



# AEROSPACE INFORMATION REPORT

**AIR5661™****REV. A**

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Superseding AIR5661

## (R) Compartment Decompression Analysis

### RATIONALE

This report provides data and analysis methods for calculation of internal and external airplane compartment pressures during rapid discharge of cabin pressure. This revision provides several clarifications and corrections. Overall scope and content are substantially unchanged from the previous revision.

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## 1. SCOPE

This SAE Aerospace Information Report (AIR) provides data and general analysis methods for calculation of internal and external, pressurized and unpressurized airplane compartment pressures during rapid discharge of cabin pressure. References to the applicable current FAA and EASA rules and advisory material are provided. While rules and interpretations can be expected to evolve, numerous airplanes have been approved under current and past rules that will have a continuing need for analysis of production and field modifications, alterations and repairs. The data and basic principles provided by this report are adaptable to any compartment decompression analysis requirement.

### 1.1 Purpose

The purpose of this report is to provide a method to predict transient differential pressures across internal pressure barriers (such as floor panels and bulkheads), within external compartments adjacent to the pressure vessel (such as fairings and tailcone) and the occupied compartment pressure altitudes resulting from cabin decompression events prescribed by FAA and JAA/EASA regulations and Special Conditions. The analysis methods in this report can be used as a design tool to determine the following:

- The maximum permissible openings in the pressure vessel from loss of antennae, duct couplings, seals, etc., that will limit maximum transient cabin pressure altitude to acceptable levels. If the pressure vessel opening can result from a fatigue crack, the allowable opening size may define the required structural inspection intervals.
- The minimum permissible vent openings through internal partitions and structure that will limit panel pressure differentials to structurally acceptable levels during decompression events.
- The minimum permissible vent openings through external fairings and structure that will limit panel pressure differentials to structurally acceptable levels during decompression events.
- The maximum permissible cockpit door weight and door unlatching pressure to limit cockpit partition loads to acceptable levels during a cockpit structure decompression.
- The airplane descent rate required to limit maximum transient cabin pressure altitude to acceptable levels during emergency descent, which may size lift dump and drag devices and their required extension/operating speed capabilities.

The analysis methods in this report can also be used as a validation tool for a specified aircraft configuration. Predicted pressure differentials that would result from a decompression event for a specified airplane configuration can be used for structural analysis and substantiation. Analysis to determine cabin pressure altitudes can be used in lieu of flight testing.

## 2. REFERENCES

### 2.1 Applicable Documents

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

#### 2.1.1 SAE Publications

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

AIR825/1 Introduction to Oxygen Equipment for Aircraft

AIR825/8 Continuous Flow Oxygen Systems

AIR825/9 Demand Oxygen Systems

- AIR1168/1 Thermodynamics of Incompressible and Compressible Fluid Flow
- AIR1168/5 Aerothermodynamic Test Instrumentation and Measurement
- AIR1168/6 Aircraft Fuel Weight Penalty Due to Air Conditioning
- AIR1168/7 Aerospace Pressurization System Design

#### 2.1.2 EASA Publications

Available from European Aviation Safety Agency, Ottoplatz, 1, D-50679 Cologne, Germany, Tel: +49 221 8999 000, [www.easa.europa.eu](http://www.easa.europa.eu).

- AMC 20-128A Design Considerations for Minimizing Hazards Caused by Uncontained Turbine Engine and Auxiliary Power Unit Rotor Failure
- CS-23 Certification Specifications for Normal, Utility, Aerobatic and Commuter Category Aeroplanes
- CS-25 Certification Specifications for Large Aeroplanes
- EU OPS 1 Common technical requirements and administrative procedures applicable to commercial transportation by aircraft

#### 2.1.3 FAA Publications

Available from Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591, Tel: 866-835-5322, [www.faa.gov](http://www.faa.gov).

- AC 20-128A Design Considerations for Minimizing Hazards Caused by Uncontained Turbine Engine and Auxiliary Power Unit Rotor Failure, Initiated by ANM-110, 3/25/97
- AC 25-20 Pressurization, Ventilation and Oxygen Systems Assessment for Subsonic 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

14 CFR Part 23 Airworthiness Standards: Normal, Utility, Acrobatic, and Commuter Category Airplanes

14 CFR Part 25 Airworthiness Standards: Transport Category Airplanes

FAA Memorandum from Manager, Transport Airplane Directorate, ANM-100 - Certification of Strengthened Flightdeck Doors on Transport Category Airplanes, Dated November 6, 2001, Revised December 3, 2002

FAA Memo ANM-03-112-16, March 24, 2006 - Interim Policy on Amendment 25-87 Requirements

#### 2.1.4 NACA Publications

Available from NASA Technical Services, NASA STI Program STI Support Services, Mail Stop 148, NASA Langley Research Center, Hampton, VA 23681-2199, 757-864-9658, Fax: 757-864-6500, <http://ntrs.nasa.gov/>

- WR-L-23 Variation With Mach Number of Static and Total Pressures Through Various Screens; Originally Issued as Confidential Bulletin No. L5F28, Alfred A. Adler, Feb. 1946

|             |                                                                                                                                                                                                                  |
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| Report 933  | Performance of Conical Jet Nozzles in Terms of Flow and Velocity Coefficients; Ralph E. Grey, Jr. and H. Dean Wilestead, Sept. 7, 1948                                                                           |
| Report 1235 | Standard Atmosphere - Tables and Data for Altitudes to 65,800 Feet, NACA Langley Aeronautical Laboratory (Langley Field, Va, United States); International Civil Aviation Organization (Montreal, Canada.), 1955 |
| TN 1947     | Investigation of Flow Coefficients of Circular, Square, and Elliptical Orifices at High Pressure Ratios; Edmund E. Callaghan and Dean T. Bowden, Sept 1949                                                       |
| TN 3359     | An Investigation of Drains Discharging Liquid into Subsonic and Transonic Streams; Allen R. Vick and Frank V. Silhan, March 1955                                                                                 |
| TN 3466     | An Investigation of the Discharge and Drag Characteristics of Auxiliary-Air Outlets Discharging into a Transonic Stream; Paul E. Dewey and Allen R. Vick, July 1955                                              |
| TN 3924     | Discharge Coefficients for Combustor-Liner Air-Entry Holes II - Flush Rectangular Holes, Step Louvers, and Scoops; Ralph T. Dittrich, April 1958                                                                 |

#### 2.1.5 NASA Publications

Available from NASA Technical Services, NASA STI Program STI Support Services, Mail Stop 148, NASA Langley Research Center, Hampton, VA 23681-2199, 757-864-9658, Fax: 757-864-6500, <http://ntrs.nasa.gov/>

