Mode Formation and Bifurcation in Decelerating Taylor Vortex Flow

Takashi WATANABE
Center for Information Media Studies, Nagoya University
Furo-cho, Chikusa-ku, Nagoya, 464-8603, Japan
watanabe@info.human.nagoya-u.ac.jp

Hiroyuki FURUKAWA
Graduate School of Human Informatics, Nagoya University
Furo-cho, Chikusa-ku, Nagoya, 464-8601, Japan
hiroyuki@info.human.nagoya-u.ac.jp

The flow between a concentric cylinder system with the inner cylinder rotating and the outer cylinder at rest develops, as the rotation speed increases, into Couette flow, Taylor vortex flow, wavy Taylor vortex flow and turbulent flow. Taylor vortex flows between cylinders of finite length are classified into three modes: primary mode, normal secondary mode and anomalous mode. The primary mode appears when the rotation speed gradually increases, and it has an even number of cells. The normal secondary mode also has an even number of cells, but the cell number is different from the number of the primary mode. The anomalous mode has anomalous cell(s) on both or either of end walls. The anomalous cell gives outward flow near the end wall, which is opposite to the direction of flow in other modes. The Taylor vortex flow includes some types of separation flows which depend on the flow modes. This flow appears in journal bearings, a variety of fluid machinery and chemical reactors. The change of modes causes the unsteady variations of property values such as torque and rate of reaction. Therefore the analysis and prediction of the flow is important from the engineering point of view.

With the characteristic length being the gap between cylinders, the Reynolds number Re is defined by the rotation speed and the aspect ratio Γ is a non-dimensional length of cylinders. They are dominant parameters which determine modes of Taylor vortices. In the present study, the numerical investigation is carried out on the decelerating Taylor vortex flows. The governing equations are unsteady Navier-Stokes equations and they are solved by the finite difference methods. The end of walls of cylinders is fixed. The result is compared with experimental result.

Figure 1 shows critical loci where the decelerating Taylor vortex flow exchanges from the normal secondary mode to the primary mode. Bifurcations from 4-cell to 2-cell, from 6-cell to 4-cell and from 8-cell to 6-cell, are observed. Bifurcations from the anomalous mode to the pri-

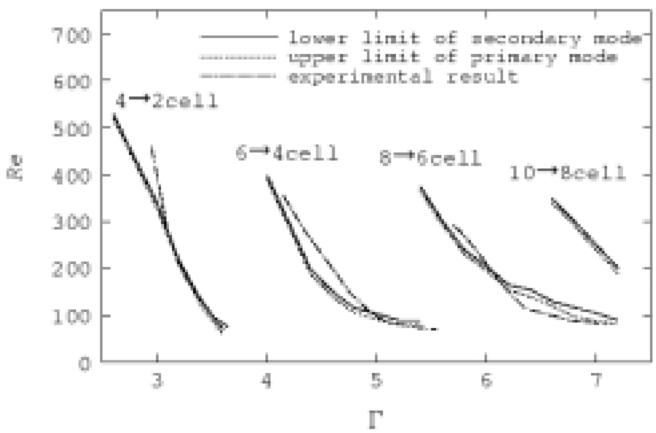

Fig.1 Bifurcation from secondary normal mode to primary mode

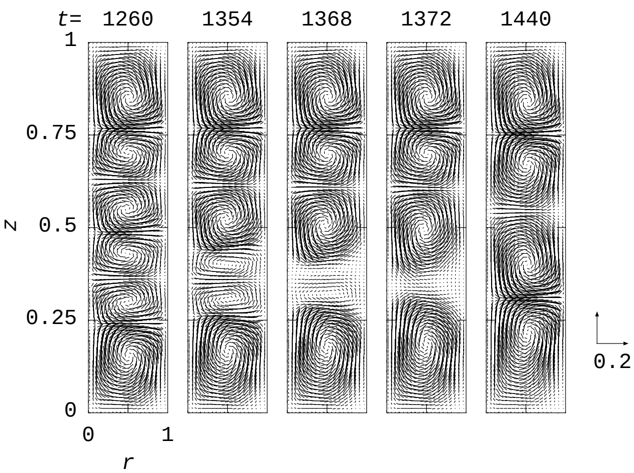

Fig.2 Development of flow field from secondary normal mode to primary mode ($\Gamma = 4.6$, $Re = 150 \rightarrow 140$). Deceleration starts at $t = 450$ and ends at $t = 900$

mary mode, which are not shown in Figure 1, also appear. The range of the Reynolds numbers in which flow modes exchange from the normal secondary modes to the primary modes is determined. The result agrees quite well with experimental evidences. The numerical prediction presents the range of the Reynolds number in which 10-cell flow exchanges to 8-cell flow. This bifurcation has not yet been found by experiment.

