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# Experimental study of gaseous and particulate contaminants distribution in an aircraft cabin

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## HIGHLIGHTS

- Investigated methods for contaminants distribution measurement in a MD-82 aircraft.
- Compared the effect of different sampling grids, source styles.
- Analyzed the tracking behavior of studied particles, and compared with SF6.

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## ABSTRACT

The environment of the aircraft cabin greatly influences the comfort and health of passengers and crew members. Contaminant transport has a strong effect on disease spreading in the cabin environment. To obtain the complex cabin contaminant distribution fields accurately and completely, which is also essential to provide solid and precise data for computational fluid dynamics (CFD) model validation, this paper aimed to investigate and improve the method for simultaneous particle and gaseous contaminant fields measurement. The experiment was conducted in a functional MD-82 aircraft. Sulfur hexafluoride ($SF_6$) was used as tracer gas, and Di-Ethyl-Hexyl-Sebacat (DEHS) was used as particulate contaminant. The whole measurement was completed in a part of the economy-class cabin without heating manikins or occupied with heating manikins. The experimental method, in terms of pollutant source setting, sampling points and schedule, was investigated. Statistical analysis showed that appropriately modified sampling grid was able to provide reasonable data. A small difference in the source locations can lead to a significant difference in cabin contaminant fields. And the relationship between gaseous and particulate pollutant transport was also discussed through tracking behavior analysis.



## 1. Introduction

As millions of people are traveling by air every year, aircraft cabin environment is important to the travelers. Long exposure time in the aircraft cabin environment containing contaminant such as pathogenic aerosol may make passengers sick. Mangili and Gendreau (2005) evaluates the risk of respirable infectious disease (Tuberculosis-TB and Severe Acute Respiratory Syndrome-SARS) transmission in commercial aircraft cabins and concluded that air travel is an important factor in the spread of respirable infectious diseases worldwide. In addition, the high passenger density (Mangili and Gendreau, 2005) and lower personal fresh air rate than for the buildings environment result in a high concentration of $CO_2$ (Haghighat et al., 1999). And the use of various cleaning products in the cabin leads to a high concentration of VOCs such as ethanol and acetone (Nagda and Rector, 2003). These particulate and gaseous pollutants can be removed by the cabin ventilation system. Therefore, to provide a healthy and comfortable cabin environment for passengers, and to design better ventilation system, it is important to study the feature of contaminant distributions in the cabin.

For experimental studies of contaminant distribution in aircraft cabin, Table 1 shows a summary of the research in the past decade. Our review finds that most of the measurement studies adopted mock up cabins which may not represent actual contaminant distribution in airliner cabins. Some used water-filled scaled model, but the different scale and working fluid further complicate the equivalent analysis for the full scale cabin environment (Thatcher et al., 2004). In addition, the two main points missing consideration in previous experimental studies are: First, how to set the

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**Table 1**
Literatures on experimental studies of contaminants distribution and transport in aircraft cabin.

| Reference | Facility | Pollutant | Occupancy | Sampling points | Research data |
|---|---|---|---|---|---|
| Wang et al., 2006 | 5 Rows, 35 seats, 2 aisles cabin mock up at University of Illinois | $CO_2$ | No heat sources from passengers was considered | 1 Point at the breathing level of each seat | The distribution principle of gaseous contaminants. |
| Yan et al., 2009 | 5 Rows, 35 seats, 2 aisles cabin mock up at University of Illinois | $CO_2$ | No heat sources from passengers was considered | 1 Point at the breathing level of each seat | Simulation and measurement of airflow and gaseous contaminants. |
| Sze To et al., 2009 | 3 Rows, 21 seats, 2 aisles cabin mock up at Technical University of Denmark | Polydispersed aerosol of NaCl and glycerin | 15 Heating cylinders (60 W each) as passenger manikins (no “leg”) | 1 Point per seat horizontally, 3 point at each seat vertically | Dispersion and deposition of expiratory aerosols with different diameter. |
| Zhang et al., 2009 | 4 Rows, 28 seats, 2 aisles cabin mock up at Purdue University | $SF_6$ and mono-dispersed DEHS particles (0.7 μm) | 14 Heating boxes as passenger manikins (83 W each) | Gas: 8 locations at 6 seats, 3–6 points vertically at each location. Particle: 8 locations at 6 seats, 3–6 points vertically at each location. | The measured and predicted distribution of contaminants in the cabin. |
| Zhang et al., 2012 | 7 Rows, 49 seats, 2 aisles cabin mock up at Dalian University of Technology | $CO_2$ | 35 Thermal manikins as passenger manikins (75 W each) | 13 Locations at 11 seats, 5 points vertically at each location. | The measured and predicted distribution of velocity, temperature, contaminants around manikins. |
| Poussou et al., 2010 | Aircraft cabin, reduced-scale mock up | Uranine ($C_{20}H_{10}O_5S_2Na$) | A moving plastic box | 5 Sections with Particle Image Velocimetry and Planar Laser-Induced Fluorescence. | The effects of a moving human body on flow and contaminants transport inside an aircraft cabin. |

contaminant source was not clearly described, which would influence the concentration distribution. Second, the number of sampling points was usually limited, and whether they were enough for obtaining complete and accurate fields for simulation validation was not discussed.

Lab experimental measurement in mock up cabins is costly and time consuming, and whether it can be accurate enough to represent the real cabin environment is always controversial. Numerical simulation is another important way to study the pollutant transport and distribution due to its cost, time and labor saving nature compared with the experimental method (Pepper and Wang, 2011; Zhai et al., 2012). However, one numerical model must be validated before it can be applied for design or research purpose. Yan et al. (2009) found the simulation results of tracer gas transport cannot be clearly indicated by the experimental data possibly due to the “sampling points were too coarse to describe the concentration gradient”. Wan et al. (2009) also discussed the measurement uncertainty because of low particle concentration while comparing with the numerical results. In Zhang’s et al. (2009) study, the predicted tracer gas and particle concentration did not agree well with the measurement which may be due to the measurement uncertainty caused by unstable airflow. In summary, there is a general agreement that an accurate and complete measurement is essential for numerical method validation.

In this study, the experimental measurement is carried out in a functional MD-82 aircraft cabin for a most realistic condition. The objective of this study is to investigate the method for accurate and complete concentration field measurement for both particulate and gaseous contaminants. The contours of contaminant distribution at 8 lateral and 6 longitudinal sections are obtained. The effect of sampling grid, source generation setting which is essential for experiment in the cabin is discussed. We also investigate the difference between gas and particle distribution and analyze the particle tracking behavior which can indicate the effect of velocity fields on particle distribution.

## 2. Experimental method

### 2.1. Experiment facility

Fig. 1 shows the functional MD-82 aircraft used in the current study. To provide a stable thermal boundary condition, the aircraft cabin was insulated. The size of the cabin was 2.91 m ($W$) × 40 m ($L$) × 2.04 m ($H$). It was a single-aisle cabin with 3 rows of seats (12 seats) in the first-class cabin, and 28 rows of seats (130 seats) in the economy-class cabin. The air was supplied from upper-side, and was exhausted through side walls near the floor. The MD-82 aircraft cabin environment was controlled by a ground air-conditioning cart (GAC). The total airflow supplied by the GAC to the cabin was 10 L s$^{-1}$ person$^{-1}$. The air temperature was controlled at 20 ± 1 °C in the experiment. Twelve heating manikins (75 W each) were placed in the first-class cabin and they were uniformly wrapped

**Fig. 1.** Insulated MD-82 aircraft facility with envelope.