Altitude Exposures During Commercial Flight: A Reappraisal

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Background: Hypobaric hypoxia during commercial air travel has the potential to cause or worsen hypoxemia in individuals with pre-existing cardiopulmonary compromise. Knowledge of cabin altitude pressures aboard contemporary flights is essential to counseling patients accurately about flying safety. The objective of the study was to measure peak cabin altitudes during U.S. domestic commercial flights on a variety of aircraft. ***Methods:*** A handheld mountaineering altimeter was carried by the investigators in the plane cabin during commercial air travel and peak cabin altitude measured. The values were then compared between aircraft models, aircraft classes, and distances flown. ***Results:*** The average peak cabin altitude on 207 flights aboard 17 different aircraft was 6341 ± 1813 ft (1933 m ± 553 m), significantly higher than when measured in a similar fashion in 1988. Peak cabin altitude was significantly higher for flights longer than 750 mi (7085 ± 801 ft) compared to shorter flights (5160 ± 2290 ft/1573 ± 698 m). Cabin altitude increased linearly with flight distance for flights up to 750 mi in length, but was independent of flight distance for flights exceeding 750 mi. Peak cabin altitude was less than 5000 ft (1524 m) in 70% of flights shorter than 500 mi. Peak cabin altitudes greater than 8000 ft (2438 m) were measured on approximately 10% of the total flights. ***Conclusions:*** Peak cabin altitude on commercial aircraft flights has risen over time. Cabin altitude is lower with flights of shorter distance. Physicians should take these factors into account when determining an individual's need for supplemental oxygen during commercial air travel.

Keywords: cabin altitude, aircraft, hypoxia.

FOR DECADES, physicians have been concerned about the effects of hypobaric hypoxia on patients with cardiopulmonary disease during commercial air travel (1,3,11). Because an airplane cabin is not typically pressurized to sea level during flight, the reduction in ambient pressure and accompanying reduction in inspired partial pressure of oxygen (P_io_2) leads to desaturation of arterial blood hemoglobin. While commercial air travel poses no significant health risk for most passengers, individuals who have reduced arterial oxygen saturation at sea level may develop significant hypoxemia during flight (1,11).

Federal Aviation Administration regulations require that aircraft be constructed to be capable of maintaining minimum cabin pressurization equivalent to 8000 ft (2438 m) altitude at the plane's maximum operating altitude (14). Physicians in turn have attempted to predict the effect that the altitude exposure will have on their compromised patients and advise accordingly regarding the need for supplemental oxygen during air travel (1). In recent years, studies in this regard have included not only patients with chronic obstructive pulmonary disease (4), but also adults with cystic fibrosis (10) and patients with restrictive lung disease (5). Methods used to prognosticate safety have included pulmonary function test guidelines (3), predictive algorithms based upon resting arterial blood values with or without pulmonary function test modification (8,15), response to hypobaric hypoxia in altitude chambers (4,5) or in mountain laboratories at high elevation (6), exercise testing (4), and response to breathing a hypoxic gas mixture chosen to simulate the P_io_2 at 5000 or 8000 ft (1524 or 2438 m) (9,10,13).

Currently, a high altitude simulation test (HAST) is considered the best method available to evaluate patients with cardiopulmonary compromise with an equivocal need for supplemental oxygen during air travel (1,13). During a HAST, patients breathe an hypoxic gas mixture with 15.1% oxygen, yielding a P_io_2 of 110 mmHg, simulating the maximum allowable cabin altitude of 8000 ft (2438 m). However, the ambient pressure found in air cabins at cruising altitude is variable and may evolve with the design of new aircraft (6).

In this study, we measured peak cabin altitude achieved in over 200 U.S. domestic commercial flights from 2005 to 2011 in an attempt to better define the magnitude of hypoxia to which patients are exposed during commercial air travel. We also sought to determine the proportion of flights with a peak cabin altitude that exceeded 8000 ft (2438 m) and the relationship between cabin altitude and flight distance or aircraft type.

