



AEROSPACE RECOMMENDED PRACTICE

ARP1270™

REV. C

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Superseding ARP1270B

(R) Aircraft Cabin Pressurization System Criteria

RATIONALE

Revision C is issued to provide general restructuring and alignment of the document with system engineering best design and safety practices.

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1. SCOPE

This report, in conjunction with other referenced SAE documents, provides recommendations for development of aircraft cabin pressure control systems and equipment, with particular emphasis on performance objectives, requirements definition, operational scenarios, design practices, safety processes, and verification methods.

The objective of a Cabin Pressure Control System (CPCS) is to regulate aircraft cabin pressure throughout the operational flight envelope, in order to ensure occupant safety, aircraft safety, and passenger comfort.

The system should comply with all relevant certification and safety requirements, particularly in the areas of:

- a. Maintaining a breathable environment within occupied compartments
- b. Protecting the fuselage structure against excessive positive and negative differential pressure loads
- c. Supporting cabin egress on ground

The system should have the capability to schedule cabin pressure at rates of change that are comfortable to crew and passengers.

Careful consideration should be given to external system interfaces and the role of CPCS in providing supporting functions.

The system should be fault tolerant and reliable, support crew awareness of key system parameters and failure conditions, and support efficient fault isolation and resolution by maintenance crews.

If applicable, the system design should provision for high altitude airport operation or application on a freighter configuration aircraft.

The system architecture and design should minimize aircraft fuel burn through optimized weight.

To this end, the complexity and level of automation of the system should be carefully evaluated within the context of a functional hazard assessment and the overall impact to system reliability, maintainability, and cost of ownership.

This recommended practice is applicable to pressurized aircraft, both civil and military, regardless of the number of passengers or crew.

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: 1-877-606-7323 (U.S. and Canada only) or 1-724-776-4970 (outside U.S. and Canada), www.sae.org.

AIR822	Oxygen Systems for General Aviation
AIR825/1	Introduction to Oxygen Equipment for Aircraft
AIR1168/7	Aerospace Pressurization System Design

ARP488	Cabin Emergency Exits Design and Operation - Transport Category Aircraft
ARP4754	Guidelines for Development of Civil Aircraft and Systems
ARP4761	Guidelines for Conducting the Safety Assessment Process on Civil Aircraft, Systems, and Equipment

2.1.2 ANSI Publications

Copies of these documents are available online at <https://webstore.ansi.org>.

IEEE/ASTM/ANSI SI 10	Standard for Use of the International System of Units (SI): the Modern Metric System Revision and Redesignation of ANSI/ IEEE Std 268-1992 and ASTM E380
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2.1.3 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9500, www.astm.org.

ASTM F3227/F3227M	Standard Specification for Environmental Systems in Aircraft
ASTM F3230	Standard Practice for Safety Assessment of Systems and Equipment in Small Aircraft
ASTM F3061/F3061M	Standard Specification for Systems and Equipment in Aircraft

2.1.4 Code of Federal Regulations (CFR) Publications

Copies of these documents are available online at www.ecfr.gov.

14 CFR Part 23	Airworthiness Standards: Normal, Utility, Acrobatic, and Commuter Category Airplanes
14 CFR Part 25	Airworthiness Standards: Transport Category Airplanes
14 CFR Part 27	Airworthiness Standards: Normal Category Rotorcraft
14 CFR Part 29	Airworthiness Standards: Transport Category Rotorcraft

2.1.5 EASA Publications

Available from European Union Aviation Safety Agency, Konrad-Adenauer-Ufer 3, D-50668 Cologne, Germany, Tel: +49 221 8999 000, www.easa.europa.eu.

AMC 25.1309	System Design and Analysis
CS-23	Certification Specifications for Normal-Category Aeroplanes
CS-25	Certification Specifications for Large Aeroplanes
CS-27	Certification Specifications for Small Rotorcraft
CS-29	Certification Specifications for Large Rotorcraft

2.1.6 EUROCAE Publications

Available from EUROCAE Secretariat, 9-23 Rue Paul Lafargue, 93200 Saint-Denis, France, Tel: +33 1 49 46 19 65, www.eurocae.net.

ED-14 Environmental conditions and test procedures for airborne equipment

2.1.7 FAA Publications

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

AC 25.1309 System Design and Analysis

AC 25-20 Pressurization, Ventilation and Oxygen Systems Assessment for High Altitude Flight Including High Altitude Operation, FAA Advisory Circular, Initiated by ANM 110, 9/10/1996

AC 25-22 Certification of Transport Airplane Mechanical Systems, FAA Advisory Circular, Initiated by ANM 110, 3/14/2000

AC 25.783-1A Fuselage Doors and Hatches, FAA Advisory Circular, Initiated by ANM 115, 4/25/2005

AC 61-107A Operations of Aircraft at Altitudes Above 25,000 Feet MSL and/or Mach Numbers (MMO) Greater Than .75, FAA Advisory Circular, Initiated by AFS-820, 1/2/2003.

2.1.8 NASA Publications

Copies of these documents are available online at <https://ntrs.nasa.gov/>.

NACA Report 1235 Standard Atmosphere - Tables and Data for Altitudes to 65,800 Feet

2.1.9 RTCA Publications

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

DO-160 Environmental Conditions and Test Procedures for Airborne Equipment

DO-178 Software Considerations in Airborne Systems and Equipment Certification

DO-254 Design Assurance Guidance for Airborne Electronic Hardware

2.1.10 U.S. Government Publications

Copies of these documents are available online at <https://quicksearch.dla.mil>.

JSSG-2009 Air Vehicle Subsystems

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

MIL-R-9345 Regulator, Air Pressure Aircraft Cabin, General Specification

MIL-STD-810 Environmental Engineering Considerations and Laboratory Tests

2.1.11 Other Publications

- [1] Armstrong, H.G., and Heim, J.W. (1937). The effect of flight on the middle ear. *JAMA*, 109(6), 417-421.
- [2] Chapin, S.L. (1991) An active interface between medical science and aeronautical technology: the physiological investigations for the XC-35. *History and Philosophy of the Life Sciences*, 13(2), 235-248.
- [3] Cleaves, V.F., and Watson, A.C. (1968, June 16-19). *A method of evaluating cabin pressure transients with regard to effects on the occupants* [Conference paper]. Aviation and Space: Progress and Prospects; Proceedings of the Annual Aviation and Space Conference, Beverly Hills, California, USA, p. 405.
- [4] Raeke, J.W., and Freedman, T. (1961, April 24-27). *Human response to rapid recompression*. Aerospace Medical Association Meeting, Chicago, Illinois, USA.
- [5] Spealman, C.R., and Cherry, J.C. (1958). Middle ear perception of pressure and pain in descent from altitude. *Aviation Medicine*.
- [6] Waggoner, J.N. (1967). Human tolerance to changes in aircraft cabin pressurization. *Aerospace Medicine*.

2.2 Definitions

AIR DATA COMPUTER: Avionics component that converts pitot static pressures to electronic signals for use by primary flight instruments and other systems, such as CPCS.

BAROMETRIC CORRECTION: Pressure correction applied to altimeter, FMS, or CPCS to compensate the altitude calculation for non-standard atmospheric pressure.

CABIN ALT: Cabin Pressure Altitude

CABIN RATE: Cabin Pressure Altitude Rate-of-Change

CONTROLLER: Cabin Pressurization Controller

DUMP: To rapidly reduce cabin pressure.

ENVIRONMENTAL CONTROL SYSTEM: Supplies a regulated flow of air to the cabin for the purpose of pressurization, ventilation, and temperature control.

ENGINE INDICATING AND CREW ALERTING SYSTEM: Electronic display of engine indications and annunciations. May consist of separate Engine Indicating and Crew Alert Systems.

FLIGHT MANAGEMENT SYSTEM: Programmable navigation aid that stores and distributes flight plan data to other systems, such as autopilot and CPCS.

GEOPOTENTIAL ALTITUDE: True Geometric Altitude above Mean Sea Level

ISOBARIC: Constant Pressure

MAX DIFFERENTIAL PRESSURE: The maximum pressure difference measured between the cabin and ambient.

MAINTENANCE DATA ACQUISITION UNIT: Centralized data acquisition and storage device for fault, service, and maintenance related data generated automatically by aircraft systems.

MASTER MINIMUM EQUIPMENT LIST: FAA approved document which defines allowable operating and maintenance procedures for dispatch with inoperative equipment.

