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INVESTIGATION OF CABIN AIR QUALITY ABOARD COMMERCIAL AIRLINERS

N. Nagda, R. Fortmann, M. Koontz
GEOMET Technologies, Inc.
Germantown, Maryland
U.S.A. 20874

A. Konheim
U.S. Department of Transportation
Washington, D.C.
U.S.A. 20590

During 1989, 92 randomly selected flights were monitored to determine prevailing levels of environmental tobacco smoke (ETS) and other pollutants in the airliner cabin environment. Selected ETS contaminants (nicotine, respirable suspended particles, and carbon monoxide) as well as ozone, microbial aerosols, carbon dioxide, and other environmental variables were measured in different parts of airliner cabins. Particle and nicotine concentrations were highest in the smoking section and were somewhat higher in the boundary region near smoking than in other no-smoking sections or on nonsmoking flights. Measured carbon dioxide levels were frequently above existing comfort (odor) criteria. Levels of carbon monoxide, ozone, and microbial aerosols were generally quite low.

INTRODUCTION

The airliner cabin environment has been of great concern for the last twenty years to various elements of the U.S. Federal Government, special interest groups organized to advocate public or industry positons, and the general public itself. During the mid-1980s, the Committee on Airliner Cabin Air Quality assembled by the National Academy of Sciences performed a systematic review of existing information relating to health and safety aspects of the airliner cabin environment aboard civil commercial aircraft. The committee's report (1) identified several potential sources of environmental quality problems on aircraft, including tobacco smoke, ozone, cosmic radiation, humidity, and microbial aerosols. The committee also recommended that smoking be banned on all commercial flights to lessen irritation and comfort of nonsmoking passengers and cabin crew members, to reduce potential health hazards from exposure to environmental tobacco smoke (ETS), to eliminate the possiblity of fires caused by cigarettes, and to bring the cabin air quality into line with established standards for other closed environments.

Public Law 100-200, enacted in 1987 and effective for two years beginning in April 1988, prohibited smoking by passengers on any scheduled domestic commercial flight of two hours or shorter duration. In December 1988, the U.S. Department of Transportation (DOT) contracted with GEOMET Technologies, Inc., to conduct a study to resolve certain technical questions related to potential continuation or broadening of the prohibitions in the law. The methods and monitoring results from that study (2) are the subject of this paper.

As the final report for the study was being prepared, the U.S. Congress enacted Public Law 101-164, which has banned smoking on all domestic flights of six hours or less beginning February 25, 1990. Although the results related to smoking in airliner cabins are therefore of less consequence in the United States, the study methods and results should be generally applicable to international flights and to domestic flights in other countries.

MATERIALS AND METHODS

Air pollutants were selected for monitoring that had known or suspected sources in the aircraft and could be monitored or sampled in airliner cabins with small, unobtrusive instrumentation. The ETS contaminants monitored during the study were nicotine, respirable suspended particles (RSP), and carbon monoxide (CO). The other pollutants that were monitored were ozone and microbial aerosols. In addition, carbon dioxide (CO_2) was monitored. The monitoring package configured for the study consisted of instruments and sensors for measurement of time-varying concentrations of contaminants in addition to samplers for collection of time-integrated samples. It also included a data acquisition system for recording outputs from the continuous monitors. The instrument was packaged in a single, compact carry-on bag typical of that carried by airline passengers.

Nicotine was measured through collection of time-integrated samples and CO was measured with portable continuous monitors; RSP was measured both by integrated and continuous methods, with an optical sensor in the latter case. CO_2 and ozone were measured with time-integrated samples whereas short-term samples were collected for microbial aerosols (bacteria and fungi) near the end of each flight, prior to descent. Temperature, relative humidity, and cabin air pressure were monitored continuously with portable sensors. Air exchange rates were measured using constant release and integrated sampling of perfluorocarbon tracers. Smoking rates were estimated through technician observations of the number of lighted cigarettes during a one-minute interval every 15 minutes and collection of cigarette butts at the end of most monitored flights. All aspects of the measurement protocol were pretested on four commercial flights that were monitored over a three-day period in March 1989.

Monitoring was to be performed by each technician at an assigned seat. Based on pretest monitoring at a variety of locations, the following four locations were chosen for monitoring on smoking flights: coach smoking section; boundary region of the no-smoking section within three nonsmoking rows near the coach smoking section; middle of the no-smoking section; and remote no-smoking section (i.e., as far as possible from coach smoking, usually near the first-class smoking and no-smoking sections). Because less substantial variations were expected on nonsmoking flights, two locations (middle and rear of the plane) were chosen for those flights. ETS contaminants were monitored at all seat locations and other pollutants were monitored at half of the locations. The instrument package was typically placed on the technician's lap or lap tray to obtain measurements of contaminants most representative of passenger breathing levels.

