SAE INTERNATIONAL

AEROSPACE STANDARD

AS4073™	REV. B
Issued 1993-08 Revised 2019-08 Reaffirmed 2024-10 Superseding AS4073A	

(R) Air Cycle Air Conditioning Systems for Air Vehicles

RATIONALE

This document revision updates references and specifications.

AS4073B has been reaffirmed to comply with the SAE Five-Year Review policy.

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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 and JSSG-2009.

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. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

AMS-H-6875 Heat Treatment of Steel Raw Materials

AMS2175 Castings, Classification and Inspection of

AIR1826 Acoustical Considerations for Aircraft Environmental Control System Design

ARP699 High Temperature Pneumatic Duct Systems for Aircraft

ARP780 Environmental Systems Schematic Symbols

AS4395 Fitting End, Flared, Tube Connection, Design Standard

AS4396 Fitting End, Bulkhead, Flared, Tube Connection, Design Standard

AS5202 Port or Fitting End, Internal Straight Thread, Design Standard

AS8879 Screw Threads - UNJ Profile, Inch Controlled Radius Root with Increased Minor Diameter

AS71051 Pipe Threads, Taper, Aeronautical National Form, Symbol ANPT - Design and Inspection Standard

2.1.2 U.S. Department of Defense Publications

Available from DLA Document Services, Building 4/D, 700 Robbins Avenue, Philadelphia, PA 19111-5094, Tel: 215-697-6396, https://quicksearch.dla.mil/.

JSSG-2009 Air Vehicle Subsystems

MIL-A-8625 Anodic Coatings, for Aluminum and Aluminum Alloys

MIL-DTL-5002 Surface Treatments Inorganic Coatings

MIL-DTL-5541 Chemical Conversion Coatings on Aluminum Alloys

MIL-DTL-8834 Detail Specification: Switches, Toggle, Positive Break, General Specification for

MIL-E-18927 Environmental Control Systems, Aircraft, General Requirements for

MIL-HDBK-310 Global Climatic Data for Developing Military Products

MIL-HDBK-831 Military Handbook: Preparation of Test Reports

MIL-I-8500 Interchangeability and Replaceability of Component Parts for Aircraft and Missiles

MIL-S-7742 Screw Threads, Standard, Optimum Selected Series, General Specification for

MIL-STD-130 Identification Marking of U.S. Military Property

MIL-STD-461 Electromagnetic Emission and Susceptibility Requirements for the Control of Electromagnetic Interference

MIL-STD-704 Aircraft Electric Power Characteristics

MIL-STD-810 Environmental Test Methods and Engineering Guidelines

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-1474 Noise Limits

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-7179 Finishes, Coatings, and Sealants for the Protection of Aerospace Weapon System

MIL-STD-31000 Technical Data Packages (TDP)

2.1.3 AWS Publications

Available from American Welding Society, 8669 NW 36 Street, #130, Miami, FL 33166-6672, Tel: 1-800-443-9353 or 305-443-9353, www.aws.org.

AWS C3.4 Specification for Torch Brazing

AWS C3.5 Specifications for Induction Brazing

AWS C3.6 Specification for Furnace Brazing

AWS C3.7 Specification for Aluminum Brazing

AWS D17.1 Specification for Fusion Welding for Aerospace Applications

2.1.4 NAS Publications

Available from Aerospace Industries Association, 1000 Wilson Boulevard, Suite 1700, Arlington, VA 22209-3928, Tel: 703-358-1000, www.aia-aerospace.org.

NASM33540 Safety Wiring and Cotter Pinning, General Practice for

2.1.5 Other Publications

High Temperature Properties. (2019). The Stainless Steel Information Center, Specialty Steel Industry of North America. 3050 K Street, N.W., Washington, DC 20007, Tel 1-202-342-8630. http://www.ssina.com/composition/temperature.html.

