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INTERNATIONAL
400 Commonwealth Drive, Warrendale, PA 15096-0001

AEROSPACE STANDARD

SAE AS4073

Issued 1993-08
Reaffirmed 2000-03

Air Cycle Air Conditioning Systems for Military Air Vehicles

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1. SCOPE:

This SAE Aerospace Standard (AS) defines the requirements for air cycle air conditioning systems used on military air vehicles for cooling, heating, ventilation, and moisture and contamination control. General recommendations for an air conditioning system, which may include an air cycle system as a cooling source, are included in MIL-E-18927E (AS) and MIL-E-87145 (USAF).

Air cycle air conditioning systems include those components which condition high temperature and high pressure air for delivery to occupied and equipment compartments and to electrical and electronic equipment. This document is applicable to open and closed loop air cycle systems. Definitions are contained in Section 5 of this document.

2. APPLICABLE DOCUMENTS:

2.1 SAE Publications:

Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

ARP780	Environmental Systems Schematic Symbols
AIR1826	Acoustical Considerations for Aircraft Environmental Control System Design

2.2 U.S. Government Publications:

Available from Standardization Documents Order Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.

DOD-D-1000	Drawing, Engineering and Associated List
MIL-S-5002	Surface Treatments and Inorganic Coatings for Metal Surfaces of Weapons Systems
MIL-C-5541	Chemical Conversion Coatings on Aluminum Alloys
MIL-H-6875	Heat Treatment of Steel, Process for
MIL-P-7105	Pipe Threads, Taper, Aeronautical National Form, Symbol
MIL-F-7179	Finishes, Coatings, and Sealants for the Protection of Aerospace Weapon System
MIL-S-7742	Screw Threads, Standard, Optimum Selected Series, General Specification for
MIL-B-7883	Brazing of Steels, Copper, Copper Alloys, Nickel Alloys, Aluminum and Aluminum Alloys
MIL-I-8500	Interchangeability and Replaceability of Component Parts for Aircraft and Missiles
MIL-W-8611	Welding, Metal Arc and Gas, Steels, and Corrosion and Heat Resistant Alloys, Process for
MIL-A-8625	Anodic Coatings, For Aluminum and Aluminum Alloys
MIL-S-8879	Screw Threads, Controlled Radius Root with Increased Minor Diameter, General Specification for
MIL-E-18927	Environmental Control Systems, Aircraft, General Requirements for
MIL-E-87145	Environmental Control, Airborne

2.2 (Continued):

MIL-STD-130	Identification Marking of U.S. Military Property
MIL-STD-210	Climatic Information to Determine Design and Test Requirements for Military Systems and Equipment
MIL-STD-461	Electromagnetic Emission and Susceptibility Requirements for the Control of Electromagnetic Interference
MIL-STD-490	Specification Practices
MIL-STD-704	Aircraft Electric Power Characteristics
MIL-STD-810	Environmental Test Methods and Engineering Guidelines
MIL-STD-831	Test Reports, Preparation of MIL-STD-882 System Safety Program Requirements
MIL-STD-882	System Safety Program Requirements
MIL-STD-889	Dissimilar Metals
MIL-STD-1472	Human Engineering Design Criteria for Military Systems, Equipment and Facilities
MIL-STD-1568	Materials and Processes for Corrosion Prevention and Control in Aerospace Weapon Systems
MIL-STD-1587	Materials and Processes Requirements for Air Force Weapon Systems
MIL-STD-1789	Sound Pressure Levels in Aircraft
MIL-STD-2175	Castings, Classing and Inspection of
MS 33540	Safety Wiring and Cotter Pinning, General Practice of
MS 33649	Boss, Fluid Connection - Internal Straight Thread
MS 33656	Fitting End, Standard Dimensions for Flared Tube Connection and Gasket Seal
MS 33657	Fitting End, Standard Dimensions for Bulkhead Flared Tube Connections

2.3 Other Documents:

AFOSH STANDARD 161-8 Permissible Exposure Limits for Chemical Substances

3. RECOMMENDED REQUIREMENTS:

This section contains recommended requirements for inclusion in Section 3 Requirements of a detail specification prepared for procurement of air cycle air conditioning systems for use on new or retrofit on existing military aircraft. The format of this section is based on MIL-STD-490A, Appendix III.

3.1 System Definition:

This paragraph should contain a comprehensive definition of the system to be developed. A functional schematic drawing and identification of major components shall be included. Use ARP780 as a guide in the preparation of the schematic drawing.

3.2 Characteristics:

3.2.1 Performance: The system shall provide air at the flow rates, temperatures, pressures, and moisture and contaminant levels necessary to meet the environmental control and environmental protection performance requirements specified in the detail specification. The detail specification shall define the following operational conditions, where applicable, throughout the ground and flight operating envelope of the air vehicle:

a. Temperature, pressure, humidity, and level of contaminants of bleed air, ram air, or compressed ram air at the inlet to the system

b. Temperature and pressure of the compartment where the system is installed

c. Occupied and equipment compartment pressure schedules

d. Heat sink inlet temperature, pressure, flow rate, and maximum allowable heat input

e. Minimum air flows required for all operating conditions

f. Supply air distribution ducting and heat sink system pressure drop and flow rate

g. Allowable quantity of occupied and equipment compartment air to be recirculated

h. Maximum allowable engine horsepower and bleed air extraction

i. Maximum allowable electrical power

3.2.1.1 Useful Life: The nonoperating components of the system shall be designed to have a life equal to or greater than that of the air vehicle on which the system is to be installed. The useful life of the operating components of the system shall be as specified in the detail specification. Throughout the useful life, component overhaul is permissible provided the component can be overhauled economically.

3.2.1.2 Endurance Life: Components which cannot be overhauled economically shall have an endurance life equal to the useful life. Recommended minimum endurance life for system components which can be overhauled is shown in Table 1:

TABLE 1 - Endurance Life

Air Vehicle Application	Minimum Endurance Life in Operating Hours (Ground & Flight)
Cargo, bomber, and early warning	20 000
Fighter, helicopter, and trainer	10 000
Missile	1 500
All others[1]	-

[1]Operating hours will be defined by the detail specification.

In addition, endurance tests as specified in Section 4 shall be conducted to show that the system components comply with design requirements. The number of endurance test cycles for system components of missile and all other applications shall be reduced as defined in the detail specification.

3.2.1.3 Contamination: Air contamination levels within occupied compartments as a result of system operation shall not exceed the permissible exposure limits (PELs) established in AFOSH Standard 161-8.

3.2.1.4 Noise Level: Noise levels within occupied compartments as a result of system operation shall conform to the requirements of the detail specification, which may have varying requirements for different operating modes. Use AIR1826 as a guide for reducing system noise levels. Use MIL-STD-1789 as a guide for establishing allowable noise levels.

3.2.1.5 Leakage: Internal and external leakage rates for all system components shall not exceed the values specified in the detail specification. System performance requirements shall be met at maximum allowable leakage rates.

3.2.1.6 Equipment Warmup Time: The system shall be capable of operating at full capacity within 60 s of initial operation after soaking in the ambient temperature extremes outlined in 3.2.5.

3.2.2 Physical Characteristics:

3.2.2.1 Weight: The weight of the system shall not exceed the maximum allowable weight specified in the detail specification.

3.2.2.2 Size and Configuration: The size and configuration of the system and its components and assemblies shall be in accordance with the detail specification. Where desirable, the complete system or a major portion thereof shall be preassembled into a compact package; however, system configuration shall be compatible with service and repair requirements while installed in the air vehicle.

3.2.2.3 Handling Provisions: Preassembled packages and components whose weight exceeds the lifting capability of one person as defined by MIL-STD-1472 shall have provisions for the use of handling aids to enable lifting the assembly or component into and out of the air vehicle and for placing the assembly or component on the ground. These provisions shall not in any way hinder the use of the normal mounting points.

3.2.2.4 Flange Orientation: To facilitate assembly, the system shall be designed to provide for freedom in the relative orientation of inlet and discharge flange planes consistent with the overall design philosophy of the aircraft. Detail requirements will be specified in the detail specification.

3.2.2.5 Mounting: The system mounting provisions shall be such that structural loads are not reacted at the duct connections and stress is not induced into system components when installed in the air vehicle. Mounting provisions shall be capable of withstanding the inertia loads as specified in the detail specification. The system shall have provisions for mounting to the air vehicle as required by the detail specification.

3.2.2.6 Structural Integrity:

3.2.2.6.1 Proof Pressure: Unless otherwise specified in the detail specification, all system components which are exposed to positive or negative pressure shall withstand, without permanent deformation, a proof pressure equal to the greater of the following:

a. 1.5 times the gage pressure with the component at the associated temperature for the most adverse pressure and temperature condition that occurs during normal operation

b. 1.1 times the gage pressure with the component at the associated temperature for the most adverse pressure and temperature condition that occurs in the event of failure of a pressure or temperature control device.

3.2.2.6.2 Burst Pressure: Unless otherwise specified in the detail specification, all system components which are exposed to positive or negative pressure shall withstand, without rupture a burst pressure equal to the greater of the following:

a. 2.5 times the gage pressure with the component at the associated temperature for most adverse pressure and temperature condition that occurs during normal operation

b. 1.5 times the gage pressure with the component at the associated temperature for the most adverse pressure and temperature condition that occurs in the event of failure of a pressure or temperature control device.

