Numerical and experimental direct observation of vortex reconnection in a turbulent swirling flow

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Vortex reconnection in the von Kármán (VK) flow

Goal: Identify if reconnecting vortex structures in numerical and experimental datasets of the von Kármán flow are linked to the occurrence of finite-time singularities (FTS).

Theorem: Beale, Kato, and Majda (1984) proved that if a FTS occurs at time t_c, then $\int_0^{t_c} ||\boldsymbol{\omega}(\boldsymbol{x}, t)||_\infty dt = \infty$, i.e., $\boldsymbol{\omega} = \nabla \times \boldsymbol{u}$ becomes unbounded as $t \to t_c$.

Vortex reconnection:

- Process where two vortices approaching closely cut and connect to each other.
- Vortex tubes with arbitrary orientations become antiparallel due to mutual induction (Siggia, 1985; Boratav, Pelz, and Zabusky, 1992; Yao and Hussain, 2022).

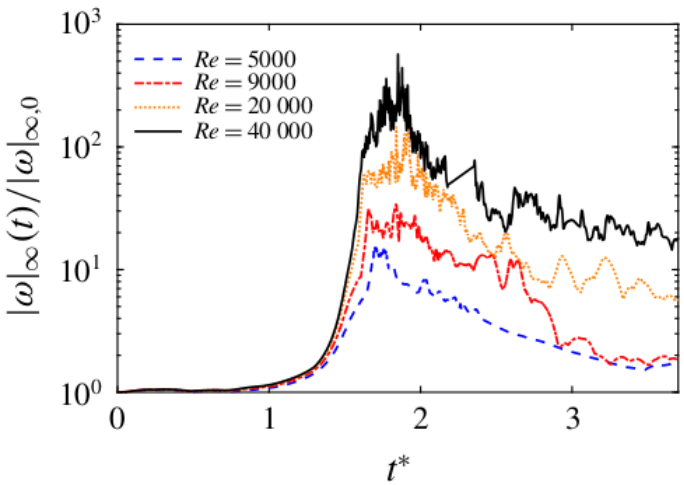

Figure 1: Time evolution of maximum vorticity magnitude at different Re (Yao and Hussain, 2022).

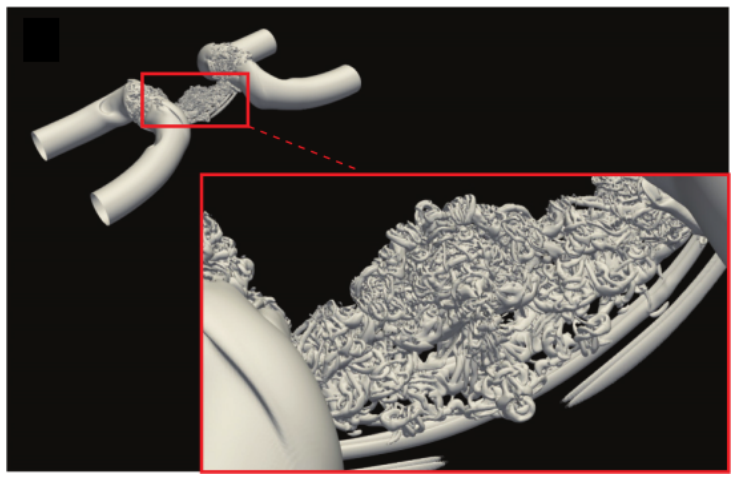

Figure 2: Reconnection of antiparallel vortex tubes at $Re = 40,000$ (Yao and Hussain, 2022).

Methodology and initial results

Method:

- Identify vortex structures with a suitable scalar indicator (Q, λ_2 or Δ criterion).
- Apply a threshold τ identified with percolation analysis (Harikrishnan et al., 2021).
- Filter structures having a fractal dimension less than 1.
- Track vortices with spatial overlap technique for structures having at least 50% overlap.
- Identify vortex reconnection with an Enstrophy-based criterion (Kang, Yun, and Protas, 2020).
- Identify potential singularities with the Duchon-Robert indicator (Dubrulle, 2019).

What's next?

- Track large number of structures, explore sub-Kolmogorov scales $\eta/4$ (expected) with new experimental dataset.

DNS of VK at Re = 6000:

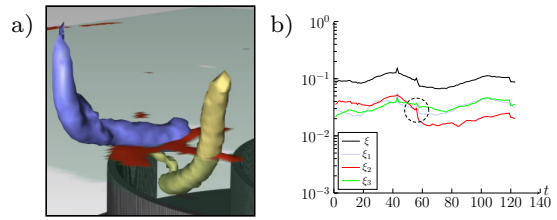

Figure 3: (a) Strong DR (red patch) can be seen at the plane of reconnection of the blue and yellow vortex structures (b) Enstrophy ξ and its components ξ_1, ξ_2, ξ_3 versus time t.

VK experiment at Re = 6300:

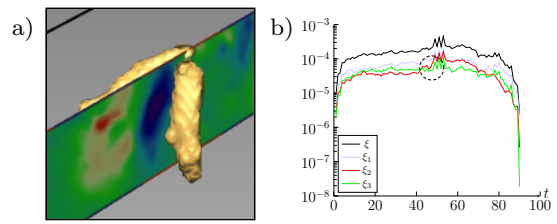

Figure 4: (a) DR patch at the plane of reconnection of the yellow vortex structures (b) Similar to figure 3 (b).