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Reduction of the Recirculation Region of a Backward-Facing Step Flow

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Extended Abstract

Backward-facing step flow is a common flow phenomenon in engine inlets, combustor flame holders, and turbine blades. The flow is generally associated with an upstream flow that results in a separated shear layer as the flow transcends the step. Beneath this shear layer is a recirculation region characterized by a system of vortices whose extent is a function of the geometry of the flow system and the inlet flow conditions. As the recirculation region can be a zone of unwanted localized heating / cooling and a major contribution to head losses, it is often desirable to reduce the extent of this region through active or passive means. A number of numerical studies have shown the prospect of using porous-like inserts to achieve this purpose at minimal differential pressure cost. However, this has been analysed mostly for laminar flows [1, 2]. Studies of turbulent flow with porous inserts in backward-facing step flows are rare [3]. To fill this apparent need, an experimental study of the reduction of the recirculation region for a turbulent flow using a thin porous insert is presented.

The study is accomplished using an open channel backward-facing step flow system in a flume. The expansion ratio (*i.e.* expanded depth to upstream depth ratio) of the system is 1.3 and the aspect ratio (*i.e.* ratio of channel width to step height h) is 3.1. With a downstream depth of approximately 0.1m and the maximum velocity of the approach flow 0.280m/s, the Froude number and the Reynolds number (based on maximum velocity and step height) is maintained at ~ 0.28 and 6900 respectively. A porous mat is installed behind the step. The mat is of open surface area 40%, filling fraction 3%, length $8h$, thickness $0.12h$, and covering the entire width of the test channel. The effect of the porous mat is tested by modifying the location of the mat at $6h$ and $3h$ respectively. The results are compared with measurements without any porous insert. The measurements are based on velocity data obtained from the application of a high-resolution planar particle image velocimetry in multiple planes within the recirculation region, and along the central span of the channel flow.

An examination of the reattachment lengths of the test results show that by locating the porous insert at a streamwise distance of $6h$ or less behind the step, the streamwise extent of the recirculation region can be reduced. While this reduction is only marginal when the porous insert is located at $6h$, it is over 20% at $3h$. At the reattachment region, the increment in mean wall-normal velocity due to the porous mat is significant, as are the decrements of turbulence intensities and Reynolds stresses. Consequently, there is a significant cut-back in the production of turbulence kinetic energy due to the presence of the porous insert. Regardless of these differences, the transport of turbulence kinetic energy appears to be unaffected by the presence of a porous insert. Two-point correlations of the velocity fluctuations show that the sizes of the coherent structures and their convection by the mean flow are not significantly modified by the porous inserts. Overall, the flow data obtained reinforces the potential effectiveness of porous inserts being used to enhance efficiencies of backward-facing step flow systems.

References

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