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| CR-61241   | Experimental Determination of General Venting Characteristics, NASA Contractor's Report, Baker, J. M.; Glasgow, R. M.; Walters, W. P., George C. Marshall Space Flight Center, Huntsville, Alabama, July 1968 |
| TM X-53734 | Compartment Venting and Pipe Flow With Heat Addition, NASA Technical Memorandum, Struck, H. G. and Harkins, John A., George C. Marshall Space Flight Center, Huntsville, Alabama, April 23, 1968              |
| TM-X-74335 | U.S. Standard Atmosphere, 1976                                                                                                                                                                                |

#### 2.1.6 NASA Standards

Available from NASA Man-Systems Integration Standards, <http://msis.jsc.nasa.gov/>

NASA-STD-3000 Man-Systems Integration Standards, Revision B, July 1995

#### 2.1.7 U.S. Federal Register

Available from Government Printing Office, 732 North Capitol St. NW, Washington, DC 20401 and from <http://www.gpoaccess.gov/fr>.

|                     |                                                                                                                                                                                 |
|---------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| US Federal Register | Vol. 45, page 60172, Sept. 11, 1980, Amendment 25-54: Airworthiness Review Program - Amendment No. 8A: Aircraft, Engine, and Propeller Airworthiness, and Procedural Amendments |
| US Federal Register | Vol. 51, No. 52, Pages 9432-9433, Tuesday, March 18, 1986, Docket No. 23243, Withdrawal of Notice of Proposed Rulemaking, "Pilot Oxygen Mask Requirements"                      |
| US Federal Register | Vol. 55, page 13477, April 10, 1990, Amendment 25-71: Improved Structural Requirements for Pressurized Cabins and Compartments in Transport Category Airplanes                  |

US Federal Register Vol. 60, No. 177, Page 47464, September 13, 1995, Docket No. NM-111, Special Condition No. 25-ANM-106, Final Special Conditions: Israel Aircraft Industries Model Galaxy Series Airplane, High Altitude Operation

US Federal Register Vol. 65, No. 30, Pages 7283-7287, Monday, February 14, 2000, Docket No. CE154, Special Condition No. 23-102-SC, Final Special Conditions: Cessna Aircraft Company, Model 525A, High Altitude Operation

#### 2.1.8 National Transportation Safety Board Publications

Available from NTSB Headquarters, 490 L'Enfant Plaza, SW, Washington, DC 20594, Tel: 202-314-6000, [www.nts.gov](http://www.nts.gov).

NTSB/AAR-89/0 Aircraft Accident Report, ALOHA AIRLINES, FLIGHT 243, NEAR MAUI, HAWAII, APRIL 28, 1988, BOEING 737-200, N73711

#### 2.1.9 Other Applicable References

82009 - Compressible Flow of Gases, ESDU International, 27 Corsham St., London N1 6UA, UK, Feb. 2004

Anderson, John D., Jr. - Introduction to Flight, McGraw-Hill Book Co., New York, 1978

Dutton, J. Craig and Coverdill, Robert E. - Experiments to Study the Gaseous Discharge and Filling of Vessels, Department of Mechanical and Industrial Engineering, University of Illinois at Urbana-Champaign Urbana, IL 61801, USA, Published in International Journal of Engineering Education, Vol 13, No 2, pg 123-134, 1997

Haber, Fritz - On the Physical Process of Explosive Decompression, USAF School of Aviation Medicine, Randolph Field, Texas, October 1950, Published in the Journal of Aviation Medicine, December 1950

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Karlsson, Björn and Quintiere, Jim - Enclosure Fire Dynamics, CRC Press LLC, Boca Raton, FL, 2000

Kent's Mechanical Engineers' Handbook, Power Volume, J. Kenneth Salisbury, Editor, John Wiley & Sons, Inc., New York, NY, 12th Edition, 1954

Miller, Richard W. - Flow Measurement Engineering Handbook, McGraw-Hill Book Co., New York, NY, 3<sup>rd</sup> Edition, 1996

Veldman, Roger L. - Enhancing Commercial Aircraft Survivability Via Active Venting, Doctorate Dissertation Submitted to Western Michigan University, Department of Mechanical and Aeronautical Engineering, Bell and Howell Information and Learning Co., Ann Arbor, MI, 2001

#### 2.2 Related Publications

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

##### 2.2.1 SAE Publications

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

ARP1270 Aircraft Cabin Pressurization Criteria

### 2.2.2 Other Related Publications

AIAA-1994-1411 - DECOMP, A Multi-Compartment Rapid Decompression Analysis Code, Wayne E. Frazer, E-Systems, IN:AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference, 35th, Hilton Head, SC, Apr. 18-20, 1994, Technical Papers. Pt. 2 (A94-23876 06-39), Washington, DC, American Institute of Aeronautics and Astronautics, 1994, p. 829-832

AIAA-2004-0054 - Bréard, Cyrille and Lednicer, David - A CFD Analysis of Sudden Cockpit Decompression, Analytical Methods, Inc., AIAA Aerospace Sciences Meeting and Exhibit, 2004

AM 67-14 - An Evaluation of the Potential Decompression Hazards In Small Pressurized Aircraft, John J. Swearingen, FAA Office Of Aviation Medicine, June 1967

AM 70-12 - Physiological Tolerable Decompression Profiles for Supersonic Transport Type Certification, Stanley R. Mohler, FAA Office Of Aviation Medicine, July 1970

AM-99/4 - Concepts Providing for Physiological Protection After Aircraft Decompression in the Altitude Range of 60,000 to 80,000 Feet above Sea Level, Robert P. Garner, FAA Office Of Aviation Medicine, February 1999

SP-8060 - Compartment Venting, NASA Special Publication, NASA Space Vehicle Design Criteria (Structures), November 1970

TR 54-446 - A Method for More Accurate Design Estimation of Air Leakage from Cabins and Cockpits of Pressurized Aircraft, A. B. Nutt, WADC Technical Report, Sept. 1954

Demetriades, Serge T. - Decompression of a Punctured Pressurized Cabin, Northrop Corp./Noriar Division, Sept. 1, 1959, ASTIA AD 229671

Mohler, Stanley R., M.D. - Quick Response by Pilots Remains Key to Surviving Cabin Decompression, Human Factors and Aviation Medicine, Vol. 47, No. 1, Flight Safety Foundation, 601 Madison Street, Suite 300, Alexandria, Virginia U.S. 22314-1756

Muraca, R. J. - A Method for Determining the Time-Dependant Pressures in a Series of Chambers Connected to an External Pressure Whose Variation with Time is Known, Master's Thesis, University of Virginia, 1968 (Available from the author on request, care of NASA Langley Research Center)

Smith, Chester W. - Calculation of Flow of Air and Diatomic Gases, Published in the Journal of Aeronautic Sciences, June 1946

### 2.3 Definitions

Decompression and depressurization are often used interchangeably. The definitions used in this report follow.

