ON INFLOW BOUNDARY CONDITIONS FOR LARGE EDDY SIMULATION OF TURBULENT SWIRLING JETS

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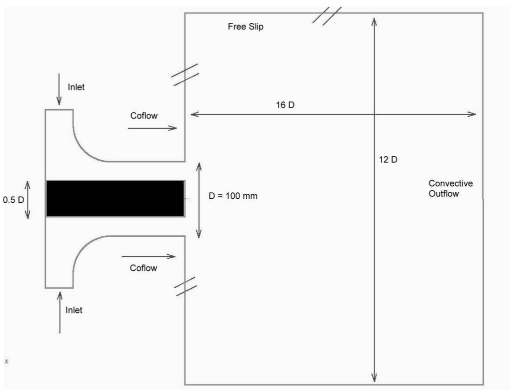
Summary For a swirling jet, three LES have been performed with different inflow boundary conditions. It is shown that good agreement of mean and rms velocities is not, in general, sufficient for a realistic representation of the experimental conditions. The unsteady large scale structures of the flow must also be taken into account. Also, for swirling jets, the simulation of the flow in the actual swirl generator is not always needed. A less expensive strategy is proposed.

Large Eddy Simulations (LES) of spatially inhomogeneous flows require unsteady inflow boundary conditions with a proper representation of the turbulent fluctuations. The results are often highly sensitive to these boundary conditions. In the validation of the different approaches to the problem,[1, 2], it is usual to compare first and second order moments of the velocity field with the corresponding experimental data. We will show that this is not sufficient in flows containing highly unsteady large scale coherent structures. A good representation of the turbulence statistics does not necessarily guarantee a good representation of these features.

In this paper, three-dimensional incompressible LES of an unconfined annular swirling jet are presented. The geometry of the reference case, which is based on experiments performed at the University of Karlsruhe [3], is shown in Fig. 1. It includes a crude representation of the inlet duct upstream of the jet exit. The Reynolds number of the flow based on the bulk velocity u_b and the jet diameter D is $Re = 163000$. The Swirl number defined in Fig. 1 is $S = 0.9$. With this level of swirl, a central recirculation zone is formed. The simulations are performed with the code LESOCC2, using a second order accurate finite volume method. In the reference case (Sim 1), top-hat profiles are imposed at the radial inflow and the inlet swirl is designed so that the swirl at the jet exit matches the swirl in the experiment. In a second simulation (Sim 2), the inflow plane is placed directly at the jet exit $x = 0$ and the inflow conditions are obtained by performing a separate, periodic LES of swirling flow in an annular pipe using body forces as described in [4]. A third simulation (Sim 3) was performed using the same procedure but the inflow plane is now located at $x = -D$. Therefore, the geometry shown in Fig 1 corresponds to the computational domain of Sim 1. The computational domain of Sim 2 starts at the jet exit $x = 0$ and the domain of Sim 3 starts upstream of the jet exit at $x = -D$. In all three simulations, the block structured mesh consists of about 2.5 million cells. No-slip boundary conditions are applied at the walls. The entrainment is simulated using a mild coflow and free-slip conditions are applied at the open side boundary which is placed far away from the region of interest. A convective outflow condition is used at the exit boundary. The Smagorinsky and the dynamic subgrid-scale models have been employed, the latter with smoothing by temporal relaxation.



$$S = \frac{\int_0^R \rho u w r^2 \, dr}{R \int_0^R \rho u^2 r \, dr}$$

u axial velocity

w tangential velocity

FIG. 1: Geometry of the flow and definition of the swirl number .

In Sim 1, large scale precessing vortex cores are observed, typical for this kind of flow [5]. A characteristic picture is shown in Fig. 3d. Fig. 3a shows a typical frequency spectrum exhibiting a pronounced peak at twice the precessing frequency due to the presence of two structures.

In Sim 2, the inlet plane is placed at the jet nozzle ($x = 0$) and the experimental mean axial and tangential velocity profiles measured very close to the jet exit are enforced as described above. Figs. 2a and 2b show a comparison between measurements and calculations at an axial location half a diameter downstream of the jet exit. The agreement is excellent for the mean velocities and very good for the fluctuations. The results from Sim 1 and 3 (not shown here) are virtually the same for these quantities. The frequency spectrum of Sim 2, however, does not show any peak, Fig. 3b, and no large scale organized motion can be seen in iso-surface plots, Fig. 3e. Hence good agreement with mean and rms experimental velocities is not always enough for the realistic representation of inflow conditions in an unsteady calculation.

