AEROSPACE RECOMMENDED PRACTICE	ARP1270™	REV. B
	Issued 1976-01 Revised 2010-05 Reaffirmed 2015-10 Superseding ARP1270A	

(R) Aircraft Cabin Pressurization Criteria

RATIONALE

ARP1270B has been reaffirmed to comply with the SAE five-year review policy.

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1. SCOPE

This ARP covers the basic criteria for the design of cabin pressure control systems (CPCS) for general aviation, commercial and military pressurized aircraft.

1.1 Purpose

Pressurization of the aircraft cabin is generally the most satisfactory method of achieving required partial pressures of oxygen for both crew and passengers during high-altitude flight. It provides a nearly normal environment in the cabin for the safety and comfort of the occupants by maintaining the internal cabin pressure higher than the flight altitude pressure. This permits normal physiological functions without the encumbrance of pressure suits or supplemental oxygen.

The purpose of this recommended practice is to provide the aerospace industry with guidelines encompassing the safety, comfort, automation and technical design considerations of aircraft cabin pressure control systems.

Goals are:

a. To ensure aircraft and occupant safety

b. To maintain crew and flight attendant performance

c. To ensure aircraft passenger comfort

Field of Application:

This recommended practice is applicable to pressurized aircraft, both civil and military, regardless of the number of passengers or crew. The Cabin Pressure Control System (CPCS) shall provide maximum safety to the passengers and crew throughout changes in cabin pressure altitude during the entire aircraft flight, as well as during ground operation. Additionally, the CPCS shall maximize passenger and crew comfort to the greatest extent possible, without exceeding aircraft structural safety limits.

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 724-776-4970 (outside USA), www.sae.org.

ARP488	Exits and Their Operation - Air Transport Cabin Emergency
AIR822	Oxygen Systems for General Aviation
AIR825/1	Introduction to Oxygen Equipment for Aircraft
AIR1168/7	Aerospace Pressurization System Design
AS5379	Valves, Safety, Cabin Air, General Specification For

2.1.2 American National Standards Institute Publications

Available from American National Standards Institute, 25 West 43rd, New York, NY 10036-8002, Tel: 212-642-4900, www.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

2.1.3 European Aviation Safety Agency Publications

Available from European Aviation Safety Agency, Otto Platz 1, Postfach 101253, D-50452, Cologne, Germany, Tel: +49-221-8999-000, www.easa.eu.int.

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

CS-25 Certification Specifications for Large Aeroplanes

CS-27 Certification Specifications for Small Rotorcraft

CS-29 Certification Specifications for Large Rotorcraft

2.1.4 Federal Aviation Administration Publications

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

AC 25-17 Transport Airplane Cabin Interiors Crashworthiness Handbook, FAA Advisory Circular, Initiated by ANM-110, 7/15/1991

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, 04/25/2005

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.

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 NACA Publications

Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161, www.ntis.gov.

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

2.1.6 Radio Technical Commission for Aeronautics Publications

Available from Radio Technical Commission for Aeronautics Inc., 1828 L Street, NW, Suite 805, Washington, DC 20036, Tel: 202-833-9339, www.rtca.org.

DO-160F Environmental Conditions and Test Procedures for Airborne Equipment

DO-178B Software Considerations in Airborne Systems and Equipment Certification

DO-254 Design Assurance Guidance for Airborne Electronic Hardware

2.1.7 U.S. Government Publications

Available from the Document Automation and Production Service (DAPS), Building 4/D, 700 Robbins Avenue, Philadelphia, PA 19111-5094, Tel: 215-697-6257, http://assist.daps.dla.mil/quicksearch/.

JSSG-2009 Air Vehicle Subsystems

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

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

MIL-STD-810F Environmental Engineering Considerations and Laboratory Tests

2.2 Applicable References

Armstrong, Harry G., MD and Heim, J.W., PhD- “The effect of Flight on the Middle Ear”, AMA Journal, August 7, 1937

Cleeves, V. F. and Watson, A. C.- “A Method of Evaluating Cabin Pressure Transients With Regard to Effects on the Occupants”, Aviation and Space: Progress and Prospects; Proceedings of the Annual Aviation and Space Conference, Beverly Hills, California, June 16-19, 1968, pp 405.

Raeke, James W., MS and Freedman, Toby, MD- “Human Respnose to Rapid Recompression”, Aerospace Assn Meeting, April 24-27, 1961

Spealman, Clair R., PhD and Cherry, John C., BS- "Middle Ear Perception of Pressure and Pain in Descent from Altitude", Aviation Medicine, February 1958

Waggoner, James N., MD- “Human Tolerance to Changes in Aircraft Cabin Pressurization”, Aerospace Medicine, 9 March, 1967

2.3 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.

CAPTURE - When the cabin altitude intercepts the set landing altitude or schedule boundary.

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 - 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 condition.

STANDARD ATMOSPHERE - The atmosphere as defined by the latest U.S. or ISA Standard Atmosphere Altitude Reference.

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.

2.4 Terminology

∆P	Delta Pressure
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
CPCS	Cabin Pressurization Control System
CS	Certification Specification
DEC	Decrease
DP	Differential Pressure
EASA	European Aviation Safety Agency
ECS	Environmental Control System
E/E	Electronic Equipment
EEDP	Equivalent Eardrum Differential Pressure
EICAS	Engine Indicating and Crew Alerting System
FAA	Federal Aviation Administration
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
INC	Increase
ISA	International Standard Atmosphere
LRU	Line Replaceable Unit
m/min	Meters per Minute
MDAU	Maintenance Data Acquisition Unit
MMEL	Master Minimum Equipment List
MTBUR	Mean Time Between Unscheduled Removals
POST	Power On Self Test
SI	Systeme International
SL	Sea Level
SLA	Set or Selected Landing Altitude
SLft	SL Feet

SLm SL Meters

T/O Take-Off

TUC Time of Useful Consciousness

WOW Weight on Wheels

USCS United States Customary System

2.5 Standard Atmosphere Definition

2.5.1 Standard Atmosphere Up To 11 000 m (36,089.24 ft)

The SI relation for static air pressure variation with altitude is:

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

where:

H = Pressure Altitude, m

In USCS units, this relation is:

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

where:

H = Pressure Altitude, ft

The SI relation for pressure altitude as a function of static air pressure is:

$$H = 44332.3 \times \left[1 - \left(\frac{P}{101.325}\right)^{0.190253}\right] \quad , \quad \text{m} \qquad \text{(Eq. 2a)}$$

where:

P = Pressure, kPa

In USCS units, this relation is:

$$H = 145447 \times \left[1 - \left(\frac{P}{14.695949}\right)^{0.190253}\right] \quad , \quad \text{ft} \qquad \text{(Eq. 2b)}$$

where:

P = Pressure, lbf/in^2

2.5.2 Standard Atmosphere From 11 000 m to 20 000 m (36 089.24 ft to 65 616.80 ft)

The SI relation for static air pressure variation with altitude is:

$$P = 0.223356 \times 101.325 \times e^{-0.000157688 \times (H - 11000)} \quad , \quad kPa \qquad \text{(Eq. 3a)}$$

where:

H = Pressure Altitude, m

In USCS units, this relation is:

$$P = 0.223356 \times 14.695949 \times e^{-0.0000480627 \times (H - 36089.24)} \quad , \quad lbf/in^2 \qquad \text{(Eq. 3b)}$$

where:

H = Pressure Altitude, ft

The SI relation for pressure altitude as a function of static air pressure is:

$$H = 11000 - 6341.64 \times Ln\left[4.47716 \times \left(\frac{P}{101.325}\right)\right] \quad , \quad m \qquad \text{(Eq. 4a)}$$

where:

P = Pressure, kPa

In USCS units, this relation is:

$$H = 36089.24 - 20806.2 \times Ln\left[4.47716 \times \left(\frac{P}{14.695949}\right)\right] \quad , \quad ft \qquad \text{(Eq. 4b)}$$

where:

P = Pressure, lbf/in^2

2.6 Units & Conversion Factors

Conversion factors are obtained from IEEE/ASTM/ANSI SI 10.

TABLE 1- PRESSURE CONVERSIONS

Multiply →	In Hg	In WG	mb	mm Hg	Pascal	lbf/ft^2	lbf/in^2
To Obtain ↓	----------Times---------- ↓	↓	↓	↓	↓	↓	↓
In Hg	---	0.0735559	0.02952998	0.03937008	2.952998×10^{-4}	0.01413903	2.036020
In WG (4°C)	13.5951	---	0.401463	0.535240	4.01463×10^{-3}	0.192227	27.6807
mb	33.86389	2.49089	---	1.333224	0.01000000	0.4788026	68.94757
mm Hg	25.40000	1.86832	0.7500615	---	7.500615×10^{-3}	0.3591312	51.71492
Pascal	3386.389	249.089	100.0000	133.3224	---	47.88026	6894.757
lbf/ft^2	70.72621	5.20219	2.088544	2.784497	0.02088544	---	144.0000
lbf/in^2	0.4911542	0.0361263	0.01450377	0.01933678	1.450377×10^{-4}	6.944444×10^{-3}	---

In Hg = Inches of Mercury, at 0 °C with a density of 13.5951 gm/cm^3, with g_c = 980.665 cm/s^2

In WG = Inches of Water (Gage), at 4 °C with a density of 1.000000 gm/cm^3, with g_c = 980.665 cm/s^2

mb = Millibar = Hectopascal = 100 Pascals

mm Hg = Millimeters of Mercury

Pa = Pascal = N/m^2 = $kg/m\text{-}s^2$

HP = Hectopascal = 100 Pascal

lbf/ft^2 = Pounds per Square Foot

lbf/in^2 = Pounds per Square Inch

SL Standard Ambient Pressure:

By Definition of the 1976 U.S. Standard Atmosphere:

P_0 = 101325.0 Pa

By Conversion:

P_0 = 760 mm Hg at 0 °C with a density of 13.5951 gm/cm^3, with g_c = 980.665 cm/s^2

= 1013.250 mb (HP)

= 101.3250 kPa

= 29.92126 In Hg

= 406.783 In WG at 4 °C with a density of 1.000000 gm/cm^3, with g_c = 980.665 cm/s^2

= 2116.216 lbf/ft^2

= 14.695949 lbf/in^2

At Standard Conditions:

1 SLm/min = 12.0 Pa/min

1 SLft/min = 0.0765 lbf/ft^2/min

To convert feet to meters, multipy by 0.3048

3. SYSTEM DESIGN PHILOSOPHY

3.1 Background

Aircraft cabins have been pressurized on an experimental basis since the nineteen twenties. Patents from that era show cabin air being supplied from engine driven superchargers; one of the first major applications on a large aircraft was the WW-II B-29 bomber. Since that time all systems have used the same basic approach which is to supply a relatively constant airflow to the cabin from engine driven superchargers or turbochargers, or in the case of a jet engine from the main engine compressor; and then to control cabin pressure by modulating the flow of air overboard through one or more outflow valves. Since overpressurization can cause a structural failure of the fuselage, a redundant pressure limiting function is also needed. This is accomplished with separate positive pressure relief valves (safety valves) or a differential pressure topping control as part of the outflow valve.

While military aircraft cabin pressure control requirements and design implementation have had little change, commercial aircraft systems have evolved to sophisticated controls that provide a high level of passenger comfort and safety while minimizing crew workload. Military combat aircraft employ a fixed isobaric and differential pressure schedule, while non-combat military transports employ a crew- selectable isobaric cabin altitude.

Most of the early cabin pressure control systems were pneumatically powered using the cabin-to-ambient differential pressure as the actuation or servo pressure to move the outflow valve, as well as to generate the control pressure from the control panel inputs. Thus they were self powered, generally consisting of two valves with each valve doubling as both an outflow and safety valve, and they were therefore both lightweight and safe. However, they had poor response to transient disturbances such as changes in cabin air inflow and, in the early jets, to rapid changes in ambient pressure due to takeoff rotation and rapid climbout. This latter problem resulted because the cabin is unpressurized during takeoff, and since outflow valves are normally located on the bottom of the plane, the pressure rise during rotation due to the ground effect restricted the cabin air outflow. This phenomena became known as the “rotation bump” because of the resulting surge in cabin pressure.

These systems were also subject to contamination from dirt and especially tobacco tar, and therefore required high maintenance. Moreover, they also required much attention from the flight crew who had to monitor and reselect the rate of change to insure that the correct pressure schedule was maintained. Thus as the commercial transport jet age progressed through the early sixties, the performance deficiencies of these systems became more of a problem. System advances of that era incorporated electronics, and had dual outflow valves, one of which provided thrust recovery by exiting the cabin air through a variable nozzle. However, the valve arrangement was complicated and heavy and there was no system automation.

When Boeing was in the early design stage of the 737 there arose a need for more automation to reduce the cockpit workload, especially since they planned to eliminate the flight engineer thus reducing the cockpit crew from three to two. They therefore requested proposals for a completely new automated, electronic system that would not require any crew action during flight and would provide rapid response to control transients and reduce the rotation bump. They also wanted a simple, lightweight outflow valve design that would provide thrust recovery from the exhaust air. The resulting system allowed the crew to pre-select the cruise and landing field altitudes prior to takeoff, and then the system automatically controlled the rate during flight. Another feature of the system was an outflow valve with a gate which protruded from the skin line during takeoff to deflect the airstream away from the opening which created a suction, thus allowing the system to maintain control during takeoff to eliminate the rotation bump. When the valve was nearly closed for cruise it formed a thrust nozzle which provided thrust recovery.

