BURSTING PHENOMENA OF BOUNDARY LAYER INDUCED BY 2D VORTEX PATCH

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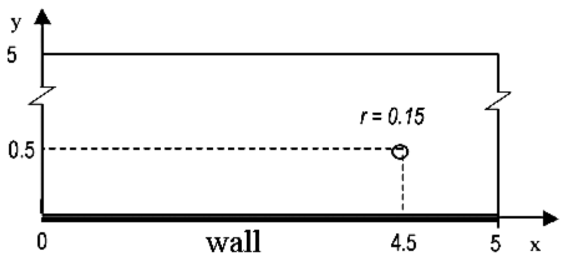
Summary Bursting phenomena induced by the near wall vortex patch is studied by numerical solution of the Navier-Stokes equation. The vortex particle method was used. The response of the wall-layer interaction was investigated in wide range of Reynolds number in order to identify dynamical feature of boundary layer that lead to sudden eruption. It was found that viscosity controls the whole process of sudden eruption. The low value of viscosity lead to the regenerative character of bursting phenomena.

INTRODUCTION

The main interest of this paper related to eruption or bursting phenomena of boundary layer caused by 2D vortex patch interacting with a wall [2]. Such patch can be regarded as 2D cross section of streamwise vortices in real 3D flow [3, 4]. Due to simplicity of 2D description of fluid motion many dynamical feature that depend on Reynolds number can be investigated. We focus our attention to the process whereby the wall layer breaks down and erupts into the outer region. The interaction of vortices with solid boundaries has the fundamental meaning for the study of unsteady separation of boundary layer, the transition processes and near wall turbulence [2, 3, 4]. The wall is the only source of vorticity in the flow and the mechanism of how the new vorticity is transmitted into the flow has the primary meaning in understanding how a turbulent boundary layer sustains itself. The investigation was carried out by numerical solution of Navier–Stokes equation by the vortex particle method.

FORMULATION OF THE PROBLEM

The scheme of computational domain with small vortex patch, r=0.15, was presented in figure 1. Beside of the figure it was given the the vorticity-streamfunction equation of fluid motion. At the begin the fluid above the wall was at rest.



$$\begin{gathered}\omega_t + \mathbf{u}\cdot\nabla\omega = \nu\Delta\omega \\ \Delta\psi = -\omega, \quad u = \partial_y\psi, \quad v = -\partial_x\psi \\ \psi|_{x=0} = \psi|_{x=L}\,, \qquad \psi|_{y=0} = \psi|_{y=top} = 0\end{gathered} \tag{1}$$

Figure 1. Scheme of computational domain

The vortex patch with circulation $\Gamma = -0.3534$, ($\omega_p = -5$) was replaced by 121 of vortex particles. The Reynolds number was defined on the basis of circulation of vortex patch $Re_\Gamma = \Gamma/\nu$. The equations (1) was solved by vortex-cell-method [1]. Effect of viscosity was simulated by particle-strength-exchange method (PSE). Non-slip conation on the wall was realized by generation of vorticity at the wall. It was used uniform grid with the step h=0.01 and for the solution of differential equation for the displacements of the vortex particles the second order Runge–Kutta method with $\Delta t = 0.01$ was used. To avoid the problem with cluster of particles and in order to reduced the error of simulation of viscosity effect by PSE the remeshing (redistribution particle mass to the grid nodes) was carry out at every time step using the second order interpolation kernel. The circulation of one vortex particle was redistributed on 9 gird nodes.

NUMERICAL RESULTS

The key structure which lead to bursting phenomena is formation small recirculation zone bellow the vortex patch with two stagnation point A and B, Fig.2. The whole recirculation region is moving slowly, parallel to the x-axis but it is much greater being stretched in vertical direction. The saddle point is created (it is marked by 'S' in figure 2). Upper part of this recirculation zone tears off and moves into outer flow. This is a real separation phenomena. The fluid particles from the near wall region are transported into the flow, Fig.3.