METHODS

From 2005-2011, physicians in the Pulmonary, Critical Care, and Hyperbaric Medicine section at Virginia Mason Medical Center in Seattle, WA, carried an altimeter when

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they flew on domestic commercial flights. The device was a Suunto Escape 203 mountaineering altimeter (Suunto Corporation, Vantaa, Finland) with an altitude range from −1600 to 29,500 ft (−500 to 9000 m) and a resolution of ± 3 ft (0.914 m). When the departure airport elevation was not known to the operator, he or she boarded the aircraft and, with the cabin door still open, set the device's ambient altitude to 0 ft, then started the device in "log" mode. During flight, the altimeter translated the drop in barometric pressure to altitude gained and recorded the maximum altitude since takeoff. At the arrival airport, log mode was stopped and the maximum altitude achieved during that flight read from the device and recorded, along with type of aircraft, airline, and route flown.

The maximum cabin altitudes measured in this way represented only the altitude gain from the departure airport. Elevations of departure airports were obtained (2) and added to the gain recorded by the altimeter to get actual maximum cabin altitude. In approximately one-third of flights, the airport elevation was known from a prior flight and the altimeter calibrated to actual altitude prior to the flight. Mileage for flight routes was obtained from a standard online resource (2).

Cabin altitudes and flight distances are expressed as mean ± SD. One-way ANOVA was used to compare peak cabin altitudes achieved by the three classes of aircraft flown. Regression analysis was used to compare cabin altitude with flight distance. Unpaired *t*-tests were used to compare cabin altitudes on flights less than and greater than 750 mi, as well as to compare mean peak cabin altitudes from a 1988 study by Cottrell (7) with the present one. This study was not IRB-regulated research since no human subjects were involved.

RESULTS

Peak cabin altitude during commercial air travel was 6341 ± 1813 ft (1933 ± 553 m). These data were recorded during 207 domestic flights on 17 aircraft types operated by 17 different airlines. There were 170 (82%) flights on large commercial jets, 24 flights (12%) on smaller regional jets, and 13 flights (6%) on turboprop aircraft (**Table I**). Boeing 737 jets accounted for 39% (81 of 207) of all flights. Peak cabin altitudes were highest for commercial jets (6819 ± 1265 ft/2078 ± 386 m; mean ± SD), followed by regional jets (4798 ± 2262 ft/1462 ± 689.5 m), and then turboprop aircraft (2949 ± 1905 ft/899 ± 581 m). Each was statistically different from the other two classes of planes ($F = 58.00$, d.f. = 2, $P < 0.0001$).

Peak cabin altitude increased linearly with flight distance for flights up to 750 mi ($r^2 = 0.67$, $P < 0.0001$, **Fig. 1**). For flights longer than 750 mi, cabin altitude plateaued and was independent of flight distance ($r^2 = 0.013$, $P = 0.19$). Consequently, flights longer than 750 mi achieved an average peak cabin altitude (7085 ± 801 ft/2160 ± 244 m) that was significantly higher than that achieved for flights of 750 mi or less (5160 ± 2290 ft/1573 ± 698 m) ($P < 0.0001$). Among flights shorter than 750 mi, 42% achieved a peak cabin altitude of less than 5000 ft (1524 m). Among flights shorter than 500 mi, 70% achieved a peak cabin altitude of less than 5000 ft (1524 m).

The same relationship between cabin altitude and flight distance is seen regardless of aircraft type (**Figs. 2A-C**). Although commercial jets accounted for most of the long distance flights, shorter flights on commercial jets were also associated with lower peak cabin altitudes (Fig. 2C). Specifically, the linear relationship between peak cabin altitude and flight distance for flights less than 750 mi was not statistically different when commercial

TABLE I. PEAK CABIN ALTITUDES AND FLIGHT DISTANCES FOR ALL TYPES OF PLANES.

