

This thesis investigates the use of data-driven and learning-based methodologies for the analysis and active control of turbulent flows, with a specific focus on the experimental implementation of deep reinforcement learning (DRL). While DRL has demonstrated significant potential for flow control in numerical studies, its practical deployment in laboratory environments remains limited by sensing constraints, actuation bandwidth, latency, and interpretability.

The work addresses these challenges by developing an integrated experimental framework in which DRL-based controllers are coupled with real-time sensing and actuation systems. The proposed approach is applied to a set of canonical and application-oriented flow configurations, including bluff-body wake control and gust alleviation, demonstrating that learning-based controllers can achieve robust performance under realistic experimental conditions. Particular attention is devoted to the design of state representations, reward formulations, and control architectures that are compatible with the limitations of physical experiments.

Beyond control performance, the thesis explores the role of explainable artificial intelligence (XAI) as a tool for the a posteriori interpretation of learning-based models in fluid mechanics. Feature attribution and gradient-based methods are employed to identify the flow structures and regions that most strongly influence the predictions of neural networks trained on experimental data. In parallel, reduced-order modelling techniques based on autoencoders and latent-space dynamics are investigated to provide compact and interpretable representations of unsteady flow fields.

Overall, this work contributes to bridging the gap between numerical studies and experimental realisations of AI-driven flow control. By combining reinforcement learning, explainability, and reduced-order modelling within a unified experimental context, the thesis provides insight into both the feasibility and the physical interpretation of learning-based approaches for aerodynamic flow analysis and control.