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Cabin air quality and health risks:

A review and synthesis of the available data

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*and W. Allan Crawford**

Data on airline air quality is reviewed with particular reference to possible health risk. Cabin air quality is determined by a variety of physical and chemical factors. Most chemical factors investigated easily meet existing or proposed standards; however, carbon dioxide levels indicate that cabin air can be stuffy and air quality could be improved by increased ventilation. The levels of environmental tobacco smoke components which have been monitored indicate that ETS is unlikely to pose a significant health risk to passengers or flight attendants.

The advent of large scale commercial airliner operations at high altitude has emphasized the needs of aviation medicine to examine occupational and environmental health factors for flight attendants and passengers. This is not a recent concept and was addressed more than four decades ago in the classic production by McFarland[1]. The health of passengers and crews, the effects of low humidity, ventilation rates, temperature, pressurization, air quality, odors, well-being and illnesses and the presence and complaints of tobacco smoke were all considered.

Some items have changed since the time of McFarland's work. Airliners are bigger, faster, fly higher, carry more passengers and are more numerous. They are safer, more sophisticated and more comfortable. With the arrival of jet aircraft and flying at higher altitudes the ozone problem was encountered and partly controlled[2]. The ionizing radiation hazard was also recognized and risks evaluated and found to be acceptably low[2]. The issue of radiation has once again been further evaluated by Geomet[3], commissioned by the U.S. Department of Transportation (DOT) with indications that the hazards are much greater than originally estimated with regard to cancer in crews and frequent travellers.

The most recent changes have been related to the attitudes of people to the visible presence and odor of environmental tobacco smoke (ETS). Segregation into smoking and nonsmoking zones has been adopted in most airlines and in some countries total bans on smoking have been applied to domestic flights (Canada and Australia) and flights of 6 hours or less (USA). These changes in attitude have been induced by the evolution of a concern that retention of ETS components may present a small risk to health. That concern has been nurtured in anti-smoking and smoking cessation programs with little scientific input.

This paper briefly examines the relevant data. The key questions, as in all aerospace and environmental research, are:

1. What health or physiological effects may take place?
2. What are the environmental components of note in qualitative and quantitative terms?
3. What is the retained dose?
4. How can control be exerted and will such controls be effective in reducing the commonly occurring complaints of passengers and flight attendants?

Health or physiological effects that may take place

◆ *Acute Effects*

There is a paucity of data on acute effects of air quality on airlines with perhaps the exception of irritative effects to the eyes of those exposed to relatively high concentrations of ETS. Weber and Grandjean[4] reviewed the research and came to the following conclusions albeit from studies in chambers, not aircraft.

(a) acrolein and formaldehyde are responsible to only a minor extent for the irritation due to sidestream smoke;

(b) the gas phase is responsible to a large extent for the annoyance due to sidestream smoke; ▶

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(c) the particulate phase is responsible to a very large extent for the irritating effects of sidestream smoke, since eye blink rate and subjective eye irritation are much lower with the gas phase alone than with the total sidestream smoke.

However, using CO as a surrogate they postulated a Tentative Threshold Limit Value for ETS of 1.7 - 2.3 mg CO m^{-3}. Actual measurements of CO by Malmfors et al.[5] and Geomet[3] have been in the range of 0.8 - 1.1 ppm, the higher levels being found in the smoking section of airliners.

◆ *Chronic Effects: Respiratory and Cardiovascular Effects of ETS*

The hypotheses that the breathing of ETS may have adverse effect on lung function and induce chronic obstructive pulmonary disease have not been vindicated by the elatively few studies that have been undertaken. These have been reviewed by the National Academy Science/National Research Council; NAS/NRC[6] and the U.S.Surgeon General: USSG[7]. The major problems are the inevitable confounding by indoor and outdoor air pollution, current or previous lung infections and occupational exposures to fumes and particles. The lungs are exposed from the first breath of life to numerous potentially hostile agents, particularly in an urban lifestyle. The air pollutants in airliners that have been measured and reported by the NAS/NRC[2], Geomet[3], Oldaker and Conrad[8], Malmfors[5] and others are well within various standards set for the general public and for occupations. Detailed findings will be described in a subsequent section. Only minor physiological changes or no changes have been reported.

