Direct Numerical Simulation of Time Evolution of Vortex Ring

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Introduction:

Vortex ring can be useful to generate thrust force for e.g., jellyfish, but its mechanism has not been clarified. In this field, it seems that numerical simulation has an important role of understanding the propulsion mechanism of creature. A vortex ring in a tube, refered to confined vortex ring, have been far less studied compared with unconfined vortex rings, despite their importance for many practical applications.

The present work shows we can run direct numerical simulation (DNS) in this field using COMSOL Multiphysics®.
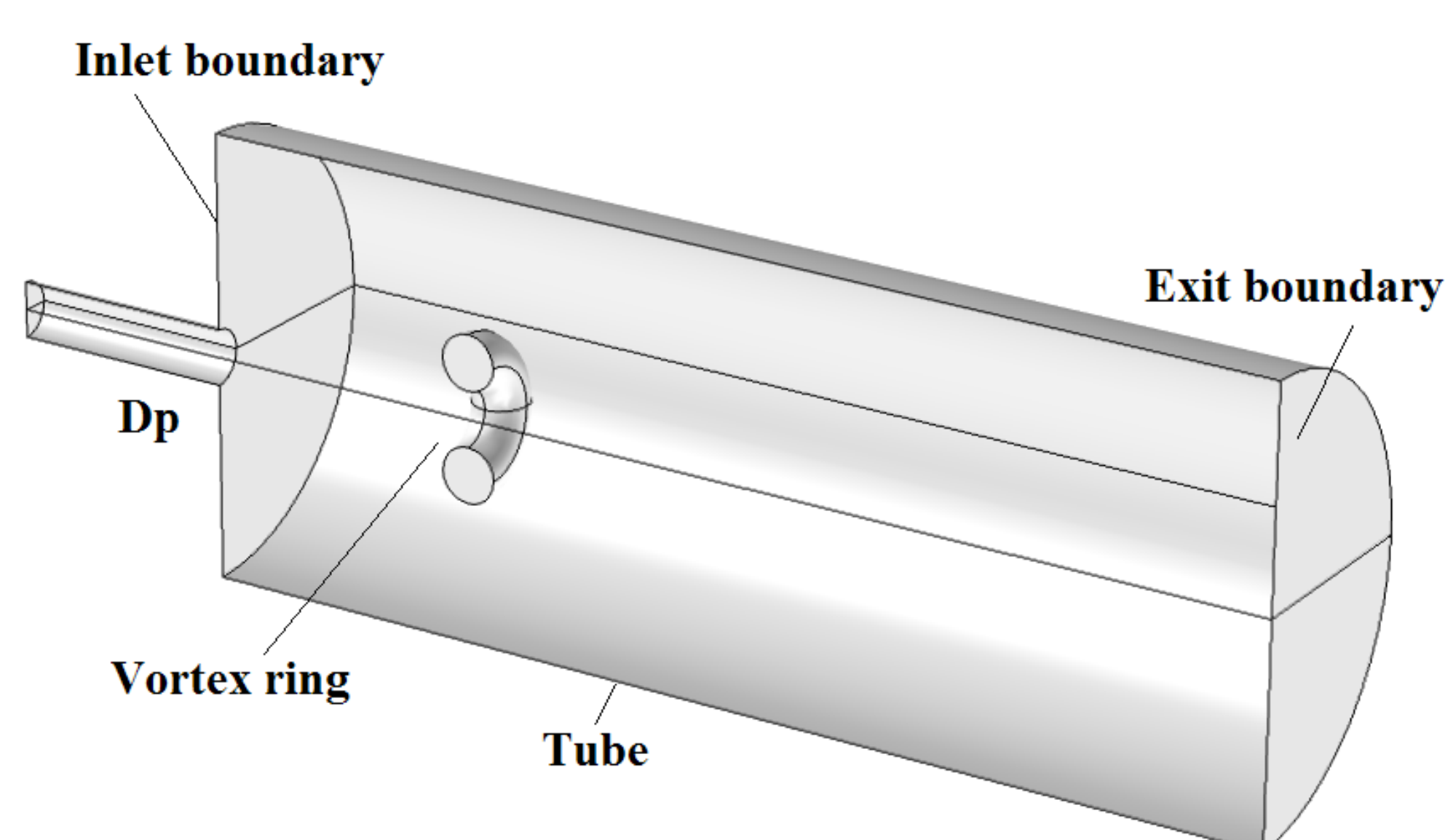

Figure 1. Confined vortex ring.

