A study of vortex ring generation by a circular disc

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Present work is mainly based on a numerical simulation of the vortex ring generation by an impulsive started disc. The simulation is carried out by the commercial software ANSYS Fluent 14.5. Its solver is based on finite volume method. Basic theory used in Fluent is by discretising transport equation

$$\frac{\partial}{\partial t}\int_V \rho\phi dV + \oint_A \rho\phi \mathbf{V} d\mathbf{A} = \oint_A \Gamma_\phi \nabla\phi d\mathbf{A} + \int_V S_\phi dV$$

A first order implicit time marching scheme is used for time transient. Second-order upwind scheme is employed for diffusion term discretization. Pressure-velocity coupling can be achieved by the SIMPLE scheme. Fig. 1 showed the computational domain.

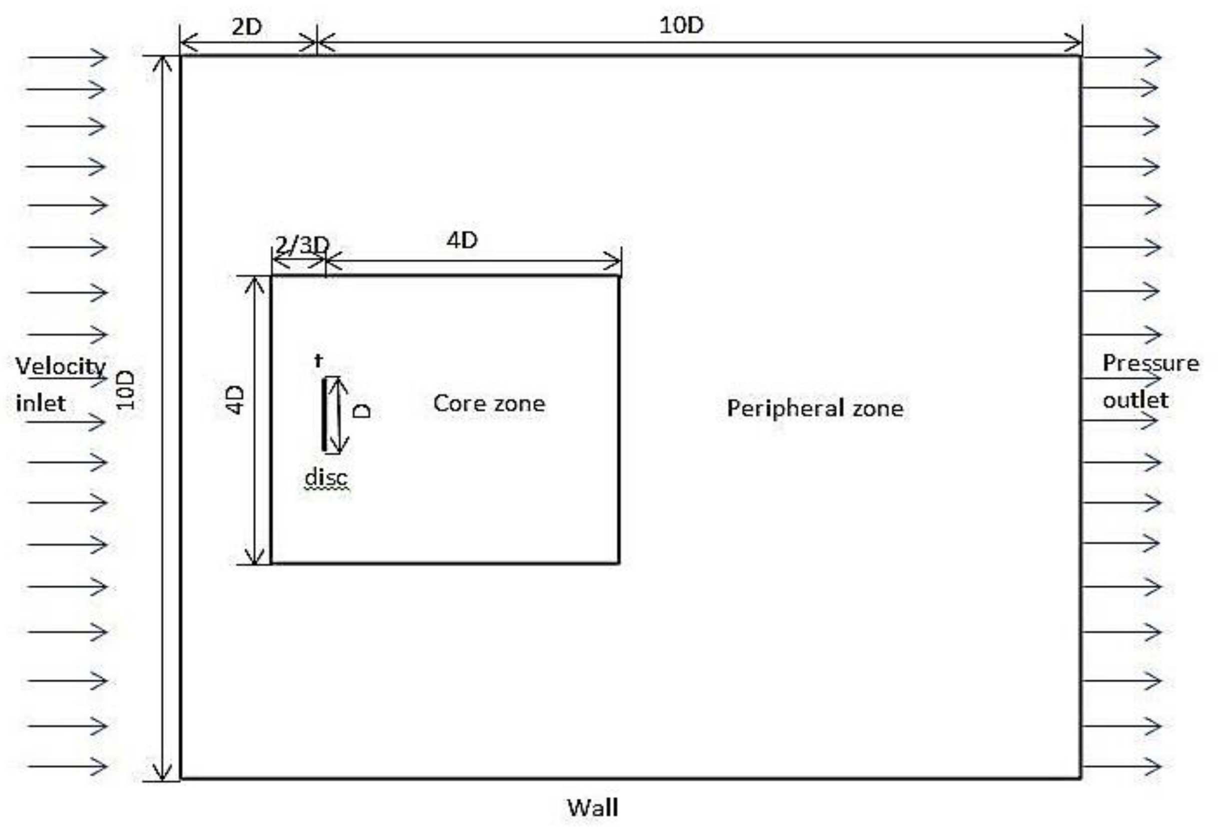


Fig. 1 Computational domain

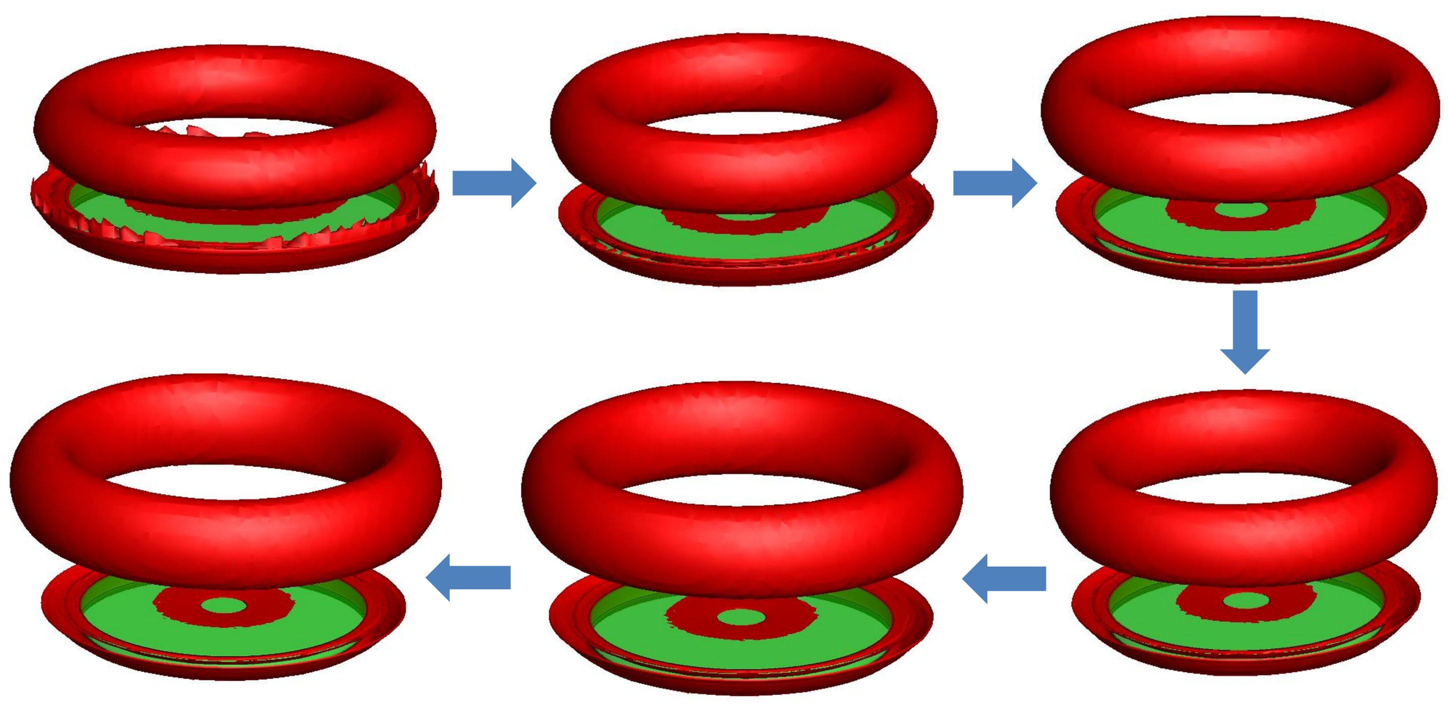
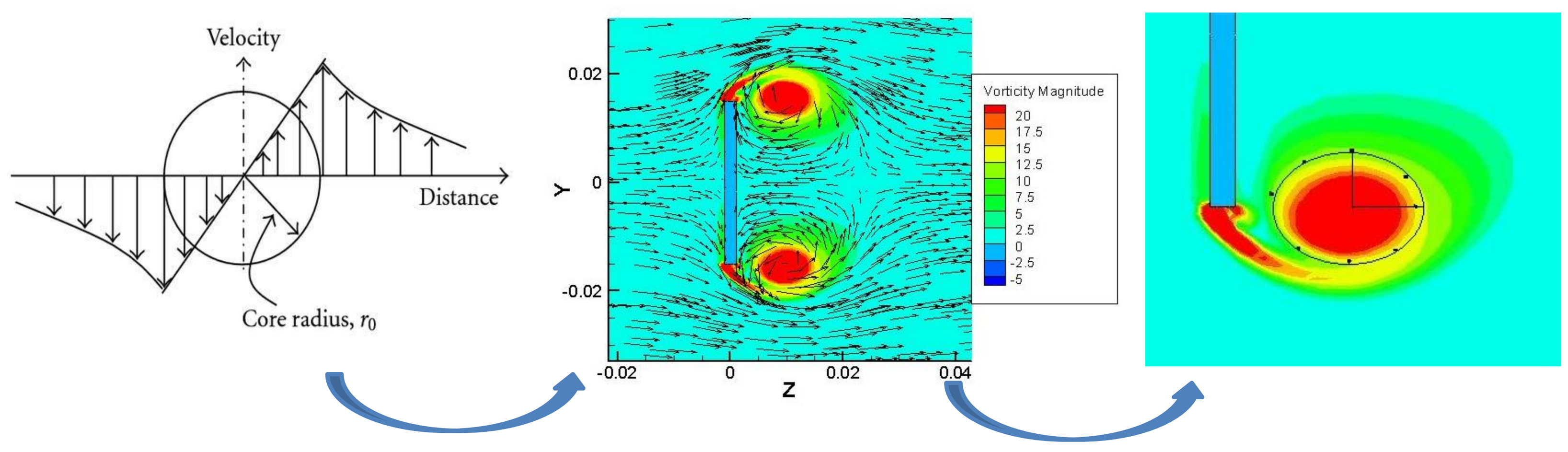


