Exemption No. 9943

UNITED STATES OF AMERICA
DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
RENTON, WASHINGTON 98057-3356

In the matter of the petition of **The Boeing Company** for an exemption from §§ 25.841(a)(2) and 25.841(a)(3) of Title 14, Code of Federal Regulations	**Regulatory Docket No. FAA-2008-0826**

PARTIAL GRANT OF EXEMPTION

By letter dated July 25, 2008 (BDCO-08-02707)) C. M. Thompson, Lead Project Administrator, Development Projects, The Boeing Company, P.O. Box 3707, Seattle, WA 98124-2207, petitioned to exempt the Model 747-8/-8F airplanes from the requirements of Title 14, Code of Federal Regulations (14 CFR) 25.841(a)(2) and (a)(3), as amended by Amendment 25-87. The FAA requested additional material and Boeing intermittently sent material, with the final submission on July 2, 2009. If granted, the exemption would relieve these airplanes from the requirement that—during a decompression caused by failures of the engines —airplane cabin pressure altitude not exceed 25,000 feet for more than 2 minutes or exceed 40,000 feet for any duration.

The petitioner requests relief from the following regulation(s):

> **Section 25.841(a)(2),** at Amendment 25-87, requires that "The airplane must be designed so that occupants will not be exposed to a cabin pressure altitude that exceeds the following after decompression from any failure condition not shown to be extremely improbable:
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> (i) Twenty-five thousand (25,000) feet for more than 2 minutes; or
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> (ii) Forty thousand (40,000) feet for any duration."
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> **Section 25.841(a)(3)** at Amendment 25-87, requires that "Fuselage structure, engine and system failures are to be considered in evaluating the cabin decompression."

The petitioner supports its request with the following information:

The following information summarizes the petition submitted by The Boeing Company. The complete petition is available at the Department of Transportation's Docket Operations, or on the Internet at http://regulations.

The Boeing Model 747-8/-8F airplanes are designed to cruise at a maximum altitude of 43,000 feet pressure altitude. Should an uncontained engine rotor burst event occur, it is possible that the cabin pressure could exceed the limits contained in current regulations. Boeing offers the following justification in support of its petition for exemption. Some of this justification is based on cabin decompression evaluations performed and reported by the Mechanical Systems Harmonization Working Group (MSHWG) under the auspices of the Aviation Rulemaking Advisory Committee (ARAC).[1]

The Boeing Company requests an exemption from compliance with §§ 25.841(a)(2) and 25.841(a)(3) for cabin depressurization that can occur from uncontained engine rotor failures that result in large holes in the fuselage (i.e., those holes with an effective area exceeding 266 $inches^2$ for the 747-8F model and 275 $inches^2$ for the 747-8 model). Based on fleet service experience Boeing states that these are rare events. To substantiate its position, Boeing provided an estimate of the probability of 1/3 of a disc fragment from an uncontained engine rotor event hitting the fuselage during an entire airplane flight cycle to be of the order of 6.4×10^{-9} for 2nd and 3rd generation of engines.

In addition, Boeing reports that the new airplane complies with the latest FAA requirements and, therefore, offers a significantly higher basic level of safety than previously certified transport category airplanes. Modern transport category airplanes have a 45 year safety record with millions of hours at altitudes similar to the maximum cruise altitude proposed for the Model 747-8/-8F airplanes. In addition, Boeing observes that neither the Joint Airworthiness Authorities nor the European Aviation Safety Administration has implemented similar restrictions (i.e., § 25.841(a)(2) and (a)(3)).

Boeing notes that very few, if any, decompression incidents have exposed an airplane cabin to pressure altitude profiles which pose a risk of injury to passengers. Industry history reveals that few cases of catastrophic decompressions at high altitude have occurred, and those that have occurred have typically involved small business jets. The petitioner observes that the FAA has cited a few cases of rotor burst in cruise. In one such instance, the crew of a DC-10 crossing New Mexico reported several cases of initial decompression sickness, apparently with no permanent injuries.

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[1] The Final Report of the MSHWG, dated August 2003, was approved by a majority of the members of ARAC's Transport Airplane Engine Issues Group (TAEIG). Seven members of TAEIG voted to submit the report as a recommendation to the FAA, two members voted against submitting the report, and one member abstained.

