Analysis of Air Distribution and Comfort in Large Space Environment Simulator

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Abstract. The objective of this paper is to analyze the air distribution and comfort in large space environment simulator under different air supply for the same boundary and initial conditions. This is done by conducting the numerical simulations and contrasting the distribution of velocity and temperature field, PMV-PPD and air age. It can be analyzed that the influence of several air supply on air quality and thermal comfort inside the equipment, which can be as a reference for the improvement and optimization of airflow distribution with the device. This device owns three openable doors, which locate in the bottom, middle and top of the equipment. Open one of them, the ventilation will be achieved. Computational Fluid Dynamics (CFD) is used for it is easier and less time consuming to accomplish that purpose. In general, different air supply have important effect on the air distribution and comfort inside the device. Meanwhile, the comfort is acceptable in most area, however, the air age is on the high side.

1. Introduction
Space Environment simulator, which is used to simulate the vacuum and solar radiation environment, provides a test platform for Manned spacecraft and large-scale satellites. It is an indispensable major infrastructure for space development. In term of large space environment simulator, the space is relatively closed, the ventilation cycle is long, therefore, the heat and humidity generated by people, lighting and other equipment during the preparation and finish of the test will gradually deteriorate the environment inside the equipment and can not meet the comfort requirements of the staff. At the same time, it can not meet the requirements of environment parameters of spacecraft, so it is necessary to consider this effect in engineering design.

The computational fluid dynamics method (CFD) is the most commonly used method for air distribution design and evaluation\cite{1,2}. The software Airpak\cite{3} and Fluent are widely used in the published papers, air distribution, thermal comfort and air quality can be evaluated and analyzed. However, it is difficult to create complex models such as large space environment simulation equipment using Airpak software, so this paper uses commercial CFD software Fluent to simulate and calculate the flow field, and UDF method\cite{4} to write the corresponding procedures to achieve the required functions, thus resulting in intuitive thermal comfort and air quality indicators.

In this paper, different air supply modes are used to model a large space environment simulator without changing other parameters, and the air distribution in the equipment is simulated numerically, the influence of air supply mode on thermal comfort and air quality is analyzed and discussed, which provides a reference for the improvement and optimization of air distribution in environmental simulator.
At present, there are many kinds of evaluation indexes of thermal comfort and air quality, such as effective temperature, thermal stress index and PMV, etc. Based on PMV-PPD AND AIR AGE index, the air distribution and air quality can be predicted and evaluated, and scientific, reasonable and intuitive conclusions can be drawn.

2. Geometric and mathematical models

2.1. Geometric models

In this paper, a large space environment simulator is studied. As shown in Fig. 1, the whole equipment is cylindrical, with a diameter of 17 meters and a height of 22 meters. The space station's core is assumed to be placed on a circular support inside the equipment, with four people around the station (see figure 2).

![Figure 1](attachment:image1.png)

**Figure 1** Physical model of the device

![Figure 2](attachment:image2.png)

**Figure 2** Distribution of space station and people

The main parameters are set as follows: The air outlet is set as the velocity inlet, and the inlet velocity is set as negative (-10.1 m/s) to simulate the situation of the pumping air; the doors 1, 2 and 3 all adopt the outlet pressure, and the reflux condition is set at 20°C, the relative humidity is 50% (achieved by converting the Mass Fraction of water vapor into component transport in Fluent), the diameter of Gate 1 is 4m, and the sizes of Gate 2 and Gate 3 are 1.9m×0.8m. The core section of the space station can be roughly simplified to 15.1 m in length as shown in figure 2, the maximum diameter is 4.2 m, the personnel set as the 0.45m×0.25m×1.8m cuboid, with the standing posture, and adopt the fixed heat flow boundary, the value can be 20 W/m², the lighting equipment adopts the fluorescent lamp, the size set as the 0.3m×0.3m×0.3m cuboid, adopting the fixed heat flow boundary, the value can be 48 W/m²; Other wall surfaces may be considered as adiabatic boundaries. The following will consider the air distribution, thermal comfort and air quality in the equipment with doors 1,2 and 3 open separately.

3. Numerical simulation results and analysis

In order to better describe the simulation results, the following three sections are selected, as shown in figure 3, the sections corresponding to X=0 m and Y=0 m, and the sections corresponding to z=1.15 m in the main working area.
3.1. Distribution of PMV and PPD
As can be seen from Fig. 4 ~ Fig. 6, when door 1 or door 2 is open, the PMV value in the device is basically around -0.37, and rises slightly in the area of personnel, around -0.33, while when door 3 is open, on the right side of the space station, the area affected by the TUYERE has a PMV value of -0.34, and the other areas have a PMV value of -0.32. For the main working area, the PMV value is about -0.36 when the door 1 or door 2 is open, while the PMV value is as low as -1.3 when the door 3 is open, the human body feels cold, and the PMV value is relatively high in the personnel area, reach to -0.27.
Accordingly, it can be seen from the PPD distribution cloud map that the PPD value in most areas of the equipment is about 7.8% when the door 1 or door 2 is open, while the PPD value is slightly lower when the door 3 is open, about 7.2%; For the main work area, PPD is slightly lower in the personnel area when door 1 or door 2 is open, while other areas are around 7.8%. The maximum PPD value in the tuyere area is 55% when door 3 is open, indicating a high percentage of unsatisfied Thermal Comfort, PPD levels in other areas were around 7.2%. Thermal Comfort is acceptable when PMV is between -0.5 and + 0.5 and PPD is less than 10% according to ISO 7730. Therefore, the thermal comfort of the device is better when door 1 or door 2 is open.

3.2 Air Age distribution

As can be seen from Fig. 7, the average age of air in the main working area is highest when door 1 is open, at about 1385s; when door 2 is open, on the side near the Tuyere, the average air age is about 1202s in the main working area, 1555s on the other side, and 1692s in the top area of the device, the average air age of the main working area is about 333s on the side near the Tuyere, about 1666s on the other side, and about 2595s on the top of the equipment.

In general, except when the door 3 is open, the air on the side near the tuyere enters the working area almost interchangeably and the air is relatively fresh, the air experiences a longer mixing time and stays in the equipment for a longer period of time, the average age of the air is older.
4. Conclusion

(1) In this paper, Fluent software and UDF programming are used to simulate the air distribution of a large-scale space environment simulator under different air supply forms. By comparing the velocity field, temperature field, PMV-PPD and air age distribution in the equipment, the influence of different air supply modes on air quality and thermal comfort of human body can be seen, which can provide reference for improvement and optimization of air distribution in environmental simulator.

(2) Under other initial conditions, different air supply modes have great influence on thermal comfort and air quality in the environment simulation equipment. In addition, the thermal comfort of most areas is within acceptable range except the area near the Tuyere, and the distribution of air age in the equipment is larger than that in the Tuyere area.

(3) As a further study, the effects of CO2 human exhaled can be considered, so as to better analyze human thermal comfort and air quality in equipment and make a more comprehensive and reasonable evaluation.

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