INFLUENCE OF MIXING VENTILATION AND UNDERFLOOR AIR DISTRIBUITION ON THE DISPERSION OF EXPIRATORY DROPLETS IN AN AIRCRAFT CABIN: AN EXPERIMENTAL ANALYSIS

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Abstract

The air distribution system commonly used in aircraft cabins consists of air supply at the top of the cabin with exhaust air at the bottom, with mixing air within the cabin. Due to this mixing characteristic, this system can disperse infectious diseases through the cabin air. The global outbreak of SARS (Severe Acute Respiratory Syndrome) virus in 2003 showed that the spread of airborne contaminants is still an uncontrollable event, since it was quickly spread around the world, mainly because infected people who traveled by plane to distant cities. Facts like these have motivated governments, companies and research institutions to invest heavily in research and development. New aircraft ventilation and air distribution systems based on displacement ventilation and underfloor air distribution are beginning to be tested. In this context, in the present work was performed an experimental analysis of expiratory droplets dispersion inside a 12 seats 3 rows 4 abreast regional aircraft cabin, where heated mannequins were used to simulate the presence of people. The tests were performed considering mixing ventilation (MV) and underfloor air distribution (UFAD), under the same air supply rate and two air supply temperatures: 18 ±0,5 °C and 22 ±0,5 °C. The experiments were performed with full outside air and with the control of the particles greater than 2 μm in the outside air. Expiratory droplets were generated at two points of the cabin: near the fuselage and near the aisle. These particles were generated and counted in the breathing zone, 1,10 m from the floor, in each seat in the aircraft. The results show that the point of injection of particles, and the air supply temperature, have great influence on the dispersion and particle concentration throughout the cabin. A lower air temperature in the cabin favours the formation of thermal plumes within the passengers, increasing the ventilation efficiency in removing particles from the cabin. The UFAD system had the lowest dispersion and greater efficiency in removing expiratory droplets from the cabin, being promising also for its use in aircraft cabins. The increase in expiratory removal of droplets from 2 to 3μm UFAD system with respect to conventional MV was up to 45.5 % and from 3 to 5μm was up to 63.4%.

Keywords: air quality, airborne contamination, ventilation systems, aircraft

1 Introduction

There are many difficulties when it comes to air quality in aircraft cabins. It requires large efforts to provide a healthy and comfortable environment to pilots, crews and passengers.

In commercial aircraft cabins, high density occupancy rates result in relatively low ventilation per person, which can lead to a reduction in the rate of dilution of potentially pathogenic contaminants exhaled by people. Furthermore, the limited internal space with a large number of occupants causes passengers getting too close to each other.

The proximity of passengers, combined with low ventilation rates per person for a long exposure time, can create a favorable environment for transmission of infectious diseases by contact and by airborne particles Wan et al. (2009).

The global outbreak of SARS virus (Severe Acute Respiratory Syndrome) in 2003 showed that the spread of airborne contaminants can still be an uncontrollable event, since it was quickly spread around the world, mainly because it infected people traveling by plane to distant cities Olsen et al. (2003).

As a result, studies of contamination in aircraft cabins have been focusing on air pollution resulting from the dispersion of expiratory pollutants generated by people Wan et al. (2005), Zhang et al. (2009), Wan et al. (2009), Sze To et al. (2009), Yan et al. (2009), Gupta et al. (2011), Conceição, (2012), Bosbach et al. (2012), Chen et al. (2012), Pang et al. (2013).

Although the understanding of airborne contamination on aircraft and other types of environments have evolved greatly, little is known about the dynamics of particles and the influence of new ventilation systems in particles dispersion to control and prevent their spread Morawska, (2005), Li et al. (2007), Yang, (2007), Nielsen, (2008), Müller et al. (2011), Bosbach et al. (2012).

1.1 Ventilation systems in aircraft cabins

The ventilation system commonly used in aircraft cabins is the supply air from the top, through the ceiling, and exhaustion to the bottom, with mixing of the air in the cabin, Mixing Ventilation – MV. The result is a nearly uniform temperature in the cabin and a wide dispersion of contaminants.