'he data on the effects of ETS constituent absorption on the cardiovascular system are so limited that the NAS/NRC[6] considered them to be insufficient to allow an estimate of risk.

For persons who already have compromised respiratory and cardio-vascular systems the lowered partial pressure of oxygen at cabin altitudes of 6-8000 feet is much more of a hazard[9] than the low levels of CO or nicotine that have been measured in aircraft.

◆ *Lung Cancer*

Crawford[10] has noted that the most emotive concern in men and women is the threat of developing a cancer - a cancer of any kind. Lung cancer is the most common form of cancer in males and in females is second to cancer of the breast. As ETS is the only material that can be observed in the cabin air of commercial airliners it is of particular importance to place it in context with regard to possible effect on incidence of lung cancer.

It is noteworthy that Doll and Peto[11] and Garfinkel[12] have not discerned a trend for the increase in lung cancer in nonsmokers over decades which would have been expected had exposure to ETS presented a real risk. With the increase in the number of smokers in the 1910-70 period and therefore an increase in the numbers of people exposed to ETS, if there was an impact it should have been observed. It is of note that the histological studies of Auerbach et al.[13] found virtually no atypical cells in the bronchial mucosae of nonsmokers.

The inhalation of ETS per se has been associated only in epidemiologic studies of lung cancer in the reportedly nonsmoking spouses exposed for decades to the smoking of their partners and is a most important and controversial issue. Crawford[10] reviewed all the major studies and found that all have major flaws. Generally no account has been taken of confounding factors. Some of the studies had too few subjects for statistical validity. Misclassification is probable and a mere 5% of such would negate the findings of most studies. In general, as Rose[14] from the London School of Public Health and Tropical Medicine has stated, a Relative Risk (RR) of less than 2.0 is difficult to interpret. Thus, a RR of 1.3 from a meta-analysis of all studies reviewed in the NAS/NRC[6] and a mere 1.13 from all U.S. studies is even more difficult to interpret. As Hernberg[15] points out, the stronger the association (meaning that the RR is high) the greater the probability of a causal relationship. Hernberg[15] explains that *"An exception is 'small' series (say smaller than 30-40) because the RR's are subject to substantial random variation"*. The majority of these studies had less than 40 cases.

The results of epidemiological studies have been so disparate and those showing significance so contentious that the NRC[6] and Wald[16] resorted to meta-analysis as has Letzel et al.[17] with again conflicting results. In 1987 the International Agency for Research in Cancer (IARC) set in motion a major international inquiry, the results of which have not been produced as of December, 1990.

There have been many reviews on the subject, only one of which[7] reaches a definitive statement of a real cause-effect relationship. That carcinogenic substances are present in the smoke of partially pyrolized tobacco leaf is not in contention, just as their presence is not in contention in the partial pyrolysis of wood, petrol, diesel fuel and broiling and braising of meat and vegetables. Urban air pollution contains carcinogens but appears not to be subject to the scrutiny allocated to tobacco smoke. Objective science on ETS has been subjugated to inadequate epidemiologic methods. It is on the evidence so far available on nonsmoking spouses of smokers and a few environmental studies in aircraft in which the levels of air pollution by ETS are less than in other densely populated areas, that decisions to curtail or ban smoking are being taken.

Layard[18] recently reviewed all 23 of the epidemiological studies including five Asian studies published in 1988. Twenty were case-control studies and three were cohort studies. He concluded that the weak and inconsistent associations all indicate that these data do not support a judgement of a causal relationship between exposure to ETS and lung cancer. Thus, a concern about lung cancer from exposure to ETS in airliners is not justified by epidemiological studies in homes.