Boeing supplied data for the Model 747-8/-8F airplanes and provided information on the likelihood of various failure events. Boeing reported that in its analysis it considered numerous failures events including a bulkhead valve or penetration in the air conditioning system failure; a window failure of any type (flight deck or cabin); a loss of a pressurized structure panel; a loss of an outflow valve; a loss of a door seal; a tire burst event; and loss of an antenna or pitot failure events. Boeing further reported that failure events, such as a loss of inflow event and loss of a bleed source, will not cause a rapid depressurization event for the airplane, so these items did not represent a limiting factor in the §§ 25.841(a)(2) and 25.841(a)(3) analysis. Additionally, many other systems and structural hole sizes were considered. The most critical hole size for the analysis was one outflow valve failing wide open. While some of the above items, seem larger than this hole size, the failure rates of these items were taken into account. For example, a flight deck window is larger than an outflow valve, but these windows are failsafe. Boeing will provide even further details on these items in the system description document. While Boeing did provide probability data for an uncontained engine failure event (since this data is pertinent to the exemption petition), Boeing did not provide any probability data for any failures where the 747-8F/747-8 design fully complies with §§ 25.841(a)(2) and 25.841(a)(3). In its decompression analysis, Boeing included a measure of the severity of exposure for occupants, based on a depressurization exposure Integral (DEI) from the Mechanical Systems Harmonization Working Group report. Boeing used the relationship between cabin pressure and the depressurization severity indicator (DSI), which is a measure of the partial pressure of oxygen, as was proposed by the Mechanical Systems Harmonization Working Group. The petitioner showed that for the worst case failures modes reviewed for this exemption, the resultant DSI levels were less than the critical value recommended by the Mechanical Systems Harmonization Working Group. The analysis considers certain design and operational features of the Model 747-8/-8F airplanes which would mitigate the effects of an increase in cabin pressure altitude. One of these design features is the cabin pressurization control system (CPCS) which was designed to minimize system failures that would lead to loss of cabin pressurization events.

The Model 747-8/-8F airplanes are designed to fly at cruise altitudes that will maximize fuel efficiency. The reduction in maximum cruise altitude resulting from compliance with §§ 25.841(a)(2) and 25.841(a)(3) for uncontained engine failure is a concern shared by other manufacturers of airplanes with wing-mounted engines seeking new or amended type certification. No transport category airplane with wing-mounted engines certificated today for operation above 39,000 feet can meet the new cabin altitude limits within the current §§ 25.841(a)(2) and 25.841(a)(3) without an exemption.

The Boeing Company mitigates risk to high cabin altitude exposure to passengers by reasonable design requirements, proven design methodologies and operational considerations regardless of the cause of the decompression event. The proposed exemption addresses the concern for safety driven by §§ 25.841(a)(2) and 25.841(a)(3).

Safety enhancement initiatives with respect to critical rotating parts (inspecting for cracks in disks and using continually updated maintenance data to refine disk inspection criteria), as well as improvement in engine technology, lessons learned, and 2nd / 3rd

generation engine design practices have resulted in a reduction in uncontained engine failure events. The uncontained engine failure rates of 2nd / 3rd generation engines compared to 1st generation engines have improved by approximately 95% based on historical Boeing data on uncontained engine failures.

A reduction in maximum cruise altitude would adversely impact the ability of the Boeing Model 747-8/-8F airplanes to compete with previously certificated airplanes which can operate at the more economical cruise altitudes, typically in excess of 37,000 feet. In addition, restricting airplane operations to lower altitudes will increase traffic congestion. Limiting operation of new generation airplanes to lower altitudes will result in higher traffic density, which in turn will result in higher cost of safety in order to maintain established air traffic vertical and horizontal separation requirements.

The Boeing Model 747-8/-8F airplanes will meet the latest amendments in effect at the time of application. The net result is that the Model 747-8/-8F airplanes incorporate all the safety advancements as intended within these later amendments. Any significant impact to the marketability of the Model 747-8/-8F airplanes will, at a minimum, result in a reduced number of aircraft with this higher level of safety as compared with the previous generation of aircraft, or at a maximum, preclude the manufacture of this new generation of aircraft. In either case, Amendment 25-87 results in a reduced potential for overall aviation safety improvements.

It must be reiterated that this request for exemption for §§ 25.841(a)(2) and 25.841(a)(3) is limited to only uncontained engine failures. For other sources of rapid depressurization, including system failures and specific structural failures, §§ 25.841(a)(2) and 25.841 (a)(3) will be complied with as amended by Amendment 25-87. All mechanical and/or functional interfaces that could potentially violate the physiological limits imposed by § 25.841 (a) are considered. Robust structural and systems design and the ability for the airplane to rapidly descend are key to assuring the safety of airplane occupants and are an inherent part of the Model 747-8/-8F airplanes design. The Boeing Company design practices refine the requirements into sub-requirements for systems, structures, aerodynamics, and performance in order to assure airplane level compliance.