Although the MV system typically provides an environment with low temperature stratification, problems of thermal comfort have been verified. Furthermore, its feature of mixture can more easily spread infectious diseases by the cabin air Gao et al. (2007) and Zhang et al. (2009).

To try to solve the problems of thermal comfort and air quality, new ventilation systems and air distribution on aircrafts are beginning to be studied and tested Zhang and Chen, (2007), DLR, (2011) based on displacement ventilation systems, Displacement Ventilation - DV and ventilation systems by the floor, Underfloor Air Distribution - UFAD, already applied in some buildings.

2 Objective

This article aims to conduct an experimental analysis of dispersion of expiratory particles in aircraft cabin considering two different ventilation systems: by mixing ventilation (MV) and by the underfloor air distribution (UFAD), in mock-up of commercial aircraft with 12 seats.

3 Methodology

The analysis of the dispersion of expiratory droplets was performed inside a mock-up simulating a regional aircraft cabin with 12 seats, 3 rows with 4 abreast. The experiments were performed considering mixing ventilation (MV) and underfloor air distribution (UFAD) under the same air supply rate and two air supply temperatures: 18 ±0,5 °C and 22 ±0,5 °C.

The ventilation system by mixing (MV), Figure 1, was considered the usual procedure adopted in the aerospace industry, with 40% of the supply airflow by diffusers installed at the top of the bins and 60% of the supply airflow by diffusers in part by lower side of the bins, with 100% of the exhaust air flow by grilles installed at the bottom side of the cabin. Similarly, the distribution of air through the underfloor (UFAD) system, Figure 2, was considered 100% of the supply airflow by perforated plates installed in central cabin (corridor) with 40% of the exhaust air flow by localized grids on top of the bins and 60% of the exhaust airflow through grilles located at the bottom side of the bins.

Following ASHRAE 161, (2007), in each experiment the supply airflow rate of 34 m^3 / h (20 cfm) per person was used, making a total supply airflow in the mock-up of 12 people of 408 m^3/h (240cfm). The supply airflow rate was measured and monitored from the measurement of air velocity in the exhaust duct using Pitot tubes. The experiments were performed with full outside air and with the control of the particles greater than 2 μm in the outside air.

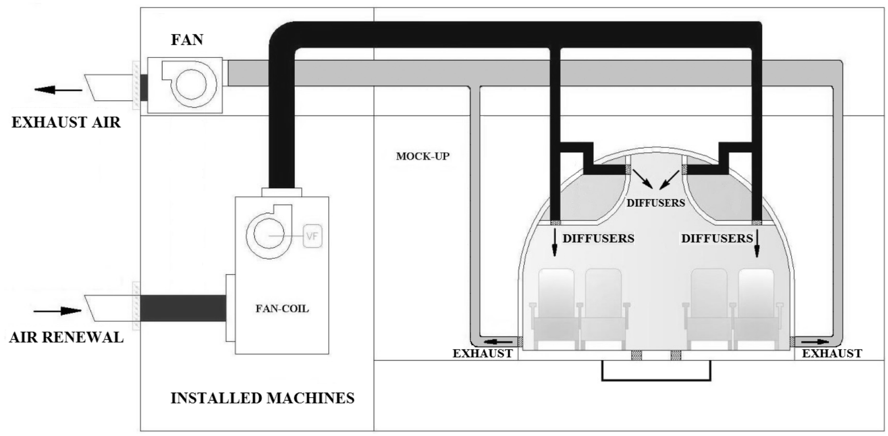

Figure 1. Air distribution system - Mixing Ventilation (MV)