The drive for more automation was renewed in the eighties by Airbus when planning the A320. Thus it was possible for complete automation, which meant no crew action at all, by using inputs from the flight management computer. This is typical of the latest state-of-the art systems on new airplane models.

3.2 Types of Cabin Pressure Control Systems

The designs of cabin pressure control systems in use vary with the application, functional requirements, degree of automation, and level of integration with other aircraft systems. Military combat aircraft pressurization requirements allow use of a simple fixed isobaric and differential pressure control pneumatic system. Non-combat military and some civil aircraft use selectable isobaric controls requiring crew inputs during flight. Modern civil transport aircraft use highly automated electronic systems that require little or no crew intervention.

The automation required of a cabin pressure control system depends on the crew workload and flexibility desired of the system. All systems contain many automatic functions. The simple fixed isobaric pneumatic system, for instance, is completely automatic. That is, provision is made for manual override only for an emergency condition. While the fixed isobaric control is suitable for many applications, it is inherently inflexible.

In general, as the degree of desired cabin pressure comfort increases, the system complexity increases and typical commercial airliner systems incorporate a considerable number of automatic features eliminating the necessity for crew attention. Automatic electronic systems are often defined as systems containing logic elements which automatically adapt the mode of cabin pressure control to changes in flight plan after takeoff. The most modern of automatic systems receive flight and landing field elevation data from other avionics systems via an electronic digital data bus. These systems require no crew input for automatic control.

3.2.1 Pneumatic System

Figure 1 shows a typical fixed isobaric type pneumatic system. All control functions and outflow valve actuation are accomplished with pneumatic pressures. The cabin pressure dump function can be provided either by a manual pneumatic valve or by an electric switch and solenoid operated valve. This type of system is in widespread use on military combat aircraft.

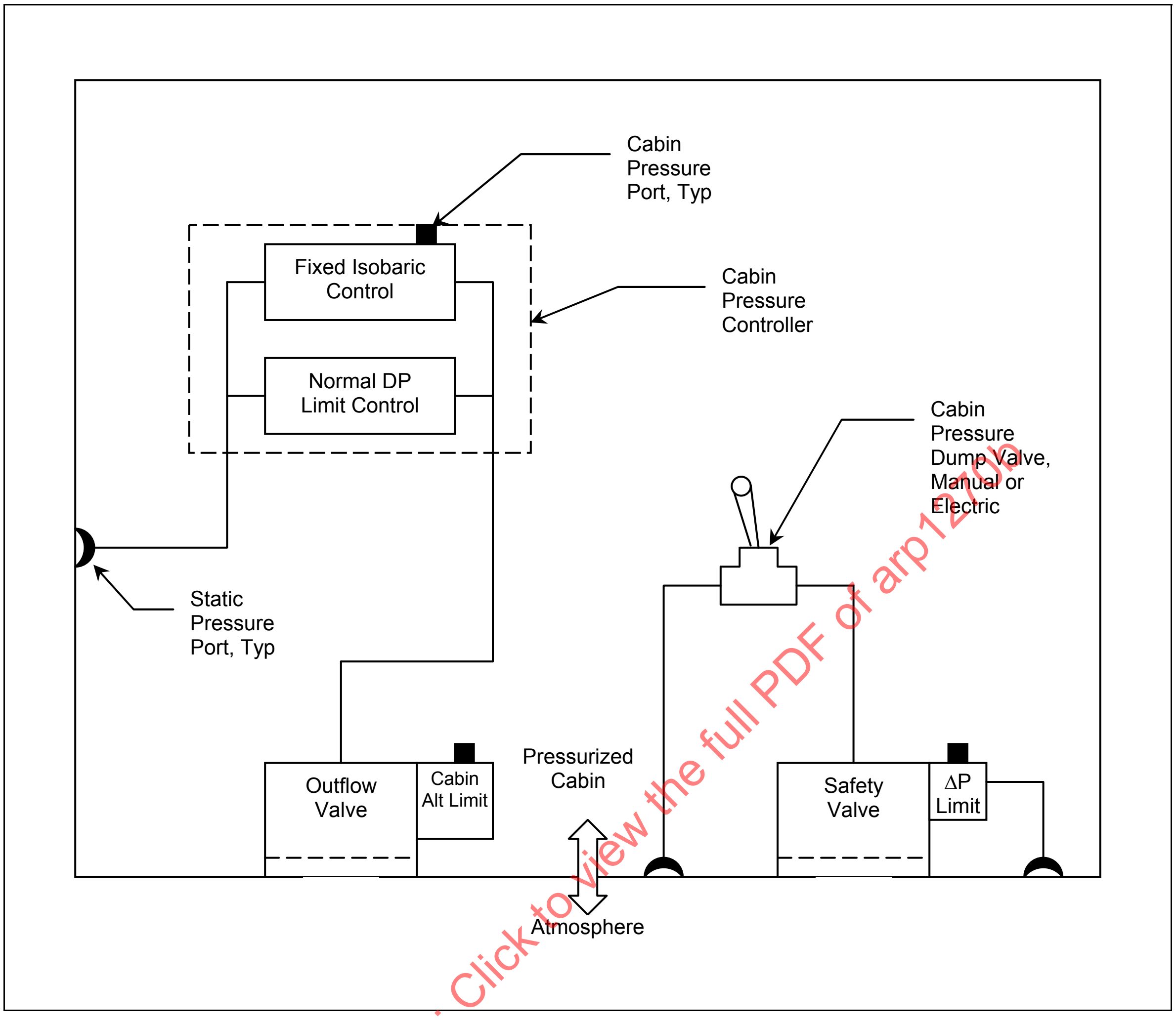

FIGURE 1 - FIXED ISOBARIC PNEUMATIC CPCS

Figure 2 shows a typical variable isobaric type pneumatic system with the cabin altitude selector and controller functions combined in a single component. Electrical power is commonly used in this type of system only for lighting the panel of the controller unit and operation of solenoid valves for automatic and manual switching of operational modes. This type of system is in widespread use on G/A aircraft.

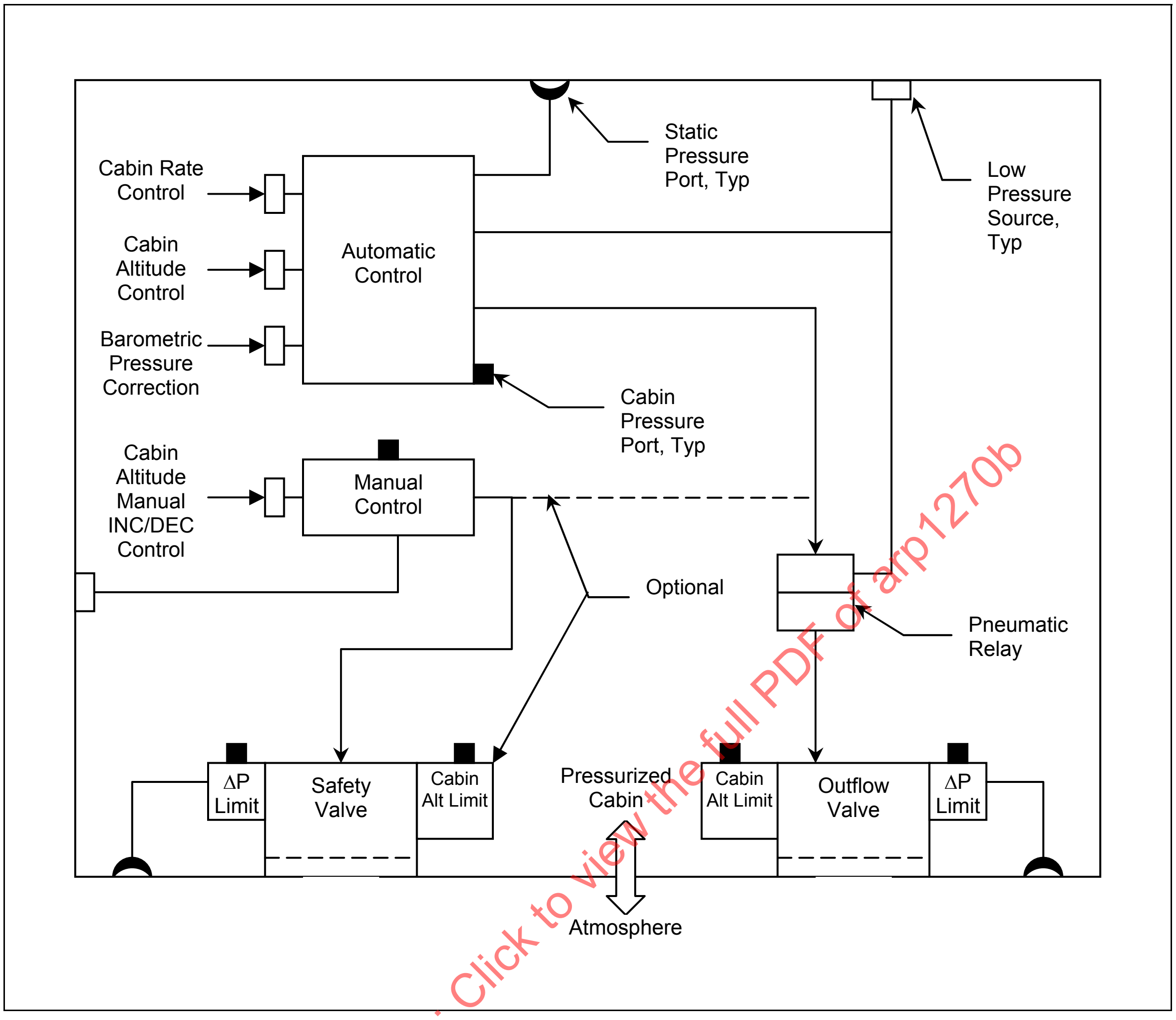

FIGURE 2 - VARIABLE ISOBARIC PNEUMATIC CPCS

3.2.2 Electronic System

Figure 3 shows a typical electronic cabin pressure control system. All control functions make use of electrical power. Outflow valve actuation is performed electrically. The cabin pressure controller is an electronic unit incorporating pressure sensing, logic and signal generating circuitry. This type of system is in widespread use and has been the focus of most current development.

Control of cabin pressure during the flight is scheduled using the information provided by other aircraft systems, such as the air data and flight management computers. Some or all of the following may be available:

a. Ambient Pressure

b. Planned Cruise Altitude

c. Planned Landing Field Altitude

d. Estimated Time to Climb

e. Estimated Time to Descend

f. Barometric Correction

Using the above information, the CPCS will optimally schedule the cabin pressure to obtain the lowest rates of pressure change consistent with the flight profile while avoiding the risk of over or under pressure. In the event that some or all of the above data is unavailable, or unexpected changes occur during the flight, alternate reconfiguration logic shall be available to reschedule the cabin pressure.

The closed loop control system senses the actual cabin pressure, compares it to the output of the pressure scheduling logic and outputs a position command to the outflow valve positioning loop. In order to provide the required accuracy and dynamic response over all operating conditions, the pressure control loop may contain integral plus proportional control as well as gain compensation which is a function of the cabin to ambient differential pressure. The control loop may also contain a derivative term.

The outflow valve positioning loop consists of the valve actuator and its drive system and feedback to provide a closed position loop which receives the position command from the pressure control loop, and thus provides closed loop control of the outflow valve position.

The outflow valve control logic should also include positive and negative pressure protection.

