Available online at www.sciencedirect.com
ScienceDirect
Building and Environment 44 (2009) 34–43
BUILDING AND ENVIRONMENT
www.elsevier.com/locate/buildenv

Experimental and CFD study of unsteady airborne pollutant transport within an aircraft cabin mock-up

Wei Yan, Yuanhui Zhang*, Yigang Sun, Dongning Li

Department of Agricultural and Biological Engineering, University of Illinois at Urbana-Champaign, 332B 1304 Pennsylvania Avenue, Urbana, IL 61801, USA

Received 15 November 2007; received in revised form 22 January 2008; accepted 23 January 2008

Abstract

It has been documented that diseases can spread within an aircraft cabin from the sneezing, coughing or breathing of a sick passenger. To understand the spreading mechanism it is very important to quantify the airflow and droplet transmission around a sneezing/coughing incident. In this project, tracer gas experiments were carried out in a full-scale Boeing 767-300 mock-up to study the global transport process of contaminated air within the cabin. Computational fluid dynamics (CFD) simulation was also used to provide additional information for understanding the principle. A steady airflow field was simulated first and then it was compared with the experimental data. The global airflow patterns were similar to those observed experimentally. This velocity field was adopted as the initial condition for further unsteady pollutant transport simulation. Experimental and simulated results were compared and discussed to develop a relationship between concentration and airflow pattern, source location, transport direction, and ventilation rate. Finally, the overall picture of concentration evolution by both experimental and simulated approaches was discussed.
© 2008 Elsevier Ltd. All rights reserved.

Keywords: Indoor air quality; Computational fluid dynamics; Tracer gas; Aircraft cabin; Ventilation

1. Introduction

Every year there are more than one billion people traveling by air throughout the world with more than 600 million passengers traveling in the US [1,2]. Complaints about cabin environments are found to be very common [3,4]. "Sick airplane syndrome" is a phrase referring to health problems in aircraft cabins, which is similar to the "sick building syndrome."

Many complaints could be explained by thermal and humidity discomfort and indoor air pollutant. According to previous research [5], sources of pollutants in the cabin air during normal operations include: (i) ground-level air pollution at the departure or arrival airport, (ii) contaminants of outdoor origin at cruise altitudes (e.g. stratospheric O_3), (iii) human bioeffluents (e.g. acetone, CO_2, ethanol, and odors), (iv) environmental tobacco smoke, (v) chemicals in cleaning supplies, and (vi) spraying pesticides on certain international flights. It is believed that these pollutants have negative effects on a passenger's health.

The target pollutant in this paper is droplets and particles from the sneezing and coughing of a sick passenger. Usually these droplets or nuclei contain micro-organisms such as viruses, which transport within the cabin and propagate disease. It is assumed that the risk of exposure is associated with flight time and the distance between source and receptor. According to previous data, the exposure risk is high when the traveling time is longer than 8 h and the distance is within two rows around the sick passenger. This could be explained by the fact that little longitudinal airflow was observed in aircraft cabins [6].

However, the "two rows" transport rule is not reliable because the aerodynamic character of a nuclei carrying virus is very complicated. Some micro-organisms rely on injection and space encroachment during the release process, while others follow airflow. For example, during the SARS outbreak in Hong Kong, there were 22 people

*Corresponding author. Tel.: +1 217 333 2693; fax: +1 217 244 0323.
E-mail addresses: weiyan2@uiuc.edu (W. Yan), yzhang1@uiuc.edu (Y. Zhang), sun4@uiuc.edu (Y. Sun), dli3@uiuc.edu (D. Li).

0360-1323/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.buildenv.2008.01.010

infected in a 3 h fight carrying 120 passengers from Hong Kong to Beijing. Among those infected, only half of the infected passengers were seated within two rows of the sick person [7] while others were beyond the two-row limitation. This indicates that the virus may follow airflow and travel far beyond two neighboring rows. However, currently there is still no reliable experimental data to study this transport mechanism.

Experiments and computational fluid dynamics (CFD) simulations are the two most effective approaches used to investigate indoor air pollutant transportation. Experiments are usually done in a full-scale mock-up section of an aircraft cabin. The technologies used to evaluate ventilation effectiveness and airflow pattern include tracer gas [8], particle image velocimetry (PIV) [9], stereoscopic particle image velocimetry (SPIV) [10], volumetric particle tracking velocimetry (VPTV) [11,12], ultrasonic anemometers [13], hotwire anemometers [14], etc. The expiratory droplets released by passengers span a wide size range. These ‘‘poly-diameter’’ droplets disperse in the cabin via different mechanisms. Some large droplets behave like airborne particles while extremely fine droplets behave similar to gas. The tracer gas method cannot represent large aerosols, because it cannot mimic the gravity effect, inertial effect, and drag force effect. But it is valid for micro-organisms when expelled from an infectious person that quickly evaporates into extremely fine droplet nuclei, which follows the airflow very well [15]. It has been used to investigate the dispersion of contaminants in indoor environments [16] and risk of exposure in commercial flights [17,18]. VPTV is a unique technology developed to measure 3D velocity without intruding into the airflow field. This technology correlates particle streaks instead of separated points, which distinguishes it from traditional PIV or SPIV. The relatively large field of view (up to several meters) makes it suitable for indoor air quality study.

