Cabin Cruising Altitudes for Regular Transport Aircraft

Aerospace Medical Association, Aviation Safety Committee, Civil Aviation Subcommittee

Aerospace Medical Association, Aviation Safety Committee, Civil Aviation Subcommittee. ***Cabin cruising altitudes for regular transport aircraft.*** **Aviat Space Environ Med 2008; 79:433–9.**

The adverse physiological effects of flight, caused by ascent to altitude and its associated reduction in barometric pressure, have been known since the first manned balloon flights in the 19th century. It soon became apparent that the way to protect the occupant of an aircraft from the effects of ascent to altitude was to enclose either the individual, or the cabin, in a sealed or pressurized environment. Of primary concern in commercial airline transport operations is the selection of a suitable cabin pressurization schedule that assures adequate oxygen partial pressures for all intended occupants. For the past several decades, 8000 ft has been accepted as the maximum operational cabin pressure altitude in the airline industry. More recent research findings on the physiological and psycho-physiological effects of mild hypoxia have provided cause for renewed discussion of the "acceptability" of a maximum cabin cruise altitude of 8000 ft; however, we did not find sufficient scientific data to recommend a change in the cabin altitude of transport category aircraft. The Aerospace Medical Association (AsMA) should support further research to evaluate the safety, performance and comfort of occupants at altitudes between 5000 and 10,000 ft.

Keywords: aviation medicine, aviation safety, cabin pressurization, physiology, hypoxia, pilot performance.

THE ADVANCES IN aircraft design during and after World War I resulted in the achievement of increased operational altitudes. This necessitated the development of systems capable of providing oxygen to aircrew in flight. The development of cabin pressurization lagged behind advances in oxygen systems. There were four reasons for this:

1. It took many years of development before aircraft had the necessary performance to be able to reach altitudes beyond the performance of then existing oxygen systems (pipe-stem oxygen system) (4).
2. The operational limits of existing oxygen systems in development were not fully understood and demanded testing and the attention of aeromedical laboratories.
3. The initial very high altitude flights were associated primarily with achieving record altitudes, and research was directed toward protecting healthy pilots from hypoxia.
4. The concept of pressurized cabins in fabric covered aircraft incurred too much of a weight penalty and was not feasible.

Significant work on pressurized cabins began in the United States and Germany in the 1920s. The first flight with a pressurized cabin was on 8 June 1921 by Lt. Harold Harris in a modified DH-9A. The first American aircraft with a pressurized cabin, the XC-35, an experimental Electra, flew in 1937 (26). With the advent of World War II, both Allied and German cockpit/cabin environment research accelerated. Research was also directed toward the structure of the fuselage. The first production pressurized civil airliner was the Boeing 307, which came into service in 1940 (3).

Pressurization systems in aircraft impose both weight and fuel penalties on operators. The material properties of aluminum alloys from which most aircraft pressure vessels are manufactured also impose limitations on cabin pressure differentials defined by maximum permitted hoop stress. Moreover, frequent pressurization/depressurization cycles impose service life limits on the hull.

With the development of the composite pressure cabin, questions emerged regarding which potential maximum cabin pressure differentials ultimately will be permitted by fully composite structural components; whether there are existing problems for flight crew or passengers at current operational cabin altitudes near 8000 ft*, or whether there may be benefits gained by operating at lower maximum cabin altitudes. Weight and strength advantages over conventional aluminum alloy

From the Aerospace Medical Association, Alexandria, VA.

This manuscript was received and accepted for publication in January 2008.

Address reprint requests to: Aerospace Medical Association, 320 S. Henry St., Alexandria, VA 22314; www.asma.org.

A report prepared by the Civil Aviation Safety Subcommittee of the Aviation Safety Committee of the Aerospace Medical Association. Members of the committee are: John Affleck; Arnold Angelici; Susan Baker, Vice Chair, Civil Aviation Safety Subcommittee; Ted Brook; Mary Cimrmancic, Chair, Civil Aviation Safety Subcommittee; Robert Cocks; Chuck DeJohn, Chair, Aviation Safety Committee; L. Dan Eldredge; James Elliott; Tony Evans; Edmond Feeks; Karen Fox; Jim Fraser; Pedita Hall; Karen Heupel; Yuki Kakimoto; Jeffrey Kyff; Matt Lewis; Guohua Li; Tom Luna; Graeme Maclarn; Roy Marsh; Joe McKeon; Eduardo Mera; Verba Moore; Mike Muhm; Brian Musselman; Donna Murdoch; Greg Ostrander; Glenn Pascoe; Eduard Ricaurte; Diane Ritter; Robert Ryan; Farhad Sahiar; Bill Salazar; Tarek Sardana, Chair, Military Aviation Safety Subcommittee; Dennis Shanahan; Joseph Sky; Tracy Smart; Jan Stepane; Nathan Villaire; Nicholas Webster, Vice Chair, Aviation Safety Committee; Deborah White; Alex Wolbrink; Andy Woodrow; Rawson Wood; A. J. Wurmstein; and Shawn Zarr.

