AEROSPACE RECOMMENDED PRACTICE

ARP1796	REV. B
Issued 1987-02 Reaffirmed 2004-06 Revised 2015-07 Superseding ARP1796A	

(R) Engine Bleed Air Systems for Aircraft

RATIONALE

Proof and Burst pressure requirements in Sections 5.1.1.6 and 5.1.1.7 have been updated to reflect current FAA, EASA and U.S. Military requirements.

TABLE OF CONTENTS

1. SCOPE

This SAE Aerospace Recommended Practice (ARP) discusses design philosophy, system and equipment requirements, installation environment and design considerations for military and commercial aircraft systems within the Air Transport Association (ATA) ATA 100 specification, Chapter 36, Pneumatic. This ATA system/chapter covers equipment used to deliver compressed air from a power source to connecting points for other systems such as air conditioning, pressurization, ice protection, cross-engine starting, air turbine motors, air driven hydraulic pumps, on board oxygen generating systems (OBOGS), on board inert gas generating systems (OBIGGS), and other pneumatic demands.

The engine bleed air system includes components for preconditioning the compressed air (temperature, pressure or flow regulation), ducting to distribute high or low pressure air to the using systems, and sensors/instruments to indicate temperature and pressure levels within the system.

The engine bleed air system may interface with the following Air Transport Association (ATA) 100 systems:

Chapter 21 - Air Conditioning

Chapter 29 - Hydraulic Power

Chapter 30 - Ice and Rain Protection

Chapter 34 - Navigation (Indication Systems/Probe Aspiration)

Chapter 36 - Pneumatics

Chapter 38 - Water/Waste

Chapter 49 - Airborne Auxiliary Power

Chapter 73 - Engine Fuel & Control

Chapter 75 - Engine Air

Chapter 78 - Engine Exhaust

Chapter 80 - Engine Starting

The interface with these systems/chapters is at the inlet of the shutoff/control valve of each associated system. This boundary definition aligns with that in the ATA 100 specification.

This document also applies to military aircraft. The system functions and interface with other systems are basically the same as commercial aircraft systems. However, military engine bleed air systems often interface with additional systems such as anti-G suit, gun gas purge, and canopy seal.

The primary emphasis of this document is on systems which use the aircraft engine as the source of the pneumatic supply. Alternate supply systems are discussed in Section 7.

1.1 Purpose

The purpose of this document is to provide guidelines and recommended practices for analysis, design, and installation of aircraft engine bleed air systems.

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.

ARP699 High Temperature Pneumatic Duct Systems for Aircraft

ARP986 Guide for Qualification Testing of Aircraft Air Valves

AIR1266 Fault Isolation in Environmental Control Systems of Commercial Transports

AIR1826 Acoustical Considerations for Aircraft Environmental Control System Design

ARP4418 Procedure for Sampling and Measurement of Engine and APU Generated Contaminants in Bleed Air Supplies from Aircraft Engines

2.1.2 Military Publications

Copies of these documents are available online at http://quicksearch.dla.mil.

MIL-STD-810 Department of Defense Test Method Standard for Environmental Engineering Considerations and Laboratory Tests

MS33740 Nipple, Pneumatic Starting, 3 Inch ID

JSSG-2009 Joint Services Specification Guide, Air Vehicle Subsystems

2.1.3 FAA Publications

Available from Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591, Tel: 866-835-5322, www.faa.gov.

Federal Aviation Regulations, Title 14 of the US Code of Federal Regulations Part 25 Airworthiness Standards: Transport Category Airplanes (14CFR25)

Federal Aviation Regulations, Title 14 of the US Code of Federal Regulations Part 121 Certification and Operations: Domestic, Flag and Supplemental Air Carriers and Commercial Operators of Large Aircraft (14CFR121)

Federal Aviation Regulations, Title 14 of the US Code of Federal Regulations Part 23 Airworthiness Standards: Normal, Utility, Acrobatic, and Commuter Category Airplanes (14CFR23)

2.1.4 ATA Publications

Available from Airlines for America (A4A), 1301 Pennsylvania Avenue, NW, Suite 1100, Washington, DC 20004, Tel: 202-626-4000, www.airlines.org.

Air Transport Association of America, Specification No. 100 - Specification for Manufacturers Technical Data

Air Transport Association of America, Airline Industry Standard: World Airlines Technical Operations Glossary (WATOG) - 8th Edition

Air Transport Association of America, Maintenance Steering Group (MSG-3)

2.1.5 RTCA Publications

Available from RTCA, Inc., 1150 18th Street, NW, Suite 910, Washington, DC 20036, Tel: 202-833-9339, www.rtca.org.