Other threat minimization philosophies employed in the 747-8F/-8 design include an automatic pressure demand mask for the pilots which will be certified to § 25.1441 (d) and separation and redundancy of key systems such as electrical power, cabin pressure control and spoiler actuation. In addition, the three passenger oxygen flow control units and all oxygen cylinders and high pressure components will be installed outside and forward of the rotorburst zone.

The petitioner's statement of public interest:

The Boeing Company 747-8F/-8 models will comply with the latest airworthiness standards (except as noted in the 747-8F/-8 Certification Basis) including

> §§ 25.841(a)(2) and 25.841(a)(3), Amendment 25-87 in all regards, except as related to an uncontained engine failure event as defined herein. Specific features of the 747-8F/-8 design mitigate the safety risk to occupants due to a decompression resulting from an uncontained engine failure. Improvements in engine technology, application of lessons learned, and 2nd and 3rd generation engine design practices have resulted in a reduction in uncontained engine failure events and the risk of a rapid depressurization. As stated above, the Boeing 747-8F/-8 will meet all the latest amendments in effect at the time of application, except as noted in the 747-8F/-8 Certification Basis. The net result is that the 747-8F/-8 incorporates the safety advancements as intended within these later amendments. The 747-8F/-8, therefore, offers a higher level of safety than all but the most recently certificated transport category airplanes.
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> In addition, the 747-8F/-8 will provide improved operating economics, and environmental improvements. Granting this petition of exemption is in the public interest because it will improve safety relative to previously certificated airplanes, while reducing operational costs by reducing the amount of fuel consumed. The cost of maintaining the level of safety within the existing air traffic management system will not be adversely impacted by continuing to allow operation in the less congested altitudes typically well above 37,000 feet. The reduction in fuel consumed will also result in reduced emissions. These benefits will accrue with no decrease in safety.

Federal Register publication

A summary notice of the petition was published in the Federal Register on August 22, 2008 (73 FR 49734), and the comment period ended September 11, 2008. Based on requests from the Association of Flight Attendants-CWA, AFL-CIO (AFA) and the Air Line Pilots Association (ALPA), another notice was published in the Federal Register on September 23, 2008 (73 FR 54883) and the comment period was reopened and closed on October 8, 2008. Both the AFA and ALPA submitted comments that oppose a grant of exemption. Their comments address the following topics:

1. Physiological effects of decompression

ALPA stated that:

> The petition cites the Mechanical Systems Harmonization Working Group (MSHWG) Depressurization Exposure Interval/Depressurization Severity Index (DEI/DSI), and a number of research papers as support for the request but do not show specific DSI/DEI calculations. The highest altitude addressed by the cited research is 40,000, but Boeing is requesting an exemption to 45,000 feet. The cited research indicates that serious harm will occur at exposure times of 1 minute 30 seconds above 40,000 feet, and the FAA

interim policy establishes a 60 second exposure limit. ALPA is very concerned that having only a 30 second buffer for a situation where permanent brain damage may occur is already reducing safety margins beyond what is acceptable. This is especially true given that the original research was done almost exclusively on volunteers who are young and in good or excellent health. Many air travelers and even some crew members may be more susceptible to the effects of hypoxia. In addition, Dr. Ernsting's research was conducted on non-human primates.

In addition, AFA reported that:

AFA had submitted to the FAA in response to an earlier Airbus petition for exemption for the A380 (Reference 8,) that a maximum cabin pressure altitude of 40,000 feet is an acceptable limit to ensure airplane occupant safety, until additional, independent research is conducted that shows otherwise. AFA further concludes that the ARAC recommendation to FAA does not substitute for an equivalent level of safety finding; therefore, this exemption is not in the public interest and would adversely affect safety in the event of a sudden decompression. AFA therefore recommends that the FAA not grant the requested exemption for the Boeing 747 -8F and 747-8, until such time that the methodologies underlying the Reference 2 Interim Policy are independently reviewed and verified (as recommended in the Reference 3 MSHWG report,) and subsequent notice and comment rulemaking is finalized that properly addresses industry concerns regarding existing Amendment 25-87 regulations.

