


Vortex bursting

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(Received 12 August 2020; published 12 November 2020)

This paper is associated with a poster winner of a 2019 APS/DFD Gallery of Fluid Motion Award for work presented at the DFD Gallery of Fluid Motion. The original poster is available online at the Gallery of Fluid Motion, <https://doi.org/10.1103/APS.DFD.2019.GFM.P0035>.

DOI: [10.1103/PhysRevFluids.5.110504](https://doi.org/10.1103/PhysRevFluids.5.110504)

A straight vortex tube with core size perturbation along its axis will generate twist waves, because the axial velocity variations tilt the vorticity vector so that an azimuthal vorticity component appears. This sets an oscillatory process in motion during which the core size undulations and corresponding twist waves travel back and forth along the axis of the vortex tube [1,2]. Such twist waves in isolation are like $m = 0$ Kelvin waves, with m the azimuthal wave number [3], which are susceptible to various instabilities that have been extensively investigated in the context of aircraft trailing vortices, e.g., specifically for helical or swirling instabilities [4]. Their dynamics and stability properties are well characterized in the context of linearized perturbation analyses of simplified vortex models (Batchelor trailing vortices and Rankine vortices) [5].

A particularly interesting event occurs when a vortex tube is endowed with an initial sinusoidal core perturbation: In this case two opposite-sign twist waves can collide, giving rise to a process referred to as vortex bursting [6–8], which is related to the core dynamics instability in Refs. [9,10]. At the location where the waves meet, a flattened disklike structure appears in the vorticity magnitude field and any passive tracers advected in the flow. The vortex lines resemble those of two opposite-sign twisted vortex rings undergoing a head-on collision, though in this case the vortex lines of the “rings” are still connected to each other within the bursting region. During this process, the enstrophy of the flow increases significantly compared to the initial state, with a proportional increase in energy dissipation. The process is then reversed, as the twist waves change their direction and untwist the core; however, at sufficiently high Reynolds numbers the nonlinear dynamics leads to various secondary instabilities in the flow behavior within the original bursting region.

Our Gallery of Fluid Motion entry visualizes the structure of vortex lines during a bursting phenomenon. The visualization was generated from a simulation of the three-dimensional incompressible Navier-Stokes equations in the vorticity-velocity formulation. We set up an initial condition of a periodic vortex tube with a Gaussian core profile and circulation-based Reynolds number of 10 000. The core thickness σ was varied as a function of the axial coordinate along the vortex tube z as $\sigma(z) = \sigma_0[1 + \sin(2\pi z/L)/2]$, with domain length $0 \leq z \leq L$ and $\sigma_0 = L/10$. In

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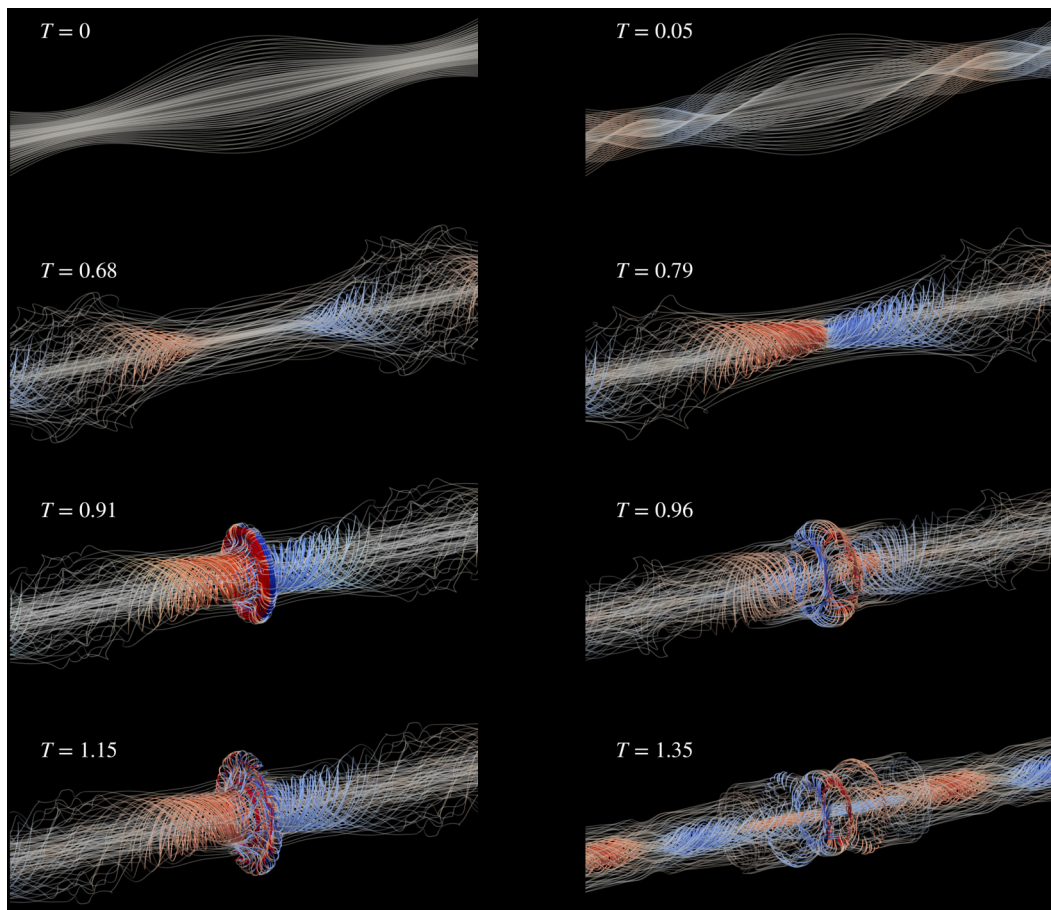


