Title: Turbulent Flow through a Degraded Channel Bed

Index No: 145/21/ Maths. /27, Registration No: SMATH1514521

Abstract

This study examines the turbulent flow characteristics in a degraded channel bed based on experimental data. The experiments were performed in the Fluvial Mechanics Laboratory of the Indian Statistical Institute, Kolkata. A Vectrino velocimeter was used to capture the three-dimensional velocity components over a degraded channel bed under equilibrium condition at different spatial locations. The data were further analyzed to investigate structure functions of turbulence, turbulence anisotropy, intermittency, and turbulent bursting phenomena etc.

The streamwise velocity, Reynolds shear and normal stresses, turbulent kinetic energy (TKE), and TKE fluxes were examined and compared with existing literature. For the advancement of the knowledge of flow over a degraded channel bed, the study explored the laws of turbulence and the TKE budget. In pursuit of this, velocity structure functions of turbulence were applied. Second- and third-order streamwise velocity structure functions, along with mixed third-order velocity structure functions, revealed the existence of an inertial subrange. The TKE dissipation rate was estimated using Kolmogorov's 4/5-law and Monin–Yaglom's 4/3-scaling laws of turbulence. The TKE budget analysis showed that near the bed, at the maximum equilibrium depth of degradation, TKE dissipation exceeds TKE production and turbulent diffusion, whereas pressure diffusion exhibits larger negative values. The distributions of anisotropic invariant maps and invariant functions indicated anisotropic turbulence near the bed, while above the initial bed level (measured before degradation takes place), turbulence tended toward three-dimensional isotropy.

Furthermore, the velocity data were processed to examine the vertical distributions of turbulence indicators and turbulence length scales at different locations of flow through a degraded channel bed. The primary focus of this study was to investigate the influence of bed degradation on flow intermittency and turbulence anisotropy using high-order structure functions and their scaling exponents. The extended self-similarity (ESS) technique was employed to estimate the scaling exponents of high-order structure functions. The results showed that below the initial bed level, the scaling exponents deviated significantly from the theoretical (K41) values, indicating enhanced intermittency. Moreover, data were analyzed to determine the scaling exponents of mixed higher-order structure functions. In this regard, $SO(3)$ symmetry decomposition was utilized to differentiate between the isotropic and anisotropic components of the scaling exponents. The anisotropic scaling exponents obtained from high-order mixed structure functions exhibited higher values than that of their isotropic parts, demonstrating flow anisotropy.

Finally, an in-depth analysis was conducted on the conditional statistics of streamwise and vertical velocity components, Reynolds stresses, and turbulent kinetic energy fluxes. Additionally, the percentage occurrence, mean duration, and frequency of bursting events within each quadrant were examined. The primary objective of this analysis was to establish a definition framework for averaging methods of quadrant analysis of turbulence over a degraded channel bed and the results were compared systematically. The findings revealed the presence of a top layer where flow properties closely resembled those of the incoming flow, as well as a mixing layer near the initial bed elevation. Near the bed, sweeps were dominant, whereas ejections became more prevalent at higher elevations.

Keywords: Turbulent flow characteristics; Open channel flow; Laws of turbulence; Structure functions; Turbulence anisotropy; Intermittency; Degraded bed flow; Bursting phenomena.

Mosedul Sarkar
Signature of Student 25-03-2025

25.03.2025
Signature of Supervisor

सहायक प्राध्यापक / Assistant Professor
भौतिकी एवं अनुप्रयुक्त गणित यूनिट
Physics and Applied Mathematics Unit
भारतीय सांख्यिकीय संस्थान
INDIAN STATISTICAL INSTITUTE
203, बैरकपुर ट्रंक रोड, कोलकाता-700108
203, Barrackpore Trunk Road, Kolkata-700108