* This paper uses traditional units, rather than SI (Système International d'unités) units because the international air transport industry traditionally refers to cabin altitude in feet or atmospheres. In addition, regulations referred to in the text were written using traditional units; therefore, **Appendix A** is provided for the conversion of units from traditional to SI units.

DOI: 10.3357/ASEM.2272.2008

construction are anticipated, with consequent belief that accepting the potential risks of mild hypoxia posed by cabin altitudes in some current transport category aircraft may need to be revisited.

Both Boeing Commercial Aircraft Company and Airbus Industries have been using composites in spars, control surfaces, and empennage structures since the 1960s. The use of fully composite pressure cabins is not new. Experience has shown success in construction and joining methods (27). The Lear Fan 2100 and Beech Starship have been designed with fully composite pressure cabins. Starship production began in 1985, but ended shortly due to manufacturing expenses. The Hawker 4000 business jet, currently in production, has a composite fuselage with a cabin pressurization of 6000 ft. The Boeing 787 concept presents a new transport category aircraft, with its fully composite fuselage and electrical pump pressurization system.

Hypoxia

The physiological basis for the effects of the ascent to altitude was originally described in 1878 by French physiologist Paul Bert. The physiological and cognitive effects of ascent to altitudes above 10,000 ft have been documented in the literature and standard texts (14,29). This research led to the standard practice of providing supplemental oxygen for occupants when the cabin altitude exceeded 10,000 ft.

Cabin pressurization of aircraft effectively transposes the relatively narrow physiologic zone to a contained, high altitude environment. Two important physiologic functions are accomplished through pressurization: 1) adequate oxygenation due to the maintenance of partial pressure of gases in air; and 2) stable environmental pressure to preclude development of a variety of gas-related problems. While cabin pressures are maintained within the parameters of the physiologic zone, supplemental oxygen is not needed by most occupants. As shown in **Table I**, for transport category aircraft in the United States, there is no requirement for all passengers to be provided supplemental oxygen until cabin pressure altitude exceeds 15,000 ft; however, crewmembers must be provided supplemental oxygen above 10,000 ft.

In the United States, the requirement to provide passenger oxygen in normal operations of turbine engine aircraft is described in Title 14 Code of Federal Regulations Part 121 Section 329, as shown in Table I. According to that regulation:

- No supplemental oxygen is required for flights at cabin altitudes below 10,000 ft.
- No supplemental oxygen is required at cabin altitudes between 10,000 ft and 14,000 ft of less than 30 min.
- For flights where cabin altitude is between 10,000 ft and 14,000 ft for more than 30 min, enough supplemental oxygen for 10% of the passengers is required for that portion of the flight at those altitudes.
- For flights at cabin altitudes between 14,000 ft and 15,000 ft, enough supplemental oxygen for that portion of the flight at those altitudes is required for 30% of passengers.
- For flights where cabin altitude exceeds 15,000 ft, supplemental oxygen for 100% of passengers is required for that portion of the flight where the cabin altitude exceeds 15,000 ft.

There is a common misconception that aircraft are required to be operated at an 8000-ft cabin pressure altitude. In essence, the 8000-ft level is set by the industry as a "best practice" compromise between an acceptable level of "mild" hypoxia, a comfortable "shirt sleeve" environment for the passengers, an acceptable pressurization life cycle for the pressure vessel, minimal structural weight penalty, and an economical use of fuel by flying at high altitude (22). For purposes of this paper, the term "mild hypoxia" refers to exposure of a normal healthy adult to the aircraft cabin environment during routine commercial air travel not exceeding 10,000 ft and/or a P_aO_2 not less than 60 mmHg.