**CA FACTOR:** An acronym used to describe an effective flow area based on flow coefficient (C) times the geometric flow area (A).

**CREW RECOGNITION TIME:** The total time from when the flight crew receives indication of excessive cabin altitude to the beginning of the emergency descent. Actions required during this period will typically include donning of oxygen masks, deploying passenger oxygen masks, configuring lift and drag devices for descent and, if necessary, slowing airplane to the descent airspeed. A time of 17 seconds is noted as acceptable in FAA AC 25-20, but a shorter time may also be accepted if justified.

**DECOMPRESSION:** An inadvertent or unintended reduction in cabin pressure, which can result from equipment failures or malfunctions or from pressure vessel failures.

**DEPRESSURIZATION:** A reduction in cabin pressure, typically performed automatically by the cabin pressurization control system such as to dump cabin pressure on landing, or manually in the case of windshield cracks, cockpit smoke evacuation, excessive cabin pressure differential, door unlatch indications, etc.

**DISCHARGE COEFFICIENT:** A correction factor used for figuring volume flow rate of a fluid through an orifice that includes the effects of contraction and turbulence loss. It is the ratio of the real mass flow rate to the mass flow rate if the flow were isentropic.

**FLOW COEFFICIENT:** A correction factor used for figuring volume flow rate of a fluid through an orifice that includes the effects of contraction and turbulence loss (covered by the coefficient of discharge), plus the compressibility effect, and the effect of an upstream velocity other than zero.

**RAPID DECOMPRESSION:** An unintended reduction in cabin pressure at a rate of 2100 m (7000 feet) per minute or more, generally accompanied by “misting” - or the formation of a cloud in the cabin as the temperature and the dew point in the cabin converge and water vapor condenses into visible droplets.<sup>1</sup> Some decompression scenarios, such as complete loss of inflow are still classified as rapid decompressions though the rate is significantly less than 2100 m/min. The potential hazards of a Rapid Decompression are that the crew could be incapacitated by hypoxia, resulting in loss of the airplane or that the passengers could suffer permanent neurological damage from oxygen deprivation.

**SLOW DECOMPRESSION:** An unintended reduction in cabin pressure that occurs if the cabin altitude rises at a rate of a few hundred feet per minute or less.<sup>2</sup> A Slow Decompression is so gradual that it is not detectable to occupants. The potential hazard of a Slow Decompression is that it may not be detected until the flight crew becomes incapacitated, potentially resulting in loss of the airplane.

**VERY RAPID DECOMPRESSION:** A violent expansion and noise from cabin air released under pressure.<sup>3</sup> Erroneously called an “Explosive Decompression” because of the loud bang that may occur from the sudden expansion of cabin air. This type of decompression occurs so suddenly that no crew action is possible. The potential hazards of a Very Rapid Decompression are that internal floor panels or partitions may be collapsed onto critical systems or become projectiles or that the sudden discharge of air into normally unpressurized external compartments may result in a hazardous loss of structural integrity that could cause loss of the airplane.

## 2.4 Symbols

Variable definitions are listed in Table 1 and values of constants are listed in Table 2.

---

<sup>1</sup> Mohler.

<sup>2</sup> Mohler.

<sup>3</sup> NTSB Report NTSB/AAR-89/03, pg. 5.

**Table 1 - Variable definitions**

| Symbol            | Definition                                                 | SI Units          | USCS Units          |
|-------------------|------------------------------------------------------------|-------------------|---------------------|
| A                 | Area                                                       | m <sup>2</sup>    | ft <sup>2</sup>     |
| A <sub>edge</sub> | Area Between Edge of Door and Frame                        | m <sup>2</sup>    | ft <sup>2</sup>     |
| A <sub>top</sub>  | Area Between Top of Door and Frame                         | m <sup>2</sup>    | ft <sup>2</sup>     |
| C                 | Flow Coefficient                                           | N/A               | N/A                 |
| C <sub>BF</sub>   | Butterfly Valve Flow Coefficient                           | N/A               | N/A                 |
| C <sub>B</sub>    | Flow Coefficient from Butterfly Thickness                  | N/A               | N/A                 |
| C <sub>D</sub>    | Discharge Coefficient                                      | N/A               | N/A                 |
| C <sub>θ</sub>    | Flow Coefficient from Butterfly Angle                      | N/A               | N/A                 |
| CA                | Effective Flow Area                                        | m <sup>2</sup>    | ft <sup>2</sup>     |
| CA <sub>o</sub>   | Valve Full Open Effective Flow Area                        | m <sup>2</sup>    | ft <sup>2</sup>     |
| CA <sub>p</sub>   | Valve Partially Open Effective Flow Area                   | m <sup>2</sup>    | ft <sup>2</sup>     |
| D                 | Diameter                                                   | m                 | ft                  |
| D <sub>u</sub>    | Upstream Diameter                                          | m                 | ft                  |
| D <sub>d</sub>    | Orifice or Nozzle Throat Diameter                          | m                 | ft                  |
| dt                | Time Increment                                             | seconds           | seconds             |
| H <sub>d</sub>    | Door Height                                                | m                 | ft                  |
| H                 | Pressure Altitude                                          | m                 | ft                  |
| J <sub>d</sub>    | Door Polar Moment of Inertia                               | kg·m <sup>2</sup> | lb·ft <sup>2</sup>  |
| m <sub>d</sub>    | Door Mass                                                  | kg                | lb                  |
| M                 | Mach Number                                                | N/A               | N/A                 |
| k                 | Polytropic Constant                                        | N/A               | N/A                 |
| P                 | Pressure                                                   | Pa                | lbf/ft <sup>2</sup> |
| P <sub>1</sub>    | Initial Pressure                                           | Pa                | lbf/ft <sup>2</sup> |
| P <sub>2</sub>    | Final Pressure                                             | Pa                | lbf/ft <sup>2</sup> |
| P <sub>u</sub>    | Upstream Pressure                                          | Pa                | lbf/ft <sup>2</sup> |
| P <sub>u1</sub>   | Initial Upstream Pressure                                  | Pa                | lbf/ft <sup>2</sup> |
| P <sub>u2</sub>   | Final Upstream Pressure                                    | Pa                | lbf/ft <sup>2</sup> |
| P <sub>d</sub>    | Downstream Pressure                                        | Pa                | lbf/ft <sup>2</sup> |
| P <sub>S</sub>    | Static Air Pressure                                        | Pa                | lbf/ft <sup>2</sup> |
| q                 | Dynamic Pressure                                           | Pa                | lbf/ft <sup>2</sup> |
| r                 | Pressure Ratio = $\frac{P_d}{P_u}$                         | N/A               | N/A                 |
| r <sub>b</sub>    | Ratio of Butterfly Thickness to Diameter                   | N/A               | N/A                 |
| r <sub>c</sub>    | Critical Pressure Ratio = $\left(\frac{P_d}{P_u}\right)_c$ | N/A               | N/A                 |
| Re <sub>D</sub>   | Reynolds Number Based on Duct Diameter                     | N/A               | N/A                 |
| t                 | Time                                                       | seconds           | seconds             |
| t'                | Time for Pressure Decay for Supercritical Flow             | seconds           | seconds             |
| t''               | Time for Pressure Decay for Subcritical Flow               | seconds           | seconds             |
| t <sub>c</sub>    | Valve Time to Travel Full Open to Full Closed              | seconds           | seconds             |
| t <sub>o</sub>    | Valve Time to Travel Full Closed to Full Open              | seconds           | seconds             |
| T                 | Temperature                                                | K                 | °R                  |
| T <sub>u</sub>    | Upstream Static Temperature                                | K                 | °R                  |
| Th                | Butterfly Thickness                                        | m                 | ft                  |