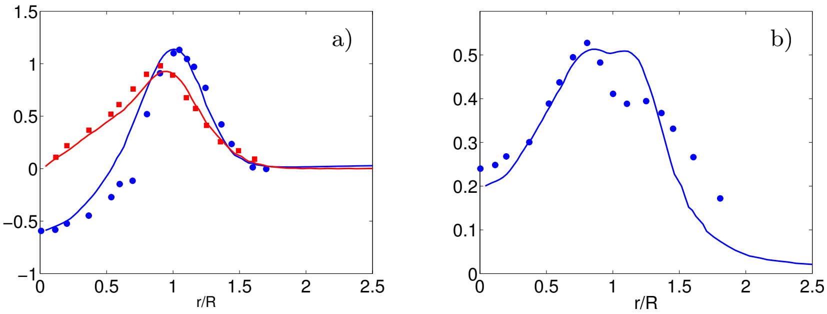


FIG. 2: Results from Sim 2 at an axial position of $x = R$. Symbols, experiment. Lines, present simulation. a) Mean axial velocity (blue) and tangential velocity (red). b) Rms fluctuations of axial velocity.

In a recent numerical investigation of a similar configuration [6], using a very complex grid to simulate the flow in the actual swirl generator, a precessing vortex core was also detected.
In Sim 3 the inlet plane is placed upstream of the jet nozzle ($x = -D$) and the inflow velocity profiles are taken from Sim 1 at that position (they might also be taken from experiments if measurements are available at that position) The precessing frequency of the structures is well obtained (Fig. 3c) and iso-surfaces show similar large-scale structures as for Sim 1. This demonstrates that an elaborate treatment of the flow in the actual swirl-generating mechanism is not necessarily needed and less expensive strategies can be employed.

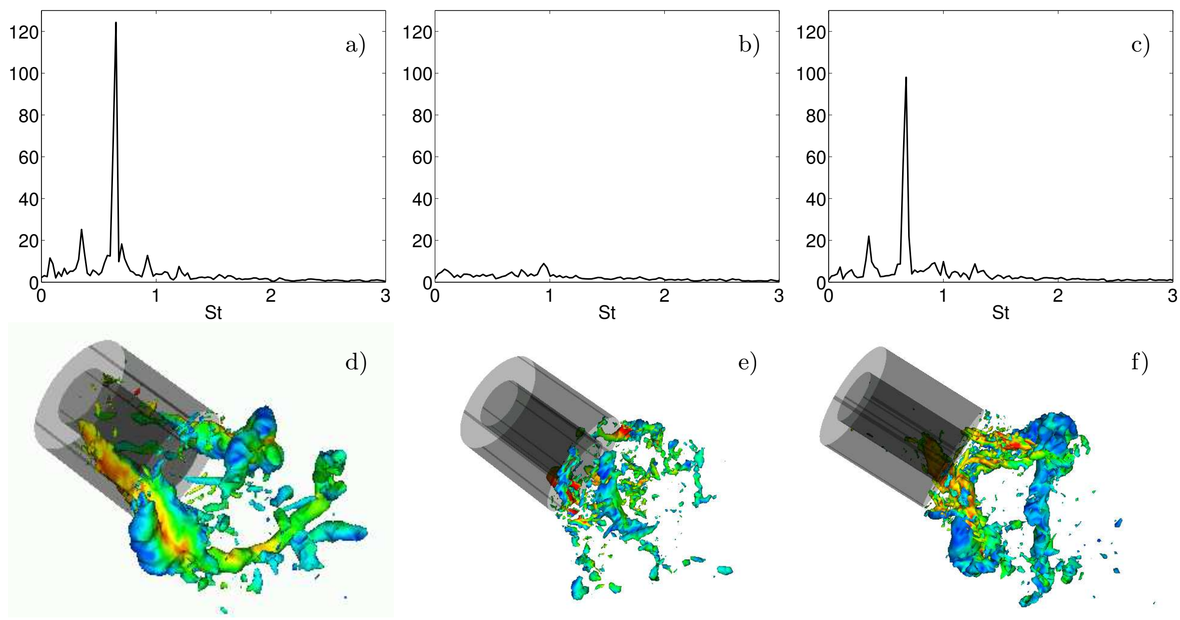


FIG. 3: a), b), c) Frequency spectrum of tangential velocity fluctuations as a function of the Strouhal number $St = fD/u_b$ at $x = 0.2D$, $r = 0.4D$. d), e), f) Isosurface of pressure fluctuation, $p- < p >= -0.4$. Color represents the modulus of the velocity vector. a), d) Sim 1. b), e) Sim 2. c), f) Sim 3.

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