Air quality studies on commercial aircraft

Several studies have been carried out in airliners in which a few flights were monitored and a limited number of chemical and/or physical parameters were measured. In addition, two larger studies were carried out in which many flights were monitored and several parameters were measured; Malmors et al.[5] and Geomet[3]. The smaller studies will be discussed first, followed by the larger, most recent studies.

1. Studies involving fewer flights

◆ *Studies on nicotine in air and nicotine and cotinine concentrations in non-smokers exposed to ETS on airliners.*

Nicotine and cotinine (a metabolic product of nicotine) are products of tobacco smoke and have been the subject of research in attempting to determine the effects of environmental tobacco smoke on nonsmokers.

Foliart et al. (19) studied flight attendants on a transoceanic flight. Blood nicotine increased from a mean of 1.6 ng ml^{-1} in five of six women to 3.2 ng ml^{-1}. After comparing these values to the 15-45 ng ml^{-1} in typical smokers, the authors concluded that physiologic effects were unlikely.

In 1988, at the request of the U.S. Surgeon General, the Smoking, Tobacco and Cancer program of the National Cancer Institute conducted a study of ETS concentrations on four Air Canada flights (Mattson et al.)[20]. The authors of the study reported a median nicotine concentration of 2 ug m-3 in nonsmoking sections and a median nicotine concentration of 12 ug m-3 in smoking sections. These figures agree well with the means reported by Oldaker and Conrad[8] (5.5 ug m-3 in nonsmoking sections and 9.2 ug m-3 in smoking sections), Oldaker et al.[21] (2.3 ug m-3 in nonsmoking and 10.6 ug m-3 in smoking sections) and Muramatsu et al.[23] (5.3 ug m-3 in nonsmoking sections and 13.5 ug m-3 in smoking sections). Drake and Johnson[22] reported nearly identical figures for data from the same study as Oldaker et al.[21]. Mattson et al.[20] also reported that passengers located in nonsmoking "boundary" seats are exposed to levels of ETS nicotine that are, on occasion, as high as those found in the smoking sections and comparable to the findings reported by Oldaker and colleagues. The authors state that no measurements were taken in the middle of the nonsmoking sections because nonsmoking passengers seated there were unlikely to be exposed to ETS.

Mattson et al.[20] also demonstrated that nicotine exposure on board airline flights can be detected as urinary cotinine in the most highly exposed nonsmoking passengers and flight attendants. This confirms the previously published article by Foliart et al.[19] on blood nicotine. There is, however, a fundamental problem in that the metabolism of nicotine and resulting cotinine levels vary widely between people and even some smokers could (by cotinine assays) be designated as nonsmokers[24].

◆ Ozone

FAA monitored flights showed 11% of flights from 1978-1979 violated the ozone standard of 0.25 ppm above 32,000 ft or 0.1 ppm during any three-hour flight[2]. Catalytic convertors, if installed and maintained, can reduce ozone concentrations.

Ozone in sufficient concentrations is known to create physical discomfort. The NRC[2] has reported that with a 0.3 ppm concentration, eye discomfort, headache and nose and throat irritation occur. The NRC reported asthmatic symptoms at 0.15 ppm. Lategola et al.[25] reported eye discomfort as the most frequent ozone symptom in their study simulating flight conditions. In descending order, headache, nasal irritation and throat irritation were the next most reported symptoms. Temporary decreased pulmonary function may also occur.

◆ Other Chemical, Physical and Biological Factors

Earlier reviews by Holcomb[26] and Crawford[10] demonstrated that a variety of chemical and physical factors may influence cabin air quality. Among these are carbon monoxide, particulate matter, carbon dioxide, relative humidity, airborne biological materials and other chemicals.

Potential irritants noted in cabin air include vapors from refuelling, outside and interior exhaust vapors and galley or toilet odors. NRC[2] suggested that a variety of ground fumes sometimes invade commercial aircraft cabins. These include CO, NO2 aldehydes (including formaldehyde), particulates and polynuclear aromatics.

