An Improved Coupled Solver in OpenFOAM for Simulation of Low Wind-Speed Flows in Built Environment

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Abstract

Computational fluid dynamics (CFD) is becoming a popular tool for predicting wind and temperature distributions in the built environment. Many regulatory bodies require the wind pattern information from CFD as one of their criteria for the evaluation of the building design. However, most CFD studies simulate the atmospheric boundary layer (ABL) without considering correctly, the different stratification effects happening at different times

The planetary boundary layer height (PBLH) varies during the day. It can be of the order of several kilometers during noon (unstable stratification) and reduce to a few hundred meters during night-time (stable stratification). However, it is computationally expensive to simulate the entire PBLH in highly dense built-up areas. As a result, most CFD simulations are restricted to the simulation of the atmospheric surface layer (ASL), ~ 0.1 times the height of PBLH. The ASL simulations are usually performed using Reynolds-Averaged Navier-Stokes (RANS) models to reduce computational cost. One of the important requirements for using RANS with ASL is the homogeneity of the wind-speed and turbulence profile in the upstream region. However, in most of these simulations, the wind profile decays in the upstream region due to the over-prediction of turbulence. Many researchers have proposed solutions to avoid the decay of the profile. However, these proposed fixes work only for neutral stratifications.

Monin-Obukhov Similarity Theory (MOST) consistent turbulence models and boundary conditions are an alternative to the usual turbulence models and sand-grain roughness-based wall-function in commercial and open-source CFD codes. The similarity theory condition is valid in both neutral and non-neutral flows. While MOST based models have received tremendous attention in the wind energy community, they are not well-known in the urban and built environment community. This study proposes the implementation of a MOST framework coupled solver, turbulence model, and boundary condition in the open-source code OpenFOAM for simulation of neutral and non-neutral stratifications. The verification cases show that the wind and turbulence profiles did not decay along the fetch for neutral, stable or unstable stratifications. Validation cases are performed at very low wind-speeds and compared with the existing solver in OpenFOAM. The new framework converges significantly faster for stable stratification cases; while for the more computationally challenging and complex unstable stratification cases, the simulation remains numerically stable even under very low wind-speeds (~ 1.0 m/s @ 10 m). Also, the present work introduces the development of a graphical user interface to wrap around the new framework, to make it easier for the end-user to set up and run the simulations.

Keywords: MOST, ABL, CFD, RANS, Built Environment