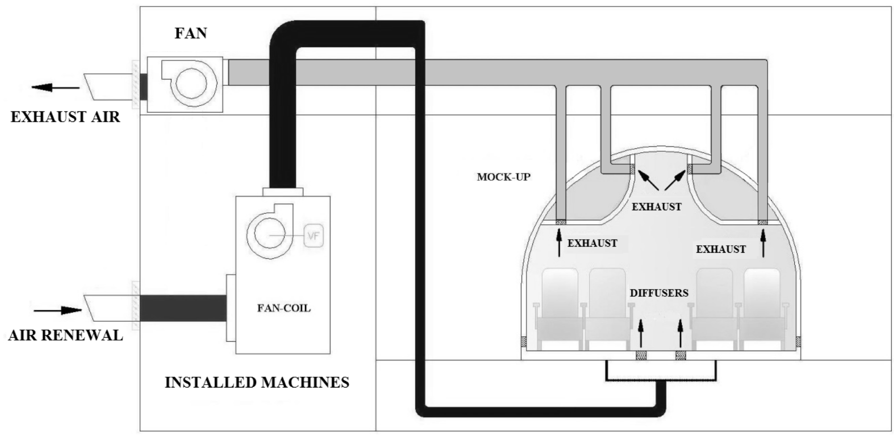

Figure 2. Air distribution system - Under floor Air distribution (UFAD)

For verifying the conditions of flow and experiment conditions in steady state, temperatures and air velocities inside the cabin were measured using thermocouples and omnidirectional anemometers, with measurement uncertainties, respectively, ± 0,5 °C e ± (0,02 + 0,02 V) m/s, which meet the accuracy requirements of the standard equipment ISO 7726, (1998).

To simulate expiratory particles was used an aerosol generator TSI Model 3475, which operates with an aerosol flow of approximately 4 L / min, similar to the average air flow rate of inhalation / exhalation of people Yan et al. (2009) with production of particles measuring 0,1 until 8 μm. In the present study it was simulated continuous aerosol generation equivalent to a person coughing with the largest amount of particles with a diameter of about 4 μm Duguid, (1946).

The measurement was performed with an optical particles counter Met One, which has 6 channels for counting particles in the range of 1 to 10 μm (1 to 2 μm, 2 to 3 μm, 3 to 5 μm, 5 to 7 μm, 7 to 10 μm, and greater than 10 μm).

Similar to the procedure implemented by Wan et al, (2005), the particles were injected by simulating passenger seated, respectively, along the fuselage and along the aisle, measuring the concentration of particles at the height of 1.10 m from the floor (breathing zone), as shown in Figure 3. All measurements were performed three times in steady state conditions.In the present work, the influence of humidity on particle concentration is small, due to the use of a liquid with low evaporation rate, the DEHS, in the generation of the aerosol Zhang et al., (2009), Conceição, (2012). Because of this, the humidity was only monitored throughout the experiments and maintained at around 50%.