B313-2018. Process Piping. (2018). ANSI/ASME B 31.3. American Society of Mechanical Engineers. Two Park Avenue, Tel, 1-973-882-1170, New York, NY. https://www.asme.org/products/codes-standards/b313-2018-process-piping. ISBN 9780791872260.

2.2 Definitions

AIR CYCLE MACHINE: An air cycle machine is either a turbine-fan assembly, turbine-compressor assembly, or turbine-fan-compressor assembly. In addition, air cycle machines may also have multiple turbines.

AIR VEHICLE: An air vehicle is any object that by virtue of lift obtained by its own buoyancy in air, or by the dynamic reaction of air over and around its surfaces, or by its reaction to a jet stream, goes through the air as a carrier of something.

COALESCER: A coalescer is a device used in a water separator to cause the small diameter water particles (submicronic) entering the separator from the expansion turbine to be combined (coalesced) into particles large enough to be affected by centrifugal forces.

CONTRACTOR: The contractor is the supplier of the air vehicle.

CRITICAL MATERIAL: A critical material is any raw or partially-processed material essential in a national emergency and not expected to be available in quantity, quality, or time to meet requirements unless stockpiling action is taken.

DETAIL SPECIFICATION: A detail specification is the contractor prepared procurement specification for the air cycle air conditioning system.

ENTRAINED MOISTURE: Entrained moisture is water which is carried along in the air as liquid water.

HEAT EXCHANGERS: Heat exchangers which are a part of the air cycle air conditioning system are precoolers, primary, secondary, intercoolers, regenerative, and evaporative. Heat exchangers are a device which transfers heat from one medium to another without mixing of the media.

LOGISTICS CRITICAL COMPONENT: Logistics critical components are those items which are selected for multiple source procurement.

MANUFACTURER: The manufacturer is the supplier of system components to the contractor.

MAXIMUM NORMAL OPERATING SPEED: Maximum normal operating speed is defined as the highest speed obtained by a piece of rotating equipment under the most severe operational condition without any failures of components which affect rotational speed of the component.

NONOPERATING COMPONENTS: Nonoperating components are those items such as heat exchangers and ducting which do not contain moving parts or electronics.

OPERATING COMPONENTS: Operating components are those items which contain moving parts and/or electronics.

PROCURING ACTIVITY: The procuring activity is the Department of Defense agency which is procuring the air vehicle.

3. RECOMMENDED REQUIREMENTS

This section contains recommended requirements for inclusion in Section 3 of a detail specification prepared for procurement of air cycle air conditioning systems for use on new or retrofit on existing military aircraft.

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.

j. Maximum pressure at the heat sink inlet to avoid wind-milling when on flight and pack off condition.

k. Pack water removal efficiency.

l. Pack internal temperature limitations, such as maximum temperature at the compressor outlet; minimum temperature at the water separation inlet.

m. Heat exchangers coatings cure temperature.

n. Maximum percentage of heat exchangers inlet area blockage that the air cycle machine fan can withstand without stall.

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 or greater than 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 exposure limits established in the detail specification.

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-1474 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 seconds 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 and thermal 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 [ARP699]:

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 [ARP699]:

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. Some OEM permit the use of a mirror or other device to view the nameplate. 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 feet (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 and internal air containing dust as defined in the detail specification or use MIL-HDBK-310 as guidance for defining external dust conditions if not available 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.

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 using MIL-STD-1587 for guidance, and corrosion control established using MIL-STD-1568 for guidance.

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. Austenitic (300 series) stainless steels can be hardened by cold working, but not by heat treatment. Table 2 provides generally accepted service temperatures for austentic and martensitic sheet.cold-rolled stainless steel shall not be used at a temperature of more than 50 °F (28 °C) below the recovery temperature.

