U.S. Department
of Transportation
**Federal Aviation
Administration**

Advisory Circular

Subject: Regulatory Guidance on Compliance with § 25.841(a)

Date: XX/XX/XXXX **AC No:** 25.841-1X
Initiated By: AIR-623

This advisory circular (AC) provides an acceptable means of showing compliance with Title 14, Code of Federal Regulations (14 CFR) 25.841(a) for transport category airplanes, specifically related to uncontained engine failures that result in rapid cabin decompression issues associated with high-altitude flight. This guidance follows in part the recommendations of the Aviation Rulemaking Advisory Committee Mechanical Systems Harmonization Working Group[1], FAA Policy[2] and exemptions that FAA has granted[3] to § 25.841(a) at Amendment 25-87. This guidance is predicated on the fact that an adequate quantity of oxygen is provided for crew operations and passengers as required in §§ 25.1441, 25.1443, 25.1445, 25.1447 and 25.1449, and on compliance to the operating regulations in 14 CFR parts 91, 121 and 135 which require that one pilot wear and use an oxygen mask when operating above 41,000 feet altitude. In addition, this AC provides guidance on compliance for airplane models for which a new, amended, or supplemental type certificate is requested, if the airplane model includes changes that affect maximum cruise altitude, engine thrust or location, cabin pressure, or airplane descent performance (i.e., changes that affect compliance with § 25.841). This AC also provides information on the benefits and risks associated with high-altitude flight.

If you have suggestions for improving this AC, you may use the Advisory Circular Feedback Form at the end of this AC.

Daniel J. Elgas,
Director, Policy and Standards Division
Aircraft Certification Service

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[1] The "Mechanical Systems Harmonization Working Group (MSHWG) Final Report on FAR 25.841(a)(2,3)," dated July 24, 2003, is available in this public docket and at https://www.faa.gov/regulations_policies/rulemaking/committees/documents/index.cfm/document/information/documentID/429.

[2] Information on how the FAA evaluates these exemptions is explained in Policy Memorandum ANM 03 112-16, "Interim Policy on High Altitude Cabin Decompression," dated March 24, 2006, available at https://drs.faa.gov/browse/excelExternalWindow/9E07590C732D2B838625870C006EBB52.0001. .

[3] Examples of exemptions that the FAA has issued are available for download at https://www.regulations.gov/ (e.g., search for "Exemption No. 8695" or "Exemption No. 10962").

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1 PURPOSE.

1.1 This AC provides acceptable means for showing compliance with the requirements of § 25.841(a)(1), (a)(2), (a)(3) and (a)(4) for transport category airplanes pertaining to cabin decompression issues associated with high-altitude flight. In addition, it provides information on the benefits and risks of high-altitude flight.

1.2 This guidance is premised on operators fulfilling the initial and recurrent emergency training provisions in accordance with 14 CFR parts 121.397, 121.417, and 121.427 for all crewmembers, including training for a rapid decompression and donning of oxygen masks. This guidance is also premised on operators and flight crewmembers complying with the requirements of 14 CFR parts 91.211, 121.333 or 135.157, as applicable.

1.2.1 The Federal Aviation Administration (FAA) created § 25.841(a)(4) to require type certificate, amended type certificate, and supplemental type certificate applicants to require the airplane flight manual (AFM) include recommended emergency descent procedures per compliance to § 25.1585. This would ensure that not only the design required in § 25.841(a)(2) and (a)(3) minimizes the effects of rapid decompression on occupants but that flight crew response further aides in minimizing the effects of rapid decompression.

1.2.2 The FAA has mandated that applicants demonstrate compliance to § 25.841(a)(2) and (a)(3) by flight testing. In addition, the FAA has found that airplane performance models may provide accurate predictions for steady-state conditions (i.e., cruise). However, the FAA has observed, based on real-world flight test data, that predicted airplane performance model estimates are less accurate in dynamic situations where environmental conditions are rapidly changing and airplane systems are responding. The FAA has observed differences in airplane performance model behavior and the FAA has required certification flight tests as a limitation in grants of exemption[4] to the requirements in this regulation to ensure an acceptable level of safety and as recommended by the Aviation Rulemaking Advisory Committee (ARAC) Mechanical Systems Harmonization Working Group (MSHWG). Any applicant proposing the use of airplane performance models to show compliance to the requirements in § 25.841(a)(2), (a)(3) and (a)(4) must[5] validate their model via performing an emergency descent from the certified cruise altitude. The FAA may require additional test data to validate the airplane performance model and find the model acceptable.

1.3 The FAA recognized the apparent operating restrictions on new airplane designs following the implementation of § 25.841 at amendment 25-87 and completed rulemaking activity supported by the creation of Policy Memorandum ANM-03-112-16,

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[4] Examples of exemptions that the FAA has issued are available for download at https://www.regulations.gov/ (e.g., search for “Exemption No. 8695” or "Exemption No. 10962").

[5] 14 CFR Part 21.33 and 25.21

Interim Policy on High Altitude Cabin Decompression, issued March 24, 2006, and in part by an ARAC MSHWG recommendation to address cabin decompressions.

In addition to a flight test demonstration of the AFM procedure that performs the emergency descent, all applicants should perform an analysis of the combination of failures that can occur (e.g., smaller engine released fragment with associated damage of airplane control surfaces).

2 APPLICABILITY.

2.1 The guidance provided in this AC is for part 25 transport category airplane manufacturers, modifiers, foreign regulatory authorities, and FAA airplane type certification engineers and their designees.

2.2 The contents of this AC do not have the force and effect of law and are not meant to bind the public in any way, and this AC is intended only to provide information to the public regarding existing requirements under the law or agency policies. Conformity with the guidance is voluntary only and nonconformity will not affect rights and obligations under existing statues and regulations. The FAA will consider other methods of demonstrating compliance that an applicant may elect to present. Terms such as “should,” “may,” and “must” are used only in the sense of ensuring applicability of this particular method of compliance when the acceptable method of compliance in this document is used. If the FAA becomes aware of circumstances in which following this AC would not result in compliance with the applicable regulations, we may require additional substantiation as the basis for finding compliance.

2.3 This material does not change, create any additional, authorize changes in, or permit deviations from existing regulatory requirements.

2.4 The associated rule and the guidance contained in this AC are intended for the subset of rapid decompression events due to uncontained engine failures (UEF). However, this AC does include general applicability to system failures and means of compliance for some structural failures. The rulemaking and this AC do not allow any change in cabin pressure regulations for the more common failures, such as those pertaining to environmental systems and structural failures. The FAA believes that the limitations in the rule and AC result in reasonable passenger safety while enabling industry to develop and operate new airplanes designed to fly above 40,000 feet. However, high-altitude flight carries an inherent danger to occupants in the event of a rapid decompression. Our analysis shows that there is an average probability of approximately 1×10^{-7} per engine hour for an UEF at cruise. New engine designs appear to provide an order of magnitude improvement to this risk. Because these UEF events are rare, the FAA considers that the benefits of operating at higher altitudes compensate for the added risk even though the risk to occupants from a rapid decompression at high-altitude is severe.

3 CANCELLATION.

The following FAA policy memorandum is cancelled by this AC:

- Memorandum ANM-03-112-16, *Interim Policy on High Altitude Cabin Decompression (Reference Amendment 25-87),* dated March 24, 2006.

The following AC is cancelled by this AC:

- AC 25-20, *Pressurization, Ventilation and Oxygen Systems Assessment for Subsonic Flight including High Altitude Operation,* issued September 10, 1996.

4 RELATED DOCUMENTS.

4.1 Regulations.

- § 25.571, *Damage-tolerance and fatigue evaluation of structure*.
- § 25.841, *Pressurized cabins*.
- § 25.843, *Tests for pressurized cabins.*
- § 25.1309*, Equipment, systems, and installations.*
- § 25.1441, *Oxygen equipment and supply*.
- § 25.1443, *Minimum mass flow of supplemental oxygen*.
- § 25.1445, *Equipment standards for the oxygen distributing system.*
- § 25.1447, *Equipment standards for oxygen dispensing units.*
- § 25.1449, *Means for determining use of oxygen*.
- § 25.1450, *Chemical oxygen generators.*
- § 25.1555, *Control markings*.
- § 25.1585, *Operating procedures*.
- § 91.211, *Supplemental oxygen.*
- § 121.333*, Supplemental oxygen for emergency descent and for first aid; turbine engine powered airplanes with pressurized cabins.*
- § 121.397, *Emergency and emergency evacuation duties.*
- § 121.417, *Crewmember emergency training*.
- § 121.427, *Recurrent training.*
- § 135.157, *Oxygen equipment requirements.*

4.2 Advisory Circulars.

The following ACs are current at the time of publication of this AC. You should use the latest version for guidance. You can view and download the latest version on the FAA's Advisory Circulars website.

4.2.1 AC 25-7D, *Flight Test Guide for Certification of Transport Category Airplanes*

4.2.2 AC 25-22, *Certification of Transport Airplane Mechanical Systems*

4.2.3 AC 25.571-1D, *Damage Tolerance and Fatigue Evaluation of Structure*

4.2.4 AC 20-128B, *Design Considerations for Minimizing Hazards Caused by Uncontained Turbine Engine and Auxiliary Power Unit Rotor Failure*

4.3 Other Documents.

The following documents are related to this AC. If any of these documents are revised after publication of this AC, you should refer to the latest version.

4.3.1 *Calculation of Flow of Air and Diatomic Gases*, Chester W. Smith, Journal of Aeronautical Science, dated June 1946.

4.3.2 Amendment 25-87 Final Rule, Docket 26070, Federal Register Volume 61, Number 109, dated June 5, 1996.

4.3.3 FAA ARM Package MSHWG Final Reports 25-831g and 25-841a.pdf.

4.3.4 *Factors influencing the time of safe unconsciousness (TSU) for commercial jet passengers following cabin decompression*, James G. Gaume, Aerospace Medicine, dated April, 1970; 41(4):382-5.

4.3.5 Amendment 25-87 ARAC tasking notice, Federal Register, Volume 66, Number 144, dated July 26, 2001.

4.3.6 *Neurological Study of Simulated Decompression in Supersonic Transport Aircraft*, Aerospace Medicine, J.B. Brierley and A. N. Nicholson, dated August 1969.

4.3.7 *Neurological Sequelae of Prolonged Decompression*, Aerospace Medicine, A.N. Nicholson and J.R. Ernsting, dated April 1967.

4.3.8 *Fundamentals of Aerospace Medicine*, Roy L. DeHart, second edition, Williams & Wilkons, 1996, Table 5.12, Respiratory Gas Pressures and Gas Exchange Ratios, pg. 91.

4.3.9 *Prevention of Hypoxia – Acceptable Compromises*, Aviation, Space, and Environmental Medicine, J. Ernsting, dated March 1978.

4.3.10 *An Analysis of the Oxygen Protection Problem at Flight Altitudes Between 40,000 and 50,000 Feet, Final Report*, prepared for the Federal Aviation Agency, Contract FA-955, by Blockley and Hanifan, dated February 20, 1961.

4.3.11 *Quick Response by Pilots Remains Key to Surviving Cabin Decompression*, Stanley R. Mohler, M.D., Human Factors & Aviation Medicine, Vol. 47, No. 1, dated Jan.-Feb. 2000.

4.3.12 *Concepts Providing for Physiological Protection after Aircraft Cabin Decompression in The Altitude Range of 60,000 to 80,000 Feet above Sea Level*, Robert P. Garner, DOT/FAA/AM-99/4, Office of Aviation Medicine, dated February, 1999.

4.3.13 *A Behavioural and Neuropathological Study of the Sequelae of Profound Hypoxia*, A.N. Nicholson, Susan A. Freeland, and J.B. Brierley, Brain Research, 22 (1970) 327-345.

4.3.14 *Hypoxia and Performance Decrement*, William F. O'Connor, Ph. D., Jim Scow, M.D., George Pendergrass, Capt., USAF, DOT/FAA/AM 66-15, dated May, 1966.

4.3.15 *Performance of a Continuous Flow Passenger Oxygen Mask at an Altitude of 40,000 Feet*, Robert P. Garner, DOT/FAA/AM-96/4, dated February, 1996.

4.3.16 *Rapid Decompression of a Transport Aircraft Cabin: Protection Against Hypoxia*, H. Marotte, C.Toure, J.M. Clere, and H. Vieillefond, Aviation, Space and Env. Medicine, dated January, 1990.

4.3.17 *Effects of Decompression on Operator Performance*, William F. O'Connor, Ph. D., George E. Pendergrass, DOT/FAA/AM 66-10, dated April, 1966.

4.3.18 *Behaviour of Naïve Subjects During Decompression: An Evaluation of Automatically Presented Passenger Oxygen Equipment*, Chisholm DM, Billings CE, Bason R, Aerospace Medicine, dated February 1, 1974.

4.3.19 *Physiologically Tolerable Decompression Profiles for Supersonic Transport Type Certification*, Stanley R. Mohler M.D. and P.V. Siegel M.D., DOT/FAA/AM 70-12, dated July 1970.

4.3.20 *Review of Interim Policy Regarding Amendment 25-87 Requirements (Altitude Rules)*, Memorandum from the Director, Civil Aerospace Medical Institute, to the Manager, Transport Airplane Directorate, dated March 30, 2004.

4.3.21 *Human Responses to a Simulated 35,000-Foot Instantaneous Decompression and the Subsequent Descent Profile Required by FAA Policy*, DOT/FAA/AM-15/8, Office of Aerospace Medicine, Washington, DC 20591, dated April 2015.

4.3.22 *Large Engine Uncontained Debris Analysis Report*, DOT/FAA/AR-99/11, Office of Aviation Research, dated May 1999.

4.3.23 *Small-Engine Uncontained Debris Analysis,* DOT/FAA/AR-99/7, Office of Aviation Research, dated February 1999.

4.3.24 *Engine Debris Penetration Testing*, DOT/FAA/AR-99/19, Office of Aviation Research, dated November 1999.

4.3.25 *Engine Debris Fuselage Penetration Testing, Phase I*, DOT/FAA/AR-01/27, Office of Aviation Research, dated August 2001.

4.3.26 *Engine Debris Fuselage Penetration Testing, Phase II*, DOT/FAA/AR-01/27, II, Office of Aviation Research, dated September 2002.

4.3.27 *Advanced Aircraft Materials, Engine Debris Penetration Testing*, DOT/FAA/AR-03/37, Office of Aviation Research and Development, dated December 2005.

4.3.28 *Uncontained Engine Debris Analysis Using the Uncontained Engine Debris Damage Assessment Model*, DOT/FAA/AR-04/16, Office of Aviation Research, dated September 2004.

4.3.29 *Reactions and Performance of Pilots Following Decompression*, G. Bennett, Aerospace Medicine, 32:134, dated February 1961.

4.3.30 *High Altitude air transport system symposium, May 23, 24, 1956, at the Institute of Aeronautical Sciences*, OCLC: 1134264, Dr. E. G. Vail.

4.3.31 *Airline Engine Safety Review Report to Congress* prepared in Response to Section 309 of the FAA Reauthorization Act of 2018 (Public Law 115-254).

5 BACKGROUND.

5.1 The FAA issued amendment 25-87 for § 25.841, effective July 5, 1996, because of an increased number of applications for transport category airplanes seeking approval to operate at cruise altitudes over 40,000 feet. Before amendment 25-87, the only limits for cabin decompression addressed decompression resulting from probable system failures and substantially lower cabin pressure altitudes. The FAA believed it was appropriate to require cabin pressure limits to ensure that all occupants be protected from permanent physiological harm following a rapid decompression at these high altitudes.

5.2 In drafting § 25.841 at amendment 25-87, the FAA believed that passenger cabins of large transport category airplanes would not experience rapid decompression because of the large cabin volume as opposed to smaller executive business jets. However, as airplane fuselages grew in size, so did the engines and the potential for increased debris during a UEF. Today, the FAA recognizes that a UEF on a large transport category airplane can cause the cabin to rapidly depressurize like smaller executive business jets.

5.3 Industry and FAA have concluded that the worst-case failure scenario that creates the largest hole is from an uncontained engine rotor burst where a third of the rotor disk may separate from the engine and penetrate the fuselage[6]. This failure can result in debris striking the fuselage, creating a large hole resulting in a rapid (within seconds) decompression of the cabin and exposure of occupants to ambient pressure.

5.4 Amendment 25-87 revised the pressurized cabin airworthiness standards for transport category airplanes. It created three new requirements governing the flightdeck/cabin environment:

5.4.1 Section 25.841(a)(2)(i): Cabin pressure not to exceed 25,000 feet for more than two minutes.

5.4.2 Section 25.841(a)(2)(ii): Cabin pressure not to exceed 40,000 feet for any time.

5.4.3 Section 25.841(a)(3): Fuselage, structure, engine and system failures are to be considered in evaluating the decompression.