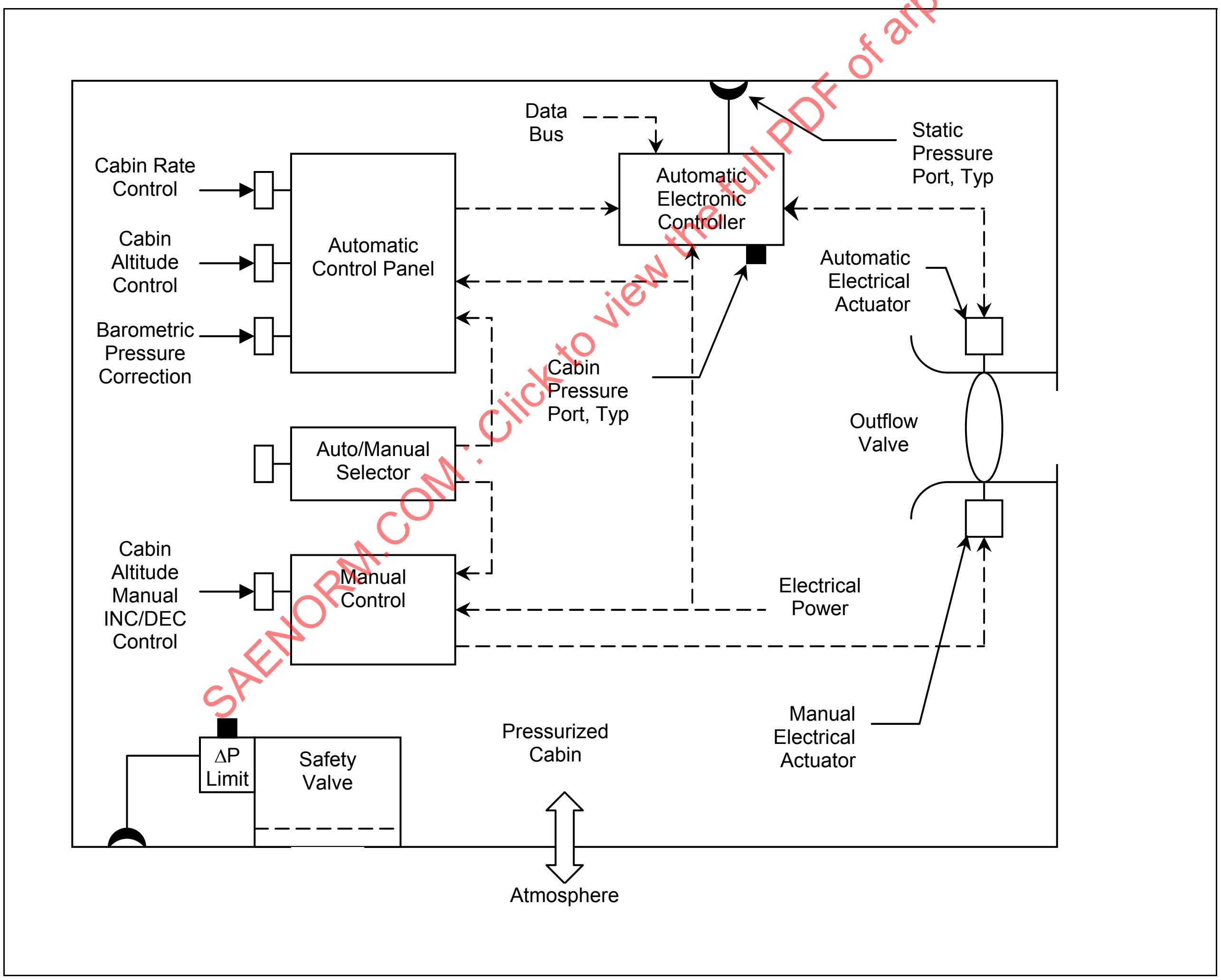

FIGURE 3 - ELECTRONIC CPCS

A variation of the electronic system integrates the CPCS controller into the outflow valve assembly and omits the cockpit CPCS display and gauges. All CPCS settings and indications (cabin pressure altitude, cabin rate of climb, cabin differential pressure, and CPCS status) are displayed on the EICAS. The CPCS control panel contains only the manual/emergency controls. This system is illustrated in Figure 4.

On some aircraft this may involve a standard aircraft-supplied computing resource that hosts supervisory CPCS application software and provides digital data interface to other systems.

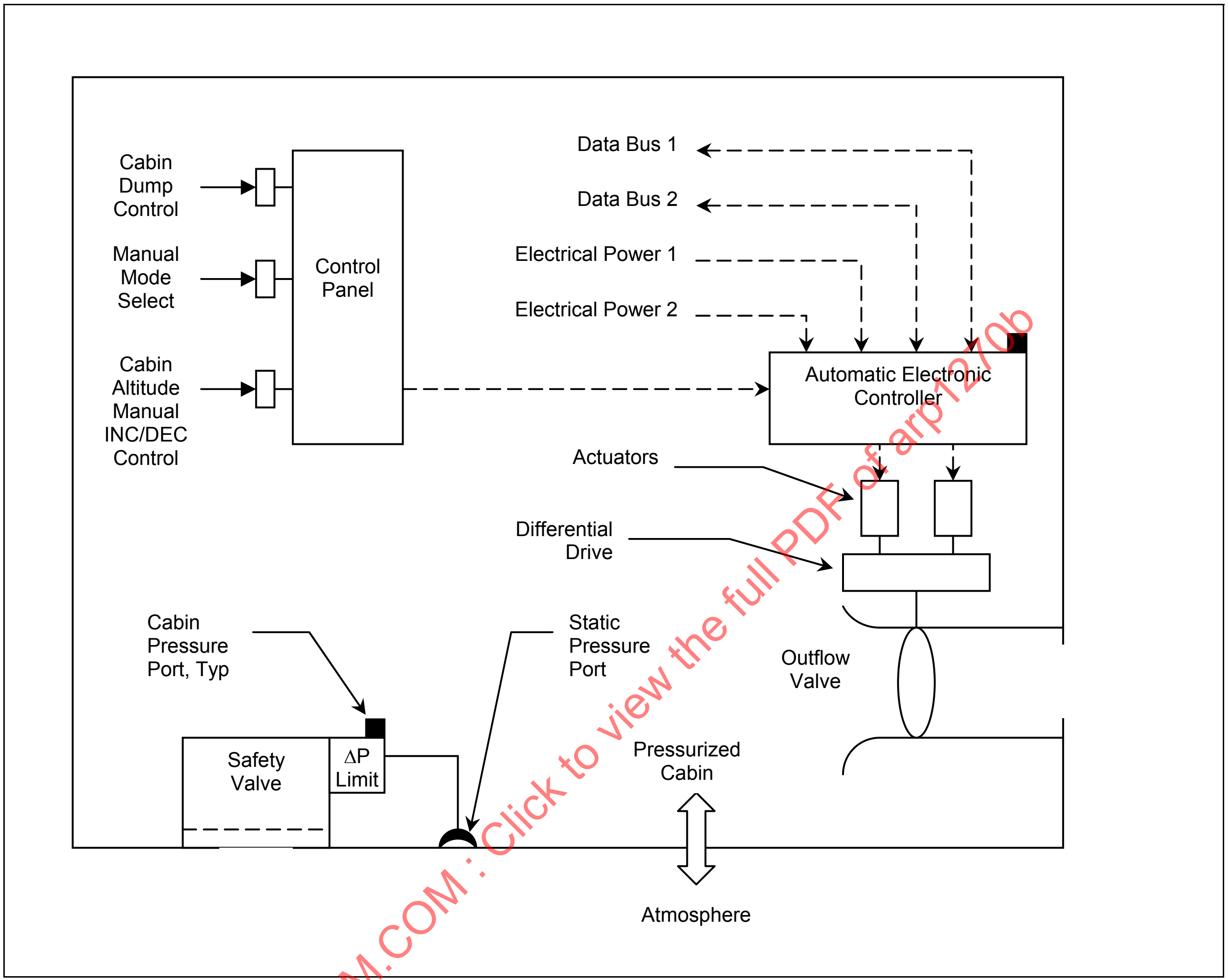

FIGURE 4 - INTEGRATED ELECTRONIC CPCS

3.2.3 Pneumatic/Electric Hybrid System

Hybrid systems, which employ both electrical and pneumatic control elements are in use. The designation of pneumatic/electric is assigned to those systems which utilize a pneumatic controller for sensing and generation of a pneumatic pressure command, a transducer element for conversion of the pneumatic signal to an electrical signal, and electrical elements for control and actuation of the outflow valves.

3.2.4 Electro-Pneumatic System

The designation of electro-pneumatic is assigned to hybrid systems which use pneumatically operated, electrically controlled, outflow valves. A typical system of this type is shown in Figure 5.

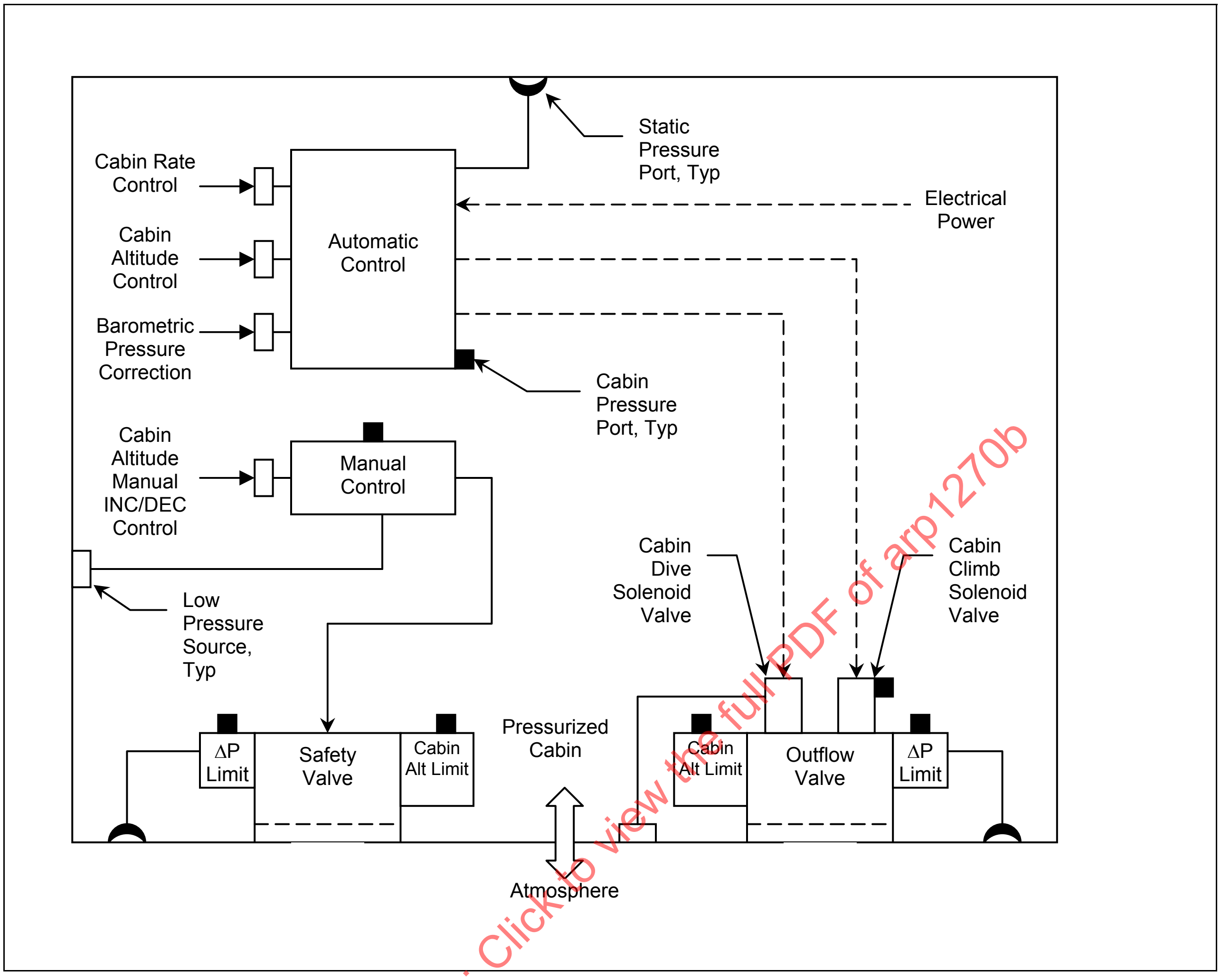

FIGURE 5 - ELECTRO-PNEUMATIC CPCS

3.3 Safety

Safety considerations for aircraft cabin pressure control systems are mandated by the civil and military regulations discussed in 4.1 and 4.2. The failure criteria applied by civil regulations is summarized as follows:

The airplane system and associated components, considered separately and in relation to other systems, shall be designed so that:

a. Catastrophic failure conditions are extremely improbable ($<10^{-9}$ probability). [1]

b. Hazardous failure conditions which can result in serious injury or cause a large reduction in safety margin or extended crew workload shall be extremely remote ($<10^{-7}$ probability).

c. Failure conditions which would have a major effect on the operation of the airplane (major failures) are remote ($<10^{-5}$ probability), and the airplane can be flown and landed safely after such a failure, without serious hazards to the occupants and without requiring exceptional skill or strength on the part of the crew.

d. Failure conditions other than those described in (a) and (b) will have only minor effects on the airplane and occupants (minor failures) and can be readily counteracted by the crew.

[1] Probability levels shown are for Part 25 and Commuter Category Part 23 airplanes. Lower levels are applied to non- Commuter Category Part 23 airplanes.

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. In considering the effects of a decompression, the cabin pressure system designer should consider:

1. The probability of a relief valve or outflow valve failing open at the maximum aircraft altitude

2. The valve size

3. The recognition time for the flight crew to respond to the failure

4. The aircraft maximum emergency descent rate.

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 12 497 m (41 000 ft). For any probable decompression failure condition, those rules required that the cabin pressure altitude not exceed 7620 m (25 000 FPA) for more than 2 minutes, or 12 192 m (40 000 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 12 497 m (41 000 ft). 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 CS23 or CS25. Airplanes to be certified under these rules for operation above 12 497 m (41 000 ft) have Special Conditions which are similar to the pertinent sections of 14 CFR Part 25 Amendment 87.

The safety functions in the following sections shall be provided and they shall be independent of the basic control functions.

3.3.1 Overpressure Relief

Overpressure relief shall be provided by at least two independent overpressure relief valves either of which can handle the maximum cabin inflow. Typically these are pneumatically self powered and based on a proven, reliable design.