RTCA/DO-160 Environmental Conditions and Test Procedures for Airborne Equipment

2.1.6 ARINC Publications

Available from ARINC, 2551 Riva Road, Annapolis, MD 21401-7435, Tel: 410-266-4000, www.arinc.com.

ARINC 604-1 Guidance for Design and Use of Built In Test Equipment:

2.1.7 ISO Publications

Available from American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, Tel: 212-642-4900, www.ansi.org.

or if using the Switzerland address:

Available from International Organization for Standardization, ISO Central Secretariat, 1, ch. de la Voie-Creuse, CP 56, CH-1211 Geneva 20, Switzerland, Tel: +41 22 749 01 11, www.iso.org.

ISO 2026 Aircraft Connections for Starting Engines by Air

2.1.8 European Aviation Safety Agency Publications

Available from European Aviation Safety Agency, Postfach 10 12 53, D-50452 Cologne, Germany, Tel: +49-221-8999-000, www.easa.eu.int.

CS-23 Certification Specifications for Normal, Utility, Aerobatic and Commuter Aeroplanes, European Regulations

CS-25 Certification Specifications for Large Aeroplanes, European Regulations

2.1.9 Other Publications

NATO Standardization Agreements (STANAG), STANAG 3372 Pneumatic Starting Nipple

2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Aerospace Technical Report.

2.2.1 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.

AIR1539 Environmental Control System Contamination

2.2.2 FAA Publications

Available from Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591, Tel: 866-835-5322, www.faa.gov.

Code of Federal Regulation, Title 29, Part 1910 Occupational Safety and Health Standards, Section 1910.1000 Air Contaminants

2.2.3 Other Publications

ACGIH TLVs and BEIs, Latest edition, ACGIH 1330 Kemper Meadow Drive, Cincinnati, OH 45240-1634, www.acgih.org.

3. DESIGN PHILOSOPHY

3.1 Regulations

The engine bleed air system shall comply with airworthiness requirements, the scope of which would be defined in the aircraft specification. Design will also be regulated by the aircraft specification. In the event of conflict, the most stringent requirements shall prevail.

3.1.1 Civil Regulations

Regulatory bodies include the United States Federal Aviation Administration (FAA) and the European Aviation Safety Agency (EASA). The FAA regulates the design of transport category aircraft in 14 CFR25. EASA regulates design in CS-25, which represents the combined requirements of the Airworthiness Authorities of the participating European nations. Typical requirements include, but are not limited, to the following paragraphs of 14 CFR25 and CS-25:

23.1111 Turbine Engine Bleed Air System

25.831 Ventilation

25.856 Thermal/Acoustic insulation materials

25.863 Flammable fluid fire protection

25.867 Fire protection: other components

25.903 Engines

25.1103 Induction system ducts and air duct systems

25.1163 Powerplant accessories

25.1181 Designated fire zones; regions included

25.1301 Function and installation

25.1309 Equipment, systems and installations

25.1322 Warning, caution and advisory lights

25.1438 Pressurization and pneumatic systems

25.1461 Equipment containing high energy rotors

CS25.1438 Pressurisation and Low Pressure Pneumatic Systems

SFAR 88 Fuel Tank System Fault Tolerance Evaluation Requirements

Operating rules based on FAA or EASA regulations are applied individually by the nation of registry. Adequate provision should be made in systems design to ensure that it is possible for the aircraft operators to meet their relevant requirements. These requirements are established by regulations such as 14CFR121. Regulatory agencies may impose special conditions on the design. These conditions will be issued with full authority of the regulatory agency, and compliance is mandatory. The existence and interpretation of such special conditions should be established at the outset of the design.

3.1.2 Military Regulations

Requirements for military aircraft bleed air systems can be found in the following specifications:

a. Air Force/Army/Navy/Marines: Bleed air systems requirements are derived for each individual aircraft through tailoring JSSG-2009.

b. STANAG: Certain bleed air system provisions are the subject of NATO Standardization Agreements.

3.2 Crew Workload

Control policy will be decided by the flight compartment configuration and the operational role of the flight crew. The crew workload imposed by systems management is an increasingly important factor in systems design. Account should also be taken of the capability of electronic displays and data processors to present relevant information only when it is needed to monitor system health and to facilitate maintenance troubleshooting.

The objectives of system design should be to minimize crew actions in normal operation, crew intervention after a single failure, and crew indications not requiring corrective action. These objectives imply a fail-passive design approach and increased redundancy.