Note: There are provisions in § 25.1441(d) for the oxygen flow rate and oxygen equipment approval for flight above 40,000 feet. Applicants should also note that there must be a sufficient quantity of oxygen to satisfy the operating requirements (e.g., § 121.333) up to the maximum certificated operating altitude of the airplane.

5.5 The FAA developed amendment 25-87 using research completed by Dr. James Gaume that focused on a concept called Time of Safe Unconsciousness (TSU)[7], as applied to passengers[8] and on material that had been developed for the U.S. Supersonic Transport Program (SST). Dr. Gaume focused on TSU and provided recommendations that were adopted as the basis for cabin altitude limitations given in the regulations. However, neither service history nor the results of several human and animal altitude chamber studies were considered in the development of the regulation. The FAA did not investigate the data until an ARAC MSHWG was tasked to review the regulation[9].

5.6 The intent of the provisions implemented by amendment 25-87 was to provide complete protection from any permanent physiological harm to all occupants, even those unable to properly don an oxygen mask. The participants of the MSHWG (FAA, other government agencies, foreign regulatory agencies, and industry) believe it is neither practical nor physiologically possible to afford this level of protection to all occupants. All occupants are at some level of risk and some occupants are at higher risk, such as the elderly, the very young, and those occupants with existing medical conditions. It was not the intent of the regulation to limit airplane operating altitude but to limit the

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[6] AC 20-128B, *Design Considerations for Minimizing Hazards Caused by Uncontained Turbine Engine and Auxiliary Power Unit Rotor Failure*, dated TBD.

[7] *Factors influencing the time of safe unconsciousness (TSU) for commercial jet passengers following cabin decompression*, James G. Gaume, Aerospace Medicine, dated April, 1970; 41(4):382-5, https://www.ncbi.nlm.nih.gov/pubmed/4392477.

[8] Amendment 25-87 Final Rule, Docket 26070, Federal Register Volume 61, Number 109, dated June 5, 1996.

[9] FAA ARM Package MSHWG Final Reports 25-831g and 25-841a.pdf, (https://www.faa.gov/regulations_policies/rulemaking/committees/documents/media/TAEmsh-vhhcp-07262001.pdf).

cabin environment following types of failures as a function of their probability of occurrence.

5.7 The FAA concludes that it is not possible to provide complete protection to all occupants per the original goal of amendment 25-87. Furthermore, there is nothing distinctive about 40,000 feet cabin limit in terms of the severity of the exposure and risk to the occupants. Occupants exposed to a 40,000 feet pressure altitude are only slightly less likely to suffer harm than those exposed to higher pressure altitudes such as 45,000 feet, if the exposure is limited to a short duration by the airplane's rapid descent. While the FAA is unable to quantify the relative risk to the occupants from exposure at 40,000 feet or 45,000 feet, the FAA Civil Aerospace Medical Institute (CAMI) recognizes that this risk is a function of the altitude (higher altitude having a greater level of risk), and duration of exposure (longer duration having a greater level of risk). The MSHWG reviewed information from the National Aviation Safety Data Analysis Center, covering airplane accidents and incidents from 1959 to the 1999. The FAA found no records of deaths from hypoxia at any altitude due to the type of inflight rapid decompression events envisioned by amendment 25-87.

5.8 Between 1959 and December 2004, there were over 3,000 loss-of-cabin-pressure events. The vast majority of these have been caused by system failures (e.g., cabin pressurization controller failures, valve failures, etc.) and structural failures (e.g., door seal failures, etc.), which have been typically recognized at low altitude within a few minutes after takeoff. Pilot error has also contributed to the number of events. The majority of these events have not subjected the occupants to exposures above 25,000 feet, which is an altitude considered physiologically significant. However, other loss-of-cabin-pressure events have subjected occupants to ambient pressures. Some of these events could have been avoided if the pressurization system included an automatic feature to ensure the pressurization system was operating during normal operation. In addition, in development of Policy Memorandum ANM-03-112-16, *Interim Policy on High Altitude Cabin Depressurization* dated March 24, 2006, FAA specialists conducted a survey of all uncontained engine failures of high bypass turbofan engines in commercial part 121 operation that occurred during cruise flight condition (i.e., step-cruise in between climb; maximum cruise altitude). The analysis showed an average probability of an uncontained engine failure at cruise of approximately $1x10^{-7}$ per engine hour. Furthermore, in response to the FAA Reauthorization Act of 2018 (Public Law 115-254), Section 309, Call to Action Airline Engine Safety Review, the FAA formed the Engine and Airframe-Engine Integration (EAEI) Review Team in September 2018. The EAEI team report included a survey of part 121 operations that showed the engine-related injury, fatality, and hull loss rate per one million departures from 1973 through 2018. The trend from 1973 through 2018 showed a steady decrease in the number of events despite an increase in the number of engines and airplanes in operation. The change in the number of events per one million departures from 1973 to 2018 represents a reduction of greater than 95 percent. The EAEI survey data supports the data previously reported in the MSHWG report and FAA Policy Memorandum ANM-03-112-16, also supports the earlier conclusion that uncontained engine failures that result in rapid decompressions are rare events.

5.9 Some of these loss-of-cabin-pressure events resulted in accidents. For example, on August 14, 2005, a Boeing 737-300 airplane, registration number 5B-DBY, operated by Helios Airways, departed Larnaca, Cyprus, at 06:07 hours for Prague, Czech Republic, via Athens, Hellas[10]. The airplane was cleared to climb to FL340. As the airplane climbed through 16,000 feet, the captain contacted the company operations center and reported a Take-off Configuration Warning and an Equipment Cooling System problem. Several communications between the captain and the operations center took place in the next eight minutes concerning the above problems and ended as the airplane climbed through 28,900 feet. Thereafter, there was no response to radio calls to the airplane. During the climb, at an airplane altitude of 18,200 feet, the passenger oxygen masks deployed in the cabin. The airplane leveled off at FL340 and continued on its programmed route. The airplane impacted terrain at 09:03 hours approximately 20.5 miles northwest of the Athens International Airport, with all 121 occupants killed. The accident was due in part to the result of loss of pressurization control.

5.10 There have been other accidents where loss of pressurization control have been a factor. The FAA believes that some of these accidents could have been avoided if the pressurization system included an automatic feature to ensure the pressurization system is operating during normal airplane operation. The FAA provides the following general guidance on this system for compliance. The automatic feature should permit the pilots to use ECS "packs-off" takeoff procedures if approved by the FAA. The feature may use other combined input such as "weight-on-wheels," altitude above ground level, etc. to meet the intended goal of ensuring that the pressurization system is operating during normal airplane operation while not impeding other non-normal operations (e.g., cargo compartment fire).

5.11 The cabin pressure altitude in most events did not exceed 15,000 feet (the pressure altitude where passenger oxygen masks are required[11] to be deployed). Similarly, uncontained engine rotor burst failures tend to be rare events. A simple calculation shows that grouping all engines and transport airplanes together yields an average probability of an UEF at cruise of approximately $1x10^{-7}$ per engine hour. New engine designs may provide an improvement to this risk. In addition, flight at higher altitudes has been shown to provide benefits to the traveling public and industry via faster air travel, lower fuel burn and lower engine emissions (e.g., CO_2, NO_X). It is because these events are considered rare that the FAA considers the risk versus benefits to be acceptable.

5.12 Section 25.841(a), as amended by amendment 25-87, provides airworthiness criteria intended to afford complete protection to all occupants from permanent physiological harm following a cabin decompression event. However, based upon FAA subsequent review, complete protection to all occupants cannot be fully achieved. Occupants who are at increased risk levels because of age, pre-existing medical conditions, etc. may

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[10] Hellenic Republic Ministry of Transport & Communications, Air Accident Investigation & Aviation & Aviation Safety Board (AAIASB), Aircraft Accident Report, Helios Airways Flight Boeing 737-31S, at Grammatiko, Hellas, on 14 August 2005.

[11] 14 CFR Part 25.1447

suffer permanent physiological harm because of exposure to hypoxic conditions during a sudden decompression.

5.13 As the maximum operating altitude of transport category airplanes increases, so does the physiological risk associated with cabin depressurization. Some existing large commercial transport category airplanes type certificated prior to amendment 25-87 are approved to operate up to 45,000 feet altitude. Special conditions were issued to address cabin depressurization concerns for operation up to 51,000 feet for several executive business jets and up to 60,000 feet for the Concorde.

5.14 Both the business jets and Concorde shared a common performance characteristic, specifically the ability to conduct a rapid descent following a sudden loss of cabin pressure. Business jets also typically feature rear fuselage-mounted engines, which incorporate an aft pressurized bulkhead located forward of the rotor burst zone, which decreases the likelihood of experiencing a rapid cabin decompression following an UEF. Amendment 25-87 incorporated criteria similar to the provisions of the special conditions into part 25 to ensure occupant safety following any failure scenario including UEF.

5.15 The ARAC MSHWG reported that the effect of amendment 25-87 is to limit the maximum operating altitude of new type designs with wing-mounted engines to 40,000 feet. Holes in the fuselage, caused by UEF, may be large enough to allow decompression of the airplane cabin to ambient pressure within seconds. Less rapid cabin depressurization may also be caused by pressurization system failures or structural failures or UEF involving smaller fragments.

6 FAILURE CONDITIONS.

6.1 Section 25.841 requires that the airplane be designed so that occupants will not be exposed to a cabin pressure altitude that exceeds specific cabin pressure altitude limits and duration within the regulation following decompression from any system failure or engine failure not shown to be extremely improbable, or any structural failure considered under § 25.571(b) or (e)(1).

6.1.1 System failures are design specific and each applicant must review their system design features and evaluate failures as required in § 25.1309. In general, applicants should consider failures of the cabin pressurization control system such as:

- outflow valve/cabin pressurization regulator valve failure (e.g., gate or electro-mechanical shaft or housing);
- positive pressure relief valve/negative pressure relief valve (e.g., gate or housing);
- cabin pressurization controller failure;

- failures of the avionics equipment compartment ventilation system (e.g., overboard ventilation valve).

6.1.2 Structural failures are design specific and each applicant must review their structural design features and evaluate failures as considered under § 25.571(b) or (e). In general, applicants should consider failures pertaining to the requirements for damage-tolerance and fatigue evaluation of transport category airplane structure. This evaluation should include widespread fatigue damage and establishing a limit of validity of the engineering data that supports the structural-maintenance program as addressed in AC 25.571-1D, *Damage Tolerance and Fatigue Evaluation of Structure*. Similarly, the requirements of § 25.571, applicable for the windshield or window panels, may be met by showing compliance with the fail-safe criteria in AC 25.775-1, *Windows and Windshields*.

6.1.3 All applicants should use a cabin pressurization model to review system failures and structural failures and perform a decompression analysis using appropriate airflow equations (e.g., those developed by Chester Smith for compressible flow[12]) to ensure compliance with the regulations for these failures or other means acceptable to the FAA. This cabin pressurization model could also be used to determine the cabin response following a worst case UEF. The analysis should be performed assuming an UEF occurs and results in a large hole where the cabin altitude instantaneously equals the airplane cruise altitude. The start of the event is defined as when the 10,000 ft. cabin pressure altitude warning occurs. No change in airplane cruise altitude is assumed unless the airplane is thrust limited at cruise (and begins descending immediately after the loss of an engine). The recognized time that an airplane descent may start is 17 seconds. The analysis should use the maximum airplane weight possible for the certified cruise altitude. Unless otherwise restricted (e.g., for possible AP speed limitation) a maximum operating speed (V_{MO}/M_{MO}) descent is assumed with one engine failed (set at flight idle throttle) and associated loss of hydraulics or other appropriate systems (e.g., electrical) due to the loss of the one engine. Other failure conditions are described in chapter 6 of this AC. Figure 1 depicts a typical time-history plot of airplane altitude and the corresponding cabin pressure during a rapid decompression event.

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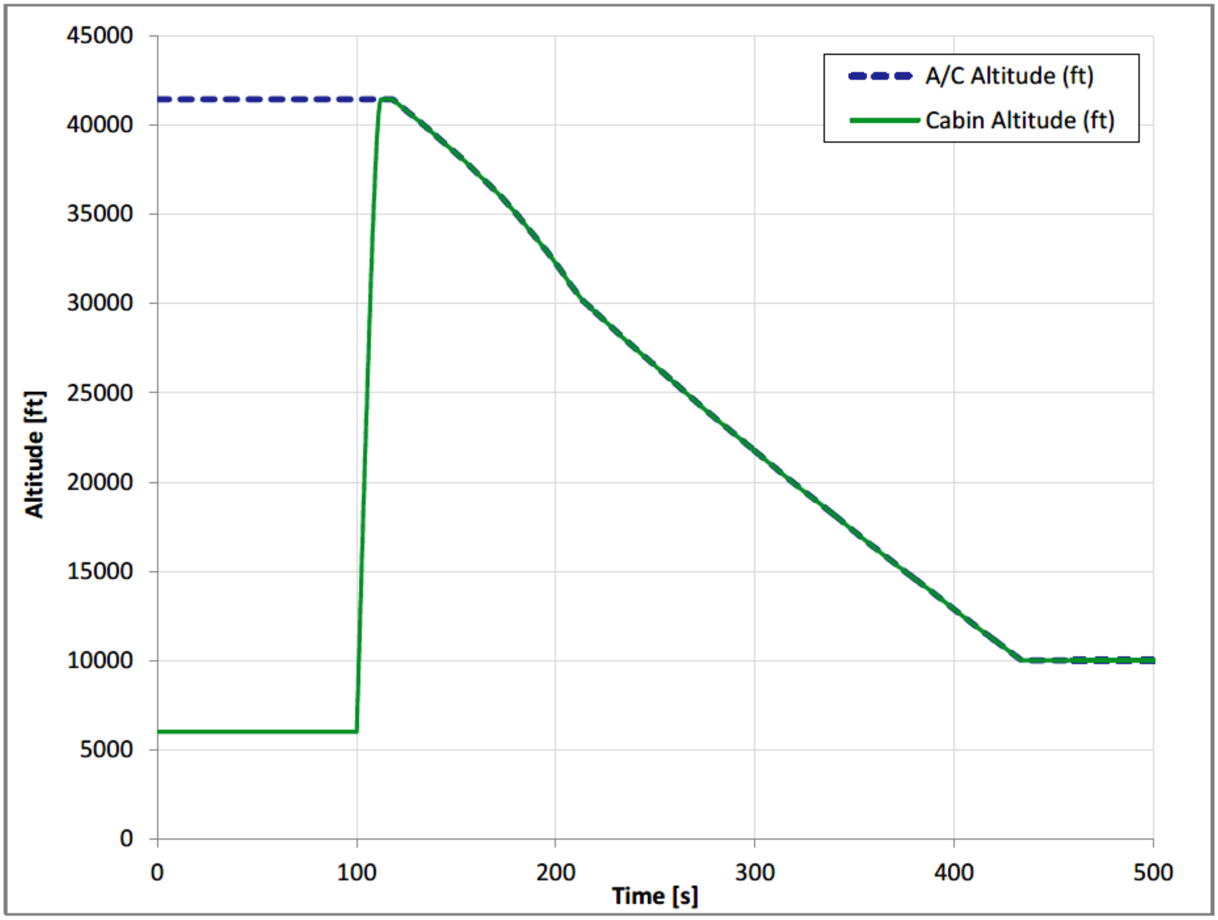
[12] Calculation of Flow of Air and Diatomic Gases, Chester W. Smith, Journal of Aeronautical Science, dated June 1946.

Figure 1: Airplane Pressure Altitude and Cabin Pressure Altitude Time-history Plot during a Rapid Decompression Event.



6.1.4 The following guidance is provided for wheel rim release and tire failures, hydraulic systems failures, windows, and windshields (e.g., mounting structure cracks, seal failures, etc.), door failures (e.g., frame cracks, seal failures, etc.), and antennas and engine failures:

6.1.4.1 Based on the current industry design standards on wheel design, testing and historic data shows that wheel rim release has not occurred during flight conditions. Additionally, the probability method for fatigue model presented by one wheel manufacturer gives substantiation that wheel failure is extremely improbable. Applicants need not consider wheel rim release.