The overpressure relief function may be accomplished by the same valves that perform the automatic or manual modulation of cabin outflow, provided that all of the following conditions are met:

a. The total number of valves performing the overpressure relief function is a least two

b. The part of the valve that commands the overpressure relief function has been segregated from the part of the valve that provides automatic or manual modulation commands

c. When driving the valve to relief, the part of the valve that commands the overpressure relief function is capable of overriding both the automatic and manual modulation commands under any operating condition

An example of this design solution is provided by electro-pneumatic systems with two outflow poppet valves: usually one valve is electrically controlled to perform automatic modulation (primary valve) and a second valve is pneumatically controlled by a backup manual mode (secondary valve). The two outflow valves are pneumatically interconnected so that the actively controlled valve (i.e. the primary valve in automatic mode or the secondary one in manual backup) can drive the other to “mirror” its movement. Normally, each of the two valves is also equipped with a bellows that performs the overpressure relief function and overrides any other driving command in either automatic or manual backup modes.

3.3.2 Negative Pressure Relief

A reverse or negative pressure relief function shall be provided to allow enough inflow to prevent the cabin negative pressure from exceeding allowable structural limits with no cabin inflow at the maximum aircraft descent. This function can be built into the safety valves or can be provided by separate valve(s).

3.3.3 Built in Safety Limits

Automated pressure scheduling and control algorithms shall contain safety algorithms to prevent, for example, a runaway valve from depressurizing the cabin beyond safe limits.

3.3.4 Ditching

If the aircraft is to be certified for ditching, the outflow valves and negative and positive pressure relief valves should be installed such that water does not enter the fuselage during ditching. If this cannot be accomplished, provisions shall be included to close the valves prior to ditching. Closure of the valves may be done manually or automatically but must be consistent with other safety and design considerations. The valve closure means shall not prevent depressurization necessary for door opening after landing. Malfunction shall not override the maximum differential pressure limiting function.

As noted in FAA AC 25-17 Section 25.801, both planned and unplanned ditching events shall be considered. Planned ditching assumes that the crew has sufficient time to configure the airplane for the event. Unplanned ditching includes such occurences as a runway overrun into water following a failed or aborted takeoff, where no crew action is possible.

3.3.5 Cabin Altitude Limiting

If the aircraft is to be approved for flight above 7620 m (25 000 ft), civil regulations require that it be designed to prevent the occupants from being exposed to pressure altitudes above 4572 m (15 000 FPA) after any probable failure condition in the CPCS. Since at least one of the valves in any CPCS has the capability to dump cabin differential pressure to a negligible level, this valve may be equipped with a cabin altitude limiting function that prevents the valve from opening enough to raise cabin pressure altitude above 4572 m (15 000 FPA), regardless of any dump command input. For freighter aircraft the cabin altitude limitation of 4572 m (15 000 FPA) may be exceeded for special operating cases, such as for smoke removal or fire suppression.

3.3.6 Cabin Pressure Dump

A control shall be provided to rapidly equalize cabin pressure differential. This can be provided by a manual control that can command the outflow valves open and overide the automatic controls or by a separate manual dump valve. Shutting off inflow to allow the cabin to bleed down may not provide a rapid enough rate of depressurization. FAA AC 25-22 Section 25.841 notes that the manual pressure control mode may provide this function if it can provide a rapid enough cabin climb rate and that a depressurization time of 2 minutes or less is typical for a maximum rate manual depressurization.

3.3.7 Cabin Pressure Dump on Landing

If the aircraft structure is not designed to withstand landing loads in conjunction with cabin differential pressure loads, the CPCS may include a means to rapidly equalize (dump) cabin pressure upon receiving Weight-On-Wheels (WOW) signal. This cabin pressure dump capability shall not be capable of overriding the Cabin Altitude Limit function. It is desirable that the CPCS incorporate sufficient logic to ignore WOW input once the aircraft is in flight above 4572 m (15 000 ft).

3.3.8 Prevention of Initiation of Pressurization If External Doors Are Not Closed, Latched and Locked

14 CFR/CS 25.783 requires that the aircraft not be capable of being pressurized to an unsafe level if any external door is not fully closed, latched and locked. This function is normally provided for each outward opening external door by a small vent door, mechanically linked to the cabin or cargo door lock and latch mechanism. Inward opening doors may not need a vent door if their opening movement automatically prevents pressurization to an unsafe level.

The vent door function can be provided by the CPCS if the CPCS implementation of this function can be shown to be equally reliable as a mechanical vent door mechanism. This cabin pressurization prevention function shall not be capable of overriding the Cabin Altitude Limit function once the airplane is pressurized and in flight. It is desirable that the CPCS incorporate sufficient logic to prevent cabin pressure dump due to door unlocked input once the aircraft is in flight above 4572 m (15 000 ft).

3.3.9 Isolation Valve

Aircraft with aft mounted engines that have a portion of the pressure vessel within the engine rotor non-containment zone may be equipped with a secondary pressure bulkhead. Typically, the compartment to be isolated from decompression is an aft baggage compartment. In event of an engine rotor non-containment that perforates this compartment, fast acting shut-off valves actuate automatically on detection of cabin altitude climbing above 4572 m (15 000 FPA) to close off the normal ventilation air paths into the compartment. If the outflow and safety valves are located on the primary aft pressure bulkhead, all outflow air has to pass through the isolation valve. In this case, this valve shall be designed so that it can not inadvertently close and cause cabin overpressurization, or else the secondary pressure bulkhead shall be provided with sufficient normal leakage to prevent excess cabin differential pressure at the max inflow rate with the isolation valve closed.

3.4 Physiological Design

Physiological design considerations include the maximum normal cabin pressure altitude the aircraft design allows, and the maximum rates of change of cabin pressure. Part 23 airplanes are required to limit cabin pressure altitude to 3048 m (10 000 FPA), while Part 25 airplanes are required to limit cabin pressure altitude to 2438 m (8000 FPA). Most commercial revenue aircraft utilize systems that operate at this limit only when the aircraft is at its maximum certified flight altitude. The exposure of the occupants to a higher cabin pressure altitude on Part 23 airplanes is accepted because of the shorter flight durations expected on this class of aircraft. Civil regulations place no limit on the cabin altitude rate of change, but most civil aircraft cabin pressure control systems are designed such that the recommended maximum rates of change of cabin pressure of 152 SLm/min (500 SLft/min) during ascent and 91 SLm/min (300 SLft/min) during descent are not normally exceeded.

3.5 Comfort

In addition to the safety requirements, the CPCS shall provide 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. Aircraft systems are also required to be lightweight, readily accessible for quick inspection and servicing, highly reliable, tolerant of a wide range of environmental conditions, withstand aircraft vibratory and maneuver loads, and to accommodate system failures occurring during flight.

The CPCS shall operate to provide desired comfort levels during at least the following segments of the flight:

a. Door closure and air inflow initiation

b. Taxi from ramp

c. Take-off and transition from “ground” to “flight” mode

d. Climb

e. Cruise

f. Descent

g. Holding

h. Approach

i. Landing and transition from “flight” to “ground” mode

j. Taxi to ramp

k. Door opening

Additional transient conditions that should be considered are switching between high and low pressure engine bleed air ports, bleed air off takeoffs and barometric correction reselection.

3.6 Crew Workload

In a typical manual isobaric CPCS, the crew is required to select cabin altitude and the maximum rate-of-change of cabin altitude. The range of isobaric cabin pressure altitude control should be adjustable from -305 to +4240 m (-1000 to +14 000 FPA), depending on the intended approved airfield altitudes. Prior to takeoff the cabin altitude is set to field pressure altitude and the cabin rate of climb control is set to a rate estimated to provide the minimum average cabin rate of climb. During climbout, the aircraft altitude scale on the controller is reset to the aircraft cruise altitude. During descent, the cabin altitude is set to the landing field elevation and the cabin rate of descent control is set to a rate estimated to provide the minimum average cabin rate of descent.

To reduce crew workload, cabin pressurization control systems can provide means to automatically set cabin altitude and cabin altitude rate of change. One method is to program cabin altitude as a function of aircraft altitude and flight status. This allows the crew to preselect (prior to take-off) the expected landing field elevation and requires no further crew action prior to landing. Another method of fully automatic control is for the CPCS to receive landing field elevation, maximum flight altitude, barometric correction and flight data from other avionics systems via digital data busses. For these systems, no crew action is required for normal cabin pressure control.

3.7 Impact of Aircraft Operation on Cabin Pressurization

Possible unanticipated operation factors that can adversely affect CPCS operation or reliability are:

Some airlines can extend intervals between major structural inspections by using operating procedures that select the maximum allowable cabin pressure altitude instead of the maximum allowable differential pressure. Cabin pressure cycles at max differential pressure may be limited to infrequent flights at the airplane max approved altitude.

Extended cold weather operations- aircraft may not see a heated hangar for weeks at a time. Condensed moisture may freeze and be undrainable. Large amounts of ice can accumulate in this period. CPCS static plumbing, drains, exhaust ducts, etc shall be designed to tolerate this scenario.

Operation with other systems inoperative - FAA MMEL procedures allow aircraft in airline service to operate with equipment inoperative. The duration allowed is based on the criticality of the equipment, but can be as long as 30 days and is subject to change as the airplane matures in service. CPCS design shall consider effects of loss of other equipment (notably, ECS, heating and cooling systems) not just for the duration of one flight as required for System Safety certification (ref 14 CFR/CS 23.1309/25.1309), but for multiple flights.

Different duty cycles - CPCS designed for General Aviation service of 600 hours/year may not provide adequate reliability and service life if that airplane is used in a fractional ownership program or commuter airline at 2400 hours/year. Commercial revenue aircraft typically range between 2500 to 4000 hours/year.

3.8 Reliability and Maintainability

CPCS components shall be designed to minimize scheduled maintenance.

All parts shall be designed to preclude incorrect installation.

Filters, if installed, shall be located and oriented to allow easy removal and installation, taking into account possible routing of static plumbing, wire harnesses, etc that are part of the CPCS component installation.

All pneumatic components shall be designed for free drainage of condensed moisture.

Case vents or ports shall be clearly marked and identified to preclude their blockage by decals or placards that may be added in service by maintenance or overhaul facilities.

Test ports shall be provided to allow for in-place testing of any component that has a recurring inspection requirement. Example: cabin altitude limiters and differential pressure limiters typically require a maintenance inspection to detect possible latent failure. Provision of test ports on these subassemblies allows for them to be tested on the aircraft, without special adapters.

Any port or vent larger than 3.2 mm (0.125 inch) diameter shall be equipped with a screen to prevent blockage by insects or foreign matter. Ports and vents on CPCS components that are normally covered by connecting tube assemblies are already protected.

Special fittings containing orifices, screens, filters, check valves, etc shall be prominently marked to preclude their inadvertent replacement by standard parts.

Adjustments that are not intended to be changed in the field shall be potted or sealed to prevent tampering.

Special tools shall not be required for recurring maintenance or for troubleshooting to the LRU level.

Plastic components shall be clearly marked as to allowable cleaning agents, torque limits for fasteners and any other limits or cautions necessary to guard against damage during maintenance, installation or removal.

4. SYSTEM DESIGN REQUIREMENTS

Cabin pressure is controlled by modulating the airflow discharged from the pressurized cabin through one or more cabin outflow valves. The cabin pressure control system includes the outflow valves, controller, selector panel and redundant positive pressure relief valves. Provisions for negative pressure relief are incorporated in the relief valves and/or included in the aircraft structure (door). The system controls the cabin ascent and descent rates to acceptable comfort levels, and maintains cabin pressure altitude in accordance with cabin-to-ambient differential pressure schedules. Recommended maximum rates of change are 152 SLm/min (500 SLft/min) during climb and 91 SLm/min (300 SLft/min) during descent. See Figure 10. Civil regulations define the maximum normal cabin pressure altitude, but the CPCS may schedule a lower cabin altitude if allowed by the cabin differential pressure capability. Modern systems provide minimum crew workload (usually requiring the crew to select only the landing field elevation if the data is not automatically provided by the FMS), and provide maximum comfort by monitoring aircraft flight via the FMS and ADC.

The CPCS outflow control valves (cabin pressure modulating valves) and safety valves (positive pressure relief valves) are generally located on the aircraft skin on large aircraft and on the forward or aft fuselage pressure bulkheads on small aircraft. Outflow valves on large aircraft are generally designed to provide additional thrust from the exhaust of the outflow air. To function efficiently, they have to be located on the aircraft skin. Locating the outflow valves on the aircraft skin avoids the handling of large airflows in the unpressurized tailcone or nose areas. However, thrust recovery valves are more complex than the butterfly valves or poppet-type valves used for bulkhead installations. The small thrust available from the outflow air on small aircraft does not justify the cost and complexity of a thrust recovery outflow valve design, allowing more flexibility in their location. The safety valves are poppet-type valves for either installation. Most modern commercial aircraft systems use electronic controllers that are located in the E/E bay. The cabin pressure control panel is located in the flight deck.

A basic design concept of civil and non-combat military CPCS design is that the authority of the control system shall be limited so that it can not override the operation of the safety features. In other words, no dump command or cabin altitude climb command may override the ability of the cabin altitude limiter to keep the cabin pressure altitude under 4572 m (15 000 FPA) and no cabin altitude dive command may override the ability of the differential pressure limiter to keep cabin differential pressure under the aircraft structural limits. If this concept can be applied to all safety functions, a CPCS design will result that requires at least two failures or malfunctions before a potentially unsafe condition can occur; one failure of a safety feature and one other failure or malfunction in a component of the CPCS to command the outflow/safety/dump valves to exceed safe operating limits. Periodic testing of any safety functions that are not used in normal CPCS operation is required to minimize the probability that they could be unavailable when needed.

