RELATING ELASTOINERTIAL TURBULENCE TO THE PHENOMENOLOGY OF POLYMER DRAG REDUCTION

Lu Zhu[1] and Li Xi[1]

[1]Department of Chemical Engineering, McMaster University, Hamilton, Ontario, Canada

ABSTRACT

A small amount of flexible polymer additives may cause drastic reduction in turbulent friction drag. The rich dynamics of polymer-turbulence interplay behind the drag reduction (DR) phenomenon is reflected in the transitions in turbulent phenomenology between several distinct stages as the fluid becomes more elastic (higher Weissenberg number Wi)[1].

Starting from the Newtonian limit, there is initially no DR (NDR) until Wi reaches its onset level $\mathrm{Wi}_{\mathrm{onset}}$. As Wi further increases, the flow enters the low-extent DR (LDR) stage, where DR effects are contained in the turbulent buffer layer only[2]. Transition to the high-extent DR (HDR) stage is manifested by several distinct markers in flow statistics, especially those in the log-law layer[2]. There are still ongoing debates about conflicting observations in the HDR stage[1]. Finally, at sufficiently high Wi, the level of DR converges to the maximum DR (MDR) limit, whose full mechanism remains unexplained.

Recent discovery of the so-called elastoinertial turbulence (EIT), a distinct type of high-Wi flow instability where polymer elasticity feeds into, rather than suppressing, turbulent fluctuations, sparked much interest among researchers. We focus on building the connection between EIT and the phenomenology of DR, especially the multistage transitions in turbulent dynamics as described above. Several interesting findings arose during our investigation. First, although EIT has been widely associated with MDR, we found that MDR cannot be described by the simple convergence to a single EIT state[3]. Second, EIT shows up a lot earlier than MDR does. Its rise to dominance marks a previously unknown transition, which would explain the seemingly contradictory observations in HDR[4]. Third, opposite to the prevailing view, transition to EIT is triggered by a new linear instability[5], which is also a sharp contrast to the laminar-turbulent transition in Newtonian fluids.

On the numerical side, EIT dynamics cannot be captured with spectral methods because its sharp stress shockfronts would be smeared by the artificial diffusion term required for numerical stability. This has cast doubt over the general reliability of spectral methods in viscoelastic fluid simulation. We show that although artificial diffusion is detrimental to EIT structures, it has minimal impact on the traditional inertia-driven turbulence (IDT), provided that the numerical diffusivity is chosen at a proper magnitude[4,6]. Therefore, artificial diffusion can not only still be used in IDT, it also provides a way for us to separate the two types of turbulent dynamics by selectively removing EIT.

ACKNOWLEDGEMENTS

The authors acknowledge the financial support from the Natural Sciences and Engineering Research Council of Canada (NSERC; Nos. RGPIN-2014-04903 and RGPIN-2022-04720) and the allocation of computing resources awarded by the Digital Research Alliance of Canada (alliancecan.ca). The computation is made possible by the facilities of the Shared Hierarchical Academic Research Computing Network (SHARCNET: sharcnet.ca).

REFERENCES

1. Xi L, Turbulent drag reduction by polymer additives: Fundamentals and recent advances, *Phys. Fluids*, **31**, 121302, 2019.
2. Zhu L, Xi L, Distinct transition in flow statistics and vortex dynamics between low- and high-extent turbulent drag reduction in polymer fluids, *J. Non-Newton. Fluid Mech.*, **262**, 115–130, 2018.
3. Zhu L, Xi L, Nonasymptotic elastoinertial turbulence for asymptotic drag reduction, *Phys. Rev. Fluids*, **6**, 014601, 2021.
4. Zhu L, Xi L, The role of elastoinertial turbulence in the multistage transitions of viscoelastic turbulent channel flow, *in preparation*.
5. Zhu L, Xi L, Direct transition to elastoinertial turbulence from a linear instability in channel flow, arXiv:2211.09366, 2022.
6. Zhu L, Xi L, Inertia-driven and elastoinertial viscoelastic turbulent channel flow simulated with a hybrid pseudo-spectral/finite-difference numerical scheme, *J. Non-Newton. Fluid Mech.*, **286**, 104410, 2020.