3.3 Safety

The high energy in engine bleed systems calls for special design and installation precautions. The effects of external leakage and bursting of components and ducts must be considered as well as internal control failures. The design shall meet the requirements of 14CFR25.1309 which addresses the acceptability of system failures and the requirement to provide adequate information to the flight crew. Other safety considerations include the following:

a. Engine bleed ports shall incorporate flow limiting devices if analysis shows that bleed duct failure will compromise the integrity of airframe hardware or the operational characteristic of the engine.

b. Bleed shutoff provisions shall be located to minimize damage in the event of a duct rupture.

c. Duct surface temperatures shall not exceed temperatures that would result in exceeding the thermal limits for nearby structure, wiring, and equipment.

d. Provisions for overheat detection, pressure relief, and ventilation shall be provided in all compartments where bleed air leakage or burst ducts could be hazardous.

e. All electrical equipment located in a flammable fluid leakage zone shall meet explosion proof criteria.

f. Flight crew operating requirements shall be minimized, especially where incorrect use of procedures can cause a subsequent failure or potentially hazardous operating condition.

g. Check valves or controls shall be provided to prevent reverse bleed flow into any bleed port.

h. Environmental requirements such as temperature, altitude, vibration, EMI, lightning strike, etc., shall be complied with. Electronic components shall have electrical bonding per appropriate military or civil aviation regulations/specifications.

i. Structural fatigue and materials compatibility issues shall be minimized by design.

3.4 Reliability and Maintainability

The system specification shall explain the maintenance philosophy to be applied to that aircraft, and set design targets for equipment reliability and maintainability costs. The various maintenance philosophies are defined in the Airline Industry Standard: World Airlines Technical Operations Glossary (WATOG). The trend toward "on condition" maintenance emphasizes the need to design for reliability and for equipment life to match that of the aircraft. A formal maintenance analysis technique, Maintenance Steering Group (MSG)-3, has evolved, and this is widely adopted in commercial airline operations.

System design has evolved from an iterative process influenced by the objectives of minimum maintenance burden, failure analyses, and a viable configuration deviation list (CDL) and master minimum equipment list (MMEL) for aircraft dispatch. Specific considerations for engine bleed air systems are:

a. Accessibility of individual components

b. Redundancy in critical equipment

c. Manual positioning of control valves for dispatch

d. Elimination of routine servicing

e. Isolation of system failures to the line replaceable unit (LRU)

3.5 Economics

An important bleed air system design objective is low cost of ownership (life cycle cost). This involves designing for a combination of low system cost, low maintenance and low operating penalties. Although the fuel burn for a given amount of engine bleed air extraction has decreased as engines have become more efficient, the availability of compressor bleed air has decreased. This is because engine bypass ratios have generally increased resulting in a decrease in total compressor airflow relative to engine thrust and bleed air requirements. This coupled with the fact that compressor bleed tends to adversely affect engine life by increasing engine operating temperature, emphasizes the importance of minimizing operating penalties. Specific considerations in achieving this objective are:

a. Use of lowest acceptable compressor stage bleed port.

b. Strict control of external leakage from pneumatically actuated components.

c. If a precooler is used, it should be designed to optimize trade-off between weight and coolant air usage (whether ram air, engine fan air, or a lower stage bleed air).

d. Equal proportioning of bleed flows from multiple-engine installation.

e. Consideration of alternate sources of compressed air.

The use of ground pneumatic power from an airport hydrant offers significant savings in ground air conditioning. The bleed air system shall be compatible with high pressure ground air supplies. Connections for ground air shall be standardized and located for minimum interference with other airport services. The military standard for ground pneumatic connections is MS33740. The International Standards Organization (ISO) standard for ground pneumatic connections is ISO 2026. The NATO standard for pneumatic starting nipple is STANAG 3372.

4. SYSTEM DESIGN REQUIREMENTS

The engine bleed air system extracts high pressure air from one or more bleed ports of each engine, controls its pressure and temperature, and delivers it to the distribution manifold. Bleed air from alternate sources such as the auxiliary power unit (APU) or high pressure ground cart is also connected to the distribution manifold. The distribution manifold receives compressed air from the above sources, controls its routing, and delivers it to the using systems. Some bleed air from each engine may be taken prior to delivery to the distribution manifold to satisfy engine pneumatic demands such as cowl anti-ice.

Crossbleed and isolation valves are required in the distribution manifold to maintain essential functions in the event of supply or using system failure. Valves (check or shutoff) are also required to prevent reverse flow through the bleed air sources (engines, APU, or ground connection).

These functions are implemented as shown on the typical bleed air system schematic of Figure 1.

4.1 System Selection

4.1.1 Actuation

Pneumatic actuated systems have been in use for many years, and offer system maturity and the advantage of continued operation with loss of aircraft electrical power.

Electric motor driven valves are normally not installed in the environment of engine bleed air systems because of the high temperature.

