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(R) Aircraft Cabin Pressurization Criteria		

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TABLE OF CONTENTS

1.	SCOPE.....	4
1.1	Purpose.....	4
2.	REFERENCES.....	4
2.1	Applicable Documents	4
2.1.1	SAE Publications.....	4
2.1.2	American National Standards Institute Publications.....	5
2.1.3	European Aviation Safety Agency Publications.....	5
2.1.4	Federal Aviation Administration Publications.....	5
2.1.5	NACA Publications.....	5
2.1.6	Radio Technical Commission for Aeronautics Publications	6
2.1.7	U.S. Government Publications.....	6
2.2	Applicable References	6
2.3	Definitions	6
2.4	Terminology	7
2.5	Standard Atmosphere Definition	9
2.5.1	Standard Atmosphere Up To 11 000 m (36,089.24 ft)	9
2.5.2	Standard Atmosphere From 11 000 m to 20 000 m (36 089.24 ft to 65 616.80 ft).....	10
2.6	Units & Conversion Factors	11
3.	SYSTEM DESIGN PHILOSOPHY	12
3.1	Background	12
3.2	Types of Cabin Pressure Control Systems	13
3.2.1	Pneumatic System	13
3.2.2	Electronic System	15
3.2.3	Pneumatic/Electric Hybrid System.....	17
3.2.4	Electro-Pneumatic System.....	17
3.3	Safety	18
3.3.1	Overpressure Relief	19
3.3.2	Negative Pressure Relief	19
3.3.3	Built in Safety Limits.....	20
3.3.4	Ditching	20
3.3.5	Cabin Altitude Limiting	20
3.3.6	Cabin Pressure Dump.....	20
3.3.7	Cabin Pressure Dump on Landing.....	20
3.3.8	Prevention of Initiation of Pressurization If External Doors Are Not Closed, Latched and Locked	20
3.3.9	Isolation Valve	21
3.4	Physiological Design.....	21
3.5	Comfort	21
3.6	Crew Workload.....	22
3.7	Impact of Aircraft Operation on Cabin Pressurization	22
3.8	Reliability and Maintainability.....	22
4.	SYSTEM DESIGN REQUIREMENTS	23
4.1	Civil Regulations	23
4.2	Military Regulations.....	24
4.3	Civil Aircraft Performance Requirements.....	25
4.3.1	Pressure Level	25
4.3.2	Rate of Pressure Change	26
4.3.3	Dynamic Performance Requirements.....	27
4.3.4	Positive and Negative Pressure Relief	28
4.3.5	Ground Requirements.....	28
4.3.6	Minimum Cabin Inflow for Rapid Descents.....	29
4.4	Control, Indication and Annunciation	31
4.4.1	Normal Automatic Controls	31
4.4.2	Manual Controls	31

4.4.3	Indication	32
4.4.4	Annunciation	32
4.5	Maintenance Functions	33
4.5.1	Built In Test	33
4.5.2	Fault Isolation and Reporting	33
4.5.3	On Board Reprogramming and Configuration Control	33
4.6	Interface with Other Systems	33
4.6.1	CPCS Inputs	33
4.6.2	CPCS Outputs	34
4.7	Tolerance Analysis	34
5.	EQUIPMENT DESIGN REQUIREMENTS	35
5.1	General Design Requirements	35
5.1.1	Static Pressure Systems	35
5.1.2	Electrical	36
5.1.3	Software and Complex Electronic Devices:	36
5.1.4	Qualification	37
5.2	Valves	37
5.2.1	Outflow Valves	38
5.2.1.1	Outflow Valve Sizing	38
5.2.1.2	Outflow Valve Design and Installation	38
5.2.2	Cabin Altitude Limiting	39
5.2.3	Safety Valve Sizing and Design	39
5.2.4	Negative Differential Pressure Relief	40
5.2.5	Dump Valves	40
5.2.6	Isolation Valves	41
5.3	Cabin Pressure Controller Design	41
5.4	Cabin Pressure Control Panel Design	42
6.	SYSTEM DYNAMIC ANALYSIS AND TEST	42
6.1	Dynamic Analysis	42
6.2	Test	42
6.2.1	Multiple Outflow Valve Installation	44
6.2.2	Scaled Outflow Valve	44
6.2.3	Testing with Volumes Less Than a Scaled Simulation	45
6.3	Test and Analysis Validation	45
7.	PHYSIOLOGICAL EFFECTS OF CABIN PRESSURE	46
7.1	Respiratory Effects	46
7.2	Ear Discomfort	48
7.2.1	Types of Pressure Changes	48
7.2.1.1	Pressure Transients	48
7.2.1.2	Sustained Pressure Changes	48
7.2.2	Ear Physiology	49
7.2.3	Physiological Effects	51
7.2.4	Physiological Effects of Cabin Pressure Transients	52
7.2.5	Physiological Effects of Sustained Pressure Change	53
8.	NOTES	53
8.1	Revision Statement	53