6.1.4.2 In accordance with § 25.841, applicants must consider pressure vessel openings resulting from uncontained engine failure, loss of antennas, or stall warning vanes, or any other system failure conditions that are not shown to be extremely improbable. The effects of such damage while operating under maximum normal cabin pressure differential must be evaluated as required in § 25.841(a)(3). Applicants may assume that the aircraft is operated as designed. In the event of an uncontained engine failure, applicants may assume that other, unrelated system or structural failures do not occur at the same time; however, loss of system capability, if linked to the loss of the one engine should be considered. Applicants should use a discharge coefficient of the resulting hole of 0.75[13] for all window and fuselage penetrations unless the applicant provides corroborating analysis and test data to show that a different discharge coefficient should be used.

6.1.4.3 Applicants do not need to consider the loss of a "typical skin panel" bound by a crack stopper pattern. Furthermore, in accordance with § 25.571, applicants may assume that propagation of a crack from stringer to stringer, frame to frame leading to the total loss of a skin panel is prevented by scheduled maintenance programs. However, in accordance with § 25.365, applicants must evaluate mid-panel cracks and cracks through skin-stringer and skin-frame combinations; any other penetrations of the pressurized skin; and cracks in pressure bulkheads. Applicants should consider the maximum pressure vessel opening resulting from an initially detectable crack propagating for a period encompassing four normal inspection intervals.

6.2 Airplane manufacturers should ensure a robust design to maximize occupant survivability in the event of failures that affect cabin pressurization. They should use redundant components and separation of systems and components to provide mitigating features and ensure safe operation in failure events. They should consider the use of redundant means to power control surfaces and other features that enhance airplane descent capability. Other design solutions such as improved passenger oxygen masks, improved engine fragment shielding, emergency ram air pressurization system, or advanced engine blade failure warning devices may exist in the future that will afford additional mitigation strategies to be utilized. The measure of severity of the environment may include the use of an UEF debris model as described previously and validated by existing data, that provides a realistic pressure vessel cumulative hole area and damage to the associated airplane systems. Consideration must[14] be given to loss of those systems that directly affect cabin pressurization and airplane descent.

6.2.1 Some airplane manufacturers have incorporated automatic emergency descent (AED) systems or autopilot modes (AED mode) that will command the airplane into a descent following a rapid loss of cabin pressure. This type of system can reduce flightcrew workload when initiation of an emergency descent is required. These systems may also provide a safety net in the event the flightcrew becomes incapacitated following a rapid decompression failure scenario. This function can be manually or automatically armed

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[13] AC 25-20, *Pressurization, Ventilation and Oxygen Systems Assessment for Subsonic Flight including High Altitude Operations,* contains guidance that an applicant should use a discharge coefficient of 0.5 for the resulting hole from loss of a window or fuselage penetrations. The MSHWG could not locate corroborating information.

[14] 14 CFR Part 25.841

and then engaged. The FAA considers the means to manually activate the AED an emergency control because it is used by the flightcrew only while executing the procedures for emergency descent. Therefore, the means to manually activate the AED must be colored in red per § 25.1555(d).

6.2.1.1 Manual arming and engagement of AED mode: After donning an oxygen mask, the flightcrew manually arms the AED mode and ensures engagement by following appropriate instructions in the AFM. This mode of operation would permit the flightcrew additional time to determine the cause of the rapid cabin decompression and attempt means to gain control of the cabin pressure.

6.2.1.2 Automatic arming and engagement of AED mode: In case of explosive decompression at high altitude, an emergency descent should be initiated quickly (i.e., within 15 seconds from the time the cabin pressure exceeds 10,000 feet pressure altitude including system tolerance). Prior to commencement of the emergency descent an alert should be provided to the flightcrew indicating that the AED mode is armed and preparing to commence an emergency descent. Following automatic engagement (no flightcrew action), a message should be displayed in red that the AED is engaged. The alert should be unambiguous and provide the flightcrew with a direct means to cancel the AED mode. In addition, prior to the automatic AED engagement, the AED should provide adequate indication in the cabin such that cabin crew and passengers can prepare for the emergency descent maneuver.

6.2.1.3 Service experience shows that automated system behavior may not always be understood or expected by the flightcrew, and therefore can lead to flightcrew confusion. Confusion about automated system behavior has been known to contribute to incidents and accidents. The use of the AED mode should be designed such that the automated behavior is predictable and unambiguous to the flightcrew.

6.2.1.3.1 Airplane manufacturers that incorporate an AED system should ensure that the system meets the performance and functional requirements of AC 25.1329. They must submit flight test data that demonstrates acceptable automatic emergency descent performance as required by § 25.841(a)(4).

6.2.1.3.2 In accordance with § 25.1309, airplane manufacturers must show that the software item development assurance level (IDAL) associated with the AED function is at a level commensurate with its function as recommended in RTCA DO-178 (latest version). The AED function must be compliant with all features of § 25.1309.

6.2.1.4 Airplane manufacturers should perform a system safety assessment of the AED mode to assess and validate the AED failure mode during simulation or actual flight test. The flightcrew should have enough information provided for all AED failure modes so they can continue to operate the system safely. The system should alert the flightcrew immediately if a failure of the autopilot (AP) /flight director (FD) /auto throttle (AT) or failure in the automated speed brake deployment prevents safe completion of the AED maneuver.

6.2.1.4.1 A unique alert should be provided whenever safe completion of the AED relies on flightcrew intervention, in lieu of a malfunctioning AP/FD/AT or failure in the automated speed brake deployment. A failure of the AP during an AED maneuver should cause the AP to disconnect with a warning alert, since immediate flightcrew intervention would be required.

6.2.1.4.2 Airplane manufacturers should assess new failure modes in the AP/FD/AT and automated speed brake deployment function as well as wiring faults in the system safety assessment. Airplane manufacturers should validate and substantiate these effects through simulation and flight test.

6.2.1.4.3 Airplane manufacturers should establish an effective means to prevent a single failure of the autopilot and/or automated speed brake deployment system from resulting in an unacceptable upset. The system should annunciate failures through aural and visual means. Airplane manufacturers should consider whether to disable the system under those conditions.

6.2.1.4.4 Airplane manufacturers should evaluate the effect of missing or erroneous minimum in route altitude (MEA) or minimum off-route altitude (MORA) data at the system level. Airplane manufacturers should substantiate through an approved data quality requirements (DQRs) document, the required data quality to be used as an agreement between an aeronautical data supplier and the design approval holder (reference AC 20-153B, paragraph 12).

6.2.1.5 Airplane manufacturers should demonstrate by flight test the effect of an AP-coupled traffic collision avoidance system or traffic alert and collision avoidance system and resolution advisories during an AED maneuver.

6.2.1.5.1 Any AP/FD-coupled inhibit logic (including detected failures) should be made clear to the flightcrew so that the pilot can begin initiating an emergency descent maneuver without the AP/FD guidance within the expected response time. If AED operation is inhibited, then the airplane manufacturer should demonstrate by flight test that a conventional, manual emergency descent maneuver always could be performed in a timely and satisfactory manner using the legacy procedure. Any autothrottle /

autothrust engage inhibit (or full thrust lockout) based on throttle lever position should be evaluated and demonstrated to not interfere with the performance of the automatic AED maneuver.

6.2.1.5.2 Airplane manufacturers should demonstrate envelope protection during AED maneuver. In addition, the airplane manufacturer should provide recommended flightcrew operating procedures for use of the AED, to include impacts on the normal flightcrew operating procedures, abnormal operating procedures and any limitations associated with the flightcrew's use of the emergency descent implementation through AP-coupled operations.

7 PHYSIOLOGICAL LIMITING CRITERIA.

The following guidance is based on work that included an extensive literature review of previous testing, creation of a physiological model and conducting a test titled *Human Responses to a simulated 35,000-Foot Instantaneous Decompression and the Subsequent Descent Profile Required by Federal Aviation Administration Policy*. This CAMI report was in support of the associated policy in FAA Memorandum ANM-03-112-16, *Interim Policy on High Altitude Cabin Decompression (Reference Amendment 25-87)* and dated March 24, 2006. The conclusions of the Office of Aerospace Medicine (AAM) and CAMI were considered in creating the associated rulemaking and this AC.

7.1 The FAA used the following sources in assessing the risk from a high-altitude decompression:

7.1.1 service history and reports on the rate of failures that lead to loss of cabin pressure from all sources, such assystem failures, structural failures and uncontained engine rotor failures;

7.1.2 the results of previous altitude chamber testing with animal and human subjects;

7.1.3 a physiological model prepared by the FAA's CAMI that approximates blood saturation level of oxygen; and,

7.1.4 results from the CAMI testing via normobaric[15] instantaneous decompression to a simulated altitude of 35,000 feet.

7.2 The response of human beings to increased altitude varies with the individual. People who smoke or are in poor health will be affected at a much lower altitude than people who are young and in good physical condition. In addition, infants, young children and elderly are at an increased level of risk. The FAA has found that there have been fatalities of passengers using supplementary oxygen during some probable failure

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[15] Defined in *Human Responses to a Simulated 35,000-Foot Instantaneous Decompression and the Subsequent Descent Profile Required by FAA Policy, DOT/FAA/AM-15/8*, Office of Aerospace Medicine, Washington, DC 20591, dated April 2015.

events that have occurred on commercial flights. The cabin pressure altitude that occurred during these events was not severe (i.e., the built-in oxygen masks did not deploy and the cabin pressure was below 15,000 feet pressure altitude). However, the passengers who were physiologically challenged at sea-level and required supplementary oxygen succumbed to the otherwise mild hypoxic insult.

7.3 Without supplementary oxygen, most people will begin to experience a reduction in night vision or general visual acuity at approximately 5,000 feet altitude. At an altitude of approximately 10,000 feet, a person will begin to display measurable deterioration in mental abilities and physical dexterity after a period of several hours. At 18,000 feet, the mental deterioration may result in unconsciousness, and the Time of Useful Consciousness (TUC) is generally about 15 minutes. At 25,000 feet, the TUC for people is about 2 - 3 minutes. At altitudes above 25,000 feet, the TUC decreases very rapidly, becoming only a few seconds at 40,000 feet. If a person is breathing 100 percent oxygen, however, the partial pressure of oxygen in the lungs at 34,000 feet altitude is the same as that for a person breathing air at sea level. At 40,000 feet, a person breathing 100 percent oxygen will have the same partial pressure of oxygen in the lungs as a person breathing air at 10,000 feet. Therefore, 34,000 feet is the highest altitude at which a person would be provided complete protection from the effects of hypoxia, and 40,000 feet is the highest altitude at which 100 percent oxygen will provide reasonable protection for the limited period of time needed to descend to a safe altitude.

7.4 The FAA completed a review of the results of earlier research material[16], service history, and a new theoretical model proposed by the ARAC tasking, some of which were not included in consideration of the regulation at amendment level 25-87. The data provided additional information that was used to approximate the severity of the decompression event and relate that severity of the risk to occupants.

7.5 A physiological model that approximates blood saturation level of oxygen was the subject of peer review, *A Physiological Modeling Analysis of Rapid Decompressions to 40,000 feet and 45,000 feet*", by D.A. Self, R.M. Shaffstall and D. Moorcroft, CAMI, presented at the Aerospace Medical Association 81st Scientific Meeting, May 9th through 13th, 2010. The FAA utilized the model to screen the historical database of decompression incidents. The model incorporates known phenomenological relationships that describe the respiratory cycle, lung mechanics, lung, venous and arterial blood flows and calculates trans-alveolar oxygen. The FAA compared predicted values versus measured levels from historical test data and believes that it is a valid tool for comparative purposes. In addition, the FAA reviewed the historical data, generated comparative plots, and generated data on simulated sudden loss of cabin pressure events to provide information on the severity of such events to occupant survivability.

7.6 AAM published report titled *Human Responses to a Simulated 35,000-Foot Instantaneous Decompression and the Subsequent Descent Profile Required by FAA Policy*, dated April 2015, included testing of a group of healthy individuals under

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[16] See sections 4.3.4 through 4.3.21 and 4.3.29 and 4.3.30 of this AC.

conditions representing the reduced oxygen content of a high-pressure altitude environment. Testing represented decompression up to 35,000 feet pressure altitude, and the results were extrapolated to the altitude exposure that would result from the alternative limits defined in this AC shown in Table 1.

7.7 Table 1 contains an oxygen deficit comparison based upon the results of the CAMI report[17] and extrapolated via the physiological model previously discussed to the limitations of the FAA policy and the guidance in this AC contained in Table 2.

Table 1. Oxygen Deficit Comparison at 35,000 Feet through 45,000 Feet Pressure Altitude.

Measure	**35,000 ft profile**	***40, 000 ft descent profile (2 min) prediction***	***45,000 ft descent profile (3 min) prediction***
Resting VO_2 (ml/min)	270.4	**270.4**	**270.4**
O_2 Flux RD to 30K (ml)	-97.53	***-125.4***	***-208.9***
Additional O_2 loss resulting increased time above 30,000 ft (ml)	-	***27.9***	***111.4***
Total O_2 Flux for Profile (ml)	+149.3	***+121.4***	***+37.9***
Total O_2 Requirement for Profile (ml)	585.8	***585.8***	***856.3***
Total O_2 Deficit for exposure (ml)	-436.5	***-464.1***	***-818.4***
Added O_2 Loss Resulting From Boyle's Law Gas Expansion (ml)	***-296.5***	***-325.9***	***-349.5***
O_2 Deficit With Boyle's Law Effects (ml)	***-733.0***	***-790.0***	***-1167.9***

7.8 The FAA also considered the following information in interpreting the results from the AAM report titled *Human Responses to a Simulated 35,000-Foot Instantaneous Decompression and the Subsequent Descent Profile Required by FAA Policy*, dated April 2015.

7.8.1 The test conditions approved by review boards (i.e., as shown in the 35,000 ft profile column in Table 1) do not represent an identical scenario to the scenario in Table 2 of this AC and represent a less severe environment. For example, the time the test subjects were held at the worst oxygen deficient state (maximum simulated altitude) was less than the 17 seconds criteria.

7.8.1.1 As reported by the ARAC MSHWG[18] a 17-second delay after decompression for crew recognition and oxygen mask donning time

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[17] *See* AAM Report titled, *Human Responses to a Simulated 35,000-Foot Instantaneous Decompression and the Subsequent Descent Profile Required by FAA Policy*, dated April 2015.

[18] FAA ARM Package MSHWG Final Reports 25-831g and 25-841a.pdf. https://www.faa.gov/regulations_policies/rulemaking/committees/documents/media/TAEmsh-vhhcp-07262001.pdf

should be applied between cabin altitude warning and initiation of action to configure for descent. The 17-second reaction time is based on the mean reaction time of aircrews given a pressure loss or other emergency in a simulator. The 17-seconds is a value that represents the 75th percentile of crew reactions. Reaction times were further studied by Bennett[19]. Forty-two pilots were exposed to airplane decompression for an overall cabin rate of climb of 30,000 feet per minute to a maximum cabin altitude of 30,000 feet. Eighty-three percent of the pilots donned the oxygen mask in 15 seconds. Emergency descent was initiated in all cases within 5 seconds of the fitting of the mask.

7.8.1.2 Furthermore, as reported in the ARAC MSHWG Report, the 17-second reaction time cited by Dr. Vail[20] is strongly supported by data. Figure 27 in reference 4.3.10 depicts a probability graph of data based on Bennett's 1961 study of 42 British Overseas Airways Corporation (BOAC) pilots reacting to surprise decompressions in realistic conditions. The graph shows that approximately 95 percent of the pilots were able to react within 17 seconds of onset of the rapid decompression. This correlates well with the 17-second rule proposed by Vail based on his Wright Development Center simulator studies: “Seventy-five per cent of the response times were 17 seconds or shorter in his experiments, Dr. Vail expressed the view that though one minute would be a desirable allowance for response time to decompression, 17 seconds should be sufficient for thoroughly trained crews.”

7.8.2 In addition, as stated in the AAM report titled, *Human Responses to a Simulated 35,000-Foot Instantaneous Decompression and the Subsequent Descent Profile Required by FAA Policy*, dated April 2015, of the original 35 subjects comprising the dataset, six subjects were disqualified after medical screening and five subjects failed to complete the profile due to incapacitation (manifested by their inability to maintain a mouthpiece seal). The FAA believes that is important that the traveling public and aviation industry understand that of the five test subjects that succumbed to the initial hypoxic insult, three subjects recovered (self-resuscitated) when they received 100 percent oxygen. However, two of these subjects needed assistance (artificial ventilation) to recover. The ages and health of all the test subjects were selected to minimize the impact of the test conditions and avoid any permanent physiological harm. It was surprising given the age and health of the test subjects, that five subjects (i.e., 17 percent of the subjects) were rendered unconscious and alarming that two subjects (i.e., 7 percent of the subjects) did not self-resuscitate and required artificial ventilation to

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[19] *Reactions and Performance of Pilots Following Decompression*, G. Bennett, Aerospace Medicine, 32:134, February 1961.