2. Pilot response to the rapid decompression

ALPA also noted that both Boeing and the MSHWG report rely on a flawless execution of a post-depressurization emergency descent by the crew. While this maneuver is taught to a basic level of proficiency during simulator training, it is not generally practiced to a degree that would guarantee the rigid adherence to the emergency descent profile required to meet even the interim policy's tight schedule of less than 1 minute above 40,000 feet. This is further complicated by the concern any pilot would have about the structural integrity of the aircraft after an UERF had breeched the fuselage, the extent of the resultant damage being unknown to the crew. It is common for pilots to be taught during training that judgment must be used in limiting the rate of an emergency descent if aircraft structural integrity is unknown, to include changing the aircraft configuration by, for example, lowering landing gear. In an actual emergency involving UERF and rapid decompression, flight crews would be expected to make accurate decisions balancing the need to descend with the need to protect the structural integrity of the airframe with unknown damage. This would likely lengthen the times of descent considerably (thus

> increasing exposure times to higher than nominal cabin altitudes) in all but a simple loss of pressurization due to system failure.
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> In the case of an engine failure, accompanied by the momentary chaos of an extremely rapid loss of cabin pressure, the pilots will receive a flood of warnings and abnormal indications to include aircraft flight path deviations. During the initial stages of this high workload scenario, potentially significant amounts of time will be needed to assess the situation and begin the appropriate descent profile. Any additional time delay could exacerbate potential harm to the passengers or crew. This is not accounted for in the Boeing petition or in the MSHWG report, but must be considered as it would result in exposure times that may be in excess of what is anticipated even with the limitation of the interim policy.

We have carefully considered all the pertinent comments received and taken them into account in our analysis of the Petition for Exemption submitted by Boeing. We agree with some elements of these comments (e.g., that existing research data is limited; that the human subjects participating in the majority of research were healthy, young males not representative of the traveling public; the need for a peer review of a means to assess risk to occupants of exposure to high altitude rapid decompression.) However, as ALPA cited, there is an acknowledgement that the decompression altitude exposure limits provided in FAA Interim Policy, PS-ANM-03-112-16, *Interim Policy on High Altitude Cabin Decompression* is supported in general by several medical doctors and flight physiologists, including those at FAA's Civil Aerospace Medical Institute (CAMI). The exposure limits in the policy were the result of literature search and review of historical altitude chamber work and the limited exposure data that exposure: above 40,000 feet (not to exceed 45,000 feet) for 1 minute; above 25,000 feet for no more than 3 minutes; above 10,000 feet for no more than 6 minutes; and provides an acceptable level of safety at an acceptable level of risk. This is not to say that the policy represents the final guidance on the subject. Rather, that the policy represents a reasonable balance between protection of the occupants versus economic benefits of high altitude flight.

We would like to clarify that Boeing did provide further information (marked proprietary) that included calculations on airplane descent rate, resulting hole size following penetration of the pressurized vessel via uncontained engine debris, and the severity of the decompression events. This information is not included in the public docket because it is proprietary information. We agree with Boeing's conclusion that using the numerical approach in the MSHWG § 25.841 Report results in DEI/DSI values that are lower than the recommendations in the report.

We share ALPA and AFA's concerns regarding the lack of physiological data. We are actively working with the FAA Office of Aerospace Medicine and specifically with the medical doctors and flight physiologists at CAMI to develop a more rigorous model of the physiological response to a rapid decompression. We anticipate that this material will be presented for peer review at the May 2010 Aerospace Medical Association (AsMA) meeting. We recommend that industry attend that meeting and/or provide comments to AsMA and us once the material is published. We look forward to comments on this important matter. Even though we plan to conduct the related activities noted above on this subject, we find that sufficient data, including service history, is available to support this proposed exemption for the Model B747-8/-8F.