OUTFLOW VALVE: The valve which controls the exhaust of ECS-supplied cabin air from the pressure vessel.

PRESSURE ALTITUDE: The altitude that corresponds to a given ambient pressure for a Standard Atmosphere.

SET LANDING ALTITUDE: The landing field elevation set on the CPCS control panel or selected for the CPCS by the FMS.

SCHEDULE BOUNDARY: The autoschedule boundary curve defined in the CPCS control law configuration.

SEA LEVEL: Mean Sea Level for definition of 0 geopotential altitude.

SQUAT SWITCH or WOW SWITCH: An airframe switch indicating a weight-on-wheels (WOW) condition.

STANDARD ATMOSPHERE: The atmosphere as defined by the latest U.S. or ISA Standard Atmosphere Altitude Reference (see Appendix A).

SYNOPTIC PAGE: A selectable display of systems operation or maintenance data on a flight deck electronic display, usually used by crew or maintenance to assist troubleshooting of system faults or failures.

TIME OF USEFUL CONSCIOUSNESS: The period of time between a person's deprivation of oxygen and the onset of physical or mental impairment which prohibits rational action.

2.3 Acronyms and Abbreviations

ΔP	Differential Pressure
AC	Advisory Circular
ADC	Air Data Computer
AFM	Aircraft Flight Manual
ALT	Altitude
BIT	Built-In Test
CABIN ALT	Cabin Pressure Altitude
CBIT	Continuous BIT
CFR	Code of Federal Regulations
CMA	Common Mode Analysis
CPCS	Cabin Pressurization Control System
CS	Certification Specification
DAL	Development Assurance Level
DEC	Decrease
EASA	European Union Aviation Safety Agency
ECS	Environmental Control System
E/E	Electronic Equipment
EEDP	Equivalent Eardrum Differential Pressure
EASA	European Union Aviation Safety Agency

FAA	Federal Aviation Administration
FDAL	Functional Development Assurance Level
FHA	Functional Hazard Assessment
FMS	Flight Management System
FMSL	Feet Mean Sea Level
FPA	Feet Pressure Altitude
ft/min	Feet per Minute
G/A	General Aviation
IBIT	Initiated BIT
IDAL	Item Development Assurance Level
INC	Increase
ISA	International Standard Atmosphere
LRU	Line Replaceable Unit
m/min	Meters per Minute
MMEL	Master Minimum Equipment List
MTBUR	Mean Time Between Unscheduled Removals
OFV	Outflow Valve
PBA	Printed Board Assembly
POST	Power On Self Test
SI	Système International
SL	Sea Level
SLA	Set or Selected Landing Altitude
SLft	SL Feet
SLm	SL Meters
T/O	Takeoff
TUC	Time of Useful Consciousness
USCS	United States Customary System
WOW	Weight on Wheels

3. REQUIREMENTS AND OPERATIONAL SCENARIOS

3.1 Pressure Level Requirements

While the basic requirement is to maintain the cabin at a pressure where the occupants can breathe easily without supplementary oxygen, which would generally be as close to sea level pressure as possible, the other consideration is aircraft structural weight, which increases as the cabin to ambient differential pressure increases. Thus, transport aircraft are designed as a compromise to hold the cabin at the minimum differential pressure necessary to provide a maximum pressure altitude of 2438 m (8000 FPA) when the aircraft is at its maximum design altitude. For example, a plane designed to fly at a maximum altitude of 12192 m (40000 feet) would be designed to withstand a differential pressure of 56.5 kPa (8.2 lbf/in²) on the fuselage. The structural implications of this can be appreciated by a quick calculation, which shows that this results in an outward force of over 10 tons on a typical cabin door. CPCS will generally schedule the maximum allowable differential pressure during flight at cruise altitude, where occupants will be exposed to the maximum allowed cabin altitude only when the airplane is operated at its maximum approved altitude. When this is combined with the lower cabin altitudes scheduled during climb and descent, the average cabin pressure altitude to which the occupant is subjected during a typical flight is significantly less than 2438 m (8000 FPA). However, there are exceptions, as some system implementations will control cabin pressure to the minimum of the pressure schedule or the destination landing field, whichever is lower, in order to limit unnecessary pressure cycles on the fuselage. For example: Assuming a selected landing field elevation of 8000 feet or higher, the system controller may hold an 8000 feet maximum cabin altitude throughout the flight profile.

Part 23 airplanes are required to limit cabin pressure altitude to 3048 m (10000 FPA), while Part 25 airplanes are required to limit cabin pressure altitude to 2438 m (8000 FPA). Part 23 airplanes approved for operation above 12497 m (41000 feet) have typically had Special Conditions that require the same 2438 m (8000 FPA) maximum cabin pressure altitude as for Part 25 airplanes. The current trend is to design for a maximum cabin pressure altitude lower than the regulatory limit. The reason for this trend is to provide increased occupant comfort. Lower cabin pressure altitude during the flight reduces hypoxia effects and a lower maximum cabin pressure altitude allows for use of lower cabin climb and descent rates for reduced risk of ear discomfort.

With the aircraft flying at less than the maximum altitude, the cabin will be at maximum differential pressure but with a certain margin accounting for immediate airplane climbs. Otherwise, the cabin would have to climb at the aircraft rate, which would violate the comfort requirements (see 3.13.2.5)

During cruise, the system provides the necessary cabin pressure control accuracy such that aircraft structural, cabin comfort, and other top-level requirements are met. This accuracy requirement can be a design architecture and cost driver, and should be set by the cognizant aircraft systems integrator. Cabin pressure control to within a range of 15 to 46 SLm (50 to 150 SLft) of the selected or scheduled value is typical. However, some airplane manufacturers may implement a different control accuracy. When the maximum cabin altitude must be limited to 2438 m (8000 FPA), the accuracy of the control system should be considered. A cabin pressure control schedule for a typical commercial flight profile is shown in Figure 1.

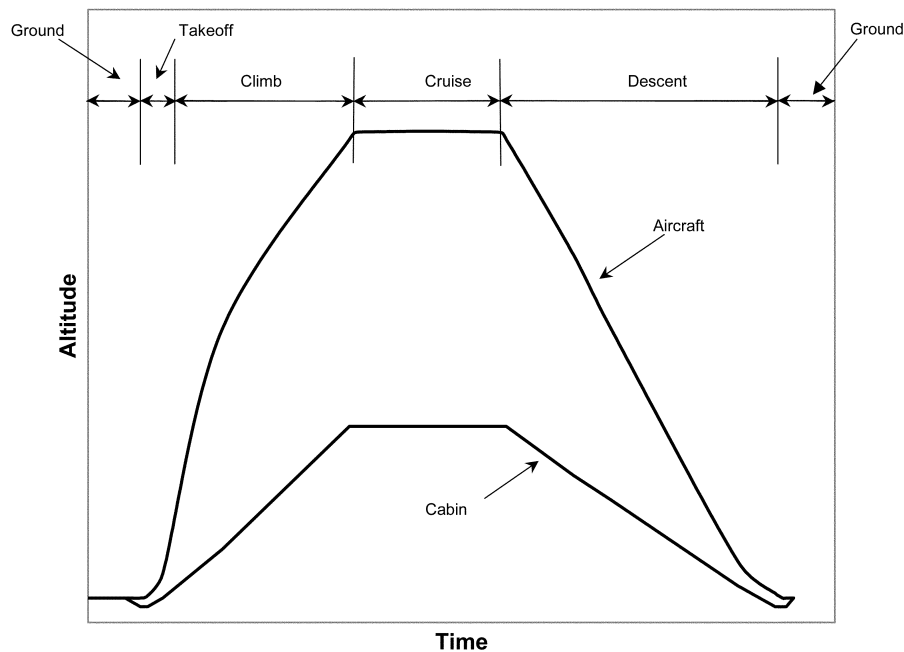


Figure 1 - Cabin pressure schedule for a typical commercial aircraft

3.2 Pressure Relief Requirements

Independent safety overrides are provided in order to prevent either a positive overpressure or a negative differential pressure due to failure in the primary pressurization control system or unusual aircraft operating conditions.

