Investigations of Vortex Breakdown

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An interesting question in the study of fluid dynamics, with applications to vortices and tornadoes, is why vortex breakdown takes place. This occurs when a single-cell vortex (pure updraft) transitions (or bifurcates) into a two-cell vortex (rotating updraft surrounding a downdraft (or stagnant) core).

A single-cell vortex, in equilibrium, has been described by the famous Serrin's "swirling vortex" solution of the steady-state Navier-Stokes equations. However, two-cell vortices are more complicated phenomena. Their interaction with the lower single-cell vortices presents a considerable challenge in understanding how this transition occurs.

We have built a vortex simulator (modeled on a Ward Chamber) at the University of St. Thomas to observe vortex breakdown. We have compared our results with videos of tornadoes where such breakdowns have occurred. A region, called the breakdown bubble, is located between the single cell and the two- cell vortices. We have observed a folding, or "kinking," of the vortex immediately above this region. A significant part of our work is devoted to an explanation of this kinking.

Vortex stretching is one of the mechanisms which intensifies rotation. For large values of pressure gradient force, when air can be viewed as incompressible, vortex stretching leads to an increase of kinetic energy inside the vortex. We believe that kinking can be explained by the conservation of kinetic energy in an incompressible inviscid fluid. The energy can be minimized by change in the direction of the vorticity vector as established the Biot-Savart Formula.