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Portfolio Paper

Visualization of Circular Subsonic Jet Flow by DNS(1)

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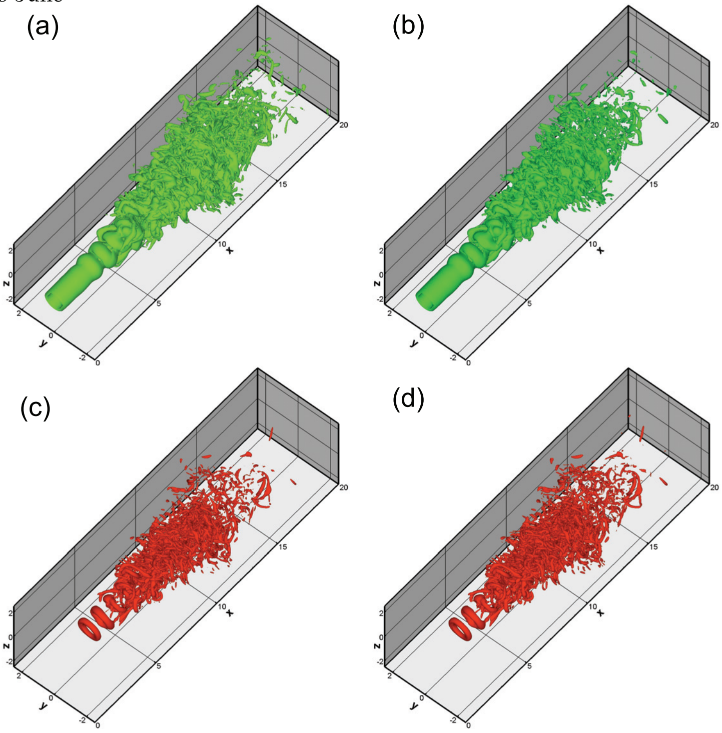

Fig. 1. Instantaneous three-dimensional images of some flow properties:
(a) vorticity magnitude
(b) $(\omega_y^2 + \omega_z^2)^{0.5}$
(c) Q: second invariant of velocity gradient tensor
(d) λ_2: second-largest eigenvalue of the symmetric tensor $S^2+\Omega^2$, where S and Ω are the symmetric and anti-symmetric components of the velocity gradient tensor

Fig. 1 shows the simulation results of direct numerical simulation of a circular jet, which issuing into large environment from a round nozzle with laminar coflow. The jet velocity is U_1 = 180m/s, coflow velocity is U_2 = 3.5m/s. The Reynolds number is 4700 based on the jet diameter, velocity $U_c = U_1 - U_2$ and air properties at 1atm and 300K. The physical domain size of the simulation is L_x/d = 20, L_y/d = 14, L_z/d = 14, where d is the jet diameter. These reference quantities are used to normalize all the flow variables: length scale l_r = d; velocity $u_r = U_c$; density ρ_r, ambient air density at 1atm and 300K. Fully compressibly three-dimensional Navier-Stokes equations are solved using eighth-order explicit difference scheme and fourth-order explicit Runge-Kutta scheme. Characteristic non-reflecting boundary conditions are used at all boundaries along with buffer zone method at outflow and sidewall boundaries of the jet. Over 20 million grid points are used here. Fig. 1(a) and fig. 1(b) show the three-dimensional instantaneous image of vorticity magnitude and $(\omega_y^2 + \omega_z^2)^{0.5}$ respectively, where ω_y and ω_z are the vorticity in y and z direction. It is clear that the contours are tubular near the jet exit and become more and more wrinkled after 2d downstream of the jet nozzle. And finally break up to many small vortex tubes further downstream. Fig. 1(c) shows the profile of velocity gradient tensor invariant Q, defined as $Q = -\frac{1}{2}\frac{\partial u_i}{\partial x_j}\frac{\partial u_j}{\partial x_i}$. Fig. 1(d) shows the λ_2-criterion to illustrate the vortex structure. The rolling up of coherent vortex rings due to Kelvin-Helmholtz instability and it's breaking up to small vortexes is clear. It is also found that the image of Q and λ_2 are almost the same. This demonstrated that the flow structure in circular jet flow can be extracted using either Q or λ_2, with no significance difference. Furthermore, it is simpler to calculate Q than λ_2, then we can make a conclusion that Q will be enough to capture the vortex structure in circular jet flow.

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