Table 2 - Generally accepted service temperatures

Material	Intermittent Service Temperature	Continuous Service Temperature
Austenitic		
304	1600 °F (870 °C)	1700 °F (925 °C)
316	1600 °F (870 °C)	1700 °F (925 °C)
309	1800 °F (980 °C)	2000 °F (1095 °C)
310	1900 °F (1035 °C)	2100 °F (1150 °C)
Martensitic		
410	1500 °F (815 °C)	1300 °F (705 °C)
420	1350 °F (735 °C)	1150 °F (620 °C)
Ferritic		
430	1600 °F (870 °C)	1500 °F (815 °C)

It may seem to be illogical that the "continuous" service temperature would be higher than the "intermittent" service temperature for the 300 series grades. The answer is that intermittent service involves "thermal cycling", which can cause the high temperature scale formed to crack and spall. This occurs because of the difference in the coefficient of expansion between the stainless metal and the scale. As a result of this scaling and cracking, there is a greater deterioration of the surface than will occur if the temperature is continuous. Therefore, the suggested intermittent service temperatures are lower. This is not the case for the 400 series (both ferritic and martensitic grades). The reason for this is not known (High Temperature Properties, 2019).

Table 2 and its footnote are used with permission of “The Stainless Steel Information Center.”

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 demonstrated adequacy of manufacturing methods.

3.3.1.1.4 Cadmium-Plated Materials

Cadmium-plated materials shall not be used except for standard parts (nuts and bolts, subject to approval by procurement authority) and shall not be utilized in locations where the temperature may exceed 450 °F (232 °C) or where exposure to fuel is possible. Cadmium plating has been recognized an environmental/health hazard.

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 AS5202. 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 AS4395 and AS4396.

3.3.1.2.5 Threads

All threads shall be class 3 in accordance with AS8879 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 AS71051 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 NASM33540. 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 AMS2175.

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-DTL-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 AMS-H-6875.

3.3.1.3.3 Passivation

Corrosion resistant alloy parts shall be passivated in accordance with MIL-DTL-5002 or other similar passivation specification. 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 after any forming.

3.3.1.3.4 Cold Stabilization

Close fitting sliding steel parts shall be cold stabilized in accordance with AMS-H-6875 to reduce warpage tendencies.

3.3.1.3.5 Welding and Brazing

Welding shall be in accordance with AWS D17.1, and brazing shall be in accordance with AWS C3.4 Specification for Torch Brazing, AWS C3.5 Specification for Induction Brazing, AWS C3.6 Specification for Furnace Brazing, and AWS C3.7 Specification for Aluminum Brazing.

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-STD-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. 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 MIL-STD-31000. 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. 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 hours 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 hours 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 hours 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 consistent with Table 1. 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. These meters are typically not used with modern digital control systems with health monitoring.

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 minutes 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.

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 minutes 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 in which 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 fully open position, shall be as specified in the detail specification. The minimum time required to close the valve from the fully 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 seconds 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 27000 feet (8230 m) altitude, and above the frost point of the bleed air at altitudes above 27000 feet (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:

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 seconds 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 27000 feet (8230 m) or as specified in the detail specification. Above 27000 feet (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 27000 feet (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 delta P 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, Polytetrafluoroethylene (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. The system shall have a bypass drain passage to drain water even if the main drain line is frozen.

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 minutes 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 pneumatic 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-hour 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 inch (4.78 mm). Minimum wall thickness shall be selected according to the greatest working pressure expected as recommended by ANSI/ASME B31.3 Code for temperatures from -325 to 100 °F. Consideration shall also be given to the maximum operating temperature, and the wall thickness selected according to the derating of allowable pressure based on the maximum temperature. The Interior diameter of fittings shall be no smaller than the inside diameter of the tubing.

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 Responsibility 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 77 °F ± 18 °F (25 °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 for all measurements shall be within the limits specified in 5.2, Part ONE-18, Tolerances for test conditions, 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 3, provides for accountability for each Section 3 requirement, corresponding Section 4 verification requirement, and method of verification.

