Vortex merger and chaotic advection

O.U. Velasco Fuentes and F.A. Velázquez Muñoz
Departamento de Oceanografía Física, Centro de Investigación Científica y de Educación Superior de Ensenada, Ensenada, Baja California, Mexico

The interaction of two like-signed vortices embedded in an otherwise quiescent fluid has been the subject of intense research for the last three decades. The single most important discovery is that a "critical distance" exists: Two vortices placed at an initial intercentroid distance smaller than a certain critical value (d_c) will merge into a single vortex (see *e.g.* Zabusky *et al.* [1]).

If the initial distance between the vortices is much larger than d_c the vortices rotate around each other quasi-steadily while undergoing little deformation. As the initial intercentroid distance decreases, the rotation becomes quasi-periodic and the vortices undergo considerable deformations (usually referred to as 'pulsations'). Finally, as the initial intercentroid distance approaches d_c the motion becomes fully aperiodic and the vortices undergo irreversible deformations in the form of thin filaments. Obviously, the motion is also aperiodic below the critical distance for merging.

In this paper we present experimental evidence of the intense stretching and folding of fluid elements that occurs during the vortex merger; which is well-known indication of chaotic particle advection. The analytical proof of chaotic particle dynamics in the velocity field of two interacting finite-area vortices has recently been given by Velasco Fuentes [2].

The experiment was carried out in a square tank of 100 cm side and 50 cm depth mounted on a rotating table. The tank was filled up to a depth of 20 cm and the rotation period of the system (T) was set to 7.5 s. Once the water inside reached a state of solid body rotation, each vortex was generated by withdrawing water during one rotation of the table. This was done using thin tubes (1 cm in diameter) placed at a distance of 15 cm. The vortices were visualized by adding dye after the generation process was completed.

Four pictures of the experimental sequence are presented in Fig. 8 (next page). Picture (a) was taken at time $t = 2T/3$ after the generation of the vortices, which are clearly visible by the patches of yellow and bright green dye in the center of the picture (the larger areas of lighter green are remnants of previous experiments). At time $t = 4T$ (picture b) the vortices have started exchanging mass, as can be seen from the filament of yellow fluid surrounding the green vortex, and the filament of green fluid surrounding the yellow vortex. Notice also that a filament of yellow fluid is being expelled behind to the green vortex (top of the figure) and that a filament of green fluid is being expelled behind to the yellow vortex (bottom of the figure). At time $t = 26T/3$ picture c) these filaments have reached the neighborhood of the vortices from which they emanated and are moving towards the opposite vortices again. The merging process is completed by time $t = 44T/3$ (picture d); note that there is limited mixing between yellow and green fluids in the interior of the new vortex.

Acknowledgments

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1. N.J. Zabusky, M.H. Hughes, and K.V. Roberts, *J. Comput. Phys.* **30** (1979) 96.
2. O.U. Velasco Fuentes, *Phys. Fluids* (2000) submitted.

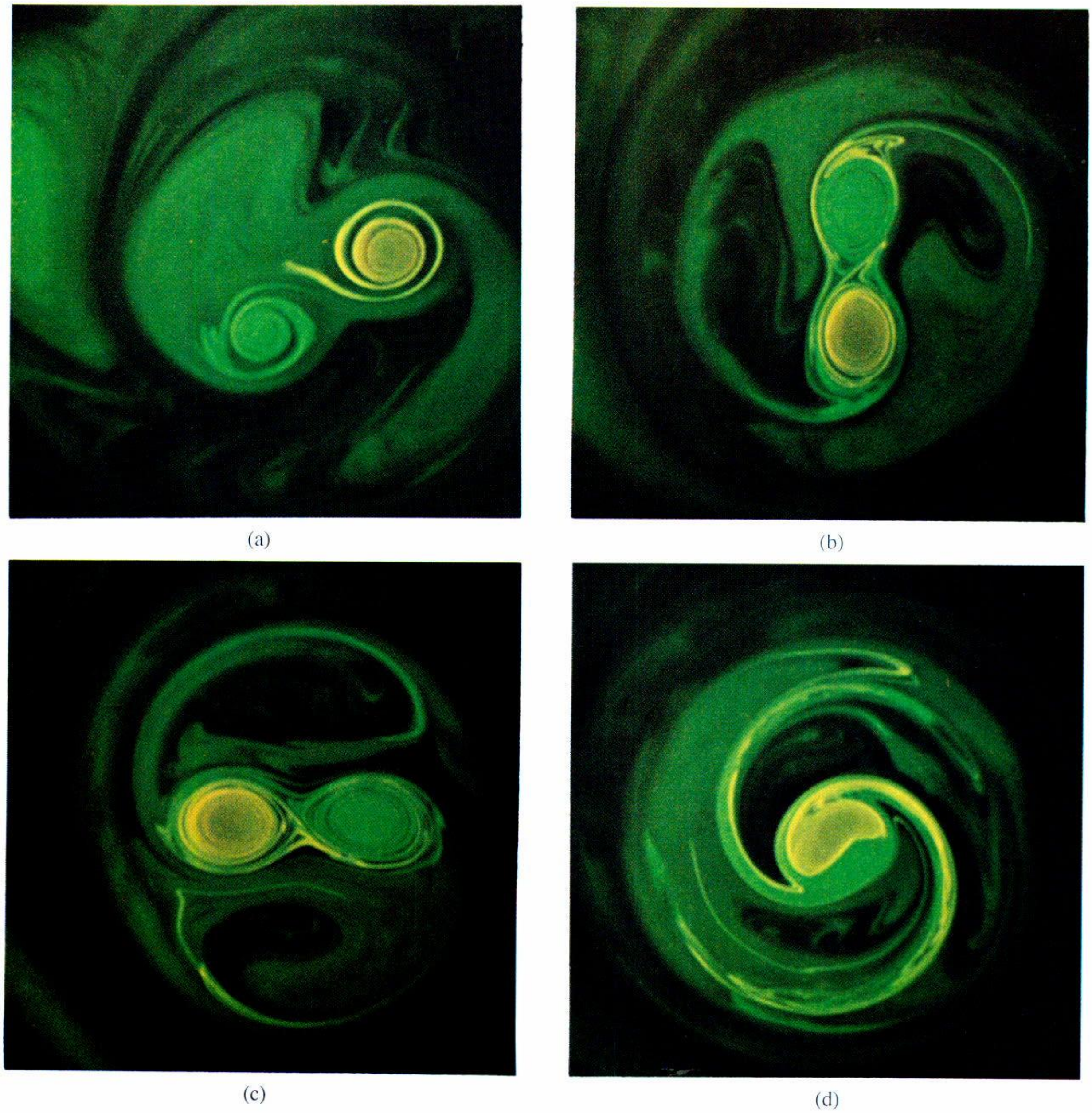

FIGURE 8. Experimental sequence showing the merging of two equal vortices in a two-dimensional, rotating fluid. The vortices are made visible by yellow and green dye (the lighter green areas are remnants of previous experiments). Pictures were taken at times $t = 2\,T/3$ (a), $t = 4\,T$ (b), $t = 26\,T/3$ (c), and $t = 44\,T/3$ (d), where $T = 7.5$ s is the rotation period of the table.