Building and Environment 82 (2014) 608–617

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Turbulence measurements of a personal airflow outlet jet in aircraft cabin

Yong Guo [a], Nan Jiang [a, b, *], Shiyong Yao [a], Shen Dai [c], Junjie Liu [c]

[a] School of Mechanical Engineering, Tianjin University, Tianjin 300072, China
[b] Tianjin Key Laboratory of Modern Engineering Mechanics, Tianjin 300072, China
[c] School of Environmental Science and Engineering, Tianjin University, Tianjin 300072, China

ARTICLE INFO

Article history:
Received 26 July 2014
Received in revised form
5 October 2014
Accepted 6 October 2014
Available online 14 October 2014

Keywords:
Personal airflow outlet
Cabin environment
Annular jet
Hot wire anemometer
Spectrum analysis
Wavelet analysis

ABSTRACT

The jet airflow field of MD-82 aircraft cabin's personal airflow outlet (PAO) is measured by constant-temperature anemometry system with the resolution higher than the smallest time-scale of turbulence. The turbulence statistics at different radial and axial positions is analyzed. The airflow field of the PAO jet is similar to a single jet beyond the point of reattachment. However, the airflow diffuses stronger than the single jet, turbulence intensity is higher, each order turbulence statistics and characteristics scales get turbulent equilibrium earlier. The inertial sub-range is found by spectrum analysis, by which the energy is cascaded from the energy-containing large scale to the small scale, and finally dissipated into heat. Moreover, wavelet analysis is employed to perform multi-scale decomposition of instantaneous turbulence fluctuating velocity signals, in order to accurately distinguish the time scales which dominate the airflow field.

1. Introduction

Generally, there are two kinds of air distribution systems in the aircraft cabin, i.e. the mixing air distribution system and the personalized air distribution system. The mixing ventilation system, currently used in commercial aircrafts, which supplies conditioned air at high velocity from the ceiling or luggage compartment level, and exhausts contaminated air at the deck level. There have been many experimental or numerical studies on the air distribution in aircraft cabin [1–7]. However, due to crowded space, limited ventilation, and prolonged exposure time, the mixing ventilation is subject to causing the spread of contaminants and diseases [8–12], inducing numerous complaints of cabin air quality [13,14], and it also is a direct cause of threat to the thermal comfort of passengers [15].

As a supplement to the mixing ventilation system, the personalized ventilation system is utilized for rapid ventilation and heat exchange, which directly blows the fresh air to the breathing area around the passengers' nose and creates an isolated micro-environment to against outside effect, which has attracted extensive investigation in building industry and aircraft cabin environment [16–37]. Stancato and Tribess [16] found that the PAO jet can influence the local thermal comfort with minimum influence on the others. Zhang and Chen [17] suggested that the personalized ventilation system provided the best air quality without draft risk, by comparing the air and contaminant distributions in the aircraft cabin with other ventilation systems. Nowadays, the personalized ventilation system has been indicated that it could decrease the level of contaminants in inhaled air and the risk of infection transmission [18–20], as well as improve the perceived air quality [21,22] and passengers' thermal comfort [23,24] in aircraft cabin, which is well developed by many researchers [18,25–28].

Most of the literatures presented in personalized ventilation system are concerned with passengers' satisfaction. However, few works exist on flow characteristics and multi-scale eddy structures of the turbulent jet. Meanwhile, the precise measurements of the PAO jet airflow field and analysis of turbulence statistics are the premise and key to realize the optimization of air distribution and prevent the spread of contaminants, etc. In the present work, IFA-300 constant temperature hot wire anemometer was employed to conduct the MD-82 aircraft cabin's PAO jet airflow field measurement. The configuration and size of the PAO are shown in

* Corresponding author. School of Mechanical Engineering, Tianjin University, Tianjin 300072, China.
E-mail address: nanj@tju.edu.cn (N. Jiang).

http://dx.doi.org/10.1016/j.buildenv.2014.10.007
0360-1323/

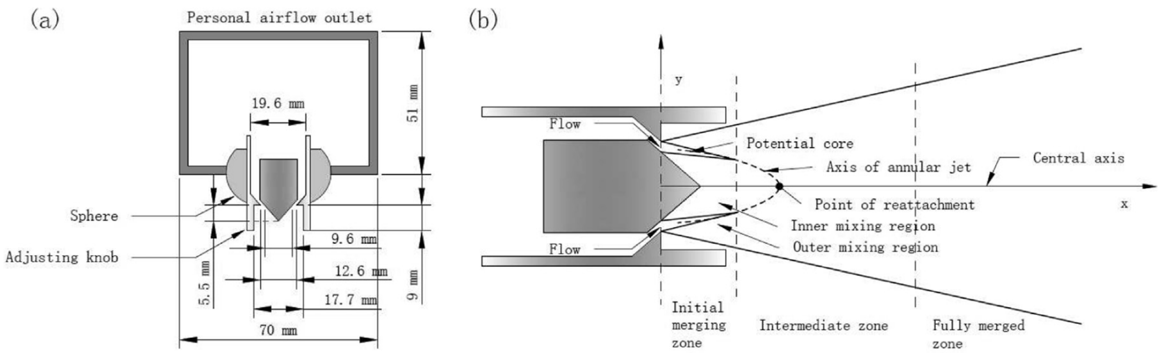

Fig. 1. (a) Configuration and size of the PAO (b) Schematic of the annular jet.