Table 3 - Verification cross reference index (VCRI)

Section 3 Requirement Reference		Verification Methods NA	Verification Methods 1	Verification Methods 2	Verification Methods 3	Verification Methods 4	Section 4 Verification Requirements
3.	Requirements	X					
3.1	Systems Definition	X					
3.2	Characteristics	X					
3.2.1	Performance			X		X	4.5.5 4.7.3 4.7.18.1
3.2.1.1	Useful Life			X		X	4.5 4.7.9 4.7.13.5
3.2.1.2	Endurance Life			X		X	4.7.10 4.7.11 4.7.18.2
3.2.1.3	Contamination					X	4.7.6
3.2.1.4	Noise Level					X	4.7.7
3.2.1.5	Leakage					X	4.7.2
3.2.1.6	Equipment Warmup Time					X	4.7.4
3.2.2	Physical Characteristics	X					
3.2.2.1	Weight		X				4.7.1.1
3.2.2.2	Size and Configuration		X				4.7.1.1
3.2.2.3	Handling Provisions		X				4.7.1.1
3.2.2.4	Flange Orientation		X				4.7.1.1
3.2.2.5	Mounting		X				4.7.1.1
3.2.2.6	Structural Integrity	X					
3.2.2.6.1	Proof Pressure					X	4.7.2
3.2.2.6.2	Burst Pressure					X	4.7.12
3.2.2.6.3	Rotating Equipment Containment					X	4.7.13.8 4.7.13.9 4.7.21.4
3.2.2.7	Service and Access		X				4.7.1.1

Table 3 - Verification cross reference index (VCRI) (continued)

Section 3 Requirement Reference		Verification Methods NA	Verification Methods 1	Verification Methods 2	Verification Methods 3	Verification Methods 4	Section 4 Verification Requirements
3.2.2.8	Electrical Requirements		X			X	4.7.1.1 4.7.4 (j)
3.2.2.9	Lubrication	X					4.7.1.1
3.2.3	Reliability			X		X	4.5.6
3.2.4	Maintainability				X	X	4.5.7
3.2.5	Environmental Conditions					X	4.7.4 4.7.5
3.2.5.1	Storage					X	4.7.4
3.2.6	Transportability		X				4.7.1.1
3.3	Design and Construction	X					
3.3.1	Materials, Parts, and Processes		X				4.7.1.1
3.3.1.1	Materials		X				4.7.1.1
3.3.1.1.1	Magnesium and Magnesium Alloys		X				4.7.1.1
3.3.1.1.2	Corrosion-Resisting Steels		X				4.7.1.1
3.3.1.1.3	Titanium and Titanium Alloys		X				4.7.1.1
3.3.1.1.4	Cadmium-Plated Materials		X				4.7.1.1
3.3.1.1.5	Neoprene		X				4.7.1.1
3.3.1.1.6	Nickel		X				4.7.1.1
3.3.1.1.7	Critical Materials		X				4.7.1.1
3.3.1.1.8	Organic Materials		X				4.7.1.1
3.3.1.1.9	Corrosion-Promoting Materials		X				4.7.1.1
3.3.1.1.10	Protective Treatment		X				4.7.1.1
3.3.1.2	Parts	X					
3.3.1.2.1	Standard and Commercial Parts		X				4.7.1.1

Table 3 - Verification cross reference index (VCRI) (continued)