Electro-pneumatic valve systems may include both electric actuated motors and pneumatic actuation.

The more recently developed electronic systems offer many potential advantages over current pneumatic systems:

a. The torque motor servo controls of electronic systems are normally more reliable than the pneumatic system controls because of a lower parts count.

b. Higher control accuracy is attainable for temperature control, pressure regulation, and flow sharing between engines.

c. Digital electronic control provides much greater flexibility in control schedules.

d. More comprehensive Built-In-Test (BIT) and reconfiguration.

Disadvantages of electronic systems include:

a. Dependence on electrical systems; pneumatic backup may be required.

b. Electronic systems are generally more costly than pneumatically-controlled systems.

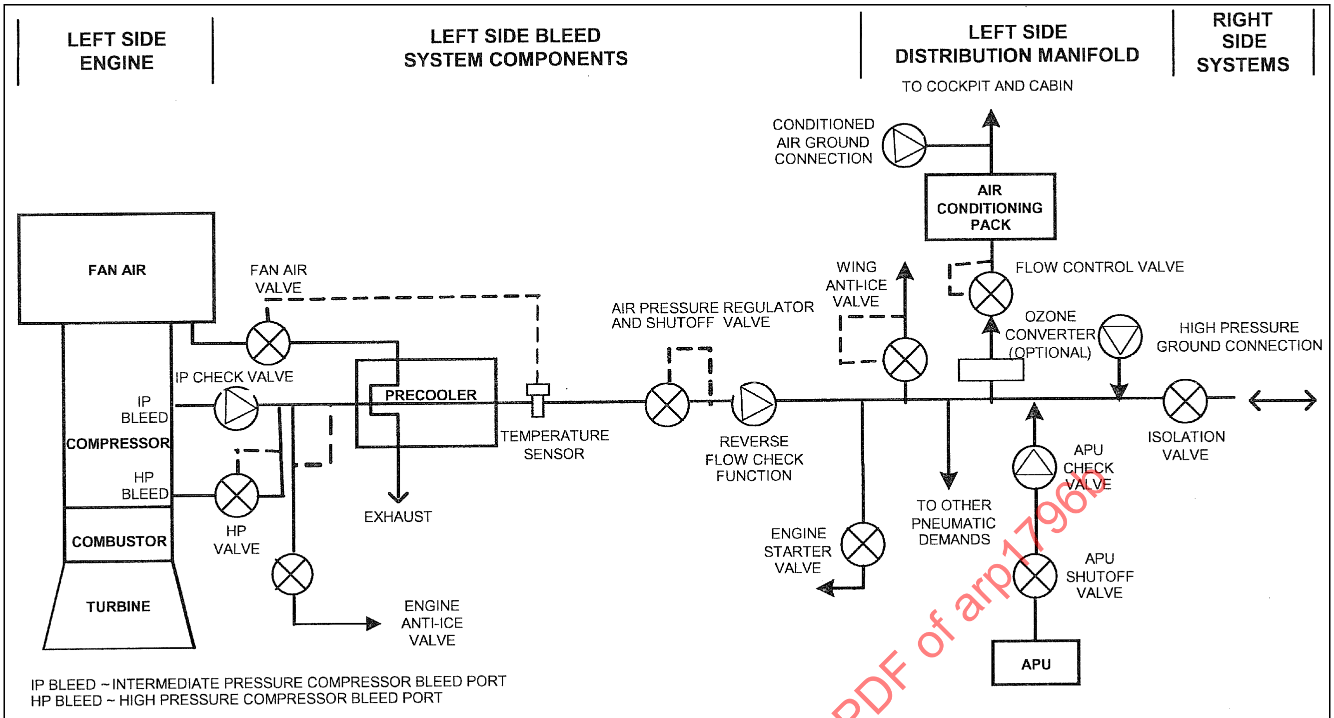

Figure 1 - Typical aircraft bleed air system

4.1.2 Controls

There are two basic types of engine bleed air system controls in use on commercial and military aircraft; pneumatic and electronic. Pneumatically controlled systems utilize pneumatic control elements to position a pneumatically actuated valve in response to pneumatic signals from pressure probes or pneumatic temperature sensors. Electronically controlled systems utilize an electronic controller to position a torque motor, which provides a pneumatic servo signal to position a pneumatically actuated valve in response to signals from electronic pressure or temperature sensors.

Pneumatic systems often include an electronic unit to perform built-in-test (BIT) and other supervisory functions.

4.2 System Design

The design of engine bleed air systems shall include the following system considerations:

a. System sizing

b. Pressure control

c. Temperature control

d. Flow management

e. Dynamic performance

f. Acoustic considerations

g. Cockpit indication and controls

h. Electrical power

i. Failure considerations

j. Built-in-test

k. Fire resistance

l. Bleed air quality

m. Ground test provisions

These design requirements are discussed in the following sections.

