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The Diagnostic Plot - Diagnosing and Scaling Turbulence Data

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ABSTRACT

A review of the diagnostic-plot method is proposed at almost 12 years from its introduction at KTH. The method consists in a new way to plot turbulence data and it has provided valuable insights and scaling laws for several canonical flow cases. Despite its empirical nature, it still provides surprisingly good assessments and correlations that can potentially lead to an enhanced understanding of turbulent flows.

1. Introduction

The diagnostic plot was introduced in 2008 [1] during the ICET measurement jamboree (see e.g. Ref. [2]) by the group at KTH as a tool to rapidly assess experimental data from turbulent boundary layers. It is known that whenever new data are retrieved from an experiment, it is of paramount importance to perform some quality control on the measured data. This is typically done by comparing the measured data with previously published results. Unfortunately, for turbulent boundary layers this usually requires the knowledge of the wall shear stress, or rather the friction velocity (usually quantified with a separate experiment with oil-film interferometry, a Preston tube, a wall wire, etc.), and of an accurate determination of the absolute probe position with respect to the wall. While the former is obtained with independent experiments before the characterization of the velocity profiles, the latter must be identified *a posteriori* since the probe support can be deflected by aerodynamic loads [3].

The diagnostic plot was indeed introduced as a scatter plot between the velocity standard deviation and the mean velocity (both normalized with the free-stream velocity in the original diagnostic-plot formulation as shown in Fig. 1, see [4]) and does not require additional information or data fitting based on a prescribed form of the mean velocity nor variance profiles. This provides a rapid approach to quickly assess the quality and collapse of experimental data without the need of elaborate data analysis, explaining the name diagnostic plot.

Similarly to the classical scaling regarding the inner and the outer region of the boundary layer, the diagnostic plot has two distinct regions: an inner region characterized by a sensible Reynolds number dependence in the buffer region, and an outer region where the data collapses for sufficiently large Reynolds number. This latter region is the most interesting one since it covers a large part of the boundary-layer thickness and it is prone to be described universally. For instance, Alfredsson et al. [5, 6] analyzed this outer region with a modified version of the diagnostic plot (the ordinate was replaced by the ratio between the velocity standard deviation and the local mean velocity rather than the free-stream velocity as shown in Fig. 2), and the authors were able to provide predictions about the emergence of an outer peak in the velocity variance distribution located further away than the near-wall peak. In this modified form, the diagnostic plot of several datasets collapsed in the outer region into a straight line, facilitating the development of empirical correlations for pipe, channels and turbulent boundary layer flows. Interestingly, such scaling structure has been also verified for higher-order statistics [7] providing new rationale in the statistical structure of turbulent flows.

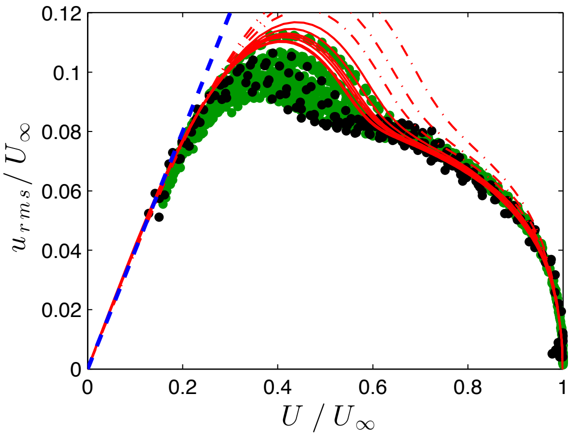

Fig. 1 Example of the diagnostic plot with turbulent boundary-layer data covering two orders of magnitude in Reynolds number in the original form presented in Ref. [1].

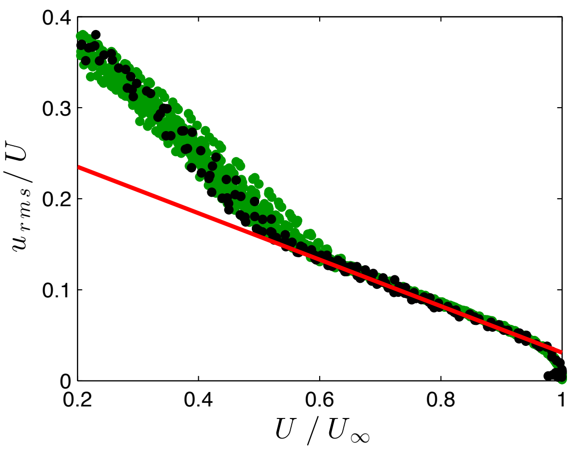

Fig. 2 Same data as in Fig. 1 but presented in the modified form, as described in Refs. [5, 6].

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Several other works have been performed in the last decade, as for instance for turbulent boundary layers over rough surfaces [8], with pressure gradients [9, 10, 11] and even in free-shear flows [12]. Despite the fact that the approach has an empirical nature, it is a valuable asset in the experimental analysis.

2. Concluding Remarks

Our aim with this contribution is to review and summarize the origin and the scientific progress related to the diagnostic-plot approach and to highlight new future directions of this groundbreaking analysis method.

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