Fig. 2 Iso-surface evolution of vorticity magnitude with dimensionless time Tn in early stage (Tn=1,2,3,4,5,6)

The evolution of the disc vortex ring is that the vortex grows with the growth of its circulation during the initial vortex development phases, shown as Fig. 2. When the circulation reaches a maximum value, vortex ring stops its growing. After this stage, an asymmetric phase takes place. Vortex core position is one important parameter to describe this problem. The dimensionless time T_n is defined as

$$T_n = \frac{Ut}{D}$$

Fig. 3 shows three steps to determine the boundary of vortex Based on Rankine vortex theory (a), velocity inner side of the core zone can be considered as linear distribution approximately. External flow rate is inversely proportional to the radius. Fig. 3(c) shows the sketch of vortex core. By locating the maximum and minimum velocity on a vortex line through vortex core, the vortex core size can be defined as the distance between the maximum and minimum velocity. The boundary of the vortex core is ensured to calculate out circulation and the position of vortex core.



(a) Original Rankine vortex (b) Velocity field and vorticity (c) Sketch map for determining vortex core

Fig. 3 Method for determining vortex core position

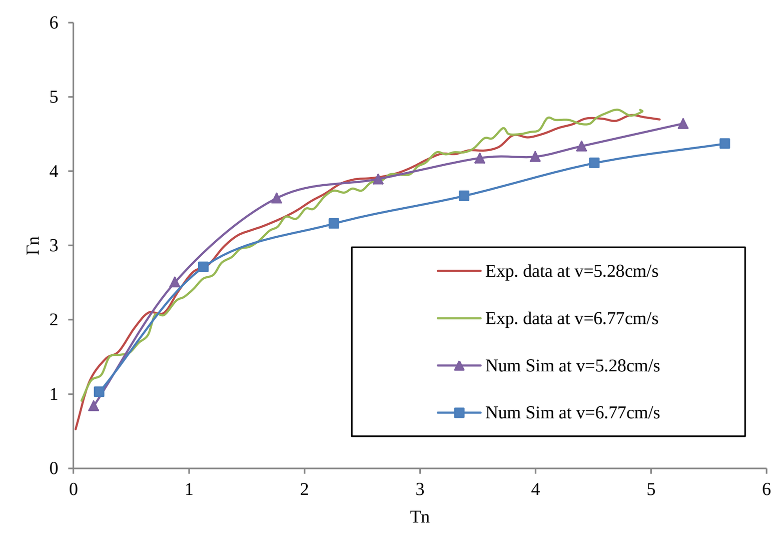
Fig. 4 shows the comparison between experimental data and numerical simulation results for two different velocities. (a) shows the evolution of circulation over time, and (c), (d) shows the vortex core position. These parameters could be calculated as

