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Experimental study on characteristics of the jet flow from an aircraft gasper

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ABSTRACT

Ventilation air distribution in commercial airliner cabins is crucial for creating a thermally comfortable and healthy cabin environment. The cabin air distribution is controlled by supply air diffusers and personal gaspers in nearly all aircrafts. Most previous studies focused on the flow field created by diffusers but ignored that created by gaspers. To study the characteristics of the jet flow from an aircraft gasper, fluid dynamic experiments were conducted on an actual gasper jet system in a simplified cabin mock-up. The gasper was taken from a retired MD82 airplane and its plenum was made in the full scale size of a real one. A high precision hot-wire anemometer was used to collect velocity magnitude and turbulence intensity data in the flow field of gasper isothermal jet. The evolution of velocity and turbulence intensity along the centreline of gasper jet under different airflow rates are analysed, results are then compared for three different opening sizes of gasper jet under the same airflow rate. Finally, a comparison between gasper jet and annular jet is presented to further discuss the experimental results. The results indicate that the flow field created by gasper is complicated near the nozzle but can be simplified when fully developed. A fitting empirical formula is developed to predict the velocity decay for gasper jet. This study also provides high quality experimental data for describing the flow field and for further validating CFD results for gasper jets.

1. Introduction

Global air traffic is estimated to be over one billion passengers annually [1,2], which demands high-performance ventilation air distribution systems to be implemented in aircraft, in order to maintain a safe, healthy, and comfortable cabin environment. Although the aerospace industries have improved the thermal comfort and hygiene in airliner cabins in the past decades [3], there are still reports of discomfort and healthy problems due to air distribution [4–6].

The air distribution in a commercial aircraft cabin is created by supplying fresh and recirculated air out of the diffusers and gaspers in an environmental control system (ECS) [7]. The air supplied from the diffusers provides mixing ventilation (MV) and that from the gaspers provides personalized ventilation (PV). For a typical single-aisle aircraft, the air is mainly supplied from the diffusers located at the upper part of the side walls and mixed in the middle of the cabin. At the lower part of the side walls, part of the air is exhausted and the other is re-circulated [8,9]. The passengers are located at the recirculation region; therefore the supplied clean air reached the passengers after mixing with the polluted (re-circulated) air. As a supplement, a passenger can turn on the gasper that delivers fresh air directly to the breathing zone. The passenger could control the air flow rate and air velocity direction.

To investigate the air distribution in an airliner cabin, there are mainly two methods available: experimental measurements and numerical simulations [8]. Experimental studies are usually thought to be more reliable. For example, Mizuno and Warfield [10] used hot-wire anemometers to measure the air velocity distributions to study the effect of cabin airflow on contaminant dispersion. Zhang et al. [11] used ultrasonic anemometers to obtain the air distribution in a full-scale, twin-aisle section of an aircraft cabin

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mockup. Liu et al. [9] applied the ultrasonic anemometers to measure the flow field in a functional MD-82 aircraft. Other investigators applied a PIV system to measure the airflow patterns in an empty cabin [12–14] or in an occupied cabin [15,16]. Compared to experimental studies, numerical studies of air distribution in an aircraft cabin are less expensive and more efficient [17–19], but CFD turbulence models also need reliable experimental data to be validated [20,21]. The experimental and numerical studies provided a deep understanding of the air distribution in airliner cabins, but most of previous studies assumed that the gaspers were turned off.

In fact, passengers usually turn on the gaspers to help achieve their preferred environment after boarding on the aircrafts. 63% of the passengers used the gaspers during the flight [22]. Fang et al. [23] also found that more than half of the occupants opened the gasper to alleviate stuffiness. Therefore, to investigate the air distribution in an airliner cabin, the influence of the air from gaspers on the cabin environment needs to be clarified.

However, there are few investigations addressing the influence of the air from gaspers on the cabin environment. Anderson [24] used CO_2 as the tracer gas to investigate the effect of gaspers on the transport of contaminants in a wide-body, 11-rows Boeing 767 aircraft cabin mock-up. The results showed that jet from the gaspers can disrupt the longitudinal transport of contaminants within the aircraft and reduce person-to-person transmission of exhaled contaminants as much as nearly 90%. However, that study did not measure the flow field and could not explain how the gaspers jet influence airflow and concentration field. Another study [25] conducted CFD simulation to find the relationship between the gasper initial jet temperature and air flow rate to the local thermal comfort on head, chest, and face. The study simplified the gasper outlet as a circular orifice (diameter equal to 10 mm) and assumed uniform air velocity boundary conditions on the gasper outlet. The simplification and assumption might bring signification errors in predicting the air distribution. Therefore, it is crucial to investigate the basic characteristics of the gasper jet, which is a fundamental issue when studying gaspers in an aircraft cabin.

