Unsteady Reynolds Averaged Navier-Stokes Modeling of Air Jets in Ventilated Premises

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Motivation and Objectives

It is well known that a ventilation efficiency strongly depends upon a type and design of an air terminal device. Though a wide range of such devices is currently available, most of them still cannot provide a uniform distribution of the air velocity in a work/living area of a ventilated room, especially if the latter has a relatively low ceiling (around 3-4 meters). In the work (1), a simple air terminal design is suggested, which claim to be very efficient in the above sense, i.e., provides a uniform air flow exactly in the "low" and highly encumbered premises. This design, presents a "box" covering an inlet air opening in the ceiling as shown schematically in Figure1. The ventilating air is supplied through a rectangular channel in the direction normal to the box "roof" and getting into the box through its two inlet openings as shown by the arrows in Figure1. It results in two impinging jets which are interacting with each other inside the box and only after that are being directed into the room through the inlet opening in the ceiling (plane ABCD in Figure 1). On the basis of the flow visualization, a high efficiency of this, "impinging-jet-device", is explained in (1) by self-oscillations of the flow inside and in the close vicinity of the device. It results in a very complicated flow structure with a great deal higher rate of the jet spreading and faster decrease of its maximum velocity than in the case of a simple jet with the same bulk velocity. An objective of the present study was to find out CFD capabilities of predicting the phenomenon observed in (1).

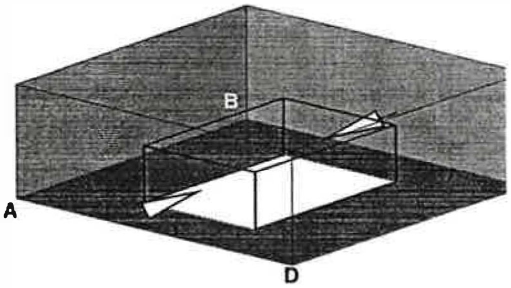

Figure 1

Governing Equations and Numerical Algorithm

For numerical modeling of the flow we have used the 3D Unsteady Reynolds Averaged Navier-Stokes equations for incompressible flow. Turbulence modeling is performed with the ν_t*-92* model (2). It is a one-equation eddy viscosity transport model currently intensively used in Russia for a wide range of aerodynamic and industrial applications and shown to be quite competitive for the mixing layers and jets (2), that is, exactly for the flows we are concerned with in the present study.

A schematic of the computational domain is shown in Figure2. It is assumed that the air is supplied into the impinging-jet-device located at the solid plate ABCD ("ceiling") trough a rectangular channel. All the other boundaries of the computational domain are treated as the free ones, i.e., are whether inlets or outlets. The boundary conditions are specified as follows. At the inlet boundary (the plane $z=1.1m$) the flow is supposed to be uniform and the eddy viscosity, ν_t, is set equal to the molecular viscosity, ν. At the solid plate the impermeability and no-slip conditions are used for the momentum equation, and the eddy viscosity is set zero.

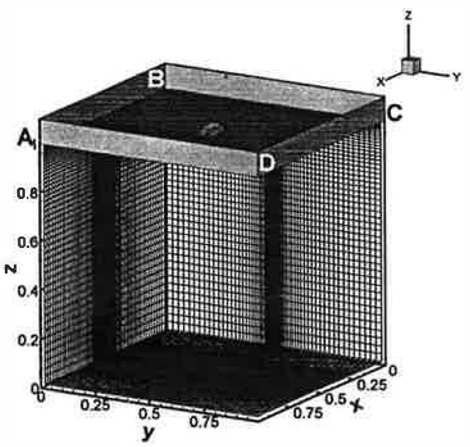

Figure 2

A numerical algorithm used in the computations is based on the projection method (3). The algorithm has the second order of accuracy in space and the first order in time.

A non-uniform staggered (MAC-type) grid of the size 90×80×65 used in the computations is shown in Figure 2. A time step in the computations was chosen so that the Courant number would be not higher than 1.0 everywhere in the domain.

Results

Computations have been performed for four Cases. Cases 1 and 3 are those with the impinging-jet-device of the cross sections $0.1\times0.05m^2$ and $0.25\times0.05m^2$. The height of the device in both cases is equal to $0.025m$. Cases 2 and 4 are similar to Cases 1 and 3 respectively. The only difference is that instead of the impinging-jet-device they have simple rectangular openings of the same cross sections ($0.1\times0.05m^2$ for Case 2 and $0.25\times0.05m^2$ for Case 4). Those two cases have been computed in order to demonstrate a drastic difference in the flow structure caused by the use of the impinging-jet-device. The air volume flow rate in all the four cases was equal to $0.01m^3/s$. This results in the Reynolds number values based on the inlet orifice effective diameter and the mean velocity equal to *11200* for Cases 1, 2 and to *17640* for Cases 3, 4.