|                        |                                              |                    |                     |
|------------------------|----------------------------------------------|--------------------|---------------------|
| V                      | Volume                                       | m <sup>3</sup>     | ft <sup>3</sup>     |
| V <sub>1</sub>         | Initial Volume                               | m <sup>3</sup>     | ft <sup>3</sup>     |
| V <sub>2</sub>         | Final Volume                                 | m <sup>3</sup>     | ft <sup>3</sup>     |
| V <sub>C</sub>         | Calibrated Airspeed                          |                    | KCAS                |
| W                      | Weight                                       | kg                 | lb                  |
| W <sub>1</sub>         | Initial Weight                               | kg                 | lb                  |
| W <sub>2</sub>         | Final Weight                                 | kg                 | lb                  |
| W <sub>d</sub>         | Door Width                                   | m                  | ft                  |
| •<br>W                 | Gravimetric Mass Flow Rate                   | kg/s               | lb/s                |
| •<br>W <sub>in</sub>   | Gravimetric Mass Inflow Rate                 | kg/s               | lb/s                |
| •<br>W <sub>out</sub>  | Gravimetric Mass Outflow Rate                | kg/s               | lb/s                |
| •<br>W <sub>out1</sub> | Initial Gravimetric Mass Outflow Rate        | kg/s               | lb/s                |
| •<br>W <sub>out2</sub> | Final Gravimetric Mass Outflow Rate          | kg/s               | lb/s                |
| X <sub>b</sub>         | Butterfly Valve Thickness                    | m                  | ft                  |
| X <sub>d</sub>         | Door Thickness                               | m                  | ft                  |
| Y                      | Expansion Factor                             | N/A                | N/A                 |
| α <sub>d</sub>         | Door Angular Acceleration                    | rad/s <sup>2</sup> | rad/s <sup>2</sup>  |
| δ                      | Density (Gravimetric)                        | kg/m <sup>3</sup>  | lb/ft <sup>3</sup>  |
| δ <sub>1</sub>         | Initial Density (Gravimetric)                | kg/m <sup>3</sup>  | lb/ft <sup>3</sup>  |
| δ <sub>2</sub>         | Final Density (Gravimetric)                  | kg/m <sup>3</sup>  | lb/ft <sup>3</sup>  |
| β                      | Geometric Diameter Ratio = $\frac{D_d}{D_u}$ | N/A                | N/A                 |
| φ                      | Theoretical Compressibility Factor           | N/A                | N/A                 |
| γ                      | Ratio of Specific Heats for Air              | N/A <sup>4</sup>   | N/A                 |
| v <sub>1</sub>         | Initial Specific Volume                      | m <sup>3</sup> /kg | ft <sup>3</sup> /lb |
| v <sub>2</sub>         | Final Specific Volume                        | m <sup>3</sup> /kg | ft <sup>3</sup> /lb |
| θ                      | Butterfly Angle from Closed                  | degrees            | degrees             |
| θ <sub>d</sub>         | Door Angle from Closed                       | radians            | radians             |
| θ <sub>i</sub>         | Initial Butterfly Angle from Closed          | degrees            | degrees             |
| τ                      | Time Constant                                | seconds            | seconds             |
| ω <sub>d</sub>         | Door Angular Velocity                        | rad/s              | rad/s               |

<sup>4</sup> Air Ratio of Specific Heats will vary with temperature. For room temperature air, a value of 1.40 may be used.



**Table 2 - Values of constants**

| Symbol           | Definition                                                     | SI Units                                   | USCS Units                                              |
|------------------|----------------------------------------------------------------|--------------------------------------------|---------------------------------------------------------|
| a                | Temperature Lapse Rate                                         | 0.006 5 K/m                                | 0.00356616 °R/ft                                        |
| B                | Constant, $\frac{g_0 \times \text{Log}(e)}{(R_a' \times T^*)}$ | 6.848 317×10 <sup>-5</sup> m <sup>-1</sup> | 2.087367×10 <sup>-5</sup> ft <sup>-1</sup>              |
| g <sub>c</sub>   | Gravitational Constant                                         | 1 kg·m/N·s <sup>2</sup>                    | 32.17405 ft/s <sup>2</sup>                              |
| g <sub>0</sub>   | SL Gravitational Acceleration                                  | 9.806 65 m/s <sup>2</sup>                  | 32.17405 ft/s <sup>2</sup>                              |
| H*               | Altitude at the Tropopause                                     | 11000 m                                    | 36 089.24 ft                                            |
| n                | Constant, $\frac{g_0}{(R_a' \times a)}$                        | 5.256 16                                   | 5.25616                                                 |
| P <sub>0</sub>   | SL Standard Air Pressure                                       | 101 325.0 Pa                               | 2116.216 lbf/ft <sup>2</sup>                            |
| R <sub>a</sub>   | Air Ideal Gas Constant                                         | 287.04 m <sup>2</sup> /s <sup>2</sup> ·K   | 53.3505 ft·lbf/lbm·°R                                   |
| R <sub>a</sub> ' | Air Ideal Gas Constant                                         | 287.04 m <sup>2</sup> /s <sup>2</sup> ·K   | 1716.5 ft <sup>2</sup> /s <sup>2</sup> ·°R <sup>5</sup> |
| T <sub>0</sub>   | SL Standard Air Temperature                                    | 288.16 K                                   | 518.688°R                                               |
| T*               | Air Temperature at the Tropopause                              | 216.66 K                                   | 389.988°R                                               |
| V <sub>0</sub>   | SL Standard Speed of Sound                                     | 340.43 m/s                                 | 1116.89 ft/s (661.74 Kt)                                |