Computational Methods:

The incompressible Navier-Stokes equations and the continuity equation are solved numerically.

$$\rho\frac{\partial \mathbf{u}}{\partial t} - \nabla \cdot \eta\left(\nabla\mathbf{u} + \left(\nabla\mathbf{u}\right)^T\right) + \rho\left(\mathbf{u}\cdot\nabla\right)\mathbf{u} + \nabla p = 0$$

$$\nabla \cdot \mathbf{u} = 0$$

When a number of mesh is enough to resolve the flow field to be computed, we could solve the Navier-Stokes equations directly although we must select shape functions of pressure and velocity fields so as to meet the Ladyzenskaya-Babuska-Brezzi condition (LBB condition) for viscous flow computation due to finite-element analysis. We can easily use P1-element for pressure and P2-element for velocity in COMSOL Multiphyiscs®.

Results:

Present results show the good agreement with Danaila and Helie (2008). They conducted direct numerical simulation based on high accurate finite-difference scheme on the same flow field.
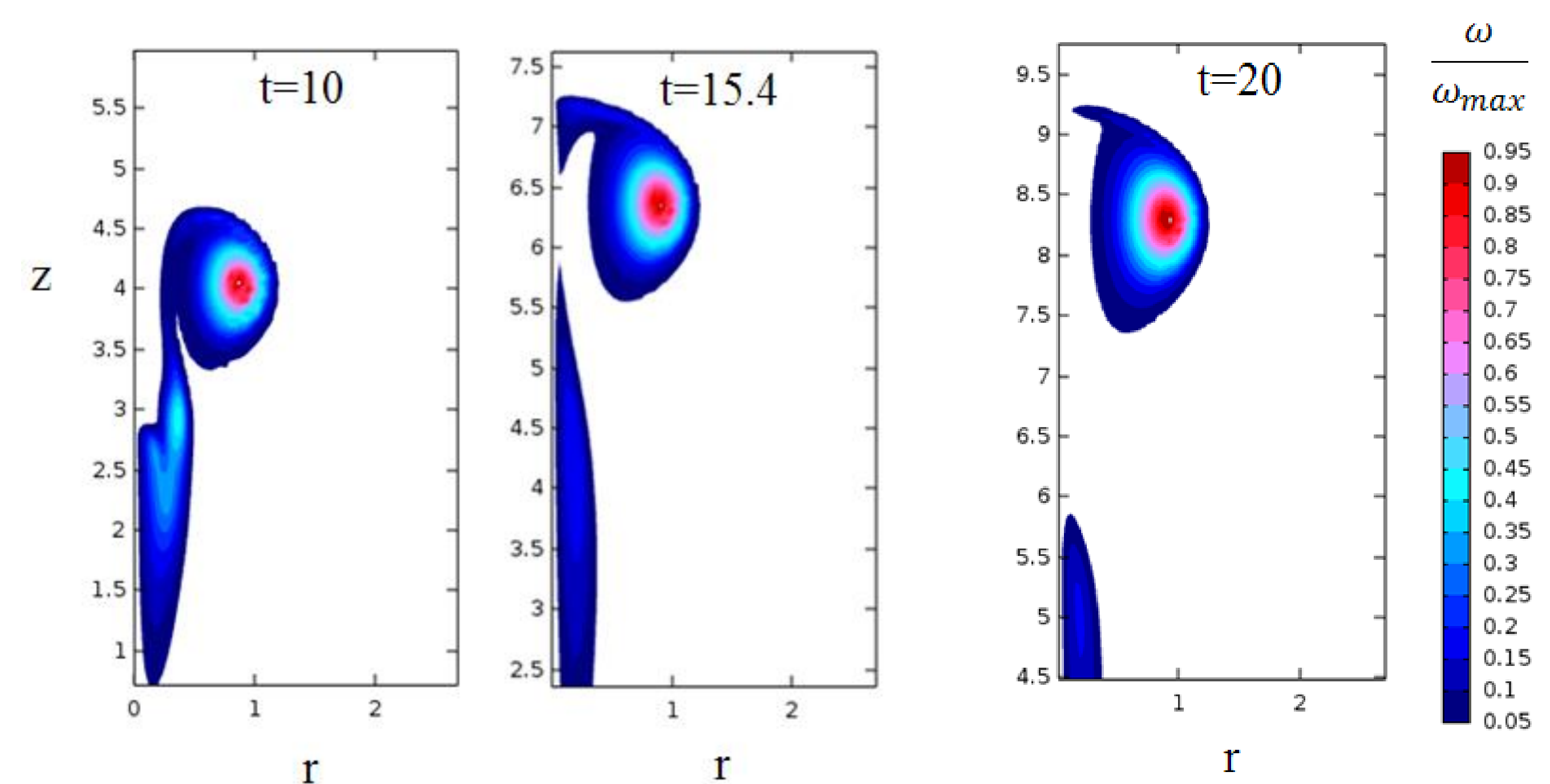