4.1 Civil Regulations

The Federal Aviation Administration (FAA) regulates the design of aircraft for operation in the United States. Type Design Rules define the requirements for FAA approval of aircraft of a particular design. 14 CFR Part 23 applies to General Aviation (G/A) and commuter aircraft certified to carry up to 19 passengers and a gross weight not to exceed 8618 kg (19 000 lb). 14 CFR Part 25 applies to transport category airplanes. Similar regulations are applied to European nations by the European Aviation Safety Agency (EASA) which represents the combined requirements of the airworthiness authorities of the participating nations.

Civil regulatory agencies may impose additional special conditions on the design when existing rules do not adequately cover a new, novel or unique design. These conditions will be issued with full authority of the regulatory agency, and compliance is mandatory.

Typical Special Conditions applied by the civil certification agencies that affect CPCS are:

- Part 23 Airplanes to be approved for operation above 12 497 m (41 000 ft)
- Part 27 Normal Category Rotorcraft with Cabin Pressurization
- Part 29 Transport Category Rotorcraft with Cabin Pressurization.

Several regulations are directly applicable to CPCS design. 14 CFR/CS 23.841 and 25.841 define most of the CPCS Type Design requirements. These paragraphs provide cabin altitude limits for various failure conditions, specific equipment redundancy requirements and flight deck indication and warning requirements. Significant differences between these two regulations are that 14 CFR/CS 23.841 allow a maximum normal cabin pressure altitude of 3048 m (10 000 FPA), while 14 CFR/CS 25.841 allow 2438 m (8000 FPA). 14 CFR §25.841 has additional requirements at Amendment 25-87.

Civil regulations require warning of excessive cabin altitude at 3048 m (10 000 FPA). Airplanes approved for operation from airfields with elevations above 3048 m (10 000 ft) are required to provide a means to shift the setting of the cabin altitude warning above the maximum approved airfield elevation. While manual means have been approved, the regulatory agencies currently require that the altitude setting shift be fully automatic, so that it can not be inadvertently selected.

14 CFR/CS 23.843 and 25.843 define functional tests requirements for CPCS.

The CPCS shall also meet the System Safety criteria of 14 CFR/CS 25.1309 “Equipment, systems, and installations”. Part 23 has similar regulations and advisory data. While the wording of 23.1309 and 25.1309 are very similar, the interpretations are different and the appropriate advisory data should be consulted.

14 CFR/CS 23.1438 and 25.1438 define proof and burst pressure requirements for CPCS components of 1.5 times and 2.0 times the max normal cabin differential pressure, respectively. The max normal cabin differential pressure will ususally be the maximum pressure allowed by normal scheduled cabin pressure controller operation. However, pneumatic systems with limited fault detection capability may be able to operate at the differential pressure limiter setting for extended periods without indication or detection. In this case, the DP limiter setting would be used as the max normal cabin differential pressure.

There are no 14 CFR/CS Part 27 or Part 29 CPCS regulations. CPCS requirements for rotorcraft will need to be applied by Special Condition and/or Interim Airworthiness Criteria.

4.2 Military Regulations

The primary military regulations relating to CPCS are currently MIL-E-18927 (Navy) and JSSG-2009. JSSG-2009 is a guide specification that provides guidelines for establishing requirements, but does not specify requirements. Below is a summary of MIL-E-18927 requirements, which would also represent typical requirements established by tailoring JSSG-2009. The aircraft specification should always be consulted to determine actual requirements.

For fighter aircraft, the pressure schedule is unpressurized from sea level to 2438 m (8000 FPA), maintaining 2438 m (8000 FPA) isobaric to 7010 m (23 000 FPA), and then a 34.5 kPa (5 lbf/in^2) differential pressure schedule above 7010 m (23 000 FPA). This schedule is shown in Figure 6. The maximum acceptable rate of pressure change for normal operation is 1.38 kPa/s (0.2 $lbf/in^2/s$). This includes all transient conditions. For emergency operation, the maximum rate shall be 3.45 kPa/s (0.5 $lbf/in^2/s$) for increasing pressure, and 6.89 kPa/s (1.0 $lbf/in^2/s$) for decreasing pressure. Tolerances on these levels are provided in the specification.

For other military aircraft (transport, electronic, etc.), a pressurization system should allow the crew to select any cabin pressure altitude between -305 m (-1000 FPA) and 3048 m (+10 000 FPA), except as limited by a maximum differential pressure. Automatic controllers which allow for selection and control of the rate of pressure change anywhere in the range of 30 to 610 m/min (100 to 2000 ft/min) shall be used. For emergency operation, the maximum rate shall be 3.45 kPa/s (0.5 lbf/in^2/s) for increasing pressure, and 6.89 kPa/s (1.0 lbf/in^2/s) for decreasing pressure. Tolerances on these levels are provided in the specification.

Structural damage or personnel injury shall not occur due to sudden compression or decompression of a single compartment aircraft or of one compartment of a multi-compartment pressurized volume.

Limits on decompression are established based on the crew systems to be used.

Normal and emergency cabin pressure release is required and specific time limits are provided in the specifications. MIL-E-18927 references MIL-R-9345 (inactive for new design) for cabin pressure regulators.

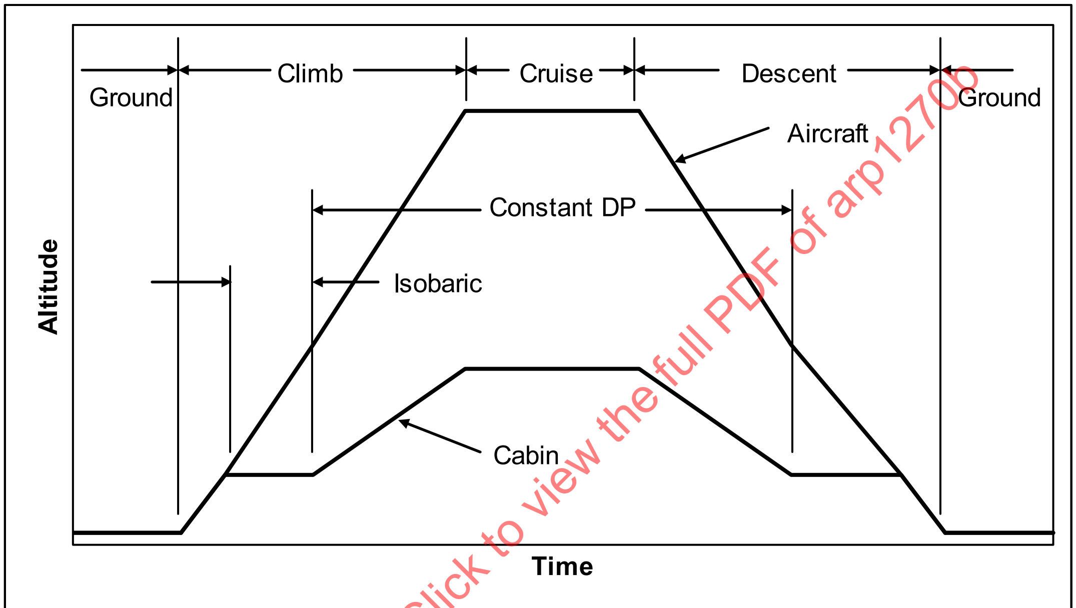

FIGURE 6 - CABIN PRESSURE SCHEDULE FOR COMBAT AIRCRAFT

4.3 Civil Aircraft Performance Requirements

4.3.1 Pressure Level

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 12 192 m (40 000 ft) would be designed to withstand a differential pressure of 56.5 kPa (8.2 lbf/in^2) 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 ten tons on a typical cabin door. Since many CPCS schedule the max allowable differential pressure during flight at cruise altitude, occupants will be exposed to the maximum allowed cabin altitude only when the airplane is operated at its max 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).

Part 23 airplanes are required to limit cabin pressure altitude to 3048 m (10 000 FPA), while Part 25 airplanes are required to limit cabin pressure altitude to 2438 m (8000 FPA). Part 23 airplanes approved for operation above 12 497 m (41 000 ft) 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 given in 4.3.2.

During cruise, the system shall provide 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 15m (50 ft) of the selected or scheduled value is a typical value.

4.3.2 Rate of Pressure Change

As a result of the required cabin pressure change during climb and descent, there is a second equally important requirement for human comfort. Since the human ear is very sensitive to rate of pressure change, the rate has to be closely controlled for large changes. Pressure changes of less than 18 m (60 SLft), equivalent to 0.22 kPa (0.032 PSI) can be made at any rate. However, as the amplitude of the change increases the rate becomes more important. The generally accepted comfort requirements are that for changes of over about 18 m (60 SLft) the rate should be limited to 152 SLm/min (500 SLft/min) for decreasing pressure (increasing altitude) and 91 SLm/min (300 SLft/min) for increasing pressure (decreasing altitude). See Figure 7. As the aircraft climbs and descends, the rate of cabin pressure change should be controlled to an acceptable rate. 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. Thus the flight crew would set the cabin altitude to correspond to the planned aircraft cruise altitude and set the rate of change to obtain the lowest rate for passenger comfort, but consistent with the aircraft's ascent rate. The system would then control the cabin rate up to the cruise altitude.

The cabin pressure control schedule for a typical commercial flight profile is shown in Figure 7. It differs dramatically from the combat aircraft cabin pressure schedule of Figure 6.

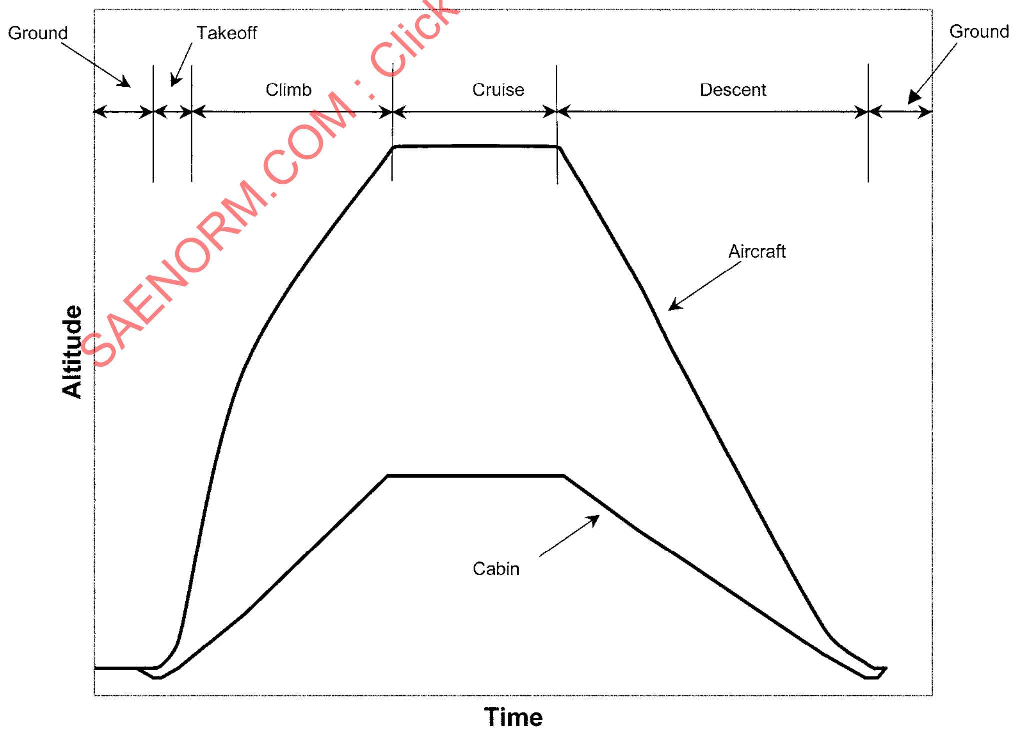

FIGURE 7 - CABIN PRESSURE SCHEDULE FOR A TYPICAL COMMERCIAL AIRCRAFT

Since the sensitivity of the ear is based on a rate of pressure change, the established comfort rates have to be defined as a sea level rate (SLm/min or SLft/min) regardless of altitude. For example, 91 m/min (300 ft/min) at sea level is 1.10 kPa/min (0.160 lbf/in^2/min), but if the cabin was at 1220 m (4000 ft), 91 m/min (300 ft/min) at that altitude would be 0.97 kPa/min (0.141 lbf/in^2/min). Modern electronic CPCS tend to control to a sea level rate over the entire altitude range whereas the older pneumatic systems controlled to an altitude rate. This is because the pneumatic systems operate by allowing air to bleed in or out of a small chamber through a variable orifice restriction. The size of the restriction would vary the rate. One wall of the chamber is a diaphragm and thus a constant rate would produce a constant force on the diaphragm and the diaphragm would operate a control element. Also, this same principle is used for rate of climb indicators which are used for monitoring the cabin rates and thus they display altitude rate. This has caused some confusion. For example, at a cabin altitude of 1524 m (5000 ft), if the CPCS is controlling to a sea level rate of 91 SLm/min (300 SLft/min), the indicator would read an altitude change rate of 106 m/min (349 ft/min).