Respirable particulates (RSP's) have been reported in flights of B-747's Oldaker et al. and Drake and Johnson (21,22) with all three air conditioning packs operating. They reported means of 13.5 and 15.0 ug m-3 of RSP's in the nonsmoking section and 37.5 to 39.0 in the smoking section. These investigators also reported on the Ultraviolet Particulate Matter (UVPM), an upper estimate of the contribution of RSP's from ETS. The means were 6.7 and 7.0 ug m-3 in the nonsmoking section and 23.9 to 26.0 in the smoking section.

Polycyclic aromatic hydrocarbons (PAH) are present at trace levels in the ambient air, in the water we drink, and in the food we eat[27]. Also, as pointed out in the NRC report[2], both passengers and crew members may be exposed to small quantities of PAH along with other materials such as CO and oxides of nitrogen from the fumes of jet engines and other fossil fuel burning engines at the airport prior to takeoff. Although traces of PAH are assumed to be present in ETS, no measurements have been made of the concentrations resulting from ETS on commercial aircraft.

Based on the quantities of ETS particulates detected in exposure studies in aircraft, the quantities of PAH in aircraft from ETS must be extremely low and would be an insignificant quantity compared to the total exposure from all other sources.

While it has been conjectured that bacteria, fungi and viruses could pollute closed cabin environments[2], no systematic investigations have yet been reported on that topic. However, one confirmed instance of a communicable disease - influenza spreading within an airplane having an inoperable ventilation system has been described[2].

2. Studies involving many flights and several parameters

◆ SAS Airline Air Quality Study

SAS cooperated in a 1988 study to measure temperature, relative humidity, nicotine, respirable particulates, carbon dioxide and carbon monoxide. The results of that study reported on by Malmfors et al.[3] shows air quality in DC-9 and MD-80 aircraft in 48 flights.

Overall data are presented below for BNS (Business Nonsmoking), BS (Business Smoking), TNS (Tourist Nonsmoking) and TS (Tourist Smoking).

This data demonstrates that overall, the temperatures were a little high and that relative humidity was low (5,28). Both of these factors are known to impact on comfort. At carbon dioxide concentrations higher than 1000 ppm, people begin to perceive the air as stuffy. These concentrations would suggest a need for more ventilation with fresh air.

Table 1

Air quality studies on 48 SAS flights: weighted mean values[3]

Parameter	BNS	BS	TNS	TS
Nicotine ug m-3	5	41	21	32
RSP ug m-3	60	250	160	220
CO ppm	0.6	1.1	0.8	1.1
CO_2 ppm	1310	1310	1270	1430
Rel. Humidity %	25	25	25	25
Temperature °C	23.9	23.8	23.6	23.4

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Carbon monoxide concentrations are well below any standards set and are below the concentrations one would expect to cause any changes in functional performance. Differences between aircraft types were apparent; respirable particulates, carbon monoxide and carbon dioxide demonstrating a trend upward, from DC-9-21 to DC-9-41 to MD-80 airliners. Calculations of fresh air ventilation available (assuming that maximum fresh air was being provided) showed declining amounts, respectively, of 22.4 cfm/person and 15.4 cfm/person for these aircraft. Reduced volumes of fresh air in these aircraft (especially in the MD-80 because of 23-30% air recirculation) may account for these differences.

Nicotine concentrations and respirable particulate concentrations are within concentrations reported in previous studies.

◆ *Airline Air Quality Study By Geomet*

A study by Geomet[3] adds to the data on air quality in airliners. The results are summarized in Table 2. Low CO, nicotine and humidity levels were reported. The high levels of CO2 reported indicated that inadequate ventilation occurred in most of the 92 flights. The reported risk conclusions are not supported by the data. However, the data does demonstrate that segregation of smokers and nonsmokers is reasonably effective to protect passengers from ETS exposure. It does not scientifically support a banning of smoking for the protection of the health of cabin staff. (A first errata sheet of importance has been issued in early 1990). Geomet investigators attempted to use tracer gas techniques but ran into technical problems. We calculate based on CO2 data that, overall, fresh air was being provided at less than 50% of the recommended U.S. Ashrae[2b] standards for office buildings, i.e., less than 10 cfm/person.