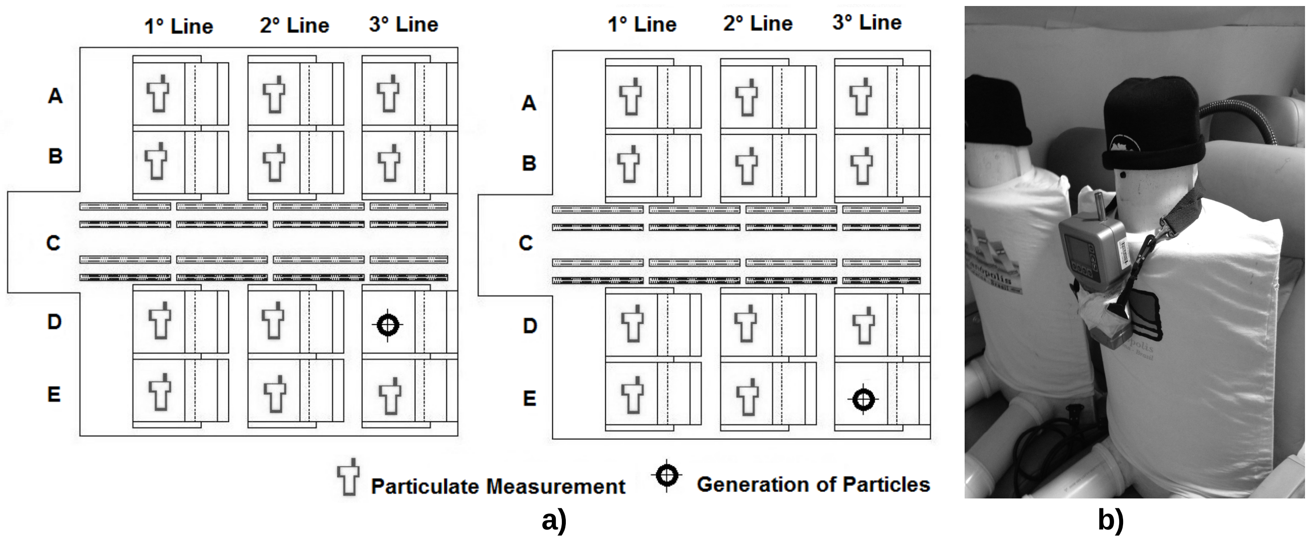

Figure 3. ***a)*** *Measurement points of particles in the mock-up and injection points at seats 3D and 3E* ***b)*** *Heated manikin and particle counter*

4 Analysis of results

In Figures 4 and 5 the results of particle concentration for UFAD and MV systems are presented considering points of injection 3D and 3E, respectively, to supply airflow with temperature of 18°C. In Figures 6 and 7 are presented the results to supply airflow with temperature of 22°C. The results are shown with measurement ranges of 2 to 3 µm, 3 to 5 µm, 5 to 7 µm, and 7 to 10 µm, with measuring ranges of 3 to 5 µm and 2,0 to 3,0 µm being of particular interest. The first because it cover 4 µm particles, which are generated in greater quantities in expiratory activities, Duguid, (1946), and the second because particles of the size of PM 2.5 are of great interest in the study of respiratory diseases Pope et al. (2002), Boldo et al. (2006).

Measurement uncertainties in the concentration of particles, presented as error bars in Figures 4 to 7, followed Poisson statistics, Kulkarni et al. (2011). The breakdown of the results, as well as those of temperature and air velocity corresponding profiles, can be found in Fabichak Jr, (2013).

From the analysis of Figures 4 to 7 it appears that, in general, there is a decrease in the concentration of particles in the breathing zone when the supply airflow is 18°C compared to supply airflow at 22°C, especially in the UFAD system. This fact is related to the formation of a larger thermal plume at temperature of supply airflow at 18°C, caused by heated mannequins in the cabin, increasing the air velocity locally and dragging a biggest number of particles to exhaust.

It can be observed that the ventilation system, MV, promotes a greater dispersion of particles throughout the cabin, a characteristic of this type of mixing ventilation system. Furthermore, this system provided a greater concentration of particles in the cabin, indicating to be less efficient in removing particles in this cabin ventilation system.

On the other hand, the underfloor system, UFAD, was more efficient in removing particles of 2 to 5 µm, and near to the injection / generation of particles, with a slight increase in the region of concentration larger particles, with the ranges of 5 to 7 µm and 7 to 10 µm, in function of upflow of particles in this ventilation system.The injection of particles into the breathing zone simulating passenger seat next to the fuselage, compared to passenger sitting next to the aisle seat of the mock-up, resulted in less dispersion of particles in the breathing zone of the cabin along both for the UFAD system and for the MV system. A similar result was obtained by Wan et al. (2005) study of the distribution of particles in aircraft with the traditional MV system.

