World Academy of Science, Engineering and Technology
International Journal of Aerospace and Mechanical Engineering
Vol:18, No:08, 2024

Modeling of Turbulent Flow for Two-Dimensional Backward-Facing Step Flow

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Abstract : This study investigates a generalized hydrodynamic equation (GHE) simplified model for the simulation of turbulent flow over a two-dimensional backward-facing step (BFS) at Reynolds number Re=132000. The GHE were derived from the generalized Boltzmann equation (GBE). GBE was obtained by first principles from the chain of Bogolubov kinetic equations and considers particles of finite dimensions. The GHE has additional terms, temporal and spatial fluctuations, compared to the Navier-Stokes equations (NSE). These terms have a timescale multiplier τ, and the GHE becomes the NSE when τ is zero. The nondimensional τ is a product of the Reynolds number and the squared length scale ratio, $\tau=Re*(l/L)^2$, where l is the apparent Kolmogorov length scale, and L is a hydrodynamic length scale. The BFS flow modeling results obtained by 2D calculations cannot match the experimental data for Re>450. One or two additional equations are required for the turbulence model to be added to the NSE, which typically has two to five parameters to be tuned for specific problems. It is shown that the GHE does not require an additional turbulence model, whereas the turbulent velocity results are in good agreement with the experimental results. A review of several studies on the simulation of flow over the BFS from 1980 to 2023 is provided. Most of these studies used different turbulence models when Re>1000. In this study, the 2D turbulent flow over a BFS with height H=L/3 (where L is the channel height) at Reynolds number Re=132000 was investigated using numerical solutions of the GHE (by a finite-element method) and compared to the solutions from the Navier-Stokes equations, k–ε turbulence model, and experimental results. The comparison included the velocity profiles at X/L=5.33 (near the end of the recirculation zone, available from the experiment), recirculation zone length, and velocity flow field. The mean velocity of NSE was obtained by averaging the solution over the number of time steps. The solution with a standard k −ε model shows a velocity profile at X/L=5.33, which has no backward flow. A standard k−ε model underpredicts the experimental recirculation zone length X/L=7.0∓0.5 by a substantial amount of 20-25%, and a more sophisticated turbulence model is needed for this problem. The obtained data confirm that the GHE results are in good agreement with the experimental results for turbulent flow over two-dimensional BFS. A turbulence model was not required in this case. The computations were stable. The solution time for the GHE is the same or less than that for the NSE and significantly less than that for the NSE with the turbulence model. The proposed approach was limited to 2D and only one Reynolds number. Further work will extend this approach to 3D flow and a higher Re.

Keywords : backward-facing step, comparison with experimental data, generalized hydrodynamic equations, separation, reattachment, turbulent flow
Conference Title : ICTFT 2024 : International Conference on Turbulent Flows and Turbulence
Conference Location : London, United Kingdom
Conference Dates : August 22-23, 2024