Mitteilung

Fachgruppe: Numerische Aerodynamik

Sensitivity Analysis of the Synthetic Turbulence Generator for Vortical Flows

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Longitudinal vortices are a common flow phenomenon, emerging downstream of sharp edges and interacting with boundary layers. Accurately predicting the formation and downstream evolution of these vortices is essential for an accurate flow prediction over aircraft. Numerical prediction of longitudinal vortices remains a subject of research, especially due to the unsatisfactory results of RANS modelling [1]. To limit uncertainties associated with complex flow cases, a simplified delta wing test case is investigated (see [1]) using Embedded Wall-Modelled LES (EWMLES).

EWMLES confines the scale-resolving region to the pivotal zones in the domain, with RANS modeling employed across the remaining regions. In contrast to standard non-zonal hybrid RANS-LES methods (HRLM), this strategy demands specific zonal treatment, alongside the introduction of synthetic turbulence at the RANS-(WM)LES interface to accelerate the transition from modelled to resolved turbulence. In such a strategy, the efficacy of RANS-(WM)LES transition is determined by the quality of the injected synthetic turbulence.

The synthetic turbulence generator (STG) of Shur et al. [2] is used in this study. It is based on the superposition of random Fourier modes such that their statistics at the interface are equal to the prescribed Reynolds stress tensor. This study conducts sensitivity analyses on various facets of the STG, with the aim of improving the quality of the synthetic turbulence and thus accelerating the transition to resolved turbulence. Specifically, we investigate the influence of the choice of (i) the length scale and (ii) the energy spectrum when applied to vortical flows.

The length scale in the STG is formulated for boundary layer flows, leaving its applicability to vortical flows uncertain. In the current investigation, we introduce modifications to the length scale in order to evaluate its impact on the development of the longitudinal vortex. To inform our modification, the results of a reference LES simualtion are used to compute the length scale based on the cross-correlation (see Fig. *1*).
Furthermore, the STG formulation adopts a modified Von Kármán spectrum as a target energy spectrum, which reads:

$$E(k) = \frac{(k/k_e)^4}{[1 + 2.4(k/k_e)^2]^{17/6}} f_\eta \, f_{\text{cut}}$$

Where k_e corresponds to the maximum of the spectrum, and f_η and f_{cut} are empirical functions. Although this spectrum is well-suited for 3D turbulence, its applicability to vortical flows, with their effects of rotation on turbulence and quasi-2D behaviour, raises uncertainties. This is assessed by modifying the spectrum to obtain an inertial range with a slope of -3, characteristic of rotating turbulence [3] and indicated by the reference LES results (see *Fig. 1*). Both the standard spectrum and two modified spectra are shown in *Fig. 1*.

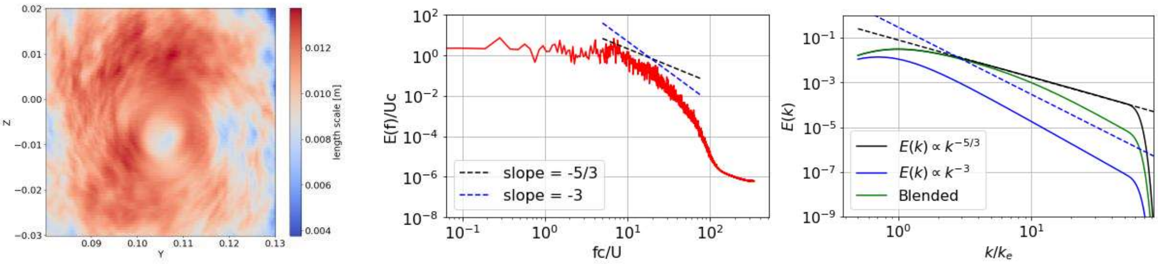

Fig. 1: Turbulent length scale based on the cross-correlation (left). TKE spectrum in the vortex core from the ref LES (middle). Standard Von Kármán spectrum and the proposed modified spectra (right).

The results with the standard STG as well as the modified length scale and energy spectrum are show in Fig. 2. It is observed that the increase of the length scale by a factor two leads to a larger vortex core and larger levels of resolved turbulent kinetic energy. The same is observed for the use of the k^{-3}-spectrum.

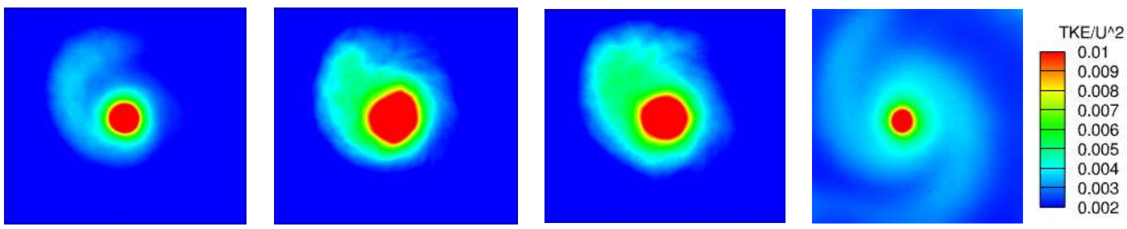

Fig. 2: Normalized TKE of the standard STG (1st column), the modified length scale (2nd column), the modified spectrum of $E(k) \propto k^{-3}$ (3rd column), and the PIV data presented in [1] (4th column).

Through these investigations, this work contributes to the understanding of synthetic turbulence generation and its application to the specific scenario of vortical flows. For the final presentation, results (including the combination of a reduced length scale obtained from the LES reference data and the blended k^{-3}-spectrum) will be shown.

References :

[1] François, D. G., Probst, S., Knopp, T., Grabe, C., Landa, T., & Radespiel, R. (2021). Numerical Simulation of the Streamwise Transport of a Delta Wing Leading-Edge Vortex. *Journal of Aircraft*, *58*(6), 1281-1293.

[2] Shur, M. L., Spalart, P. R., Strelets, M. K., & Travin, A. K. (2014). Synthetic turbulence generators for RANS-LES interfaces in zonal simulations of aerodynamic and aeroacoustic problems. *Flow, turbulence and combustion*, *93*, 63-92.

[3] Yang, X., & Domaradzki, J. A. (2004). Large eddy simulations of decaying rotating turbulence. Physics of Fluids, 16(11), 4088-4104.