## 2.5 Terminology

|       |                                             |
|-------|---------------------------------------------|
| AC    | Advisory Circular                           |
| AFM   | Airplane Flight Manual                      |
| APU   | Auxiliary Power Unit                        |
| ASME  | American Society of Mechanical Engineers    |
| ASTIA | Armed Services Technical Information Agency |
| CFD   | Computational Fluid Dynamics                |
| CFR   | Code of Federal Regulations                 |
| CS    | Certification Specification                 |
| EASA  | European Aviation Safety Agency             |
| ECS   | Environmental Control System                |
| FAA   | Federal Aviation Authority                  |
| FPA   | Feet Pressure Altitude                      |
| ICAO  | International Civil Aviation Organization   |

<sup>5</sup> A value of 1716.5 ft<sup>2</sup>/s<sup>2</sup>·°R is used in this report for the Air Ideal Gas Constant only in equations from NACA Report 1235. It has been assigned the symbol R<sub>a</sub>' to distinguish it from the value of 53.3505 ft·lbf/lbm·°R for all other occurrences in this report.

|                                  |                                                  |
|----------------------------------|--------------------------------------------------|
| JAA                              | Joint Aviation Authority                         |
| JAR                              | Joint Aviation Regulation                        |
| KCAS                             | Knots Calibrated Airspeed                        |
| Ln                               | Naperian Logarithm                               |
| Log                              | Base 10 Logarithm                                |
| MMEL                             | Master Minimum Equipment List                    |
| M <sub>MO</sub>                  | Maximum allowable operating Mach number          |
| M <sub>MO</sub> /V <sub>MO</sub> | The Lesser of M <sub>MO</sub> or V <sub>MO</sub> |
| NACA                             | National Advisory Committee for Aeronautics      |
| NASA                             | National Aeronautics and Space Administration    |
| SI                               | Système International                            |
| SL                               | Sea Level                                        |
| USCS                             | United States Customary System                   |
| V <sub>MO</sub>                  | Maximum allowable operating airspeed             |

### 3. REQUIREMENTS FOR COMPARTMENT DECOMPRESSION ANALYSES

Airplane cabin pressurization has made high altitude flight safe, comfortable and practical. Considerable effort goes into ensuring that cabin decompression does not cause injury to the crew or passengers. Flight and ground testing are used for design and development, but they are not the only tools for evaluation of the effects of cabin decompression. Analysis methods are available that can be used in lieu of expensive and potentially hazardous testing.

Cabin decompressions fall roughly into three categories:

1. **Slow:** Decompressions or depressurizations that are so gradual that they may not be detectable to occupants. The potential hazard of slow decompressions are that they may not be detected until the flight crew becomes incapacitated, potentially resulting in loss of the airplane. Monitoring and annunciation of loss of cabin pressure are required to prevent crew incapacitation or injury to passengers. Typical certification requirements are defined by 14 CFR/CS 25.841.
2. **Rapid:** Decompressions or depressurizations that occur so rapidly that immediate, rapid descent is necessary to prevent crew incapacitation or permanent injury to passengers. The potential hazards of rapid decompressions are that the crew could be incapacitated by hypoxia, resulting in loss of the airplane or that the passengers could suffer permanent neurological damage from oxygen deprivation. During the descent, the cabin altitude-time history should not exceed what is accepted as safe for the occupants. Typical certification requirements are defined by 14 CFR/CS 25.841.
3. **Very Rapid:** Decompressions that occur so suddenly that no crew action is possible. The potential hazards of very rapid decompressions are that internal floor panels or partitions may be collapsed onto critical systems or become projectiles or that the sudden discharge of air into normally unpressurized external compartments may result in a hazardous loss of structural integrity that could cause loss of the airplane. The barriers to free flow of air should be vented to limit the buildup of pressure or else be designed to have the strength to withstand the transient pressure differentials. Typical certification requirements are defined by 14 CFR/CS 25.365.

Analysis is not necessary for slow decompressions, because a decompression slow enough that it is not likely to be detected allows ample time for crew response following annunciation of excessive cabin altitude. Analyses of rapid and very rapid decompressions use generally similar methods with the following significant differences:

## Rapid Decompressions

- Except for when compartments are isolated by deliberate pressure barriers, the entire pressure vessel can be treated as a single volume. Calculations tend to be simple and straightforward.
- The analysis is complicated by continuously changing conditions of pressurization inflow rate and external pressure during the descent. Complete, derived solutions are not available except for a few very simple scenarios.
- The output of the analysis is the predicted cabin pressure altitude - time history during the decompression and descent.

## Very Rapid Decompressions

- The decompression occurs so suddenly that it is assumed that all internal and external partitions subjected to the discharge of cabin pressure impede the air flow and develop pressure differentials. The analysis tends to be relatively complex, because of the numerous volumes that exchange air.
- The outputs of the analysis are the peak pressure differentials across the pressure barriers.

This report is divided into three sections. The first section provides basic analysis methods applicable to all forms of cabin decompression analysis. The second section provides detailed analysis criteria and procedures for very rapid decompression while the third section addresses rapid decompression.

### 3.1 Maximum Cabin Altitude During a Decompression

Airplanes approved for high altitude flight are required by FAA, JAA and EASA regulations and Special Conditions to prevent exposure of the occupants to pressure altitudes that could cause permanent physiological harm or crew incapacitation during decompression events. The portion of the FAA rule applicable to the purpose of this report is:

14 CFR § 25.841 Pressurized cabins.

- (a) Pressurized cabins and compartments to be occupied must be equipped to provide a cabin pressure altitude of not more than 8000 feet at the maximum operating altitude of the airplane under normal operating conditions.
  - (1) If certification for operation over 25000 feet is requested, the airplane must be designed so that occupants will not be exposed to cabin pressure altitudes in excess of 15000 feet after any probable failure condition in the pressurization system.
  - (2) The airplane must be designed so that occupants will not be exposed to a cabin pressure altitude that exceeds the following after decompression from any failure condition not shown to be extremely improbable:
    - (i) Twenty-five thousand (25000) feet for more than 2 minutes; or
    - (ii) Forty thousand (40000) feet for any duration.
  - (3) Fuselage structure, engine and system failures are to be considered in evaluating the cabin decompression.