3.2.2.6.3 Rotating Equipment Containment: The housing and scrolls of all rotating machinery of the system shall completely contain blade failures and all fragments from:

a. Fused drive rotor failures (including tri-hub burst) at the maximum speed and temperature associated with this speed

b. Nonfused drive rotor failures (including tri-hub burst) at the maximum speed that can result from any failure inducing condition or 135% of the maximum normal speed, whichever is greater, at the temperature associated with the speed

c. Driven rotor and thrust disk failures (including tri-hub burst) at maximum speed that can result from "a" or "b" above at the temperature associated with this speed. Driven rotors shall not burst at speeds lower than the drive rotors burst speed.

Containment means that fragments may penetrate the containing housing but shall not pass through the housing. Particles or parts resulting from a failure and passing through inlet or outlet ports of the assembly shall be contained by the adjoining ducting.

3.2.2.7 Service and Access: System components and preassembled packages shall have easy accessibility, serviceability, maintainability, and component replaceability. Meters, nameplates, fluid level indicators, and gages shall be located to permit reading without the use of a mirror or other aid. Components requiring servicing prior to removal for overhaul shall be easily accessible for periodic inspection, servicing, trouble diagnosis, testing, and replacement. It shall be possible to remove and replace individual system components which require periodic removal for overhaul, servicing, or replacement without removing any other component except where not practical. Items which require removal shall be designed for quick and easy removal and replacement. Provisions shall be made for easy separation of the air cycle machine from an attached heat exchanger, if necessary, and from other accessories and interconnecting ducting. Expendable coolant tanks shall have a readily accessible fill port and overboard drain. Water separators which have coalescers shall be designed such that coalescers can be readily replaced and/or serviced. Components which have an oil lubrication system shall be designed to permit easy lubricant replenishment while the component is installed in the air vehicle.

3.2.2.8 Electrical Requirements: All electrical equipment associated with the system shall be in accordance with the detail specification. All electrical components shall not cause ignition when surrounded by an explosive atmosphere. The electrical equipment shall be designed to operate with power in accordance with MIL-STD-704.

3.2.2.9 Lubrication: Lubrication for all system components shall be in accordance with the detail specification. All lubrication filler caps and drain plugs shall be positive, self-locking devices and shall be attached with a chain or equivalent device.

3.2.3 Reliability: The mean-time-between-failures (MTBF) for the system and components thereof shall be equal to or greater than the value necessary for achievement of the required reliability of the air vehicle. The system and individual components shall meet the MTBF requirements specified for the system and components in the detail specification. Failure is defined as any malfunction which causes performance degradation outside the limits defined herein.

3.2.4 Maintainability: The quantitative maintainability requirements (e.g., mean-time-to-repair, maintenance manhours per operating hours, etc.) shall be as specified in the detail specification. These requirements shall be based on the values necessary for achieving overall air vehicle maintainability requirements. Diagnostics requirements shall be in accordance with the detail specification.

3.2.5 Environmental Conditions: The system shall provide the required performance during all flight speeds; altitudes and attitudes; rapidly changing altitudes, attitudes, and airspeeds; extremes of engine operation; extremes of vibration; extremes and rapid changes of pressurized compartment pressure altitudes; extremes of temperature; and accelerations which may be encountered during takeoff, flight, landing, or servicing of the air vehicle and during all ground operations. The system shall provide the required performance during and after exposure to the following environmental conditions, and possible combinations thereof, encountered in ground and airborne operations:

a. Temperature: External and internal temperatures, and the rates of change, that result from operation throughout the range of ground and flight temperature extremes defined by the detail specification

b. Pressure: Pressure altitudes from 1300 ft (396 m) below sea level to the operational ceiling altitude of the air vehicle and rates of pressure change as specified in the detail specification

c. Humidity: During flight and ground operation, specific humidity throughout the range defined by the detail specification

d. Salt Atmosphere: The system shall withstand, in both operating and nonoperating conditions, exposure to salt-sea atmosphere without impairment of service life or operating characteristics

e. Dust: External dust conditions of MIL-STD-210, and internal air containing dust as defined in the detail specification

f. Fungus: The system shall withstand, in both operating and nonoperating conditions, exposure to fungus growth as encountered in tropical climates without impairment of service life or operating characteristics

g. Acceleration: Acceleration levels specified in the detail specification

h. Vibration: Vibration conditions specified in the detail specification

3.2.5 (Continued):

i. Shock: Basic design shock conditions specified in the detail specification

j. Acoustical Noise: Maximum noise level to which components are exposed as defined in the detail specification

3.2.5.1 Storage: The system shall be capable of satisfactory operation after storage in the conditions as specified in the detail specification.

3.2.6 Transportability: Transportability of the system components shall comply with the requirements specified in the detail specification.

3.3 Design and Construction:

3.3.1 Materials, Parts, and Processes: Materials, parts, and processes used in the system shall conform to government specifications wherever government specifications for such materials, parts, or processes exist and are suitable for the service indicated. In cases where government specifications cannot be used, contractor specifications must be approved by the procuring activity. The use of contractor's specifications will not constitute waiver of government inspection.

3.3.1.1 Materials: Materials selection shall be made in accordance with MIL-STD-1587 and corrosion control established in accordance with MIL-STD-1568.

3.3.1.1.1 Magnesium and Magnesium Alloys: Magnesium and magnesium alloys shall not be used in any components of the system unless allowed by the detail specification.

3.3.1.1.2 Corrosion-Resisting Steels: The following limitations shall be followed in corrosion-resisting steel applications unless deviations are specifically approved by the procuring activity:

a. Unstabilized austenitic steels shall not be used above 700 °F (371 °C)

b. Cold-rolled stainless steel shall not be used at a temperature of more than 50 °F (28 °C) below the recovery temperature;

c. Precipitation hardenable stainless steels shall not be used above 750 °F (399 °C).

3.3.1.1.3 Titanium and Titanium Alloys: Titanium and titanium-based alloys may be used in applications where their use is justified in terms of weight savings, improved performance, improved serviceability, and where adequacy of manufacturing methods are demonstrated.

3.3.1.1.4 Cadmium-Plated Materials: Cadmium-plated materials shall not be used except for standard parts (nuts and bolts) and shall not be utilized in locations where the temperature may exceed 450 °F (232 °C) or where exposure to fuel is possible.

3.3.1.1.5 Neoprene: Neoprene shall not be used in locations where the temperature may exceed 250 °F (121 °C) or where exposure to silicate ester or polyalphaolefin coolant fluid is possible.

3.3.1.1.6 Nickel: Use of nickel for heat exchanger fin material in applications which may be exposed to salt or sulfur-containing atmospheres, requires approval of the procuring activity.

3.3.1.1.7 Critical Materials: Critical materials shall not be used unless approved by the procuring activity.

3.3.1.1.8 Organic Materials: Materials that are nutrients for fungi shall not be used where it is practical to avoid them, unless approved by the procuring activity. Where used, they shall be treated with a suitable fungicidal agent or otherwise protected.

3.3.1.1.9 Corrosion-Promoting Materials: Materials which might deteriorate into corrosion-promoting products shall not be used.

3.3.1.1.10 Protective Treatment: When materials are used in the system that are subject to deterioration when exposed to the environmental conditions specified herein, they shall be protected against such deterioration in a manner that will in no way prevent compliance with the requirements herein. The use of any protective coating that will crack, chip, or scale with age or extremes of climatic and environmental conditions, shall be avoided.

3.3.1.2 Parts:

3.3.1.2.1 Standard and Commercial Parts: Standard parts (MS or AN) such as screws, bolts, nuts, etc. shall be identified on drawings by their part numbers. Commercial utility parts may be used provided they possess suitable properties, conform to all requirements herein, and are replaceable by the standard parts (MS and AN) without alteration, and provided the corresponding standard part numbers are referenced in the parts list. In the event there is no suitable corresponding standard part in effect, commercial parts may be used provided they conform to all requirements herein.

3.3.1.2.2 Fasteners: Standard and conventional methods of joining shall be given first consideration. Fasteners used in applications affecting safety of flight shall have a dual locking device to prevent their loss. Attention shall be given to use of fasteners which have a proven service life. Corrosion-resistant threaded steel fasteners shall be used for all clamps, connectors, and structural applications which are exposed to temperatures in excess of 450 °F (232 °C).

3.3.1.2.3 Bosses: Fluid, including air, connection bosses shall conform to MS 33649. Bosses shall be made deep enough or shall incorporate fitting stops to prevent damage to the internal mechanism or the blocking of passages when fittings are screwed into the bosses. Bosses should be large enough to permit thread insert thread repair.

3.3.1.2.4 Tube Connectors: Any externally threaded tube connection shall conform to MS 33656 and MS 33657.

3.3.1.2.5 Threads: All threads shall be class 3 in accordance with MIL-S-8879 or MIL-S-7742. Tapered pipe threads shall not be used except for permanent closures or where temperatures exceed 275 °F (135 °C). Tapered pipe threads shall be in accordance with MIL-P-7105 and shall not be used in materials/bosses subject to stress corrosion.

