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## Multiscale inhomogeneous grids for experimental atmospheric boundary layer generation: a comparison with spires

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### Abstract

A common practice for both research and industrial applications involving the generation of a neutral atmospheric boundary layer (ABL) in a wind tunnel consists in associating a roughness fetch with an upstream array of “spires” (Irwin, 1981). This passive method enables to tailor the mean velocity profile on the basis of quantitative guidelines. At the expense of a further time-consuming trial-and-error design process, these devices can be adjusted to generate representative turbulent intensity profiles, but no representative trends of the integral length scale profile.

In parallel, the downstream evolution of regular and fractal grid-generated turbulence has been recently shown to scale with a wake-interaction model (Gomez-Fernandez *et al.*, 2012) which can be used to predict basic properties of downstream turbulence profiles in case of zero mean shear. If this scaling law were to apply to grid-generated shear flow, it would enable the independent tailoring of turbulent intensity and mean velocity profiles without trial-and-error. In order to investigate these ideas experimentally, our work makes use of Multiscale Inhomogeneous Grids (MIG), a new type of passive device defined to vary the turbulence scaling parameters with altitude, while enabling a tailoring of the mean velocity profile. Examples of MIGs are illustrated in Figure 1.

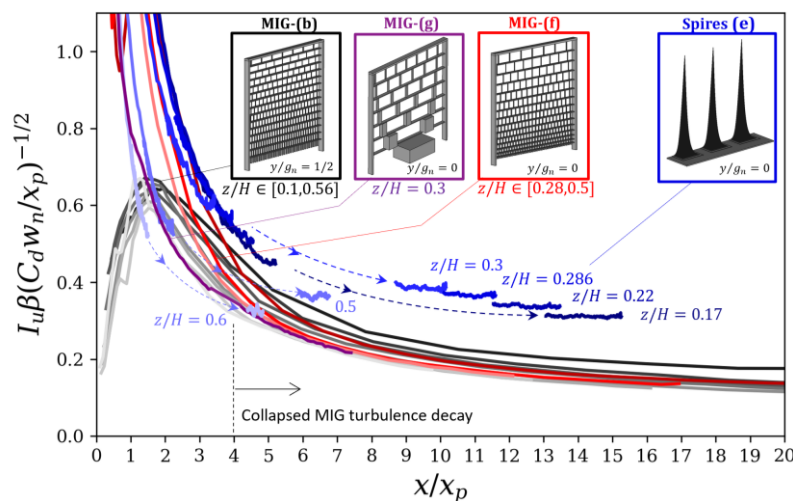


Figure 1: Normalized streamwise profiles of turbulent intensity  $I_u = u'/U$  downstream of both discrete MIG grids (b,g,f) and a continuous MIG grid (e). Each device is designed to reproduce the same

*logarithmic mean flow over the full-height  $H$  of the wind tunnel. Each profile is obtained at a given altitude  $z/H$  corresponding to a given local mean shear (lighter color means higher altitude and smaller mean shear). The axes are normalized by:  $x_p$  a wake-interaction length scale,  $C_d$  the drag of a grid's bar in isolation,  $w_n$  the width of the grid bar and  $\beta=2.88$  (Gomes-Fernandes et al., 2012).*

A general MIG design algorithm is developed for the generation of a prescribed mean flow profile. It is experimentally validated for the design of MIGs aiming to generate full-depth and part-depth neutral atmospheric boundary layer configurations. The devices are studied over both smooth and rough walls in the SCL-PIV wind tunnel of ONERA Lille using both Hot-Wire Anemometry (HWA) and stereo Particle Image Velocimetry (S-PIV). This validation process reveals the existence of a defective grid regime for specific local geometric configurations of MIGs. A set of criteria on local geometric parameters (i.e. local obstruction and local mesh aspect ratio) is suggested to avoid this defective grid regime. These criteria extend to MIGs the obstruction-based criterion usually considered when designing parallel-bar arrays or square mesh grids (Rose, 1966).

The turbulence intensity decay downstream of the designed MIGs is then studied by scaling its streamwise profile measured downstream of each vertical level of the grid by the corresponding wake-interaction parameters for zero shear grid flows (Figure 1). As expected, this scaling reveals a remnant effect of the local mean shear. However, it provides a satisfactory collapse of profiles having similar mean shear conditions, thereby justifying the usefulness of this scaling model for grid-generated shear flows.

Moreover, our work reveals that spires can be conceptually designed and studied as “continuous MIG grids”, with the expectation that the wake-interaction scaling would be as relevant for spires as it is for discrete MIGs. However, it appears in Figure 1 that turbulence decay downstream of spires does not collapse with turbulence decay downstream of discrete MIGs, even with comparable generated mean shear. A physical mechanism of a different nature appears to be at play downstream of spires in the development of turbulence intensity, despite their conceptual proximity to MIGs.

Indeed, a different turbulence production regime is observed for these two types of devices. On the one hand, spires generate one single intense shear layer with a very large Turbulence Kinetic Energy (TKE) production rate at  $z/H=0.3$ . This shear layer is separated from the naturally growing boundary layer by a well-mixed highly turbulent region. The mean shear layer decays and converges to the prescribed logarithmic mean flow profile at  $x=6H$ . On the other hand, downstream of discrete MIG grids, less intense TKE production regions are spread at each level across the height of the grid. These differences suggest (i) a spire TKE production mechanism of a different nature than planar wake-interactions alone –e.g. through massive recirculation bubbles or wakes oscillations—, and potentially (ii) a spires-generated flow structure that may enhance the interaction with the naturally-growing boundary layer. Future studies will investigate these possible mechanisms and their relation to wake-interaction mechanisms, as the resulting understanding may help improve the design process of both discrete MIG grids and continuous spires for ABL generation.

## References

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