STD-810 and ANSI-S1.1-1960.

3.7.1.5 Accessories: There are numerous accessories that may be required in addition to the basic shaker and control equipment. Some of these accessories are as follows:

a. An instrumentation quality tape recorder and playback system used to record output from the accelerometers and to play this recording back to the shaker at a later date or to program vibration levels to the machine. It may also be used to play output records back to an oscillograph for visual interpretation.

b. An intercom system may be required between the shaker room and the control room. The head set serves a dual purpose as it provides ear protection from the high levels of noise and unrestricted communication. Generally it is important that the operator be next to the component when performing frequency excursions or resonance tests. Actual visual observation, touch, and careful listening for intermittent sound are extremely important.

c. A slip table is necessary for horizontal vibration testing of large items. A slip table consists of a specially formulated heavy block, on which the fixture slides. An oil film is maintained between the block and the fixture to decrease friction.

d. Sound-proofing of the control room often helps to minimize operator fatigue and reduce errors.

e. Closed circuit television may be necessary for viewing some setups, which the operator may be unable to see or that may be hazardous if viewed at too close a range.

f. A stroboscopic light system for viewing the test item will be very useful. The flashing rate of the strobe can be controlled in the same manner as the input to the shaker.

g. An oscilloscope for viewing motion waveforms. (A camera for recording these waveforms is often required.)

h. A multichannel recording oscillograph for making permanent records of multiple signals, such as those required during the conduct of a functional test, will be mandatory on many programs.

i. An assortment of accelerometers will be found to be necessary. These devices come in various ranges and are used for monitoring the levels at various points on a fixture and for controlling the shaker power supply. Amplifiers and readout meters for these additional accelerometers will be required.

3.7.1.6 Fixture Design: In all but the simplest cases it is best to have the fixture designed by a person with extensive experience in the field. While the basic principles of design apply to fixtures as to any other device, there is considerable art involved in executing a design relatively free of unwanted resonances and amplification. It is important that the center of gravity of the test specimen be precisely determined and installed directly over the axis of the vibrator to prevent unwanted couples. Generally tests are conducted separately in the X, Y, and Z axes. Ease of mounting and ease of changing of axes are important from a cost standpoint because time charges for this equipment generally continue as long as the specimen is on the table.

3.7.1.7 Fixture Scan: If the fixture is complex, it is good practice to mount it without the test specimen or with a simulated test specimen on the vibrator, and subject it to a scan through the frequency to be used during the test. Should any resonances be observed during the scan, the fixture should be modified prior to the test. If such information is not feasible, analysis of the specimen test data should consider fixture resonance.

3.7.1.8 Location of Accelerometers: Location of the accelerometer controlling the vibratory input is very important. Some specifications state the location for this accelerometer, but others do not. There can be a significant difference in the input to the specimen depending on the specific location used. For example, if the accelerometer is mounted on the vibrator head itself, the input indicated by the accelerometer may not approximate the actual input to the test specimen if the attachments are not properly designed. If the attachments fit loosely, for example, a decoupling will occur, and in this case, only a fraction of the energy being supplied by the shaker head will be transmitted to the part. If such a difference does exist, it may be readily measured by mounting an accelerometer on the shaker head and another accelerometer on the part itself. In a similar manner, the amplification factor of the fixture at any point may be determined by mounting another accelerometer at any desired location.

3.7.1.9 Functional Test and Combined Environments: It is often necessary to conduct functional tests on equipment while vibrating, and the functional tests often include combined environments. For example, vibration may be combined with low or high pressure and low or high temperature. If fluid flow is involved, flex lines are required for input and output of the fluid. If the fluid media or any other aspect of the test is hazardous, it is necessary to conduct the test at a site with adequate protection for equipment and personnel. Such tests are usually more economically conducted by commercial laboratories, which normally have such facilities. An environment such as high or low temperature is provided by surrounding the specimen with a special environmental chamber. The bottom of the chamber consists of a flexible diaphragm, through which the motion of the shaker may be transmitted.

3.7.2 Shock Test:

3.7.2.1 Purpose: Mechanical shock tests are conducted to determine that the specimen will perform satisfactorily in service under the expected shock loads.