Cabin pressure can, to an extent, vary with altitude, meaning that if an aircraft flies lower than the maximum designed cruise altitude the cabin pressure may be lower than 8000 ft. Cabin pressure altitude at cruise will be determined by the aircraft's cabin pressure differential, the actual cruise altitude, and the ability of the pressure hull to maintain a particular pressure setting.

While it may be different in other countries, in the United States current cabin pressure altitudes used by operators are dictated by factors other than specific government regulations. Federal Aviation Regulations state that aircraft must be equipped to provide a cabin altitude of no more than 8000 ft (cabin pressure is no lower than 565 mmHg) at the maximum cruise altitude, or maximum operating altitude under normal operating conditions (15). However, no U.S. regulation requires that a transport category aircraft be operated at or below

TABLE 1. 14 CFR PART 121 SUPPLEMENTAL OXYGEN REQUIREMENTS.

	Cabin Altitude (ft)	Supplemental O_2 Requirements
Crew	10,000 ≤12,000	Oxygen must be used by each of the flight deck crewmember, and must be provided for other crewmembers, for that part of the flight at those altitudes that is of more than 30 min duration.
	> 12,000	Oxygen must be used by each of the flight deck crewmember, and must be provided for other crewmembers, during the flight time at those altitudes.
Passengers	*Reciprocating engine aircraft 8000 ≤14,000	Oxygen available for 10% of the passengers for 30 min for flights of more than 30 min.
	†Turbine aircraft 10,000 ≤14,000	Oxygen available for 10% of the passengers for 30 min for flights of more than 30 min.
	For all aircraft 14,000 ≤15,000	Oxygen available for 30% of the passengers for that part of the flight at those altitudes.
	For all aircraft > 15,000	Oxygen available for each passenger for the entire flight at those altitudes.

* 14 CFR 121.327: Supplemental oxygen: Reciprocating engine powered airplanes.
† 14 CFR 121.329: Supplemental oxygen for sustenance: Turbine engine powered airplanes.

an 8000-ft cabin pressure altitude (16). Although FAA regulations currently require that an aircraft must be capable of maintaining no greater than 8000-ft cabin altitude at the aircraft maximum operating altitude (15), it cannot be stated with confidence that operators actually maintain 8000-ft cabin altitudes. An in-flight study monitoring aircrew S_aO_2 levels and cabin altitude found that cabin altitudes varied between sea level and 8915 ft at cruising altitudes (9).

When determining the appropriate cabin altitude from a physiologic standpoint, three conditions must be considered:

1. The safety of the passengers, especially those with medical conditions, most importantly those with compromised cardiopulmonary conditions, such as chronic obstructive pulmonary disease (COPD), who might be adversely affected by a reduction in atmospheric pressure and oxygen partial pressure.
2. The ability of pilots to perform both normal and emergency operations, especially on long-duration flights.
3. The ability of the cabin crew to perform duties, both under normal conditions, which include mild exercise, and emergency conditions, which could include significant exertion.

A reduction in the ambient partial pressure of oxygen presents a potential danger to passengers with compromised cardiopulmonary systems due to lung disease or cardiovascular disease, especially if they live at low elevations. Altitude-adapted individuals with cardiorespiratory disease who reside in higher elevations would likely be less severely impacted. The paucity of documented clinically significant events may be related, in part, to the fact that mobility is limited aboard aircraft, and, furthermore, many flights never attain the maximum cabin pressure altitude ceiling of 8000 ft. Median flight altitude for commercial passenger transport aircraft has been reported to be 6215 ft in a 1988 study by Cottrell, who measured the altitude profiles in 204 scheduled national and international flights (8). The lack of medical events could also be viewed as a testimony to the relative safety of current flight practices. On the other hand, the initial effects of hypoxia are often insidious, with reduced cognitive function and other mild symptoms occurring some time before significant, more readily recognized clinical events, such as chest pain, shortness of breath, seizures, and loss of consciousness. Although there has been some disagreement among authors, likely based on the lack of a standardized incident reporting system among in-flight emergency assistance providers, most studies show a majority of serious in-flight medical emergencies are reported to be caused by cardiovascular disease and respiratory failure (6,19).

The ability of the cardiovascular system to compensate in a mild hypoxic environment may be compromised by both age and disease. Arterial oxygen tensions are lower than alveolar tensions. The alveolar-arterial gradient is approximately 8 mmHg in young healthy individuals, increases gradually with age, and is markedly elevated with cardiopulmonary disease (29). P_aO_2 (arterial PO_2) is known to decrease up to about age 70 and this is assumed to be caused by a number of changes in the mechanical properties of the lungs. The changes in respiratory mechanics with age could induce a greater ventilation/perfusion mismatch and thus explain this decrease in P_aO_2 (31).