Section 3 Requirement Reference		Verification Methods NA	Verification Methods 1	Verification Methods 2	Verification Methods 3	Verification Methods 4	Section 4 Verification Requirements
3.3.1.2.2	Fasteners		X				4.7.1.1
3.3.1.2.3	Bosses		X				4.7.1.1
3.3.1.2.4	Tube Connectors		X				4.7.1.1
3.3.1.2.5	Threads		X				4.7.1.1
3.3.1.2.6	Synthetic Rubber Parts		X				4.7.1.1
3.3.1.2.7	Safetying		X				4.7.1.1
3.3.1.2.8	Pins		X				4.7.1.1
3.3.1.2.9	Snap Rings		X				4.7.1.1
3.3.1.2.10	Castings		X				4.7.1.1
3.3.1.2.11	Inspection Seals		X				4.7.1.1
3.3.1.3	Processes	X					
3.3.1.3.1	Aluminum Alloys		X				4.7.1.1
3.3.1.3.2	Steel		X				4.7.1.1
3.3.1.3.3	Passivation		X				4.7.1.1
3.3.1.3.4	Cold Stabilization		X				4.7.1.1
3.3.1.3.5	Welding and Brazing		X				4.7.1.1
3.3.1.3.6	System Surface Finishes		X				4.7.1.1
3.3.1.3.7	Dissimilar Metals		X				4.7.1.1
3.3.2	Electromagnetic Interference					X	4.7.8
3.3.3	Nameplates and Product Marking		X				4.7.1.1
3.3.4	Workmanship		X				4.7.1.1
3.3.5	Interchangeability and Replaceability		X				4.7.1.1
3.3.6	Safety	X					
3.3.6.1	Flight Safety		X	X			4.7.1.1

Table 3 - Verification cross reference index (VCRI) (continued)

Section 3 Requirement Reference		Verification Methods NA	Verification Methods 1	Verification Methods 2	Verification Methods 3	Verification Methods 4	Section 4 Verification Requirements
3.3.6.2	Ground Safety		X				4.7.1.1
3.3.6.3	System Safety		X				4.7.1.1
3.3.6.4	Failure Concept		X	X			4.7.1.1
3.3.7	Human Performance		X				4.7.1.1
3.4	Documentation		X				4.7.1.1
3.5	Logistics	X					
3.5.1	Maintenance		X		X		4.7.1.1
3.6	Precedence		X				
3.7	Major Component Characteristics	X					
3.7.1	Air Cycle Machine		X	X	X	X	4.7.1.1 4.7.13.1
3.7.1.1	Dynamic Balance					X	4.7.13.4
3.7.1.2	Reverse Thrust Load			X		X	4.7.13.3
3.7.1.3	Elapsed Time Meter		X				4.7.1.1
3.7.1.4	Overspeed					X	4.7.13.6
3.7.1.5	Instrumentation Pickups		X				4.7.1.1 4.7.13.2
3.7.1.6	Air Cycle Machine Lubrication System		X				4.7.1.1
3.7.1.7	Rotational Acceleration					X	4.7.13.7
3.7.1.8	Bearings			X		X	4.7.10 4.7.13.2
3.7.1.9	Prevention of Adverse Effects Due to Entrained Moisture		X			X	4.7.1.1 4.7.10
3.7.1.10	Replaceable Turbine Nozzle		X				4.7.1.1
3.7.1.11	Balancing		X		X		4.7.1.1
3.7.1.12	Wheel Retention		X				4.7.1.1

Table 3 - Verification cross reference index (VCRI) (continued)

Section 3 Requirement Reference		Verification Methods NA	Verification Methods 1	Verification Methods 2	Verification Methods 3	Verification Methods 4	Section 4 Verification Requirements
3.7.1.13	Resonant Frequencies					X	4.7.13.5
3.7.2	Heat Exchangers		X	X	X	X	4.7.14.1 4.7.14.2 4.7.14.3 4.7.14.5
3.7.2.1	Water Boilers and Water Storage Tanks					X	4.7.14.4
3.7.3	Airflow Control System		X	X	X	X	4.7.1.1
3.7.3.1	Shutoff Valve		X	X		X	4.7.15.1
3.7.3.2	Pressure Regulator		X			X	4.7.15.2
3.7.3.3	Maximum Flow					X	4.7.15.3
3.7.3.4	Minimum Flow					X	4.7.15.3
3.7.3.5	Stability					X	4.7.15.4
3.7.3.6	Airflow Control System Environmental Conditions					X	4.7.4 4.7.22
3.7.4	Moisture Control Provisions					X	4.7.16.1
3.7.4.1	Low Pressure Water Removal	X					
3.7.4.1.1	Water Separator					X	4.7.16.1
3.7.4.1.1.1	Bypass Valve					X	4.7.16.3
3.7.4.1.1.2	Antifreeze Control					X	4.7.16.2
3.7.4.1.1.3	Water Separator Coalescer		X		X		4.7.1.1
3.7.4.1.1.4	Drainage		X			X	4.7.1.1 4.7.16.1
3.7.4.2	High Pressure Water Removal					X	4.7.16.1
3.7.5	Ram Air Mover		X			X	4.7.1.1 4.7.3