We share ALPA's concern regarding the response of the flight crew and the criticality of the flight maneuver. We agree that flight crew response is critical and that the flight crew must consider a balance between the survivability of the occupants versus the structural integrity and aerodynamic limits of the airplane. However, we disagree with ALPA's statement regarding lack of information in the MSHWG § 25.841 report. This was an area discussed within the MSHWG. Structural engineers, aerodynamists, and pilots from airplane manufacturers participated on the MSHWG and reviewed this question. It was a consensus of the team, which included an ALPA representative, that, following a survivable uncontained engine rotor blade worst case failure event (i.e., 1/3 rotor disk near tangential crown strike) would result in sufficient structural integrity of the airplane to permit a Vmo/Mmo rate of descent. In addition, the team reviewed the 17 seconds delay in initiation of the emergency descent by the crew, as noted in existing Advisory Circular 25-20, *Pressurization, Ventilation and Oxygen Systems Assessment for Subsonic Flight Including High Altitude Operation*, September 6, 1996, and recommended that this delay represented a reasonable approach to addressing this concern. Other areas discussed included the use of a means whereby the airplane would engage in an automatic descent in the event of a rapid cabin decompression. It should be noted that several high altitude operating transport airplanes have incorporated an automatic descent feature into their approved design. In summary, we and the applicant have considered reasonable pilot reaction times to don oxygen masks, recognize the failure event, and take appropriate action to configure the airplane for a swift descent. However, we acknowledge that additional means have been approved in the past to enhance airplane occupant survivability such as an automatic descent feature; especially on airplanes with maximum cruise altitudes above that required for the petitioner's airplane.

The FAA's analysis

The Boeing Company provided a background of the current rule and recent activities to harmonize it, a review of the safety history of high altitude commercial flight, a discussion of hypoxia physiology data upon which recent rulemaking activities are based, a discussion of the impact of compliance with uncontained engine rotor burst aspects of the existing rule, as related to economics, environmental, and air traffic considerations, and statements addressing public interest and no adverse impact to safety. In response to FAA inquiries, Boeing subsequently provided estimated cabin pressure altitude and airplane flight altitude time history plots following decompressions per emergency descent procedures, and a description of the Boeing methodology of evaluating the threat from uncontained engine rotor burst.

1. <u>Need for exemption</u>

Boeing requested relief from § 25.841(a)(2)(i), which specifies that cabin pressure altitude may not exceed 25,000 feet for more than 2 minutes after decompression from any failure condition not shown to be extremely improbable. A grant of exemption from this regulation would allow the Model 747-8/-8F airplanes to take longer than 2 minutes to descend from 43,000 feet to 25,000 feet after such decompression.

Boeing also requested relief from § 25.841(a)(2)(ii), which specifies that cabin pressure altitude may not exceed 40,000 feet for any duration after decompression from any failure condition not shown to be extremely improbable. A grant of exemption from this regulation would allow the Model 747-8/-8F airplanes cabin pressure altitude to exceed 40,000 feet after such decompression.

Boeing stated that the Model 747-8/-8F airplanes' design will meet the requirements of §§ 25.841(a)(2)(i) and (ii) for all system and structural failures but not for all types of engine failures. For some uncontained engine rotor failures that result in pressure vessel penetration by fragments, the design of the Model 747-8/-8F airplanes does not meet the requirements of §§ 25.841(a)(2)(i) and (ii). A grant of exemption from this regulation would allow the Model 747-8/-8F airplanes to operate up to 43,000 feet, which could briefly expose cabin occupants to this altitude in the event of a worst-case decompression.

Finally, Boeing requested relief from § 25.841(a)(3), which requires that an airplane manufacturer consider fuselage structure, engine, and system failures when evaluating the cabin pressure altitude following a decompression due to one of these failure events. As noted in the preamble to this regulation, "Possible modes of failure to be evaluated include malfunctions and damage from external sources such as tire burst, wheel failure, uncontained engine failure, engine fan, compressor or turbine multi blade failure, and loss of antennas…."

FAA's analysis shows that Boeing did consider these failures in its analysis. Therefore, the petitioner complies with § 25.841(a)(3), and does not need an exemption from that regulation.

2. <u>Conformance with applicable FAA policy</u>

The FAA reviewed this petition in the context of the MSHWG's final report on § 25.841(a)(2) and (a)(3) and the FAA's interim policy, *Interim Policy on High Altitude Cabin Decompression*, ANM-03-112-16, issued March 24, 2006, on the requirements of Amendment 25-87. The interim policy applies only to those decompression events which are due to uncontained engine rotor failure. The basis of the interim policy is data from research on the response of humans and other primates to changes in ambient pressure. Evaluation of these data indicates that there is a direct correlation between the alveolar partial pressure of oxygen time integral and the likelihood of fatalities or permanent physiological damage to those exposed to such pressure changes. That is, as the value of the integral increases, the likelihood of fatalities or permanent physiological damage also increases. The FAA has issued a final version of its interim policy which uses a table of altitudes and cumulative exposure times in lieu of the pressure-time integral. The values of altitude and time in the table and the results of the pressure-time integral method are in agreement.