	# Flights	Peak Cabin Altitude (mean ± SD; ft)	Range of Peak Cabin Altitudes (ft)	Flight Distance (mean ± SD; miles)	Range of Flight Distances (miles)	Cabin Altitude > 8000 ft
All flights	207	6341 ± 1813	232-8549	1189 ± 769	61-2720	20 (9.7%)
Commercial jets						
B737	81	7250 ± 1251	1958-8445	1248 ± 679	142-2690	18 (22.2%)
B757	42	6045 ± 1235	1421-7697	1566 ± 695	84-2720	0
B767	10	6372 ± 372	5853-7014	2271 ± 293	1710-2641	0
A319	9	7584 ± 459	6572-7966	1364 ± 590	337-1970	0
A320	7	7310 ± 464	6598-8058	1.467 ± 572	501-2370	1 (14.3%)
A321	3	7113 ± 368	6758-7492	2337 ± 58	2270-2370	0
MD80	18	6310 ± 1191	3779-7949	778 ± 339	177-1710	0
Total	**170**	**6819 ± 1265**	**1421-8445**	**1371 ± 706**	**84-2,2720**	**19 (11.2%)**
Regional Jets						
CRJ 50/200/700	18	4672 ± 2017	298-7474	458 ± 292	72-1120	0
ERJ 145/170	6	5177 ± 3077	1152-8549	499 ± 376	105-954	1 (16.8%)
Total	**24**	**4798 ± 2262**	**298-8549**	**468 ± 306**	**72-1120**	**1 (4.2%)**
Turboprops						
SAAB540	2	930 ± 378	662-1197	165 ± 0	165-165	0
Bombadier Q 200/400/800	8	4219 ± 1082	3084-6112	173 ± 55	103-230	0
Dash 8	3	909 ± 908	232-1940	83 ± 38	61-126	0
Total	**13**	**2949 ± 1905**	**232-6112**	**151 ± 60**	**61-230**	**0**

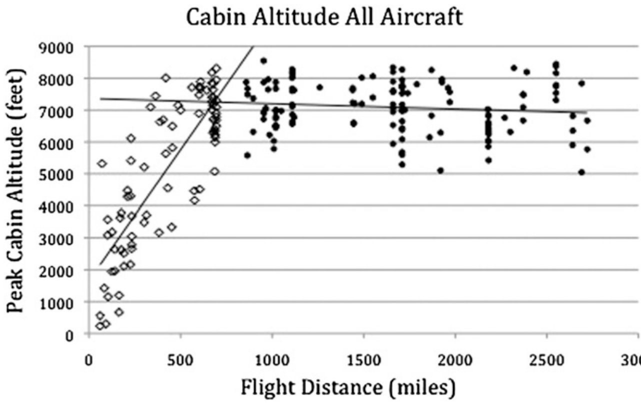

Fig. 1. Peak cabin altitude vs. flight distance measured in 207 U.S. domestic flights aboard 17 different types of aircraft. Linear regression lines are shown for flights less than (open diamonds) and greater than (filled circles) 750 mi in distance. For flights less than 750 mi (N = 80), slope = 8.2 (95% CI 6.9 to 9.5; R^2 = 0.67; $P < 0.001$). For flights greater than 750 mi (N = 127), slope = −0.17 (95% CI −0.42 to 0.08; R^2 = 0.013; P = 0.194).

jet flights were compared with the combination of regional jet and turboprop flights (**Fig. 3**). This suggests that flight distance is a better predictor of peak cabin altitude than aircraft type.

Of the total 207 flights, 20 (10%) registered a peak cabin altitude higher than 8000 ft (2438 m; 8218 ± 149 ft/2505 ± 45 m; range 8012–8549 ft/2442–2606 m). The list of planes involved included 18 Boeing 737 flights, 1 Airbus A320 flight, and 1 Embraer ERJ145 flight. The 18 Boeing 737 flights were operated by four different airlines.

DISCUSSION

Better understanding of cabin altitude aboard commercial air flights is important to predicting the degree of hypoxemia that a passenger with cardiopulmonary disease may experience during air travel. Peak cabin altitude in this study ranged from 232 ft to 8549 ft (71 m to 2606 m), corresponding to inspired oxygen tensions of 148 mmHg and 108 mmHg, respectively. Our data confirm that peak cabin altitudes aboard commercial airplanes are generally below 8000 ft (2438 m), with considerable variability to levels below 5000 ft (1524 m).

This study provides several important insights into cabin altitude aboard commercial aircraft flying within the United States. Our data argue that cabin altitudes aboard commercial aircraft are higher than in earlier decades. In 1988, Cottrell published a study very similar to this one using a handheld altimeter to measure peak cabin altitudes in 204 commercial flights (7). He reported an average peak cabin altitude of 5673 ± 2057 ft (1729 ± 627 m) aboard domestic U.S. flights and demonstrated that higher cabin altitudes were measured aboard newer aircraft models, presumably because these aircraft flew at higher cruising altitudes. We measured an average peak cabin altitude of 6341 ± 1813 ft (1933 ± 553 m), significantly higher ($P < 0.01$) than that measured by Cottrell in 1988.

