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Experimental study of particle deposition in the environmental control systems of commercial airliners

Qing Cao [a], Yudi Liu [a], Wei Liu [a, d], Chao-Hsin Lin [b], Daniel Wei [c], Steven Baughcum [b], Sharon Norris [b], Xiong Shen [a], Zhengwei Long [a, *], Qingyan Chen [a, d]

[a] Tianjin Key Laboratory of Indoor Air Environmental Quality Control, School of Environmental Science and Engineering, Tianjin University, Tianjin, China
[b] The Boeing Company, Seattle, USA
[c] Boeing Research & Technology – China, Beijing, China
[d] School of Mechanical Engineering, Purdue University, West Lafayette, IN, USA

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ABSTRACT

Serious air pollution and low on-time performance of commercial flights in China could result in more particles being deposited in the environmental control systems (ECS) of the commercial airliners and ground air-conditioning carts (GAC). The particle deposited in the ECS and GAC could cause performance issues of the airplanes and GAC. In addition, particles penetrated to the aircraft cabin could cause adverse health impact on the passengers and crew. This investigation measured the $PM_{2.5}$ particle concentrations and the quantities of particles of different sizes at the inlet and outlet of the GAC and ECS in an MD-82 airplane parked next to Tianjin Airport under different air quality levels. The results showed that the deposition rate of the $PM_{2.5}$ mass in the GAC and ECS was 40–50%, with most (30–40%) of the deposition occurring in the ECS. For particles with a diameter of 5 μm or larger, the deposition rate was greater than 90%. For particles with a diameter of 0.5 μm or less, the deposition rate was less than 25% so they entered into the aircraft cabin. In addition, particle mass and number concentration was measured on commercial flights. The results indicated that particle concentrations were high compared with that during the cruising when the airplanes were on the ground at the Chinese airports where ambient particle concentrations were also high.

1. Introduction

The environmental control system (ECS) in a commercial airliner is to maintain safety, thermal comfort, and air quality for passengers and crew by supplying conditioned air into the cabin. During a flight, the total air supply is a mixture of outside air and filtered re-circulated air. High efficiency particulate air (HEPA) filters are only used for recirculated air, not for outside air entering the aircraft.

However, the particle concentration of the outside air on the ground could be high. The mass concentration of particles with aerodynamic diameters less than 2.5 microns ($PM_{2.5}$) in major Chinese airports, as shown in Fig. 1, was 3–10 times higher than that in many major metropolitan cities in developed countries, such as 16 μg/m^3 in London, 10 μg/m^3 in Tokyo, and 14 μg/m^3 in New York [1]. As the air pollution in cities and that near the city airports was usually comparable [2], so we could assume the air pollution in London, Tokyo, and New York airports was low. For example, Ellermann et al. [3] investigated the air pollution on the apron of Copenhagen Airport and found the annual average concentration of $PM_{2.5}$ was only 17 μg/m^3. Thus, the particular matter pollution in major Chinese airports was very serious.

In addition, the statistics from Flightstats [4] shows a very low on-time performance of about 30% for three major Chinese airports, which were the lowest in the world. For example, Shanghai CS Capital [5] estimated that passengers and crew spend extra 40 min on average in aircraft cabins between door closing and taking-off. Accordingly, GAC or APU has to be operated for a long time to supply air to an aircraft during the waiting period. Therefore, in China, a significant amount of particles could be brought into the commercial airliners before taking off.

The outside air from a ground air-conditioning cart or APU will

* Corresponding author. School of Environmental Science and Engineering, Tianjin University, 92 Weijin Road, Tianjin 300072, China.
E-mail address: longzw@tju.edu.cn (Z. Long).

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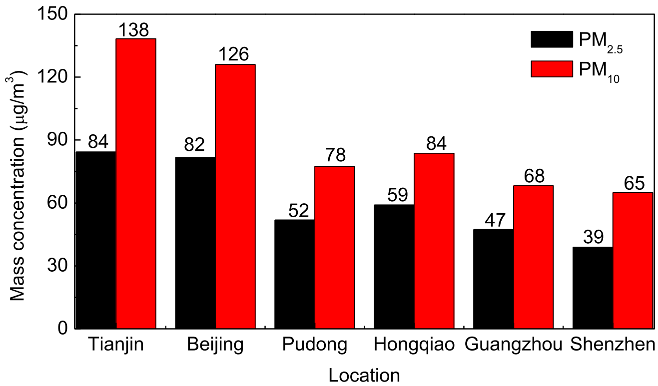

Fig. 1. Annual average PM2.5 and PM10 mass concentration at six major airports in China measured from March 1, 2014 to February 28, 2015 [2].

go through the ECS, which consists of heat exchangers, fans, turbines, and manifolds, before it is delivered into the cabin. The particles in the outside air are likely to deposit on the surface of the ECS components and ducts. The particle deposition on the ECS components would affect the performance and shorten the service life. For example, the increased particle concentration in the air will add mass loading to the HEPA filters when the air is circulated. Particle deposited on heat exchangers, turbines, and fans will decrease their efficiencies [6]. Meanwhile, such deposition can reduce the airflow rate through ducts, especially small diameter ducts, and thus can degrade the performance of the ventilation system [7]. Furthermore, the particle deposition on the duct systems would potentially increase the possibility of microbial contamination [8]. The accumulated dust and microorganisms in the supply air duct could turn into a pollution source [9], which will be brought into the aircraft cabin and be harmful to the health of the passengers and crew [10–12]. Therefore, it is important to investigate how much the particles were deposited in the ECS during ground operation. Our literature review shows that the past investigations on particle deposition in aircraft cabins focused on the particle transport inside the cabins during flights [13–16]. Few investigations were available on the particle deposition in the ECS.