The target sample size for the study was 60 to 120 smoking flights on jet aircraft, including some international flights. A smaller set of 20 to 40 nonsmoking flights was targeted to provide a baseline for comparison. A total of 70 airports that collectively accounted for 90 percent of U.S. enplanements during 1987 was used as the sampling frame for selection of flights to be monitored. Airports of departure were randomly selected for study flights to provide proportional representation of airports associated with all smoking and nonsmoking flights scheduled for departure during January 1989, based on computer data files supplied by DOT. The specific flights to be monitored were chosen by randomly chaining together the selected airports of departure, subject to constraints relating to the smoking/nonsmoking status of flights. In total, 92 flights were monitored between April and June 1989--23 nonsmoking flights and 69 smoking flights which included eight international flights.

RESULTS AND DISCUSSION

A wide range of smoking rates was observed, ranging from as little as one cigarette per hour to as much as one cigarette per minute. Comparative analyses indicated that smoking rates based on technician observations agreed very well with rates based on collected cigarette butts. An average of 20 cigarettes per hour, or 68 cigarettes per flight, was smoked by passengers in the coach smoking section on smoking flights that were monitored. The average smoking rate per smoking-section passenger was 1.5 cigarettes per hour, during periods when smoking was allowed.

Based on both gravimetric and optical measurements, RSP concentrations were highest in the smoking section, averaging near 175 micrograms per cubic meter ($\mu g/m^3$) compared to a background level of 35 to 40 $\mu g/m^3$ on nonsmoking flights. Differences across the no-smoking sections of the aircraft for smoking flights, and differences between these no-smoking sections and nonsmoking flights, were less pronounced. The optical measurement method indicated some migration of ETS contaminants into the no-smoking sections on smoking flights in terms of one-minute peak RSP concentrations. Levels of ETS contaminants that were measured on smoking and nonsmoking flights are summarized in Table 1.

Observed effects of tobacco smoking, based on gas-phase measurements, were more discernible for nicotine than for CO. Beyond the marked increase in nicotine in the smoking section, the boundary region of the no-smoking section was most affected. Differences between nicotine levels for the remaining no-smoking locations and levels on nonsmoking flights were within the range of measurement uncertainty, but nicotine levels were more often above detection limits in the no-smoking locations of smoking flights than on nonsmoking flights. The only discernible effect for CO was in the smoking section itself.

Measured RSP levels in the boundary region of the no-smoking section were strongly related to observed smoking rates (i.e., higher levels when smoking rates were higher) and to the distance from the coach smoking section (i.e., higher levels at shorter distances). Measured levels of nicotine and CO in the boundary region did not correlate with smoking rates or distance from the smoking section, but measured levels of all ETS contaminants in the smoking section were strongly related to smoking rates.

Relatively high CO_2 levels were measured, averaging over 1,500 $\mu L/L$ across all monitored flights (Table 2). Measured CO_2 concentrations exceeded

1,000 μL/L, the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) level associated with satisfaction of comfort (odor) criteria (3), on 87 percent of the monitored flights. Monitored ozone levels were relatively low, averaging an order of magnitude below the Federal Aviation Administration three-hour standard of 0.10 μL/L (4) and never exceeding this level. Bacteria levels were higher than fungi levels and somewhat higher in smoking than nonsmoking sections, but the measured bacteria and fungi levels in all cases were low, relative to those that have been measured in residential environments through cross-sectional studies (5).

Some difficulties were encountered in measuring air exchange rates, particularly for aircraft without recirculation, due to the limited number of tracer sources and samplers that could be deployed within the constraints of remaining unobtrusive and the lower extent of lateral air movement within the airliner cabin. Based on measurement results for aircraft with recirculation, there were some indications that air exchange rates were higher on smoking than nonsmoking flights, but the number of measurements was too limited to allow firm conclusions.

Relative humidity levels measured during the study were quite low, below 25 percent for about 90 percent of the monitored flights. Humidity levels were lower on smoking flights (average of 15.5 percent) than on nonsmoking flights (average of 21.5 percent). Temperatures averaged near 24 °C (75 °F) for both smoking and nonsmoking flights.

ASSESSMENT OF MITIGATION OPTIONS

Mitigation options were not explored for ozone or microbial aerosols because of the low levels that were measured in this study. For ETS, procedural options such as restriction of smoking and technological options such as increased ventilation were assessed. Of these options, a total ban on smoking was estimated to provide the greatest benefit at least cost. Estimated benefits were based on reduced lung-cancer mortality risks associated with reductions in ETS levels, as estimated from an airliner cabin air quality model similar to that described by Ryan et al. (6). Costs for procedural options associated with smokers' inconvenience and discomfort, or displacement of smokers to other modes of transportation, could not be estimated due to data limitations.

