FROM LOCALIZED PERIODIC ORBITS TO TRANSIENTS IN PIPE FLOW

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Abstract Hydrodynamic instability in wall bounded shear flows is abrupt and directly results in very complex spatio-temporal patterns even close to onset. This sudden scenario has challenged the application of dynamical systems concepts to describe the onset of turbulence. We present a bifurcation scenario leading from spatially localized relative periodic orbits to chaotic transients in pipe flow.

INTRODUCTION

The onset of turbulence in shear flows remains a challenge despite more than a century of investigations, starting with Osborne Reynolds [3]. The laminar flow is linearly stable so transition occurs only via finite amplitude perturbations and gives rise to extremely complex dynamics. In addition, turbulence is at first spatially localized (in the form of puffs in pipe flow [5]). An understanding of the transition scenario thus requires the identification of underlying coherent sutrctures, such as traveling waves [1, 4], but featuring streamwise localisation like puffs.

NUMERICAL SIMULATIONS

We performed numerical simulations of pipe flow with a spectral code [2] and by restriction to the two-fold-mirror-symmetric subspace were able to identify a streamwise localised relative periodic orbit. This was found to be stable in the subspace and could thus be obtained directly by time-stepping. Application of a Newton-Krylov method confirmed this result.

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By continuing this relative periodic orbit in Reynolds number we could identify a Neimark-Sacker bifurcation spawning a stable relative two-torus, which at larger Reynolds number becomes chaotic via a Shilnikov-like scenario. The ensuing chaotic attractor turns into a repeller at larger Reynolds number, and the resulting localised strctures become puffs: localized transient spots of turbulence.

CONCLUSIONS

Low dimensional dynamical systems concepts applied to transition in shear flow have led to a growing understanding of subcritical transition to turbulence over the last decade. Our work elucidates a phase-space mechanism for the formation of puffs (albeit in a symmetry subspace). We speculate that the transition in full space follows a similar scenario.

References

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