

PROCEEDINGS

A Physics-Guided Framework for Reconstructing Near-Wall Turbulence in Wall-Modelled LES

Yunjiu Yang^{1,2} and Xiaolei Yang^{1,2,*}

¹The State Key Laboratory of Nonlinear Mechanics, Institute of Mechanics, Chinese Academy of Sciences, Beijing, 100190, China

²School of Engineering Science, University of Chinese Academy of Sciences, Beijing, 100049, China

*Corresponding Author: Xiaolei Yang. Email: xyang@imech.ac.cn

ABSTRACT

Wall-modelled large-eddy simulation (WMLES) provides an affordable route to high-Reynolds-number wall turbulence, but its near-wall fidelity often remains limited: outer-layer motions may be reasonably captured, while the large-scale wall-shear signal and the resulting near-wall statistics can still be inaccurate [1–4]. This motivates methods that do not rely directly on the raw WMLES wall signal, but instead reconstruct the large-scale wall shear stress from outer-layer information and then use a physics-based near-wall model to recover the missing statistics.

In this work, we present a physics-guided framework for reconstructing near-wall turbulence from existing WMLES data. The method combines three ingredients. First, a spectral redistribution step reshapes the large-scale energy distribution of outer-layer velocity slices toward a DNS-based reference. Second, a DNS-trained spectral linear stochastic estimation (SLSE) kernel maps the outer-layer large-scale velocity field to the large-scale wall-shear vector [5,6]. Third, the reconstructed wall shear drives a quasi-steady-quasi-homogeneous (QSQH) synthesis of near-wall velocity fields from precomputed universal boxes [7,8].

The framework is built on the inner–outer interaction picture of wall turbulence, in which large-scale motions leave a coherent footprint at the wall and modulate the near-wall cycle [5,9]. The QSQH component further assumes that, when the large-scale wall-friction field varies slowly enough, the near-wall response can be represented in local wall units defined by the large-scale friction velocity and direction [7,8]. Applied to turbulent channel flow, the method restores a more DNS-like low-wavenumber wall-shear spectrum and improves reconstructed near-wall mean velocity and turbulence intensities over a range of Reynolds numbers. The framework is solver-independent, computationally inexpensive, and offers a practical route to enhancing the near-wall statistical fidelity of WMLES without modifying the underlying LES solver or wall model.

KEYWORDS

Wall-bounded turbulence; wall-modelled large-eddy simulation; synthetic turbulence

Funding Statement: This work was supported by NSFC Excellence Research Group Program for “Multiscale Problems in Nonlinear Mechanics” (No. 12588201), the Strategic Priority Research Program of Chinese Academy of Sciences (CAS, No. XDB0620102), National Natural Science Foundation of China (No. 12172360), and CAS Project for Young Scientists in Basic Research (YSBR-087).

Conflicts of Interest: The authors declare no conflicts of interest to report regarding the present study.

References

1. Kawai, S., Larsson, J. (2012). Wall-modeling in large eddy simulation: length scales, grid resolution, and accuracy.



Copyright © 2026 The Author(s). Published by Tech Science Press.

This work is licensed under a Creative Commons Attribution 4.0 International License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

- Physics of Fluids*, 24(1), 015105.
2. Kawai, S., Larsson, J. (2013). Dynamic non-equilibrium wall-modeling for large eddy simulation at high Reynolds numbers. *Physics of Fluids*, 25(1), 015105.
 3. Larsson, J., Kawai, S., Bodart, J., Bermejo-Moreno, I. (2016). Large eddy simulation with modeled wall-stress: recent progress and future directions. *Mechanical Engineering Reviews*, 3(1), 15-00418.
 4. Bose, S. T., Park, G. I. (2018). Wall-Modeled Large-Eddy Simulation for Complex Turbulent Flows. *Annual review of fluid mechanics*, 50, 535 - 561.
 5. Baars, W. J., Hutchins, N., Marusic, I. (2016). Spectral stochastic estimation of high-Reynolds-number wall-bounded turbulence for a refined inner-outer interaction model. *Physical Review Fluids*, 1(5), 054406.
 6. Lee, M., Moser, R. D. (2015). Direct numerical simulation of turbulent channel flow up to $Re_\tau \approx 5200$. *Journal of Fluid Mechanics*, 774, 395–415.
 7. Chernyshenko, S. I. (2021). Extension of QSQH theory of scale interaction in near-wall turbulence to all velocity components. *Journal of Fluid Mechanics*, 916, A52.
 8. Chernyshenko, S. I., Zhang, C., Butt, H., Beit-Sadi, M. (2019). A large-scale filter for applications of QSQH theory of scale interactions in near-wall turbulence. *Fluid Dynamics Research*, 51(1), 011406.
 9. Marusic, I., Mathis, R., Hutchins, N. (2010). Predictive model for wall-bounded turbulent flow. *Science*, 329, 193–196.