Accordingly, the FAA's interim policy focuses on minimizing the likelihood that—if a person is exposed to high altitude cabin pressure from any failure not shown to be extremely improbable—

he/she will suffer permanent physiological damage. To analyze petitions for exemption from § 25.841(a)(2), the FAA requires information about emergency descent rates, any design features that increase such rates, other design features that offset the inherent increased risk of exposure to high altitude cabin pressure, and operational procedures. Information provided by Boeing in its petition for exemption, and in additional material to support its petition for exemption adequately addresses these areas.

As stated above and in its interim policy, the FAA acknowledges that there is a lack of relevant data on the effects of exposure to high altitude cabin pressure following decompression; particularly, those effects on people of various ages, people with circulatory or respiratory diseases, or certain other medical conditions.

Boeing used the criteria recommended in the FAA's interim policy and its design incorporates the FAA's recommended cabin altitude-time limits to ensure airplane descent performance. The FAA believes that this methodology is conservative because it assumes a lower partial pressure of oxygen than would likely be present during decompression at 43,000 feet.

Boeing provided descent profiles for the Model 747-8/-8F airplanes, based on conservative estimates of descent performance for failure scenarios, as described in the FAA's interim policy. The descent profiles indicate that the Model 747-8/-8F airplanes can descend rapidly from 43,000 feet altitude to below 25,000 feet.

Boeing also performed a depressurization analysis based upon maximum cruise flight conditions, and defined the envelope of vulnerability of passengers following failures that result in a decompression. Boeing also identified design and operational features of the Model 747-8/-8F airplanes which would mitigate the effects of an increase in cabin pressure altitude.

The decompression analysis used several measures recommended in the MSHWG final report on 25.841(a)(2) and (3), dated October 2003. Specifically, Boeing estimated the severity of exposure to high altitude cabin pressure for occupants, based on calculation of a Depressurization Exposure Integral (DEI). The analysis also considers the relationship between cabin pressure and the Depressurization Severity Indicator (DSI), a measure of the partial pressure of oxygen. The analysis indicates that the physiological effect of a slight increase in the length of time spent above 25,000 feet is within the uncertainty band of available physiological data. The Boeing analysis also shows that—for the worst case failure modes reviewed for this exemption—resultant DSI levels were less than the critical value recommended by the MSHWG.

The FAA reviewed information provided by Boeing about design features and operational procedures that ensure that the descent capability of the Model 747-8/-8F airplanes provides adequate occupant survival. We concluded that the design features and operational procedures associated with rapid decompression followed by an emergency descent support granting an exemption.

3. Review of historical data and research

The FAA reviewed databases from its National Aviation Safety Data Analysis Center, covering 1959 to the present. Since 1959 there have been approximately 3,000 instances of loss-of-cabin-pressure. The vast majority of these have been caused by system failures, (e.g., cabin pressurization controller failures and valve failures) and structural failures, (e.g., door seal failures) which have typically been recognized at low altitude within a few minutes after takeoff. Pilot error has also contributed to a number of events. The majority of these events have not subjected the occupants to exposures above 25,000 feet (an altitude considered physiologically significant). Indeed, the cabin pressure altitude in most events did not exceed 15,000 feet (the cabin pressure altitude at which passenger oxygen masks are deployed).

Similarly, uncontained engine rotor burst failures tend to be very rare. A simple calculation shows that grouping all engines and transport airplanes together yields an average probability of an uncontained engine failure at cruise of approximately $1x10^{-7}$ per engine hour. New engine designs appear to reduce this probability by an order of magnitude. The FAA found, as noted in the MSHWG report on § 25.841(a), that no fatalities from hypoxia were due to in-flight rapid decompression events as envisioned by Amendment 25-87. The data indicate that decompression is not a significant cause of fatalities. It is because these events are so rare that the FAA considers the risk to be acceptable.

In addition, Boeing provided the FAA with proprietary data from its analysis of uncontained engine rotor failures and the size and number of holes in the fuselage resulting from such failures. Using historical service data and theoretical values, the petitioner performed decompression analysis for several scenarios. Boeing analyzed the probability of uncontained engine rotor failure and of penetration of the fuselage of the Model 747-8/-8F airplanes from fragments of various sizes resulting from such failures. This analysis was used to assess the threat of such an event to occupants of the airplane. The FAA did not agree with one assumption in the Boeing analysis, regarding the exclusion of larger holes from two historical events. However, the petitioner's analysis was conducted in a manner consistent with the recommendations within the MSHWG report and existing regulatory advisory guidance and its data showed that even for the largest survivable hole the Model 747-8/-8F airplanes would be able to meet the FAA's interim policy criteria.