3.3.1.2.6 Synthetic Rubber Parts: Elastomeric components shall be fabricated from materials having maximum practicable ozone and aging resistance consistent with performance requirements and applicable specifications. Synthetic materials that will limit the storage life of the equipment shall not be used without specific approval by the procuring activity.

3.3.1.2.7 Safetying: Where practicable, threaded parts, such as nuts and bolts, shall be safetied in accordance with MS 33540. Other means of safety shall be subject to approval by the procuring activity.

3.3.1.2.8 Pins: Spring pins, roll pins, and groove pins shall not be used unless approved by the procuring activity. Taper pins shall not be used as mechanical fasteners unless retained by nuts.

3.3.1.2.9 Snap Rings: Snap rings shall not be used in any application where improper installation or dislocation of the ring could cause failure or malfunction of a component or subsystem or where the accumulation of tolerances could allow destructive end play or looseness. If snap rings are used, they should be installed and removed with standard pin-type pliers whenever possible. Snap rings shall not be used where they carry structural loads or are not positively retained.

3.3.1.2.10 Castings: Castings shall be controlled and inspected in accordance with MIL-STD-2175.

3.3.1.2.11 Inspection Seals: A seal must be provided at each strategic location to indicate if disassembly has been made after inspection. The vendor shall determine the locations for the seal placement. These seals shall be located on all sensing line connections and control linkages, as practicable.

3.3.1.3 Processes:

3.3.1.3.1 Aluminum Alloys: Aluminum alloys shall be protected to resist corrosion and wear in accordance with MIL-A-8625 except that protection in accordance with MIL-C-5541 may be used where design conditions permit.

3.3.1.3.2 Steel: Steel shall be of the corrosion resistant type or shall be suitably protected to resist corrosion. Steel and steel alloys shall be heat treated in accordance with the applicable provisions of MIL-H-6875.

3.3.1.3.3 Passivation: Corrosion resistant alloy parts shall be passivated in accordance with MIL-S-5002. Where passivation of final assemblies will result in entrapment of acids, the passivation may be accomplished on subassemblies. Where passivation of subassemblies will result in entrapment of acids, the passivation may be accomplished subsequent to any forming.

3.3.1.3.4 Cold Stabilization: Close fitting sliding steel parts shall be cold stabilized in accordance with MIL-H-6875 to reduce warpage tendencies.

3.3.1.3.5 Welding and Brazing: Welding shall be in accordance with MIL-W-8611, and brazing shall be in accordance with MIL-B-7883.

3.3.1.3.6 System Surface Finishes: The system surfaces shall be finished with applicable materials and corrosion protective systems selected in accordance with MIL-F-7179.

3.3.1.3.7 Dissimilar Metals: All parts of the system shall be designed to provide protection against electrolytic (galvanic) corrosion through contact of dissimilar metals so they will perform satisfactorily for the useful life of the component under all operational and climatic conditions indicated herein. Dissimilar metals are defined in MIL-STD-889.

3.3.2 Electromagnetic Interference: The system shall meet the requirements of MIL-STD-461.

3.3.3 Nameplates and Product Marking: Each part or assembly of the system shall be permanently marked in accordance with MIL-STD-130. The required marking shall be applied in such a manner that it will not be effaced or obliterated as a result of service usage during the life of the component. The part number and serial number for each part or assembly shall be shown on a nameplate or the information may be etched, engraved, embossed, or stamped in a suitable location on the component. Nameplates shall be securely fastened to the component. Nameplates shall not be wired onto the component. Component assemblies which may be reversed, such as valves and filters, shall incorporate a clearly visible and permanent external marking to indicate flow direction. All control sensing ports shall be permanently and clearly identified. Decal markings shall not be used.

3.3.4 Workmanship: Workmanship and finish on all parts shall be in accordance with the normal high grade manufacturing practices for aircraft accessories and equipment. Particular attention shall be given to neatness and thoroughness of marking parts, plating, painting, machine screw assembling, welding, and brazing, and freedom of parts from burrs and sharp edges.

3.3.5 Interchangeability and Replaceability: All system parts having the same manufacturer's part number shall be functionally, structurally, and dimensionally interchangeable. Drawings for altered or selected items of the system shall comply with DOD-D-1000. Parts interchangeability shall be in accordance with MIL-I-8500. It shall be possible to replace any component assembly of the system without requiring replacement of other components. Connectors shall be uniquely keyed to prevent sensors of similar configuration but with different part numbers from being installed in the wrong location.

3.3.6 Safety:

3.3.6.1 Flight Safety: The system design shall be consistent with accepted aircraft practices and shall provide against failure which may indirectly reduce crew efficiency, hinder flight, or endanger life. The system design shall include consideration of possible hazards created by human error or equipment failure so that, insofar as possible, injury to personnel or damage to the air vehicle will be eliminated. Ducting and components shall be insulated or shrouded as required to prevent overheating of wiring, structure, or other components, eliminate personnel hazard, or eliminate potential fire hazard. Entry and retention of combustible fluid under or within insulation shall be prevented. All insulation shall be flame resistant.

3.3.6.2 Ground Safety: The system shall be designed to provide adequate accessibility for safe servicing, inspection, maintenance, and installation in all areas. The system shall be so constructed that such items as control knobs, handles, or any other such apparatus do not have sharp-edged projections which would be hazardous to personnel.

3.3.6.3 System Safety: The provisions of MIL-STD-882 shall be applied to the system to the extent specified by the procuring activity.

3.3.6.4 Failure Concept: The system shall be designed in accordance with the "single failure" concept; that is, any failure within a given component shall not result in failure of another component. In general, mechanical components such as valves which are associated with hot airflow shall be designed to fail in the closed position. Components associated with the cold airflow shall be designed to fail in the open or safe position.

3.3.7 Human Performance: The system shall be designed to permit optimum performance by maintenance personnel. This shall be accomplished through systematic application of the principles and procedures of human engineering. Design details shall comply with the human engineering design standards established by MIL-STD-1472. In particular, system configuration shall be compatible with service and repair requirements while installed in the air vehicle.

3.4 Documentation:

This paragraph should specify the plan for system documentation such as: specifications, drawings, technical manuals, test plans and procedures, installation instruction data.

3.5 Logistics:

3.5.1 Maintenance: The system shall be designed to permit maintenance, other than overhaul of the air cycle machine, at organizational and field maintenance levels. Except as otherwise specified herein, system components shall not require removal from the air vehicle for servicing in less than 3000 h of operation. Under normal operating conditions, filters and water separator coalescers shall not require removal from the air vehicle for cleaning in less than 500 h of operation. Careful consideration shall be given in the design of components to simplify their overhaul. The necessity for special tools and fixtures to perform maintenance and overhaul shall be kept to a minimum. All rotating equipment shall be designed in such a manner that, for purposes of overhaul, the rotating parts can be assembled and balanced as a unit and installed without requiring rebalancing in the aircraft installed position. Air cycle machines and high-speed fans which use lubrication systems shall not require the changing or addition of oil at intervals of less than 1000 h of operation.

3.6 Precedence:

This paragraph shall either specify the order of precedence of requirements or assign weights to indicate the relative importance of characteristics and other requirements. It shall also establish the order of precedence of the detail specification relative to referenced documents.

3.7 Major Component Characteristics:

3.7.1 Air Cycle Machine: The air cycle machine shall possess the characteristics of ruggedness, high efficiency, low weight, and minimum volume.

3.7.1.1 Dynamic Balance: While operating within the air vehicle, the air cycle machine shall not transmit to the structure of the air vehicle vibration of an amplitude and "g" level greater than that specified in the detail specification within the permissible speed of the air cycle machine.

3.7.1.2 Reverse Thrust Load: The air cycle machine shall be designed to satisfactorily withstand reverse thrust loads that could result from the normal back-pressure loads on the turbine wheel resulting from such things as valve closing or freezing of the water separator. Where applicable, ball bearing air cycle machines shall be so designed that reverse thrust forces opposing bearing preload direction will not exceed the initial preload force under the most severe condition. During maximum reverse thrust load conditions, there shall be no rubbing of the turbine, fan, or compressor wheel against the housing or mating parts.

3.7.1.3 Elapsed Time Meter: If a time-totalizing meter is required, it shall be installed on each air cycle machine to register actual operating time of the assembly up to 9999 h. The meter shall be located so that it cannot be easily damaged and so that mirrors are not necessary for reading the meter when the air cycle machine is installed in the air vehicle.

3.7.1.4 Overspeed: The air cycle machine shall be so designed that operation at the highest single failure speed for a period of 5 min is possible without rubbing of the turbine, fan, or compressor wheel against the housing or mating parts and without any adverse effect upon other components of the machine.

3.7.1.5 Instrumentation Pickups: Thermocouples located to sense critical bearing temperatures shall be provided on ball bearing machines for use during development and acceptance testing. A method shall be incorporated into the air cycle machine which will permit measurement of the rotational speed of the machine. This may be accomplished by means of a magnetized nut or part on the rotating shaft. For air bearing machines, a method shall be provided to measure shaft displacement during development and acceptance testing. It should be possible, with a specially instrumented unit, to measure displacement during flight testing, if required.