4.2.1 System Sizing

The bleed air system components and ducting shall be sized to satisfy the pressure and flow requirements of the using system while limiting bleed air temperature to acceptable levels. For ducts which are not in fire zones, duct surface temperature limits shall be based upon the ignition temperature of combustible fluids which could be present. Current commercial aircraft practice for fuel vapor zones allows an exposed surface temperature of 232 °C (450 °F) with shutdown at 260 °C (500 °F). If these temperatures are exceeded, sufficient ventilation should be provided to prevent accumulation of flammable fluid vapors. The duct surface temperature requirement can be satisfied by bleed port selection, alternate system approaches (as described in Section 7), insulation on the ducts, shrouding of the ducts, or any combination of these. If ram air is used as a precooler coolant, a means of inducing air flow on the ground may be required. This can be done with a fan or bleed air powered ejector.

The bleed air temperature shall be sufficiently cool at the air conditioning pack inlets and other user systems so the life limit of any part of the pack will not be affected, and user systems produce adequate performance. It is desirable to limit this temperature to allow use of aluminum heat exchangers in air conditioning packs. The bleed air temperature must also be sufficiently hot for ice protection and to provide adequate cabin heating. For example, the bleed air temperature control requirements may be satisfied by a heat exchanger (precooler) located in the nacelle or pylon area of each engine. The precooler reduces bleed air temperature to acceptable levels, normally using engine fan air or ram air as the coolant (heat sink).

Engine bleed air temperature and pressure requirements should be carefully considered since the downstream distribution ducting weight is affected by these parameters. Bleed air ducting design should follow the recommendations of ARP699.

4.2.1.1 Precooler Sizing

Factors which determine precooler size include the following:

a. Temperature decrease required in bleed air

b. Maximum flow rate of bleed air to be cooled

c. Allowable bleed air pressure drop

d. Temperature difference between coolant inlet and bleed air discharge

e. Allowable coolant pressure drop

f. Densities of coolant and bleed air

g. Installation constraints

h. Type of core (tubular versus plate-fin)

i. Maintainability requirements such as cleanability (size of passages) and repairability

j. Weight/shape optimization

k. Type of material used to fabricate heat exchanger

Conditions which make any combination of these factors large in an adverse direction should be checked for their effect on precooler size and weight. The allowable bleed air coolant pressure drops should be as generous as possible within the constraints of the system requirements and duct sizing criteria.

Certain aircraft operating conditions or system failure modes may result in severe precooler design conditions. The following are examples of such conditions.

a. Failure of one bleed system after dispatch with minimum allowable number of bleed systems operating, such that bleed air services must be concentrated on remaining system(s).

b. Operation of bleed air ice protection systems.

c. Incorrect crew procedures.

d. Aircraft hold in icing with only one bleed system operative for a two-engine aircraft, with air conditioning and all bleed air ice protection systems on (this is usually a critical design condition).

Some of these conditions may warrant using special operating procedures or allowing the discharge temperature to approach the upper temperature limit to avoid using an extremely heavy precooler.

4.2.1.2 Valves and Ducting

System allowable pressure drop and/or Mach number limitations determine the size (diameter) of bleed air systems, valves and ducting. Valve and duct size shall be sufficient to provide adequate pressure to the using systems at the critical operating conditions such as engine start, cabin pressurization during descent, and aircraft hold in icing conditions. The duct Mach number in normal operation should be limited to 0.25 to be consistent with low pressure drop and to maintain good system fatigue life.

4.2.2 Pressure Control

Pressure regulation shall be set to the lowest level required for engine start and any other using-system requirements during normal or single failure conditions, or with minimum equipment operable at dispatch. Tolerance of pressure regulation should be compatible with ducting design and engine flow sharing requirements. Close tolerance pressure regulation might require external pressure sensing instead of downstream sensing internal to the valve body. External sensing lines shall be routed to prevent accumulation of moisture and formation of ice.

Engine bleed port switching shall be designed to use intermediate stage bleed during all cruise operation. When intermediate stage bleed pressures are not adequate the system shall automatically switch to high stage bleed. It shall be an objective to avoid subjecting downstream systems to rapid, large pressure fluctuations.

Overpressure protection shall be provided for a flowing system and for a closed-off system. Protection for the flowing condition may be in the form of backup pressure regulation, relief valves, or overpressure shutoff valves. The flowing system overpressure protection shall be sufficiently responsive to protect against pressure transients caused by rapid throttle motion, and shall be set sufficiently higher than normal operating control to preclude actuation of the protective devices in normal operation. Relief valves to protect a closed-off system shall be sized to accommodate maximum normal leakage from the primary bleed air supply valves with zero leakage of downstream valves. Relief valve discharge shall be ducted overboard or properly ventilated.

