ME – MTech (Res) Thesis Colloquium

Prediction and Control of regime transitions in Quasi two-dimensional flows

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ABSTRACT

Abrupt transitions between long-lived flow regimes are an observed feature of some turbulent flows. These transitions are accompanied by a rapid increase in energy dissipation, which qualifies them as extreme events. In an electromagnetically driven quasi two-dimensional (Q2D) chessboard-like flow characterised by long-lived large-scale circulations (LSCs), these regime transitions manifest as reversals and excursions (R&Es) in the orientation of the LSC. This study employs two-dimensional direct numerical simulations (DNS) accelerated by a fast Poisson solver framework to investigate the origin of R&Es and to develop predictive closed-loop control strategies.

A dynamical-systems interpretation of such flow transitions reveals that the dynamics of R&Es are governed by exact coherent structures (ECSs), rather than arising as purely noise-induced transitions during chaotic evolution. In particular, R&Es are shown to revolve around two unstable periodic orbits (UPOs), which organise turbulent trajectories in phase space and provide a deterministic framework for predicting imminent transitions. Using a metric to quantify distance from one of the UPOs, a closed-loop control strategy is designed that successfully mitigates imminent R&Es. Further, laboratory experiments confirm that UPOs are approached prior to regime transitions and demonstrate successful control of such events. Statistics of LSC lifetimes indicate that the dynamics are governed by transient chaos associated with a chaotic saddle, providing a statistical interpretation of the two LSC regimes as metastable states.

ABOUT THE SPEAKER

Rajath Kashyap S is an MTech(Res) student in the Chaos and Turbulence (CAT) lab, Department of Mechanical Engineering, IISc, Bengaluru. He completed his BTech in Mechanical Engineering from PES University, Bengaluru in 2023. His research interests include Computational Fluid Dynamics and Fluid Dynamics.