Occupational and environmental air quality standards

Air quality standards are set in an attempt by national agencies to protect the health and welfare of working and general populations. It is interesting then to compare the values for standards set by these agencies to the values reported in airline air quality studies (See Table 3). These occupational values represent concentrations that are considered not harmful to persons exposed for 8 hours/day, 40 hours/week, 52 weeks per year over a working lifetime. Most frequent fliers and airline attendants would be exposed to no more than 50% of these exposure times. At present there are no airline standards.

Passengers and airline attendants are *exposed to only a fraction of the amount of* materials for which standards are either set or are proposed. However, it is also important to note that relative humidity is very low, partial pressure of oxygen is lower than at ground level and ozone may be present. Therefore, there may be a combination of factors that cause individuals to experience eye irritation or upper respiratory tract problems. People already suffering from various illnesses including chronic cardiovascular disease, pulmonary conditions such as cystic fibrosis, chronic emphysema, cyanotic congenital heart disease, chronic asthma and coronary insufficiency may be adversely compromised by flight travel even in nonsmoking flights

Table 2
Air quality on 92 flights performed by Geomet[3]

Parameter	69 Smoking Flights: Smoking Section	69 Smoking Flights: Non-smoking Section	23 Non-smoking Flights: Middle Row
Nicotine µg m^{-3}	13.4	0.04	0.00
RSP µg m^{-3}	176	31	40
CO ppm	1.4	0.7	0.5
CO_2 ppm	1562	1568	1756*
Rel. Humidity %	15.5*		21.5*
Temperature °C	24.3*		24.1*
Ozone ppm	0.01	0.01	0.02
Bacteria cfu m^{-3}**	163	131	131
Fungi cfu m^{-3}**	5.9	5.0	9.0

* Represents value for entire aircraft
** These were taken at the end of the flight and may not be representative assays

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Table 3
Data from airline studies compared to air quality standards

Parameter	Standard	Time Period	Source	Mean Values Reported In Modern Commercial Aircraft
Nicotine	500 μg m⁻³	8 hours	OSHA-US	0.04-41
	500 μg m⁻³	8 hours	UK	
CO	500 ppm	8 hours	OSHA-US	0.5-5.0*
	35 ppm	8 hours	ASS-SWEDEN	
	35 ppm	1 hour	EPA-US	
	9 ppm	8 hours	EPA-US	
	50 ppm	·	FAA-US	
CO_2	5000 ppm	8 hours	OSHA-US	550-1756
	1000 ppm	Instantaneous	U.S. ASHRAE and JAPAN	
Respirable Particulates	5000 μg m⁻³	8 hours	OSHA	14-250** (< 5 microns)
	260 μg m⁻³	24 hours	EPA-US	
	150 μg m⁻³	8 hours	JAPAN	
	5000 μg m⁻³	8 hours	UK	
	40 μg m⁻³	1 year	WHO	
	120 μg m⁻³	24 hours	WHO	

* *The 5.0 ppm values reported at 50 % ventilation (half-pack operation)*

** *These are total RSP's not specific to ETS*

Exposure to respirable particulates

There has been a suggestion made by Geomet[3] that relative risk of lung cancer can be projected for airline passengers and attendants based on dose of exposure to RSP's or by extrapolating from the lung cancer epidemiological studies reviewed in an earlier section. It is important to recognize that the measured values that have been reported represent the concentration of material in the air; the external exposure. From that information one can reasonably estimate the retained dose of materials such as respirable particulates if you know the volume of air inhaled, the percent of the material retained and the duration of exposure. Arundel et al [30] reported on calculations of retained dose of respirable particulates from ETS to office workers compared to direct smokers using data from the literature. For respiratory volume under moderate working activity they used 0.62 m³/hr for women and 1.08 for men. Percent retention was calculated at 11% for nonsmokers. They calculated an average smoker's total retained dose per year of 90,885 mg for women and 113,150 mg for men based on cigarette consumption of 29.3/day, a tar delivery/cigarette of 10.6 mg for women and 13.2 mg for men and 80 percent retention.

