Mechanical Engineering Dissertation Defense

Drag Reduction in Oscillating Pipe Flow: Statistics and Structures

School for Engineering of Matter, Transport and Energy

Daniel Coxe

Advisors: Ronald Adrian and Yulia Peet

Abstract

Fluid drag is present in all manners of engineering problems. It causes inefficiencies in some situations such as skin friction drag on hydroshape but in others it can be beneficial as in heat transfer were it increases Nusselt number. The focus of this is work is understanding the former. Skin friction is controlled via spanwise wall oscillation in turbulent pipe flow. This drag reduction technique - implemented by a spanwise wall velocity boundary condition - is studied extensively by its measured effects on long time averaged statiscal quantites, conditional averages, statistic measures of structural modifications, and by its impact on the regeneration cycle of a conditional eddy. The overwhelming evidence shows that, although inner scale actuation is the target of the drag reduction technique, wall oscillations have measurable impacts on structures far outside the log-layer of the flow and structures which are larger than is canonically referred to as large scale structure for the given Reynolds number. The reason for this is shown to be the modification it makes to the coherence of small and intermediate scale ejection events, events which look like hairpin vortices, to form so-called packets which become large and very large scale structures. This is shown through instantaneous visualizations which show re-orientation of the low speed streaks (which also cause high speed streaks to re-orient but that is not directly addressable at the moment) and the re-orientation of quasi-streamwise vortical motion into a motion which becomes more spanwise aligned depending on the instantaneous wall position/velocity. The level of re-orientation is measured to show that it is \emph{not} just an artefact of not being able to view the whole three-dimensional domain (vortices and streaks are measured to have distinct bias in their spanwise tilt). Lastly, three dimensional conditional averages of the velocity fields and the regeneration of a conditional eddy structure are presented to confirm the observed phenomenon a) from a statistically stationary perspective and b) to monitor what the temporal dynamics of ejection event are. This provides convincing evidence that a significant portion of the drag reduction method is the disruption of the near wall cycle by forcing a sub-optimal regeneration pattern, one that is not axially aligned.

August 26, 2025; 1:00pm; ECG G214

Arizona State University