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A systematic approach to the generation of synthetic turbulence using spectral methods

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Abstract

In this paper, a systematic discussion on the generation of synthetic turbulence using spectral methods is presented. After a brief introduction which reviews existing methodologies, the role played by the fulfillment of the divergence-free condition and Taylor assumption is investigated. Special attention is given to the case in which such random fields are applied as inflow condition for Computational Fluid Dynamics simulations. Subsequently, a new methodology of general applicability for the generation of synthetic turbulence is proposed. The strength of the new approach lies in its generality and conceptual simplicity. The obtained random field fulfills the divergence-free condition as well as Taylor assumption and it is approximately characterized by preselected spectral content in each spatial direction, so also providing direct control over all turbulence integral scales. Synthetic turbulent fields characterised by different spectral content are generated confirming the soundness of the proposed approach and showing its ability to target strongly anisotropic fields. Finally, some remarks on the generation of inhomogeneous fields, obtained by combination of homogeneous ones, are provided so generalising the proposed procedure.

Keywords: Synthetic turbulence, Random fields, LES, Inflow conditions

1. Introduction

The generation of synthetic turbulent fields is receiving increasing attention in literature due to its wide applicability for the definition of initial and boundary conditions used in Computational Fluid Dynamics simulations. Recently, the spreading of scale resolving turbulence models such as LES and hybrid RANS/LES approaches, fostered by the continuous increase of the available computational power, further raised the attention of the scientific community on such topic.

Numerous research works have been presented throughout the years regarding optimal techniques for the generation of unsteady turbulent inflow conditions and detailed reviews of the state of the art have been presented by Tabor and Baba-Ahmedi (2010) and, more recently, by Wu (2017). Comparisons between currently available methods can be found, for instance, in (Keating et al., 2004; Schluter et al., 2004; Montorfano et al., 2013; Shur et al., 2014; Yan and Li, 2015).

Briefly, it can be said that methodologies are usually subdivided into two main categories: recycling/rescaling methods and approaches which involve the generation of synthetic random fields.

The first category groups techniques in which turbulent fluctuations are extracted from an auxiliary simulation or are continuously recycled within the numerical simulation itself. In its simplest versions, this is usually obtained by building the inflow boundary condition from the velocity field extracted in correspondence of a plane, parallel to the inflow patch, and located downstream with respect to it. Such techniques can incorporate numerous technicalities, such as rescaling operations, aiming at improving the obtained results and have been successfully applied in many circumstances (Lund et al., 1998; Wu, 2017).

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