3.7.1.6 Lubrication System: Air cycle machines which use oil for bearing lubrication shall have a self-contained lubrication system. The oil utilized in the lubrication system shall conform to the requirements of the detail specification. The lubrication system of air cycle machines which use a wet sump shall have provisions which will permit ground personnel to readily check the oil level while the system is installed in the air vehicle. Cotton packed sumps shall be serviced at predetermined time intervals. Oil reservoir pressurization from an external source shall not be required. The air cycle machine shall be designed to preclude the possibility of water entering the lubrication system, and the lubrication system shall have adequate venting to prevent condensation inside the sump. The lubrication system shall be designed to prevent the introduction of oil or other contaminants into the conditioned air supply.

3.7.1.7 Rotational Acceleration: The air cycle machine shall be capable of withstanding accelerations in rotative speed which are of a 20% greater rate than the maximum expected rate which will be encountered throughout the complete range of operating conditions without adverse effect on operation or life of the air cycle machine.

3.7.1.8 Bearings: Bearings which are adequate for the loads, speeds, and temperature involved shall be selected for use in the air cycle machine. The bearings shall be provided with sufficient cooling and lubrication to ensure fulfillment of the specified life requirements. If cooling air is required for the bearings, the manufacturer shall prepare a detailed design analysis of the bearing installations to be used in the air cycle machine. This analysis shall be supplied to the bearing manufacturer, if applicable, for recommendations and shall also be supplied to the procuring activity for information. Also, the bearing manufacturer's recommendations and comments shall be supplied to the procuring activity. Air cycle machines employing self-energized air bearings shall meet the following requirements:

a. With the air cycle machine at rest, rotation shall begin before the inlet pressure level cited in the detail specification is reached.

b. With the air cycle machine rotating and with inlet pressure decreasing, the air cycle machine shall continue to rotate normally till the pressure level cited in the detail specification is reached.

c. The air cycle machine shall meet the requirements of (a) and (b) after 5000 start-stop cycles.

d. The air cycle machine shall withstand sudden shutdown from any speed throughout the range of normal operating conditions without damage.

3.7.1.8 (Continued):

e. Prolonged operation at minimum turbine outlet temperature shall not reduce air cycle machine life.

f. Prolonged operation at maximum temperature shall not reduce air cycle machine life.

Air cycle machines incorporating ball type bearings shall have design measures to preclude bearing brinelling during nonoperation transportation and storage environment.

3.7.1.9 Prevention of Adverse Effects Due to Entrained Moisture: The air cycle machine and control system shall be so designed that either entrained moisture is precluded from entering the turbine or that the turbine cannot be adversely affected by entrained moisture in the air entering the turbine or by entrained moisture or ice which results from the expansion process through the turbine.

3.7.1.10 Replaceable Turbine Nozzle: The air cycle machine turbine inlet nozzle shall be replaceable as a single unit and shall not be a part of the torus or any other major part.

3.7.1.11 Balancing: The air cycle machine shall be so designed to permit balancing by grinding without reducing structural integrity. This may be accomplished through use of a balancing ring.

3.7.1.12 Wheel Retention: Turbine, compressor, and fan wheels shall be positively retained on the shaft. Shrink or press fit is unacceptable.

3.7.1.13 Resonant Frequencies: Resonant blade frequencies shall be above the excitation frequencies of the system.

3.7.2 Heat Exchangers: Heat exchangers shall be constructed of corrosion resistant materials or provide for adequate corrosion resistance. Heat exchangers shall be designed to minimize ram air drag and bleed air pressure drop. Heat exchangers which are exposed to direct impact of rain shall be so designed that they will not be damaged by a rainfall rate of 4.0 in/h (10.2 cm/h) for a duration of 5 min at the maximum low level speed of the air vehicle. Heat exchangers which dissipate heat from the bleed air or compressed ram air into fuel or coolants other than water shall be so designed that a single structural failure will not result in leakage of fuel or coolant fluid into the supply air if leakage could create the possibility of fire or explosion or result in excessive toxicity levels or noxious odors in occupied compartments. All heat exchangers shall be designed to satisfactorily withstand the pressure and temperature cycling encountered throughout the required operational life. In applications where hot air is introduced into cooler air upstream from a heat exchanger, the hot air shall be evenly mixed with the cooler air prior to reaching the inlet of the heat exchanger. Ram air heat exchangers shall be designed to eliminate functional problems due to operation in icing conditions and in dust contaminated environments as specified in the detail specification.

3.7.2.1 Water Boilers and Water Storage Tanks: Water boilers and water storage tanks, which may be used for providing a supplemental heat sink for the system during high-speed flight conditions, shall be constructed of corrosion resistant materials. Water consumption shall be minimized and consistent with other design parameters. Water boilers and storage tanks shall be capable of operating under all conditions and shall withstand repeated freeze and thaw cycles without use of an antifreeze. The water storage tanks shall be provided with a readily accessible fill port and overboard drain. Pressurized water storage tanks shall be protected against excessive pressure. Water storage tanks using airframe structural members shall be avoided, and no damage to the air vehicle shall be possible under any conditions of flight, landing, or other normal operation when the water is completely frozen. The steam shall be exhausted overboard, and these exhaust provisions shall be designed to minimize water "carry over" and water loss due to attitudes other than level flight. Exhausted steam shall not accumulate as ice on any part of the air vehicle. Water boilers shall be designed for use of potable water. A means of access for inspection of water boiler heat exchangers and storage tanks, while installed in the air vehicle, shall be provided.

3.7.3 Airflow Control System: The amount of airflow to each air cycle system shall be controlled by an airflow control system. The system shall be designed to minimize required airflow consistent with thermal demands, pressurization, noise, air temperature, distribution, and ventilation requirements. Provisions shall be incorporated to reduce system flow to eliminate overheat, overpressure, and overspeed conditions. The temperature settings and response time for flow reduction shall be selected to protect system components from damage and to preclude system shutdowns during transients occurring in normal operation.

3.7.3.1 Shutoff Valve: A valve which will permit the crew to shut off all air supplied by the system to compartments for heating, cooling, ventilation, and pressurization shall be installed as a portion of each air cycle system. The valve shall have the highest degree of reliability achievable. Closing the valve shall not shut off the air supply for those auxiliary functions which are deemed critical in the detail specification. Examples of auxiliary functions which might be considered critical are canopy defogging/defrosting, engine inlet de-icing, rain removal, anti-g suit pressurization, and pressure suit ventilation and pressurization. The maximum time required to close the valve from any degree of opening, including the full open position, shall be as specified in the detail specification. The minimum time required to close the valve from the full open position shall be as specified in the detail specification. The normal and failure mode position (open or closed) of the valve shall be determined from a failure mode and effect analysis. The shutoff feature may be incorporated in the flow control valve.

3.7.3.2 Pressure Regulator: If required by the detail specification, a pressure-regulating or limiting device shall be incorporated in the air cycle pack. The pressure regulator and shutoff valve may be combined into one assembly. The pressure regulator performance shall be as specified in the detail specification.

3.7.3.3 Maximum Flow: As an emergency measure in the event of failure of the normal operating control system, a flow limiting device shall be provided which shall assure that system flow will not exceed the value specified in the detail specification.

3.7.3.4 Minimum Flow: For a normal operating system, the flow control system shall be designed to assure that the minimum flow rate, as specified in the detail specification, will always be met or exceeded for all ground and flight conditions.

3.7.3.5 Stability: The airflow control system shall respond to any change in the operating conditions such that the airflow rate through the system will return to the normal control limits within 4 s from the time a change has occurred and system inlet conditions are stabilized. The control system shall not become unstable when subjected to any transient condition of the air vehicle. The airflow control system shall be stable when operating with the compartment temperature control system which is used in conjunction with the air cycle system.

3.7.3.6 Airflow Control System Environmental Conditions: The effects of humidity, freezing of condensate in lines, high and low energy starting, local heating, vibration, and pressure and thermal shock shall be carefully considered in component design and shall not deleteriously affect their operation or service life. Control devices including orifices shall be designed to prevent malfunctions due to freezing of moisture, corrosion, or contamination within the devices.

3.7.4 Moisture Control Provisions: All air cycle systems shall have provisions which will assure that air delivered to occupied compartments and noncold plate cooled electronic equipment is free of excessive entrained moisture. The system shall be constructed so that all components are located or fitted with proper insulation, drainage, and venting to preclude moisture accumulation during system operation and shutdown. Means shall be incorporated to prevent accumulation of water at shutoff and modulating valves.

3.7.4.1 Low Pressure Water Removal:

3.7.4.1.1 Water Separator: The maximum quantity of entrained moisture in the water separator discharge air shall not exceed the values cited in the detail specification. Any entrained moisture in the discharge air must be eliminated to meet 3.7.4.

3.7.4.1.1.1 Bypass Valve: An integral bypass valve which will allow passage of airflow around a blocked separator device shall be incorporated. The bypass valve shall be so located and designed that its operation will not be degraded below acceptable limits by ice buildup. The bypass shall be sized to pass sufficient flow for maintaining required ventilation and pressurization. A means shall be provided for indicating if the bypass valve has activated so that maintenance personnel can take corrective action.

