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Insights for Modelling Turbulence in a Backward-Facing Step Flow in a Narrow Channel

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Extended Abstract

Turbulent backward-facing step (BFS) flows in narrow channels apply to scenarios where the aspect ratio (channel width to depth ratio of the expanded channel) is less than 10. While such flows may be prevalent in practical cases such as compact cooling devices and turbine blade cooling channels with ribs, detailed experimental flow measurements are relatively expensive and rare [1, 2]. To facilitate parametric design at an amenable cost, it is imperative to employ appropriate tools that model the turbulent flow field. This is particularly important due to the complicated flow phenomena of the recirculation region, where flow separation is rampant and deterministic of the associated pressure differential cost of the flow system. However, current turbulent modelling tools are not sufficiently tuned for such a complex flow. This work is aimed at addressing this need. To that end, multicomponent velocity measurements of the flow field in the recirculation region of a narrow-channelled BFS are obtained and assessed to provide insights into how turbulence may be modelled.

The experimental data is obtained using two-dimensional two-component high resolution particle image velocimetry. The measurements were conducted in an optically accessible channel, designed to simulate a closed BFS of step height h, aspect ratio 7.7 and expansion ratio 1.25. With the Reynolds number of the in-coming flow based on the maximum streamwise velocity and h at ~6200, turbulent flow in the channel was assured. Measurements across multiple spanwise planes of the recirculation region were subsequently obtained and evaluated. This was done to specifically study low and high-order moment turbulence statistics of the flow field relevant for turbulent modelling.

The results show intricate and distinctive trends of the turbulent eddy viscosity, Prandtl mixing length, and coefficients of the Kolmogorov-Prandtl (K-P) expression for single and two-equation models. In the separated region, the eddy viscosity distributions in the wall-normal direction vary most with distance from the step up to $0.3h$. The profiles are different from other flows. Notably, they deviate remarkably from that observed in a turbulent boundary layer (TBL) flow, with maximum values far exceeding it as well as that of a wide-channelled BFS flow [3]. The mixing length profiles over the bottom wall are, on the other hand, similarly distributed in the streamwise direction. However, when assessed as a length scale in the K-P expression, the mixing length yields a coefficient that is not unity. The evaluation of planar estimates of the production and dissipation of energy yield coefficients of the K-P expression that are also non-uniform. They also suggest that underlying basis of a Smagorinsky-Lilly large eddy simulation model is inapplicable in the separated region of a narrow-channelled BFS flow.

These results reveal that for narrow-channelled BFS flows, a single-equation turbulence model may be appropriately used to provide acceptable simulations. However, much more complex accounts of Reynolds stresses should be considered for accurate predictions of eddy viscosity-based turbulence models.

References

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