From wall measurements to three-dimensional turbulent-flow fields

A. Cuéllar-Martín*, A. Güemes*, A. Ianiro*, R. Vinuesa†, O. Flores* and S. Discetti*

Linear methods have successfully reconstructed turbulent flow fields in channel flows using wall measurements up to the logarithmic region[1]. Recently, convolutional neural networks have been used to incorporate non-linear effects, with particular success of generative adversarial neural networks (GANs) [2,3,4].

This study aims to estimate three-dimensional (3D) turbulent channel flows using GANs from wall-shear stress and pressure measurements. It expands on previous research by estimating one-shot full 3D fields instead of individual wall-parallel planes that require separate training for each of them. Despite increased output size, a similar network with a moderate increase in training parameters can accurately predict 3D data at a cost comparable to that of the previous 2D models.

GANs include two networks competing against each other during training. The generator network takes wall measurements of pressure and wall-shear stress and generates 3D velocity fields. Meanwhile, the discriminator network determines whether the flow field is original or created by the generator. This study used 3D convolutional layers in the GANs to address this setup, applied over DNS data of a turbulent open-channel flow at friction-based Reynolds number of 200.

The network can predict the flow field with slightly higher error compared to 2D single-plane estimation, but generates the entire volume in one direct query, making the process more efficient. The accuracy of the velocity fluctuations is high in the viscous layer but worsens progressively through the buffer and logarithmic layers, as seen in figure 1 and consistently with what observed for 2D GANs and linear methods[4]. We observe that GANs are able to reconstruct accurately wall-attached structures, while strong attenuation is observed on wall-detached ones.

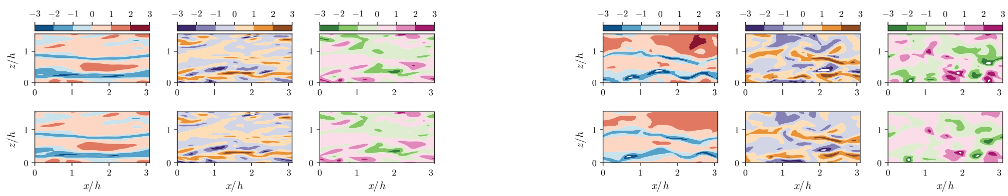

Figure 1: (Top) Reference and (bottom) predicted instantaneous fields of (left) u, (middle) v and (right) w, for $y^+ = 10$ (Left group) and $y^+ = 40$ (Right group).

---

*Dep. Aerospace Engineering, Universidad Carlos III de Madrid, Legan, Madrid, Spain
†FLOW, Engineering Mechanics, KTH Royal Institute of Technology, Stockholm, Sweden

[1] Encinar M. P. and Jiménez J., *Phys. Rev. Fluid* **4** (11), 114603 (2019).
[2] Güemes A. et al, *Phys. Fluid* **31** (12), 125112 (2019).
[3] Guastoni L. et al, *J. Fluid Mech.* **928**, A27 (2021).
[4] Güemes A. et al, *Phys. Fluid* **33** (7), 075121 (2021).

ACKNOWLEDGEMENTS This contribution has received funding from the Spanish Ministry of Universities under the *Formación de Profesorado Universitario (FPU) 2020* programme, and from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement No 949085, NEXTFLOW).