[Doc. No. 5066, 29 FR 18291, Dec. 24, 1964, as amended by Amdt. 25-38, 41 FR 55466, Dec. 20, 1976, Amdt. 25-87, 61 FR 28695, June 5, 1996]

The altitude-time limits for several typical high altitude special conditions are shown in Figure 1.

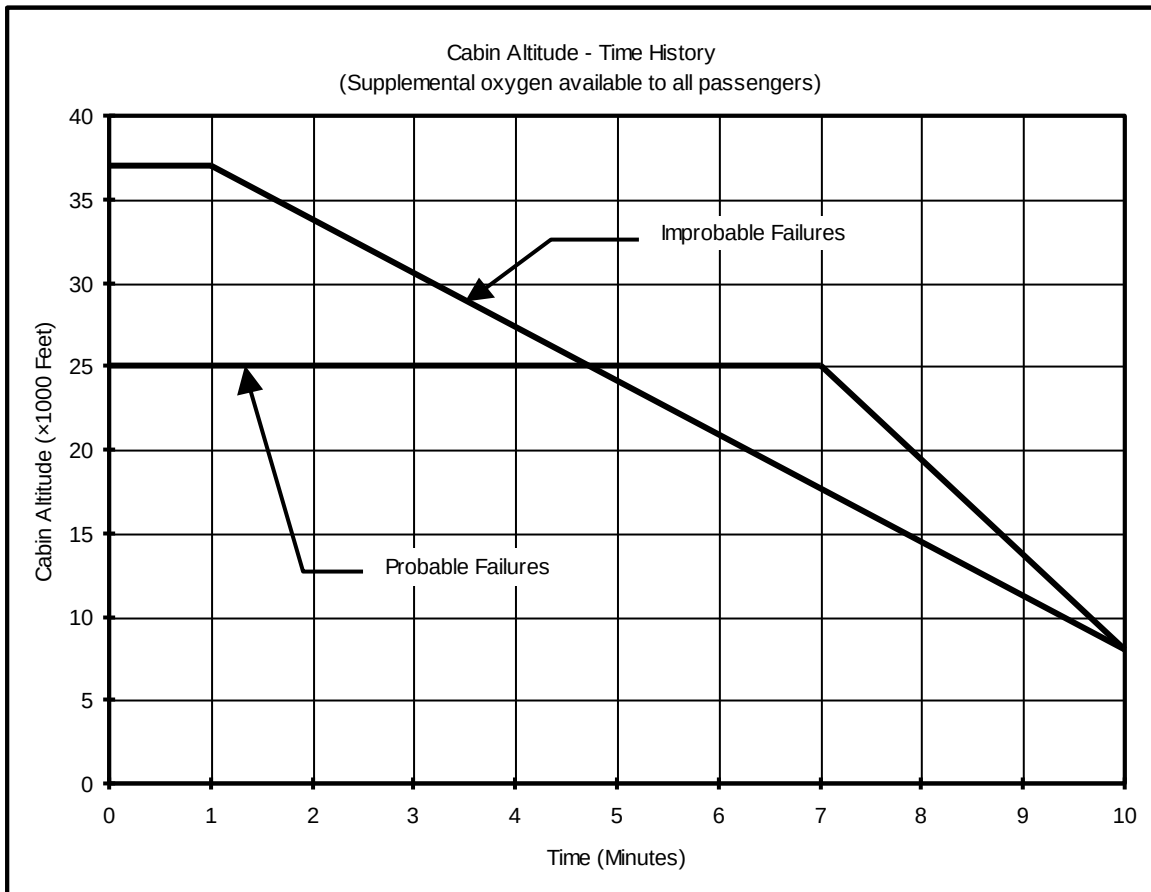


**Figure 1 - Cabin altitude-time limits for typical high altitude special conditions <sup>6</sup>**

FAA Interim Policy Memo ANM-03-112-16, Dated March 24, 2006 provides a methodology acceptable to the FAA for request for exemption from the requirements of §25.841(a)(2)(i) and (ii), applicable only to decompressions following an engine rotor noncontainment hitting the pressurized cabin for airplanes with wing-mounted engines. Table 3 provides the criteria from the memo.

**Table 3 - FAA interim policy allowable exposure time versus altitude**

| Cabin Pressure Altitude<br>[meters] | Cabin Pressure Altitude<br>[feet] | Maximum Total Exposure Time<br>[minutes] |
|-------------------------------------|-----------------------------------|------------------------------------------|
| Above 13716                         | (45000)                           | 0                                        |
| Above 12192                         | (40000)                           | 1                                        |
| Above 7620                          | (25000)                           | 3                                        |
| Above 3048                          | (10000)                           | 6                                        |

<sup>6</sup> These typical high altitude special conditions also provide the following alternate criteria: probable failures - cabin altitude shall not exceed 25000 feet for more than 2 minutes and 30000 feet maximum. Improbable failures - cabin altitude shall not exceed 30000 feet for more than 2 minutes and 40000 feet maximum.

### 3.2 Pressure Differentials Across Internal Barriers Due to Sudden Cabin Decompression

If an opening suddenly occurs in the pressure vessel, the escape of air can cause significant pressure loads on internal partitions and floor panels. Damage to internal pressure barriers, such as collapse of floor panels that cause damage to flight controls systems, can result in loss of the airplane.

14 CFR/CS 25.365 requires that an airplane be able to survive a sudden pressure vessel failure.<sup>7</sup> Damage is allowed, but the airplane shall be able to continue flight and land. It also includes requirements to protect occupants from injury from debris that could be propelled by the decompression. As the rule text has evolved over the years it has introduced significant changes in hole sizes to be considered, treating the pressure differentials as limit or ultimate loads, etc. Earlier versions of the text as contained in 14 CFR 25 or JAR-25/CS-25 may be applicable via the Type Certification Basis to a particular airplane or modification thereto. The text of the current rule applicable to the purpose of this report is:

14 CFR/CS 25.365 Pressurized cabin loads.

(e) Any structure, component or part, inside or outside a pressurized compartment, the failure of which could interfere with continued safe flight and landing, must be designed to withstand the effects of a sudden release of pressure through an opening in any compartment at any operating altitude due to:

(1) Penetration from Engine Disintegration;

(2) Any opening up to:

$H_o = P A_s$ , where,

$H_o$  = Maximum opening, need not exceed 20 ft<sup>2</sup>.