3.7.4.1.1.2 Antifreeze Control: Water separators which are exposed to the possibility of freezing conditions shall be protected by antifreeze control provisions. This shall be accomplished either by sensing the dry-bulb temperature of the air entering or leaving the separator and maintaining this temperature at a minimum of 35 °F (2 °C) below 27 000 ft (8230 m) altitude, and above the frost point of the bleed air at altitudes above 27 000 ft (8230 m) by mixing hot air with turbine discharge air, or by sensing pressure drop across a screen and adding hot air to turbine discharge air as required to maintain the pressure drop across the screen below a preset maximum allowable value. The provisions for adding warm air to prevent freezing shall meet the following requirements:

3.7.4.1.1.2 (Continued):

a. The water separator air temperature control shall not cause the airflow control or compartment temperature control to cycle continuously under any operating conditions.

b. After any change in operating conditions, the water separator temperature control shall function to stabilize the water separator air temperature within 30 s from the time the change has occurred and system inlet conditions are stabilized.

c. The water separator air temperature control shall maintain an essentially stable water separator discharge temperature within an allowable temperature range of 37 °F ± 2 °F (2.8 °C ± 1 °C) for all altitudes between sea level and 27 000 ft (8230 m) or as specified in the detail specification. Above 27 000 ft (8230 m) altitude, the water separator discharge temperature must be maintained above the frost point of the bleed air and not allowed to drop below 0 °F (-18 °C). If the temperature of the water separator discharge setpoint is allowed to decrease with ambient humidity as the aircraft gains altitude above 27 000 ft (8230 m), then the setpoint control shall be done in a gradual, stable manner.

d. The water separator temperature control shall be stable when operating in conjunction with the airflow control and compartment temperature control;

e. If a screen is used to control freezing, there must be no interaction between the deltaP control and water separator safety relief valve for all operating conditions. Valve reset pressure must be considered.

3.7.4.1.1.3 Water Separator Coalescer: Water separators which utilize a coalescer shall be designed for quick and easy removal and replacement of the coalescer. The coalescer shall be washable and/or commercially dry cleanable. It is recommended that the coalescer be made of polyester fiber, PTFE, or materials of similar capabilities in coalescer use.

3.7.4.1.1.4 Drainage: A drain line shall be provided to drain away liquid water that is removed by the water separator. The design (orientation, sizing, length, etc.) of the drain line shall be such that the overall pressure drop of the line is small enough to allow all water removed by the separator to drain off at all aircraft attitudes at the maximum ambient humidity conditions. The drain line shall be designed to prevent freezing that could cause blockage.

3.7.4.2 High Pressure Water Removal: High pressure water removal provisions shall meet the requirements of the detail specification.

3.7.5 Ram Air Mover: In all bootstrap air cycle systems and in simple air cycle systems where the fan wheel of the air cycle machine does not create sufficient ram air heat sink flow, a means shall be incorporated to induce adequate airflow during ground and low-speed flight operations. A fan or bleed air ejector, which is automatically shut off when not required, shall be used for inducing airflow through the ram air circuit. If a fan is used, either the installation shall be designed so that the fan does not windmill or windmilling shall not adversely affect the service life or safety of the fan. The fan may be electrically, hydraulically, or bleed-air driven. The device which controls operation of the ram air mover shall be designed to normally fail in the safe position. The fan shall not be damaged or caused to malfunction due to a failure of the fan control device in the open or on position.

3.7.6 Valves: Valves used in the system shall meet the following requirements:

a. Direction of airflow shall be indicated by a flow arrow cast into, or otherwise permanently marked on, each valve body.

b. Each shutoff or modulating valve shall incorporate an external means for visually indicating proper function.

c. Regardless of whether the valve is closed or open, no internal part of a shutoff or modulating valve shall project beyond either end of the valve body, unless dictated by installation constraints.

d. Resonant excitation of any valve, induced by aerodynamic forces or vibration environment, shall not affect the performance of the valve within the specified operating range.

e. Sensing lines and filters to prevent foreign material from entering the control mechanism shall be an integral part of pneumatic valves. Accessibility of filters is an essential feature, and the location of each filter shall be clearly indicated by a permanent marking;

f. All valves shall meet the requirements herein regardless of direction of gravity.

g. The direction of input shaft rotation to manually open shutoff valves shall be indicated by an arrow and the word "OPEN" shall be cast in or otherwise permanently marked on the valve.

h. Electric actuators for valves shall be in accordance with the requirements of the detail specification.

i. All valve microswitches shall be hermetically sealed and shall be replaceable without requiring disassembly of the valve other than the housing cover.

j. Valve design shall prevent backward installation and improper connection of sensing lines or electrical wiring.

3.7.7 Temperature Controls: Temperature controls shall provide stable control of temperature during steady-state conditions and shall provide rapid recovery from the effects of transient conditions. Specific steady-state and transient temperature control performance shall be within the limits defined in the detail specification. Temperature controls shall be insensitive to normal fluctuations in aircraft electrical power.

3.7.7.1 Temperature Sensors: Each temperature sensor shall be located so that enough airflow is circulated over it so that the accuracy and response time of the sensor is adequate to truly characterize the fluid temperature. The sensor may provide either an electrical or pneumatic signal. Each sensor shall be so designed that it will not be damaged by ice particles, aerodynamic forces, or vibration. Resistance Temperature Device (RTD) type sensors shall be used in a manner to preclude adverse self-heating conditions. The operating characteristics of sensors shall not exceed the specified tolerance range over their operating life. The sensor response shall be fast enough to prevent control instabilities.

3.7.8 System Controller: Control of the system shall be provided automatically by a controller utilizing installed sensors, aircraft data and other information as required to provide stable operation of the system under all steady-state and transient flight conditions, and environments. The controller shall meet the requirements specified in the detail specification. The selection of an independent controller or one integrated with other aircraft control functions shall be in accordance with the requirements in the detail specification. Data bus interfaces shall be in accordance with the detail specification. Manual backup control shall be provided as specified in the detail specification.

3.7.8.1 Digital Control: If digital control is selected or required by the detail specification, the software architecture and development shall be in accordance with the detail specification.

3.7.9 Fans: All electrically driven fans shall be provided with permanently lubricated bearings, and lubricant replenishment shall not be required except at overhaul. Fans shall be capable of operating for 5 min at 120% of normal maximum operating speed without damage. All fans shall meet the containment requirements of 3.2.2.6.3. Hydraulically and bleed air driven fans shall meet the requirements of the detail specification. Fan performance and noise level shall meet the requirements specified in the detail specification. A screen or inherent design configuration shall prevent injury to personnel and protect the fan from foreign object damage. A braking feature shall be incorporated if windmilling is possible.

3.7.10 Pneumatically Actuated Components: All components which utilize pnuematic actuating mechanisms shall be protected by filter(s) or other means to prevent contaminants from entering the controlling mechanisms. Control mechanisms shall be designed with clearances which are not easily plugged by contamination. The system shall be designed for a minimum number of filters. The filter screen porosity should be designed to prevent entry of particles into the control mechanism which would adversely affect operation of the control mechanism. Filters shall be readily accessible for inspection and maintenance and shall have a minimum of 600 h service life without maintenance. Filters shall be designed so as to prohibit flow blockage. All bleed and sensing lines and all their fittings used in pneumatic control systems shall have an outside diameter of at least 0.188 in (4.78 mm). Continuous drainage shall be provided in pneumatic controls so that accumulation of condensation, freezing, and corrosion will not occur. All pneumatically actuated components shall be made of corrosion-resistant materials. Provisions shall be incorporated to prevent entrained moisture from entering the control mechanisms of all pneumatically actuated components. Pressure pickups should use reverse facing stream pitot tubes to reduce contamination wherever the flow effect on the signal can be accepted.

3.7.11 Ducting, Couplings, and Insulation: All ducting, couplings, and insulation used as a part of the system shall meet the requirements of the detail specification.

3.8 Mockup:

A mockup of the system and the compartment where it is installed shall be prepared for examination and approval by the procuring activity as soon as the air vehicle contractor has established the installation features of the system. The mockup shall be based on simulated full-scale hardware or a three-dimensional computer model as required by the detail specification, and shall be updated and maintained as necessary throughout the program.

4. QUALITY ASSURANCE PROVISIONS:

4.1 Reponsibility for Tests:

Unless otherwise specified in the contract or purchase order, the manufacturer is responsible for the performance of all inspection and test requirements as specified herein. Except as otherwise specified in the contract or order, the manufacturer may use his own or any other facilities suitable for the performance of the inspection and test requirements specified herein, unless disapproved by the contractor. The contractor reserves the right to perform any of the inspections or tests set forth herein where such inspections and tests are deemed necessary to assure supplies and services conform to prescribed requirements. The manufacturer shall utilize the most cost-effective procedure for quality assurance for all phases from initial development up to production.

4.2 Classification of Tests:

The inspection of the system shall be classified as:

a. Preproduction tests (4.5)
b. Quality conformance tests (4.6)

4.3 Test Conditions:

Unless otherwise specified, all tests shall be conducted at an atmospheric pressure of 24 to 30.5 in Hg (81 to 103 kPa), an ambient temperature of 73 °F ± 18 °F (23 °C ± 10 °C), and an ambient relative humidity of 50% ± 30%. When tests are conducted with atmospheric pressure, temperature, or relative humidity substantially different from the specified values, proper allowance shall be made for variance from specified conditions. Actual pressure, temperature, and relative humidity shall be recorded during each test.

4.3.1 Tolerances: Tolerance and accuracy for all measurements shall be within the limits specified in paragraphs 5.1.1 and 5.1.2 of MIL-STD-810.