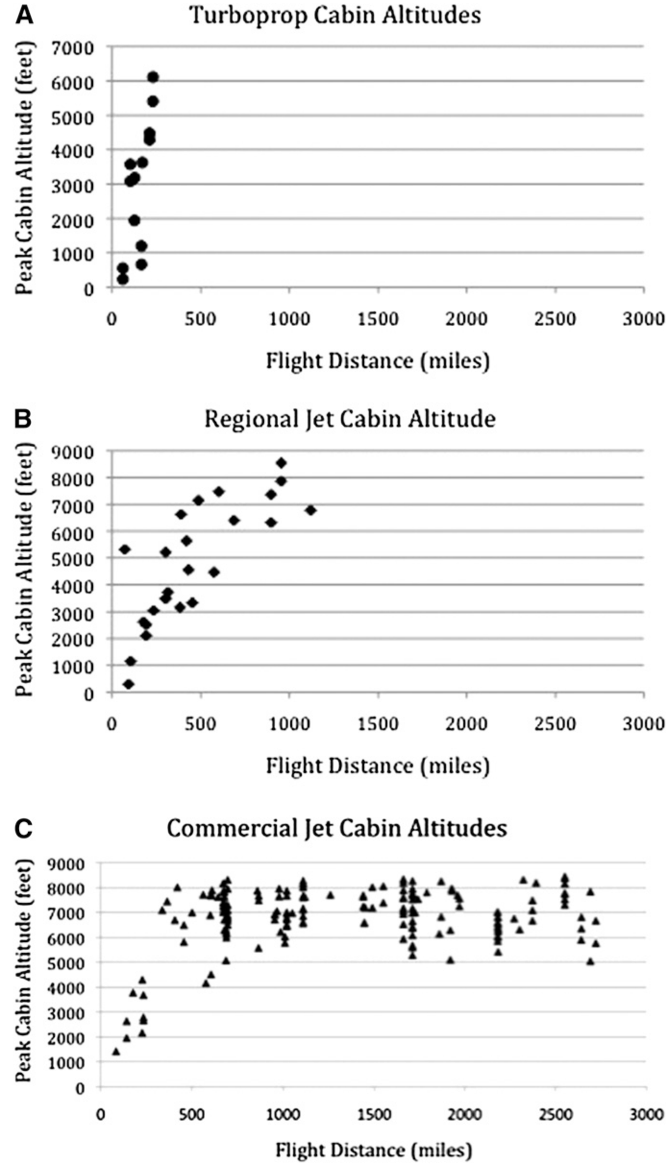

Fig. 2. A) Peak cabin altitudes measured during flights aboard turboprop aircraft. B) Peak cabin altitudes measured during flights on regional jet aircraft. C) Peak cabin altitudes measured on flights on large commercial jets.

Although we observed variability in cabin altitude among different aircraft models, our data suggest newer aircraft (Boeing 757/767 compared to the Boeing 727; Airbus 321 compared to the older Airbus 320) are not associated with higher cabin altitudes (Table I). In fact, future planes built with strong, lightweight composite materials will allow passenger cabins to be pressurized to even lower altitudes than is currently the case. For example, cabin altitudes in the new Boeing 787 are likely to remain below 6000 ft (1829 m) (6).

The older age of the commercial airplane fleet is another possible explanation for the higher cabin altitudes measured in this study. A plane's fuselage develops air leaks with years of use, allowing pressurized air in the passenger cabin to leak unintended into the external environment. This raises cabin altitude in an older versus