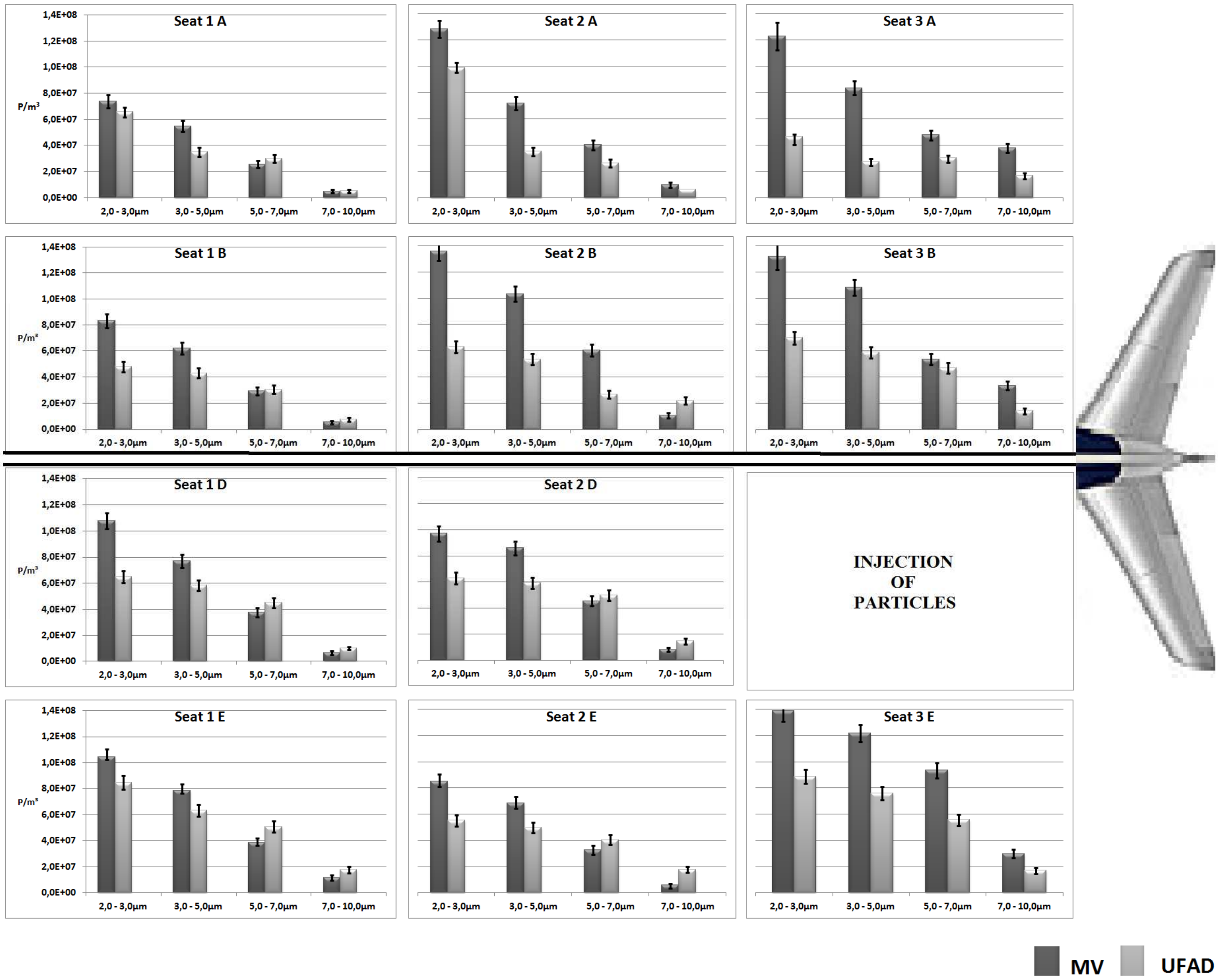

Figure 4. Particle concentration for air supply temperature of 18 ° C, injection of particles in 3D seat

5 Conclusion

The UFAD system showed more promising results regarding the efficiency in the dispersion and removal of expiratory particles in the cabin. With respect to the increase in the removal of expiratory particles of 2 to 3 µm, the UFAD system compared to conventional systems MV was up to 45.5%, and 3 to 5 µm, was up to 63.4%.