4.3.2 Cleanliness: Test units shall be reasonably free of oil, grease, fuels, water, chips, dust, dirt, and any other foreign matter.

4.4 Mockup:

The mockup of the system and the compartment where it is installed shall be utilized for purposes of inspecting physical fit of components. A 3-D computerized model may be specified in lieu of physical mockups.

4.5 Preproduction Testing:

Preproduction tests shall be accomplished to verify that the design and performance requirements of Section 3 have been satisfied. Compliance with requirements shall be verified wholly or partially by inspection, review of analytical data, demonstration, or test and review of test data, or combinations of these, as specified in Table 2. The VCRI provides for accountability for each Section 3 requirement, corresponding Section 4 verification requirement, and method of verification.

4.5.1 Test Plan: At least 90 days prior to the start of preproduction tests, the contractor shall submit to the procuring activity for approval of the test plan to be followed by the manufacturer. The test plan shall be submitted in accordance with the data requirements of the contract. This plan shall include, as a minimum, a listing of all components to be tested along with their contractor and manufacturer part numbers, a description of the test facilities, list of instrumentation to be used, a description of the test procedure for all tests to be conducted, and the order of testing. In the event the manufacturer plans to pass some tests on the basis of similarity, data justifying similarity shall be submitted to the procuring activity for approval at the time of submittal of the test plan. Data required for justifying passage of tests on the basis of similarity shall include the following:

a. The necessary data for each component to determine size, weight, construction, function, pressure and temperature exposure, and materials similarity.

b. The test reports of the previously qualified component.

4.5.2 Test Specimens: The preproduction test specimens shall be production run units or units with the same characteristics including finish, weight, material, and subject to the same quality assurance controls as production run units. The preproduction test program shall consist of both component testing and complete system testing. If a failure occurs during testing which necessitates a design change, analysis is required to determine which portion of the test program will require repeating with the newly designed component. If it is necessary to change the sequence of testing specified herein for systems or components, the manufacturer shall give a complete explanation in the test plan submitted for approval. It will not be necessary to conduct the component tests on the same test specimens used in the system tests.

4.5.3 System Tests: Unless otherwise required by the detail specification or statement of work, two complete systems shall be subjected to the tests specified in Table 3 in the sequence listed therein. Unless otherwise specified, each system shall be installed in a manner which duplicates the air vehicle installation. With approval of the procuring activity, some of the environmental tests listed in Table 3 may be conducted on a component basis rather than the complete system.

4.5.4 Component Tests: The following tests shall be performed on the system components. All component tests, except those for the air cycle machine which are destructive-type tests, shall be conducted on the same unit and in the sequence shown.

a. Air cycle machine

(1) Performance: 4.7.13.1
(2) Bearing temperature evaluation: 4.7.13.2
(3) Reverse thrust load: 4.7.13.3
(4) Critical speed: 4.7.13.4
(5) Blade vibration: 4.7.13.5
(6) Overspeed spin: 4.7.13.6
(7) Rotational acceleration: 4.7.13.7
(8) Wheel spin-to-failure: 4.7.13.8
(9) Containment: 4.7.13.9

4.5.4 (Continued):

b. Heat exchangers:

(1) Proof pressure and leakage: 4.7.2
(2) Heat exchanger performance: 4.7.14.1
(3) Pressure-temperature cycling: 4.7.14.2
(4) Thermal shock: 4.7.14.3
(5) Freeze and thaw: 4.7.14.4
(6) Rain resistance: 4.4.14.5
(7) Burst pressure: 4.7.12

In addition, a proof pressure and leakage test and a minimum performance test shall be conducted following tests (3) through (6).

c. Airflow control system:

(1) Shutoff valve performance: 4.7.15.1
(2) Pressure regulator performance: 4.7.15.2
(3) Maximum and minimum flow: 4.7.15.3
(4) Stability: 4.7.15.4

d. Moisture control provisions:

(1) Proof pressure and leakage: 4.7.2
(2) Performance: 4.7.16.1
(3) Water separator antifreeze control: 4.7.16.2
(4) Water separator bypass: 4.7.16.3

e. Shutoff valves:

(1) Proof pressure and leakage: 4.7.2
(2) Performance: 4.7.17.1
(3) Endurance: 4.7.17.2
(4) Burst pressure: 4.7.12

f. Modulating valves:

(1) Proof pressure and leakage: 4.7.2
(2) Performance: 4.7.17.1
(3) Endurance: 4.7.17.3
(4) Burst pressure: 4.7.12

g. Check valves:

(1) Proof pressure and leakage: 4.7.2
(2) Performance: 4.7.17.1
(3) Endurance: 4.7.17.4
(4) Burst pressure: 4.7.12

4.5.4 (Continued):

h. Switches:

(1) Performance: 4.7.18.1
(2) Endurance: 4.7.18.2

i. Sensors:

(1) Performance: 4.7.19.1
(2) Endurance: 4.7.19.2

j. Temperature control and system controller:

(1) Performance: 4.7.20

k. Fans:

(1) Performance: 4.7.21.1
(2) Overspeed: 4.7.21.2
(3) Endurance: 4.7.21.3
(4) Containment: 4.7.21.4

l. Pneumatically actuated components:

(1) Entrained and condensed moisture removal: 4.7.22.1
(2) Accelerated internal corrosion and humidity: 4.7.22.2
(3) Freezing condensate: 4.7.22.3

4.5.5 Ground and Flight Tests: During preproduction ground and flight tests of the air vehicle, the contractor shall evaluate system performance and show that requirements of Section 3 are met when the system is installed in the air vehicle.

4.5.6 Reliability: During preproduction testing, the contractor shall prove by analyses, laboratory testing, and ground and flight testing on the air vehicle that the system meets the requirements of 3.2.3. A portion of the reliability testing shall include a sufficient number of rotating assemblies to demonstrate freedom from infant mortality.

4.5.7 Maintainability: During preproduction testing, the contractor shall prove by demonstration, laboratory testing, and ground and flight testing on the air vehicle that the system meets the requirements of 3.2.4.

4.5.8 Test Report: The contractor shall submit a test report to the procuring activity for review and approval in accordance with the results of inspections, demonstrations, and tests conducted to show compliance with the requirements of Section 3. The report shall be prepared in accordance with MIL-STD-831. The report shall include the following photographs:

a. System during performance test
b. System during vibration test
c. System during explosive atmosphere test
d. System during and following humidity test
e. System during and following salt-fog test
f. Rotating equipment following containment test
g. System during attitude test at extreme attitude
h. System components prior to any system testing and following completion of system tests

4.6 Quality Conformance Tests:

Each production component and system shall have successfully completed certain minimum testing to assure its compliance with the detail specification. As applicable, quality conformance testing shall include but not be limited to the following type of tests:

a. Examination of product: 4.7.1.2
b. Proof pressure and leakage: 4.7.2
c. Minimum functional: 4.7.23
d. Rotational overspeed: 4.7.24

4.7 Test Methods:

4.7.1 Examination of Product:

4.7.1.1 Examination of Product (preproduction test samples): Each component of the system shall be inspected to determine compliance with all of the inspection requirements specified in Table 2.

4.7.1.2 Examination of Product (production units): Each component shall be examined to assure compliance with the requirements of this specification and those of the detail specification. Such inspection shall include, but shall not be limited to, the requirements of identification marking, physical measurements, weight, continuity of required wiring, proper wiring, finish, freedom from damage, and maintenance of the required standard of workmanship. The inspection shall assure that all production components represent in all respects those which have been subjected to the preproduction tests specified herein.

4.7.2 Proof Pressure and Leakage: Each component of the system shall be tested to verify compliance with 3.2.2.6.1 and 3.2.1.5. The proof pressure shall be applied to each component or subassembly of a component for a minimum of 2 min. Should the test temperature be different from the temperature associated with the most adverse condition, correction of the applied pressure is required, to compensate for the ratio of allowable stresses at both temperatures. The leakage test shall be conducted at normal maximum operating pressure of the component.