$$\Gamma = \iint \omega ds = \sum_i \omega_i dxdr$$

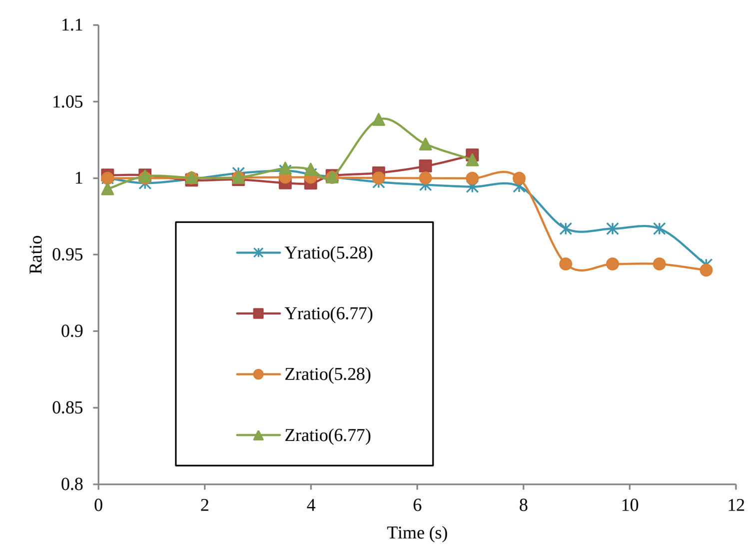
$$\Gamma_n = \frac{\Gamma}{\Gamma_c} \text{, where } \Gamma_c = \frac{UD}{2}$$

$$X_{core} = \frac{\sum_i X_i \omega_i}{\sum_i \omega_i}.$$

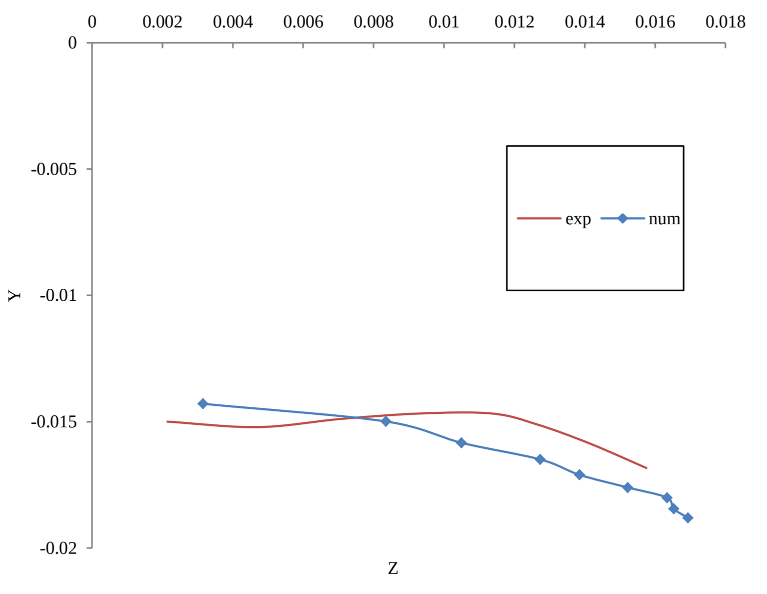
Both experimental and modelling results show that a large velocity brings to a short symmetry phase with large circulation as compared to small incoming velocity. Meanwhile, Rankine vortex method provides a new analytical means for our future investigation on vortex ring problem.



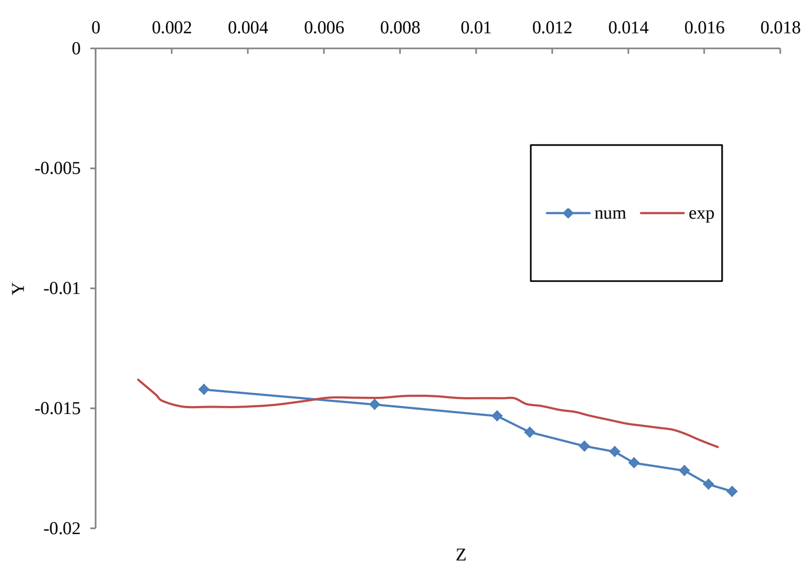
(a) Dimensionless circulation comparison



(b) Coordinate ratio presents for the symmetry breaking



(c) Vortex core position at v=6.77cm/s



(d) Vortex core position at v=5.28cm/s

Fig. 4 Numerical simulation results and experimental data

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