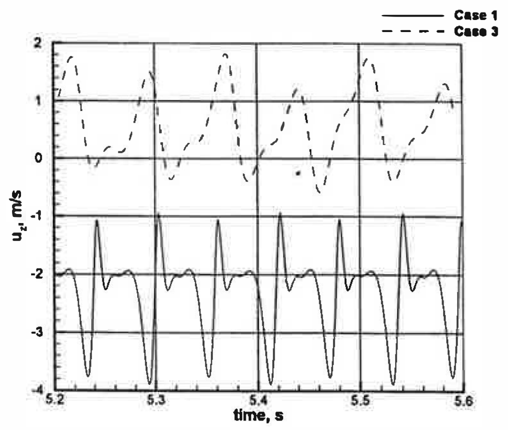

Figure 3

The major results of the study performed are as follows. For Cases 1 and 3, we did obtain an unsteady self-oscillating solutions, while for Cases 2 and 4, the solutions are steady-state independently of the initial fields being used. As an illustration, in Figure 3 we present the "time-histories" of the local value of the velocity component, u_Z, at the point $x=0.5m$, $y=0.5m$, $z=1m$ for Cases 1 and 3. One can see that the spectra, amplitudes, and periods of the oscillations are quite different for the two cases. The Strouhal number based on the mean velocity, equivalent diameter of the device cross-section and oscillations period turned out to be equal *3.12* for Case 1 and *0.97* for the Case 3.

Analysis of the flow-pattern inside and in a close vicinity of the device shows that the oscillations are caused by the interacting of the impinging jets, which results in a 3D instability and periodic alteration of the flow parameters. The resulting flowfields downstream of the device turns out to be rather complicated and strongly dependent of the device geometry. For instance, as seen in Figure 4, where we present isosurfaces of the time averaged velocity magnitude $|V|=0.4m/s$, the "short" and "long" devices (Figure 4a and 4b) are generating quite different velocity fields. However in both cases the effective width of the jet is much larger and its maximum velocity is decreasing much faster than those with no device (Figure 4c, d) when the flow is steady-state. These results are quite consistent with the flow visualization in (1).

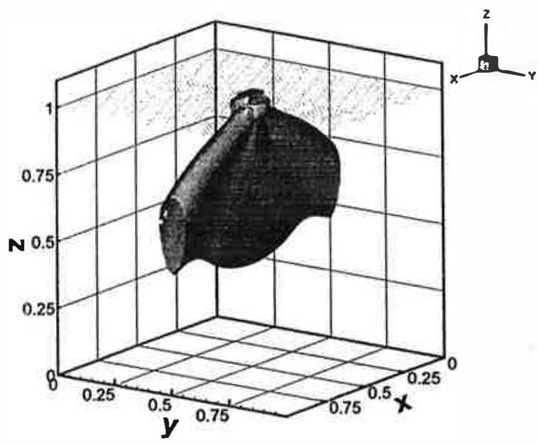

Figure 4a

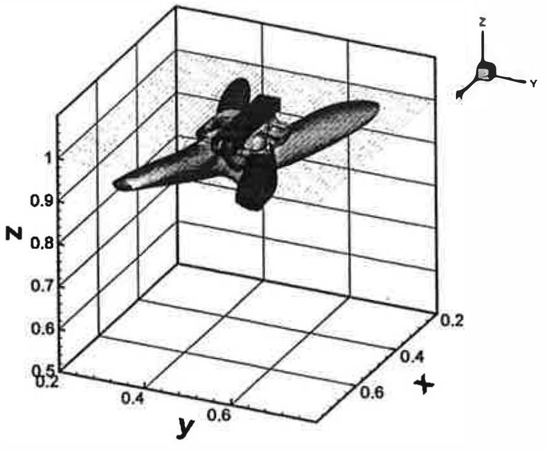

Figure 4b

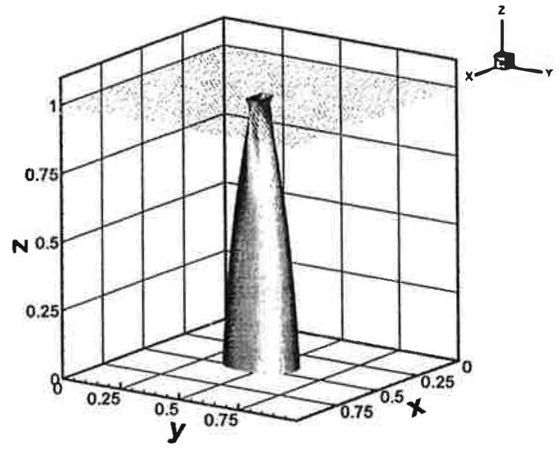

Figure 4c

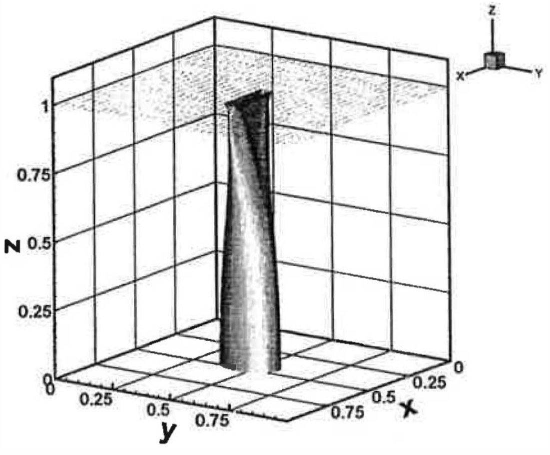

Figure 4d

Analysis of the snapshots of the velocity fields shows that in Case 1, i.e., with the short device, its two inlets are working by turn, i.e., during one half of the period the air is flowing through the left inlet and during another half of the period – through the right inlet. For the long device (Case 3) the picture is more complex. At any specific moment all the four jets seen in Figure 4b are existing and their directions are gradually varying in time.

On the basis of the performed study we can conclude that, at least qualitatively, 3D Unsteady Reynolds Averaged Navier-Stokes equations are capable of predicting the complex unsteady phenomena observed in the experiments (1) and, therefore, they can be used for optimization of the impinging-jets-devices for the air supply into ventilated industrial and living premises.

References

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