The negative pressure effect could result from a rapid descent where the aircraft overran the cabin; that is, the ambient pressure increase was so fast due to a rapid descent that it became higher than the cabin pressure, thus causing the external pressure to be higher than the cabin pressure. This situation may cause structural damage since the fuselage is usually not designed for a higher external pressure. Therefore, some means are provided to allow ambient airflow into the cabin. For more details on positive and negative pressure relief, see 5.2.1.1, 5.2.1.2, 7.1.2, and 7.1.3.

3.3 Decompression Requirements

A primary risk to the safety of passengers and aircraft is the possibility of cabin decompression (decrease in cabin pressure) caused by failure of the pressurization system or rupture of the cabin pressure vessel. Such a decompression could result in increased structural loads on portions of the airframe resulting in damage to flight critical systems and a decrease of cabin pressure below the level necessary for minimal physiological requirements for survival.

The requirement to consider the effects of decompression at high altitude was originally defined by Special Condition, only for aircraft to be approved for operation above 12497 m (41000 feet). For any probable decompression failure condition, those rules required that the cabin pressure altitude not exceed 7620 m (25000 FPA) for more than 2 minutes, or 12192 m (40000 FPA) for any duration. 14 CFR Part 25 airplanes certified since adoption of § 25.841 Amendment 87 are required to comply with these requirements even if not approved for operation above 12497 m (41000 feet). FAA AC 25 20 provides guidance for showing compliance to this rule. At this time, there is no comparable set of rules in 14 CFR Part 23, EASA CS-23, or EASA CS-25. Airplanes to be certified under these rules for operation above 12497 m (41000 feet) have Special Conditions which are similar to the pertinent sections of 14 CFR Part 25 Amendment 87.

3.4 Ground Requirements

Another basic requirement is that when the aircraft is on the ground, the cabin to ambient differential pressure is low enough to allow the cabin doors and escape hatches to be opened easily for quick passenger evacuation.

Typical ground residual cabin pressure differential is usually only about 0.25 to 0.5 kPa (0.036 to 0.072 lbf/in²) for avoiding violent door opening.

Normal ground pressure differentials are typically held to lower levels to minimize the potential for occupant discomfort during door opening and closing.

Door and emergency exit unlatching, opening, and closing are demonstrated with the maximum expected residual cabin differential pressure.

ARP488 establishes that opening the exit at the maximum residual cabin pressure at which the exit can be opened does not create a hazard to the person opening the exit. It also establishes the maximum forces required to open the doors.

For emergency evacuation, ARP488D recommends demonstration of emergency exit unlatching at 1.7 kPa (0.25 lbf/in²) cabin differential.

Ground pre-pressurization for takeoff is typically to 31 to 91 SLm (100 to 300 SLft), equivalent to 0.365 to 1.10 kPa (0.053 to 0.159 lbf/in²) below takeoff altitude.

If ground pre pressurization differentials can cause unacceptable door unlatching and opening loads, the CPCS includes sufficient logic to dump ground pre-pressurization following an aborted takeoff or from other signal indicating need for emergency evacuation.

3.5 Prevention of Pressurization

FAA AC 25.783-1A requires keeping the differential pressure below 3.45 kPa (0.5 lbf/in²) in the event that an external door is not closed, latched, and locked.

3.6 Cabin Inflow Requirements

Figure 2 indicates the cabin air gravimetric inflow rate required to provide a given cabin altitude descent rate for various size cabin volumes. For unpressurized descents, this is the amount of inflow that must be provided so that the cabin differential pressure does not become negative. For example, the cabin air inflow rate required in an aircraft descending at 3048 m/min (10000 ft/min) with a cabin volume of 566 m³ (20000 ft³) is about 192 kg/min (425 lb/min).

For pressurized flight, this is the amount of pressurization air that has to be added to the cabin to produce the desired cabin altitude descent rate. Structural leakage and controlled outflow has to be added to this to determine the total required inflow rate. Depending on the design and performance of the CPCS, additional inflow may be required to provide enough air to modulate the pressure control. Some systems cannot accurately control rate or differential below a certain flow rate.

Figure 2 is based on a cabin pressure altitude of 2438 m (8000 FPA) and 21 °C (70 °F) air temperature. The cabin inflow rate required to provide the desired cabin altitude rate of change at other conditions can be calculated from the following formula. Note that these are instantaneous rates, because they will change as the cabin pressure changes.

$$\frac{dm}{dt} = -3.37949 \times 10^{-6} \times \frac{dH}{dt} \times V \times P_C^{0.809747}, \text{ kg/min} \quad (\text{Eq. 1a})$$

where:

$\frac{dH}{dt}$ = cabin altitude climb or descent rate, m/min (negative for descent)

V = cabin effective volume, m³

P_C = cabin absolute pressure, kPa

In USCS units, the relation is:

$$\frac{dm}{dt} = -3.07068 \times 10^{-7} \times \frac{dH}{dt} \times V \times P_C^{0.809747} \quad , \text{ lb/min} \quad (\text{Eq. 1b})$$

where:

$\frac{dH}{dt}$ = cabin altitude climb or descent rate, ft/min (negative for descent)

V = cabin effective volume, ft³

P_c = cabin absolute pressure, lbf/in²

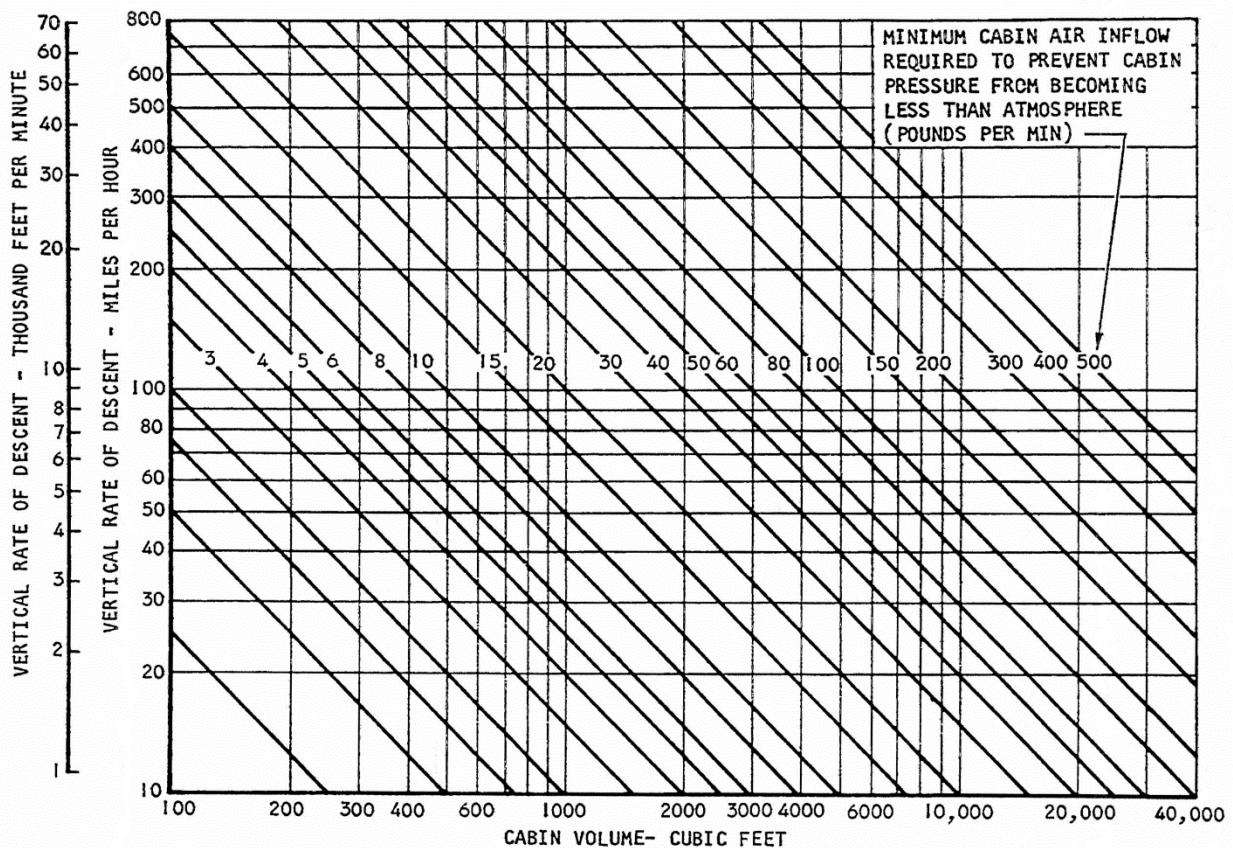


Figure 2 - Minimum cabin air inflow required to prevent cabin pressure from becoming less than ambient

For cabin pressure altitudes below 11000 m (36089 FMSL), which should always apply, the following equation may be substituted for P_C :

$$P_C = 101.325 \times \left(1 - 2.25569 \times 10^{-5} \times H\right)^{5.25616}, \text{ kPa} \quad (\text{Eq. 2a})$$

where:

H = cabin pressure altitude, m

In USCS units, this relation is:

$$P_C = 14.695949 \times \left(1 - 6.87535 \times 10^{-6} \times H\right)^{5.25616}, \text{ lbf/in}^2 \quad (\text{Eq. 2b})$$

where:

H = cabin pressure altitude, FPA

These equations are derived from the Standard Atmosphere model contained in NACA Report 1235 and the Ideal Gas Law.