4.7.3 Performance: Prior to preproduction tests, the contractor shall analytically evaluate system performance to verify compliance with the requirements of 3.2.1. Steady-state performance shall be demonstrated for the conditions defined by MIL-E-87145, Appendix D, Paragraph 80.2.1.1 or system design point conditions defined in the detail specification. The complete system shall be subjected to testing to verify compliance with the requirements of 3.2.1 and compatibility with the control system during simulated steady-state and transient ground and flight conditions of the air vehicle for hot, standard, and cold day temperature conditions and for all possible ambient humidity conditions. The system shall be installed in a manner which duplicates the air vehicle installation. The system shall be controlled by the same control system which will be used in the air vehicle, and the pressure drop of the distribution ducting shall be simulated. In addition, the ambient temperature of the system shall simulate that of the air vehicle installation for each test condition. The test setup shall be adequately instrumented to provide at least the following data, where applicable:

a. System total inlet airflow and inlet pressure and temperature
b. Turbine and compressor airflow
c. Bypass airflow
d. System inlet and outlet moisture content
e. Compressor and fan inlet and outlet temperature and pressure
f. Inlet temperature and pressure for each heat exchanger
g. Outlet temperature and pressure for each heat exchanger
h. Turbine inlet temperature and pressure
i. Turbine discharge temperature and pressure
j. Water separator discharge temperature and pressure
k. System discharge temperature and pressure
l. Air cycle machine revolutions per minute
m. Air cycle machine ball bearing temperature
n. Heat sink flow rate
o. Heat sink inlet and exit temperature and pressure
p. Air cycle machine oil sump temperature
q. System ambient temperature, pressure, and relative humidity
r. System capacity in terms of refrigeration or heating available
s. Duct pressure drops

4.7.4 Environmental Tests: The following environmental tests shall be conducted on all components of the system in accordance with the general requirements and specified procedures of MIL-STD-810, unless otherwise noted. These tests shall determine compliance with the environmental conditions of 3.2.5.

a. High temperature: Method 501
b. Low pressure: Method 500
c. Temperature shock: Method 503
d. Low temperature : Method 502
e. Humidity: Method 507
f. Fungus: Method 508. This test shall be performed unless analysis proves no susceptibility exists in the system.
g. Salt-fog: Method 509
h. Dust:

    (1) External exposure: Method 510
    (2) Internal exposure: Bleed air inlet to the system shall be subjected to inhalation of air containing dust at a concentration of 4.4×10^{-5} lb of sand per pound of air (4.4×10^{-5} kg/kg). This specified dust contaminant shall consist of crushed quartz with the total particle size distribution as specified in method 510. The system shall be exposed to air with this dust concentration for 1 h under simulated hot day, full-cooling ground operating conditions. All valves shall be cycled 15 cycles at the end of each 15 min of operation throughout the 1 h period. At the conclusion of this test, there shall be no reduction in system performance. The requirements of 3.2.1.3 are waived when running this test.

i. Acceleration: Method 513
j. Explosive atmosphere: Method 511
k. Shock: Method 516
l. Vibration: Method 514
m. Gunfire vibration: Method 519
n. Acoustic noise: Method 515. This test may be deleted for all components of the system which are located in areas where the noise level is 130 dB overall or less.

4.7.5 Attitude: The attitude test shall consist of mounting the system in different attitudes simulating typical vehicle operating attitudes as defined in the detail specification. Satisfactory operation shall be demonstrated for the maximum time period associated with each attitude extreme.

4.7.6 Air Contamination: The conditioned air at the exit of the system shall be analyzed to determine compliance with 3.2.1.3. As a minimum, the air shall be analyzed following startup, during normal maximum air cycle rotational speed, and during the various attitudes evaluated by 4.7.5.

4.7.7 Noise Level: The noise level at the conditioned air discharge and ram air inlet and exit shall be measured during maximum airflow operation and shall meet the requirement of 3.2.1.4.

4.7.8 Electromagnetic Interference: All electrical components of the system shall be tested as specified in MIL-STD-461.

4.7.9 Flow Resonance: All components of the system with internal airflow shall be subjected to flow tests to determine resonance conditions. The components shall be subjected to the complete range of required operating flows and temperatures. If a resonant condition is found, the component shall be subjected to a 50 h test using the flow rate and temperature producing the most severe resonance. The component shall show no structural deterioration at the end of the 50 h test period and shall successfully pass the leakage requirements.

4.7.10 Endurance: The complete system shall be subjected to endurance testing under simulated air vehicle operating conditions to verify compliance with 3.2.1.2. The endurance test time shall be prorated among typical ground and flight conditions. The percentage of the total endurance time for each ground and flight condition shall approximate that expected during service usage. At each test condition, the time shall be divided so that 10% of the time is at hot day conditions, 10% at cold day conditions, and 80% at standard day conditions, unless accelerated mission profile testing is being utilized. During the endurance test, no components, parts, systems, etc. may be replaced, repaired, or maintained. Minor maintenance such as replenishment of lubrication is allowable for oil lubricated units; however, a record of the quantity of lubricant added and time of replenishment shall be kept and included in the test report. The air cycle machine oil sump shall be checked periodically for the presence of water. If any water is found, this shall be considered a system failure. During the endurance test, the oil sump shall be vented to an ambient pressure corresponding to the pressure altitude for the particular test condition that is being simulated. The data required in 4.7.3 shall be recorded at the beginning and end of each different test condition of the endurance test.

4.7.11 Disassembly and Inspection: The system shall be disassembled and inspected for any damage or deterioration which would adversely affect subsequent operation. All temperature sensors shall be inspected by the x-ray method.

4.7.12 Burst Pressure: All components of the system, where applicable, shall be tested to verify compliance with 3.2.2.6.2. Should the test temperature be different from the temperature associated with the most adverse condition, correction of applied pressure is required, to compensate for the ratio of allowable stresses at both temperatures.

4.7.13 Air Cycle Machine Tests:

4.7.13.1 Air Cycle Machine Performance: The manufacturer shall conduct sufficient tests to construct performance maps applicable to and indicating the complete range of possible operating conditions of the air cycle machine for the entire range of pressurized and unpressurized flight conditions. Extrapolations of test results will be permissible and shall be so noted on the performance map.

4.7.13.2 Bearing Temperature Evaluation: Testing shall be accomplished to establish bearing temperatures for minimum and maximum operation.

4.7.13.3 Reverse Thrust Load: One air cycle machine shall be subjected to a reverse thrust load test to determine compliance with 3.7.1.2. In lieu of this test, proof of compliance with the reverse thrust load requirement may be provided through calculations and illustrations of pertinent design features.

4.7.13.4 Critical Speed: The air cycle machine shall be mounted in a position simulating its air vehicle installation. It shall be operated throughout its complete range of rotational speed up to and including normal maximum operating speed in small increments to determine whether a critical speed exists. Vibration exceeding the maximum permissible value specified in the detail specification shall be cause for rejection.

4.7.13.5 Blade Vibration: Resonant mode shapes of the blades, within the maximum operating speed and overspeed ranges, shall be determined analytically, holographically, or by other appropriate technical methodology. Strain gages shall be placed on the blades at their points of maximum deflection for all modes found and tested to demonstrate freedom from destructive resonant blade vibrations from 0 to 110% of normal maximum speed at conditions representative of service operation. If resonant peak vibrations are encountered which might be concluded to cause marginal endurance life, a sufficient number of revolutions shall be run at resonant points to establish that fatigue of the blades is satisfactory for the normal useful life. If no resonant points are found, the air cycle machine shall be speed cycle tested up to at least 110% of maximum normal operating speed for a sufficient number of cycles to prove that the fatigue life is satisfactory to meet 3.2.1.1.

4.7.13.6 Overspeed Spin: An air cycle machine shall be operated for a period of 5 min at the highest speed associated with a single failure at maximum operating temperature. No rubbing, cracks, or other adverse effects shall be noted.

4.7.13.7 Rotational Acceleration: One air cycle machine shall be subjected to a 300 cycle rotational acceleration test. One cycle shall consist of accelerating the air cycle machine from rest to maximum normal operating speed, operating it at maximum speed for 5 min, and then allowing the machine to return to rest. The rate of acceleration shall be 20% greater than the maximum possible expected in the air vehicle.

4.7.13.8 Wheel Spin-to-Failure: At least five of each type of wheel used in the air cycle machine shall be spun to destruction outside of the air cycle machine housing. The speed at which failure of each wheel occurs shall be noted, and all failures shall occur within the speed range specified in the detail specification. This test shall be conducted at room temperature. After the test, the manufacturer shall compute failure speed at maximum operating temperature based on results at room temperature. If the wheel failure speed is higher than the achievable rig speed, criteria such as bore growth may be used.

4.7.13.9 Containment: Containment of turbine wheel failure (tri-hub burst) shall be demonstrated on one unit at the maximum fuse speed, if fused, or if not fused, at the maximum speed that can result from any failure inducing condition or 135% of the maximum normal speed, whichever is greater, at the temperatures associated with these speeds. Containment of fan and compressor wheel failure (tri-hub burst) shall also be demonstrated on one unit at the turbine wheel containment speed and at the pressure and temperature associated with this speed. If the required temperature is not attained, the burst speed must be increased to compensate for the differences in material properties.

4.7.14 Heat Exchanger Tests:

4.7.14.1 Heat Exchanger Performance: The manufacturer shall conduct sufficient tests to construct a performance map applicable to the complete range of possible operating conditions. Extrapolations are permissible and shall be so noted on the performance map. The performance data shall show the pressure drop and effectiveness of the heat exchanger for various flow rates and temperatures.