$A_s$  = Maximum cross-sectional area of the pressurized shell ft<sup>2</sup>; and

$P = (A_s/6240) + 0.024$

(3) Any Opening Caused by Airplane or Equipment Failures Not Shown to be Extremely Improbable.

(f) In complying with paragraph (e) of this section, the fail-safe features of the design may be considered in determining the probability of failure or penetration and probable size of openings, provided that possible improper operation of closure devices and inadvertent door openings are also considered. Furthermore, the resulting differential pressure loads must be combined in a rational and conservative manner with 1 g level flight loads and any loads arising from emergency depressurization conditions. These loads may be considered as ultimate conditions; however, any deformations associated with these conditions must not interfere with continued safe flight and landing. The pressure relief provided by intercompartment venting may also be considered.

(g) Bulkheads, floors, and partitions in pressurized compartments for occupants must be designed to withstand the conditions specified in paragraph (e) of this section. In addition, reasonable design precautions must be taken to minimize the probability of parts becoming detached and injuring occupants while in their seats.

[Doc. No. 5066, 29 FR 18291, Dec. 24, 1964, as amended by Amdt. 25-54, 45 FR 60172, Sept. 11, 1980; Amdt. 25-71, 55 FR 13477, April 10, 1990; Amdt. 25-72, 55 FR 29776, July 20, 1990, Amdt. 25-87, 61 FR 28695, June 5, 1996]

<sup>7</sup> Refer to US Federal Register preamble to the final rule for 14 CFR Part 25, Amendment 71, 55 FR 13477, April 10, 1990.

The interpretation provided in the US Federal Register preambles to the Final Rules for 14 CFR Part 25 Amendments 54 and 71 requires that the hole size per 14 CFR/CS 25.365(e)(2) shall be evaluated, even if there is no fuselage opening of this size because holes can result from detonation of bombs, corrosion and errors in maintenance, production and operation. The exception allowed is if the compartment is so small that the hole would overlap into the adjacent compartment. Then, evaluation is required of the largest opening that could occur without overlap. As a separate condition, the small compartment would then be combined with an adjacent pressurized compartment and both considered as a single compartment for the maximum size opening specified.

The rules require that holes from uncontained engine and APU rotor fragments be evaluated if any part of the pressure vessel is within the fragment trajectory. FAA AC 25-20 and AC 20-128A provide criteria for rotor fragment trajectory analysis for US certified airplanes. An entire window shall be assumed lost, if it is in the rotor non-containment zone. Current large transport airplanes with aft fuselage or wing-mounted engines generally have some portion of the pressure vessel within the engine rotor non-containment zone. Some small business jet airplanes with aft-mounted engines are able to place their pressure bulkhead entirely forward of the engine rotor non-containment zone, using the unpressurized tailcone space for baggage. Some others that have their aft pressure bulkhead within the rotor non-containment zone add a secondary aft pressure bulkhead. The volume between the primary and secondary aft pressure bulkheads is used for baggage and the secondary bulkhead is provided with fast acting shut-off valves to isolate the baggage compartment in case it is penetrated by an engine rotor fragment.

Other openings which should be evaluated include doors, windows, windshield, tire burst damage and openings resulting from airplane and equipment failures. 14 CFR/CS 25.783(b) require that door opening in flight shall be extremely improbable. However, 14 CFR §25.783(h) allows for door opening in flight if it can not cause a hazard. 14 CFR/CS 25.775(d) require that windows and windshields on airplanes approved for high altitude flight shall be of redundant structural design, such that sufficient strength remains to carry pressurization loads should a single pane fail. FAA AC 25-20 provides the additional criteria required to show that structurally redundant window and windshield installations also meet the Extremely Improbable criteria of 14 CFR §25.365(e)(3). EASA has not yet adopted FAA AC 25-20 and applies criteria in addition to those contained in FAA AC 25-20 for showing compliance with CS 25.365(e).

14 CFR/CS 25.775(b) and 25.571(e) prohibit windshield penetration from birdstrike. However, bird penetrations of windshields in excess of the regulatory requirements have occurred in service and (partial) windshield loss may therefore have to be considered for decompression in spite of compliance with 14 CFR/CS 25.775(b). Birdstrike can result in fuselage penetration as long as it does not cause hazard. 14 CFR/CS 25.571(a) and 25.729(f) prohibit hazard from a tire burst or loose tread, but do not prohibit penetration. Equipment failures (ducting, check valves, etc.) and airplane failures (loss of antennae, fatigue cracks, etc.) should be evaluated, if they can cause significant pressure differentials. However, equipment and airplane failures will also need to be evaluated for protection of occupants from hypoxic injury, which will generally result in more stringent criteria. Refer to 3.1.

If operating rules require the airplane be equipped with a flightdeck door, 14 CFR/CS 25.795 require the door installation to be resistant to intrusion and ballistic penetration. FAA memorandum dated November 6, 2001 provides criteria for decompression analysis of intrusion resistant flightdeck doors.<sup>8</sup> Freighters may not be required to have a secure flightdeck door if adequate ground security measures are provided.

### 3.3 Pressures in Adjacent External Compartments Due to Very Rapid Cabin Decompression

14 CFR/CS 25.365 require that the effects of sudden discharge of cabin pressure into normally unpressurized external compartments adjacent to the pressure vessel be evaluated. Sudden venting of cabin pressure into an external compartment that is not intended to carry significant pressure loads can cause hazard to the airplane by loss of structural integrity or damage to critical systems. Depending on the airplane configuration, these compartments may include tail surfaces, engine pylons, wing-fuselage fairings, wheel wells, radomes, fuel tanks, tailcone, nose compartment and baggage compartments.

Section 3.2 discusses causes of pressure vessel openings. Only those that vent into the adjoining compartments need be evaluated.

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<sup>8</sup> FAA Memorandum from Manager, Transport Airplane Directorate, ANM-100 - Certification of Strengthened Flightdeck Doors on Transport Category Airplanes, Dated November 6, 2001, Revised December 3, 2002.