3.7 Control Requirements

3.7.1 Normal Operation

The operating controls can be performed through a cabin pressure control panel located in the aircraft flight deck and the available controls depend on the level of automation of the system. Control over the following parameters is typically required for normal operations:

- a. Cabin Pressure Altitude
- b. Cabin Pressure Altitude Rate of Change
- c. Barometric Correction
- d. CPCS Operating Mode (Auto, Manual, Dump)
- e. Landing Field Elevation
- f. Outflow Valve Position

Some or all of these functions may be set automatically by other aircraft systems or calculated internally by an automatic CPCS. Simple isobaric or cabin altitude limiter systems may have fixed values for some or all of these settings with no crew control capability. Automatic systems may include manual override capability of automatic functions to allow dispatch with a failed automatic system or for abnormal/emergency operations. An alternative to providing an automatic system with a manual operating mode is to provide two independent automatic systems.

3.7.2 Abnormal Operation

Depending on CPCS and aircraft design, control of the following additional functions may be required for abnormal/emergency operations:

- a. Special Valve Positioning for Cockpit Smoke Evacuation or Ditching or loss of one outflow valve automatic control for systems with two outflow valves or ram air evacuation
- b. Manual Outflow Valve Position Control
- c. Manual Cabin Pressure Altitude Increase/Decrease
- d. Manual Cabin Pressure Rate of Change
- e. Cabin Pressure Dump

Operation and range of these controls will depend on the specific CPCS and aircraft design.

Manual override control can have many implementations.

In the case of manual outflow valve control, the position of the outflow valve(s) is controlled by the flight crew to control the cabin altitude and rate using the cabin altitude and rate indications as feedback to the flight crew. This manual control functionality requires some flight crew workload.

Other implementations of manual control can reduce flight crew workload, for example: allowing the crew to select the desired cabin pressure altitude or rate of change.

In a typical manual isobaric CPCS, the crew is required to select cabin altitude and the maximum rate of change of cabin altitude. The selection range of manual controls is at least as great as provided by any automatic function. The selectable range of cabin pressure altitude control should be from at least -305 m (-1000 feet), or the lowest approved airplane operating field elevation, to the highest approved airplane operating field elevation. For aircraft intended for operation from airfields above 3048 m (10000 feet), the upper range of isobaric cabin altitude adjustment may be as high as 4267 to 4420 m (14000 to 14500 feet). The maximum selectable cabin altitude should not overlap the settings of passenger oxygen mask auto deploy or cabin altitude high warning annunciation. The range of manual control of cabin pressure altitude rate of change is based on the cabin altitude at the max approved airplane operating altitude and the extreme range of aircraft climb and descent rates, but should generally be from at least 15 to 610 SLm/min (50 to 2000 SLft/min).

Manual Cabin Pressure Dump capability is required to rapidly equalize cabin differential pressure for cockpit smoke evacuation and in event of a window crack or door unlatched indication. Manual cabin pressure dump is usually provided to enable cabin pressure to be reduced at a rate greater than the one provided by the automatic system. The crew is able to select a manual dump rate as fast or as slow as the pilot judges the emergency requires or the flight manual specifies. FAA AC 25-22 Section 25.841 notes that typical maximum depressurization rates for large transport aircraft will open the dump valve in 30 seconds, and the depressurization that follows will occur in 2 minutes or less (with inflow on). Special dump valve positioning for cockpit smoke evacuation or ditching is accomplished with the minimum number of crew actions possible and should not require continuous crew attention.

3.8 Indication and Annunciation Requirements

3.8.1 Indication

The following indications are continuously displayed:

- a. Cabin Pressure Altitude
- b. Cabin Differential Pressure
- c. Cabin Pressure Altitude Rate of Change

These parameters can be displayed by dedicated pneumatic gauges, on the CPCS control and indication panel, or on the flight deck crew alerting system. The indications show the caution and warning ranges, amber for caution and red for warning. CPCS operating mode, if normal, needs not be displayed on the flight deck crew alerting system, but should always be displayed on the CPCS Control Panel. If an automatic CPCS is being operated in an abnormal manual mode, some flag of the CPCS status should be continuously displayed on the CPCS control and indication panel and/or the flight deck crew alerting system, if crew awareness or action is required.

Additional indications may be provided at the flight engineer station or on synoptic pages of the flight deck crew alerting system:

- a. Outflow and Safety Valve Positions
- b. Maintenance Fault Codes

The resolution of any indication should be at least as high as the resolution specified in any operating procedure, maintenance procedure or functional test that uses that indication. In manual mode, the outflow valve position(s) and cabin altitude, cabin rate, and cabin differential pressure should be provided by means independent of those used for automatic control.

3.8.2 Annunciation

The following annunciations are required:

- a. Cabin Altitude High Warning
- b. Annunciation of any other condition if it requires crew action or awareness, such as a CPCS failure or malfunction that would require crew to monitor cabin altitude and control it manually.

Part 23 and Part 25 require warning of Cabin Altitude High at or below 3048 m (10000 FPA). However, for operation from airfields above 3048 m (10000 feet), the Cabin Altitude High Warning annunciation is shifted, since the aircraft takes off with the cabin pressure altitude at or near the field elevation. An indication should be provided to the crew whenever the Cabin Altitude High Warning annunciation is shifted. Examples of methods used in the past to shift this annunciation to a higher altitude, generally 4420 m (14500 FPA), are:

- a. For manual systems - a manual cockpit switch that shifts the warning altitude from 3048 to 4420 m (10000 to 14500 FPA).
- b. For automatic systems - logic within the controller that detects when the planned takeoff or landing field elevation is above 3048 m (10000 FPA) and shifts the warning altitude from 3048 to 4420 m (10000 to 14500 FPA).

Since Part 23 and Part 25 require the Cabin Altitude High Warning to be no higher than 3048 m (10000 FPA), a Finding of Equivalent Level of Safety is required for approval of this cabin altitude warning shift.

Annunciation is provided in a form that draws immediate attention from the flight crew. Redlines on indicators are not acceptable in lieu of annunciations.

A Differential Pressure High Warning annunciation indicates a malfunction or failure of the CPCS that causes the differential to exceed the design maximum differential pressure. Because of the reliability and redundancy of max differential pressure protection features, regulations and advisory data allow use of a redline on the cabin differential pressure indicator in lieu of an annunciation. If the overpressurization can occur gradually enough, there may be no obvious indication of excessive differential pressure. Particular aircraft designs may require an annunciation, in addition to the redline due to differential pressure gauge location, crew workload, etc.

3.9 Fault Detection and Reporting Requirements

3.9.1 Built-In Test

Simple pneumatic systems have no Built-In Test (BIT) functions, and fault detection is provided by the indications and annunciations listed (see 3.8.1 and 3.8.2).

Electronically controlled systems can provide as much BIT as can be economically designed into the system.

BIT design can have several major objectives:

- a. Determine if there is a loss or degradation of functionality for flight crew awareness and corrective action (care should be taken not to make BIT monitors too sensitive, as slightly degraded functionality may be preferable to BIT induced loss of functionality)
- b. Eliminate the potential for dormant/latent defects that could result in loss of protective functionality (e.g., functionality required to achieve safety assessment objectives without maintenance crew action)
- c. Fault isolation to enable maintenance (line level or shop level) actions (BIT for fault isolation should be carefully considered, as increased complexity can drive product design, cost, and development complexity).

Critical system status (e.g., loss of function) indication should be continuously available for pilot situational awareness. Faults detected during BIT are reported to the annunciation system and/or stored in the aircraft central maintenance system, depending on the required action (crew awareness or maintenance) and aircraft capabilities.