The following formulae provide a means to convert from an altitude difference or pressure altitude rate of change at altitude to the SL equivalent value:

$$\Delta H_{SL} = \Delta H \times \left(1 - 2.25569 \times 10^{-5} \times H\right)^{4.25616} \quad \text{, SLm or SLm/min} \qquad \text{(Eq. 5a)}$$

where:

H = Cabin Pressure Altitude, m

ΔH = Altitude Change, or Pressure Altitude Rate of Change, m or m/min

For USCS units, this relation is:

$$\Delta H_{SL} = \Delta H \times \left(1 - 6.87535 \times 10^{-6} \times H\right)^{4.25616} \quad \text{, SLft or SL ft/min} \qquad \text{(Eq. 5b)}$$

where:

H = Cabin Pressure Altitude, FPA

ΔH = Altitude Change, or Pressure Altitude Rate of Change, ft or ft/min

4.3.3 Dynamic Performance Requirements

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 de-activating 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 15 m to 91 m (50 ft to 300 ft) below field pressure altitude. The actual ground pressurization limit however, shall be 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 10. 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 shall be 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 shall be 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.

4.3.4 Positive and Negative Pressure Relief

Independent safety overrides shall be provided in order to prevent either a positive overpressure or a negative or reverse 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 shall be provided to allow ambient airflow into the cabin. For more details on positive and negative pressure relief see 4.9.3 and 4.9.4.

4.3.5 Ground Requirements

Another basic requirement is that when the aircraft is on the ground, the cabin to ambient differential pressure shall be low enough to allow the cabin doors and escape hatches to be opened easily for quick passenger evacuation. This requires a much larger outflow/dump valve area for ground operation than is required during normal pressurized flight. Typical ground residual cabin pressure differential is usually only about 0.25 to 0.5 kPa (0.036 to 0.072 lbf/in^2).

Door and emergency exit unlatching, opening and closing shall be demonstrated with the maximum expected residual cabin differential pressure. Ground pre-pressurization for take-off, is typically to 31 to 91 SLm (100 to 300 SLft), equivalent to 0.365 kPa to 1.10 kPa (0.053 to 0.159 lbf/in^2). Normal ground pressure differentials with the outflow valves fully open are typically held to lower levels to minimize the potential for occupant discomfort during door opening and closing. For emergency evacuation, SAE ARP488 recommends demonstration of emergency exit unlatching at 1.7 kPa (0.25 lbf/in^2) cabin differential. FAA AC 25.783-1A allows a maximum of 3.4 kPa (0.5 lbf/in^2) pressure differential for opening of cabin entry doors. If ground pre-pressurization differentials can cause unacceptable door unlatching and opening loads, the CPCS shall include sufficient logic to dump ground pre-pressurization following an aborted take-off or from other signal indicating need for emergency evacuation.

The cabin pressure vent door that is required by 14 CFR/CS 25.783(c) is intended to prevent the initial cabin pressurization if an external cabin door is not closed, latched and locked. It is not intended to vent pressure rapidly if a door is unlocked while there is significant pressure in the cabin.

Ground pre-pressurization for take-off is typically initiated by the CPCS based on signals that all external doors are closed, latched and locked and the throttles are above taxi power. On high performance aircraft, the relatively short time from power-up for take-off and rotation may not allow the CPCS adequate time to transition from dump mode to control mode. On aircraft that use a bleeds off take-off procedure the initiation of inflow may coincide with the CPCS capture of cabin pressure control, resulting in an unpleasant cabin pressure bump. To allow adequate time for CPCS transition from dump to control mode, the initiation of ground pre-pressurization can be based on some earlier event, such as all external doors closed, latched and locked and aircraft is taxiing. Prepressurization is maintained through takeoff, unless the CPCS provides a dump command.

The determination of total valve area required to limit the ground residual pressure to the desired level shall account for the additional pressure drop of interior upholstery, furnishings and any ducting or louvers that the outflow air must pass through.

4.3.6 Minimum Cabin Inflow for Rapid Descents

Figure 8 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 3647 m/min (10 000 ft/min) with a cabin volume of 566 m^3 (20 000 ft^3) is about 192 kg/min (425 lbm/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 the outflow valve enough air to modulate. Some systems can not accurately control rate or differential below a certain flow rate.

Figure 8 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.

$$\frac{dm}{dt} = -3.37949 \times 10^{-7} \times \frac{dH}{dt} \times V \times P_C^{\,0.809747} \quad \text{, kg/min} \qquad \text{(Eq. 6a)}$$

where:

$\frac{dH}{dt}$ = Cabin Altitude Climb or Descent Rate, m/min (Negative for Descent)

V = Cabin Effective Volume, m^3

P_c = Cabin Absolute Pressure, kPa

In USCS units, the relation is:

$$\frac{dm}{dt} = -3.07068 \times 10^{-7} \times \frac{dH}{dt} \times V \times P_C^{\,0.809747} \quad \text{, lbm/min} \qquad \text{(Eq. 6b)}$$

where:

$\frac{dH}{dt}$ = Cabin Altitude Climb or Descent Rate, ft/min (Negative for Descent)

V = Cabin Effective Volume, ft^3

P_c = Cabin Absolute Pressure, lbf/in^2

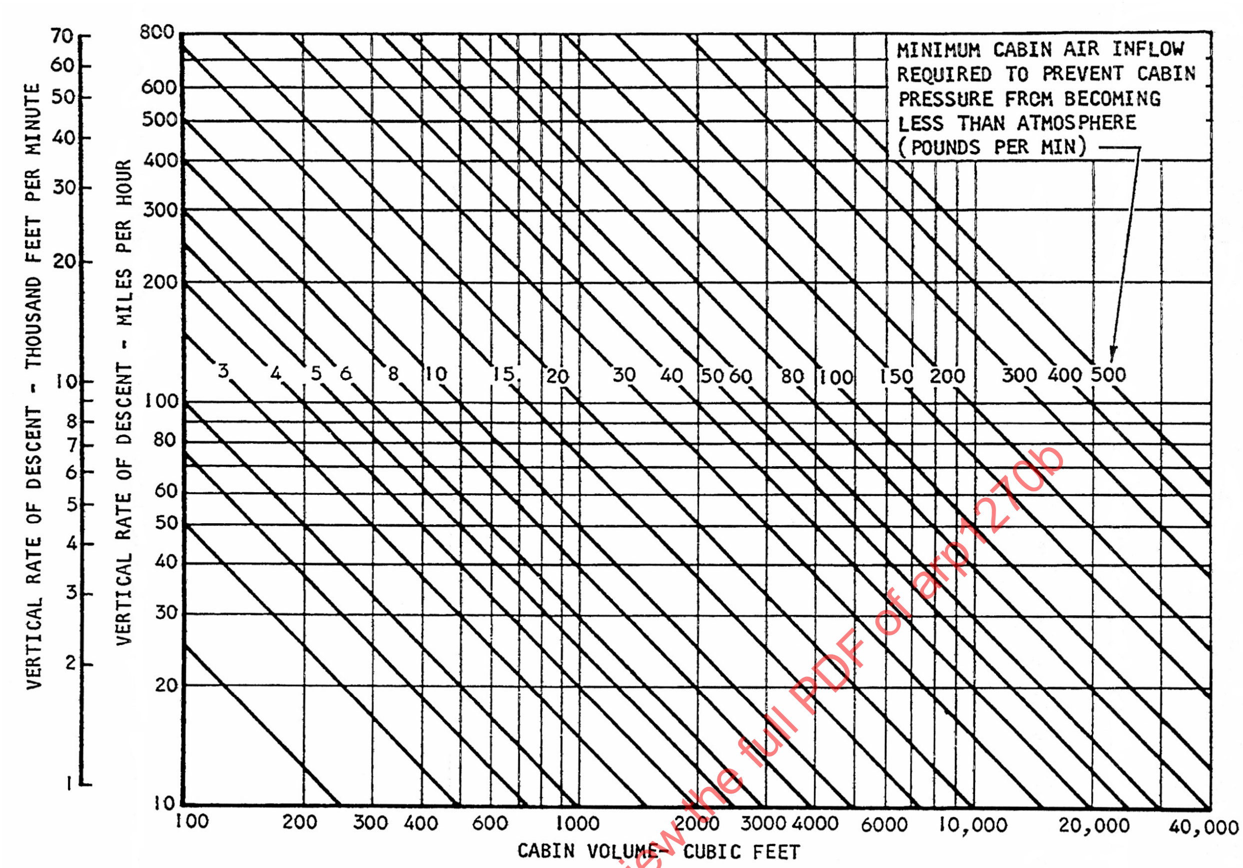

FIGURE 8 - MINIMUM CABIN AIR INFLOW REQUIRED TO PREVENT CABIN PRESSURE FROM BECOMING LESS THAN AMBIENT

For cabin pressure altitudes below 11 000 m (36089.24 FMSL), which should always apply, the following equation may be substituted for P_C:

$$P_C = 101.325 \times \left(1 - 2.25569 \times 10^{-5} \times H\right)^{5.25616} \text{, kPa} \quad \text{(Eq. 7a)}$$

where:

H = Cabin Pressure Altitude, m

In USCS units, this relation is:

$$P_C = 14.695949 \times \left(1 - 6.87535 \times 10^{-6} \times H\right)^{5.25616} \text{, lbf/in}^2 \quad \text{(Eq. 7b)}$$

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.

4.4 Control, Indication and Annunciation

4.4.1 Normal Automatic Controls

The operating controls are included on 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 functions 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

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 independant automatic systems.

4.4.2 Manual Controls

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 Cabin Pressure Altitude Increase/Decrease

c. Manual Cabin Pressure Rate of Change

d. Cabin Pressure Dump

Operation and range of these controls will depend on the specific CPCS and aircraft design. Manual override control shall be accomplished with minimal crew actions and should not require continuous crew attention.

The selection range of manual controls shall be at least as great as provided by any automatic function. The selectable range of cabin pressure altitude control shall be from at least -305 m (-1000 ft) to the highest approved airplane operating field elevation. For aircraft intended for operation from airfields above 3048 m (10 000 ft), the upper range of isobaric cabin altitude adjustment may be as high as 4240 to 4420 m (14 000 to 14 500 ft). The maximim 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 shall be 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 can be provided by the automatic system. The crew shall be 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 shall be accomplished with the minimum number of crew actions possible and should not require continuous crew attention.

4.4.3 Indication

The following indications shall be 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 EICAS. The indications shall show the caution and warning ranges, amber for caution and red for warning. CPCS operating mode, if Normal, need not be displayed on the EICAS, 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 shall be continuously displayed on the CPCS control and indication panel and/or the EICAS, if crew awareness or action is required.

Additional indications may be provided at the flight engineer station or on synoptic pages of the EICAS:

a. Outflow and Safety Valve Positions

b. Maintenance Fault Codes

The resolution of any indication shall 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 shall be provided by means independent of those used for automatic control.

4.4.4 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 (10 000 FPA). However, for operation from airfields above 3048 m (10 000 ft) the Cabin Altitude High Warning annunciation shall be shifted, since the aircraft takes off with the cabin presure altitude at or near the field elevation. Methods used in the past to shift this annunciation to a higher altitude, generally 4420 m (14 500 FPA), are:

a. For manual systems - a manual cockpit switch that shifts the warning altitude from 3048 to 4420 m (10 000 to 14 500 FPA).

b. For automatic systems - logic within the controller that detects when the planned take-off or landing field elevation is above 3048 m (10 000 FPA) and shifts the warning altitude from 3048 to 4420 m (10 000 to 14 500 FPA).

Since Part 23 and Part 25 require the Cabin Altitude High Warning to be no higher than 3048 m (10 000 FPA), a Finding of Equivalent Level of Safety is required for approval of this cabin altitude warning shift.

Annunciation shall be 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 overpresurization 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.

4.5 Maintenance Functions

4.5.1 Built In Test

Simple pneumatic systems have no Built In Test (BIT) functions. All fault detection is provided by the indications and annunciations listed in 4.4.3 and 4.4.4.

Electronic systems can provide as much BIT as can be economically designed into the system. BIT for the current automatic electronic systems falls into the following categories:

a. POST - "Power On Self Test"- Tests CPCS on system power up. Note that power interrupts can occur at any point in time (including in flight), so mechanical tests that slew valves open and closed are not recommended for this type of BIT.

b. CBIT - "Continuous BIT" - System operation and validity of external signals are continuously monitored. System status indication is continuously available and faults are immediately reported to the annunciation system and/or stored in the Maintenance Data Acquisition Unit (MDAU).

c. 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.

d. Maintenance Mode - A selectable operating mode that allows performance of certain functional tests. May interfere with normal operating modes.

4.5.2 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 shall then be 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.

4.5.3 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 shall be maintained. Reprogramming and software version verification can usually be accomplished via the aircraft's central maintenance system.

4.6 Interface with Other Systems

All external inputs and outputs are dependent on the CPCS design. Except for power inputs, they are in the form of pneumatic signals, switched discrete or analog electrical signals or digital electronic data.