In order to study the characteristics of the jet from an aircraft gasper, this paper conducted high quality experiments to obtain its velocity profiles. The results were further analyzed to develop an empirical formula for the velocity profiles inside the jet, which could provide simplified boundary conditions for CFD simulation.

2. Method

2.1. Experiment setup

The experiments were carried out inside a simplified aircraft cabin mockup placed in a thermostatic chamber to maintain a stable thermal environment as shown in Fig. 1(a). The cabin was made by tempered glasses and its dimension was 3.2 m (length) × 3.0 m (width) × 2.2 m (height). A gasper from a functional retired MD-82 aircraft was mounted in the middle of upper-wall (Fig. 1(b)). There was a cone inside the outlet to change the air supply area, which was mainly used to control the air flow rates. The air supply area was an annulus that had a constant outer diameter ($D_0 = 12.6$ mm). The inner diameter was changed when passengers adjusted the gasper opening. The opening size $h = 2.0$ mm at the maximum opening.

Dry and clean air was provided and stabilized by using an air compressor and an air storage tank, respectively. A float flowmeter was used to control and monitor the air flow rates. Before entering to the cabin mockup, the air was injected into a plenum chamber horizontally as shown in Fig. 1(b). The plenum chamber was established in the same size with the real one in MD-82 aircraft [9] to make the experimental more realistic. Finally, the jet was discharged vertically downward and freely into the cabin. The jet air temperature was the same with that of the thermostatic chamber to create isothermal flow in the cabin mockup. The cabin mockup was not mounted with other diffusers besides the tested gasper, so it created the aircraft cabin environment with the gasper-on without other general ventilation effect.

2.2. Experiment procedure

Since the air flow rate and the gasper opening width both could affect the characteristic of the jet, the influence of these two parameters was investigated respectively. The air velocity profiles were first measured with three air flow rates ($Q_1 = 0.94$ l/s, $Q_2 = 1.18$ l/s, and $Q_3 = 1.42$ l/s) when the gasper was at its maximum opening width. The Q_1 and Q_3 were chosen because they were minimum and maximum airflow capability of the gasper according to Boeing company and ASHRAE161 [7]. Then, under the same flow rate ($Q_4 = 1.00$ l/s), the air velocity profiles were measured with three opening sizes of 1.0, 1.5, and 2.0 mm, which corresponded to half/three-quarter/full open of gasper, respectively.

The air velocity was measured with a hot-wire anemometer that composed of a single-wire mini-probe and a TSI IFA 300 processor at the sampling frequency of 100 kHz. The sampling frequency was large enough to obtain the turbulent characteristics of the gasper jet flow. The hot-wire anemometer was calibrated before experiments and its resolution was less than 0.01 m/s including the errors introduced by the data acquisition systems that should provide a very good accuracy for the present investigation. The probe (shown in Fig. 1(b)) was moved automatically by a three dimensions coordinate frame and its control cabinet from one position to another to change the mounted point on a vertical pole. The pole was calibrated by a vertical laser. The resolution of the coordinate frame

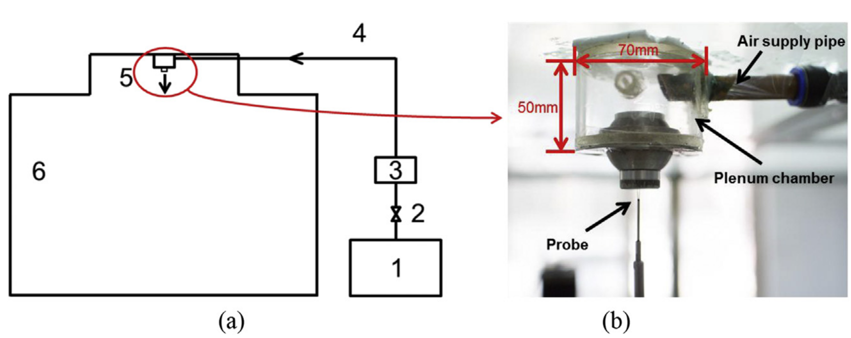

Fig. 1. (a) Schematic of the experiment setup: 1 – air compressor and air storage tank, 2 – control valve, 3 – float flowmeter, 4 – air supply pipe, 5 – gasper and its plenum chamber, and 6 – simplified aircraft cabin. (b) Photo of gasper and its plenum chamber model.