BIT for modern automatic electronic systems falls into the following categories:

- a. POST (Power On Self Test) or PBIT (Power On BIT): Tests CPCS on system power up. Note that power interrupts can occur at any point in time (including in flight), so, safeguards/inhibits must be in place to avoid triggering the POST/PBIT tests after a power interrupt in flight. This is especially important if mechanical tests that slew valves open and closed are part of the POST/ PBIT.
- b. CBIT (Continuous BIT): System operation and validity of external signals are continuously monitored.
- c. EBIT (Event BIT): Test is launched when a defined condition is met. Adverse impact to aircraft or system configuration is prevented to avoid side effects and ensure test effectiveness.
- d. IBIT (Initiated BIT): Also known as Push to Test. Upon activation, it checks parameters that are not continuously monitored, but can be checked without significantly affecting normal system operation.
- e. Maintenance Mode: A selectable operating mode that allows performance of certain functional tests. May interfere with normal operating modes.

3.9.2 Fault Isolation and Reporting

Fault isolation algorithms are used in conjunction with the built-in test to isolate faults to a line replaceable unit. The output is reported either through the aircraft's central maintenance system or via a panel on the front of the cabin pressure controller. A second tier of algorithms isolate faults to a shop replaceable unit level where interrogation by shop test equipment can display these faults to be repaired in the shop.

3.10 On-Board Reprogramming and Configuration Control

The capability for on-board reprogramming of electronic CPCS is a desirable feature. However, strict control of the software configuration is maintained. Reprogramming and software version verification can usually be accomplished via the aircraft's central maintenance system. See 6.4.

3.11 Interfaces Requirements

3.11.1 Inputs Requirements

Signals listed in the following notional table may come directly from the systems of origin or through avionics interface

Table 1 - Example of CPCS inputs

Aircraft interface	Input to CPCS
Power	Electrical, Pneumatic, Vacuum
Avionics	Cruise altitude, time to climb, time to top of descent, takeoff/landing altitudes, barometric correction, Throttle Position
Air Data System	Air/ground signals, ambient pressure and rate, aircraft speed
Flight Deck	Auto/manual mode selection, cabin altitude and rate targets, OFV drive signals, dump signal, ditching mode
Protective Systems	Smoke/fire signals
Air Conditioning System	Inflow
Air Distribution System	Alternate ventilation signal
Structures- Doors	Door open status

3.11.2 Outputs Requirements

Signals listed in the following notional table may go directly to systems or through avionics interface

Table 2 - Example of CPCS outputs

Aircraft interface	Output from CPCS
Avionics	Cabin pressure, differential pressure, valve position, fault data for indication and alerting, passenger Oxygen Mask Autodeploy, Cabin Altitude High Warning Annunciation Inhibit for high altitude airfield operation
Flight Deck	Signals for supporting indications (status, cabin pressure or altitude, pressure schedule, cabin rate of change, differential pressure, valve position), alert
Maintenance System	Fault Data

3.12 Tolerance Requirements

Following are some of the sources of variability and inaccuracy in operation of a CPCS:

- a. **Component Manufacturing Variability:** Setting, linearity, and proportionality of transducers, aneroids, mechanisms vary from part to part. Can be minimized by individual calibrations, testing and selection, etc.
- b. **Component Assembly Variability:** Equipment assembly and calibration variation that is intrinsic to the assembly and calibration process.
- c. **Component Non-Repeatability:** Variation in operation that is intrinsic to the design, due to hysteresis, vibration, and other environmental effects that cannot be eliminated by calibration.
- d. **Environmental Effects:** Change in output due to temperature, attitude, vibration, etc., that can be corrected for by calibration or by addition of correction circuits or mechanisms.
- e. **Component Drift:** Change in output with age or cycles. Can be partially corrected for by calibration, if the amount of drift can be accurately predicted. Can be minimized with burn in and/or vibration bench break in.
- f. **Control Loop Static Accuracy:** The accuracy with which the entire CPCS can regulate to a fixed target altitude or rate. Intrinsic to the design of CPCS, but will be influenced by other sources of variability.
- g. **Control Loop Dynamic Accuracy:** The accuracy with which the entire CPCS can regulate to a changing target altitude or rate. Intrinsic to the design of CPCS, but will be influenced by other sources of variability.
- h. **External Input Accuracy:** Any form of offset, imprecision, or random variability in the accuracy of external inputs to the CPCS. Offsets, such as a fixed static source position error, can be corrected for by calibration. Imprecision, such as availability of aircraft altitude digital data in 15 m (50 feet) resolution, is tolerated. Random variability may be present in all inputs and is reduced at the source or tolerated. Even switched discrete signals may require a debounce period.

All of the listed sources of variability can be reduced to an unmeasurable level. However, it is uneconomical and usually unnecessary to provide this degree of accuracy. The nature of Cabin Pressurization Control is such that all sources of variability should be addressed and minimized to a certain extent to provide acceptable system operation.

The following sources of variability cannot be eliminated and are accounted for in design, development, and approval of a CPCS:

- a. **Effective Cabin Volume:** Varies with quantity of passengers, cargo carried, and volumes of cabin interior monuments. Can be defined as a range of values.
- b. **Aircraft Climb and Descent Rate:** Varies with aircraft weight, outside air temperature, operational procedures, etc.
- c. **Atmospheric Pressure:** At altitudes above the transition altitude, operating rules require altitude indication to be based on the pressure altitude. At altitudes below the transition level, altitude measurement is based on a calculated geopotential altitude, which is determined from the measured static pressure, the reported SL corrected barometric pressure, and a standard atmosphere model.
- d. **Aircraft leakage:** Varies based on environmental factors and with age of the aircraft. Can be specified as a range of values from expected minimum leakage for a new aircraft to expected maximum leakage for an end of life aircraft.
- e. **Inflow transients:** Inflow varies throughout the flight envelope based on a multitude of factors, including day type, air conditioning flow schedule/occupant count, engine throttle movement, engine bleed pressure regulation, on/off switching of other systems that rely on engine bleed consumption, such as air conditioning packs, ice protection system, air driven pumps, etc.

3.13 Comfort and Physiological Requirements

In addition to the safety requirements, the CPCS provides a comfortable environment for the passengers and crew. This presents a significant challenge because of the substantial changes in cabin pressure and aircraft altitude during flight.

3.13.1 Respiratory Effects

A symptom of reduced cabin pressure experienced during aircraft flight can be hypoxia. Hypoxia is defined as a deficiency of oxygen reaching the tissues of the body. It occurs when the body cannot assimilate an adequate supply of oxygen to function normally. While the inability of the body to assimilate adequate oxygen is the technical basis of hypoxia, its actual onset in the aircraft cabin occupant results from a reduction in the partial pressure of oxygen in the cabin. As the aircraft cabin pressure is reduced during a flight, the partial pressure of oxygen is also reduced.

The severity of individual hypoxia cases is dependent on the severity and duration of the individual oxygen deficiency. The oxygen deficiency may be achieved by a high cabin altitude for a relatively short period of time, or a lower cabin altitude for a relatively longer period of time. Table 3 illustrates typical altitude exposures and the elapsed time until loss of consciousness for typical aircraft passengers. The effects of hypoxia are progressively more serious as available oxygen content is reduced. Additionally, individual physiological variations affect the level of hypoxia for a given level of cabin oxygen content. Some physiological variables affecting the onset of hypoxia include age, physical activity, and drug or alcohol presence in the body.

Civil Type Design and Operating Rules require protection of aircraft crew and passengers from hazardous levels of hypoxia. 14 CFR/CS 25.841(a) require that the cabin pressure altitude be limited to 2438 m (8000 FPA) at the maximum operating altitude of the aircraft under normal operating conditions. 14 CFR/CS 23.841(b)(6) allow a cabin pressure altitude of 3048 m (10000 FPA). However, Part 23 aircraft intended for long duration high altitude flight may also be required by Special Condition to provide a maximum 2438 m (8000 FPA) cabin pressure altitude. 14 CFR/CS 25.841(a)(1) and 23.841(a) require aircraft to be approved for operation above 7620 m (25000 feet) to be able to maintain a cabin pressure altitude of no more than 4572 m (15000 FPA) following any probable failure or malfunction in the systems involved in the pressurization. 14 CFR/CS 23.1441 through 23.1449 and 25.1441 through 25.1449 provide requirements for supplemental oxygen equipment standards, flow rates, mask performance, and oxygen availability.