4.6.1 CPCS Inputs

a. Power Inputs - Electrical, Pneumatic, Vacuum

b. Control Inputs - System Operating Mode, Cabin Pressure Altitude, and Rate of Change, Dump Command

c. Data Inputs - Aircraft Altitude and Climb Rate, Throttle Position, Baro Correction, T/O and Landing Field Elevations, Static Pressure

d. Systems Inputs - WOW, Inflow and ECS System Operation, Cabin Door Status

4.6.2 CPCS Outputs

a. Data Outputs - CPCS Status, Faults, Annunciations, Maintenance Messages, Cabin Pressure Altitude and Rate of Change

b. Control Outputs - Passenger Oxygen Mask Autodeploy, Cabin Altitude High Warning Annunciation Inhibit for high altitude airfield operation

4.7 Tolerance Analysis

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 varies 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 Nonrepeatability - variation in operation that is intrinsic to the design, due to hysterisis, vibration and other environmental effects that can not 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 ft) resolution, shall be tolerated. Random variability may be present in all inputs and shall be 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 shall be accounted for in design, development and approval of a CPCS:

a. Effective Cabin Volume - varies with quantity of passengers and cargo carried. 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 5486 m (18 000 ft), operating rules require altitude indication to be based on the pressure altitude. At altitudes below 5486 m (18 000 ft), 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. Because the geopotential and pressure altitude calculations are not corrected for air temperature, the indicated altitude can differ from the actual altitude by hundreds of feet at extreme high or low air temperatures. A CPCS can compensate for this for ground operation, takeoff and climb by basing the prepressurization and climb pressurization schedule on the measured field pressure altitude.

5. EQUIPMENT DESIGN REQUIREMENTS

A CPCS usually consists of several components, each with its own technical requirements. Consideration shall be given to the individual technical component requirements to ensure that they are complementary, and the overall system requirements are satisfied.

The simplest CPCS includes an outflow valve calibrated to control the cabin pressure to a constant cabin-to-ambient differential pressure and safety valves used to prevent aircraft structural damage should the outflow valve fail.

5.1 General Design Requirements

5.1.1 Static Pressure Systems

Static sensing ports shall be located in areas where airplane airspeed, attitude, external configuration, icing, or operation of other systems will not adversely affect the accuracy of the static signal. However, a primary factor in selection of a general location for static ports is proximity to the Outflow/Safety Valves to minimize plumbing length and weight and potential for moisture traps. Small changes in static port location can have considerable effect on static pressure error. Static pressure error can cause shift in setpoints of relief and outflow valves, resulting in nuisance illumination of "Cabin Altitude High" and "Over Max Differential Pressure" annunciators, erroneous maintenance messages and/or operation above redline on the Cabin Differential Pressure and Cabin Altitude indications.

Static error for external static ports may vary with airspeed and airplane angle of attack. Ice protection may be required for static ports located on the forward fuselage. External static ports will generally be located low on the fuselage, to enhance natural drainage of moisture and shall be located where they can be inspected during pre-flight for obstructions. If blockage of static plumbing or external ports is possible, it may be necessary to provide duplicate plumbing and ports. To minimize effects of aircraft yaw, it may be necessary to locate duplicate ports in a symmetrical arrangement on left and right sides of the aircraft.

Internal static ports located in an unpressurized nose compartment, wing fairing or tailcone offer some advantages over external ports. They are not prone to icing or blockage from foreign objects (insects, bird droppings, road grit, etc.). Screens on the internal ports also help identify the port as a deliberate opening, rather than an uncapped fitting. Internal ports have the disadvantage of being affected not only by airspeed and angle of attack but also by operation of other systems in those compartments, such as wheel well doors, ventilation systems, etc.

Static ports shall not be located in wheel wells or any other area where slush, snow or mud thrown up by the tires can cause blockage. Static ports shall not be located where they can be blocked by drainage of moisture or other fluids from system or airframe drains or vents. Static ports should not be located in a CPCS valve exhaust duct, because of the potential instability this can cause in the CPCS valve operation. Static ports should not be located in an ECS exhaust duct, because of the potential for interaction between the CPCS valve and ECS operation. All static ports, whether internal or external, shall be labeled as to their function and their need to kept clear.

All static lines shall be routed in such a manner as to prevent water traps and drainage toward valves where the freezing of condensation could affect operation of the CPCS. Their design shall be to the same standards as the aircraft primary static pressure system. Location of the static ports to act as natural drains for the system is recommended. Addition of manual drains to long plumbing runs with traps, to be actuated during preflight walkaround or for periodic maintenance is not recommended. They may be inaccessible on large aircraft and may be ineffective unless provided with heaters to ensure the accumulated moisture is liquid and drainable. A CPCS static system can share static ports with other systems only if it can be shown there is no interaction between the CPCS and the other systems and that there are no unacceptable common failure modes or conditions caused by the sharing. Redundant cabin pressure relief valves should have completely separate sensing ports from the aircraft static system and from each other to preclude duplicate malfunction due to line leakage or blockage.

5.1.2 Electrical

If the CPCS or its components use aircraft electrical power, the CPCS shall be designed to tolerate normal power variations, including interruptions, voltage and frequency variations and voltage spikes, without significant effect on the aircraft or occupants. Complete loss of function of the CPCS is acceptable for the duration of an interruption as long as the resulting condition is safe. Following restoration of electrical power, the CPCS should resume operation with no crew attention, no fault annunciations (except to indicate that normal CPCS status has been restored) and minimum upset from its previous operating condition. For power variations that cause no detectable loss of CPCS function, it is recommended that any "CPCS Fail" annunciation or maintenance messages be inhibited.

Likewise, if the CPCS uses data signals from other aircraft systems, it shall be designed to tolerate data signal loss for whatever duration is normal for the aircraft data bus system, without significant effect on the aircraft or occupants. Following restoration of data signals, the CPCS should resume operation with no crew attention and minimum upset from its previous operating condition. The CPCS shall be designed to tolerate short duration data signal loss that causes no detectable loss of CPCS function without annunciating a fault or generating a maintenance message. Sustained data signal loss for a duration that has a detectable effect on CPCS operation, or requires crew action shall be annunciated (and logged by the MDAU, if installed).

If the CPCS has multiple channels, such as an automatic primary and a manual secondary channel, each control path shall be provided with an independent power source. Similarly, if ability to shut off inflow is intended as a mitigation for complete loss of cabin pressurization control, the power source for the shutoff controls shall be independent from the cabin pressurization controls.

5.1.3 Software and Complex Electronic Devices:

The criticality of the function provided by software determines its classification per RTCA DO-178. The expense and time required to validate the software increases greatly with the criticality of the function it provides. Consequently, it is desirable to keep any software used by a CPCS to the lowest possible level of criticality.

Some aspects of CPCS operation can only be verified by operation on an aircraft installation. Parameters that are likely to change from the initial design phase to the final certified configuration are:

a. Cabin climb and descent rate schedules

b. Power supply and data signal dropout duration

c. Static position error corrections

d. Display lighting levels and dimming schedules

If particular values for any of these parameters are validated as part of the core code, any change may require revalidation of the core code. For any parameter that is likely to change as part of the CPCS/aircraft development and certification process it is desirable to validate the software for the entire range of values expected for these parameters and to partition the core code from these variable parameters.

Complex electronic devices, such as Field Programmable Gate Arrays (FPGAs), Programmable Logic Devices (PLDs), and Application Specific Integrated Circuits (ASICs) require classification and design assurance validation per RTCA DO-254 or other approved industry standard. As with software, the validation effort increases greatly with the criticallity of the function the device provides.

5.1.4 Qualification

Qualification test requirements for cabin pressurization control equipment shall be specified based on the applicable tests defined by MIL-STD-810 or RTCA DO-160 or other accepted industry standards. The specific tests and test levels will defined by the airframe manufacturer responsible for approving that equipment.

MIL-STD-810 notes that the prefered method to determine the equipment installed operating environment for qualification testing is by measurement during flight testing of the complete aircraft at the critical environmental conditions. If this is not possible, MIL-STD-810 and RTCA DO-160 also provide predefined standardized environmental test levels, based on equipment location in the aircraft (such as whether it is inside or outside the pressure vessel), type of aircraft (jet or turboprop) and approved aircraft operating conditions (temperature and altitude). For components located at a boundary between two environments, the more severe qualification environment should be used. For example, if an outflow valve is installed on a pressure bulkhead inside the pressure and temperature controlled environment, it should be qualified to environmental requirements appropriate for equipment installed in the uncontrolled environment on the other side of the bulkhead.

If CPCS equipment is qualified to predefined standardized environmental requirements, 14 CFR/CS 23.1301(c) & 25.1301(c) require verification that the equipment has been qualified to levels at least as severe as the installed environment.

5.2 Valves

All cabin pressure control systems incorporate a valve or valves which regulate the cabin overboard flow rate (the cabin inflow minus leakage) to control the pressure inside the cabin.

CPCS valves can have any combination of these basic functions:

a. Outflow Control

b. Cabin Altitude Limiting

c. Differential Pressure Relief

d. Reverse Differential Pressure Relief

e. Cabin Pressure Dump

To comply with Civil Type Certification rules, the minimum number of valves required to provide all of the essential functions is two. At least two valves shall provide Differential Pressure Relief. At least two valves shall provide Reverse Differential Pressure Relief, unless a single valve can be shown to be sufficiently reliable. Except for a simple cabin altitude limiter CPCS, at least one valve shall provide Outflow Control. While other means of rapidly equalizing cabin pressure may be possible, use of at least one valve to provide Cabin Pressure Dump function is predominant. For aircraft to be approved for operation above 7620 m (25 000 ft) the aircraft shall be able to maintain a cabin pressure altitude of no more than 4572 m (15 000 FPA) following any probable failure or malfunction in the CPCS. If the CPCS failure or malfunction on these aircraft can cause Outflow, Differential Pressure Relief or Dump valves to dump cabin pressure to an altitude above 4572 m (15 000 FPA), it will be necessary to equip these valves with a Cabin Altitude Limiting function.

In the following sections dealing with the sizing and design of valves, valves having multiple functions shall be sized for whichever function results in the greatest flow area. For valve installations where a function is shared or duplicated by several valves, the total flow area of all of the valves performing this function shall be considered in the sizing of the individual valves. In determining which valves having a particular function are active, a thorough Failure Modes and Effects Analysis of the CPCS and all other aircraft systems that can affect operation of the CPCS shall be performed. For sizing of Differential Pressure Relief valves, one of the two required valves shall be assumed failed. For sizing of Outflow Control valves, all valves that perform this function shall be assumed active, to ensure the CPCS is optimally tuned for the outflow area available in normal aircraft operation.

For valve installations that use exhaust ducts, each valve shall be provided a separate duct, to minimize possibility of interaction between valves and preclude possibility of simultaneous malfunction of multiple valves due to blockage of a common outlet. CPCS valves should not have common outlets with ECS or other air duct systems, due to potential for interaction between the CPCS valve and the other airflow sources. Outlet louvers shall be visible for inspection during preflight walkaround and provided screens or closely spaced lovers to prevent obstruction by nesting birds. Ground plugs are a less desirable alternative, because of possibility that plugs will not be used, even if provided and that plugs may inadvertently be left in the outlet for flight. All valve exhaust ducts shall be provided with moisture drains, unless they are self draining through the outlet. The valve shall not be located at a trap location or low point in an exhaust duct, even if it is provided with drains. Blockage of a moisture drain can result in accumulation of water that can freeze and disable the valve. If water can become trapped on one side of a normally closed valve, such as a reverse differential relief valve, operation of the valve can allow the water to run back into the cabin, damaging upholstery, furnishings, equipment, etc. For aircraft intended to be approved for ditching, any CPCS valve that can be opened by the water loads should be located above the water line or provided with some means to command them closed for ditching.

Valve exhaust air inlets within the cabin shall be designed and located to preclude blockage or jamming by baggage, coats, insulation or debris. Consideration shall be given to potential interiors and seating modifications that can adversely affect valve airflow. SAE AIR1168/7 also addresses the potential for collapse of ducting connected to outflow valves within the pressure vessel due to rapid cabin decompression.

5.2.1 Outflow Valves

5.2.1.1 Outflow Valve Sizing

Outflow Control valves are rarely sized solely for the amount of air they are required to modulate to control cabin altitude and rate of climb. Since it is desirable for the CPCS to smoothly transition from dump (ground operation) to flight (modulate) operation with a minimum of cabin pressure bumps, the Outflow Control valve is usually sized and operated as a dump valve, so that cabin pressure and rate of change are continuously controlled. CPCS that functions by passing control between valves for different phases of operation may be more difficult to make operate smoothly.

Outflow Control valves require a certain minimum flow to modulate in order to smoothly control cabin pressure and rate of change. This amount will be in addition to the airframe leakage and the valve closed leak rate. The minimum required Outflow Control valve flow will vary with valve design and shall be established early in an aircraft/CPCS development program, since this may be one of the key parameters that establishes allowable airframe leak rate and required pressurization inflow rate schedules.

5.2.1.2 Outflow Valve Design and Installation

The outflow valve shall be designed to permit complete pressure control at full design differential with one air inflow source.

Outflow valve design should minimize both the accumulation of tars, dirt, etc and the effect of any such accumulations on operation. They shall also be easily cleanable.

Systems that have two or more outflow valves shall be able to permit complete pressure control over the full pressurization design range with all inflow sources operable and one outflow valve inoperative. This capability enhances aircraft dispatchability and safety.