[20] *An Analysis of the Oxygen Protection Problem at Flight Altitudes Between 40,000 and 50,000 Feet*, Final Report, prepared for the Federal Aviation Agency, Contract FA-955, by Blockley and Hanifan, February 20, 1961.

recover. CAMI and FAA technical specialists believe that these percentages represent a minimum risk present.

7.8.3 The test subjects represented a sample of the population least likely to suffer permanent physiological harm in the event of a rapid decompression at high altitude. The test resulted in several subjects experiencing the effects of hypoxia as a result of a rapid decompression at 35,000 feet. The test reaffirmed the FAA's position that exposure to hypoxia cannot be eliminated for the minimum risk occupants and especially not those occupants with the highest risk exposure. Therefore, in accordance with 25.841(a)(4), flightcrew must be trained to ensure an immediate response to a decompression event to provide occupant survival.

7.9 The primary means to ensure occupant survivability rests in quickly bringing the occupants to a cabin pressure where they can survive (i.e., a lower cabin pressure altitude as given in Table 2 and Table 3 of this AC). Airplane manufacturers should use design features that facilitate rapid airplane descent from high altitudes to ensure that the occupants will not be subjected to pressure altitudes for durations longer than those given in the following Table. The maximum airplane operating altitude and maximum cabin pressure being considered is 45,000 feet. The FAA believes that the severity of exposure to 45,000 feet pressure altitude represents the maximum altitude that permits reasonable occupant survival.

Table 2. Cabin Pressure Altitude versus the Maximum Total Exposure Time above the Altitude for § 25.841(a)(2).

Cabin Pressure Altitude [feet]	**Maximum Total Exposure Time [minutes]**
Above 40,000	0
Above 25,000	2
Above 10,000	6

Table 3. Cabin Pressure Altitude versus the Maximum Total Exposure Time above the Altitude for § 25.841(a)(3).

Cabin Pressure Altitude [feet]	Maximum Total Exposure Time [minutes]
Above 45,000	0
Above 40,000	1
Above 25,000	3
Above 10,000	6

7.10 The time noted in the second column of Table 2 and Table 3 is the maximum total time spent above the indicated cabin pressure altitude. The times in the table for cabin pressure altitudes of 45,000 feet, 40,000 feet and 25,000 feet are absolute (i.e., no tolerance). However, a tolerance of one-minute is acceptable for the time given for 10,000 feet cabin pressure altitude.

7.11 In analyzing system and structural damage caused by fragments from a UEF, additional structural damage can be assumed to be limited to that engine. Regarding engine powered systems, other than losing the thrust, engine air bleed, and engine accessory power on the engine suffering the UEF, the operation of other airplane systems can be assumed to be normal. Therefore, the airplane should be capable of performing a V_{MO}/M_{MO} emergency descent (i.e., spoilers fully deployed if appropriate, maximum descent rate, V_{MO}/M_{MO} speed) and meeting the maximum total exposure time duration.

7.12 This guidance takes into account operating rules in 14 CFR parts 91, 121 and 135 which require (a) that one pilot wear and use their oxygen mask when operating above 41,000 feet altitude and (b) that an adequate quantity of oxygen is provided for crew operations. The guidance in this AC is also premised on the condition that—in the airplane maintenance manual—the airplane manufacturer and the airline operator include any required maintenance and checks of supplemental oxygen systems prior to each flight. Furthermore, the guidance in this AC is premised on the condition that—if dispatch is deemed appropriate with a malfunctioning system that is required to ensure that the airplane is capable of performing an emergency descent (i.e., spoilers fully deployed, if appropriate; maximum descent rate; maximum operating limit V_{MO}/M_{MO} speed)—then the master minimum equipment list (MMEL) will limit dispatch to a maximum flight altitude of 40,000 feet, unless other regulations or limitations require a lower altitude. Though V_{MO}/M_{MO} is normally the best speed for a rapid decompression descent, the pilots should follow the recommended emergency descent procedures in the AFM.

7.12.1 Rather than propose the use of complicated calculations to determine the oxygen deficit of occupants as provided in Table 1 of this AC, the FAA believes that the limits in the exposure duration in Table 2 of this AC provide an environment that meets the intended goal of enabling survival for many of the occupants in the event of a rapid decompression. However, the FAA acknowledges that young children and elderly occupants, as well as those who have medical conditions are more likely to suffer permanent physiological harm in the event of a rapid decompression at high altitude.

7.13 All applicants showing compliance to § 25.841 must conduct flight testing and demonstrate that the emergency descent capability of their airplane will meet the conditions in Table 2 and Table 3 of this AC. In addition, flight testing should be conducted if significant changes are made to an airplane, such as changes that affect engine thrust, cabin pressure, cruise altitude or airplane descent rate (e.g., changes in airplane control surfaces or actuation; software; etc.). The presence of a modified auto-pilot system (e.g., one that includes an automatic emergency descent function) should be subjected to flight testing to ensure the airplane in this mode of operation meets the conditions in Table 2 and Table 3 of this AC.

7.14 Since occupant survival depends on immediate and rapid descent from high altitude, in accordance with § 25.841(a)(4), applicable rapid decompression procedures for the flightcrew must be included in the emergency procedures section of the AFM. This information should also be included in the flightcrew operating manual (FCOM). This guidance is premised on operators fulfilling the initial and recurrent emergency training provisions in accordance with §§ 121.397, 121.417, and 121.427 for all crewmembers, including training for a rapid decompression and donning of oxygen masks. This guidance is also premised on operators and flight crewmembers complying with the requirements of §§ 91.211, 121.333 or 135.157, as applicable. In addition, normal operating procedures should be included in the AFM to ensure that the quantity of supplemental oxygen before each flight is sufficient for the intended operation. The primary means to ensure occupant survivability rests in quickly bringing the occupants to a cabin pressure where they can survive (i.e., a lower cabin pressure altitude as given in Table 2 of this AC). Airplane manufacturers should use design features that facilitate rapid airplane descent from high altitudes to ensure that the occupants will not be subjected to pressure altitudes for durations longer than those given in Table 2 of this AC.

7.15 Due to the uncertainty in the potential severity of the cabin environment following decompression and the uncertainty in the response of the occupants to that environment, the FAA is following the recommendation of the ARAC MSHWG Report[21] that recommends that regulatory authorities impose both quantitative and qualitative means to demonstrate compliance. This is not unlike the requirements that exist in § 25.1309.

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[21] FAA ARM Package MSHWG Final Reports 25-831g and 25-841a.pdf. https://www.faa.gov/regulations_policies/rulemaking/committees/documents/media/TAEmsh-vhhcp-07262001.pdf

8 DEPRESSURIZATION ANALYSIS.

8.1 Sections 25.841(a) and 25.1447(c) are intended to ensure that, following a failure or combination of failures leading to a decompression at the maximum certificated altitude, the flightcrew will remain alert and able to safely fly and land the airplane; and occupants of the cabin will be provided reasonable protection from the effects of hypoxia. Section 25.841(a)(2) is intended to prevent exposing the airplane occupants to extreme environmental conditions resulting from any system failure not shown to be extremely improbable, or any structural failure considered under § 25.571(b) or (e)(1). In addition, § 25.841(a)(3) is intended to prevent exposing the airplane occupants to extreme environmental conditions resulting from any UEF not shown to be extremely improbable. Pilots should follow the approved emergency descent procedures following these failure events. Compliance must be demonstrated by airplane flight tests, as required in § 25.841(a)(4) for the failure condition having the most severe effect. In addition, all failure conditions should be reviewed by performing a decompression analysis to ensure compliance.

8.2 A decompression analysis consists of a review of failure conditions that can result in a loss of pressurization control of the airplane and the resulting airplane response. Typically, compliance is demonstrated by analysis, where an applicant calculates the cabin pressure-time history using the failure condition that results in a critical hole size and location, and accounting for the specific design features and operational procedures (i.e., AFM emergency procedures) of the airplane, and calculates the airplane response via an emergency descent profile.

8.3 The analysis should start at the maximum airplane altitude and, as necessary to show compliance, use appropriate emergency descent procedures. Typical probable pressurization failures, similar to ventilation failures, are failures of a single air conditioning bleed system, failures of dual air conditioning systems or dual bleed air systems when the systems have common control systems, or other similar single failures. Other probable failure conditions that should be considered involve failures in the outflow valve control or the outflow valve itself. Structural failures/cracks should be considered in the analysis as the maximum pressure vessel opening resulting from an initially detectable crack propagating for a period encompassing four normal inspection intervals. Mid-panel cracks and cracks through skin-stringer and skin-frame combinations must be evaluated in accordance with § 25.571.

8.4 The worst-case rapid decompression may occur because of a single large hole (e.g., 1/3rd rotor disk UEF with a fuselage tangential strike) or a combination of failures (e.g., slightly less than 1/3rd rotor disk UEF with debris that strike the fuselage producing a smaller hole than the 1/3rd rotor disk failure PLUS debris that results in loss of control surfaces preventing full deflection and resulting in a slower descent). The methodology and assumptions defined in AC 20-128B, *Design Considerations for Minimizing Hazards caused by Uncontained Turbine Engine and Auxiliary Power Unit Rotor Failure*, may be used to perform the engine analysis for the 1/3rd rotor disk failure. A discharge coefficient of the resulting hole of 0.75[22] should be used by applicants for all window and fuselage penetrations unless the applicant provides corroborating analysis and test data to show that a different discharge coefficient should be used. Applicants may use a conservative methodology for a worst-case scenario by assuming that the 1/3rd rotor disk UEF results in a large enough hole that results in cabin pressure reaching ambient pressure immediately.

8.5 However, when evaluating the risk to the airplane and occupants from engine debris less than the 1/3rd rotor disk UEF, the applicant should perform the analysis using an engine debris model to determine the critical components likely to be damaged by the debris and to evaluate the consequences. For example, the FAA Aircraft Catastrophic Failure Prevention Program (CFPP) resulted in the creation of the Uncontained Engine Debris Damage Assessment Model (UEDDAM). The FAA Aircraft CFPP included several activities addressing uncontained engine debris[23]. In one such activity, the FAA tasked the U.S. Naval Air Warfare Center Weapons Division (NAWCWPNS) at China Lake, CA to develop an uncontained engine debris analysis tool to assess effects of uncontained engine debris on airplane and which could be used for airplane design, assessment, and certification. NAWCWPNS selected SURVICE Engineering with UEDDAM tool development. The use of UEDDAM is one recommended method. The FAA does not mandate the use of UEDDAM but the FAA must[24] find the engine debris model used by the applicant in certification acceptable.

8.6 When an engine experiences an uncontained failure and releases debris, the actual trajectories that the fragments travel are affected by multiple factors. The specific design and operation of the airplane, the design of the engine, the size and shape of the debris, the location of the engine and the rotational and translational energy that the debris has affect the trajectory. The debris that results in the largest hole (i.e., 1/3rd of a disk) is described in AC 20-128B. The debris may exit the engine at any rotational spread angle (0° through 360°) and through any angles fore/aft of the rotational plane of the section of the engine responsible for the debris (See Figure 2 and Figure 3). While the guidance in AC 20-128B restricts these angles to specific limits, historical data used in creating the UEDDAM show a broader extent of intermediate and small fragment trajectories. Applicants should consider this information in their assessment of the debris likely to impact the airplane as shown in Figure 4.

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[22] AC 25-20, Pressurization, Ventilation and Oxygen Systems Assessment for Subsonic Flight including High Altitude Operations, contains guidance that an applicant should use a discharge coefficient of 0.5 for the resulting hole from loss of a window or fuselage penetrations. The MSHWG could not locate corroborating information regarding selection of a discharge coefficient of 0.5 and the group reached a consensus that a discharge coefficient of 0.75 was reasonable for most penetrations.

[23] See reference sections 4.3.22 through 4.3.28 of this AC.

[24] 14 CFR Part 21.33 and 25.21

Figure 2. Engine debris emerging from a simplified model of an engine and potential trajectories.

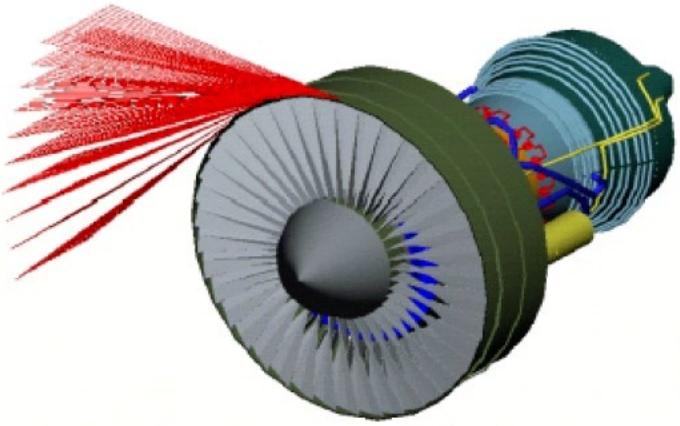


Figure 3. Engine debris emerging from a simplified model of an engine and potential trajectories.

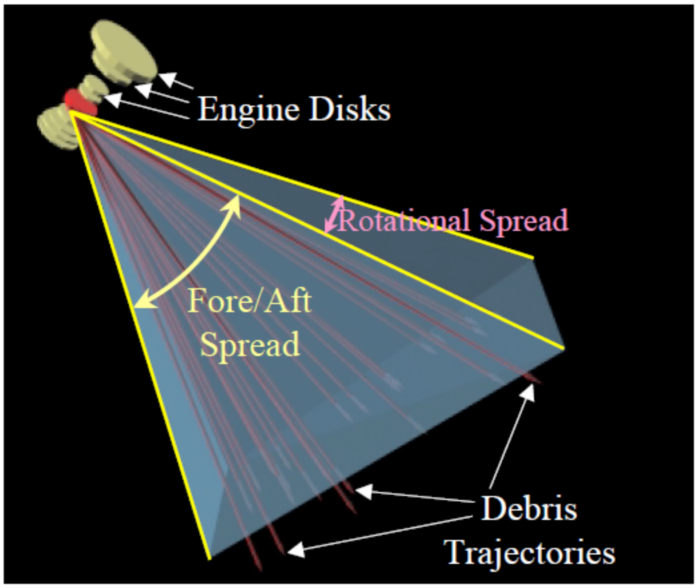
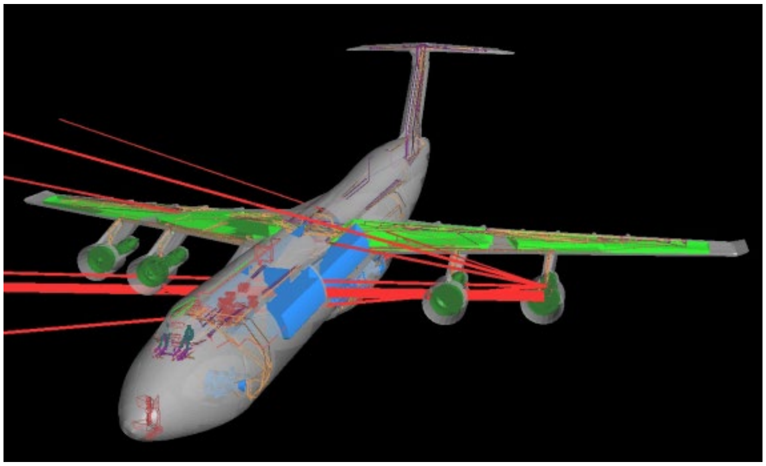


Figure 4. Engine debris trajectories for a representative airplane.



8.7 The resulting engine debris analysis and decompression analysis will provide estimates of the time that the cabin pressure altitude will reach ambient and the airplane response by performing the emergency descent (as shown in Figure 1 of this AC) per the AFM procedures. Applicants should coordinate with their certification branch project manager, who will coordinate with the FAA Flight Test Branch, on the draft airplane flight procedure following a rapid decompression and describe the use of any special features (e.g., an automatic or pilot-initiated emergency descent feature that will reconfigure the airplane for an emergency V_{MO}/M_{MO} descent) that may be used during the flight test. The intent of the flight test is to show that the airplane is capable of performing an emergency descent that limits the maximum total exposure time above the indicated altitudes as required in Table 2 of this AC.

