Experimental characterisation of elasto-inertial turbulence and maximum drag reduction asymptote

S.S.Suresh[a], B.Hof[a]

It has been known since 1940's that the addition of polymers in small quantites reduces drag very effectively[1]. This drag reduction has an upper bound, called the maximum drag reduction (MDR) asymptote[2]. Addition of sufficiently high amount of polymers also causes the onset of an "early" turbulence, termed elasto-inertial turbulence (EIT)[3]. On a Moody plot, the empirical form of the MDR asymptote when plotted, lies between the Hagen-Pouiselle and the Prandtl-Karman curves. It has often been proposed that MDR is a marginal state of Newtonian turbulence[4]. We visualize using stereoscopic PIV the flow field in a pipe flow and determine that the structures associated with Newtonian (inertial) turbulence are entirely distinct from those that appear in EIT at Re<1000, and at MDR at Re>15000. We find a compelling similarity comparing EIT and MDR, both being characterized by azimuthally extended sheets of streamwise vorticity. Such structures are completely absent in the case of Newtonian turbulence.

We find that this state in the MDR characterised by the azimuthally extended sheets of vorticity is strongly reminiscent of the structures we find in the low Re EIT regime, and that MDR state is strongly dominated by the structures present in the EIT regime. We also plot flow regimes using the Q-criterion to further strengthen our claim. Finally we find evidence from performing laser doppler velocimetry confirming that the energy spectra corresponding to EIT and MDR have the same slope of -3, distinct from the -5/3 slope associated with Newtonian turbulence.

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[a] Institute of Science and Technology, Austria

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