Cabin Altitude Research

A review of the literature revealed that cabin altitude research was divided into several areas. We evaluated two review articles, a mountain study, two simulated altitude studies, and three in-flight studies. The in-flight studies were further subdivided into physiological and performance papers.

Review Articles

In a review of the literature on the incidence of in-flight medical emergencies, Cocks and Liew (6) found that the pattern of diagnoses varied among studies, but common diagnoses included cardiac, respiratory, neurologic, vasovagal, and gastrointestinal problems. They discuss cabin environment as a consideration in responding to in-flight medical emergencies, and correlate cabin altitude pressure with the effects of hypoxia and gas expansion. Quoting Schesser, they state “At cruising altitude, the cabin pressure is set to 5,000 to 8,000 feet above mean sea level, rendering all passengers a degree of hypoxia, which can have serious effects on an already sick person” (6). This in-flight emergency pattern was confirmed by Gendreau and DeJohn, who also found that in many passengers with cardiopulmonary disease oxygen saturation may fall dramatically at ordinary cabin pressures, resulting in hypobaric hypoxia (19).

Mountain Study

Contradictory findings were obtained by Erdmann et al., in a 1998 study of 23 men (age 51 ± 9 yr) with coronary artery disease and impaired left ventricular function and a control group of 23 subjects of similar age. Citing the scarcity of literature related to the effects of exposure to altitude they conducted maximal symptom-limited bicycle stress tests on a mountain at altitudes of 3280 ft and 8200 ft during their first hours of ascent. They stated that “maximal heart rate and blood pressure did not differ between 3,280 feet and 8,200 feet. Oxygen saturation at rest and exercise remained unchanged. At 8,200 feet the exercise was terminated more often because of dyspnea, but the level of perceived exertion was similar to that of 3,280 feet. There were no complications or signs of ischemia. Thus, patients with coronary artery disease with impaired left ventricular function without residual ischemia had good tolerance to exposure at the tested altitudes. The effects in patients are comparable to those in a group of normal subjects and the risk for an adverse medical event is not increased” (13).

Simulated Altitude Studies

In a simulated altitude study by Dillard et al., “Eighteen patients/subjects, mean age 68y (± 6y), with severe COPD…were monitored at 8,000 feet…in an altitude…chamber. Mean radial artery catheter blood oxygen tension declined from a ground value of 72.4 ± 9 mmHg to

47.4 ± 6 mmHg at 8,000 feet after 45 minutes of steady state hypobaric exposure, indicating arterial blood oxygen tension (P_aO_2) declined to clinically significant levels in most patients. Detailed analysis indicated that 12 of the 18 patients/subjects had a P_aO_2 of less than 50 mmHg and 3 had a P_aO_2 below 40 mmHg. P_aO_2 levels in healthy, younger controls, was 95.6 ± 8 mmHg and 59.8 mmHg, for ground/sea level and 8,000 feet altitude, respectively. P_aCO_2 of the COPD patients at ground level was 38 ± 5 mmHg and, at altitude was 35 ± 4 mmHg, no different than P_aCO_2 values of healthy, younger controls." Patients with severe COPD most certainly would be expected to be clinically hypoxemic at cabin altitudes of 8000 ft and would be likely to use supplemental oxygen to prevent severe drops in P_aO_2 during air travel (12).

In a simulated cabin altitude/long-haul commercial flight study, Muhm et al. examined the effect of exposure to barometric pressures associated with cabin altitudes up to 8000 ft (2438 m). Participants were 502 volunteers ages 21–75 yr, each assigned to one hypobaric chamber run simulating a 20-h commercial fight at a specific barometric pressure corresponding to 650 (ground level), 4000, 6000, 7000, and 8000 ft above sea level. Measurements of arterial oxygen saturation via pulse oximetry, testing of sensory and psychomotor response, symptoms of acute mountain sickness, and reports of discomfort recorded on the Environmental Symptoms Questionnaire (ESP) IV were examined and correlated with simulated pressure altitudes (24).

