On the characterization of a modular active turbulence generator for the independent control of turbulence intensity and scales

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The assessment of the aerodynamic performance degradation for turbine passage flows had and continues to have a key role in performance and efficiency predictability. The individual role of turbulence length/time scales on the flow physics is still scarcely investigated in open literature. The isolated effects of scales are too often ignored or poorly modeled when not considered as a concurrent/dependent effect of the turbulence intensity, as nowadays the turbulence scales are difficult to generate and measure both in experiments and numerical simulations. The rationale behind the scope of this research is to enable future experimental campaigns in a low-speed turbine cascade rig with a novel turbulence generator capable to expose turbine flows to a wide range of free-stream turbulence, characterized by values of turbulence scales that can be systematically varied from the intensity levels, so that the effects of these two key parameters are isolated/ decoupled and studied independently each other. This research discusses the development of a concept for generating free-stream turbulence that: 1) provides the authority for the generation of a wide range of turbulence intensities encountered by a broad class of turbine systems, however, allowing for an independent control of turbulence scales. 2) ensure an high degree of homogeneity, isotropy and uniformity of the inlet turbulent flow fields. The proposed concept includes suppling momentum in the mainstream flow from different directions by using continuously, adjustable and distributed compressed jet injections. The experimental characterization is conducted in an auxiliary low-speed test bench with a small cross-sectional area, testing at low Mach number (~0.05) and ambient conditions. Measurements of pressure, flow velocity and turbulence features (turbulence intensity, length and time scales, turbulence isotropy and homogeneity degrees and turbulence decay, energy and spectra) at multiple planes downstream and upstream the generator are presented. Multi-wire hot-wire, traversed in stream- and cross-wise directions, is used to measure the three-components of the velocity and characterize locally the turbulence flow fields. In synergy, LES simulations and time-resolved optical PIV measurements are used to characterize the vortices dynamics and their structures formation/interaction in a 2D streamwise plane across one bar of the turbulence generator. The results indicate that the turbulence generator is capable of generating a wide range of isotropic and homogeneous turbulence levels with minimum pressure losses, by adjusting the position and the jet to mainstream velocity ratio. Values from low to high turbulence intensity (2-15%) with a low degree of non-uniformity (<5%) have been obtained with yet the ability to tune independently the integral length scale within the range of 4.5-15 mm.

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