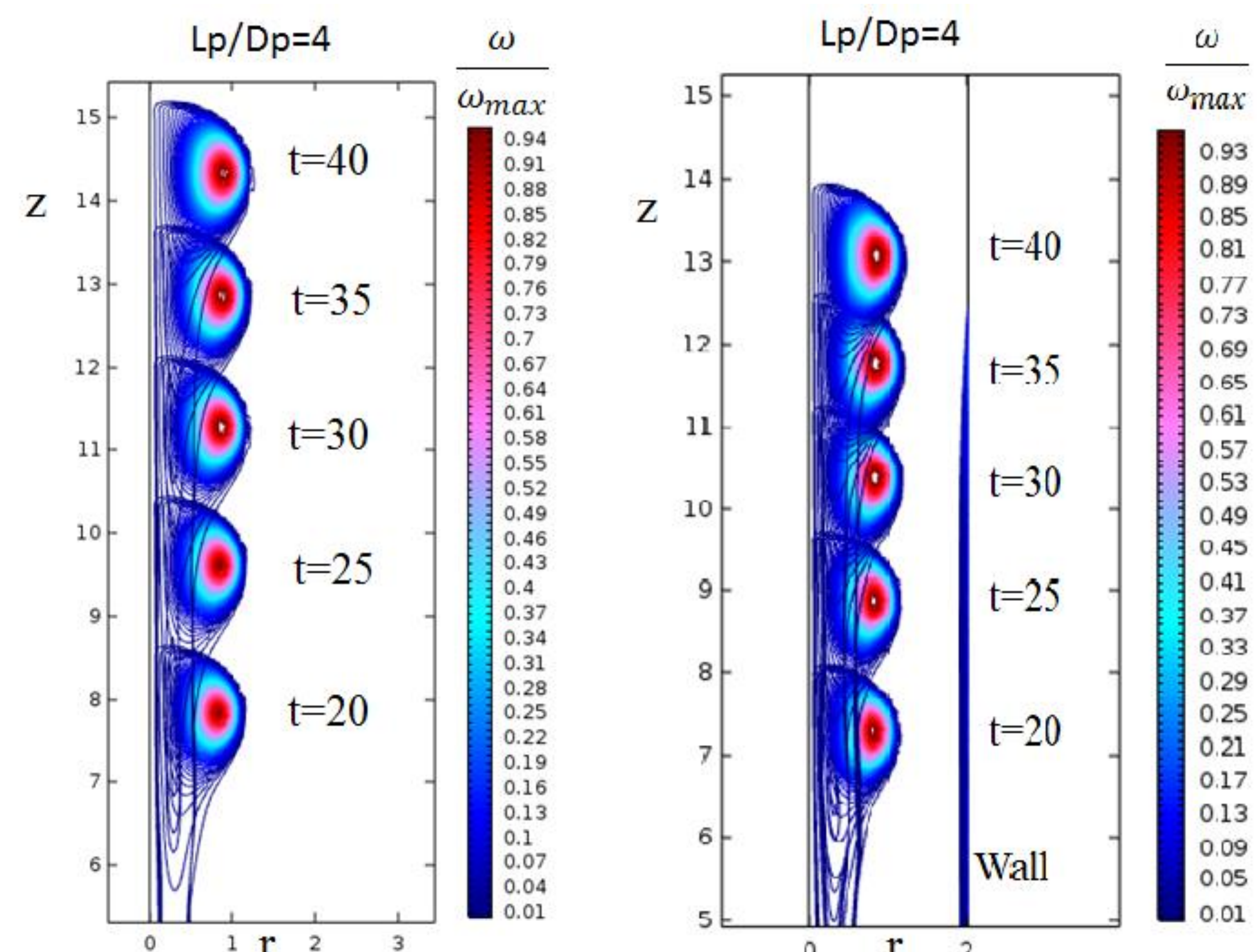**Figure 2**. Pinch-off of vortex ring at stroke ratio of Lp/Dp=6 is cleary captured.

Figure 3. Wall effect on evolution of vortex ring.

Conclusions:

We concluded that the present DNS method based on COMSOL Multiphysics® for solving confined vortex ring is validated. This suggests that the present method become a useful tool to explore new idea in this field.

References:

1. Ionut Danaila and Jerome Helie, PHSYICS OF FLUIDS, 20, 073602(2008).