Large-Scale Numerical Simulations on Mixing, Diffusion and Reaction in Complex Jet (Direct Numerical Simulation of Turbulent Swirling Jet Flows)

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Swirling jets have a wide range of industrial applicability including industrial burners, ejectors, and jet pumps. The swirl helps in the formation of the vortex breakdown bubble (VBB) which promotes the turbulent mixing of two coaxial streams.

The present work considers the coaxial jets with swirl induced in the outer annular jet. The case of no swirl is also studied for examining swirl influence. Direct numerical simulation (DNS) method is used to solve governing equations which are incompressible Navier-Stokes equation and continuity equation. The scalar transport equations are also solved separately for passive scalars originating through two jets. The inlet conditions required for DNS are produced in OpenFOAM open-source software with the nozzle configurations used in the experiment. The results are analyzed in terms of mean velocities and passive scalar distribution along with their fluctuations and are compared with the experimental results.

OpenFOAM and DNS simulations are carried out on CX400/270 and FX100 of Nagoya University's HPC facility respectively. OpenFOAM simulation is carried with MPI library. DNS code is written in FORTRAN and also parallelized using MPI. The instantaneous data of OpenFOAM simulation is saved separately and later given to DNS as inlet condition.

The figure shows DNS results for both the cases, i.e., coaxial jets without swirl ($Sw = 0$) and with a strong swirl ($Sw = 2$). It comprises of time averaged streamwise and azimuthal velocities (on top), as well as passive scalar concentrations (on bottom) along with the streamlines. Introduction of swirl generates the radial pressure gradient. As flow reaches the ambient pressure at downstream, it leads to adverse pressure gradient in axial direction. The result of this causes the vortex breakdown bubble, which is characterized by the recirculation zone (bordered by orange line). This zone acts as a barrier affecting flow to spread. The streamlines show the vortex rings with axis coincides with centerline of jets. The effect of swirling jet can also be seen on scalars distribution. The scalar through inner jet ($\overline{\phi_1}$) is diffused radially outwards with a faster rate while that of outer jet ($\overline{\phi_2}$) in both radially inward and outward directions. This implies that the swirl promotes the mixing of scalars.

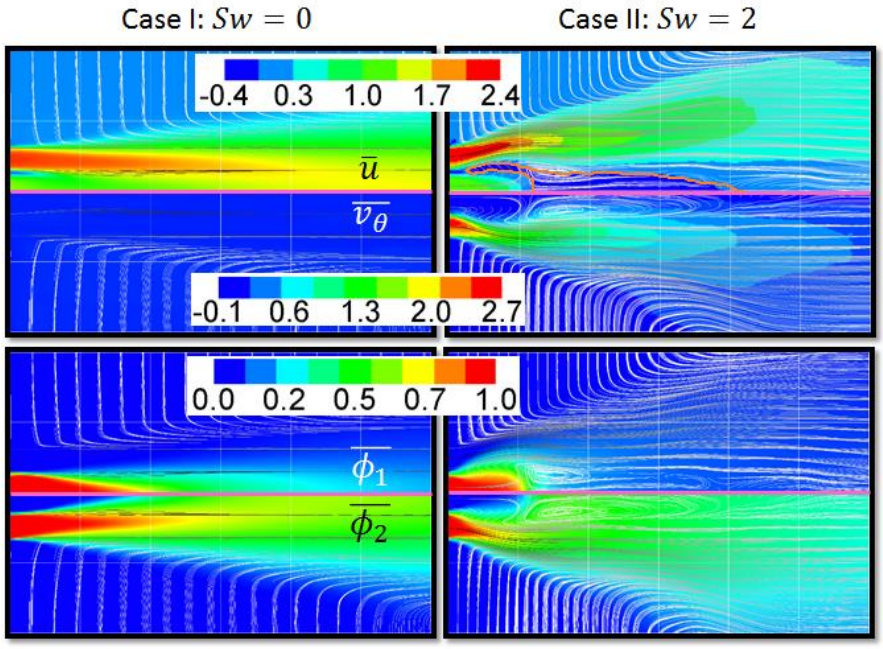

Fig: Effect of swirl on velocities and scalars (non-dimensional)