

FIG. 1. Laser cross-section of axisymmetric structures.

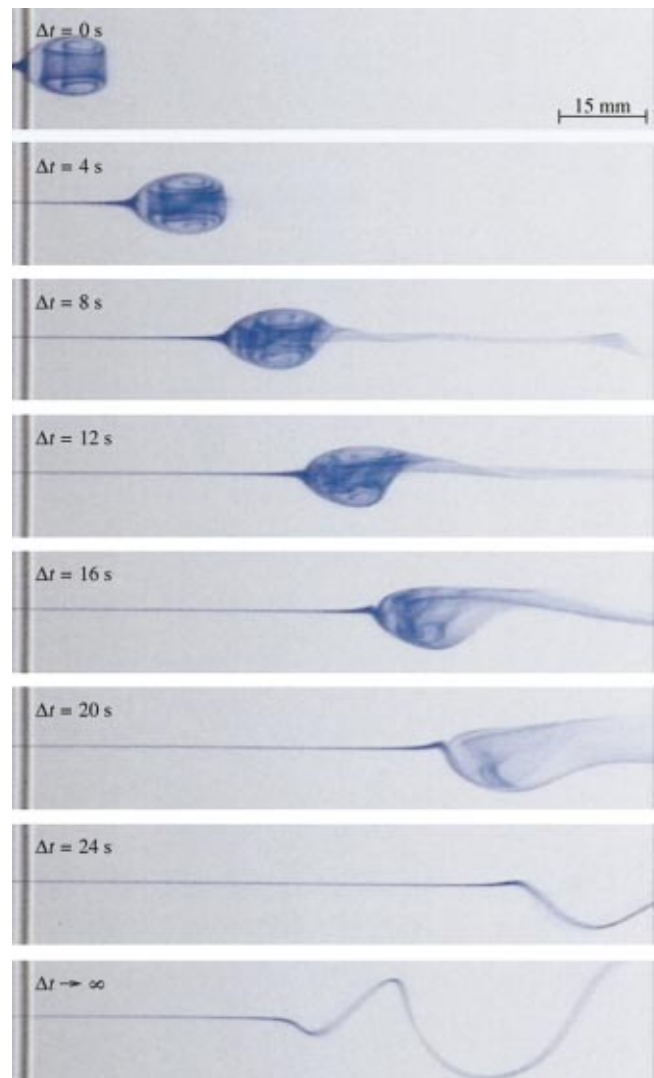


FIG. 2. Evolution to unsteady, nonaxisymmetric flow.

## Transient Behavior of Vortical Flow through a Constant Diameter Pipe

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These figures show the transient behavior of a dye filament introduced close to the axis of symmetry of a vortex when the vortex is subject to a sudden increase in swirl. The apparatus consists of a conventional guide vane arrangement to generate the swirl and a constant diameter pipe through which the vortex flows. The swirl intensity is determined by the angle of attack of the guide vanes  $\beta$ . The Reynolds number (based on the pipe diameter and the bulk axial velocity) is constant and approximately equal to 4000.

Figure 1 shows the evolution of an almost axisymmetric ringlike structure when  $\beta$  and the increment  $\Delta\beta$  are  $26^\circ$  and

$2.2^\circ$ , respectively. Note that  $\Delta t$  is the time measured from the first frame shown and that the flow is from left to right. For sufficiently small values of  $\beta$ , or small increments  $\Delta\beta$ , the disturbance decayed and was swept out of the apparatus.

When  $\beta$  or  $\Delta\beta$  were sufficiently large, the ringlike structure grew and the number of internal turns increased until it developed a periodic, nonaxisymmetric wobble. The amplitude of this wobble increased until the filament of dye assumed a distinct spiral shape. This process is shown in Fig. 2, where  $\beta$  and  $\Delta\beta$  are  $26^\circ$  and  $2.8^\circ$ , respectively. The spiral disturbance was swept out of the apparatus or, when  $\beta$  was sufficiently large, eventually meandered very slowly about an equilibrium position within the pipe. The final frame shows the asymptotic behavior for  $\beta=32^\circ$ . As  $\beta$  was further increased, the equilibrium position of the spiral moved upstream, its pitch decreased, and the rate of rotation increased.