Performance evaluation of different air distribution systems in Cabin environment

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Abstract

The purpose of this study was to evaluate the performance of different ventilation systems in an aircraft cabin mockup. The related experimental research was conducted to obtain the local mean age of air, temperature and velocity distribution under different air distribution systems by using trace gas, thermocouples, and an ultrasonic anemometer measurement system. The results showed that in a comprehensive comparison of mixing ventilation and displacement ventilation, displacement ventilation has high ventilation efficiency. The velocity nonuniformity indices (VNUI), temperature nonuniformity indices (TNUI), and heat removal efficiency (HRE) of different ventilation systems in the cabin were compared and analyzed. A cabin airflow evaluation system is proposed. Compared to the mixing air supply, the displacement ventilation has high heat removal efficiency, but it aggravates nonuniformity. Using a plurality of air inlets can improve the uniformity of air temperature and velocity distribution. Side wall air supply is necessary to improve the ventilation performance of single-aisle cabin.

Keywords

Aircraft cabin; Displacement ventilation; Mixing ventilation.

1. Introduction

There are more and more passengers choosing air travel, the cabin environment has high passenger density, the thermal comfort and safety of aircraft cabin environments have become an important problem [1][5]. The air distribution system commonly used in aircraft cabins consists of the air supply at the top and exhaust air at the bottom of the cabin, with mixing air within the cabin [2]. The contaminants transmitted during air travel are an important health issue [3]. Such as after one flight carrying a symptomatic person and 119 other persons, laboratory-confirmed SARS developed in 22 persons [6]. The cabin environment has high thermal load. The high temperatures found may induce inertia and concentration problems, which may lead to a lowering of intellectual capacity [4].

The displacement ventilation and mixing ventilation were studied and compared in this study. The purpose of this study was to evaluate the air distribution in the cabin. The experimental research was conducted to obtain the local mean age of air, temperature field and flow field of the cabin mockup under different air distribution systems by using trace gas, an ultrasonic anemometer and a thermocouple measurement system. By comparing the velocity nonuniformity indices (VNUI), temperature nonuniformity indices (TNUI), mean age of air and the heat removal efficiency (HRE) of different air distribution systems, a reasonable evaluation system of the cabin airflow was obtained.

2. Experimental

The research team set up a measurement system for obtaining accurate temperature and velocity in a seven-row cabin mockup built with the same dimensions as the Boeing 737-200 in full-scale, as shown in Fig. 1. The cabin mockup had seven rows with a single aisle. The seat pitch is 760 mm. Forty-two thermal manikins were placed in the seats and simulated the effect of the passenger positions on the airflow patterns.

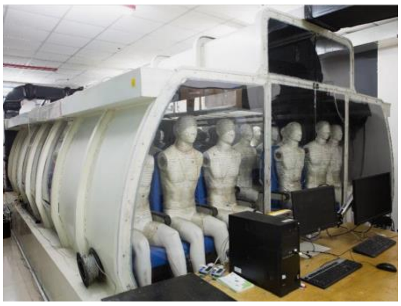

Fig. 1. The experimental facility cabin mockup.

Three forms of mixing ventilation are shown in Fig. 2: (a) sidewall supply and bottom return mixing ventilation: the air diffusers for the supply air are located below the luggage rack on the side walls. The diffusers detail size can be found in a previous publication [7], the supply air velocities is 2 m/s; (b) ceiling supply and bottom return mixing ventilation: this supply air from the ceiling of the cabin uses two perforated ceiling jets (the diameter is 20 mm) at an angle of 120°, the mean supply air velocities is 3.2 m/s; and (c) ceiling and sidewall supply and bottom return mixing ventilation: the supply air is provided while blowing the air volume, where the ceiling provides 40% (the mean supply air velocities is 1.3 m/s) of the volume flow rate and the sidewall supply provides 60% (the mean supply air velocities is 0.9 m/s). Three mixed ventilation systems are exhausted by positive pressure. The porous plate as outlet located symmetrically at each side of the cabin bottom with a size of 60 mm×5800 mm.