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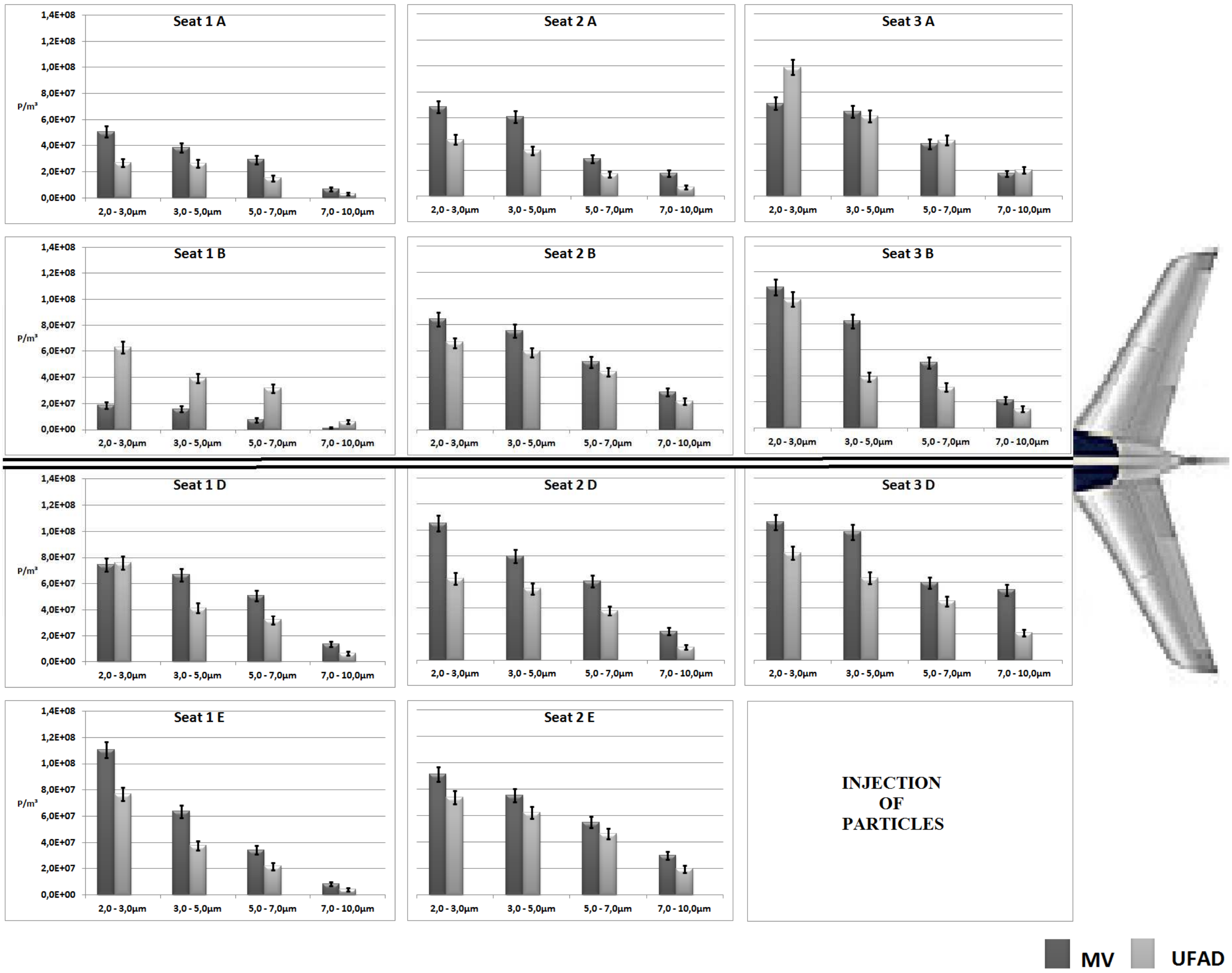

Figure 5. Particle concentration for air supply temperature of 18 ° C, injection of particles in 3E seat