Consideration should be given to scheduling the bleed port switching setpoint and the pressure regulator setting as a function of altitude for optimum bleed air management.

4.2.3 Temperature Control

Temperature control may be accomplished using bleed air bypass around the precooler or by modulating the coolant flow through the precooler. Modulating the coolant flow through the precooler is normally the most efficient means for the aircraft; however, bleed air bypass around the precooler provides control simplicity. If modulation of the coolant flow through the precooler is selected as the temperature control scheme, thrust recovery of this flow should be considered.

Temperature control sensors should be sufficiently downstream of the precooler or mixing point to ensure accurate measurement. The temperature control tolerance shall be as large as possible within the constraints of the system requirements to permit the simplest, most reliable type of temperature control.

4.2.4 Flow Management

For multiengine bleed systems it is desirable to have flow sharing between all engines. Bleed flow sharing promotes engine life by equalizing bleed extraction and, thus, engine hot section temperatures. Flow sharing shall maintain bleed for each engine within tolerances that are:

a. compatible with engine controls, and

b. consistent with engine bleed flow limits for all thrust conditions producing bleed pressures equal to pressure regulator settings.

For the two engines, two air conditioning pack configurations, flow management is commonly provided by operating with bleed air sources normally isolated, but connected by a crossover manifold and crossover valve for some operational situations.

Where multiple sources are connected to a common manifold, the low pressure sources shall be protected against reverse flow from high pressure sources. This applies to both engines and aircraft APU or ground cart sources. Reverse flow protection may take the form of dedicated check valves or multifunction (shutoff and reverse flow protection) valves.

4.2.5 Dynamic Performance

The engine bleed air system shall satisfy the steady-state performance and accuracy requirements in a stable and responsive manner with no objectionable control interactions. The control system shall not exhibit any self-induced or aircraft system induced divergent or continuously sustained oscillations in airflow, temperature or pressure.

4.2.6 Acoustic Considerations

The engine bleed air system design should include consideration of acoustic noise levels within occupied compartments as a result of operation of the bleed air system. Specific noise requirements should be detailed in the equipment design specification.

Fans and ejectors, when utilized to induce ram air flow through the precooler coolant circuit, can contribute to ramp noise.

Comprehensive discussion of acoustical considerations can be found in AIR1826.

4.2.7 Recommended Indications and Controls

The engine bleed air system controls, indicators and warning shall allow the crew to verify normal system operations, to identify any abnormal operating condition requiring crew action, and to retain control after failure of automatic functions.

4.2.7.1 Recommended indications and controls:

a. Valve position indication

b. Bleed air manifold pressure and temperature, (downstream of precooler and pressure regulating valve)

c. Overtemperature trip (shutdown)

d. Overpressure trip (shutdown)

e. Duct leak or zone overheat (leak detection system)

As a minimum the crew should have shutoff indication and control of each bleed source.

4.2.8 Electrical Power

The bleed air system electrical design requirements shall consider the following:

a. Independent circuits and supplies for control and indication functions.

b. Normal control of engine bleed air after reasonably probable failures in the electrical system.

c. All bleed air functions including cabin pressurization which are necessary for continued safe flight and landing must be maintained after loss of primary electrical power.

d. To minimize essential or battery power requirements, consideration must be given to the use of normally-open, normally-closed, latching-solenoid, and motorized valves.

4.2.9 Failure Considerations

A fault and failure analysis should be conducted to determine the need for normally-open, normally-closed, or latching solenoids on the bleed control valves, or valves which remain in the last commanded position.

Valves which require manual wrenching for dispatch shall permit locking only in a safe position.

An air pressure regulator and shut-off valve downstream of the bleed junction on aircraft, such as military aircraft, where the bleed air from two engines are combined prior to supplying the using subsystems should be considered. This allows critical subsystems such as OBOGS to operate with a fail-open condition of one of the upstream valves. This also results in lower weight and cost of the downstream components, which can be designed to a lower single failure pressure requirements.

Shutoff valves to isolate critical areas should be considered where a duct burst, coupling, or clamp failure could expose these areas to very rapid pressure or temperature rise. Automatic isolation should also be considered if crew response would be too slow.

Potential ingestion of failed parts by the engine or air cycle machine should be considered in design of bleed system components.

A system should be provided to detect bleed air leakage that could cause damage or compromise safety.

Care must be taken when locating remote pilot controls required for torque motors, pneumatic control elements, and pressure sensors to avoid servo line leakage or freezing.