In a later study the authors reported symptoms of acute mountain sickness in 7.4% of subjects, without significant variation among altitudes. Reports of discomfort increased with increasing altitude, particularly at 7000 to 8000 ft. An approximate 4% drop in oxygen saturation is reported in subjects ascending to 7000 or 8000 ft from 650 ft (ground level). The authors stated that "…[t]his degree of hypoxemia did not affect the occurrence of acute mountain sickness, other adverse health outcomes, or impairment of sensory or psychomotor performance, but it was associated with an increased prevalence of discomfort after 3 to 9 hours. Exercise reduced muscular discomfort but did not significantly affect other ESP-IV factors." The authors conclude that their findings are in agreement with earlier researchers that healthy individuals are not adversely affected by a cabin pressure altitude of 8000 ft, but there are fewer reports of discomfort at 6000 ft cabin altitude or lower (25).

In-Flight Studies

We evaluated four in-flight studies. The in-flight studies were further subdivided into physiological and performance papers. Other than the controlled research environment used to study subjects, there is a paucity of published data on the relationship between cabin altitude and the incidence of actual in-flight medical incidents.

Aldrette and Aldrette concluded that passengers flying at cabin altitudes of between 6050 ft and 8450 ft ran the risk of exacerbating cardiac, pulmonary, and hematologic diseases (1). Coker and Partridge, in an editorial in *Thorax* 2004 (7), reported that respiratory cases were the third most common cause of diversions following cardiac and neurological causes. They reported that at a cabin altitude of 8000 ft, the arterial oxygen tension (P_aO_2) will fall between 56 and 60 mmHg. Such levels may worsen hypoxia in patients with lung disease, especially if the subject is hypoxemic at sea level (7). This was confirmed by Muhm in 2004 when he applied statistical methods to predict the levels at which passengers require supplemental oxygen at 8000 ft (24). Mortazavi et al. concluded that oxygen supplementation during air travel is needed for individuals with an estimated P_aO_2 below 55 mmHg at 8000 ft cabin altitude; however, these data are based on small studies and represent a limited group of diseases (23). It has also been shown that mild exercise such as walking along the aisle may promote more serious hypoxemia during air travel, dropping P_aO_2 to critical levels in passengers with COPD (5). It has been reported that the P_aO_2 of patients with COPD dropped to as low as 40 mmHg or lower during routine air travel. Schwartz et al. showed that the mean P_aO_2 dropped from 68 mmHg at sea level to 51 mmHg at 5415 ft and 44 mmHg at 7380 ft in patients with COPD. This demonstrates that mild hypoxemia may develop into severe hypoxemia during commercial air flights (30).

Initial recognition that flights of 8 to 12 h left a pilot sleepy and unable to concentrate, with a general lack of motivation, at a pressure altitude equivalent of 8000 ft was noted by Lovelace, Bray and Gagge in 1946. Further, they noted that the "comfort of passengers and efficiency of crews demands the use, wherever possible, of isobarics of 5,000 feet or lower" (21). Cottrell et al. studied 42 aircrew members on 22 regularly scheduled flights. They found that while the cabin altitudes varied between sea level and 8915 ft, mean S_aO_2 levels varied from 97.0–88.6% during cruise with large individual variations. Unfortunately, the investigators did not address human performance issues (9).

Incidental findings during studies at the Royal Air Force Institute of Aviation Medicine showed that the ability of subjects who learned tasks while breathing air at 8000 ft was impaired, compared with subjects who learned the task while breathing 100% oxygen at that altitude (18). Further studies by Denison et al. suggested that the performance of complex orientation tasks used in the study was impaired by mild hypoxia induced by breathing air at either 5000 ft or 8000 ft while the task was being learned but not after the subjects had practiced it (11). Impairment in the learning phase was barely detectable at 5000 ft, but was considerable at 8000 ft, the generally acceptable maximum cruising cabin altitude in passenger aircraft. These original studies, performed between 1960 and 1965, were repeated by several independent investigators; all confirming that very mild hypoxia impairs performance of complex tasks in the learning phase (2,10,17,20,28). These studies demonstrated that there is a prolongation in the learning time of new tasks when breathing air at altitudes of up to 10,000 ft and that the intensity of this effect increases with the complexity of the task. Choice reaction times, for example, are prolonged when breathing air at 5000 ft to 7000 ft. If the task is well learned, the intensity of the hypoxia must be greater to achieve the same decrements in performance.