9 FLIGHT TEST COMPLIANCE DEMONSTRATION.

9.1 Regardless of the results of the physiological analysis, uncontained engine analysis, airplane descent performance model, cabin decompression model, all applicants must demonstrate by flight testing that their airplane model is capable of descent from the maximum cruise altitude within the times shown in Table 2 and Table 3 of this AC to successfully demonstrate compliance to § 25.841(a) at Amendment 25-XXX. The FAA has not accepted aerodynamic performance analysis predictions in lieu of certification flight-testing for dynamic conditions (e.g., an emergency descent from cruise altitude to Flight Level 100 or 10,000 feet). In addition, in certain cases where the FAA has accepted analytical airplane performance models during steady-state conditions in lieu of test data, the FAA has required that the predictions of the model be validated by certification test data. It is likely that any such request to use aerodynamic performance analysis to demonstrate compliance to § 25.841(a) at Amendment 25-XXX would require an airplane certification flight test to provide data to validate the aerodynamic performance analysis predictions. FAA considers that this guidance follows the recommendations of industry[25] and the precedents established in FAA exemptions to § 25.841(a) at Amendment 25-87[26].

9.2 For certification tests, the airplane and relevant systems should be in the type design configuration. The flight test should consider the results of a safety assessment on the damage that can occur in the event of an uncontained engine rotor and ensure that the airplane's design features and operational procedures can result in successful compliance. In demonstrating compliance with § 25.841(a), it should be assumed that the oxygen equipment is being used above an airplane operational altitude of 41,000 feet and that an emergency descent is made in accordance with an approved emergency procedure in the AFM as required in § 25.1585. Crew recognition time for decompression and oxygen mask donning time should be applied between the cabin altitude warning and the beginning of action for descent.

9.3 Applicants should consider MMEL dispatch configurations (e.g., speed brakes manual control system) and the potential to adversely impact emergency descent that would lead to limits on airplane cruise altitude. The FAA will limit the maximum operating altitude to an appropriate level for all entries that could affect the descent performance unless otherwise demonstrated compliance with § 25.841(a).

9.4 Applicants should coordinate with their FAA certification branch project manager, who will coordinate with the FAA Flight Test Branch on the draft AFM procedure following a rapid decompression and the use of special features (e.g., an automatic or pilot-initiated emergency descent feature, which will reconfigure the airplane for an emergency V_{MO}/M_{MO} descent), which may be used during the flight test. The intent of the flight test is to show that the airplane is capable of performing an emergency descent per Table 2 and Table 3 of this AC.

9.5 While some variation in the actual flight test conditions may occur due to specific details of the airplane and engine design, applicants should follow these test condition guidelines:

9.5.1 Starting Altitude.

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[25] The "Mechanical Systems Harmonization Working Group (MSHWG) Final Report on FAR 25.841(a)(2,3)," dated July 24, 2003, the ARAC MSHWG recommended [page 53] that "*Analysis and test data shall be provided to successfully demonstrate compliance.*" The report is available in the docket and at https://www.faa.gov/regulations_policies/rulemaking/committees/documents/index.cfm/document/information/documentID/429.

[26] As explained in the NPRM and in this AC this requirement is based upon an ARAC MSHWG Report on 25.841(a)(2)&(3) and on FAA Grants of Exemption to 14 CFR Part 25.841(a)(2) at Amendment 25-87. The ARAC MSHWG recommended [page 53] that "Analysis and test data shall be provided to successfully demonstrate compliance." FAA retained the recommendation in the grants of exemption. All grants of exemption included a condition that the petitioner must submit certification flight test data for their model airplane to corroborate that, after decompression at the maximum certificated airplane indicated operating pressure altitude, the cabin pressure altitude will not exceed 25,000 feet for more than 3 minutes or 40,000 feet for more than 1 minute. Examples of exemptions that the FAA has issued are available for download at https://www.regulations.gov/ (e.g., search for "Exemption No. 8695" or "Exemption No. 10962").

The airplane maximum operational altitude (e.g., 45,000 feet) as stated in the airplane flight manual.

9.5.2 Starting Airplane Configuration.

Typical cruise values of airplane weight and center-of-gravity (cg).

9.5.3 Starting Mach Number.

The airplane should be at the maximum achievable Mach number in normal cruise operations. Applicant should discuss with the FAA the use of auto-pilot (AP) and the appropriate limitations in speed targeting (e.g., at cruise the maximum Mach number with AP - ON targeting may be MMO - 5kts) and the use of auto-thrust.

9.5.4 Starting Time.

The test engine simulating the one engine inoperative (OEI) condition (i.e., the engine designated as experiencing the uncontained failure) should not be shut down. The test engine should be placed in flight idle throughout the maneuver. The test condition begins at this time, assumed UEF and immediate cabin pressure warning at 10,000 cabin pressure resulting in Time=Zero.

9.5.5 A 17-second delay after decompression (i.e., cabin pressure warning annunciation at 10,000 feet cabin pressure) for oxygen mask donning, crew recognition of the problem, and establishment of crew communications should be applied between cabin altitude warning and initiation of action to configure for descent. The 17-second time delay is considered appropriate for designs with quick donning oxygen masks (i.e., 5 seconds to don) for pilots, clear annunciation of the pressurization warning (visual and auditory), and well understood (memory) AFM procedures. The FAA Flight Test Branch pilot input will confirm if these conditions are met for an applicant’s design and intended AFM procedure prior to the actual flight test.

9.5.6 For airplanes that use hydraulic power to control spoilers, ailerons, and other airflow devices that are deployed in the event of an emergency descent configuration, the airplane hydraulic system should be configured to simulate the resulting loss of their function following the OEI. For example, this may include loss of one hydraulic system and subsequent loss of single or multiple airplane spoilers. For systems that use electrical power to control spoilers, ailerons, and other airflow devices to enhance descent performance, the airplane electrical system should be configured to simulate the resulting loss of function following OEI. The resulting configurations should be reviewed and found to be the most conservative case given an OEI condition.

9.5.7 Unless the airplane design incorporates an automatic or pilot-initiated emergency descent feature which will reconfigure the airplane for an emergency V_{MO}/M_{MO} descent prior to 17 seconds, initiation of the descent should begin 17 seconds after the test engine has been placed in flight idle. As noted previously, 17 seconds simulates crew reaction time after the UEF condition. If the airplane does incorporate an automatic or pilot-initiated emergency descent feature, which will reconfigure the airplane for an emergency V_{MO}/M_{MO} descent, then the applicant should discuss with the FAA when initiation of the emergency descent should occur.

9.5.7.1 If the applicant desires to perform the test with an automatic emergency descent feature that reconfigures the airplane for an emergency V_{MO}/M_{MO} descent once a preset pressure value is reached, then the pressure source to the sensor should be controlled to simulate the activation pressure. Initiation of the descent would start upon activation of the automatic emergency descent feature.

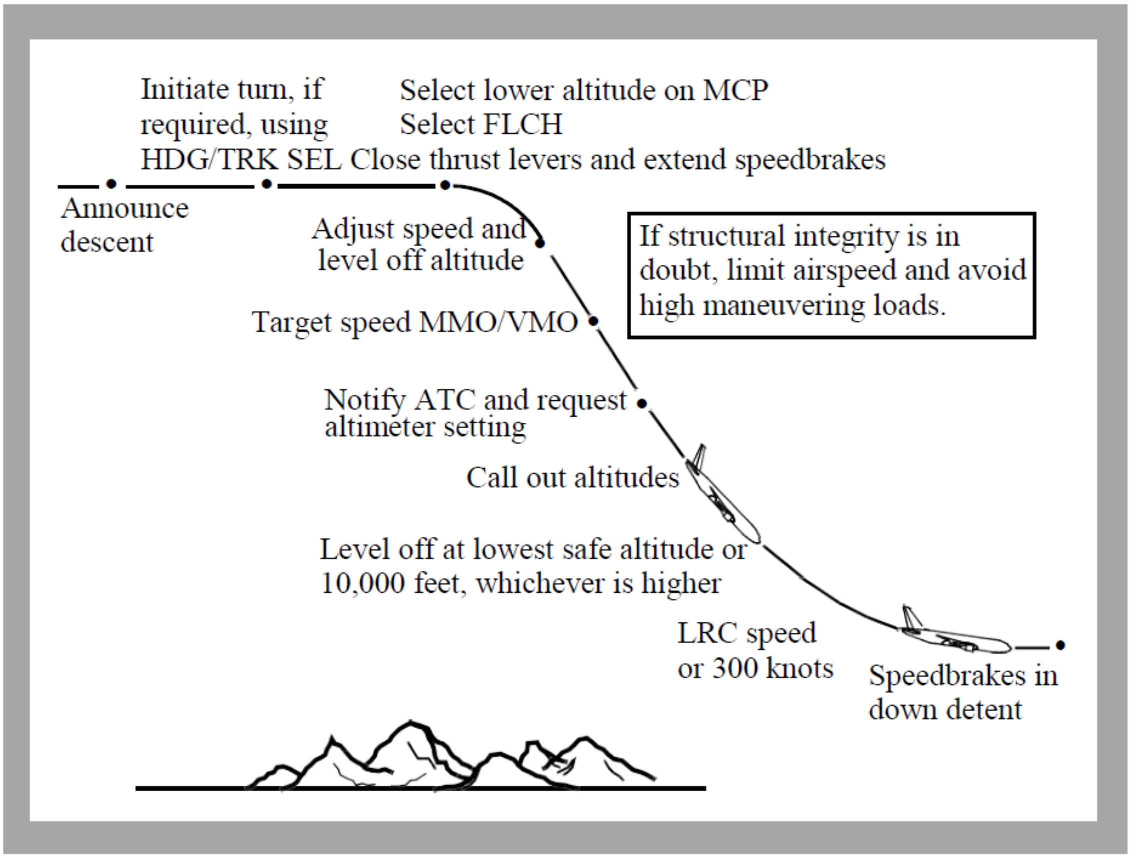
9.5.7.2 If the applicant desires to perform the test with a pilot-initiated emergency descent feature that reconfigures the airplane for an emergency V_{MO}/M_{MO} descent once a pilot activates the system, then initiation of the descent would start upon activation of the pilot-initiated emergency descent feature. However, this should not occur at a time prior to the accepted time of 5 seconds for a pilot to don a quick donning oxygen mask.

9.5.8 The airplane should perform a continuous descent from the maximum cruise altitude/flight level (FL) to FL100 (10,000 feet) (i.e., spoilers fully deployed if appropriate, maximum descent rate, V_{MO}/M_{MO} speed). The instructions in the AFM should be clear and based on typical and conservative pilot training. For example, the FAA expects that typical transport category airplanes would perform an emergency descent with AUTOPILOT ON and straight ahead. During the emergency descent the airplane maneuvers flown (e.g., airplane bank angles during the descent) should not exceed those maneuvers that typical airlines pilots would be expected to perform. The FAA may place a limit to the flight maneuvers during emergency descent to ensure less experienced pilots would be able to fly the maneuver.

9.5.9 The demonstration flight test should be conducted in good weather with no head/tailwind gradients, a stable atmosphere, no temperature inversion, and with an average delta-International Standard Atmosphere (ISA) close to zero.

9.5.10 The time that the airplane passes through 40,000 feet; 25,000 feet; and 10,000 feet should be recorded. Additional parameters of interest include airplane flight altitude, airplane flight speed, airplane Mach number, airplane bank angle, airplane heading, cabin pressure, cabin delta pressure, engine throttle settings, control surface positions, and pressure outflow valve positions.

Figure 5. Airplane Emergency Descent.



10 BENEFITS AND RISKS OF HIGH-ALTITUDE FLIGHT.

10.1 The FAA believes that § 25.841 at amendment 25-XX, provides benefits to the traveling public and industry. However, as addressed in section 7 of this AC, there is risk to occupant safety with this change. Permitting airplanes to fly above 40,000 feet offers real and tangible benefits to the traveling public, the aerospace industry, and the U.S. economy by lowering congestion, improving fuel economy, and lowering pollution. The ARAC MSHWG provided compelling economic information on the severity of retaining the current § 25.841(a)(2) for wing-mounted engine transport airplanes. The material that the ARAC MSHWG presented provides additional information that FAA considered, and it is included in Appendix A2.

Appendix A. Definitions.

A.1 TERMS USED THROUGHOUT THIS ADVISORY CIRCULAR.

A.1.1 Hypoxia.

Hypoxia is an insufficient supply of oxygen. Hypoxia results from the reduced oxygen partial pressure in the inspired air caused by the decrease in barometric pressure with increasing altitude.

A.1.2 Physiological Altitude Limits.

A.1.2.1 This refers to the altitude that a person begins to experience detrimental physiological effects. The response of human beings to increased altitude varies with the individual. People who smoke or are in poor health will be affected at a much lower altitude than people who are young and in good physical condition. In addition, infants, young children and elderly are at an increased level of risk.

A.1.2.2 The FAA has found that there have been fatalities of elderly passengers using supplementary oxygen during some probable failure events that have occurred on commercial flights. The cabin pressure altitude that occurred during these events was not severe (i.e., the cabin pressure was below 14,990 feet pressure altitude and the built-in oxygen masks did not deploy). However, these passengers succumbed to the exposure to hypoxic conditions during the decompression. Without supplementary oxygen, most people will begin to experience a reduction in night vision or general visual acuity at approximately 5,000 feet altitude.

A.1.2.3 At an altitude of approximately 10,000 feet, a person will begin to display measurable deterioration in mental abilities and physical dexterity after a period of several hours. At 18,000 feet, the mental deterioration may result in unconsciousness, and the Time of Useful Consciousness (TUC) is generally about 15 minutes. At 25,000 feet, the TUC for most people ranges from 3 to 10 minutes. At altitudes above 25,000 feet, the TUC decreases very rapidly, becoming only a few seconds at 40,000 feet. If a person is breathing 100 percent oxygen, however, the partial pressure of oxygen in the lungs at 34,000 feet altitude is the same as that for a person breathing air at sea level. At 40,000 feet, a person breathing 100 percent oxygen will have the same partial pressure of oxygen in the lungs as a person breathing air at 10,000 feet. Therefore, 34,000 feet is the highest altitude at which a person would be provided complete protection from the effects of hypoxia, and 40,000 feet is the highest altitude at which 100 percent oxygen will provide reasonable protection for the limited period of time needed to descend to a safe altitude.

A.1.3 Probable Failures.

Probable failures are failures anticipated to occur one or more times during the entire operational life of each airplane. The probability of occurrence is on the order of 1×10^{-5} or greater (see AC 25.1309-1A). The consequences of the failure or the required corrective action may not significantly impact the safety of the airplane or the ability of the crew to cope with adverse operating conditions.

A.1.4 Improbable Failures.

Improbable failures are failures that are not expected to occur during the total operational life of a random single airplane of a particular type, but that may occur during the total operational life of all airplanes of a particular type. The probability of occurrence is on the order of 1×10^{-5} or less, but greater than 1×10^{-9}. The consequences of the failure or the required corrective action must not prevent the continued safe flight and landing of the airplane.

A.1.5 Extremely Improbable Failures.

Extremely improbable failures are failures so unlikely that they need not be considered to ever occur, unless engineering judgment would require their consideration. The probability of occurrence is on the order of 1×10^{-9} or less. This category includes failures or combinations of failures that would prevent the continued safe flight and landing of the airplane.

A.1.6 Diluter Demand Oxygen System.

A flightcrew oxygen system consisting of a close-fitting mask with a regulator that supplies a flow of oxygen dependent upon cabin altitude. Regulators approved for use up to 40,000 feet are designed to provide zero percent cylinder oxygen and 100 percent cabin air at cabin altitudes of 8,000 feet or less, with the ratio changing to 100 percent oxygen and zero percent cabin air at approximately 34,000 feet cabin altitude. Regulators approved up to 45,000 feet are designed to provide forty percent cylinder oxygen and 60 percent cabin air at lower altitudes, with the ratio changing to 100 percent at the higher altitude. Oxygen is supplied only when the user inhales, reducing the amount of oxygen that is required.

A.1.7 Pressure Demand Oxygen System.

An oxygen system similar to diluter demand equipment, except that oxygen is supplied to the mask under pressure at cabin altitudes above approximately 34,000 feet. This pressurized supply of oxygen provides some additional protection against hypoxia at altitudes up to 40,000 feet.

A.1.8 Pressure Demand Mask with Mask-Mounted Regulator.

A pressure demand mask with the regulator attached directly to the mask, rather than mounted on the instrument panel or other area within the flightdeck. The mask-mounted regulator eliminates the problem of a long hose that must be purged of air before 100 percent oxygen begins flowing into the mask.

A.1.9 Continuous Flow Oxygen System.

The oxygen system usually provided for passengers. The passenger mask typically has a reservoir bag, which collects oxygen from the continuous flow oxygen system during the time when the mask user is exhaling. The oxygen collected in the reservoir bag allows a higher inspiratory flow rate during the inhalation cycle, which reduces the amount of air dilution. Ambient air is added to the supplied oxygen during inhalation after the reservoir bag oxygen supply is depleted. The exhaled air is released to the cabin.