4.2.10 Built-In-Test

Systems which require automatic built-in-test (BIT) to check proper operation of a number of line replaceable units (LRUs) should include the following design considerations:

a. BIT can be accomplished without the addition of extra equipment.

b. Devices used for built-in-test (BIT) should not be combined with those for normal system operation or with its monitoring devices if they would degrade system reliability.

c. Generally, multiple LRU failures should not be summed into one operation indication.

d. Automatically stored information should be stored so that fault information from the last several flights is obtainable; this should be separately obtainable if it aids fault isolation. Oldest information should be automatically dropped from memory, as new information is stored.

e. Wire check capability should be considered; faulty wires and connectors can cause erroneous LRU removals.

Comprehensive discussion of fault isolation, BIT and BITE can be found in AIR1266 and ARINC 604.

4.2.11 Fire Resistance

The FAA has designated the following compartments as fire zones:

a. Engine compressor and accessory section(s).

b. The combustor, turbine, and tailpipe sections that contain lines or components carrying flammable fluids or gases.

c. The APU compartment.

d. Any fuel burning heater and other combustion heater installation.

The following fire resistant requirements apply to engine bleed air systems:

a. Air shall not be added to a fire in quantities that will increase the fire intensity.

b. Air shall not be added that will adversely affect the capability of the fire extinguishing system.

c. Bleed air from other engines shall not be added to a fire in a fire zone.

d. Fire shall not be able to progress from a fire zone through ducts, past the firewall boundary.

4.2.12 Engine Bleed Air Quality

Refer to ARP4418 for engine bleed air requirements and test methods.

Bleed Air quality shall meet the requirements of ARP4418. For aircraft such as military aircraft where the engine may have been designed prior to the design of the aircraft, it may be necessary to add filters to meet the above contamination requirements in the occupied compartments. Other sources of high pressure air such as APUs, auxiliary compressors and ground support equipment need to be reviewed for possible contamination. The outside air contaminants shall be evaluated in addition to the engine generated contaminants. Air contaminants around airports may contribute a significant portion of cabin environment contamination while operating on the ground or at lower altitudes up to flight level 10.

4.2.13 Ground Test Provisions

Provisions should be incorporated for connection of test equipment for leak and pressure testing, in situ component functional checks and monitoring of performance.

Provisions shall be incorporated to permit ground testing of ducting and components without the need for engine operation.

Ground interrogation using built-in-test (BIT) is particularly valuable in the engine bleed air system, to detect component failures without the need for engine operation. Care must be taken to avoid any significant increase in system complexity.

5. COMPONENT DESIGN REQUIREMENTS

This section provides recommendations for component design and installation requirements.

5.1 Component Design

5.1.1 General Design Recommendations

5.1.1.1 Materials and Processes

Component parts of the bleed air system shall be constructed of materials which are considered acceptable for the particular use and shall be made and furnished with the degree, uniformity and grade of workmanship required to meet the reliability and safety goals.

5.1.1.2 Environmental Requirements

Component parts of the bleed air system shall be designed for storage and operation before, during and after exposure to the environmental conditions to which they will be subjected, including vibration, shock, acceleration loads, humidity, salt fog, temperature, and pressure.

5.1.1.3 Failure Mode

The component failure mode shall comply with the system mode developed in 3.3.

5.1.1.4 Safety

Component designs shall conform to regulations in 14 CFR Part 23, 25, EASA CS-23 and/or CS-25 as applicable.

5.1.1.5 Leakage

External leakage rates for all components shall be as low as practical, and shall not exceed values specified in the equipment design specification.

5.1.1.6 Proof Pressure

After being subjected to the applicable Proof Pressure conditions of Table 1 and on normal operating conditions being restored, components of the bleed air system shall operate normally and there should be no detrimental permanent distortion, increase in leakage or damage that would prevent the component from performing its intended function. FAA, EASA and U.S. Military requirements are listed in Table 1. In general, bleed system components shall withstand a proof pressure equal to 1.5 times the maximum normal operating pressure, with the component at the associated temperature for the most adverse pressure and temperature condition(s) that occurs during normal operation. Transient pressures should be considered in determining the proof and burst pressures when the transients are of a sufficient time duration and/or frequency of occurrence. EASA imposes additional requirements associated with failure conditions and their probability of occurrence (to be calculated on the basis of combined reliability estimates). JSSG-2009 also recommends a proof pressure capability of 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 an upstream pressure or temperature control device.