This study conducted simultaneous measurements of $PM_{2.5}$ mass concentration, particle number and size distribution at the inlet and outlet of the ECS of an MD-82 airplane for simulating ground operations. In addition, the particle concentration was also measured on commercial flights to confirm the findings. The measured data were further analyzed to understand the particle deposition in the ECS.

2. Experiments and methods

2.1. Site description

This investigation used a retired MD-82 airplane as the main experimental rig. The airplane was parked adjacent to the runway of Tianjin Binhai International Airport, as shown in Fig. 2(a). The airport had 10 million passengers in 2013 and was ranked 24th in China. The air quality in Tianjin was the tenth worst in China, and the $PM_{2.5}$ annual average concentration was 83 μg/m^3 in 2014 (China Environmental State Bulletin, 2014). Particular matter measurements were conducted at the MD-82 parking position where was only 460 m away from the runway. Three air quality monitoring stations around Tianjin airport as shown in Fig. 2(b) could provide the ambient air pollution data for the airport.

2.2. Sampling and instrumentation

In order to obtain the particle deposition rate in the ECS, simultaneous measurements of particle concentration were conducted inside and outside the cabin under different air quality conditions. The measurements in the MD-82 airplane were mainly conducted in the afternoon from November 2014 to April 2015. Fig. 3(a) shows the MD-82 airplane was connected with a GAC that supplied conditioned air to the airplane. The GAC maintained the supply-air temperature at 20 ± 1 °C. The airflow rate was controlled

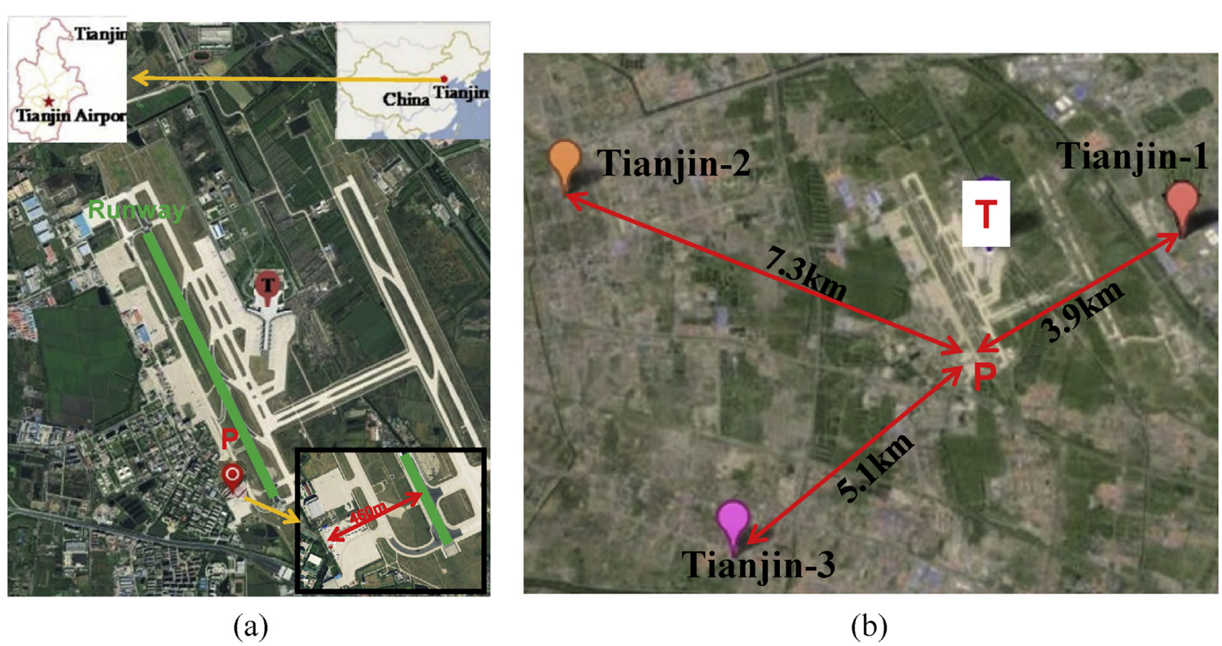

Fig. 2. (a) The MD-82 airplane parked at location P at Tianjin Binhai International Airport, where T is the terminal and the green line is the runway, and (b) Tianjin-1, Tianjin-2, and Tianjin-3 are the three air quality monitoring stations near the airport (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).