A.1.10 V_{MO}.

An airplane V_{MO} is the recommended maximum operating velocity/speed for the airplane.

A.1.11 M_{MO}.

An airplane M_{MO} is the recommended maximum operating Mach number for the airplane.

A.1.12 Bypass Ratio Engine.

Current generation gas turbine engines may be categorized by bypass ratio. Bypass ratio is the ratio of the mass-flow of air bypassing the engine core traveling and through the fan, compared to the mass-flow of air passing through the core and traveling through the combustor and turbine.

A.1.13 MEA – Minimum En Route Altitude (MEA).

The MEA is the lowest published altitude between radio fixes that assures acceptable navigational signal coverage and meets obstacle clearance requirements between those fixes.

A.1.14 MORA – Minimum Off Route Altitude (MORA).

The minimum off-route altitude named MORA is an altitude that provides 2,000 feet of terrain clearance in mountainous areas and 1,000 feet in non-mountainous regions; at the same time it provides a reference point of clearance of 10 nm from the route centerline.

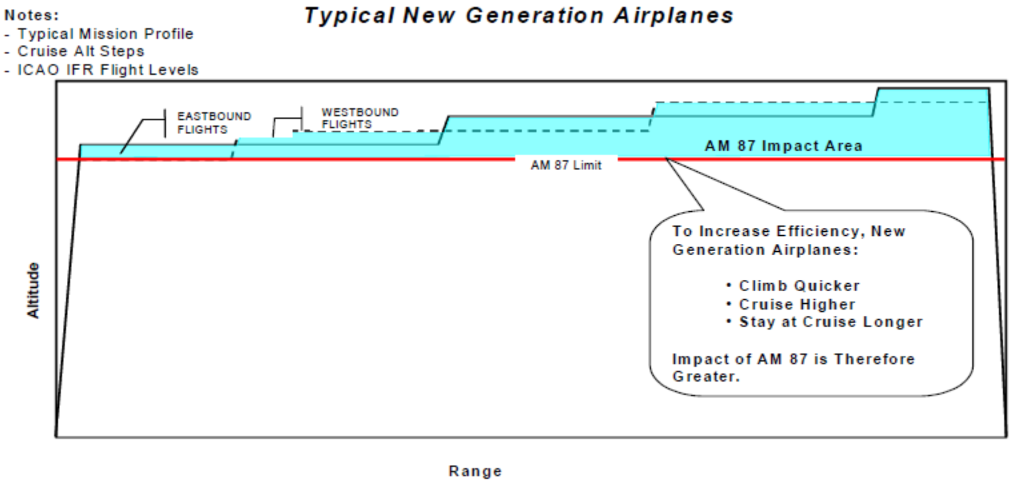
A.2 BENEFITS AND RISKS OF HIGH-ALTITUDE FLIGHT.

A.2.1 As determined by the ARAC MSHWG, if compliance with § 25.841 at amendment 25 87 limited airplanes operations to a maximum altitude of 40,000 feet, this would impose a significant disadvantage to newly designed airplanes that have safety advantages over older airplanes currently allowed to operate at higher altitudes. Additionally, compliance with § 25.841 at amendment 25-87 would delay the introduction of these airplanes and the benefits of advanced technology. Similarly, the ARAC MSHWG reported that the provisions of § 25.841(a)(2) and (3) at amendment 25-87, if left unchanged, would limit new or derivative transport airplanes with wing-mounted engines to operating altitudes well below 40,000 feet. This has major cost impacts as new or changed airplane models may not be able to compete with previously certificated airplanes, which did not have to comply with the requirements at amendment 25-87. Airplanes certificated at amendment 25-87 would be limited to altitudes of 37,000 to 39,000 feet under § 25.841 and would no longer be able to compete with earlier certificated airplanes that can operate at altitudes above 40,000 feet.

A.2.2 The cost impact of amendment 25-87 to the aviation industry and the flying public, both here in the United States and in Europe, is predicted to be significant[27]. While it is difficult to place specific dollar impact on these requirements, it is clear that most new airplane programs are severely impacted, as they must request exemptions. No high-altitude (above 39,000 feet maximum altitude) airplane with wing-mounted engines certified today can meet the new altitude limits with the current § 25.841(a)(3).

A.2.3 A primary concern of industry is that new and derivative airplanes with wing-mounted engines designed to meet § 25.841 as amended at amendment 25-87 will have significantly higher design and operating costs than currently certified airplanes. These higher costs will impact the ability of manufacturers to introduce new airplanes that can compete with previously approved airplanes. The economic viability of transport category airplanes with wing-mounted engines under development would suffer, because maximum operating altitudes would be limited to around 35,000 to 39,000 feet under the current rule.

Figure 6. Cruise Altitude for Best Fuel Burn.



Note: Figure 6 above illustrates that typical cruise altitudes for new generation airplanes (e.g., Airbus A350, Boeing 787, etc.) would be adversely impacted by restrictions in maximum cruise altitude to remain within the requirements of § 25.841(a)(2) at amendment 25-87.

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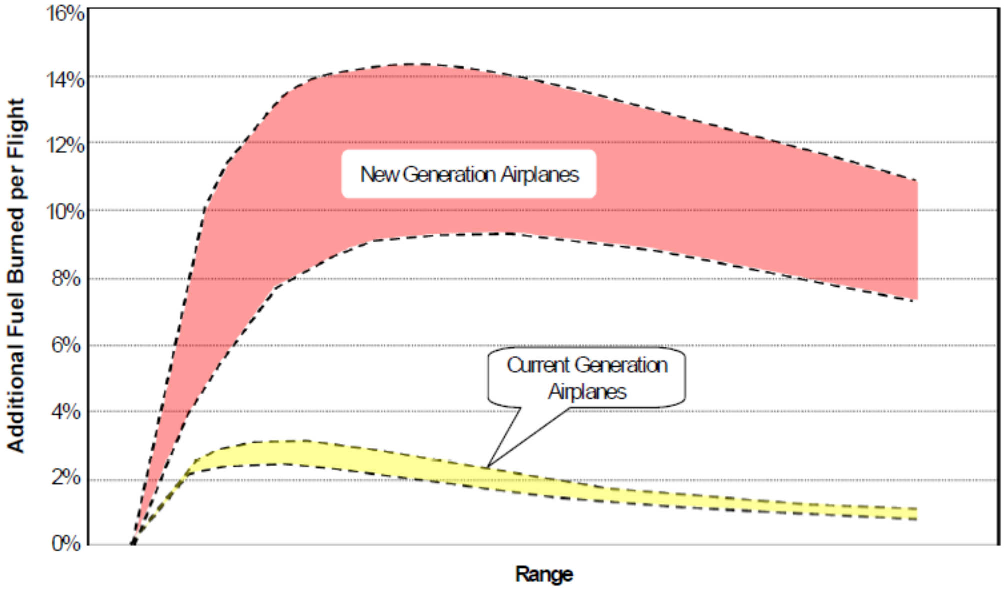
[27] See FAA ARM Package MSHWG Final Reports 25-831g and 25-841a.pdf (https://www.faa.gov/regulations_policies/rulemaking/committees/documents/media/TAEmsh-vhhcp-07262001.pdf).

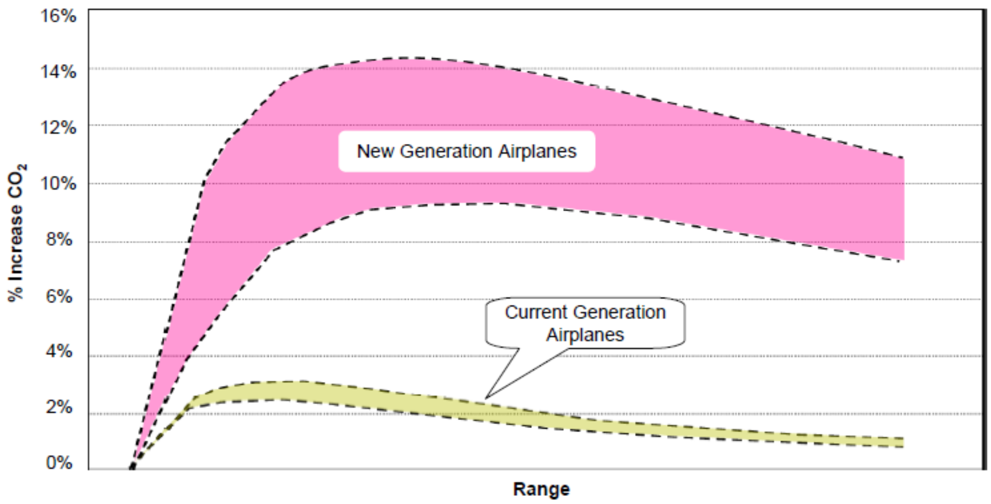
Figure 7. Additional Fuel Burned Due to Amendment 25-87 Imposed Altitude Limits.



AM 87 Significantly Diminishes Fuel Efficiency of New Generation Airplanes

Note: Figure 7 above shows that fuel burn for new generation airplanes (e.g., Airbus A350, Boeing 787, etc.) would be adversely impacted by restrictions in maximum cruise altitude to remain within the requirements of § 25.841(a)(2) at amendment 25-87.

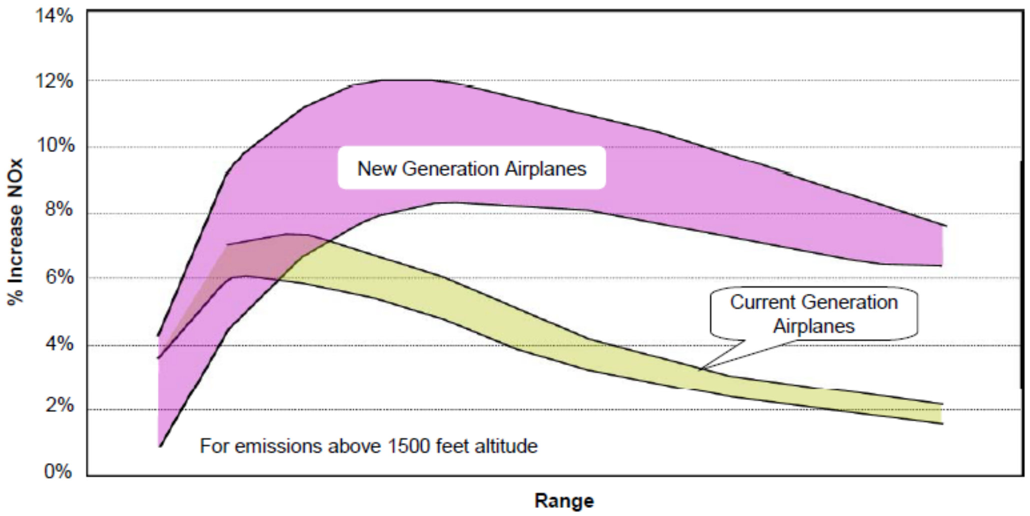
Figure 8. Increased CO2 Emissions Under Amendment 25-87 Imposed Altitude Limits.



AM 87 Has A Potential Negative Effect On The Environment

Note: Figure 8 above shows that carbon dioxide (CO_2) emissions for new generation airplanes (e.g., Airbus A350, Boeing 787, etc.) would be adversely impacted by restrictions in maximum cruise altitude to remain within the requirements of § 25.841(a)(2) at amendment 25-87.

Figure 9. Increased NOx Emissions Under Amendment 25-87 Imposed Altitude Limits.

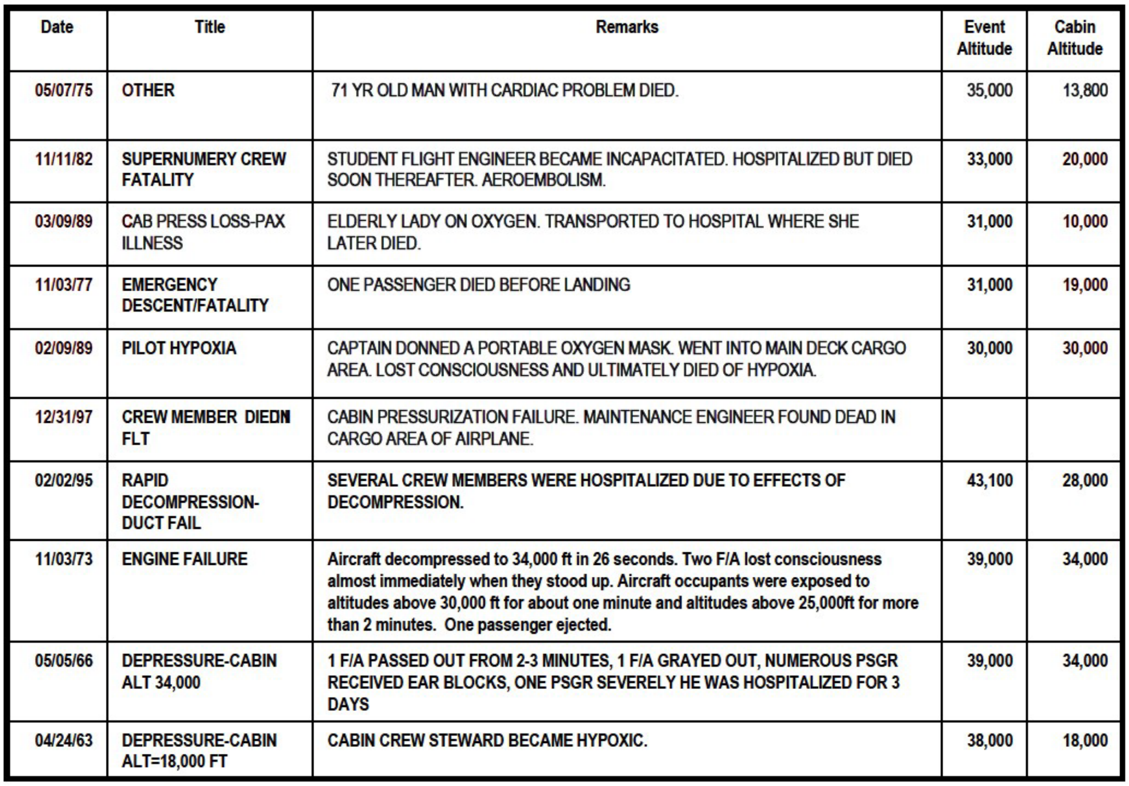


Note: Figure 9 above shows that nitrous oxide (NO_x) emissions for new generation airplanes (e.g., Airbus A350, Boeing 787, etc.) would be adversely impacted by restrictions in maximum cruise altitude to remain within the requirements of § 25.841(a)(2) at amendment 25-87.

A.2.4 The FAA acknowledges that there is an increased level of risk to occupants from a rapid decompression at altitude. The following information may help in understanding the overall risk. Previously certified large transport category airplanes incorporating established design practices have safely operated at altitudes in excess of 40,000 feet for more than 20 years, representing many millions of flight hours. Historically, relatively few accidents or incidents have occurred during cruise. According to the statistics, only 6 percent of accidents in the worldwide commercial fleet history have occurred during cruise; even though the highest percentage of the flight time (57 percent) is at cruise. Industry experience shows that very few cases of catastrophic decompressions at high altitude have occurred, notably in small business jets.

A.2.5 In the MSHWG Report, the FAA cited three cases as examples of rotor burst in cruise. In one case, a DC-10 crossing New Mexico (near Albuquerque) reported several cases of initial decompression sickness apparently with no permanent injuries. However, it was noted that 24 passengers and crewmembers were brought to the hospital at Kirtland AFB for treatment of symptoms including hypoxia. Because there was no follow-up on these occupants, there is no way to assess the extent of injuries sustained during this decompression event. In this case, it is believed by industry that rotor burst was induced via crew action. In the second case (near Sioux City, Iowa), the airplane damage was aft of the pressure bulkhead, thus no rapid decompression occurred. The FAA cites this event to estimate the damage if the debris field had been forward of the pressure bulkhead. In the third case (near Pensacola, Florida), the airplane was on takeoff when the event occurred (not cruise) and the flightdeck crew successfully performed a rejected takeoff. Thus, this case did not encounter a rapid decompression. Figure 16 depicts the historical uncontained engine failure total fuselage hole areas along with the Sioux City and Pensacola events shown. The FAA cited these three cases because they were "data rich" events (i.e., approximate number of impacts from uncontained engine debris recorded; dimensions of penetrations/holes recorded; some debris recovered; etc.). In addition to the "data rich" events discussed above, there have been another nine UEF at cruise identified to the FAA.

