Active and hibernating turbulence in channel flow of Newtonian and viscoelastic fluids

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Abstract

Turbulent channel flow of drag-reducing polymer solutions is simulated in minimal flow geometries. Even in the Newtonian limit, we find intervals of “hibernating” turbulence that display many features of the universal maximum drag reduction (MDR) asymptote observed in polymer solutions: weak streamwise vortices, nearly nonexistent streamwise variations and a mean velocity gradient that quantitatively matches experiments. As viscoelasticity increases, the frequency of these intervals also increases, while the intervals themselves are unchanged, leading to flows that increasingly resemble MDR.

Drag reduction by polymers-phenomena

Schematic

Experiments

Near lamellar-turbulence transition.

MDR (maximum drag reduction): insensitive to polymer-related properties.

Maximum drag reduction

Re=3600 W=0 (Newtonian)

Wi = 80, β=0.97, Ex=103

57% DR

Waite, P. B., Aiche J, 1975

Channel flow: near-wall structure

Re=3600

Wi = 0 (Newtonian)

Lx = 360.0

Mean flow rate vs. Wi

Flow rate: active and hibernating

Active and hibernating turbulence

Mean flow rate vs. Wi

Re=3600 W=0

Wi=29

β=0.97

Ex=103

Viscous sublayer

Newtonian log-law

Virk MDR

Active and hibernating turbulence

Time series of mean velocity and wall shear rate

Selected snapshots during a hibernation interval (Wi=29):

Hibernation:

• Very weak vortices and streaks,
• Very weak streamwise dependence,
• “Near-Virk” mean velocity profile (even in Newtonian flow!)

Hypothesis 1: on intermittency and MDR

Timescales of hibernation

As Wi increases:

• Lifetime of active turbulence is reduced.
• Duration of hibernation is almost invariant.
• Hibernation takes a larger fraction of time.

Viscoelasticity compresses the lifetime of active turbulence intervals while having little effect on hibernation itself.

Hypothesis 2: hibernation is a saddle point

Active turbulence/sedimental stretching of polymer molecules

Polymer stretches increase, Polymeric stress decreases, Hibernating flow: weak vortices, Reproduction of streamwise streakiness.

Prediction: hibernation dominates as MDR is approached.

Flow structure in hibernation

Acknowledgments

Fabian Waleffe, John Gibson, NSF-CBET

MFU results: overview

Active and hibernating turbulence

Observation: Normal “active” turbulence is punctuated by long periods of low wall shear rate accompanied by increasing mean velocity and followed by a burst in shear rate

• Hibernation
• Isolated in both Newtonian and viscoelastic flows
• Quantifiable with identification criteria:

\( (\lambda_0/\beta) < 1.89 \)

\( |\Delta \lambda_{avg}/\lambda_{avg}| > 0.50 \)

Mean flow rate vs. Wi

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