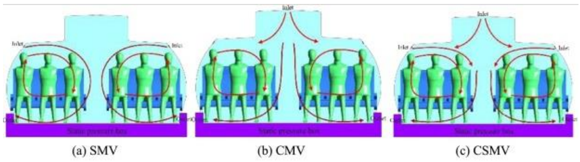

Fig. 2. Illustration of mixing ventilation (MV) principles. (a) Sidewall supply and bottom return mixing ventilation (SMV); (b) Ceiling supply and bottom return mixing ventilation (CMV); (c) Ceiling and sidewall supply and bottom return mixing ventilation (CSMV).

The displacement ventilation is depicted in Fig. 3(a). The fresh air is supplied by static pressure box from the bottom inlets of the cabin. The static pressure box can make inlet velocity more uniform. Then, exhaust to outdoor through the cabin ceiling. Finally, a large-scale flow structure is formed. The outlet of the displacement ventilation system operated inversely to ceiling mixing ventilation. In addition, this study combined displacement ventilation and mixing ventilation, as shown in Fig. 3(b), where the bottom provided 70% of the volume flow rates, and the sidewall supply provided 30%.

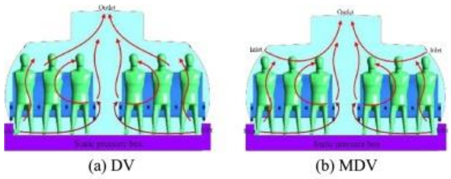

Fig. 3. Illustration of displacement ventilation (DV) principles. (a) Displacement ventilation (DV); (b) Combination of MV and DV (MDV).

The experiments were conducted under cooling conditions. All the thermal manikins were turned on under cooling conditions. The temperature field was measured in the cross section in front of the fourth seat row of thermal manikins. The measurement planes are located relatively to the passenger dummy surface 150 mm, as shown in Fig. 4. To obtain the thermal field, ordinary Type T thermocouples were applied to determine the temperature distribution with an accuracy of ±1 °C. The measuring point used uniform distribution measurements. The sampling spatial resolution was 100×100 mm2. Then, each measurement lasted for 300 s. The sampling rate was constant at 1 Hz for each measuring location.

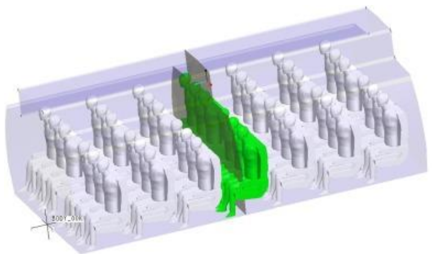

Fig. 4. Measured cross section of the cabin mockup.

3. Results And Discussion

The flow field of the mixing ventilation was analyzed as shown in Fig. 4. The velocity distributions were measured with same airflow rate under different ventilation systems in the seven-row cabin mockup.

The distribution of the flow field under the three different mixing ventilation systems is shown in Fig. 5. Under the three kinds of mixing ventilation, two large scale circulations are formed around the passengers on both sides of the aisle. This phenomenon is more obvious in the form of sidewall mixing ventilation (SMV) air supply, which is caused by the intersection of two jets.

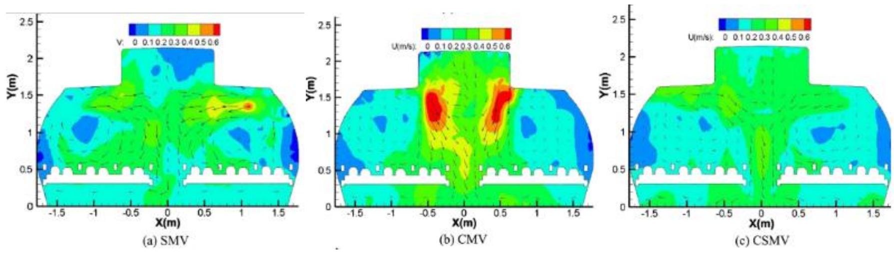

Fig. 5. Flow field of mixing ventilation.

The temperature distribution of three different mixing ventilations is shown in Fig. 6. In the occupied zone, the air was heated by manikin thermal convection. A high temperature zone was observed close to the two side walls, possibly produced by large scale, low-speed circulation in this zone. Due to the role of the large-scale circulation, the mixing ventilation can cause heat accumulation in the cabin. This phenomenon is more serious under ceiling supply mixing ventilation (CMV). From the above comparison, the ceiling and sidewall supply and bottom return mixing ventilation (CSMV) has better airflow performance.