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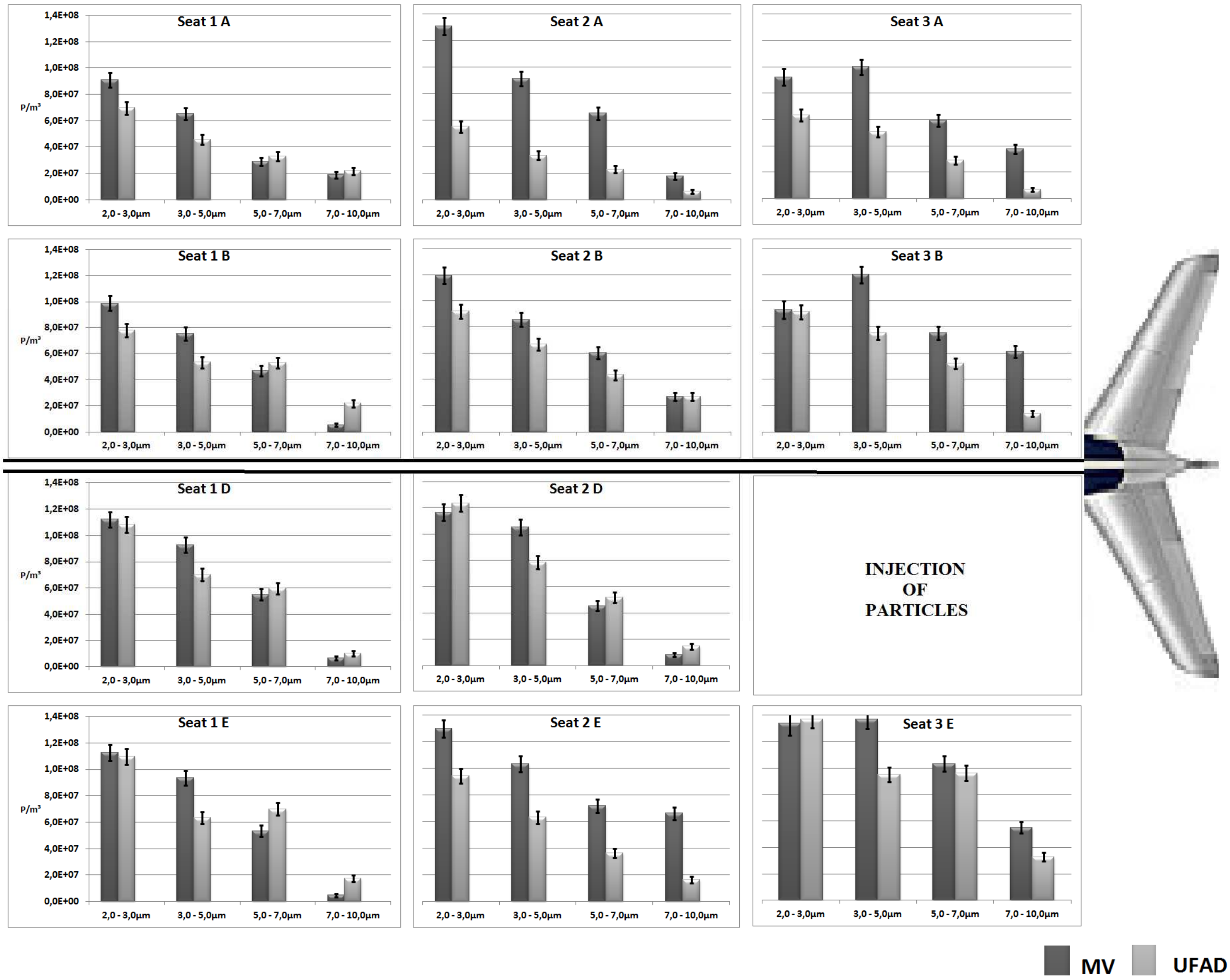

Figure 6. Particle concentration for air supply temperature of 22 ° C, injection of particles in 3D seat