The FAA concurs with the petitioner that uncontained engine rotor failures are rare events, and this consideration had a bearing on the granting of the exemption. Our analysis in this case is in contrast to our analysis of an earlier petition for exemption from a different applicant for an airplane with a lower cruise altitude (41,000 feet). The petition submitted by a previous applicant included estimates of the probability of occurrence of an uncontained engine rotor failure. In that case, the altitude excursion above 40,000 feet was less than 1,000 feet. The FAA concluded that the risk associated with exposure of the occupants to the slightly higher altitude was essentially the same as the risk of exposure at 40,000 feet. In other words, the risk from exposure at altitude was essentially the same with or without the grant of an exemption. Therefore, the rarity of uncontained engine rotor failures did not significantly enter into consideration regarding the previous grant of exemption.

4. Holes from uncontained engine rotor failure

The FAA evaluated the Boeing methodology for determining the size of holes in the fuselage and/or wings caused by uncontained engine rotor failure. The FAA concluded that the method makes some assumptions which one could question. However, this issue is not of great significance since the FAA required Boeing to assume a failure which produced a very large hole in the fuselage, causing a sudden decompression.

5. Use of supplemental oxygen

As discussed below, the FAA has analyzed the Boeing petition in the context of those recommendations, the part 25 requirements pertaining to supplemental oxygen, and certain technical standards for supplemental oxygen equipment. Section 25.1441(d) requires approval of oxygen equipment for airplanes that are approved to operate above 40,000 feet altitude. Section 25.1443 specifies the minimum mass flow of supplemental oxygen for flightcrew and passenger oxygen systems up to a cabin altitude of 40,000 feet. Part 25 does not contain standards for oxygen systems above 40,000 feet. However, FAA Technical Standard Orders (TSOs) provide requirements for diluter demand pressure breathing regulators (TSO-C89, *Oxygen Regulators*, *Demand*) and demand oxygen masks (TSO-C78, *Crewmember Demand Oxygen Masks*) up to 43,000 feet. In addition, SAE International Standard AS 8027, *Crew Member Oxygen Regulators*, *Demand*, provides specifications for diluter demand pressure breathing regulators up to 45,000 feet. It is the FAA's understanding that no diluter demand pressure breathing regulators available for commercial airplanes meet all the requirements of TSO-C89 or AS 8027.

As part of the certification work on the Model 747-8/-8F airplanes Boeing must substantiate the adequacy of the supplemental oxygen systems installed for the flightcrew for the cabin altitudes that they can be exposed to above 40,000 feet.

Flightcrew pressure breathing equipment requires training to ensure effective use. Pressure breathing requires physical effort to exhale and minimal effort to inhale. This reversal of the normal breathing cycle can lead to hyperventilation. Training of passengers to use pressure breathing equipment safely is considered impractical. The FAA determined that an acceptable means of compliance for the fixed and portable oxygen systems used by flight attendants and passengers would be to install oxygen equipment that is certificated to 40,000 feet and limit exposure to the reduced pressure environment above 40,000 feet via airplane descent performance. The FAA believes that, ultimately, occupant survival during a decompression event depends upon the airplane's swift descent to a lower altitude. In its review of the petitioner's airplane descent profile, the FAA finds that the Model 747-8/-8F airplanes can descend at acceptable rates.

6. Conclusion of FAA analysis

Permitting airplanes to fly above 40,000 feet does offer real and tangible benefits to the aerospace industry, the traveling public, and the U.S. economy by reducing congestion, improving fuel economy, and reducing pollution. If compliance with § 25.841 at Amendment 25-87 were to limit airplanes operations to a maximum altitude of 40,000 feet, it would impose a significant disadvantage on newly designed airplanes that have many safety advantages over older airplanes currently allowed to operate at higher altitudes. This would delay the introduction of these airplanes and the benefits of their more advanced technology.

Based upon its evaluation of the data and analysis provided by Boeing, the FAA has determined that there is sufficient justification for a partial grant of exemption from § 25.841(a)(2)(i) and (ii).