Over the entire normal aircraft and pneumatic system operating ranges, there may be several combinations of pressures and temperatures to be evaluated for proof pressure compliance. Failure conditions may add numerous other proof pressure and temperature combinations. The most severe pressure and temperature combination resulting from all the requirements in Table 1 is generally determined by analysis of the lowest stress margin of the component. This is done by comparing the stress level of the part at each Table 1 condition to the elevated temperature yield strength characteristics of the materials used.

Table 1 - Proof certification requirements

Requirement	14 CFR §25.1438	EASA CS/AMC 25.1438	JSSG-2009
Normal Operation	$1.5 \times P_1$ @ T_1	$1.5 \times P_1$ @ T_1	$1.5 \times P_1$ @ T_1 Typical $2 \times P_1$ @ T_1 Desired
Reasonably Probable Failure Conditions ($<10^{-3}$)		$1.33 \times P_2$ @ T_2	
Remote Failure Conditions ($<10^{-5}$)		$1.0 \times P_3$ @ T_3	
Failure of a pressure or temperature control device			$1.1 \times P_5$ @ T_5 Typical

where:

P_1 = Most critical value of pressure encountered during normal functioning

T_1 = Combination of internal and external temperatures which can be encountered in association with pressure P_1

P_2 = Most critical value of pressure corresponding to a probability of occurrence 'reasonably probable'

T_2 = Combination of internal and external temperatures which can be encountered in association with pressure P_2

P_3 = Most critical value of pressure corresponding to a probability of occurrence 'remote'

T_3 = Combination of internal and external temperatures which can be encountered in association with pressure P_3

P_5 = Most critical value of pressure corresponding to a failure of a pressure control device or associated pressure corresponding to a failure of a temperature control device

T_5 = Combination of internal and external temperatures which can be encountered in association with pressure P_5 or most critical temperature corresponding to a failure of a temperature control device

5.1.1.7 Burst Pressure

Components of the bleed air system shall be capable of withstanding the applicable burst pressure conditions of Table 2 without rupture or excessive leakage. Correct functioning of the component is not required when normal operating conditions have been restored. FAA, EASA and U.S. Military requirements are listed in Table 2. In general, bleed system components shall withstand a burst pressure equal to 3.0 times the maximum normal operating pressure, with the component at the associated temperature for the most adverse pressure and temperature condition(s) that occurs during normal operation. Transient pressures should be considered in determining the proof and burst pressures when the transients are of a sufficient time duration and/or frequency of occurrence. EASA imposes additional requirements associated with failure conditions and their probability of occurrence (to be calculated on the basis of combined reliability estimates). JSSG-2009 recommends a burst pressure capability of 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 an upstream pressure or temperature control device.

Over the entire normal aircraft and pneumatic system operating ranges, there may be several combinations of pressures and temperatures to be evaluated for burst pressure compliance. Failure conditions may add numerous other burst pressure and temperature combinations. The most severe pressure and temperature combination resulting from all the requirements in Table 2 is generally determined by analysis of the lowest stress margin of the component. This is done by comparing the stress level of the part at each Table 2 condition to the elevated temperature ultimate strength characteristics of the materials used.

Table 2 - Burst certification requirements

Requirement	14 CFR §25.1438	EASA CS/AMC 25.1438	JSSG-2009
Normal Operation	$3.0 \times P_1$ @ T_1	$3.0 \times P_1$ @ T_1	$2.5 \times P_1$ @ T_1 Typical $4 \times P_1$ @ T_1 Desired
Reasonably Probable Failure Conditions ($<10^{-3}$)		$2.66 \times P_2$ @ T_2	
Remote Failure Conditions ($<10^{-5}$)		$2.0 \times P_3$ @ T_3	
Extremely Remote Failure Conditions ($<10^{-7}$)		$1.0 \times P_4$ @ T_4	
Failure of a pressure or temperature control device			$1.5 \times P_5$ @ T_5 Typical

where:

P_1 = Most critical value of pressure encountered during normal functioning

T_1 = Combination of internal and external temperatures which can be encountered in association with pressure P_1

P_2 = Most critical value of pressure corresponding to a probability of occurrence 'reasonably probable'

T_2 = Combination of internal and external temperatures which can be encountered in association with pressure P_2

P_3 = Most critical value of pressure corresponding to a probability of occurrence 'remote'

T_3 = Combination of internal and external temperatures which can be encountered in association with pressure P_3

P_4 = Most critical value of pressure corresponding to a probability of occurrence 'extremely remote'

T_4 = Combination of internal and external temperatures which can be encountered in association with pressure P_4

P_5 = Most critical value of pressure corresponding to a failure of a pressure control device or associated pressure corresponding to a failure of a temperature control device

T_5 = Combination of internal and external temperatures which can be encountered in association with pressure P_5 or most critical temperature corresponding to a failure of a temperature control device