From One Dimensional Turbulence to Wall Modeling

Lukas Weber
1 Department of Mechanical and Mechatronics Engineering, University of Waterloo, Waterloo, Ontario, CANADA

Recent advancements in computing technology have made wall-modeled large eddy simulations (WMLES) an appealing tool for the aerospace industry. Compared to RANS, the current dominant approach to turbulence modeling, WMLES is considered to potentially be more accurate, less dependent on empiricism, and more capable of capturing effects like flow separation and wake dynamics [1]. Unfortunately, the accuracy of a WMLES simulation depends on the quality of the wall model. By nature, wall models are simplifications of the navier-stokes equations, meaning that to some degree, a portion of the flow physics will be ignored. This limitation turns into a critical issue when a wall model ignores essential behaviours in a flow; For example, if a wall model is incapable of modeling flow detachment or temperature effects [1]. In order to improve wall modeled LES, various AI-based wall models are under consideration. Instead of attempting to find reasonable analytical wall models, a set of high-fidelity simulations is used to create a set of training data which can be used to accurately predict near wall behaviours [2] [3]. One dimensional turbulence (ODT) is a statistical approach used to calculate flow profiles in a particularly efficient manner [6]. ODT has been shown to produce excellent results in various incredibly challenging flow conditions, including at extremely high reynolds and peclet numbers, and in the presence of chemical reactions, and under hypersonic conditions, under many of these conditions, DNS results are prohibitively expensive, while RANS struggles to produce accurate results [4] [5] [6]. My work aims to develop one-dimensional turbulence as a viable tool for wall modeling. This means overcoming several challenges, including extending ODT to compressible flows, improving computational efficiency, and creating parallel and GPU-based implementations, and systematizing parameter optimization, in order ultimately create a high-fidelity wall-model database.

Email address for correspondence: *l4weber@uwaterloo.ca*

References

[1] S. T. Bose and G. I. Park, "Wall-Modeled Large-Eddy Simulation for Complex Turbulent Flows," *Annual Review of Fluid Mechanics*, vol. 50, pp. 535–561, Jan. 2018. doi: 10.1146/annurev-fluid-122316-045241.

[2] R. Ma, Y. Yuan, G. Arranz, Y. Ling, R. Agrawal, M. P. Whitmore, A. Elnahhas, C. Pederson, and A. Lozano-Durán, "Building-block-flow model for LES of high-speed flows," *Journal of Fluid Mechanics*, Cambridge University Press.

[3] X. I. A. Yang, S. Zafar, J.-X. Wang, and H. Xiao, "Predictive large-eddy-simulation wall modeling via physics-informed neural networks," *Physical Review Fluids*, vol. 4, p. 034602, Mar. 2019. doi: 10.1103/PhysRevFluids.4.034602.

[4] P. Nath, *One-Dimensional Turbulence: From Extreme Reynolds Number Turbulence to Hypersonic Turbulent Boundary Layers*, Ph.D. thesis, Department of Mechanical and Mechatronics Engineering, University of Waterloo, Waterloo, Ontario, Canada, 2025.

[5] T. Echekki, A. R. Kerstein, T. D. Dreeben, and J.-Y. Chen, *One-dimensional turbulence simulation of turbulent jet diffusion flames: Model formulation and illustrative applications*, Combustion and Flame, vol. 125, pp. 1083–1105, 2001.

[6] D. O. Lignell, A. R. Kerstein, G. Sun, and E. I. Monson, *Mesh adaption for efficient multiscale implementation of one-dimensional turbulence*, Flow, Turbulence and Combustion, vol. 89, pp. 273–295, 2012.

Email address for correspondence: *l4weber@uwaterloo.ca*