Outflow valve location has an effect on the airflow distribution within the airplane. Location of the outflow valve(s) at one end of the cabin can cause poor distribution of the cabin airflow, with higher than desired air velocities (drafts) at the end of the airplane near the valves, and less than required airflow at the extreme opposite end. Air collection ducting, and use of the under-floor area as a collection center have been useful in minimizing this effect.

Outflow valve acoustic noise levels shall be considered in the location of the valves within the cabin. Acoustic treatment of the valves may be required due to the high velocities of the air exiting through the valve, especially in small cabin aircraft where the outflow valve is near the airplane occupants.

The outflow valve exit characteristics are highly affected by the slipstream effects and local ambient pressure. Gross changes in the local ambient pressure may cause cabin pressure transients. This phenomenon is especially critical at rotation, during the airplane take-off roll. The location of the outflow valve with regard to unstable or inconsistent local ambient pressure effects shall be considered. Wakes from variable surfaces (control elements, landing gear and thrust reverses) shall be avoided. Spoiler devices may be utilized during flight regimes where variable local ambient pressure conditions cannot otherwise be avoided by proper location of the valves.

For outflow valve installations that exhaust into the nose compartment, wing fairing or tailcone, exhaust ducting from the valve to the exterior of the aircraft should be provided. If exhaust ducting can not be provided, the potential effects of condensation and freezing of the relatively humid cabin air moisture on structure, flight controls, electrical systems, etc in that compartment shall be considered. The constant flow of cabin air can result in accumulation of considerable amounts of moisture in these compartments.

If thrust recovery outflow valves are not used, the exhaust air from the outflow valve can be used for ventilation and heating of an unpressurized compartment. The outflow valve can also be located and installed so that all air entering the valve is first drawn through an avionics cabinet, providing backup cooling in the event of avionics blower failure. As long as the additional pressure drop through the cabinet is not excessive, this additional cooling is free and aids in rejecting the hot exhaust air from the avionics cabinet directly overboard.

5.2.2 Cabin Altitude Limiting

For civil aircraft to be approved for operation above 7620 m (25 000 ft), the aircraft shall be able to maintain a cabin pressure altitude of no more than 4572 m (15 000 FPA) following any probable failure or malfunction in the Pressurization Systems. If the CPCS design is such that all probable failures that could cause cabin pressure to dump come from a pneumatic Cabin Pressure Controller, the Cabin Altitude Limiter can be implemented as a separate valve between the Controller and the Outflow/Safety/Dump valves. The Cabin Altitude Limiter valve intercepts and overrides any Controller command to dump cabin pressure to an altitude above 4572 m (15 000 FPA). A Cabin Altitude Limiter valve can also be integrated into each Outflow/Safety/Dump valve that requires this function. While this may be only a packaging choice (fewer separate components means less weight, cost, plumbing, etc), the particular CPCS design may require limiter integration into the Outflow/Safety/Dump valve to enable the limiter to override dump commands from other CPCS components, or failures that originate from within the Outflow/Safety/Dump valve.

5.2.3 Safety Valve Sizing and Design

Special purpose valves shall be included in the CPCS to prevent damage to the aircraft structure due to excessive pressure differentials. Two or more cabin positive pressure relief valves, sometimes called safety valves, shall be provided. These valves are normally closed. Safety valves shall be independent of each other and static pressure plumbing shall be independent of all other static pressure systems.

Outflow control valves may also function as safety valves, if suitable differential pressure limiting controls are provided for them.

The valves shall be sized to permit control of differential pressure at the defined structural limit and at the maximum flow conditions. The maximum flow condition should be based on one of the relief valves being closed, the aircraft climbing at maximum rate, and the maximum normal cabin inflow. Failure conditions in the inflow system that could result in greatly increased inflow rates may also have to be considered.

The maximum flow capacity of each of the safety valves shall be based on the lowest altitude at which it is possible to reach the safety relief setting assuming complete failure of the outflow valve(s). This could be any altitude between sea level and the flight level at which maximum pressure differential is obtained. It should be noted that the flow which passes through the valve is increased when the airplane is climbing.

5.2.4 Negative Differential Pressure Relief

Negative pressure relief shall be provided to protect the airplane from excessive negative pressure. This feature is sometimes included in the safety valve and sometimes included as part of a cabin door design. Two negative pressure relief valves are required unless the design is simple enough to reasonably preclude malfunction. A swing check device is considered simple enough to meet the single valve requirement. Location of the valves for negative relief shall be such that aircraft ditching does not allow water flow into the cabin. Incorporating ditching overrides into negative relief valves located below the water line is cumbersome and proper valve location can minimize interface requirements and flight crew actions in the event of a ditching situation.

The negative pressure relief valve flow requirements shall be based on either emergency rate of descent with an unpressurized airplane with zero cabin inflow or the maximum fuselage structural opening at the most negative pressure location on the pressure shell. Careful consideration should be given to inlet pressure losses, local static pressure conditions and the ambient airstream when arriving at final sizing. The negative pressure relief valve flow requirements can be calculated with the equations in 4.3.6.

Negative differential pressure relief check valves are commonly incorporated into fresh air ventilation systems on small aircraft. In this case the check valve receives ambient air through some type of ram scoop, to cause positive ventilation when the aircraft is operated unpressurized. When the aircraft is intended to be operated pressurized it is assumed that cabin positive differential pressure will keep the check valve closed. However, at rotation and during climbout, the ram air pressure on the check valve may exceed the cabin differential pressure, allowing the check valve to pop open or flutter between open and shut. This can cause unpleasant cabin pressure bumps, noise and drafts of untempered ambient air. As for ditching considerations, a manual or automatic override can be added to the ram air check valve. This override shall not override the negative differential pressure relief function of the valve. A better solution may be to provide the fresh air ventilation system with a manual shutoff valve and to add a separate negative differential pressure relief check valve that is in an aerodynamically neutral or slightly pressurized location.

5.2.5 Dump Valves

The dump valve(s) shall be sized for unpressurized operation by considering the maximum amount of cabin air inflow, the effective flow area of other outflow valves and openings, the range of landing field expected during operation, the door opening requirements and the pressure transient occurring when the last cabin door is closed. Typically, small aircraft are designed for a cabin-to-atmosphere differential pressure of 0.73 kPa (200 SLft) or less for ground operation with full air inflow rate to the cabin. Military aircraft are designed with ground differential pressures as high as 3.45 kPa (0.5 lbf/in^2) while on the ground with full air inflow. Large aircraft are typically designed for the minimum practical cabin-to-atmosphere ground differential pressure during ground operation -- usually approximately 0.37 kPa (100 SLft) with full air inflow.

The dump valve effective area required to provide a specified cabin residual pressure differential at a steady inflow rate can be calculated from the following equation:

$$CA = 6.452 \times \dot{m} \times \sqrt{\frac{T_C}{P_C \times \Delta P}} \quad , \text{cm}^2 \qquad \text{(Eq. 8a)}$$

where:

C = Valve or Opening Discharge Coefficient

A = Valve or Opening Area, cm^2

$\dot{m}$ = Gravimetric Air Mass Flow Rate, kg/min

T_c = Cabin Air Temperature, K

P_c = Air Pressure Inside Cabin, kPa

ΔP = Pressure Drop Across Valve or Opening, kPa

For USCS units, this relation is:

$$CA = 0.006944 \times \dot{m} \times \sqrt{\frac{T_C}{P_C \times \Delta P}}, \text{ in}^2 \quad \text{(Eq. 8b)}$$

where:

C = Valve or Opening Discharge Coefficient

A = Valve or Opening Area, in^2

$\dot{m}$ = Gravimetric Air Mass Flow Rate, lbm/min

T_c = Cabin Air Temperature, °R

P_c = Air Pressure Inside Cabin, lbf/in^2

ΔP = Pressure Drop Across Valve or Opening, lbf/in^2

This equation is a simplification of the compressible flow equations and is sufficiently accurate as long as ΔP does not exceed 10% of P_c (when both are expressed in the same units).

If dump valve function can be disabled by loss of a power source so that the only way to depressurize the cabin is by shutting off all inflow, it may be necessary to provide alternate power sources or depressurization means, such as a simple mechanical dump valve. If unattended ground operations with Ground Air Cart or APU is to be approved, means shall be provided to ensure the aircraft can not inadvertantly become pressurized. Possible methods are:

a. Interlock between the CPCS and the inflow control valves that prevent inflow unless CPCS is powered and in dump mode.

b. Addition of a mechanical dump valve.

5.2.6 Isolation Valves

Isolation valves may be required if a portion of the pressure vessel is located within the engine rotor non-containment zone and this area is isolated from the main cabin by a secondary pressure bulkhead. Typical applications for this type of valve are mid-sized airplanes with aft mounted engines with the primary aft pressure bulkhead located within the engine rotor non-containment zone. A secondary pressure bulkhead is added forward of the engine rotor non-containment zone and the bulkhead is equipped with a normally open, fast-acting valve that automatically closes on sensing pressure altitude in the aft compartment rising through 4572 m (15 000 FPA). The space between the bulkheads is used for baggage. The valve allows for heating, cooling and pressure equalization of the baggage compartment, which enable baggage access in flight.

If the outflow and safety valves are located on the primary aft pressure bulkhead, all outflow air has to pass through the Secondary Pressure Bulkhead Shut-Off Valve. This requirement sizes the isolation valve. In addition, this valve shall be designed so that it can not inadvertently close and cause risk of cabin overpressurization, or else the Secondary Pressure Bulkhead shall be provided with just enough normal leakage to prevent excess cabin differential pressure at the maximum inflow rate.

5.3 Cabin Pressure Controller Design

The unit which receives the input signals from the altitude selector and provides an output signal for control of the outflow valves is commonly called the cabin pressure controller. For pneumatic systems, the altitude selector and controller functions are often incorporated in a single unit mounted in the crew compartment. For this type of controller the input selections provide mechanical adjustments to the pneumatic controls and the output signal is in the form of pressure. For systems using electronic controllers, the controller may be integrated with the Cabin Pressure Control Panel, integrated with the Outflow Control Valve or separate and remotely located, using electrical input and output signals. The remote electronic controller may be integrated within a single unit performing other similar control functions. The remote controller packaging may also allow it to be installed in a more protected environment in the aircraft.

5.4 Cabin Pressure Control Panel Design

Aircraft cabin pressure control systems can be categorized as either fixed or variable isobaric systems. These terms relate to the basic purpose of cabin pressure control, which is to regulate cabin pressure to a constant altitude at a safe level independent of aircraft flight altitude. Fixed isobaric systems do not incorporate a means for selection of the isobaric altitude. These systems always limit cabin altitude at the same level and the cabin is allowed to climb with the aircraft up to this level. Fixed isobaric systems are generally used on military fighter aircraft where freedom from crew attention is imperative and comfort is a secondary consideration.

Variable isobaric systems incorporate an altitude selector permitting either the flight crew to vary the selected isobaric cabin altitude or the automatic control logic to vary the isobaric cabin altitude based on the flight plan and aircraft structural pressure differential limitations. The selector is mounted in a location accessible to the flight crew. The face panel of the selector is provided with control knobs and indicator scales for adjustment of the isobaric altitude. Also, depending on the type and sophistication of the control system, a knob and scale may be provided for limitation of cabin pressure rate of change and for making correction for variation of the landing field barometric pressure, for outflow valve position indication and balancing control, for switching between system operating modes, for safety warning lights, etc. The altitude selector is the instrument whereby crew inputs are relayed to the cabin pressure control system. The altitude selector may be integrated within a single unit performing other similar crew interface functions.

6. SYSTEM DYNAMIC ANALYSIS AND TEST

6.1 Dynamic Analysis

As part of the cabin pressure system design process, a dynamic analysis of the system and its constituent components should be performed. Operation of the planned design can then be simulated to verify the desired system operation before prototype hardware is manufactured.

Once the design is verified by analysis, prototype hardware should then be tested in a laboratory simulation. Such tests are usually conducted in a test facility where air pressures and flow rates can be precisely controlled.

The computer simulation serves to predict the detailed transient response and stability margin of the system. The simulation offers the following benefits, ultimately reducing the cost of laboratory testing.

a. Detailed system characteristics may be varied to explore their effects on the total system performance.

b. Nonlinearities in system components may be simulated.

c. Effects of actual aircraft flight profiles and operational procedures may be simulated with results directly comparable to flight performance.

d. Saturation levels of the system components may be simulated and the effects of the saturation levels on the system's ability to control cabin pressure.

6.2 Test

Once the computer simulations confirm the desired performance characteristics of the system, it is desirable to test prototype hardware in a simulated environment, prior to full system testing. In a typical laboratory tank-test facility, a large tank is divided into two control volumes to simulate the aircraft installation: an ambient chamber; and a cabin chamber. Separating the two chambers is a bulkhead that serves to simulate the aircraft skin. Outflow valves and relief valves may be mounted on the bulkhead to provide variable fluid communication between the cabin and ambient chambers. Generic computers can be programmed with the system control laws and the system performance can be tested. By varying the pressure in the ambient chamber and the inflow into the cabin chamber, aircraft flight profiles may be simulated. This hardware-in-the-loop testing allows rapid verification of system control laws.