### 3.4 Modifications to Previously Approved Airplanes

Any modifications to the airplane design should be approved in accordance with the requirements of the certification basis. Lengthening or shortening a fuselage to create a derivative airplane would have an obvious effect on decompression certification. Addition or relocation of pressure vessel openings has such an obvious impact on decompressions that the maximum allowable pressure vessel opening may be specified on the airplane Type Certification Data Sheet.<sup>9</sup>

Examples of other factors that are not as obvious are:

- Addition of equipment or furnishings that significantly change the compartment air volume or block existing decompression airflow paths. For example, a freighter conversion can greatly reduce cabin air volume, while a VIP conversion could significantly increase air volume.
- Change to stronger door latches or addition of items of mass on doors that are intended to open during a decompression and relieve loads on critical structure.
- Location of seating closer to a frangible partition.
- Repair or modification that increases the strength or stiffness of an external fairing adjacent to a pressure vessel that prevents it from deflecting during a decompression to relieve load from critical structure.

This brief list is intended only to show that the design intent related to prevention of hazard from decompressions may not be readily apparent.

## 4. DESIGN MEASURES

### 4.1 Design Measures for Protection of Occupants from Excessive Cabin Altitude

FAA, JAA, and EASA rules and Special Conditions for airplanes approved for high altitude flight require that supplemental oxygen be readily available to all occupants. Passenger masks are required to deploy automatically and provide oxygen if cabin altitude exceeds 4572 m (15000 feet) and flight crewmembers are required to be provided with quick-don masks that can be donned with one hand in less than 5 seconds. Availability of supplemental oxygen is not complete protection from hypoxia. Phase-diluter masks provided for passenger do not provide adequate protection above 12192 m (40000 feet) and provide protection for only limited durations above 7620 m (25000 feet). Pressure-Demand crew masks do not provide adequate protection from rapid decompressions above 12497 m (41000 feet), unless oxygen is pre-breathed<sup>10</sup>. FAA operating rules require at least one flight crewmember to be using oxygen during high altitude flight, but there are no comparable requirements in EU OPS 1 or for international flight (ICAO).

Emergency descent alone, whether initiated by the crew or by an auto-descend system does not provide complete protection from rapid cabin decompression. An airplane may not exceed its maximum allowable airspeed during an emergency descent. High performance airplanes that can cruise at their max allowable airspeed may need to decelerate before they can initiate emergency descent. Use of emergency descent will generally be combined with other measures, such as limiting the size of potential pressure vessel leaks or use of a supplemental inflow system to limit the cabin climb rate.

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<sup>9</sup> Refer to FAA Type Certification Data Sheet No. A1WI - "Any modifications to the pressure vessel must be approved in accordance with the requirements as shown in the certification basis. This includes modifications which could result in a pressure vessel opening, either through crack-growth or antenna loss, greater than 3.00 in<sup>2</sup>."

<sup>10</sup> For protection capabilities of supplemental oxygen equipment, refer to:  
AIR825/1 - Introduction to Oxygen Equipment for Aircraft  
AIR825/8 - Continuous Flow Oxygen Systems  
AIR825/9 - Demand Oxygen Systems

An auto-descend system can bring an airplane down from altitude even if the crew is incapacitated. This is typically implemented by additional programming in the autopilot. When the autopilot receives signal of excessive cabin altitude (typically at 3048 m (10000 feet)) it puts the airplane into a max rate descent, turns it from its flight path and levels off at an altitude that is safe for unpressurized flight. The reason for the change to flight path is that airplanes are controlled to flight lanes with traffic flying in the opposite direction at alternating flight levels. An auto-descend system may be able to exceed the performance of the crew in initiating an emergency descent, since it can act immediately on indication of excessive cabin altitude while reaction time testing of flight crews described in FAA AC 25-20 shows a 75<sup>th</sup> percentile reaction time of 17 seconds. However, the crew may not regain consciousness for several minutes if incapacitated by rapid decompression at high altitude<sup>11</sup>. The auto-descend system may not be able to equal crew performance if it cannot be given authority over all required lift and drag devices (which may include landing gear) and the authority to execute maneuvers (such as a split-S to bleed off excess airspeed) as aggressively as the crew.

Warning of excessive cabin altitude is required by regulation before the cabin altitude reaches 3048 m (10000 FPA). Cabin altitude warning is primarily of benefit for gradual decompressions, since rapid decompression is inherently detectable.

Airframe and system design measures which can limit cabin altitudes from decompression include:

Minimizing the size of every pressure vessel opening. For example, an antenna, stall vane or pitot mast may require a cutout through the pressure vessel that exceeds the allowable opening size. An internal pressure barrier (shroud) can be added inside the pressure vessel over the base of the component with an opening only large enough for the cable or hose connector.

Installing components on the inside of the pressure vessel, wherever possible. Pressure loads will hold the component against the pressure vessel opening should its attaching fasteners fail.

Providing structurally redundant attachments of components to the pressure vessel. Is an antenna installed with four bolts one attachment or four? Depending on guidance from the Certifying Authority, there may be no credit for use of multiple fasteners, especially if the location of the component makes all of the attachments vulnerable to the same environmental factors (such as corrosion of belly mounted antenna fasteners) or the same manufacturing or material defect. A dissimilar-redundant attachment can be considered and the ability of the backup attachment method to hold the component in place would need to be demonstrated.

Providing multiple door seals. If hazardous decompression can result from a door seal blowout or deflation, a secondary seal can be added behind it. If both seals require inflation pressure, each should use a separate pressure source, so that a single failure can not cause loss of both seals. Since loss of a single seal would not be immediately apparent, monitoring of pressure supplied to inflatable seals, direct visual inspection and/or periodic functional testing of each seal may be required to prevent latent failure of a single seal from going undetected.

Providing partitioned door seals. Placing partitions in the door seal will limit deflation of the seal to only a single damaged section. The spacing of the partitions would be defined by the pressure vessel leakage area allowable for decompressions.

Providing captive door seals with multiple sealing surfaces. The door-to-frame gap can be limited so that the seal can not extrude from the opening and the seal can be provided with multiple sealing surfaces so that a seal split at any one point will not cause a leak past the other sealing surface. This is similar to providing a secondary door seal, except that both seals are combined into a single component. Door seal failure might result in an increase in leakage, but less than if the seal extruded out the gap and departed the airplane. The ability of the seal to remain in place with maximum gap that would result from failure of a single door latch would have to be demonstrated. If the door is used on every flight, the seal would have to be inspectable during preflight to verify it has not fallen off of the door when the door was open.

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<sup>11</sup> Discussion of the need for oxygen pre-breathing in order to prevent crew incapacitation from sudden decompression to pressure altitude above 12497 m (41000 feet) is provided in US Federal Register Vol. 51, No. 52, Pages 9432-9433, Tuesday, March 10, 1986, Docket No. 23243, Withdrawal of Notice of Proposed Rulemaking, "Pilot Oxygen Mask Requirements".