Proceedings of the 1st international Symposium on AI and Fluid Mechanics
Abstract No S1 A6

Manipulation of the turbulent wall cycle via multi-agent deep reinforcement learning

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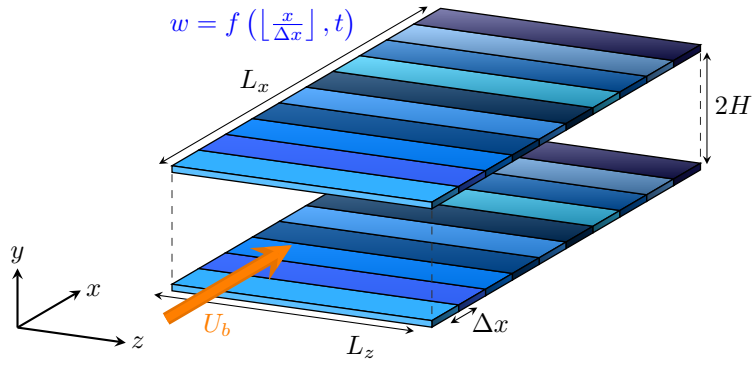
Abstract

The wall cycle[1] in wall-bounded turbulent flows represents a complex turbulence regeneration mechanism, with most control strategies implementing uniform actuation across the wall surface. We present a novel approach introducing spatially distributed control where the wall is segmented into strips aligned with the spanwise direction, each controlled by an independent deep reinforcement learning (DRL) agent, enabling more precise and localised control of turbulent structures.

Our computational framework[2] integrates StableBaselines3 DRL libraries with the DNS solver CaNS to accommodate multiple concurrent learning agents, each developing policies for modifying local boundary conditions. The implementation maintains efficient parallel computing capabilities through MPI wrappers, crucial for handling the increased computational complexity of multiple agents.

Initial results demonstrate that this distributed control approach achieves superior performance in drag reduction compared to uniform actuation methods. Results show that agents naturally coordinate through their influence on the flow field, achieving more robust control strategies. The approach demonstrates particular effectiveness in maintaining coherent velocity streaks while adapting to local flow variations. Analysis of the emergent control patterns provides insights into both near-wall turbulence mechanisms and the potential of multi-agent DRL systems in fluid dynamics, paving the way for more sophisticated flow manipulation strategies.



A schematic of the DRL control strategy in a channel flow configuration is shown in the figure above. The wall is segmented into spanwise-aligned strips of width Δx, where each strip is independently controlled by a DRL agent. The wall actuation w for each strip is determined by a function f of the local flow properties and time.

[1] Javier Jiménez and Alfredo Pinelli. The autonomous cycle of near-wall turbulence. Journal of Fluid Mechanics, 389:335–359, June 1999. Publisher: Cambridge University Press.

[2] Giorgio Maria Cavallazzi, Luca Guastoni, Ricardo Vinuesa, and Alfredo Pinelli. Deep Reinforcement Learning for the Management of the Wall Regeneration Cycle in Wall-Bounded Turbulent Flows. Flow, Turbulence and Combustion, November 2024

Keywords:
Deep Reinforcement Learning, Multi-agent, Wall cycle, Flow control, Turbulence