Relative to the case of unrestricted smoking, the two-hour ban in effect during the past two years was estimated to reduce risks ascribable to ETS exposure on domestic flights by about 45 percent. A four-hour ban would reduce risks by about 86 percent, and a six-hour ban would reduce risks by approximately 98 percent. A different type of strategy to curtail smoking, such as allowing smoking during a 10-minute period every two hours, could reduce average exposures to ETS by as much as 70 percent. However, such a strategy could substantially increase the risks of respiratory and other irritant effects from acute exposure to ETS during the brief periods when smoking would be allowed.

Increasing ventilation rates could lower ETS exposures by as much as 33 percent, but associated fuel penalties would result in costs estimated to be far greater than the benefits. Improved filter efficiency was estimated to provide only a marginal reduction (about 5 percent) in ETS exposures.

For removal of CO_2, sorption on solid adsorbent beds whose adsorbent capacity for CO_2 can be regenerated by heating was considered to be a method with potential benefits for aircraft with recirculation. Cost or reliability data were not available for comparison with costs of additional ventilation, which could also be used to bring CO_2 levels closer to the guidelines specified by ASHRAE.

CONCLUSIONS

Levels of ETS contaminants monitored during the study were substantially higher in smoking sections of the aircraft than in no-smoking areas, and these levels were strongly correlated with observed smoking rates. There was some evidence of ETS migration to the no-smoking boundary region near the smoking section, particularly for RSP concentrations in this region that were strongly related to smoking rates and distance from the smoking section. Monitored CO_2 levels were sufficiently high and monitored humidity levels were sufficiently low to pose potential comfort problems for aircraft occupants. Ozone levels on all monitored flights were well below existing standards for airliner environments, and monitored levels of microbial aerosols were below those in residential environments that have been characterized through cross-sectional studies.

ACKNOWLEDGEMENT

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REFERENCES

1. National Research Council (1986) The Airliner Cabin Environment: Air Quality and Safety. National Academy Press, Washington, D.C.

2. Nagda NL, Fortmann RC, Koontz MD, Baker SR, Ginevan ME (1989) Airliner Cabin Environment: Contaminant Measurements, Health Risks, and Mitigation Options. Report No. DOT-P-15-89-5, U.S. Department of Transportation, Washington, D.C.

3. ASHRAE (1989) Ventilation for Acceptable Indoor Air Quality. ASHRAE Standard 62-1989, American Society of Heating, Refrigerating and Air Conditioning Engineers, Atlanta, Georgia.

4. Code of Federal Regulations, Title 14, Pt. 25.832 (1985) Cabin Ozone Concentrations. U.S. Government Printing Office, Washington, D.C.

5. Tyndell RL, Dudney CS, Hawthorne AR, Jernigan R, Ironside K, Metler P (1987) Microflora of the Typical Home. Proceedings of the 4th International Conference on Indoor Air Quality and Climate 1:617-621. Institute for Water, Soil and Air Hygiene, Berlin (West).

6. Ryan PB, Spengler J, Halfpenny P (1988) Sequential Box Models for Indoor Air Quality: Application to Airliner Cabin Air Quality. Atmos Environ 22:1031-1038.

Table 1. Average Concentrations of ETS Contaminants on Smoking and Nonsmoking Flights

Parameter	Smoking Flights[1]				Nonsmoking Flights	
	Smoking Section	No-smoking Section				
		Boundary Rows	Middle Rows	Remote Rows	Rear Rows	Middle Rows
<u>Particle-Phase Measurements</u>						
Average RSP[2], $\mu g/m^3$	75.8	53.6	30.7	35.0	34.8	40.0
Peak RSP[3] (1 minute), $\mu g/m^3$	883.4	211.8	68.7	69.6		
<u>Gas-Phase Measurements</u>						
Average Nicotine, $\mu g/m^3$	13.43	0.26	0.04	0.05	0.00	0.08
Percent Nicotine Samples Below Minimum Detection	4.3	54.4	82.6	66.7	100.0	78.3
Average CO, µL/L	1.4	0.6	0.7	0.8	0.6	0.5
Peak CO (1 minute), µL/L	3.4	1.4	1.7	1.6	1.3	0.9

[1] An average of 13.7 percent of the passengers were assigned to the coach smoking section on monitored smoking flights.
[2] Average of gravimetric and optical measurement results.
[3] Optical method measurements.

Table 2. Average Concentrations of Selected Pollutants on Smoking and Nonsmoking Flights

Parameter	Smoking Flights		Nonsmoking Flights
	Smoking Rows	Middle Rows	
Average CO_2, µL/L	1562	1568	1756
Percent CO_2 Samples ≥ 1,000 µL/L	87.0	88.1	87.0
Average Ozone, µL/L	0.01	0.01	0.02
Percent Ozone Samples ≥ 0.1 µL/L	0.0	0.0	0.0
Average Bacteria, CFU/m^3	162.7	131.2	131.1
Average Fungi, CFU/m^3	5.9	5.0	9.0