Discussion

Physiology

Intuitively one would expect that there is an altitude "threshold" for elderly healthy subjects. The exact altitude of this "threshold" is unknown; however, aeromedical experience supports the notion that 8000 ft represents a more physiologically challenging environment compared to lower cabin altitudes. At 8000 ft cabin altitude it is reasonable to assume the lower P_ao_2 levels in elderly, healthy subjects would produce decrements in cognitive, physical, and psychophysical performance. In addition, greater decrements could be expected in an elderly passenger population with cardiopulmonary disease. The implicit creation of "one threshold altitude" is a challenging task as the discussion in the literature and in operational contexts and studies revolves primarily around estimates of blood oxygen content (i.e., oxygen saturation), rarely actual measured blood gases, and the discussion also does not take into account other important parameters that influence clinical states. In fact one could stipulate that the more difficult task of assessing tissue oxygen delivery ought to be our key clinical concern as opposed to parameters that estimate peripheral oxygen content. This also highlights the importance of hyperventilation and acid base status in regard to the ability of the hemoglobin molecule to release oxygen at the tissue level. Additional data is needed to fully explain the physiologic changes that occur at altitude and how patients with cardiopulmonary compromise may be able to compensate successfully in that environment.

Performance

Routine flying tasks are over-learned skills and are reinforced in regular simulator training sessions in the airline environment. However, the frequency of currency training may vary from one type of flight operation to another, which suggests that the level of over-learning of procedures in air taxi, charter, and other non-regular public transport operations using pressurized aircraft may also be variable. Consequently, it is implied that a disparity in training at sea level may be a factor in affecting the potential for reduced aircrew performance under the effects of the mild hypoxia experienced at 8000 ft.

A literature search of the aviation medicine and aviation training literature using Medline, Google Academic, and the Psych databases revealed no studies to test this hypothesis. This is an area in which AsMA could be influential in stimulating research to determine if there are performance differences between public transport pilots who receive regular currency training and pilots operating pressurized aircraft in a less regulated training environment.

The adverse effects of mild hypoxia on physical and psycho-physiological performance are cause for concern, particularly for commercial pilots who, unlike military aircrew, do not normally use supplemental oxygen. In the 10th Annual Armstrong Lecture, Ernsting submitted his opinion that, when combined with less-rehearsed tasks, such as in an emergency scenario, "…the mild hypoxia produced by breathing air at an altitude of 8,000 feet should not be accepted for aircrew engaged in air operations because of the very significant impairment of ability to respond to a novel complex situation which it induces" (14). Fortunately the high level of training (over-learning) and relatively low exertional demands typically placed on commercial pilots appear to mitigate the adverse effects of this "mild hypoxia" on their flying performance, judgment, and overall flight safety during routine flight.

The 8000-ft cabin altitude has also been discussed as a cause of potential decrement in performance in flights of extremely long duration. However, such flights pose performance challenges even for well-oxygenated pilots and crew, and effects of mild hypoxia are difficult to identify independent of general feelings of fatigue and impaired vigilance that can be attributed more to the need for sleep than for want of oxygen, although mild hypoxia may have an additive decrement on performance at lower altitudes.

A unique, and often overlooked group that must function safely in the commercial flight environment, are the cabin crew. They have increased physical labor requirements relative to cockpit crew. Flight attendant duties vary, depending on type and duration of flight; however, all are required to do some lifting, pushing, reaching, and walking that places upon them greater oxygen consumption demands than those of pilots. There is a need for further research regarding the effect of physical exertion by cabin crew at 6000-, 8000-, and 10,000-ft cabin altitudes performing their routine tasks and during an emergency. In addition, the safety of passengers is dependant on their ability to respond in an emergency. Performance decrements experienced by pilots and other aircrew have not been adequately studied, and it remains unknown how mild hypoxia affects their ability to handle an emergency.

Conclusions

One of the likely reasons there have been minimal problems due to the mild hypoxia associated with cabin altitudes in flight is that the vast majority of the time they are maintained below 8000 ft. However, research has shown that this hypoxia impairs aircrew performance and exacerbates the symptoms of passengers with certain cardiopulmonary and respiratory conditions. It might, therefore, be expected that a lower cabin altitude would be preferable, especially for medically compromised passengers.

On the other hand, research to support a reduction in cabin altitude to optimize crew performance and the safety and comfort of passengers is inconclusive and there is a longstanding and impressive safety record for the 8000-ft cabin altitude currently used by air carriers. However, as the needs of the crew and their passengers are of paramount importance, and as current research findings are inconclusive, further research to determine the needs of the exposed group of people is of great importance, and is urgent.