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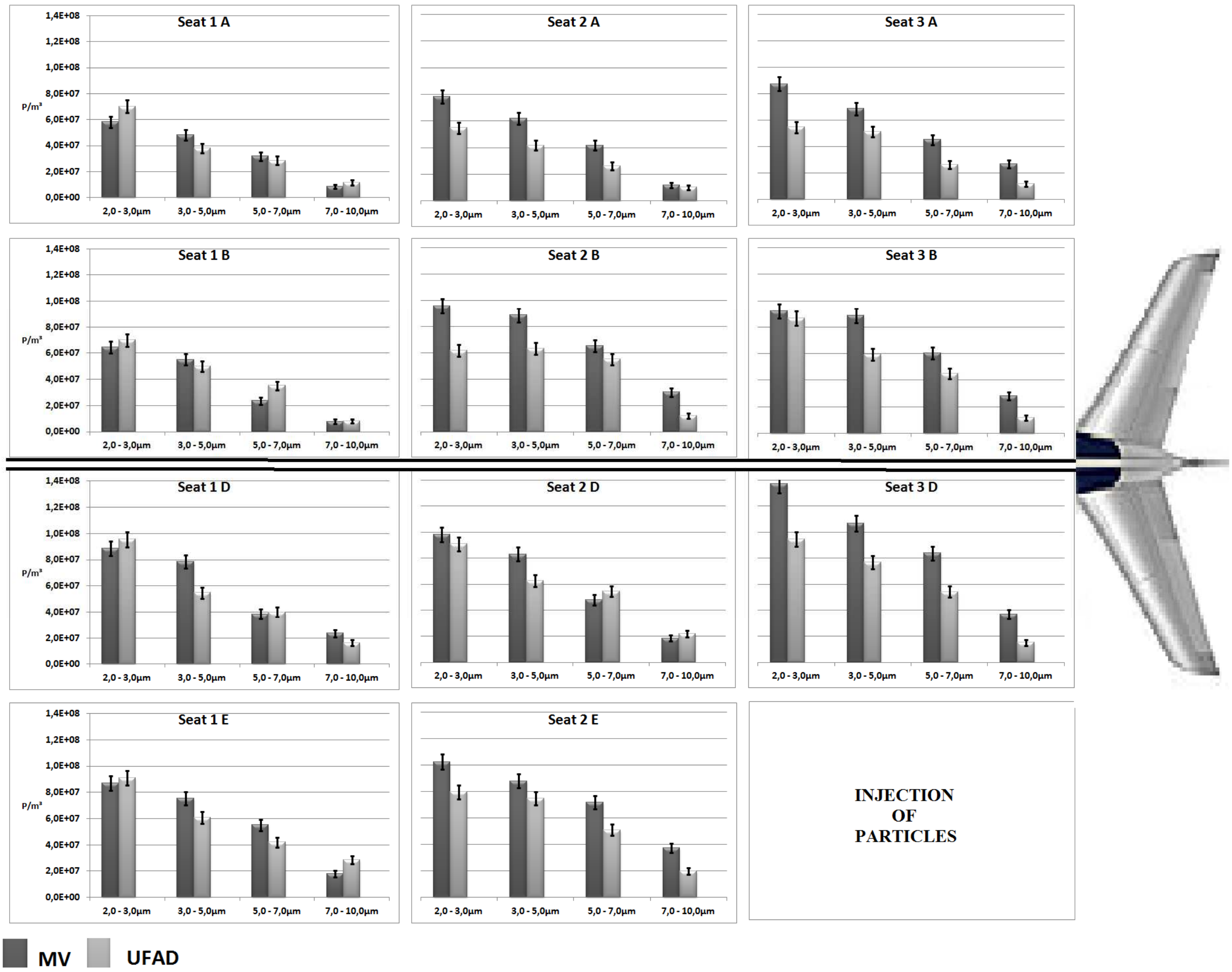

Figure 7. Particle concentration for air supply temperature of 22 ° C, injection of particles in 3E seat

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