Table 3 - Physiological effects of hypoxia

Pressure Altitude, FPA	Atmospheric Pressure, mm Hg	Tracheal Oxygen Partial Pressure, mm Hg	Effects
5000	632.38	122.3	Onset of impairment of night vision.
10,000	522.76	99.4	Mild and acceptable effects on judgment. Fatigue for long durations.
12,500	474.04	89.3	Impaired judgment, memory, alertness and coordination for long durations.
14,000	446.63	83.5	Dimming of vision, impaired judgment, memory, alertness and coordination for 1 to 2 hour durations. Headache, drowsiness, and either euphoria or irritability.
16,000	412.09	76.3	Loss of peripheral vision. Severely impaired judgment, memory, alertness and coordination. Disorientation, belligerence, and/or euphoria.
18,000	379.78	69.6	Seriously impaired. Overconfident and euphoric due to oxygen deprivation. TUC of 20 to 30 minutes.
20,000	349.53	63.2	On the brink of collapse. TUC of 5 to 12 minutes.
25,000	282.40	49.2	Seriously impaired after brief exposures to this altitude. TUC of 3 to 6 minutes.
30,000	226.13	37.4	TUC of 1 minute.
35,000	179.33	27.7	TUC of 30 to 40 seconds.
40,000	141.18	19.7	TUC of 10 to 20 seconds.
45,000	111.13	13.4	TUC of 10 seconds. Even if pilot is able to don mask and begin oxygen flow, loss of consciousness will usually result.

Note: Data sources are AIR822, AIR825/1, and FAA AC 61-107A.

3.13.2 Ear Discomfort

Pressure changes in the cabin can cause discomfort in the middle ear by causing a differential pressure to develop across the eardrum. Because nearly every aircraft flight requires a change in cabin pressure, this physiological effect is inevitably the ultimate criteria by which the airline passenger and crew evaluate cabin pressurization control system performance.

3.13.2.1 Types of Pressure Changes

Pressure changes in the cabin can be classified into two broad categories:

- a. Step pressure transients (bumps)
- b. Sustained pressure changes

3.13.2.1.1 Pressure Transients

Pressure transients are short duration cabin pressure changes of sufficient magnitude that may cause passenger discomfort. Proper design of the controls and equipment of the air conditioning and pressurization systems can minimize transients and significantly enhance passenger comfort.

3.13.2.1.2 Sustained Pressure Changes

Sustained pressure changes are those changes in cabin altitude necessary for the defined operation of the aircraft and the altitude difference between the takeoff field and the landing field.

The ideal design for passenger comfort would be to minimize the cabin pressure rate of change by slowing rating cabin altitude from the takeoff field altitude directly to the landing field altitude. This is generally not done for two reasons; first, fuel usage considerations dictate that the aircraft fly at a high cruise altitude; and second, the structural weight considerations require that the differential pressure between the cabin and ambient be limited. Therefore, depending on the altitude of the takeoff and destination fields (i.e., above or below 8000 feet), cabin altitude is increased or decreased as the aircraft climbs to the cruise altitude and then increased or decreased after the aircraft starts to descend to the landing field altitude.

The variation in cabin altitude as the aircraft climbs and descends is controlled by the cabin pressure control system so that the rate of change produces minimal passenger discomfort. Generally, 152 SLm/min (500 SLft/min) during climb and -91 SLm/min (-300 SLft/min) during descent is considered acceptable from the perspective of passenger comfort. Figure 3 depicts design limits for short duration cabin pressure changes.

In the original work of Armstrong and Heim from 1937 (refer to Armstrong and Heim, 1937), according to the laboratory description (refer to the article of Chapin, 1991), these cabin pressure changes were estimated from the pressure change read on columns of mercury divided by the measured time period. Therefore, it is possible that the established curves were based on an averaged dataset.

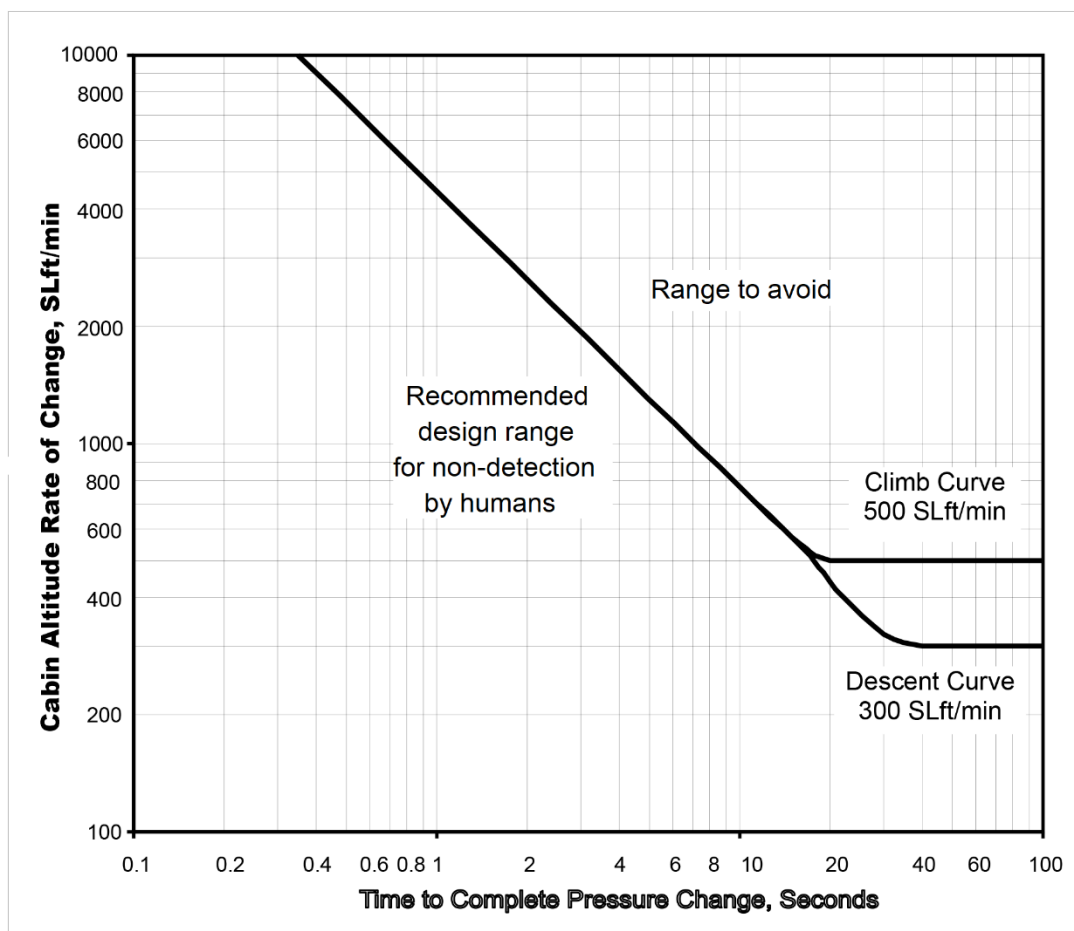


Figure 3 - Design limits for short duration cabin pressure changes based on threshold of detection by humans

3.13.2.2 Ear Physiology

The human ear consists of three basic sections: the outer ear, the middle ear, and the inner ear (see Figure 4). The outer ear consists of the external fleshy ear and the external auditory canal terminating at the eardrum.

On the inner side of the eardrum is the cavity of the middle ear. Near ambient pressure is maintained in the middle ear cavity through the internal auditory canal, the Eustachian tube. Sound waves are sensed as a momentary pressure differential across the eardrum which causes the eardrum to oscillate. Movement of the eardrum is magnified by the leverage of the ossicles (the ear bones) and is directed to the inner ear.

The inner ear consists of the cochlea and the semicircular canal. The fluid-filled cochlea reacts to movements of the ear bones and transmits nerve pulses to the brain. When a constant pressure differential exists across the eardrum, the ear bones are displaced and the pressure is applied to the inner ear. This is the foremost cause of ear discomfort during pressurized flight.

From the standpoint of pressurization control systems, the ear may be considered as an air-filled, closed cavity with pressure equalization possible only when the Eustachian tube is open (see Figure 4).

