Symmetry-induced high-moment turbulent scaling laws of a spatially evolving turbulent round jet

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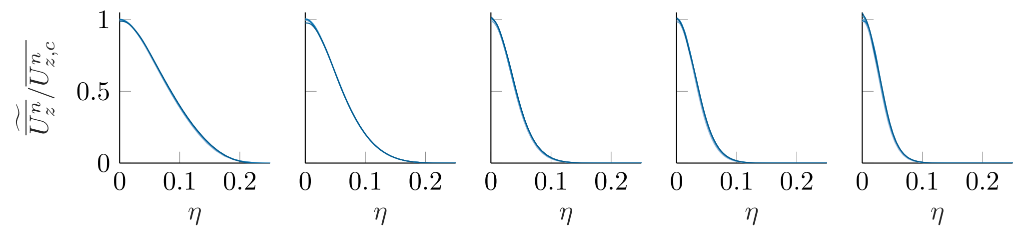
In most experiments as well as numerical simulations of turbulent round jets, self-similarity is observed primarily for the mean velocity. Here, using symmetry methods, we calculate similarity-type scaling laws for arbitrarily high moments of velocity from the infinite set of multi-point moment equations. Most centrally, symmetry theory provides moments based on instantaneous rather than fluctuation velocities.

To prove its validity, a large-scale direct numerical simulation (DNS) of a turbulent jet flow was conducted at a Reynolds number of $Re = 3500$ and a box length of $z/D = 75$. As an inlet, we utilize a fully turbulent pipe flow to obtain self-similarity at small z, and we calculate almost 200 washouts for a very good statistical convergence of high moments.

Virtually perfect similarity compared to symmetry theory is observed in the $z/D = 25 - 65$ range and this is especially true for U_z-moments up to order $n = 10$ (see Fig. 1). In matching theory and DNS data, we observe that statistical symmetries are negligible for turbulent jets, and this is very different to near-wall turbulence where they are significant for high moment scaling laws[1]. In this work, prefactors of near-wall high order moment scaling-laws were found to scale exponentially with order n and this is also observed presently. Additionally, the U_z-moments show Gaussian-like curves that get increasingly narrower with n. Transforming the governing equations with the symmetry-based scaling laws and assuming a Gaussian for the U_z-moments allows us to find an expression for the instantaneous $\overline{U_r U_z}$ correlation which compares well with the DNS data.

Finally, converting the instantaneous moments to those of fluctuations is straightforward, but will be omitted since uncertainty grows exponentially for $n > 2$ and a sensible interpretation is therefore lost[2].



(a) $n = 1$ (b) $n = 2$ (c) $n = 5$ (d) $n = 7$ (e) $n = 10$

Figure 1: The radial profiles of the n^{th} axial moment normalized with the scaling laws at different distances from the orifice: $z = 25$ (——), $z = 35$ (——), $z = 45$ (——), $z = 55$ (——), $z = 65$ (——).

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[1] Oberlack et al, *Phys. Rev. Lett.* **128**, 024502 (2022).
[2] Oberlack et al, *Phys. Rev. Lett.* **130**, 069403 (2023).