1. Pilots must be able to perform learned tasks as well as respond to emergencies with speed and accuracy.
2. Cabin crewmembers must be able to effectively perform their jobs, which include mild to moderate physical work. They are also integral to the safety of passengers during an emergency.
3. Individuals with cardio-pulmonary disease are at highest risk.
4. Older healthy individuals have slightly increased risks due to physiologic changes associated with age that must be considered.
5. Young healthy passengers are at the least risk.

Most studies performed flight-related tasks in a simulated environment, but failed to evaluate the performance of each of these groups. Also, most in-flight studies do not report the altitude of the event. In addition, it must be stressed that normal, routine flight must be considered separately from an emergency. As new aircraft are designed and built, it is essential that the cabin pressurization schedules be based on solid evidence concerning the safety, performance, and comfort of aircrew and passengers in all aviation environments.

Recommendations

Based upon this review, it is the recommendation of the Aviation Safety Committee that there is insufficient evidence to recommend a change in the rules or practices governing maximum design or operational cabin altitude of transport category aircraft; however, AsMA should adopt a position to support further research to evaluate safety, performance, and comfort in both normal fight profiles and emergencies at altitudes between 5000 and 10,000 ft. These altitudes represent normal operational and emergency cabin altitudes often used in commercial and business aviation. In addition to experimental research, it is recommended that AsMA support clinical and epidemiologic studies of the risk, risk factors, medical and operational consequences related to the exposure to the current maximum cabin altitude of 8000 ft. Sufficient empirical evidence for any measurable adverse effects on health and safety of the current cabin altitude is essential to decision making in research, rule making, and operations.

ACKNOWLEDGMENTS

The Aviation Safety Committee gratefully acknowledges the unselfish contributions of Mrs. Julie Larcher of Advancia Corporation for her excellent support during the preparation of this manuscript. The Committee also acknowledges the excellent contributions of Ms. Katherine Wade, the Civil Aerospace Medical Institute Librarian, and Mr. Joseph Franzello, the Supervisory Medical and Biological Sciences Librarian, Aeromedical Library, Brooks City-Base, whose skill and professionalism made it possible for us to obtain the reference materials necessary to produce this position paper.