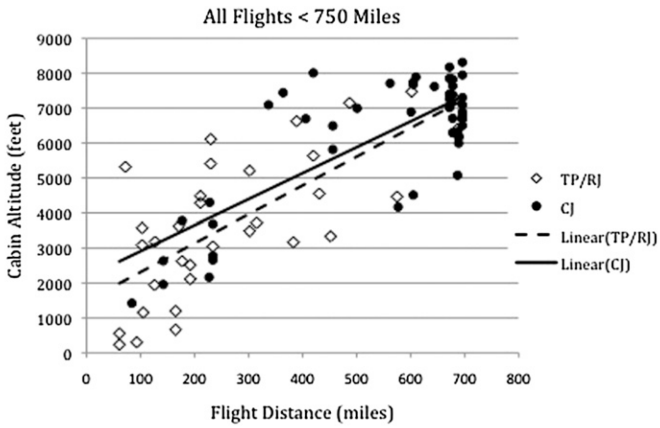

Fig. 3. Peak cabin altitudes vs. flight distance on all flights less than 750 mi in distance, with turboprop (TP) plus regional jet (RJ) flights combined (both open diamond) compared to large commercial jet (CJ) flights (filled circles). Linear regression lines shown TP/RJ flights (dashed) and CJ flights (solid). For TP/RJ (N = 32), slope = 8.2 (95% CI 5.0 to 11.5; $P < 0.001$). For CJ (N = 48), slope = 7.4 (95% CI 5.6 to 9.2; $P < 0.001$).

newer plane of the same model at the same cruising altitude. Because the age of the airplanes flown in this and other studies was not recorded, we cannot determine the contribution of airplane age to the observed variability in cabin altitude. Additional studies would be needed to determine how airplane age and model affects cabin altitude, although it is unclear whether this information can be practically applied to pre-travel patient assessment unless an airline flies only one model and age of plane.

Flight distance may be a useful predictor of cabin altitude for short flights. Flights shorter than 750 mi were associated with a cabin altitude almost 2000 ft (610 m) lower than longer flights. When flights were shorter than 750 mi, cabin altitude decreased linearly with flight distance, so that the shortest flights were associated with the least hypoxic stress (Fig. 1). In fact, peak cabin altitude was less than 5000 ft (1524 m) in 70% of flights shorter than 500 mi. Further study is needed to determine whether the association of higher inspired oxygen tensions and shorter flight distances should influence clinical decisions regarding the need for supplemental oxygen during air travel.

It should be noted that our study was limited to domestic flights on domestic airlines within the United States, with a maximum flight distance of 2720 mi. There are certainly longer routes in the world and we are unable to comment on their cabin altitudes, although they would be expected to maintain a ceiling of 8000 ft (2438 m). Whether a 5-h flight at 8000 ft (2438 m) is physiologically similar to a 15-h flight at the same altitude remains to be studied.

The HAST is considered the most accurate way to predict in-flight hypoxia in the absence of a hypobaric chamber (1,13). The updated British Thoracic Society guidelines recommend use of supplemental oxygen when a HAST predicts a P_aO_2 less than 50 mmHg, or an oxygen saturation less than 85% (1). During the HAST, individuals breathe a hypoxic gas mixture containing 15.1% oxygen in nitrogen, simulating the P_iO_2 of 108 encountered by passengers at 8000 ft (2438 m) elevation. However, Kelly (12) has shown that the HAST exposes passengers to more severe hypoxia than is encountered during air travel. This finding is supported by the large fraction of cabin altitudes below 8000 ft (2438 m) reported in this study. Since only 30% of flights shorter than 500 mi exceeded a peak cabin altitude of 5000 ft (1524 m), a HAST using 17.1% oxygen (simulating an altitude of 5000 ft) could be used to simulate flights of short duration (e.g., less than 500–750 mi). The safety of this approach and its accuracy in predicting arterial oxygen tensions during flights of short duration requires investigation before it can be endorsed.

As noted, this study confirms the appropriateness of using 8000 ft (2438 m) altitude to simulate the maximum hypoxic stress encountered during commercial air travel. Only 10% of the flights in this study exceeded a cabin altitude of 8000 ft (2438 m), with the highest value measured at 8549 ft (2606 m). When prescribing in-flight oxygen, one need not account for this small percentage of flights that exceeded 8000 ft (2438 m) because the small increase in altitude above 8000 ft results in only a small change in P_iO_2. For example, when altitude increases from 8000 ft (2438 m) to 8500 ft (2591 m), the barometric pressure decreases from 574 mmHg to 564 mmHg, resulting in a 2-mmHg drop in P_iO_2. Thus, the change in P_iO_2 is minimal for an increase in altitude from 8000 ft to 8500 ft (2438 m to 2591 m).

