Formation of mini vortex rings arising from a vortex pair impinging on a wavy wall

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The study of counter-rotating vortex pairs has applications in fundamental turbulence, as well as practical applications such as wingtip vortices generated behind aircraft. Isolated vortex pairs, not in ground effect, can become unstable to short-wave [1] or long-wave instabilities [2]. Vortex-ground interactions are of particular interest in regard to the development of instabilities and vortex decay, as aircraft trailing vortices pose an increased hazard to following aircraft at takeoffs and landings. When a vortex pair approaches a ground plane, the boundary layer that forms on the surface separates, generating secondary vorticity and causing the primary pair to rebound from the wall. For a vortex pair with the long-wave Crow instability interacting with a flat boundary, the topology of the pair changes. This results in rebounding vortical structures, whose form is dependent on the extent of the instability prior to wall interaction [3]. In this work we examine the impingement of a two-dimensional (2D) vortex pair onto a wavy wall (see Fig. 1). By considering

FIG. 1. Both the primary and secondary vortices of the back vortex are visualized simultaneously in a cross section of the longitudinal plane. The poster associated with this image is available at <https://doi.org/10.1103/APS.DFD.2016.GFM.P0020>

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SARAH E. MORRIS AND C. H. K. WILLIAMSON

FIG. 2. Schematic of a 2D vortex pair impinging on a wavy wall. The transverse plane (green) and longitudinal plane (blue) are shown. The poster associated with this image is available at <https://doi.org/10.1103/APS.DFD.2016.GFM.P0020>

FIG. 3. Primary vortex pair at two different times shown in a transverse cross section through the valley. The poster associated with these images is available at <https://doi.org/10.1103/APS.DFD.2016.GFM.P0020>

FIG. 4. Secondary vorticity of the back vortex shown in a cross section of the longitudinal plane. A vortex loop pinching off into a ring can be seen in the valleys. The poster associated with these images is available at <https://doi.org/10.1103/APS.DFD.2016.GFM.P0020>

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the complementary experiment of a straight vortex pair encountering a wavy wall (rather than a wavy vortex pair impinging on a flat wall), certain characteristic features of the two flows are found to be similar.

Two long computer-controlled flaps are lowered into a water tank and closed to generate a counterrotating vortex pair, which travels downward under its own induced velocity. The vortices then impinge upon transparent wavy hillocks that are custom cast with Crystal Clear 200 acrylic resin, which sits upon a transparent acrylic ground plane that fits the length of the tank (see Fig. 2).

A key feature of this experiment is the ability to visualize the primary and secondary vortices either independently or concurrently via laser-induced fluorescence of fluorescein dye. The flow is illuminated using an argon ion laser. The primary vortex pair is made visible by directly painting the flaps with dye (see Fig. 3), whereas dye is carefully pooled (prior to the experiment) on the surface of the hillocks to visualize the secondary vortices (see Fig. 4).

The 2D vortex pair first interacts with the “hills” of the boundary, resulting in earlier localized secondary vorticity generation. This leads to the formation of secondary vortex loops in the “valleys,” wherein these loops pinch off into rising vortex rings, two per fundamental wavelength. In addition to the topological modifications, we also observe an increased rate of circulation decay compared to a 2D vortex pair impinging on a flat wall.

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