The mode exchange process from 6-cell to 4-

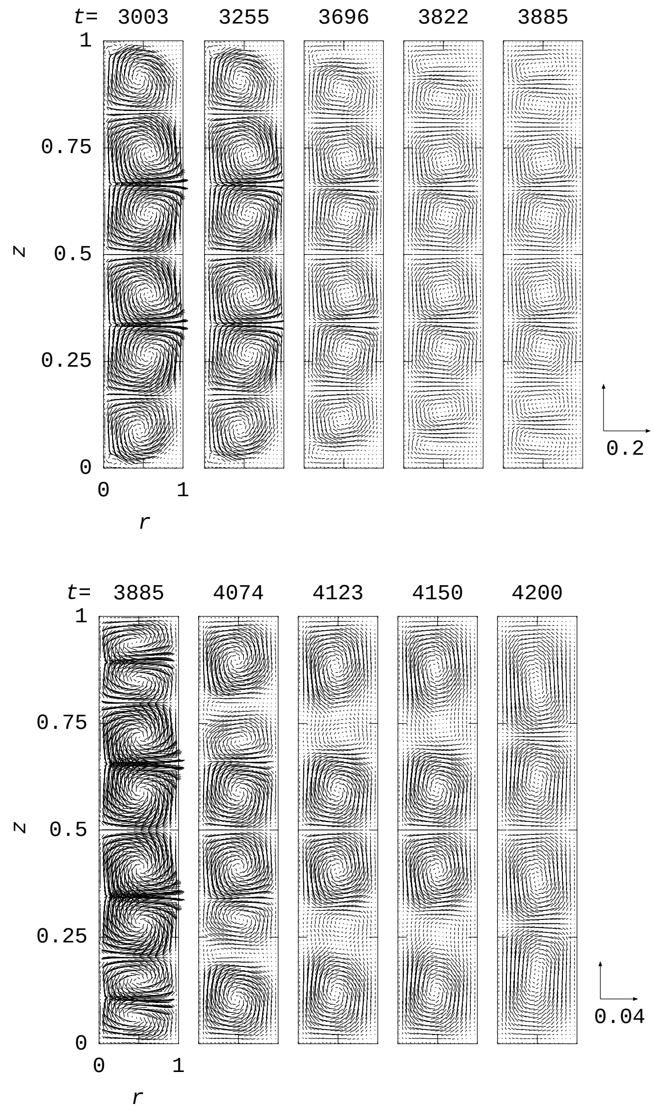

Fig.3 Development of flow field from secondary anomalous mode to primary mode ($\Gamma = 5.4$, $Re = 700 \rightarrow 80$). Deceleration starts at $t = 2100$ and ends at $t = 4200$

cell is shown in Figure 2. The bifurcation from the normal secondary mode begins with the gradual weakening of a pair of two cells. Between the two cells, the flow separates from the surface of the outer cylinder and it reattaches on the surface of the inner cylinder. Then the pair is collapsed by adjacent cells and it is finally disappeared. The bifurcation processes may not be symmetric with respect to the mid-plane in the

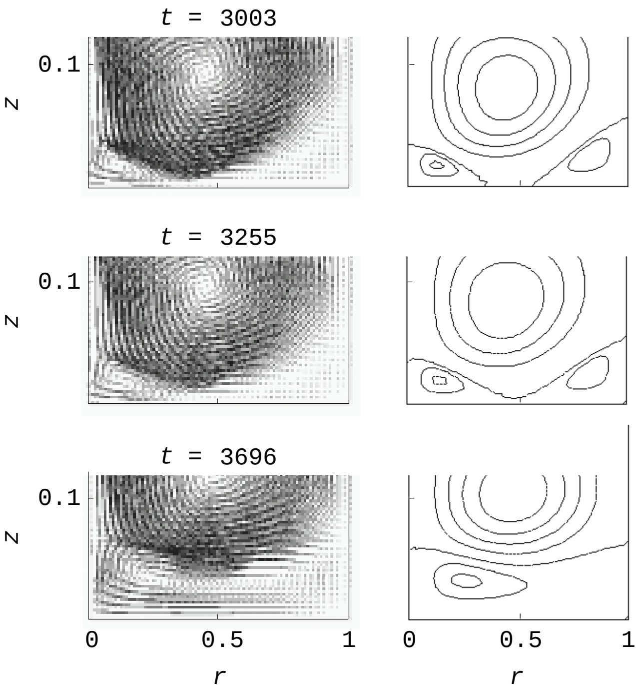

Fig.4 Velocity vectors and contours of stream function ψ near end wall with anomalous cell ($\Gamma = 5.4$, $Re = 700 \to 80$)

axial direction.

For the bifurcation from the anomalous 6-cell flow to the primary 4-cell flow, Figure 3 is the variation of velocity vectors in the whole (r,z) plane, and Figure 4 shows enlarged velocity vectors and contours of the Stokes's stream function ψ near the end wall. An anomalous cell accompanies with extra cells at both of the inner cylinder side and the outer cylinder side. There exists a surface of separation between the anomalous cell and the extra cell. Along the line of separation on the end wall, the direction of the limiting streamline has only a circumferential component and the radial component is zero. As the rotation speed decreases, the extra cells merge with each other and form one new normal cell, and the separation on the end wall disappears. While the new cell grows up, the pair of cells neighboring to the new cell decays and the flow mode becomes normal.