Table 3 - Verification cross reference index (VCRI) (continued)

Section 3 Requirement Reference		Verification Methods NA	Verification Methods 1	Verification Methods 2	Verification Methods 3	Verification Methods 4	Section 4 Verification Requirements
3.7.6	Valves		X			X	4.7.17.1 4.7.17.2 4.7.17.3 4.7.17.4
3.7.7	Temperature Controls					X	4.7.20
3.7.7.1	Temperature Sensors					X	4.7.19.1 4.7.19.2
3.7.8	System Controller					X	4.7.20
3.7.8.1	Digital Control					X	4.7.20
3.7.9	Fans					X	4.7.21.1 4.7.21.2 4.7.21.3 4.7.21.4
3.7.10	Pneumatically Actuated Components		X			X	4.7.22.1 4.7.22.2 4.7.22.3
3.7.11	Ducting, Couplings and Insulation		X				4.7.1.1
3.8	Mockup		X				4.4

NOTES: NA = Not Applicable
1 = Inspection
2 = Analysis
3 = Demonstration
4 = Test

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 based on 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

A complete system shall be subjected to the tests specified in Table 4 in the sequence listed therein unless additional tests are required by the detail specification or statement of work. 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 4 may be conducted on a component basis rather than the complete system.

Table 4 - System and component level tests

System Test Sequence	System Test Title	Paragraph No.	Component Test Title	Paragraph No.
1	Examination of Product	4.7.1	Examination of Product	4.7.1
2	Proof Pressure & Leakage	4.7.2	Proof Pressure	4.7.2
3	Minimum Performance – Pretest	4.7.3	Burst Pressure	4.7.12
4	Attitude	4.7.5	High Temperature	4.7.4(a)
5	Air Contamination	4.7.6	Low Pressure	4.7.4(b)
6	Noise Level	4.7.7	Temperature Shock	4.7.4(c)
7	Electromagnetic Interference	4.7.8	Low Temperature	4.7.4(d)
8	Flow Resonance	4.7.9	Humidity	4.7.4(e)
9	Endurance	4,7,10	Fungus	4.7.4(f)
10	Disassembly and Inspection	4.7.11	Salt Fog	4.7.4(g)
11	Air Cycle Machine	4.7.13 Subparagraphs 1 through 9	Dust	4.7.4(h)
12	Heat Exchangers	4.7.2 and 4.7.14 Subparagraphs 1-5, 12	Acceleration	4.7.4(i)
13	Airflow Control System	4.7.15	Explosive Atmosphere	4.7.4(j)
14	Moisture Control	4.7.16	Shock	4.7.4(k)
15	Post Test Leakage Test	4,7,2	Vibration	4.7.4 (l)
16	Minimum Performance Post-Test	4.7.3	Gunfire	4.7.4(m)
17	Disassembly & Inspection	4.7.11	Acoustic Noise	4.7.4(n)
			Airflow Control System	4.7.15 subparagraphs 1 through 4
			Acoustic Noise	4.7.4(n)
			Valve Tests	4.7.17
			Switch Tests	4.7.18
			Sensor Tests	4.7.19
			Temperature Control and System Controller Performance	4.7.20
			Fan Tests	4.7.21
			Accelerated Internal Corrosion and Humidity	4.7.22
			Minimum Function	4.7.23
			Rotational Speed	4.7.24

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

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

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 using MIL-HDBK-831 as guidance. 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 minutes. 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 derived from JSSG-2009 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