Large viscosity is able to stop of growing of recirculation zone or even prevent to create its at all. For small value of viscosity we can observed the cascade of small vortices arising form the wall and also repeating (regeneration) of the process caused by the new patch of vorticity that goes around the main vortex and interact with the wall.

In Fig.4 one can see the very complex flow in boundary layer induced by the counter–rotating vortex patches. The complexity of the flow stems from the eruption phenomena.

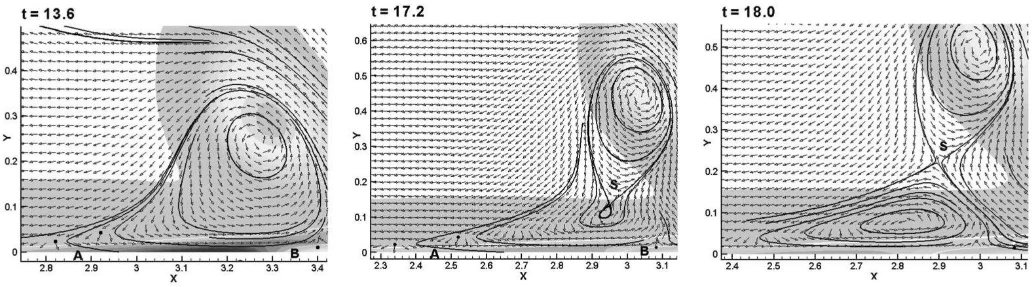


Figure 2. Close-up region below of the vortex patch,Re=3534: evolution of the recirculation zone. One can see the two stagnetion point A and B, the streamlines and non-scaled velocity vectors on the fond of the vorticity field.

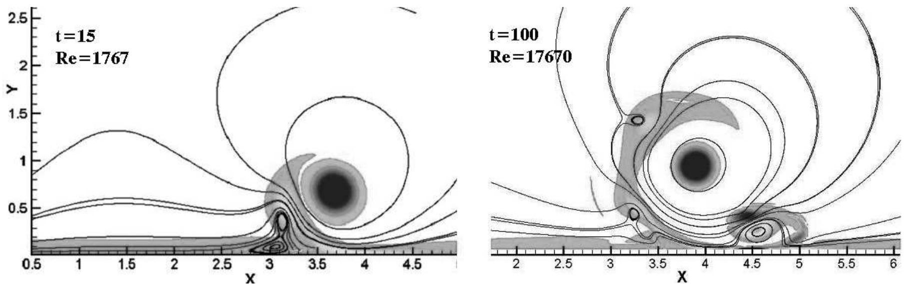


Figure 3. The left figure: stretching of the recirculating zone and formation of the saddle point Re=1767; the right figure: the cascade of small vortices carried to the flow as well creation of the new vortex patch can be seen, Re=17670

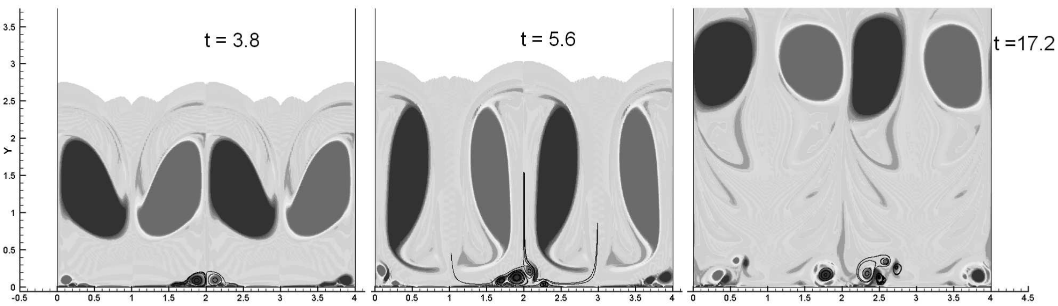


Figure 4. Eruptions of vorticity from solid wall induced by the counter–rotating vortex patches, Re=17670

CONCLUSIONS

Despite the simplicity of the 2D model, one can improved his intuition about the interaction of the vortex with the wall. It seems to have fundamental meaning in understanding of the regeneration processes in near wall turbulence.

References

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