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 Response to Rapid Recompression", Aerospace Assn Meeting, April 24-27, 1961

Speelman, 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

ΔP	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	Système 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:

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

where:

H = Pressure Altitude, m

In USCS units, this relation is:

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

where:

H = Pressure Altitude, ft

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

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

where:

P = Pressure, kPa

In USCS units, this relation is:

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

where:

P = Pressure, lbf/in²

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:

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

where:

H = Pressure Altitude, m

In USCS units, this relation is:

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

where:

H = Pressure Altitude, ft

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

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

where:

P = Pressure, kPa

In USCS units, this relation is:

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

where:

P = Pressure, lbf/in²

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 ↓	↓	↓	↓	↓	↓	↓	↓
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/cm³, with $g_c = 980.665 \text{ cm/s}^2$

In WG = Inches of Water (Gage), at 4 °C with a density of 1.000000 gm/cm³, with $g_c = 980.665 \text{ cm/s}^2$

mb = Millibar = Hectopascal = 100 Pascals

mm Hg = Millimeters of Mercury

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

HP = Hectopascal = 100 Pascal

lbf/ft² = Pounds per Square Foot

lbf/in² = Pounds per Square Inch

SL Standard Ambient Pressure:

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

$P_0 = 101325.0 \text{ Pa}$

By Conversion:

$$\begin{aligned}P_0 &= 760 \text{ mm Hg at } 0^\circ\text{C with a density of } 13.5951 \text{ gm/cm}^3, \text{ with } g_c = 980.665 \text{ cm/s}^2 \\&= 1013.250 \text{ mb (HP)} \\&= 101.3250 \text{ kPa} \\&= 29.92126 \text{ In Hg} \\&= 406.783 \text{ In WG at } 4^\circ\text{C with a density of } 1.000000 \text{ gm/cm}^3, \text{ with } g_c = 980.665 \text{ cm/s}^2 \\&= 2116.216 \text{ lbf/ft}^2 \\&= 14.695949 \text{ lbf/in}^2\end{aligned}$$

At Standard Conditions:

$$1 \text{ SLm/min} = 12.0 \text{ Pa/min}$$

$$1 \text{ SLft/min} = 0.0765 \text{ lbf/ft}^2/\text{min}$$

To convert feet to meters, multiply 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.