Near the middle ear cavity, the Eustachian tube is surrounded by bone and remains open. Near the nasal passage, the Eustachian tube is normally closed by the surrounding membranous tissue.

The Eustachian tube opens occasionally by involuntary contraction of the Eustachian tube dilator muscles. This muscle action equalizes pressure across the eardrum. Voluntary opening of the Eustachian tube can be accomplished by swallowing, yawning, or by learned contraction of the dilator muscles. While the cabin is repressurizing, equalization can be accomplished by utilizing the Valsalva maneuver, where one suppresses a forced exhalation of air by pinching the nose shut and maintaining the mouth closed, at which time a roaring in the ears will indicate when the effort is successful.

Positive pressure in the middle ear tends to force the Eustachian tube open and is self-relieving. Negative pressure in the middle ear tends to hold the Eustachian tube closed. For this reason, greater ear discomfort caused by pressure changes is normally associated with descent in cabin pressure altitude. Consequently, sleeping passengers and small children are more likely to experience discomfort during cabin descent than during cabin ascent.

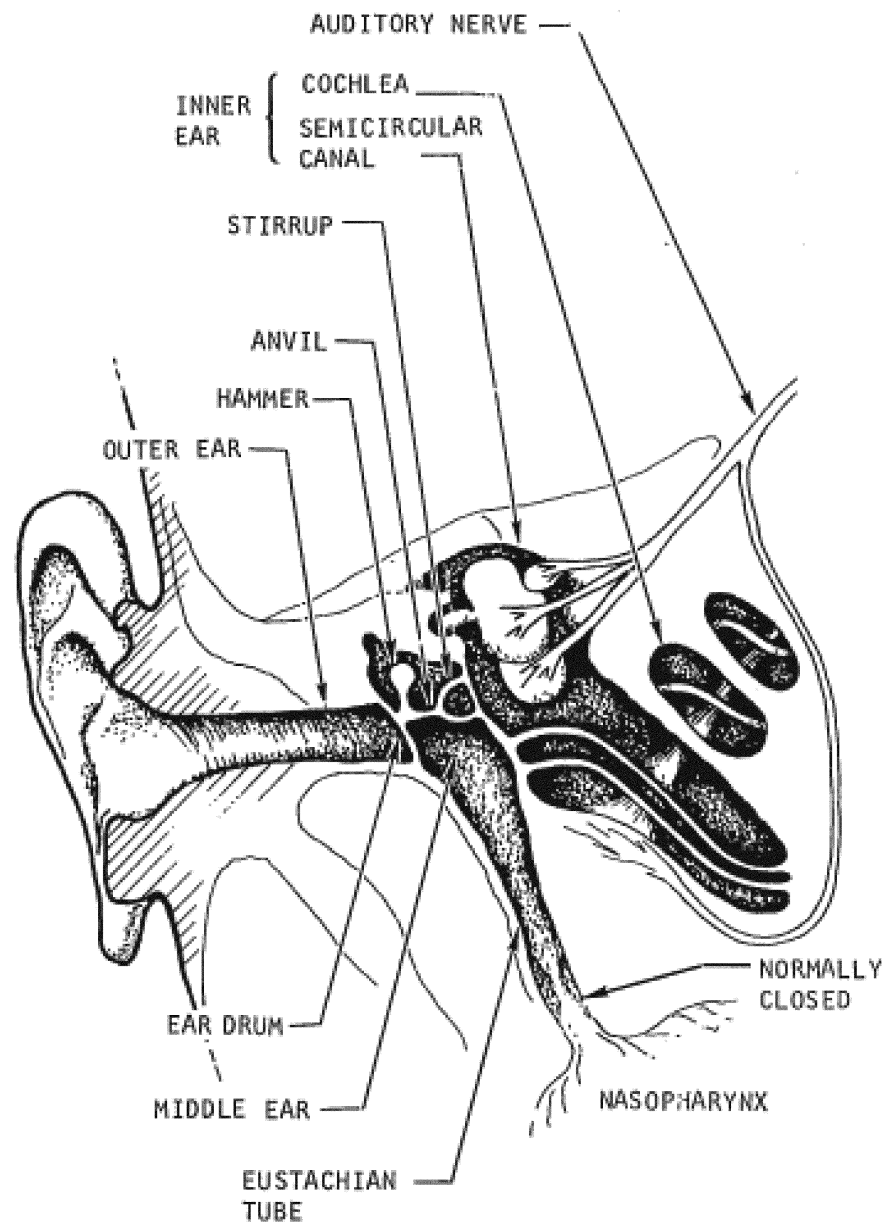


Figure 4 - Physiology of the human ear

3.13.2.3 Physiological Effects

Figure 5 illustrates the physiological effects of a pressure differential across the eardrum. While a small differential pressure across the eardrum will cause some discomfort, an excessive differential pressure of 13.5 kPa (1.96 lbf/in²), equivalent to 1128 SLm (3700 SLft) can cause it to rupture. Rupture of the membrane itself is preceded by rupture of the blood vessels crossing the membrane, thus causing bleeding from the middle ear. Hearing ability of the affected ear is degraded by about 30 decibels until healing restores the ear to its original capability. Healing is evident within 12 to 24 hours and is usually complete within 2 weeks to a month.

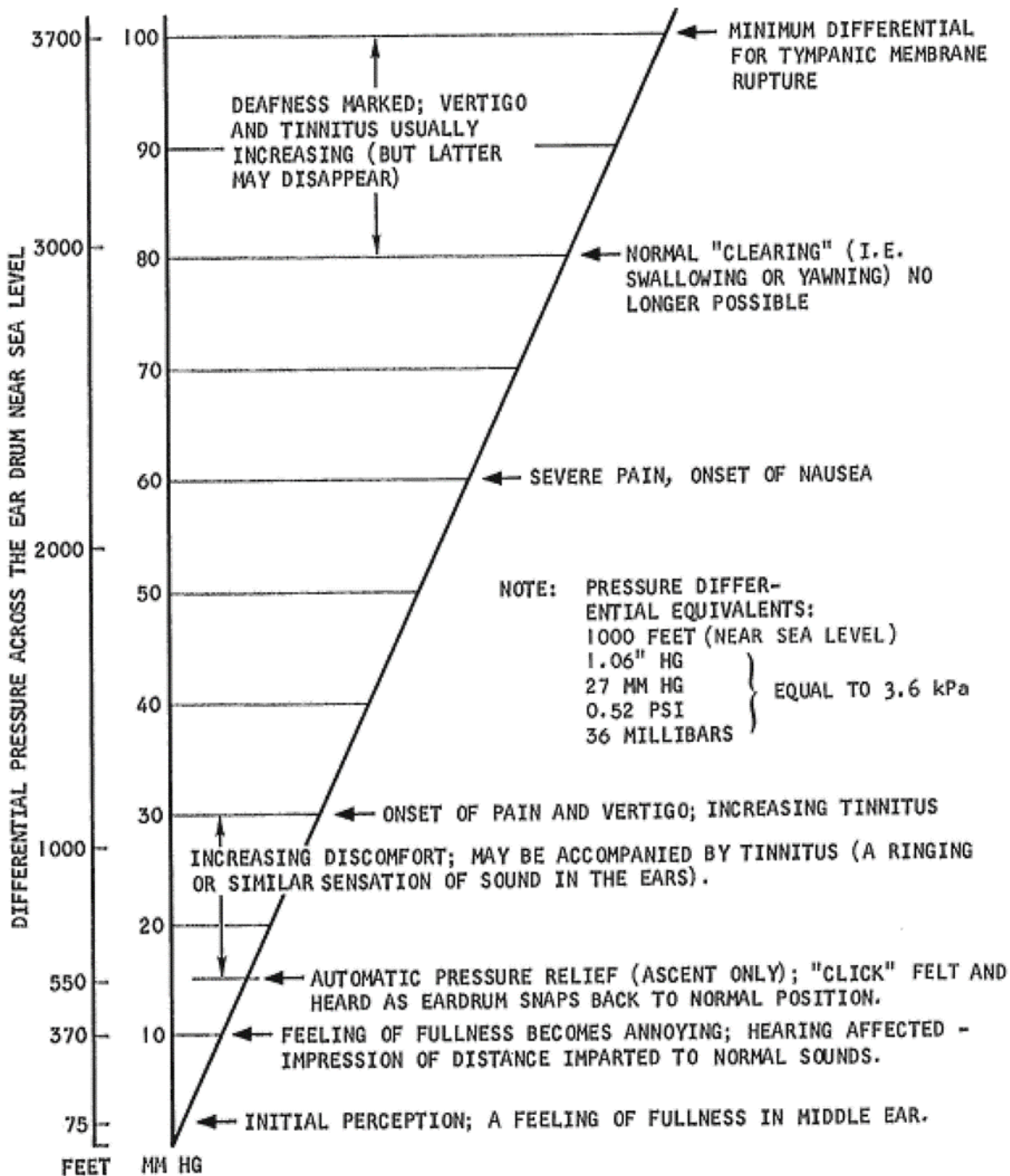


Figure 5 - Physiological effects of pressure differential on the normal human ear (increasing pressure only)

