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Markovian Properties of Velocity Increments in Boundary Layer Turbulence

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Abstract

Markovian properties of the turbulent velocity increments in a flat plate boundary layer at $\mathrm{Re}_\theta = 19\ 100$ are investigated using hot-wire anemometry measurements of the streamwise velocity component in a wind tunnel. Increments of the longitudinal velocities at different wall-normal positions show that the flow exhibits Markovian properties when the separation between different scales, or the Markov-Einstein coherence length, is on the order of the Taylor microscale, λ. The results indicate that Markovian nature of turbulence evolves across the boundary layer showing certain characteristics pertaining to the distance to the wall. The connection between the Markovian properties of turbulent boundary layer and existence of the spectral gap is explored. Markovianity of the process is also discussed in relation to the nonlocal nonlinear versus local nonlinear transfer of energy, triadic interactions and dissipation.

Keywords: Markov theory, turbulence, boundary layer

1. Introduction

Markovian properties of the velocity increments of turbulent velocity fluctuations have recently been investigated for different flows, i.e. high Reynolds number axisymmetric turbulent jet [1, 2], high Reynolds number grid turbulence [3], cylinder wake turbulence[4], fractal-generated grid turbulence [5] and wind turbine array boundary layer [6, 7]. These studies have concluded that statistics of longitudinal velocity increments exhibit Markovian properties when scale difference (or size difference between the scales) approximately equals to the Taylor microscale, λ. This is a common observation even though the flows and Reynolds numbers of investigated cases are different [8].

One of the most difficult aspects of turbulence is existence of a wide range of scales in the flow. The large (integral) scales, which are characterized by the boundary conditions of the flow, are the scales where the turbulence kinetic energy is injected into the flow. The kinetic energy is then transferred from large scales to smaller scales through the turbulence cascade, which forms a hierarchy of scales at different sizes. At the other extreme, the smallest scales (characterized by the Kolmogorov microscale) dissipate the turbulence kinetic energy into internal energy by the action of viscosity. At very high Reynolds numbers, Kolmogorov's classical turbulence theory suggests a layer between the large, energy containing, and small, dissipative scales [9]. This layer is indeed formed by a range of scales which are independent of both extremes of the spectrum and called inertial sublayer.

All fluid motion, whether turbulent or laminar, are governed by the Navier-Stokes equation. The instantaneous, incompressible momentum equations for a Newtonian fluid reads as follows:

$$\frac{\partial \tilde{u}_i}{\partial t} + \frac{\partial \tilde{u}_i \tilde{u}_j}{\partial x_j} = -\frac{1}{\rho}\frac{\partial \tilde{p}}{\partial x_i} + \nu \frac{\partial \tilde{u}_i \tilde{u}_j}{\partial x_i \partial x_j} \tag{1}$$

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