MME SEMINAR SERIES

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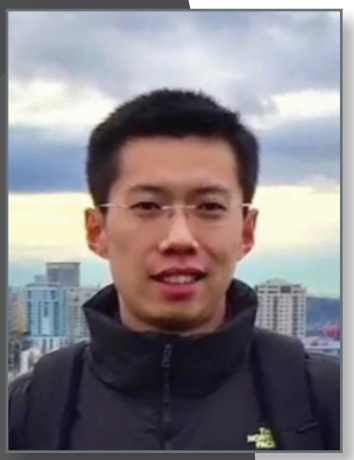
Vortex-Breakdown and Wall-Separation States in Swirling Flows in Finite-Length Pipes



Yuxin Zhang, PhD

Instructor, Mechanical Engineering,
Washington State University Tri-Cities

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12:10 - 1:00 pm | BSEL 102

Abstract

The dynamics of inviscid-limit, incompressible and axisymmetric swirling flows in finite-length, long circular pipes with varying geometries is studied through global analysis techniques and numerical simulations. The inlet flow is described by fixed-in-time profiles of the circumferential and axial velocity together with a fixed azimuthal vorticity, while the outlet flow is characterized by a state with zero radial velocity. A numerical algorithm based on the upwind finite-difference method for the evolution of the circulation and azimuthal vorticity together with a Poisson solver for the solution of the stream function in terms of the azimuthal vorticity is developed. The convergence of computed results with mesh refinement is demonstrated. Moreover, a mathematical analysis that is based on the Squire-Long equation (SLE) is formulated to identify steady-state solutions of the problem with special conditions to describe states with separation zones. These solutions include the base columnar flow state, a decelerated flow along the centerline, an accelerated flow along the centerline, a vortex-breakdown state and a wall-separation state. The problem is then reduced to the columnar (axially independent) SLE, with centerline and wall conditions for the solution of the outlet flow stream function. The numerical simulations realize the various flow states and show correlation between time-asymptotic states and steady states predicted according to the SLE and the columnar SLE problems. The simulations also shed light on the stability of the various steady states. Results show that pipe divergence promotes the appearance of breakdown states at lower inlet swirl levels while pipe contraction delays the appearance of vortex breakdown to higher swirl levels and promotes formation of wall-separation states. The influence of various inlet swirling flow profiles on the manifold of steady states in a straight, finite-length pipe and on flow dynamics is also investigated. Depending on the inlet profiles, flows may first exhibit vortex breakdown while others wall-separation states.

Bio

Dr. Yuxin Zhang is an Instructor of Mechanical Engineering at Washington State University Tri-Cities in Richland, WA. He received his PhD in Aeronautical Engineering at Rensselaer Polytechnic Institute (RPI) in Troy, NY. His dissertation research focused on swirling flow states in finite-length pipes with various geometries and inlet flow profiles. His research interests include theoretical and computational fluid mechanics with a focus on vortex dynamics, flow instability, and reacting compressible flow. He received the Mechanical, Aerospace and Nuclear Engineering Teaching Award from RPI in 2017 and the National Scholarship from the Ministry of Education of China in 2013.

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