4.7.14.2 Pressure-Temperature Cycling: Each heat exchanger of the system shall be subjected to 5000 pressure-temperature cycles. One cycle shall consist of the following:

a. Simultaneously introduce hot air and coolant to the heat exchanger at condition I subparagraphs (a) and (b)

b. Increase hot air and coolant flow rate, temperature, and pressure at a rate equivalent to operational conditions at the heat exchanger inlet until condition II subparagraphs (a) and (b) is met and outlet temperatures are stabilized and

c. Then reduce, at a rate equivalent to operational conditions at the heat exchanger inlet, the hot airflow rate, temperature, and pressure and the coolant flow rate, temperature, and pressure to condition I subparagraphs (a) and (b) and maintain conditions until outlet temperatures are stabilized. Condition I and II are as follows:

(1) Condition I:

(a) Hot air:

1. Flow rate: Minimum
2. Temperature: That which is associated with minimum flow
3. Pressure: That which is associated with minimum flow

(b) Coolant:

1. Flow rate: Quantity that occurs during minimum hot airflow
2. Temperature: Value that occurs during minimum hot airflow
3. Pressure: Value that occurs during minimum hot airflow

(2) Condition II:

(a) Hot air:

1. Flow rate: Maximum
2. Temperature: That which is associated with maximum flow
3. Pressure: That which is associated with maximum flow

(b) Coolant:

1. Flow rate: Quantity that occurs during maximum hot airflow
2. Temperature: Value that occurs during maximum hot airflow
3. Pressure: Value that occurs during maximum hot airflow

4.7.14.2 (Continued):

Following completion of the test, the high pressure side of the heat exchanger while exposed to maximum operating temperature shall be subjected to 10 000 pressure cycles. One cycle shall consist of rapidly raising pressure from ambient to maximum operating pressure and then rapidly decreasing pressure to ambient. Prior to and following completion of the above tests, the heat exchanger shall be leakage tested and shall meet the requirements of 3.2.1.5.

4.7.14.3 Thermal Shock: Each heat exchanger shall be subjected to a thermal shock test which shall consist of temperature cycling the complete heat exchanger from cold soak at -65 °F (-54 °C) to the expected maximum inlet air temperature which will occur during a -65 °F (-54 °C) ambient temperature. A cycle shall consist of low temperature stabilization at -65 °F (-54 °C), then raising the inlet air temperature to the maximum until stabilized, and then lowering to the original temperature simulating the maximum expected rate of change for increasing and decreasing temperatures. This shall be repeated for three cycles. Prior to and following completion of the thermal shock test, the heat exchanger shall be leakage tested and shall meet the requirements of 3.2.1.5.

4.7.14.4 Freeze and Thaw: Heat exchangers and storage tanks which use water shall be tested to demonstrate their capability to withstand the freeze and thaw conditions expected during service life. The heat exchanger and storage tank shall be filled with water and then exposed to an ambient temperature for a period of time which will assure complete freezing of the water. Thawing shall then be accomplished by applying heat in a manner and at the rate simulating operational conditions. The number of freeze and thaw cycles shall be the number expected throughout the life of the air vehicle and shall be stated in the detail specification. However, in no case shall the number be less than 50 cycles. If several possible ways of thawing the water will occur in the particular installation, the number of test cycles shall be divided in a realistic manner between each of the possible heating methods. Prior to and following completion of the freeze and thaw test, the heat exchanger and water storage tanks shall satisfactorily meet the leakage requirements.

4.7.14.5 Rain Resistance: Ram air heat exchangers, which are so located that rain droplets can impact directly on the heat transfer surface, shall be subjected to a rain resistance test. This test shall consist of exposing the heat exchanger for 1 h to the quantity of rain which would be intercepted by the ram air scoop when the air vehicle is flying at maximum low level speed through rain which is falling at the rate of 4.0 in/h (10.2 cm/h). The functional capability (heat transfer) of the heat exchanger shall not be impaired by this test. Heat exchangers which do not use finned heat transfer surfaces are not required to undergo this test.

4.7.15 Airflow Control System Tests:

4.7.15.1 Shutoff Valve Performance: The airflow control system shutoff valve shall be subjected to tests to demonstrate compliance with 3.7.3.1.

4.7.15.2 Pressure Regulator Performance: The airflow control system pressure regulator shall be subjected to tests to demonstrate compliance with the pressure regulator performance tolerance requirements of 3.7.3.2.

4.7.15.3 Maximum and Minimum Flow: The airflow control system shall be subjected to tests to demonstrate compliance with the maximum and minimum flow requirements of 3.7.3.3 and 3.7.3.4.

4.7.15.4 Stability: The airflow control system shall be subjected to tests to demonstrate compliance with 3.7.3.5.

4.7.16 Moisture Control Tests:

4.7.16.1 Performance: Performance testing shall be conducted to enable construction of a performance map which shows water separator efficiency as a function of flow rate and inlet entrained moisture content. In addition, the water separator pressure drop as a function of flow rate shall be determined for the normal flow direction and for flow through the bypass only.

4.7.16.2 Water Separator Antifreeze Control: Testing shall be conducted to determine compliance with 3.7.4.1.1.2.

4.7.16.3 Water Separator Bypass: Satisfactory operation of the water separator bypass shall be demonstrated following blockage of the water separator by ice buildup due to ice being discharged from the system air cycle machine. The bypass shall not block closed when in the bypass mode, using actual ice for more than the maximum flight duration expected in service. Following this demonstration, the bypass valve shall be cycled 1000 times from closed to open to closed without malfunction.

4.7.17 Valve Tests:

4.7.17.1 Performance: Performance testing shall be conducted to demonstrate adequacy of opening and closing times, proof pressure, pressure drop, leakage, and accuracy and repeatability of valve movements to commanded positions, if applicable.

4.7.17.2 Shutoff Valve Endurance: Each shutoff valve used in the system shall be cycled 10 000 times from the fully closed to the fully open to the fully closed position. The valve operating conditions, ambient and inlet, for this test shall be consistent with the normal operation of the valve as installed in the system. Following completion of this test, the valve shall satisfactorily meet opening and closing, proof pressure, and leakage requirements.

4.7.17.3 Modulating Valve Endurance: Each modulating valve used in the system shall be cycled 10 000 times from the fully closed to the fully open to the fully closed position and 40 000 times from within 25% of the fully closed to the fully open position and then to within 25% of the fully closed position. The valve operating conditions, ambient and inlet airflow and temperature, for this test shall be consistent with the normal operation of the valve as installed in the system. Following completion of this test, the valve shall satisfactorily meet opening and closing, proof pressure, and leakage requirements.

4.7.17.4 Check Valve Endurance: Check valves shall be tested as installed in the air vehicle throughout the full range of flow rate. There shall be no flutter or instability that would adversely affect life. Each check valve used in the system shall be cycled 50 000 times. A cycle is defined as movement of the flapper or poppet from the fully closed to the fully open and back to the fully closed position. The valve operating conditions, ambient and inlet, for this test shall be consistent with the normal operation of the valves as installed in the system. Following completion of this test, the check valve shall satisfactorily meet the leakage requirements.

4.7.18 Switch Tests:

4.7.18.1 Performance: Each switch used in the system shall be tested to determine that it operates as required.

4.7.18.2 Endurance: Switches shall be cycled 100 000 times at maximum normal working conditions and shall satisfactorily meet the operating requirements.

4.7.19 Sensor Tests:

4.7.19.1 Performance: Each pressure or temperature sensor used in the system shall be tested to assure that it performs as required.

4.7.19.2 Endurance: Sensors shall be cycled for the number of times specified in the detail specification at maximum normal working conditions and shall satisfactorily meet the operating requirements. Sensors shall be calibrated prior to test and X-rayed after the endurance test.

4.7.20 Temperature Control and System Controller Performance: Each temperature control and the system controller shall be tested sufficiently to determine it complies with 3.7.7 and 3.7.8.

4.7.21 Fan Tests:

4.7.21.1 Performance: Sufficient testing shall be conducted in order for the vendor to provide a characteristic performance curve for all operational conditions of the fan.

4.7.21.2 Overspeed: The fan shall be operated for a period of 5 min at 120% of normal maximum operating speed. No rubbing or other adverse effects shall be noted.

4.7.21.3 Endurance: The fan shall be subjected to an endurance test of 1000 h of operation and shall satisfactorily meet the operating requirements. The endurance time shall be prorated among typical ground and flight conditions. Any distortion of the inlet flow due to the installation should be duplicated during the endurance test. This test will not be required if the fan is operated throughout the complete test time of 4.7.10.

4.7.21.4 Containment: A containment test shall be conducted to determine compliance with 3.2.2.6.3.

4.7.22 Pneumatically Actuated Component Tests:

4.7.22.1 Entrained and Condensed Moisture Removal: Sufficient performance testing shall be conducted to verify that entrained and condensed moisture is prevented from entering the control mechanisms of all pneumatically actuated components for all operational conditions.

4.7.22.2 Accelerated Internal Corrosion and Humidity: All pneumatically operated control components of the system shall be subjected to the following test procedure:

a. Components shall be oriented in the same attitude as they will be installed in the air vehicle during all phases of testing

b. All internal surfaces which are exposed to pneumatic air shall be thoroughly wetted by supplying a solution of 5% (by weight) of sodium chloride in water to the component. Valves shall be cycled five times from closed to open to closed during the wetting operation;

c. The components shall then be purged by use of factory air and all valves shall be cycled as in item (b)

d. The components shall then be placed in 130 °F ± 5 °F (54 °C ± 3 °C), 100% relative humidity environment, and baked for 1 h. At the conclusion of each bake period, the internal surfaces shall be flushed with clear water and valves shall be simultaneously cycled as in item (b). A functional check shall then be conducted to determine if a malfunction or degradation has occurred;

e. Items (b) through (d) constitute one cycle. All components shall be cycled as follows:

(1) 10 cycles with a 1 h bake period
(2) 10 cycles with a 2 h bake period
(3) 10 cycles with a 5 h bake period

Each component shall be disassembled and inspected at the completion of each 10 cycles. Any evidence of corrosion, damage, or malfunction shall be considered failure of the test.