Compared with experimental methods, CFD can provide more detailed information with lesser expense. The earliest numerical study for aircraft cabins was conducted by Aboosaidi et al. [19]. With the development of IT, capabilities of computers have improved quickly. Increasingly realistic cabin geometry and manikins have been used in the CFD study. Singh et al. [20] used a heated cylinder to represent a passenger in an aircraft cabin. Lin et al. [21,22] used a more detailed geometry to study airflow and pollutant transport in cabins. Zhang and Chen [23] used an actual cabin to study novel air distribution systems for a commercial aircraft cabin.

In the current work, both tracer gas experiment and CFD simulation are used to study the airborne pollutant transport mechanism within an aircraft cabin. The entire unsteady tracer gas dispersion process is monitored by tracer gas experiments to study the accumulation and discharge of pollutants within cabin. Due to limitations of the experiment, only the concentration at the horizontal breathing zone is recorded. CFD analysis is processed to provide further detailed information, which is not provided by experimental data. The simulated steady velocity field is compared to VPTV experiment data [12]. The unsteady pollutant dispersion is simulated using this steady velocity and zero initial concentration condition. The whole evolution picture is achieved based on these approaches.

2. Experiment

A full-scale aircraft cabin mock-up, based on a Boeing 767-300, is used for the experiment. An overview of the system setup is showed in Fig. 1.

Conditioned air is supplied by a long narrow overhead diffuser and exhausted though the grills installed at the bottom of the sidewalls. As in an actual airplane, the air supply rate is adjustable. In this experiment, it is set at 816 m^3/h (479.5 cfm), 1052 m^3/h (618.18 cfm), and 1259 m^3/h (739.8 cfm), corresponding to 80%, 100%, and 120% of the full ventilation load of a realistic operating condition, respectively. These values were recommended by the Boeing Company.

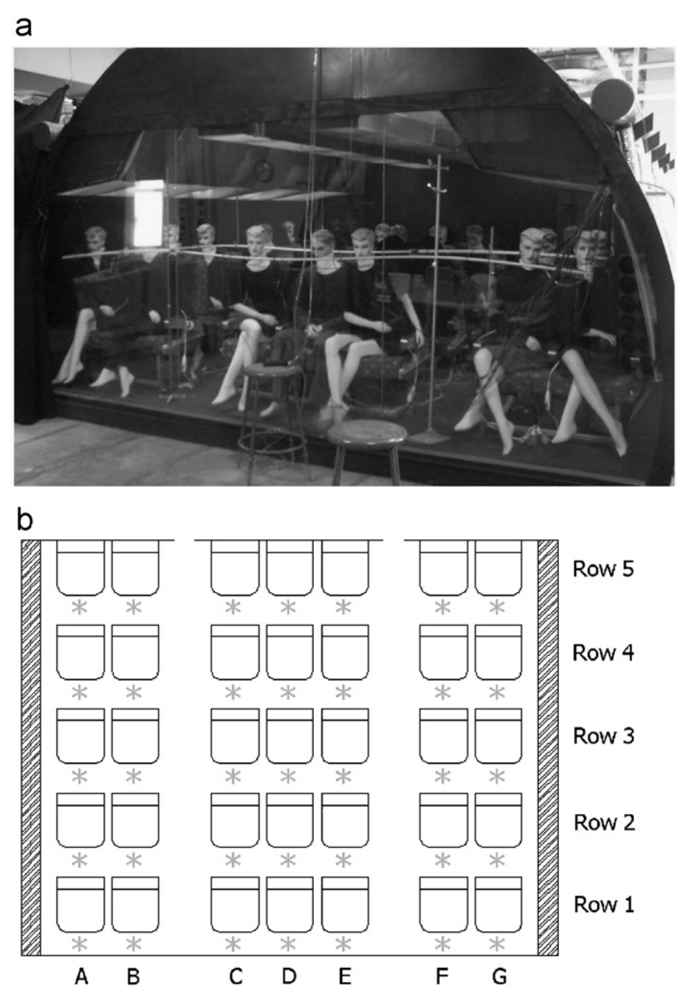

Fig. 1. Full-scale aircraft cabin experimental setup: (a) front view of experimental setup and (b) sampling point locations.

Download English Version:

https://daneshyari.com/en/article/249789

Download Persian Version:

https://daneshyari.com/article/249789

Daneshyari.com