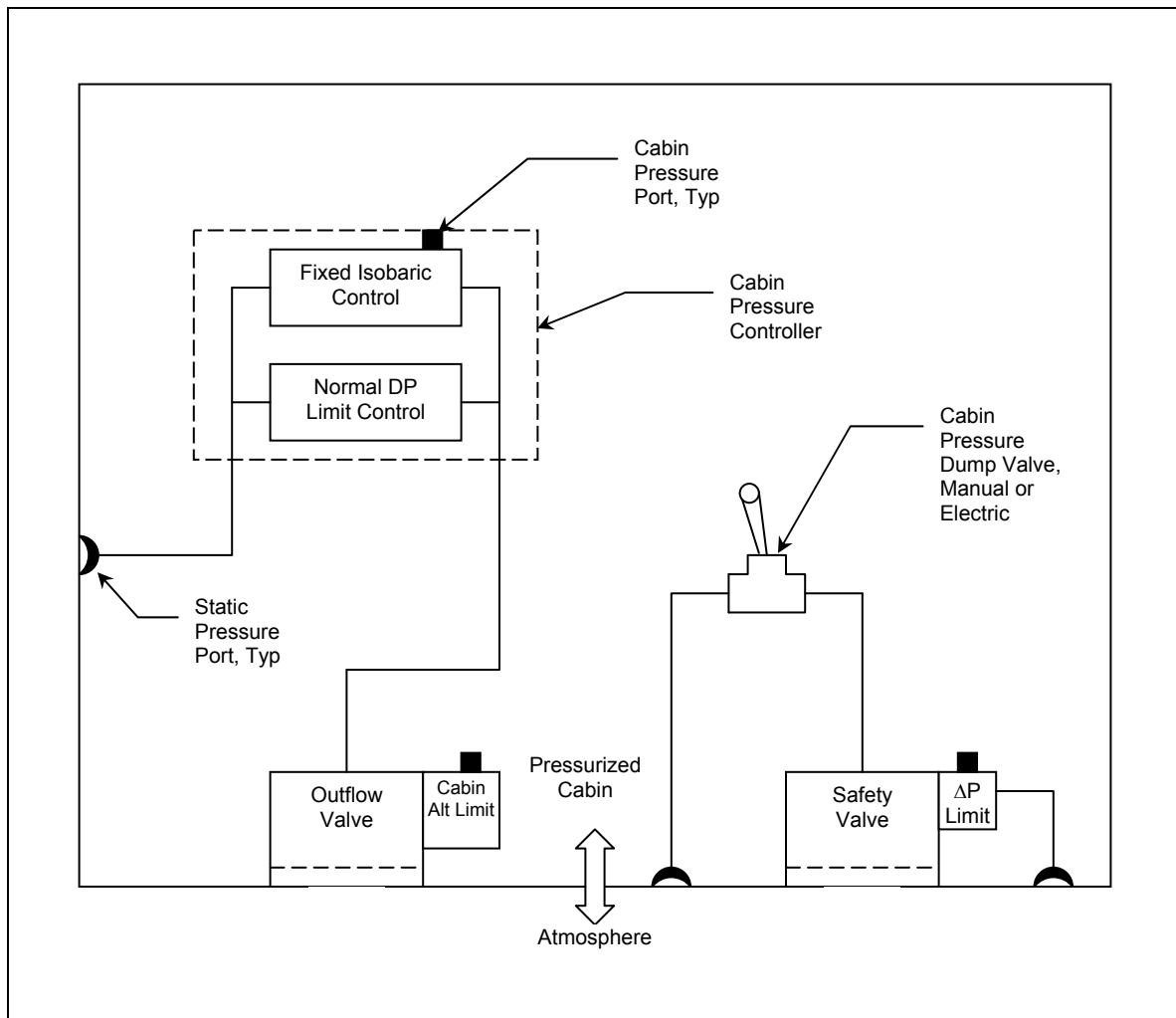


FIGURE 1 - FIXED ISOBARIC PNEUMATIC CPCS

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.