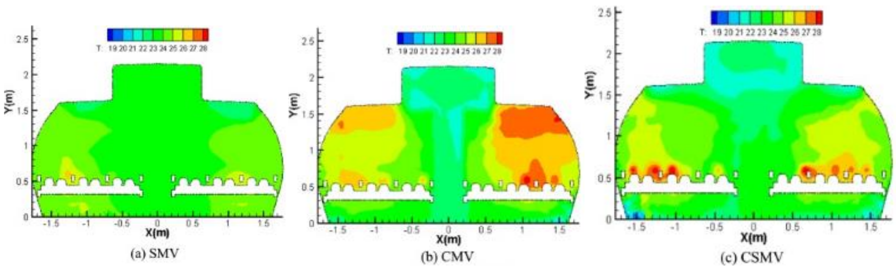

Fig. 6. Temperature field of mixing ventilation.

The flow field of displacement ventilation is shown in Fig. 7. The velocity was obviously lower than the mixing ventilation. From Craven's research, the velocities of the human thermal plume could reach up to 0.2 m/s [8]. The velocity of the whole field is close to the thermal plume flows. By comparing the inlet velocities of the two kinds of displacement ventilation, the velocity of the combination of mixing ventilation and displacement ventilation (MDV) was obviously lower than the displacement ventilation (DV). Due to the blocking effect of the seats, both sides of the inlet air flows confluence at the aisle. Then, the human thermal plume entrainment of the air flow is close to the two side walls. Finally, the air flow gathers to the cabin ceiling and exhausts with the thermal plume rising role.

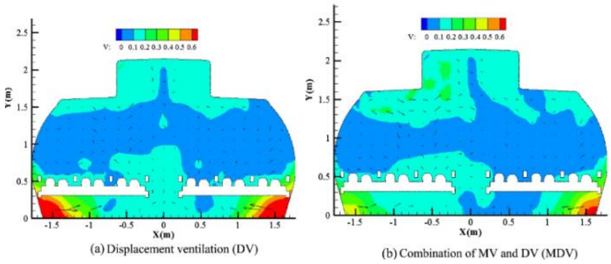

Fig. 7. Flow field of displacement ventilation.

The temperature fields of the displacement ventilation are shown in Fig. 8. The temperature below the seat is lower. At the bottom of the seat, the cold lake effect was formed in the cabin. Owing to the role of the low-speed human thermal plume, each passenger heat loss is homogeneous, and the temperature distribution is more uniform above the leg. In the displacement ventilation system (DV), there is too much cold air in the aisle. Therefore, the combination of MV and DV (MDV) has more advantages.

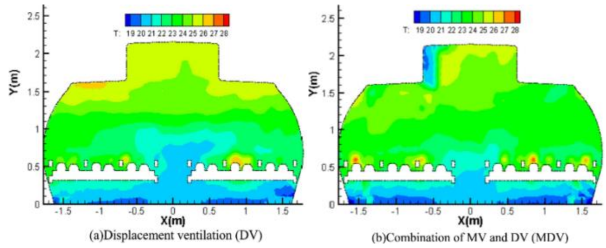

Fig. 8. Temperature field of displacement ventilation.

As shown in Fig. 9, the result is the average mean age of air of the three passengers at breathing zones on the right side of the aisle. Comparison with the different air distribution systems, the mean age of air is longer under ceiling supply and bottom return mixing ventilation (CMV) in the cabin, indicating that the CMV has the worst ventilation efficiency. The mean age of air of displacement ventilation was significantly shorter than the mean age of air of the mixing ventilation. However, comparing the three kinds of mixing ventilation, the mixing ventilation added to the side air supply ventilation system can reduce mean age of air. The performance almost as good as the displacement ventilation.

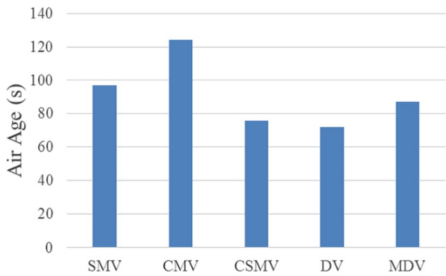

Fig. 9. Mean age of air under different air ventilation systems.

