Pavel Rudolf

V. Kaplan Department of Fluid Engineering, Faculty of Mechanical Engineering,
Brno University of Technology, Czech Republic
rudolf@fme.vutbr.cz

Swirling flows in engineering applications

The lecture focuses on the physics and computational modeling of swirling flows, with particular emphasis on swirling flow stability and vortex rope dynamics in hydraulic machinery. Drawing on extensive experimental and numerical research conducted at the Brno University of Technology, the course explores fundamental mechanisms of vortex formation, their modal structure, and methods of suppression through both passive and active control.

The first part of the lecture introduces the phenomenon of the vortex rope, commonly occurring in draft tubes of Francis turbines and other swirling configurations. Based on a series of experiments in a controlled swirl generator setup the topic of vortex breakdown, the stability problems of swirling flows and identification of the swirling coherent structures are presented.

The second part is dedicated to computational simulation approaches for swirling flows, especially correct turbulence modeling.

The third part delves into the modal analysis of unsteady swirling flows, employing techniques such as Proper Orthogonal Decomposition (POD) and Spectral POD. These tools are used to extract dominant coherent structures and analyze their evolution and stability. Results illustrating how energy-rich helical modes can be isolated and tracked across various flow regimes will be presented. The development of reduced-order models based on POD amplitudes will be introduced, providing a framework for real-time flow state estimation and control design.

The final segment addresses active and passive flow control, including active swirl modulation. Building on the outcomes of laboratory tests and numerical simulations, the lecture presents successful strategies for suppressing harmful flow oscillations associated with vortex rope formation. The potential of closed-loop control using data-driven models and reinforcement learning will also be discussed as a forward-looking approach to flow stabilization.

Throughout the lecture, original research papers, doctoral theses, and case studies from the author's research group will serve as core material, offering direct insight into the state-of-the-art in swirling flow dynamics and control.