FIG. 1. Time evolution of the initial vortex tube (top left) through the bursting process (left to right, top to bottom). We visualize the vorticity field through the instantaneous vortex lines in the flow, colored by the azimuthal vorticity component. A close-up of $T = 0.91$ is provided in Fig. 2.

Fig. 1 we show the time evolution of the vorticity field, where we nondimensionalize the time t through $T = t\Gamma_0/L^2$, with Γ_0 the circulation of the tube. Though the vorticity vector is initially directed in the z direction everywhere, the azimuthal velocity has strong gradients in the axial direction. Consequently, the vorticity vectors get tilted and two opposite-chirality helical structures develop, which are then transported in opposite directions by their associated axial velocity. When they meet, a vortex bursting event occurs (Fig. 2) and is accompanied by significantly increased enstrophy and thus energy dissipation.

The vortex lines have never been visualized before at this high Reynolds number and there are several open questions related to this phenomenon at sufficiently high Reynolds numbers, including the effect on the long-time stability of the vortex tube and the possibility of vortex reconnection within the bursting region. Current work is focused on further understanding these effects.

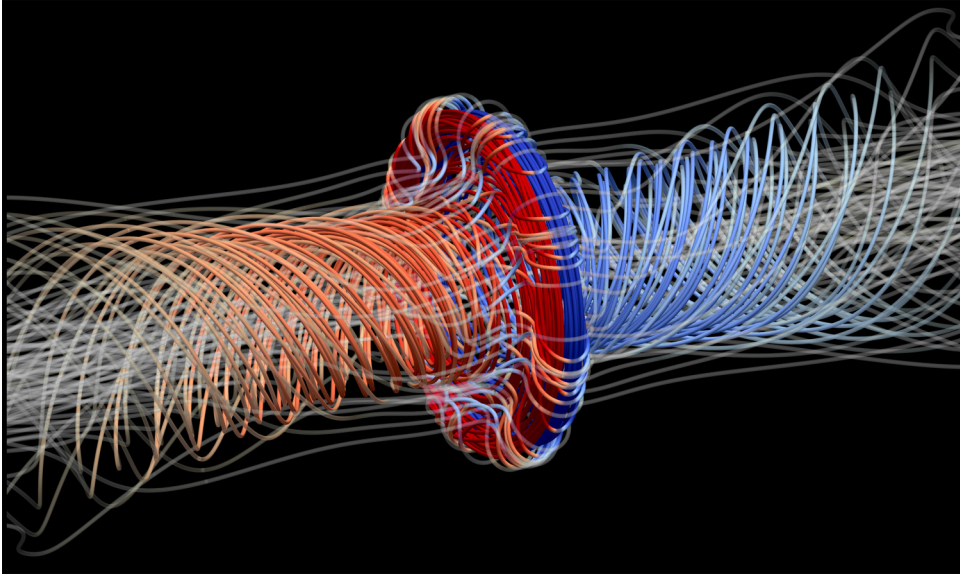


FIG. 2. Close-up of the vortex lines, colored by the azimuthal vorticity component, during the bursting process at $T = 0.91$.

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