One limitation of our study is the uneven distribution of planes flown. We chose flights based on convenience rather than plane type, resulting in a plurality of flights on B737 aircraft. Further, there are many models of B737 and these were not tracked. While this distribution of aircraft may realistically capture the cabin altitudes faced by the flying public on U.S domestic flights, cabin altitudes measured in less frequently traveled aircraft should be viewed with caution.

We measured only peak cabin altitude during flights rather than continuous altitudes or the time spent at peak altitude. It is conceivable that the peak altitudes recorded were only transiently achieved and the passengers were predominantly exposed to lower altitudes. Finally, we did not have access to cruising altitude or age of the plane being flown, limiting insight into the relationship between cabin altitude, cruising altitude, and airplane age.

This study demonstrates that peak cabin altitudes during U.S. domestic commercial flights have risen significantly since 1988. Peak cabin altitude increases linearly with flight distance for flights less than 750 mi so that shorter flights are associated with less hypoxia. When prescribing supplemental oxygen for air travel, clinicians should recognize that simulating 8000 ft (2438 m) altitude by breathing 15.1% oxygen during a HAST may overestimate the degree of hypoxia present in the air cabin. A HAST using 17.1% oxygen should be considered in selected low-risk individuals whose flights are shorter than 500 to 750 mi.

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REFERENCES

1. Ahmedzai S, Balfour-Lynn IM, Bewick T, Buchdahl R, Coker RK, et al.; British Thoracic Society Standards of Care Committee. Managing passengers with stable respiratory disease planning air travel: British Thoracic Society recommendations. Thorax 2011; 66(Suppl. 1):i1–30.
2. AirportCityCodes.com. Citywise full airport details. Accessed August 31, 2012, from http://www.airportcitycodes.com/aaa/CCDBFrame.html.
3. AMA Commission on Emergency Medical Services. Medical aspects of transportation aboard commercial aircraft. JAMA 1982; 247: 1007–11.
4. Christensen CC, Ryg M, Refvem OK, Skjonsberg OH. Development of severe hypoxaemia in chronic obstructive pulmonary disease patients at 2,348 m (8,000 ft) altitude. Eur Respir J 2000; 15:635–9.
5. Christensen CC, Ryg M, Refvem OK, Skjonsberg OH. Effect of hypobaric hypoxia on blood gases in patients with restrictive lung disease. Eur Respir J 2002; 20:300–5.
6. InternationalCNN. 787 Dreamliner takes flight. Accessed August 31, 2012, from http://www.cnngo.com/explorations/life/whats-so-special-about-Boeing-dreamliner-766616.
7. Cottrell JJ. Altitude exposures during aircraft flight: flying higher. Chest 1988; 93:81–4.
8. Dillard TA, Berg BW, Rajagopal KR, Dooley J, Mehm WJ. Hypoxemia during air travel in patients with chronic obstructive pulmonary disease. Ann Intern Med 1989; 111:362–7.
9. Dine CJ, Kreider ME. Hypoxia altitude simulation test. Chest 2008; 133:1002–5.
10. Fischer R, Lang SM, Bruckner K, Hoyer H-X, Meyer S, et al. Lung function in adults with cystic fibrosis at altitude: Impact on air travel. Eur Respir J 2005; 25:718–24.
11. Gong H Jr.. Advising pulmonary patients about commercial air travel. J Respir Dis 1990; 11:484–99.
12. Kelly PT, Swanney MP, Seccombe LM, Frampton C, Peters MJ, Beckert L. Air travel hypoxemia vs. the hypoxia inhalation test in passengers with COPD. Chest 2008; 133:920–6.
13. Mohr LC. The hypoxia altitude simulation test: an increasingly performed test for the evaluation of patients prior to air travel. Chest 2008; 133:839–42.
14. Pressurized cabins. 14 C.F.R., Section 25.841 . Oklahoma City, OK: FAA; 2006.
15. Schwartz JS, Bencowitz HZ, Moser KM. Air travel hypoxemia with chronic obstructive pulmonary disease. Ann Intern Med 1984; 100:473–7.