3.13.2.4 Physiological Effects of Cabin Pressure Transients and Rates

The pressure transient required to reach the threshold of feeling in the ear varies for different individuals. Also, the threshold of feeling for any particular individual is dependent upon the rate of change of pressure. The ear is less sensitive at the rates of change normally associated with typical scheduled cabin pressure changes between -1.83 and $+1.10$ kPa/s (-300 to $+500$ SLft/min), for increasing pressure (decreasing altitude) and decreasing pressure (increasing altitude), respectively. The physiological reason for difference in the comfort rates for climb and descent is that air can more easily escape from the inside of the ear through the tiny Eustachian tubes than it can enter.

The results of the work of Spealman and Cherry (1958) show no threshold of feeling lower than 0.22 kPa (60 SLft) equivalent altitude difference across the eardrum (see Figure 6) at any rate or from any altitude. However, as the amplitude of the change increases the rate becomes more important.

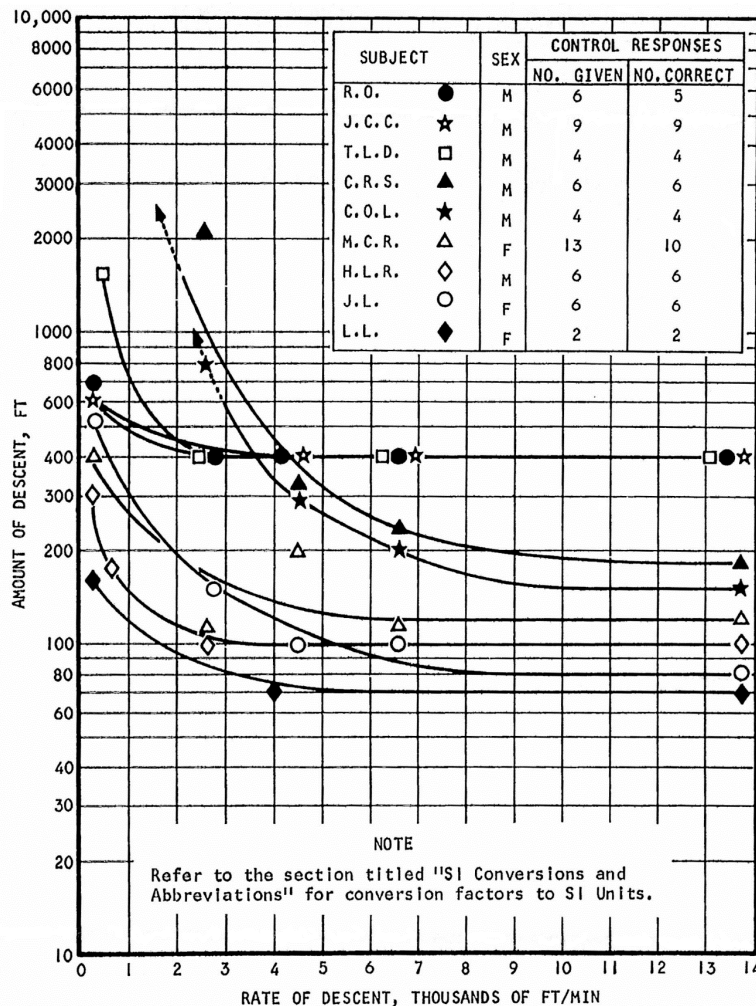


Figure 6 - Altitude changes just perceptible to the middle ear in relation to rate of descent

One method of defining design limits for cabin pressure transients, based on threshold of detection by humans is shown in Figure 3. This curve may be used to determine the maximum acceptable time for a sustained cabin pressure rate. For example, from Figure 3, the maximum acceptable time for a sustained pressure change rate of 305 SLm/min (1000 SLft/min) is approximately 7 seconds. It should also be noted that when the descent rate data from Figure 3 is converted to an equivalent amount of descent versus descent rate, it closely follows the lowest curve of Figure 6.

Another method, known as the Equivalent Eardrum Differential Pressure (EEDP), considers the sensory perception of the average individual on the basis of time integration of the eardrum differential pressure due to rate changes (refer to Cleaves and Watson, 1968). This method is based on a fixed physical model of the human ear and gives results similar to those shown in Figure 3.

3.13.2.5 Physiological Effects of Sustained Pressure Change

The human ear is capable of withstanding extremely rapid pressure changes. Tests have demonstrated these capabilities at rates far in excess of commercial airline requirements. However, the subjects of these tests were healthy adults with normal ears. They were well trained in the techniques of clearing the middle ear during rapid descent. During repeated descents from 2896 m (9500 feet) to sea level pressure in 5 seconds, 6.06 kPa/s (0.878 (lb/in²)/s) were recorded without sinus pain or discomfort (refer to Raeke and Freedman, 1961).

Commercial airline travel is measured in the tens of millions of passengers annually. This group includes large numbers of individuals who are unable to ventilate the middle ear properly during descent. These are:

- a. Sleeping passengers (swallowing at decreased intervals)
- b. Children
- c. Passengers with colds, sinus congestion or abnormal ear passages
- d. Passengers who are unaware of the techniques for equalization of pressure in the middle ear (refer to Waggoner, 1967)

The average person swallows involuntarily about every 60 to 75 seconds. A rate of climb or descent of 61 SLm/min (200 SLft/min) will usually not cause discomfort. 152 SLm/min (500 SLft/min) ascent or -91 SLm/min (-300 SLft/min) descent will cause only slight discomfort even though no effort is made to ventilate the middle ear artificially. However, a passenger with severe restriction of the middle ear passage (such as might occur from a head cold) can experience extreme pain or eardrum rupture while the passenger with normal passages would experience no discomfort at these rates of change.

The rate of change comfort limits are based on testing of healthy, adult subjects. More research using a population better representing the flying public may be warranted.

3.13.3 Transients

Passenger comfort requires that the system have adequate response to handle transients that result from the takeoff rotation, rapid changes in aircraft climb or descent rates, landing, engine power change, adding or subtracting a cooling pack, activating or deactivating pneumatic anti-icing and engine bleed stage switchover operation. The system may be required to operate with a slightly pressurized cabin on the ground to minimize the pressure transients associated with takeoff and landing. This ground pressurization is generally in the range of 30 to 91 m (100 to 300 feet) below field pressure altitude. The actual ground pressurization limit, however, is consistent with regulations governing door opening and emergency egress requirements.

To provide an acceptable level of passenger comfort, the system should include means to limit cabin pressure transients to a short duration change in cabin pressure altitude not to exceed the limits of Figure 3. These short duration pressure changes are caused by one or a combination of the following:

- a. High rates of change of cabin air inflow which may be caused by rapid engine or cabin air source variations
- b. High rates of change of local ambient static pressure at the overboard location of the cabin air outflow valve, such as may occur during aircraft rotation just prior to takeoff
- c. Rapid changes in the cabin outflow area, such as occurs when the last cabin door is closed

The CPCS is designed to provide the acceptable level of passenger comfort with the maximum cabin air inflow rate change either increasing or decreasing. Depending upon the cabin air source design, a cabin inflow rate control or sequencing of the inflow packs may be desirable. The CPCS should also be designed to provide passenger comfort with the maximum rate of change of local ambient pressure at the outflow valve exhaust port. If, due to the location of the outflow valve, the local ambient pressure exceeds the desired cabin pressure, aerodynamic means may be included in the outflow valve design to reduce the local ambient static pressure to an acceptable value. The CPCS valves that perform a ground pressure dump function are sized in conjunction with other dump valves, such as vent flaps for external doors, to limit the pressure change that occurs when a cabin door is closed when the maximum normal inflow is present. This pressure change should not cause passenger discomfort.