The velocity nonuniformity indices (VNUI) of different air distributions are shown in Fig. 10. Mixing ventilation has good uniformity. Comparing the three kinds of mixing ventilation systems, the ceiling and sidewall supply ventilation has the best uniformity. The ceiling air supply is the worst. Comparing the two kinds of displacement ventilation system, the velocity of the combination of MV and DV (MDV) has more uniformity. Therefore, using multiple inlets can improve the uniformity.

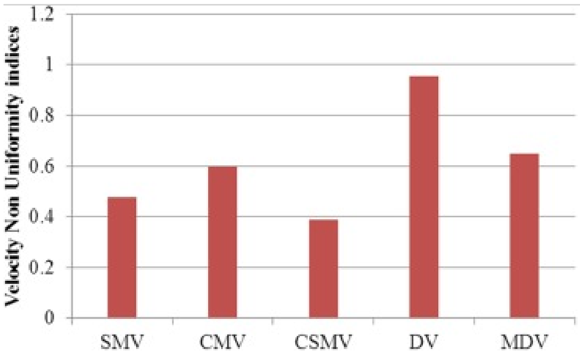

Fig. 10. Velocity nonuniformity indices of different air distribution systems.

The air temperature nonuniformity indices (TNUI) of different air distributions are shown in Fig. 11. Owing to the role of circulation, the temperature has good uniformity under mixing ventilation. Comparing the three kinds of mixing ventilation systems, the sidewall supply ventilation has the best uniformity, and the ceiling supply system is the worst. The displacement ventilation system obviously exhibits the phenomenon of temperature stratification. Therefore, the temperature nonuniformity indices are not as good as the mixing ventilation. Comparing the two kinds of displacement ventilation systems, the temperature of the combination of MV and DV (MDV) is more uniform than the DV system.

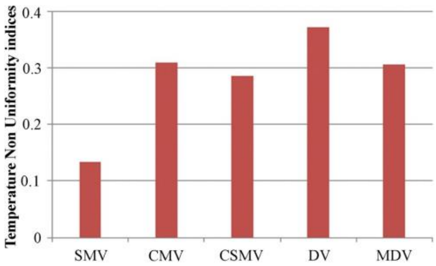

Fig. 11. Temperature nonuniformity indices of different air distribution systems.

The comparison of the heat removal efficiency (HRE) of different air distribution systems is shown in Fig. 12. The displacement ventilation has high heat removal efficiency and energy utilization efficiency. The mixing ventilation will form a large-scale circulation around the passengers but is not conducive to timely discharge of heat. Comparing the five kinds of air distribution under the mixing ventilation and the displacement ventilation, it is necessary to use the side air supply in the single aisle cabin.

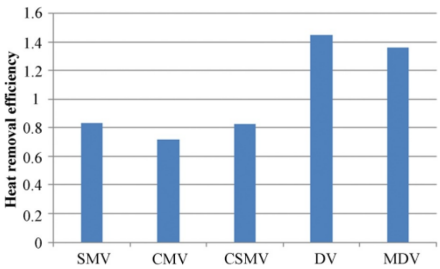

Fig. 12. Heat removal efficiency of different air distributions.

In order to quantitative statements on the thermal passenger comfort, the Fig. 13 show the mean percentage of dissatisfied due to temperature stratifications from the temperature and the velocity data. The percentage of dissatisfied is lower under mixing ventilation than displacement ventilation. Therefore auxiliary side air supply, the performance can be improved.

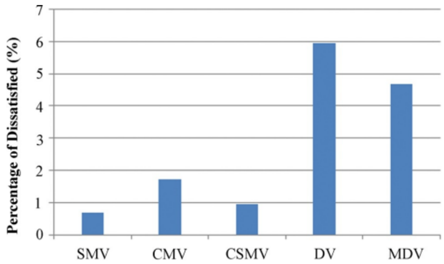

Fig. 13. Percentage of dissatisfied of different air distributions.

4. Conclution

The performance of different ventilation systems in a cabin, the ventilation efficiency (mean age of air), the velocity distribution and the temperature distribution were compared and analyzed. In a comprehensive comparison of mixing ventilation and displacement ventilation, the displacement ventilation shows high ventilation efficiency and high energy efficiency. Mixing ventilation can cause heat accumulation in the cabin, and the flow field is affected by large scale circulation.

Acknowledgements

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