This partial grant of exemption does not provide relief from § 25.841(a) for any other system and structural failure events not shown to be extremely improbable. The petitioner will have to demonstrate compliance for those failures events, and this partial grant is predicated on the belief that the applicant will successfully demonstrate compliance for the Boeing Model 747-8/-8F airplanes. As noted in the MSHWG report on § 25.841(a), tire burst in flight is not extremely improbable as demonstrated by historic data. The ground loads are not applicable in flight and for this condition tires are extremely robust; according to § 25.729(f)(1) and historic data, the tire burst occurs in flight and as it is very difficult to demonstrate that tire cannot be burst in case of overheat, it is not possible to demonstrate that this event does not occur in high altitude flight. Therefore, the tire burst event must be considered in the depressurization analysis. In addition, pressure vessel openings resulting from loss of antennas, or stall warning vanes, or any system failure conditions that are not shown to be extremely improbable must be considered. The effects of such damage while operating under maximum normal cabin pressure differential must be evaluated. Also, structural cracks will be addressed as per the existing Amendment 25-87 preamble, i.e., "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 addition, this partial grant of exemption is predicated on the requirement that the Boeing Model 747-8/-8F airplanes successfully demonstrate compliance with §§ 25.1441, 25.1443, 25.1445, 25.1447 and 25.1449.

This partial grant of exemption takes into account operating rules in 14 CFR parts 91, 121 and 135 which require (a) that one pilot wear and use his oxygen mask when operating above 41,000 feet altitude and (b) that an adequate quantity of oxygen is provided for crew operations. This partial grant of exemption 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. In addition, this partial grant of exemption 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) must 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 Airplane Flight Manual. Rather than place an MMEL dispatch limitation as an explicit condition of granting the exemption, we have determined that it is appropriate for the FAA Flight Operations Evaluation Board to evaluate the matter of dispatch with a malfunctioning system that is required to ensure that the airplane is capable of performing an emergency descent.

The applicable rapid decompression procedures for the flightcrew must be included in the emergency procedures section of the Airplane Flight Manual. This information should also be included in the Boeing Flight Crew Operating Manual. Note that initial and recurrent emergency training for all crewmembers, in accordance with §§ 121.397, 121.417, and 121.427, must include training for a rapid decompression and donning of oxygen masks.

Regarding the provisions of § 25.841(a)(3), the petitioner included in its analysis consideration of engine failures. In addition, as part of the normal certification process, the petitioner will consider fuselage structure, and system failures. Therefore, relief from this requirement is not necessary.

The partial grant of exemption from § 25.841(a)(2)(ii) will permit cabin pressure altitude to exceed 40,000 feet for 1 minute (but not to exceed 43,000 feet for any duration) after decompression from any uncontained engine failure condition not shown to be extremely improbable. The partial grant of exemption from § 25.841(a)(2)(i) will permit cabin pressure altitude to exceed 25,000 feet for more than 2 minutes (but not more than 3 minutes) after decompression from any uncontained engine failure condition not shown to be extremely improbable, allowing time for the airplane to descend from an altitude of 43,000 feet to 25,000 feet.

The FAA's decision

In consideration of the foregoing, I find that a partial grant of exemption is in the public interest. Therefore, pursuant to the authority contained in 49 U.S.C. §§ 40113 and 44701, delegated to me by the Administrator, The Boeing Company's petition for an exemption from the requirements of §§ 25.841(a)(2)(i) and 25.841(a)(2)(ii), as amended by Amendment 25-87, is granted for the Model 747-8/-8F airplanes.

This partial grant of exemption is subject to the following conditions:

1. The Airplane Flight Manual for the Boeing Model 747-8/-8F airplanes must indicate that the maximum indicated operating pressure altitude is 43,000 feet.

2. The Airplane Flight Manual must contain applicable flightdeck crew procedures for a rapid decompression event. The section of the Airplane Flight Manual for the Boeing Model 747-8/-8F airplanes which pertains to actions in the event of a decompression

must state that the flightdeck crew should initiate a descent at the maximum rate of descent and safe descent speed, which is typically the maximum operating speed (V_{MO}/M_{MO}) assuming structural integrity of the airplane.

3. The petitioner must submit certification flight test data for the Boeing Model 747-8/-8F airplanes that corroborate the descent profiles used in the analysis to show that after decompression at an airplane indicated operating pressure altitude of 43,000 feet; the cabin pressure altitude will not exceed 25,000 feet for more than 3 minutes or 40,000 feet for more than 1 minute.

Issued in Renton, Washington, on October 19, 2009.

Signed by Ali Bahrami

Ali Bahrami
Manager, Transport Airplane Directorate
Aircraft Certification Service