Fig. 1(a), turning the knob can drive the middle cone moving along the axis to change the flow rate, while adjusting the sphere rotation can change the jet angle. The inner diameter of adjusting knob is 17.7 mm; the outer diameter D_o of annulus (The jet exit) is 12.6 mm; the annulus width is 1.5 mm, the distance between the conical vertex and the bottom of the knob is 3.5 mm, which is 5.5 mm away from the annulus when the PAO aperture is adjusted to the maximum.

The airflow flied of the PAO can be deemed as annular jet, which have attracted extensive investigation [38–41]. The airflow field of the annular jets can be separated into the initial merging, the intermediate and the fully merged zones, as shown in Fig. 1(b). As can be seen that the initial merging zone ends with the annular jet potential core, outer mixing region and inner mixing region are separated by the potential core; the intermediate zone inherits high velocity of the potential core, and the flow merges at the reattachment point; after the intermediate zone there is the fully merged zone, in which the airflow flied is similar to the zone of established flow of a single jet, partly reflects the far field of jet is independent with the exit flow conditions.

In order to ensure the passengers' comfort inside the aircraft cabin, the PAO flow velocity should be slow enough, while the ventilation rate should maintain above a certain level to make sure the fresh air to be constantly injected, so the jet flow should have strong entrainment ability, which is helpful for jet diffusion to decay fast. However, improving the entrainment ability is always companied with increasing the turbulence intensity, which also causes uncomfortable drafts sensation [42–44], thus we need to control the turbulence intensity of the PAO airflow flied. Meanwhile, we should design the PAO jet airflow that consists of small scale (high frequency) eddies, because of the fact that uncomfortable drafts sensation could decrease with increasing the airflow frequency [45,46].

This paper presents the measured results at different radial and axial positions of the PAO jet airflow field, and we also compare the available results with a single jet. The main objectives of present work include two aspects:

1. An attempt will be made to verify the feasibility that the PAO jet can be simplified as a single jet beyond the reattachment point, which is helpful for CFD predictions. Meanwhile, it will be quantified the differences between the PAO jet and the single jet, in each order turbulence statistics and characteristics scales, etc. to deepen the understanding of the PAO jet.
2. The airflow field of the PAO jet will be tested whether or not it satisfies passengers' comfort inside the aircraft cabin by the analysis of the mean velocity, turbulence intensity and the airflow frequency.

2. Experimental method

The experiment was carried out in a simplified aircraft mockup, the PAO was installed under the ceiling of it. Air was supplied by a stable compressor which could provide a maximum flow rate of 6 m^3/h dried and near-ambient temperature airflow. Storage tank and float flowmeter, which were installed between the compressor and PAO, were employed to further stabilize the airflow. In this experiment, the PAO aperture was adjusted to the maximum and Reynolds number is 2522 based on the jet exit maximum velocity and annulus width (1.5 mm), and the background turbulence intensity is 3.3% based on the exit maximum velocity. The investigation area is from 0.5 outer diameters D_o to 14 outer diameters D_o downstream of the nozzle exit, which contains the initial merging, the intermediate and the fully merged zones. In order to compare the PAO airflow field with a single jet, a long straight pipe with 9.8 mm inner diameter was employed. The Reynolds number of the single jet is 10,615 based on the exit maximum velocity (exit centerline velocity) and inner diameter. The background turbulence intensity is same as the PAO jet.

The data were collected by using IFA-300 constant-temperature anemometry, which can continuously sense flow velocity and automatically adjust the dynamic response, then accurately measure the flow fluctuating velocity signals. Only a mini single wire (TSI model 1260A-T1.5) was used in the present work. This wire, consisting of tungsten, had a diameter of 5 μm and a length of 1.5 mm. The sampling frequency was fixed at 100 kHz and a total of 4,194,304 sampling data was collected at each spatial position. Automatic 3D-coordinate frame with resolution of 0.01 mm was employed for the probe movement. During the whole experiment, the mockup was isolated to ensure that there is no disturbance on the measured results.

3. Results and discussion

The experimental results of two typical cases will be presented and discussed in this section.

3.1. Radial results

3.1.1. Mean velocity

The contours of the local mean velocity U/U_j (U_j is the jet exit maximum velocity) of the PAO jet in the range from axial distances $0.52D_o$ to $2.82D_o$ (The initial merging and the intermediate zones) and $2.82D_o$ to $13.13D_o$ (The fully merged zone) are shown in Fig. 2(a) and (b) respectively, while Fig. 2(c) shows the contours of the local mean velocity of the single jet within the same condition. As shown in Fig. 2(a), the initial merging zone is found within the first $0.9D_o$ downstream of the annulus exit, and the boundary layer separation