Table 4. Significant Transport Category Decompression Events.[28]



Date	Title	Remarks	Event Altitude	Cabin Altitude
05/07/75	OTHER	71 YR OLD MAN WITH CARDIAC PROBLEM DIED.	35,000	13,800
11/11/82	SUPERNUMERY CREW FATALITY	STUDENT FLIGHT ENGINEER BECAME INCAPACITATED. HOSPITALIZED BUT DIED SOON THEREAFTER. AEROEMBOLISM.	33,000	20,000
03/09/89	CAB PRESS LOSS-PAX ILLNESS	ELDERLY LADY ON OXYGEN. TRANSPORTED TO HOSPITAL WHERE SHE LATER DIED.	31,000	10,000
11/03/77	EMERGENCY DESCENT/FATALITY	ONE PASSENGER DIED BEFORE LANDING	31,000	19,000
02/09/89	PILOT HYPOXIA	CAPTAIN DONNED A PORTABLE OXYGEN MASK. WENT INTO MAIN DECK CARGO AREA. LOST CONSCIOUSNESS AND ULTIMATELY DIED OF HYPOXIA.	30,000	30,000
12/31/97	CREW MEMBER DIED IN FLT	CABIN PRESSURIZATION FAILURE. MAINTENANCE ENGINEER FOUND DEAD IN CARGO AREA OF AIRPLANE.		
02/02/95	RAPID DECOMPRESSION-DUCT FAIL	SEVERAL CREW MEMBERS WERE HOSPITALIZED DUE TO EFFECTS OF DECOMPRESSION.	43,100	28,000
11/03/73	ENGINE FAILURE	Aircraft decompressed to 34,000 ft in 26 seconds. Two F/A lost consciousness almost immediately when they stood up. Aircraft occupants were exposed to altitudes above 30,000 ft for about one minute and altitudes above 25,000ft for more than 2 minutes. One passenger ejected.	39,000	34,000
05/05/66	DEPRESSURE-CABIN ALT 34,000	1 F/A PASSED OUT FROM 2-3 MINUTES, 1 F/A GRAYED OUT, NUMEROUS PSGR RECEIVED EAR BLOCKS, ONE PSGR SEVERELY HE WAS HOSPITALIZED FOR 3 DAYS	39,000	34,000
04/24/63	DEPRESSURE-CABIN ALT=18,000 FT	CABIN CREW STEWARD BECAME HYPOXIC.	38,000	18,000

Table 4 continued on next page.

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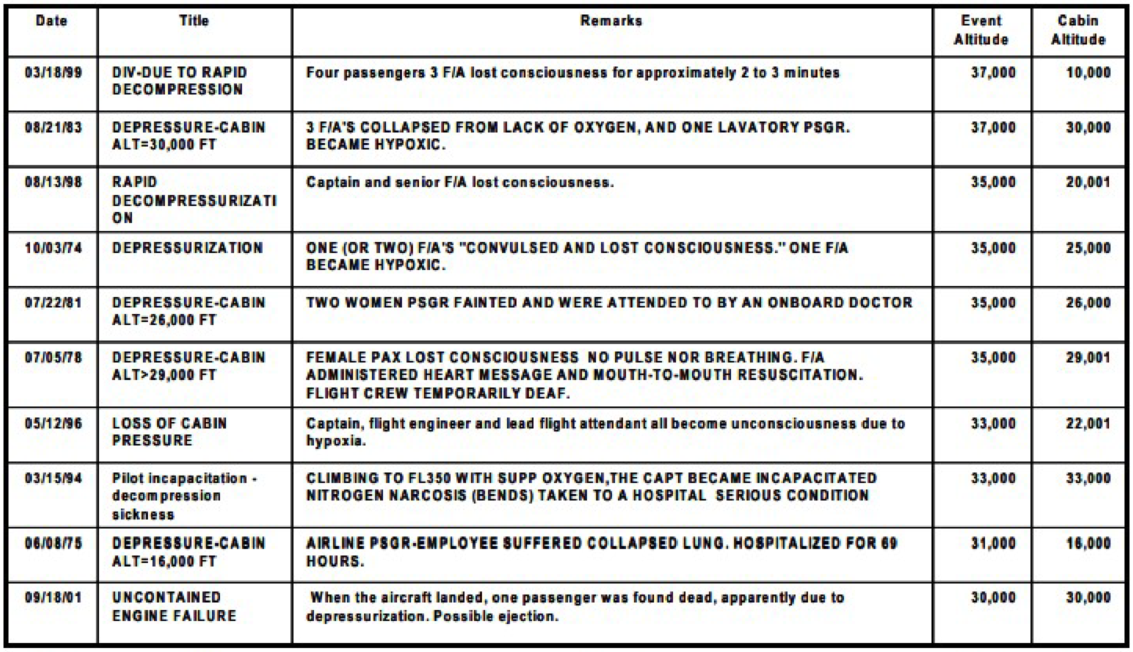
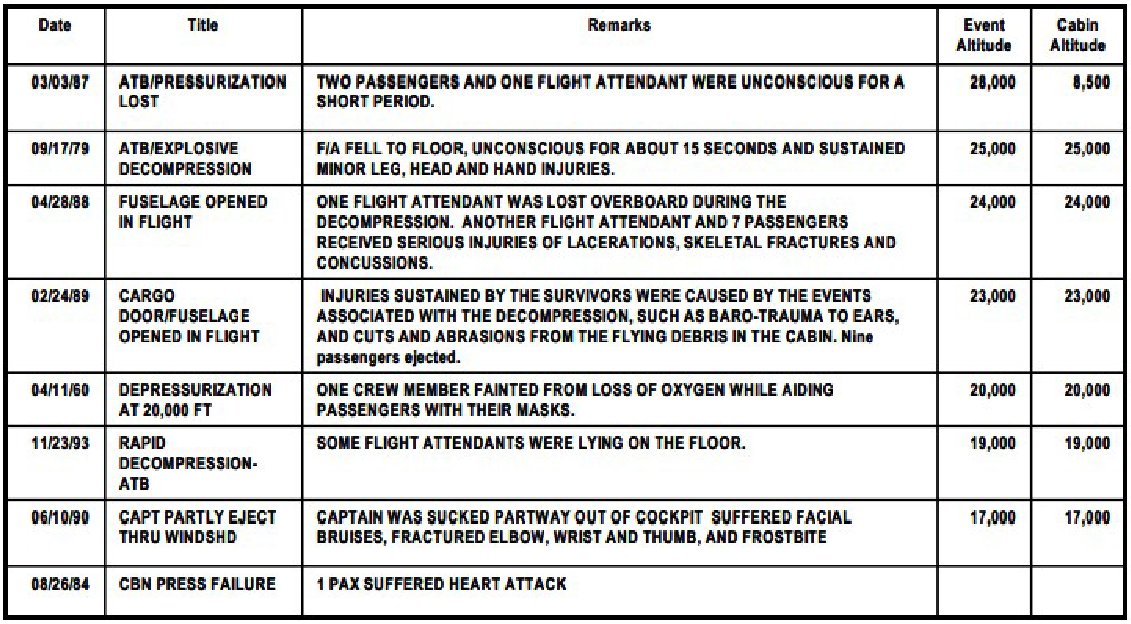
[28] See FAA ARM Package MSHWG Final Reports 25-831g and 25-841a (https://www.faa.gov/regulations_policies/rulemaking/committees/documents/media/TAEmsh-vhhcp-07262001.pdf).



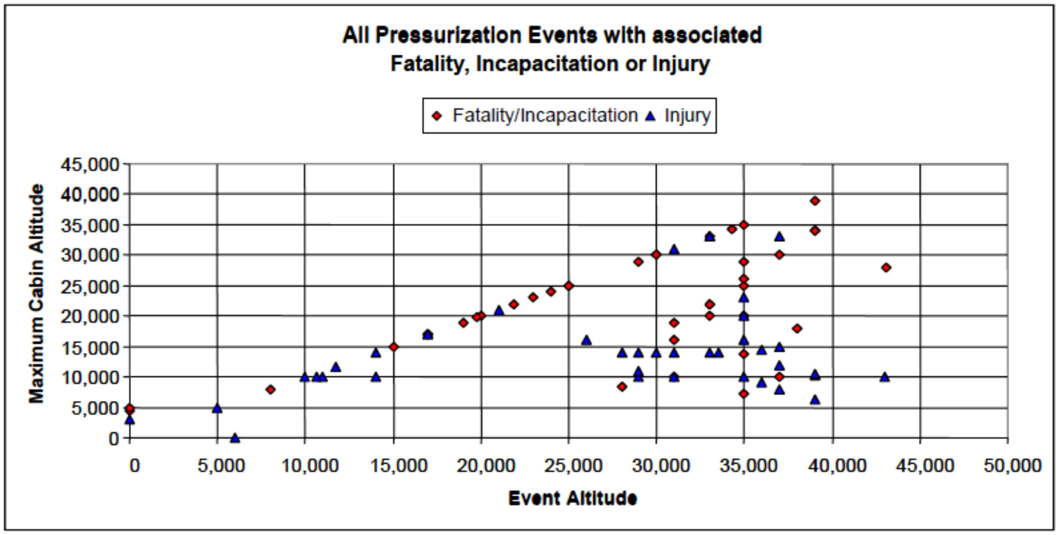
Date	Title	Remarks	Event Altitude	Cabin Altitude
03/18/99	DIV-DUE TO RAPID DECOMPRESSION	Four passengers 3 F/A lost consciousness for approximately 2 to 3 minutes	37,000	10,000
08/21/83	DEPRESSURE-CABIN ALT=30,000 FT	3 F/A'S COLLAPSED FROM LACK OF OXYGEN, AND ONE LAVATORY PSGR. BECAME HYPOXIC.	37,000	30,000
08/13/98	RAPID DECOMPRESSURIZATION	Captain and senior F/A lost consciousness.	35,000	20,001
10/03/74	DEPRESSURIZATION	ONE (OR TWO) F/A'S "CONVULSED AND LOST CONSCIOUSNESS." ONE F/A BECAME HYPOXIC.	35,000	25,000
07/22/81	DEPRESSURE-CABIN ALT=26,000 FT	TWO WOMEN PSGR FAINTED AND WERE ATTENDED TO BY AN ONBOARD DOCTOR	35,000	26,000
07/05/78	DEPRESSURE-CABIN ALT>29,000 FT	FEMALE PAX LOST CONSCIOUSNESS NO PULSE NOR BREATHING. F/A ADMINISTERED HEART MESSAGE AND MOUTH-TO-MOUTH RESUSCITATION. FLIGHT CREW TEMPORARILY DEAF.	35,000	29,001
05/12/96	LOSS OF CABIN PRESSURE	Captain, flight engineer and lead flight attendant all become unconsciousness due to hypoxia.	33,000	22,001
03/15/94	Pilot incapacitation - decompression sickness	CLIMBING TO FL350 WITH SUPP OXYGEN,THE CAPT BECAME INCAPACITATED NITROGEN NARCOSIS (BENDS) TAKEN TO A HOSPITAL SERIOUS CONDITION	33,000	33,000
06/08/75	DEPRESSURE-CABIN ALT=16,000 FT	AIRLINE PSGR-EMPLOYEE SUFFERED COLLAPSED LUNG. HOSPITALIZED FOR 69 HOURS.	31,000	16,000
09/18/01	UNCONTAINED ENGINE FAILURE	When the aircraft landed, one passenger was found dead, apparently due to depressurization. Possible ejection.	30,000	30,000



Date	Title	Remarks	Event Altitude	Cabin Altitude
03/03/87	ATB/PRESSURIZATION LOST	TWO PASSENGERS AND ONE FLIGHT ATTENDANT WERE UNCONSCIOUS FOR A SHORT PERIOD.	28,000	8,500
09/17/79	ATB/EXPLOSIVE DECOMPRESSION	F/A FELL TO FLOOR, UNCONSCIOUS FOR ABOUT 15 SECONDS AND SUSTAINED MINOR LEG, HEAD AND HAND INJURIES.	25,000	25,000
04/28/88	FUSELAGE OPENED IN FLIGHT	ONE FLIGHT ATTENDANT WAS LOST OVERBOARD DURING THE DECOMPRESSION. ANOTHER FLIGHT ATTENDANT AND 7 PASSENGERS RECEIVED SERIOUS INJURIES OF LACERATIONS, SKELETAL FRACTURES AND CONCUSSIONS.	24,000	24,000
02/24/89	CARGO DOOR/FUSELAGE OPENED IN FLIGHT	INJURIES SUSTAINED BY THE SURVIVORS WERE CAUSED BY THE EVENTS ASSOCIATED WITH THE DECOMPRESSION, SUCH AS BARO-TRAUMA TO EARS, AND CUTS AND ABRASIONS FROM THE FLYING DEBRIS IN THE CABIN. Nine passengers ejected.	23,000	23,000
04/11/60	DEPRESSURIZATION AT 20,000 FT	ONE CREW MEMBER FAINTED FROM LOSS OF OXYGEN WHILE AIDING PASSENGERS WITH THEIR MASKS.	20,000	20,000
11/23/93	RAPID DECOMPRESSION-ATB	SOME FLIGHT ATTENDANTS WERE LYING ON THE FLOOR.	19,000	19,000
06/10/90	CAPT PARTLY EJECT THRU WINDSHD	CAPTAIN WAS SUCKED PARTWAY OUT OF COCKPIT SUFFERED FACIAL BRUISES, FRACTURED ELBOW, WRIST AND THUMB, AND FROSTBITE	17,000	17,000
08/26/84	CBN PRESS FAILURE	1 PAX SUFFERED HEART ATTACK		

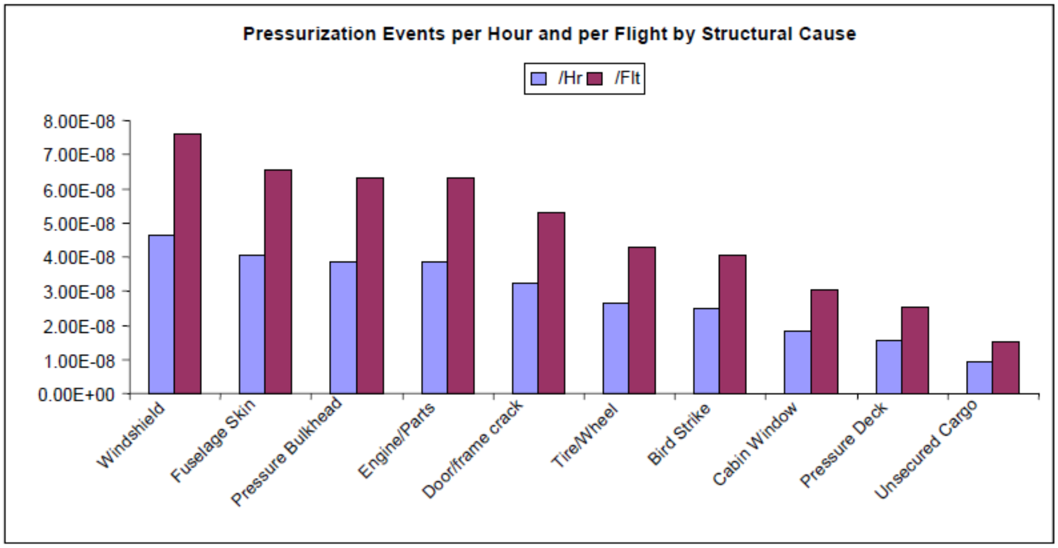
Note: Table 4 above summarizes significant transport category airplane decompression events resulting in fatalities (in red) or incapacitation. These events are plotted in Figure 10 below. Note that while fatalities were incurred, none is attributable to the scenario identified by § 25.841(a), amendment 25-87, where a large hole is created in the fuselage due to an engine rotor uncontainment and a rapid decompression occurs.

Figure 10. Pressurization Events with Fatality, Incapacitation, or Injury.



