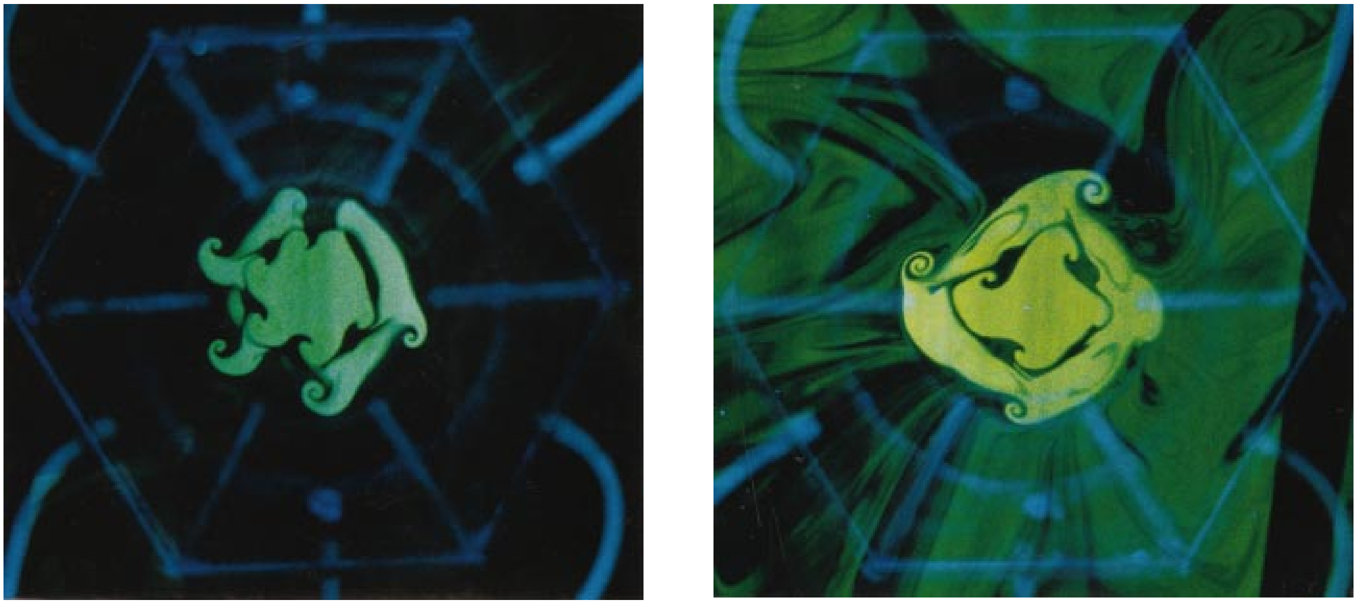

FIG. 1. Cross-sectional images at $S=0.38$ (left picture) and $S=0.49$ (right picture) of a counter-clockwise swirling jet. In the left picture, *six* intense azimuthal rolled-up structures (four in the right picture) are developing. In the absence of swirl (not shown), *seven* weak azimuthal deformations are identifiable, which develop farther downstream into mature mushroom-like structures composed of counter-rotating streamwise vortex pairs: rotation enhances the concentration of braid vorticity into secondary streamwise structures. Note that azimuthal roll-up is of one sign, thereby indicating that streamwise vortices are all co-rotating with respect to each other, and anticyclonic with respect to the base flow rotation. By contrast, in the nonswirling case, streamwise vortices are counter-rotating pairs. $\mathrm{Re}=1490$, $X=3$, where the Reynolds number is based on the nozzle exit diameter D, and X denotes the nondimensional distance x/D to the nozzle exit.

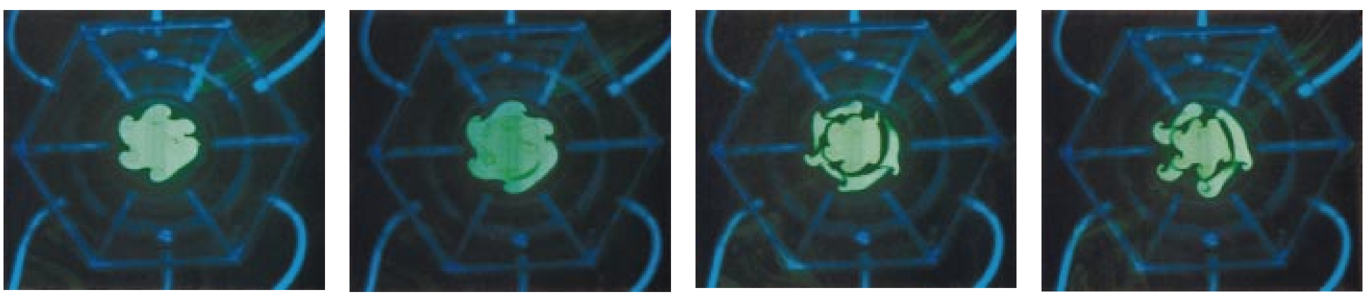

FIG. 2. This time sequence of cross-sectional views in the braid (first two pictures) and in the ring (last two pictures) at $S=0.38$ reveals the advection by the mean rotation of the secondary structures. This entrainment generates an azimuthal wave propagating cyclonically when compared to the imposed rotation, at an angular phase velocity proportional to the swirl. $\mathrm{Re}=1490$, $X=3$.

Breaking of Rotational Symmetry in a Swirling Jet Experiment

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The symmetry-breaking instabilities in swirling jets are analyzed experimentally for low swirl parameter S, where S compares the magnitudes of the azimuthal and axial velocity components. *Without swirl*, the axial shear generates vortex rings, whereas counter-rotating streamwise vortex pairs form in the braids connecting the rings due to a secondary instability. *For low swirl*, $0\leqslant S\leqslant 0.6$, we have determined that the underlying dominant instability mechanisms are direct extensions of those prevailing in classical nonrotating jets. However, significant differences appear in the development of the secondary instability: Swirl does not affect, qualitatively, the formation of vortex rings, it strengthens the development of azimuthal deformations and causes a decrease in the azimuthal wavenumber m. Finally, swirl amplifies anticyclonic streamwise vortices and attenuates cyclonic streamwise vortices.

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