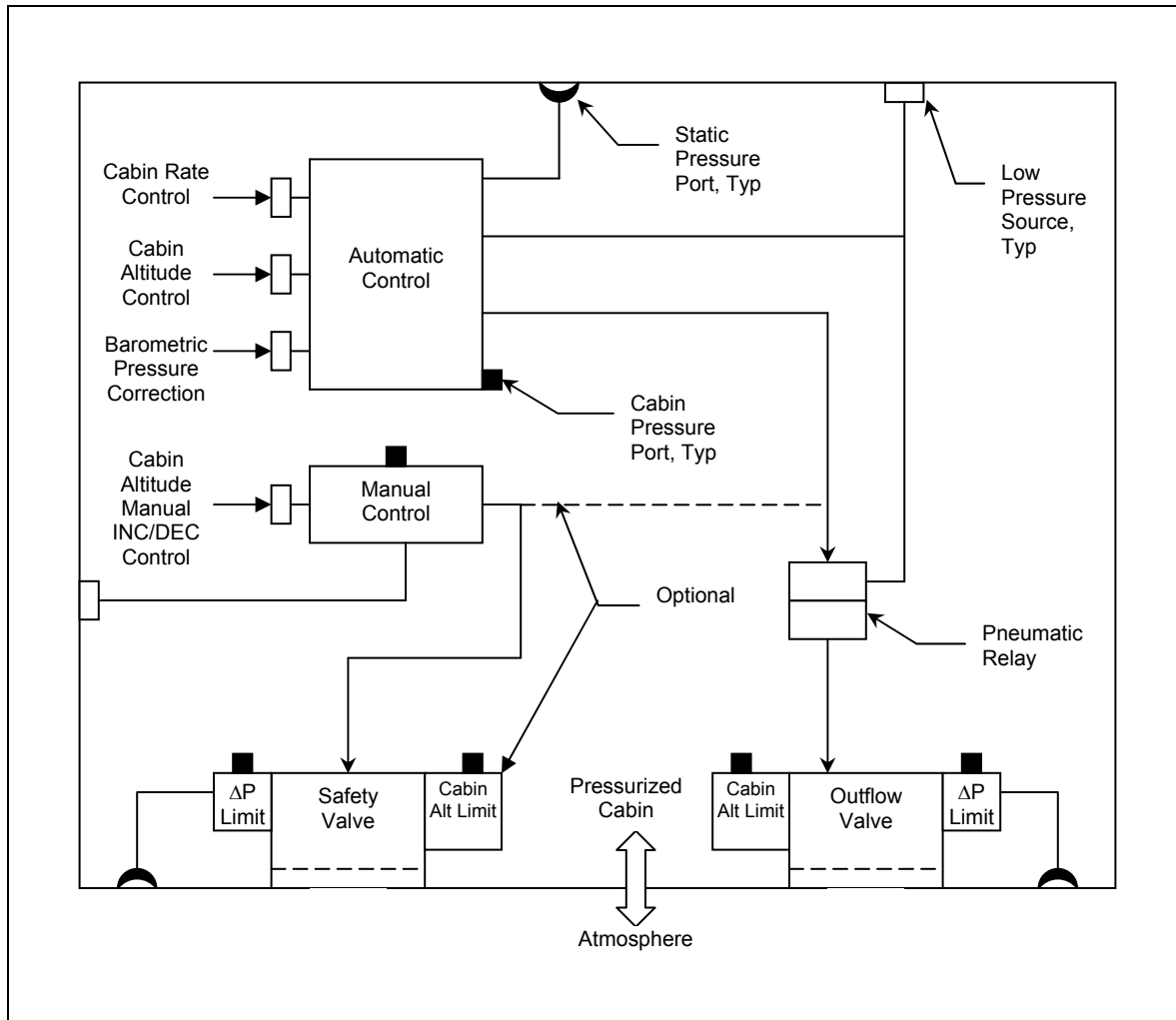


FIGURE 2 - VARIABLE ISOBARIC PNEUMATIC CPCS

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.

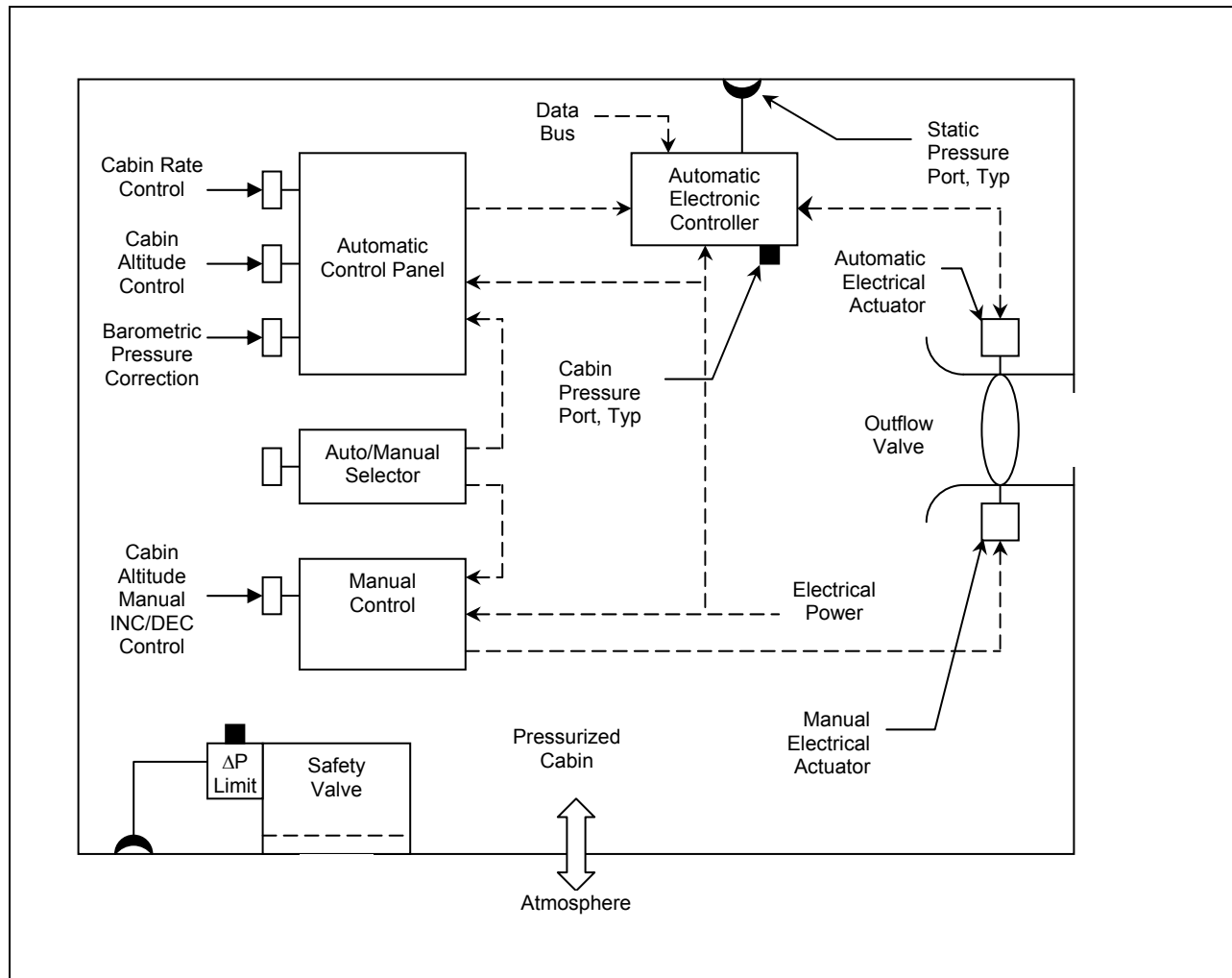


FIGURE 3 - ELECTRONIC CPCS

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.