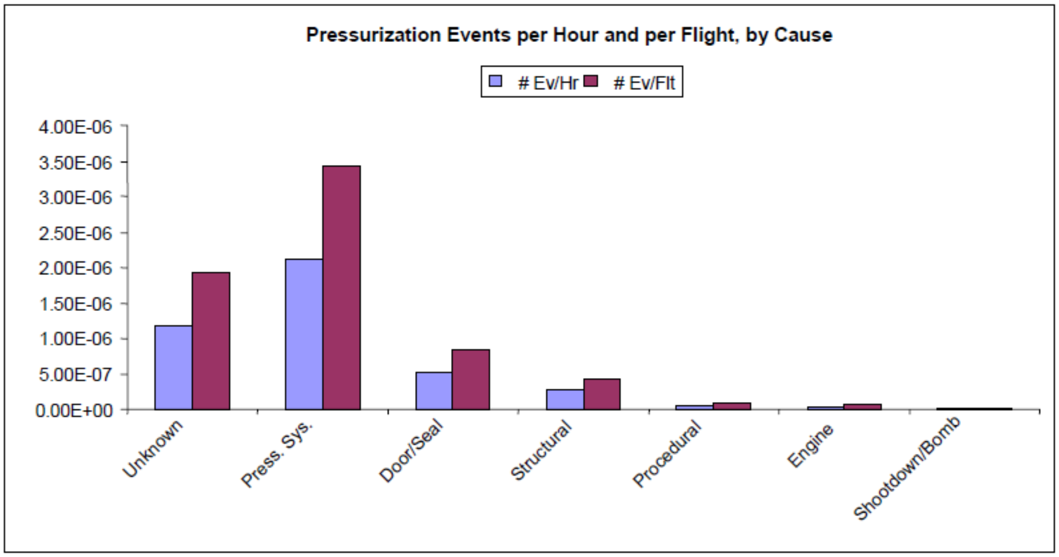
Note: Figure 10 above shows some of the 2,866 pressurization events reported since 1959 for transport category airplanes with weights over 60,000 lbs. The event altitude and cabin altitude were reported for only 873 of the total 2,866 events. Symbols may depict multiple events. Approximately 10% of the 873 events resulted in cabin pressure exposure above 15,000 feet. Sources for Figure 10 above are referenced in the MSHWG Report.

Figure 11. Pressurization Events by Structural Cause.



Note: Figure 11 above depicts pressurization events per hour and per flight due to structural cause and shows the total of 2,866 pressurization events reported since 1959 for transport category airplanes with weights over 60,000 lbs. Sources for Figure 11 above are referenced in the MSHWG Report. The reported probability in all cases is on the order of 10^{-8}.

Figure 12. Pressurization Events by Cause.



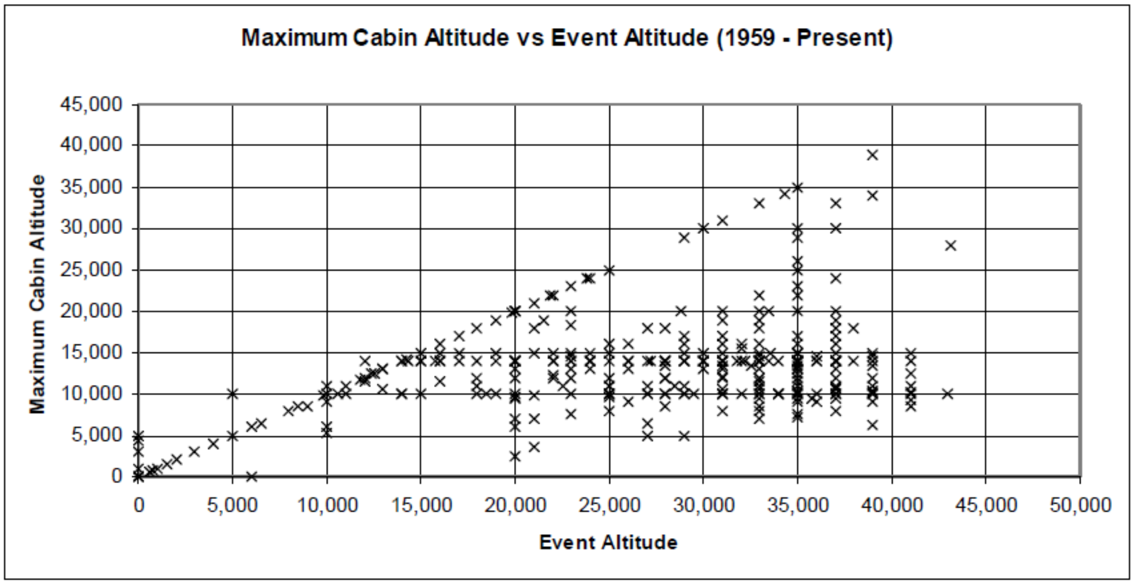
Note: Figure 12 above depicts pressurization events by cause and shows the total of 2,866 pressurization events reported since 1959 for transport category airplanes with weights over 60,000 lbs. Sources for Figure 12 above are referenced in the MSHWG Report. The events caused by uncontained engine failures contributed very little to the event total.

A.2.6 Some observations from above figures are that pressurization system faults predominate in the identified causes of decompression events:

- During initial climb up to and including maximum pressure differential (as pressure differential increases);
- In cruise (flight phase with longest time duration); and
- At/after top of descent (pressurization system mode changes, idle engine operation).

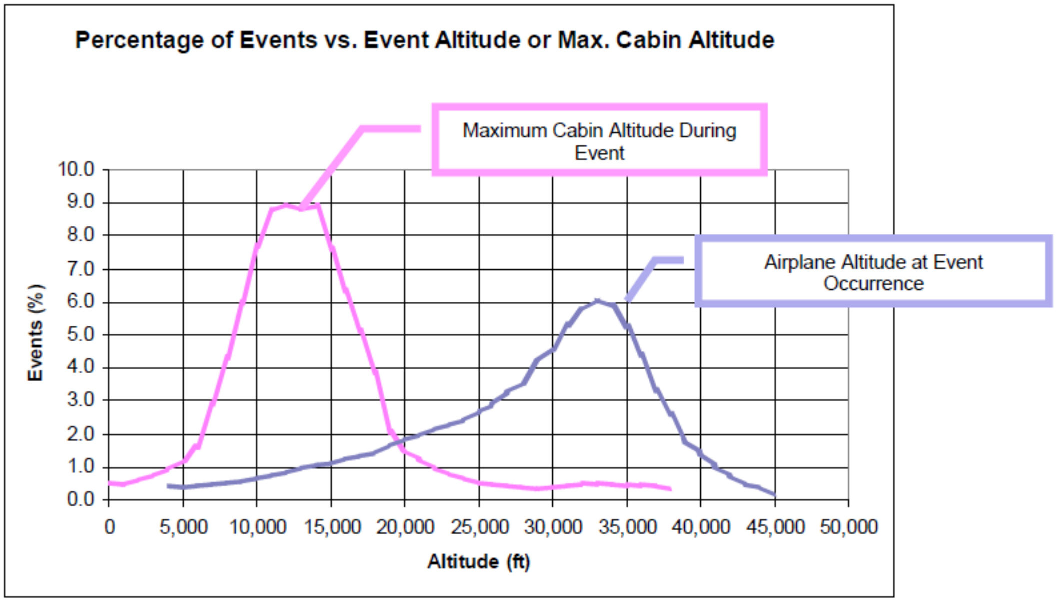
A.2.7 In addition, maintenance and operational procedure errors are important contributors to events (doors/seals, crew management of ECS). Decompressions due to engine rotor bursts are rare, albeit highly unpredictable events.

Figure 13. Pressurization Events from 1959 to 2001.



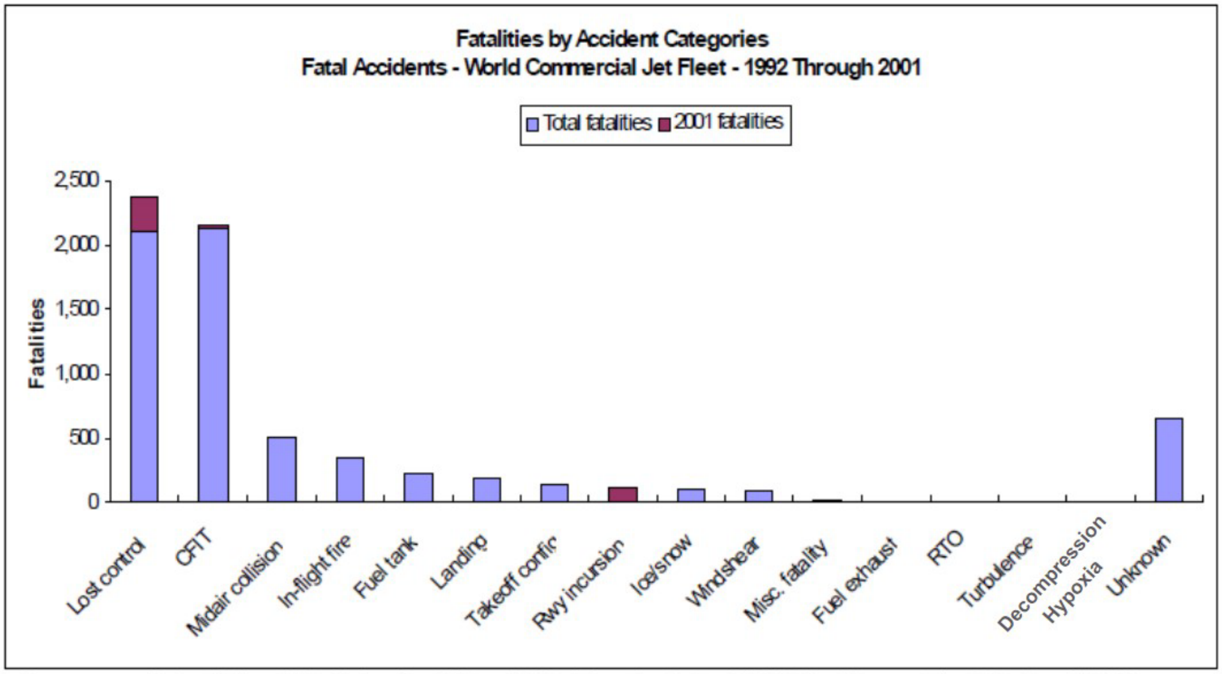
Note: Figure 13 above depicts the maximum cabin altitude reached during a decompression event versus the airplane flight altitude and shows the total of 2,866 pressurization events reported from 1959 to 2001 for transport category airplanes with weights over 60,000 lbs. All points in which the cabin altitude is shown as zero, the airplane altitude is unknown. The event altitude and cabin altitude were reported for 873 of the 2,866 events shown in Figure 13 above. Symbols may depict multiple events. Approximately 10% of the 873 events resulted in cabin pressure exposure above 15,000 feet. Sources for Figure 10 above are referenced in the MSHWG Report. No decompression event has resulted in a maximum cabin altitude above 40,000 feet, although the vast majority of flight hours in transport category airplanes since 1959 have been at altitudes below 40,000 feet.

Figure 14. Pressurization Events and Plots Percentage of Events versus Airplane Flight Altitude and Cabin Pressure Altitude.



Note: Figure 14 above depicts the distribution of cabin altitude and airplane altitude during 873 decompression events where the event altitude and cabin altitude were reported of the total 2,866 pressurization events from 1959 to 2001 for transport category airplanes with weights above 60,000 lbs. Airplane altitude is the primary parameter, since it defines the pressure differential, time duration of exposure to potentially unsafe cabin pressure altitudes, and emergency descent performance. Cabin altitude is a secondary parameter, since it is the resultant of airplane design, maintenance practices and operational procedures. Sources for Figure 14 above are referenced in the ARAC MSHWG Report. The average cabin altitude reached is well below the average airplane altitude and that cabin altitude has rarely ever exceeded 25,000 feet.

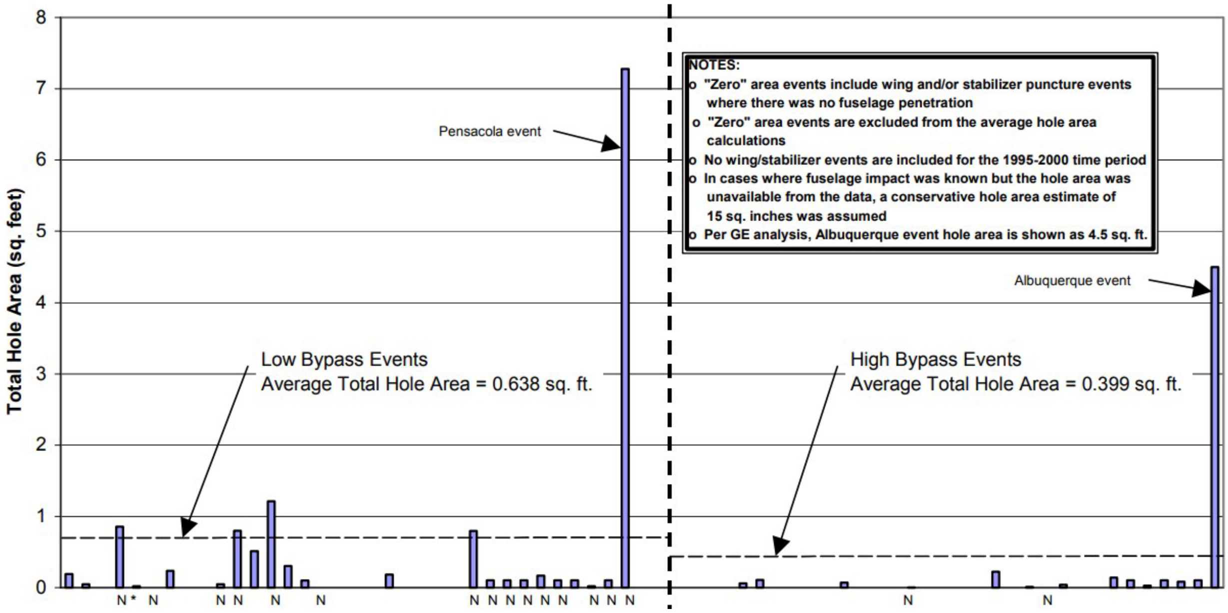
Figure 15. Fatal Accidents by Category.



Sources: Boeing Airplane Safety Engineering (ASE) and Safety Information System (SIS), National Transportation Safety Board (NTSB)

Note: Figure 15 above shows fatal accidents by category for the world commercial jet fleet of transport category airplanes for the period of 1992 to 2001. Note that no hypoxia related fatalities were due to in-flight decompression events. Relative to other causes, decompressions resulting in hypoxic fatalities are not a significant accident contributor. Of 7,171 fatalities for the period of 1992 to 2001, no hypoxia related fatalities were due to in-flight decompression events.

Figure 16. Historical Uncontained Engine Failure Total Fuselage Hole Areas Shown with Pensacola and Albuquerque Events Included.



A.2.8 There have been two accidents since the MSHWG report was issued that resulted from uncontained engine failures that are worth reporting for consideration.

A.2.9 November 4, 2010, an Airbus A380-842 airplane registered as VH-OQA experienced an uncontained engine rotor failure event[29]. The airplane had departed from Changi Airport, Singapore and was climbing through 7,000 feet when the number 2 engine, a Rolls-Royce RB211 Trent 972-84 high-bypass turbofan engine experienced a failure. A manufacturing defect in the high pressure / intermediate pressure hub assembly resulted in an internal oil fire that led to the separation of the intermediate pressure turbine disc from the drive shaft. Debris from the uncontained engine failure resulted in damage to the airframe structure and systems. However, the environmental control system / pressurization system received minor damage (i.e., left wing engine bleed ducting and APU bleed ducting). No decompression/depressurization event occurred and there were no fatalities. The flightcrew were able to safely return to Changi Airport.

A.2.10 April 17, 2018, a Boeing 737-700, N772SW, experienced an uncontained engine rotor failure event[30]. The airplane had departed from LaGuardia Airport (KLGA), New York, to Dallas Love Field (KDAL), Dallas, Texas. The airplane was climbing through about 32,000 feet when the left CFM International CFM-56-7B engine experienced a fan blade failure. Portions of the left engine inlet and fan cowl separated from the airplane; one fan cowl fragment impacted the left-side fuselage near a cabin window, and the

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[29] Australian Transport Safety Bureau, Transport Safety Report, Occurrence Investigation Report AO-2010-089, *In-flight uncontained engine failure overhead Batam Island, Indonesia 4 November 2010 VH-OQA Airbus A380-842* Final 27 June 2013.

[30] US National Transport Safety Board, Accident Report NTSB/AAR-19/03 PB2019-101439, *Left Engine Failure and Subsequent Depressurization Southwest Airlines Flight 1380, Boeing 737-7H4, N772SW, Philadelphia, Pennsylvania, April 17, 2018.*

window departed the airplane resulting in a rapid depressurization. The flightcrew conducted an emergency descent and safely landed at Philadelphia International Airport. One passenger received fatal injuries and eight passengers received minor injuries.

A.2.11 Considering the limited events that have occurred, the FAA finds that there are sufficient compelling benefits to permitting airplanes to operate at high altitudes. In addition, while there is increased level of risk for these operations the FAA estimates that there is an average probability of an UEF at cruise of approximately $1x10^{-7}$ per engine hour or the chance of an UEF at cruise is 1 divided by 10,000,000 per engine hour. However, not all engine debris strike the airplane. Other considerations affect the engine debris trajectories as described in section 7 of this AC, and further reduce the probability of an UEF.

OMB Control Number: 2120-0746
Expiration Date: 11/30/2024

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