REFERENCES

1. Aldrette JA, Aldrette LE. Oxygen concentrations in commercial aircraft flights. South Med J 1983; 76:12–4.
2. Billings CE. Evaluation of performance using the Gedye task. Aerosp Med 1974; 45:128–31.
3. Boeing Corporation. Boeing history, model 307 Stratoliner. 2007; Retrieved 7 June 2007 from: http://www.boeing.com/history/boeing/stratoliner.html.
4. Carey C. A brief history of U.S. military aviation oxygen breathing systems. 2007; Retrieved 25 October 2007 from: http://webs.lanset.com/aeolusaero/Articles/Oxygen%20Systems%20history-Pt1.htm.
5. Christensen CC, Ryg M, Refvem OK, Skjønsberg OH. Development of severe hypoxemia in chronic obstructive pulmonary disease patients at 2,438 m (8,000 ft) altitude. Eur Respir J 2000; 15: 635–9.
6. Cocks R, Liew M. Commercial aviation in-flight emergencies and the physician. Emerg Med Australas 2007; 19:1–8.
7. Coker R, Partridge M. What happens to patients with respiratory disease when they fly? Thorax 2004; 59:966–70. Comment in: Thorax 2004; 59:919–20.
8. Cottrell JJ. Altitude exposures during aircraft flight. Flying higher. Chest 1988; 93:81–4.
9. Cottrell JJ, Lebovitz BL, Fennel RG, Kohn GM. In-flight arterial saturation: continuous monitoring by pulse oximetry. Aviat Space Environ Med 1995; 66:126–30.
10. Crow TJ, Kelman GR. Psychological effects of mild hypoxia. J Physiol 1969; 204:24.
11. Denison DM, Ledwith F, Poulton EC. Complex reaction times at simulated cabin altitudes of 5000 feet and 8000 feet. Aerosp Med 1966; 37:1010–3.
12. Dillard TA, Berg BW, Rajagopal KR, Dooley JW, Mehm WJ. Hypoxemia during air travel in patients with chronic obstructive pulmonary disease. Ann Intern Med 1989; 111:362–7. Comment in: Ann Intern Med 1990; 112:547-8 and Ann Intern Med 1990; 112:147-8.
13. Erdmann J, Sun K, Masar P, Niederhauser H. Effects of exposure to altitude on men with coronary artery disease and impaired left ventricular function. Am J Cardiol 1998; 81:266–70.
14. Ernsting J. Prevention of hypoxia—acceptable compromises. 10th annual Harry G. Armstrong Lecture. Aviat Space Environ Med 1978; 49:495–502.
15. Federal Aviation Administration. Pressurized cabins. Washington, DC: FAA; 2006. 14 CFR Part 25.841.
16. Federal Aviation Administration. Supplemental oxygen for sustenance: turbine powered aircraft. Washington, DC: FAA; 2006. CFR 121.329.
17. Figarola TR, Billings CE. Effects of meprobamate and hypoxia on psychomotor performance. Aerosp Med 1966; 37:951–4.
18. Gedye J. 1964. Transient changes in the ability to reproduce a sequential operation following a rapid decompression. London: Ministry of Defence (Air), RAF Institute of Aviation Medicine; 1964. Report No. 271.
19. Gendreau MA, DeJohn C. Responding to medical events during commercial airline flights. N Engl J Med 2002; 346:1067–73. Comment in: N Engl J Med 2002; 347:535-7.
20. Ledwith F. The effects of hypoxia on choice reaction time and movement time. Ergonomics 1970; 13:465–82.
21. Lovelace W, Gagge A, Bray C. In: Lovelace W. Aviation medicine and psychology. Dayton, OH: Headquarters Air Material Command; 1946:114.
22. McFarland R. Human factors in relation to the development of pressurized cabins. Aerosp Med 1946; 12:1303–18.
23. Mortazavi A, Eisenberg M, Langleben D, Ernst P, Schiff R. Altitude-related hypoxia: risk assessment and management for passengers on commercial aircraft. Aviat Space Environ Med 2003; 74:922–7.
24. Muhm JM. Predicted arterial oxygenation at commercial aircraft cabin altitudes. Aviat Space Environ Med 2004; 75:905–12.
25. Muhm JM, Rock PB, McMullin DL, Jones SP, Lu IL, Eilers KD, et al. Effect of aircraft-cabin altitude on passenger discomfort. N Engl J Med 2007; 357:18–27.
26. National Museum of the United States Air Force. Lockheed XC-35 fact sheet. 2007; retrieved 27 April 2007 from: http://www.nationalmuseum.af.mil/factsheets/factsheet.asp?id=3296.
27. Nui M. Composite airframe structures. Los Angeles, CA: Technical Book Company; 1993: 562–73 and 590–7.

28. Pearson RG, Neal GL. Operator performance as a function of drug, hypoxia, individual, and task factors. Aerosp Med 1970; 41:154–8.
29. Pickard J. The atmosphere and respiration. In: De Hart R, Davis J, eds. Fundamentals of aerospace medicine , 3rded. Philadelphia: Lippincott Williams & Wilkins; 2002.
30. Schwartz JS, Bencowitz HZ, Moser KM. Air travel hypoxemia with chronic obstructive pulmonary disease. Ann Intern Med 1984; 100:473–7.
31. Sorbini CA, Grassi V, Solinas E, Muiesan G. Arterial oxygen tension in relation to age in healthy subjects. Respiration. 1968; 25:3–13.

Appendix A. Conversion of Feet to Meters, PSI, mmHg, inHg, and kPa.

Feet	Meters	PSI	mmHg	inHg	kPa
1000	305	14.17	732.94	28.86	97.70
2000	610	13.66	706.66	27.82	94.18
3000	914	13.17	681.15	26.82	90.80
4000	1219	12.69	656.39	25.84	87.49
5000	1524	12.23	632.36	24.90	84.32
6000	1829	11.78	609.05	23.98	81.22
7000	2134	11.34	586.44	23.09	78.19
8000	2438	10.92	564.52	22.23	75.29
9000	2743	10.50	543.26	21.39	72.40
10,000	3048	10.11	522.66	20.58	69.71
15,000	4572	8.29	428.91	16.89	57.16
20,000	6096	6.75	349.26	13.75	46.54
25,000	7620	5.45	282.04	11.10	37.58
30,000	9144	4.36	225.70	8.89	30.06
35,000	10,668	3.46	178.84	7.04	23.86

PSI = pounds per square inch, mmHg = millimeters of mercury, inHg = inches of mercury, kPa = kilopascals.