We calculated the retained dose utilizing the data on RSPs from the Geomet study based on the percentage of time that flight attendants were exposed to different concentrations of exposure in different aircraft sections: 23.2 ug m⁻³ on average for 960 hours each year.

To calculate retained dose:
RSP X Resp. Rate X Retention (%) X Hrs. per year = retained dose

For woman:
23.2 μg m⁻³ X 0.62 m³ X 0.11 X 960 = 1517 μg = 1.52 mg

For man:
23.2 μg m⁻³ X 1.08 m³ X 0.11 X 960 = 2646 μg = 2.65 mg

Based on tar delivery/cigarette of 13.2 mg for males and 10.6 mg for females, the cigarette equivalent calculation is:
1.52/10.6 = 0.14/year for woman
2.65/13.2 = 0.2/year for man

The retained dose for airline passengers would be even less than attendants. As these retained doses are so very small, the risk of health impact is unlikely to be significant.

Discussion

If ETS was the only pollutant present which can induce discomfort or disease, and it is not, then the classical control of removing the source would be effective. If smoking were banned, the need for high rates of ventilation to control odors, gasses, particulates and biological contaminants would remain as would the need for catalytic converters to control ozone. There can be no control of solar and cosmic ionizing radiation. The only practical control is by effective ventilation and filtration with a minimum of air recirculation. The trend to recirculation of 20-50% of the cabin air may be economically valid but imposes an increased risk to flight attendants and passengers from the inevitable build-up of hazards to health. One can envisage that to complement the recent recognition of the Sick Building Syndrome there will arise a Sick Airliner Syndrome which will particularly affect flight attendants.

Only the visible ETS and its odor would be removed by banning smoking leaving the invisible factors to affect comfort and health. When an effect or complaint is multifactorial the removal of but one factor of proven small concentration will have little effect on health. This could result in deterioration of air quality, for now that the only visible material is removed, airlines can easily continue to decrease fresh air intake.

Exposure to those components of ETS so far measured in airliners indicate levels which are low even in the smoking sections and in the boundary seats adjoining that section. The most exposed persons for consideration of possible long term effects are the flight attendants. Such staff may be exposed for some 800 to 960 hours per year (2,3) partly in the smoking section and mostly in the nonsmoking section particularly if recirculation of cabin air is practiced and the quantity of fresh uncontaminated air is limited.

The hypothesis of ETS retention in nonsmokers having a causal relationship with some diseases must be considered in the perspective of the exposure to pollutants of passengers and flight attendants in the totality of their lives. The great majority of passenger, air crew and flight attendants live in urban areas and are subjected to air pollutants in their homes, offices, workplaces, in transit to work and at the airports. Those whose travel has included major cities such as Los Angeles, New York, London, Tokyo and Sydney will ▶

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appreciate that the airliner cabin environment is clean in comparison with that accepted in cities as the practicable limits to achieving "clean air".

With specific regard to diseases, ETS must be viewed as but one of many air contaminants which may or may not induce disease.

Conclusion

The very low levels of components of ETS monitored in airliners do not appear to pose a measurable risk to health of passengers or flight attendants if indeed a risk exists at all. Comfort of passengers and attendants can be maximized by assuring fresh air ventilation meeting recognized standards.

A valid scientific study of the health and ill health status of flight attendants is required to assess the value of the judgment to apply restrictive nonsmoking regulations. ●

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