EFFECT OF CONFINEMENT ON THE DECAY OF VORTEX RING

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Abstract The effect of confinement on the decay of vortex ring is studied computationally using Lattice Boltzmann Method. An Initial vortex ring, introduced inside a wall bounded cubical domain, is let to evolve and its decay is noted in terms of maximum vorticity at the core and the total kinetic energy inside the domain. The study shows distinct regimes of decay in all cases of confinement ratios(ratio of vortex ring diameter to length of the cubical domain).

INTRODUCTION

Vortex rings are fundamental and stable fluid structures in nature and engineering. The vortex rings, from its formation, evolution through different regimes and upto its break down or decay, at laminar and turbulent Reynolds numbers, had been studied by various researchers. A review of these works can be found in Refs[1] and [2]. However, dynamics and decay of vortex rings in confined domains - such as that formed inside the left ventricle of human heart in diastole or that formed during fuel injection in I.C. engines - have not been studied that extensively[4]. Stewart *et al* [4] have experimentally studied the the decay of vortex rings in radially confined domains for various vortex ring confinement ratios - which they defined as the ratio of vortex ring diameter to the confinement diameter. They observed that the decay grows exponentially with decreasing confinement ratio. In the present study an axisymmetric vortex ring, with azimuthal vorticity being a Gaussian function of distance from centre of the core, is given as initial condition[3]. The vorticity distribution is of the form,

$$\begin{aligned} \omega_\theta(t=0) &= \frac{\Gamma}{\pi\sigma^2}\exp-(s/\sigma_0)^2, \\ s^2 &\equiv z^2 + (\sqrt{x^2+y^2}-R)^2, \end{aligned} \tag{1}$$

where σ_0, R and Γ are the initial core radius, ring radius and circulation of the vortex ring. The initial condition vortex rings were formed with $\sigma_0/R = 0.25$. Lattice Boltzmann method with BGK approximation for collision [5] is used for computing the time evolution of the above vortex ring, inside a cubical domain. The wall boundary conditions were implemented with mid-plane bounce back scheme, and the code was validated for lid driven cavity problem.

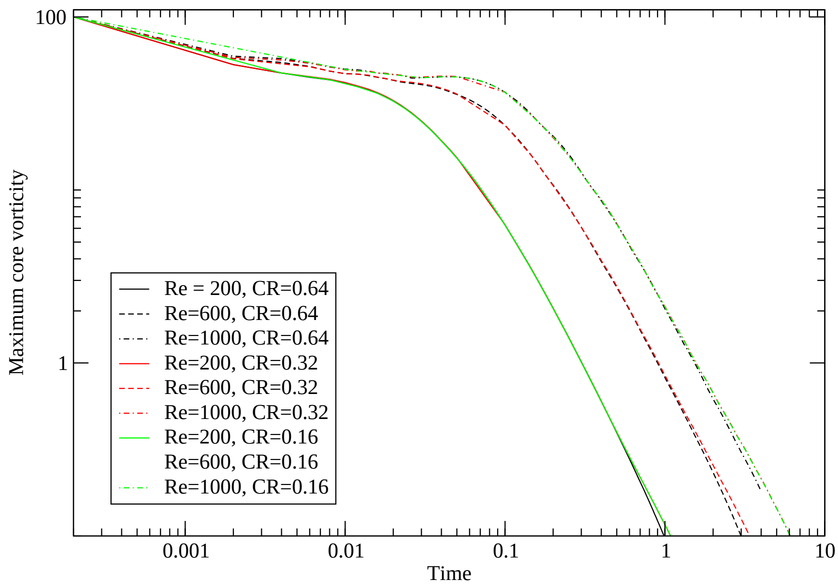

Figure 1. The maximum vorticity inside the vortex core as percent of the initial value. Axes are in logarithmic scale. CR stands for confinement ratio.

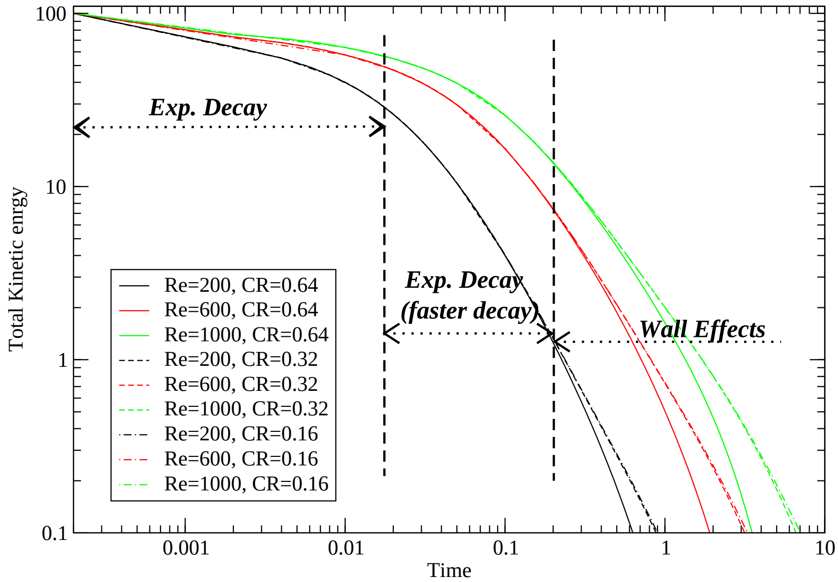

Figure 2. Total kinetic energy of the fluid inside the domain as percent of the initial value.

DECAY OF VORTEX RING

The variations of maximum vorticity at core and total fluid kinetic energy inside the the cubical domain with time are indicators of vortex decay. The maximum vorticity at the core and the total fluid kinetic energy inside the cubical domain as percentage of their initial values are plotted against time in Figure 1 and Figure 2, for different confinement ratios and Reynolds numbers. The Reynolds number here is defined using the initial circulation, Γ and the viscosity of the fluid, ν as $Re = \Gamma/\nu$. From the plots, distinctively two regimes of decay can be seen. First, after the initial development of velocities, there is a region with almost constant slope, indicating an exponential decay with respect to time. Second, there is a sudden steepening of graph indicating increased rates of decay. The time at which first regime switch to second regime depends on the Reynolds number.

The decay patterns are varying with Reynolds numbers. However, the confinement ratios does not show any effect on decay upto certain time, until which the the decay rate depends only on the Reynolds number. For higher confinement ratio the decay further steepens as compared to smaller confinement ratio after some critical time, which is due to the wall effect. Note that a higher confinement ratio represents a smaller gap between vortex ring and the wall. At this point of increased decay in the evolution of vortex ring, the side walls starts to interact in a way not present in smaller confinement ratios. From the the velocity data at this critical time, it is observed that this corresponds to starting of interaction of diffused vortex ring surface with the wall. This suggests that, in the case of dissipation, the vortex ring senses the existence of a boundary not through the induced velocity, but through diffused vorticity. A rigorous analysis will be presented at the time of conference.

References

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