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INFLUENCE OF BLOCKAGE EFFECT AND OF TURBULENCE INTENSITY ON THE FLOW AROUND U-PROFILE

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Abstract: *The significant distortion of wind tunnel data may occur, when the boundary layer of the tunnel wall interacts and modifies the flow around the tested object. To numerically evaluate the influence of this blockage effect on aerodynamic coefficients, 2D RANS simulations of airflow around porous and non-porous U-profiles in two computational domains with varying distances between the top and bottom walls were carried out. Another factor investigated in relation to aerodynamic characteristics was the turbulence intensity of the inlet stream. Simulations of the U-profile at various impact angles, using two differently sized computational domains and two levels of turbulent intensity, were performed. The mean drag and lift coefficients, fluctuating lift coefficient, and Strouhal number were evaluated.*

Keywords: U-profile, blockage effect, RANS simulation, aerodynamic characteristics, turbulent intensity.

1. Introduction

The aerodynamic characteristics of sharply edged profiles in airflow are measured at our institute using a wind tunnel, where the distance between the top and bottom walls is H=1.9 meters (Hračov and Macháček, 2023). The measured data may be influenced by the blockage effect, which arises from the finite dimensions of the wind tunnel. The presence of a bluff body reduces the tunnel's cross-sectional area, increasing the airflow velocity around the body and distorting the flow pattern. Another important factor influencing the flow characteristics is the inlet turbulence intensity. To assess the influence of the blockage effect and turbulence intensity on previously experimentally tested non-porous and porous U-profiles (with a barrier featuring 50% porosity), 2D flow simulations were performed using the RANS k-ω SST model.

2. Computational settings

The U-profile with both non-porous and porous barriers has dimensions specified in Fig. 1. These profiles were numerically analyzed for various angles of attack within the range of (-12°, 12°) in two computational domains, differing in the spacing between the confining walls. The first domain represents the actual dimensions of the wind tunnel at our institute, with a wall distance of 1.9 meters. In this case, the blockage ratio reaches a minimum value of 8% at zero attack angle.

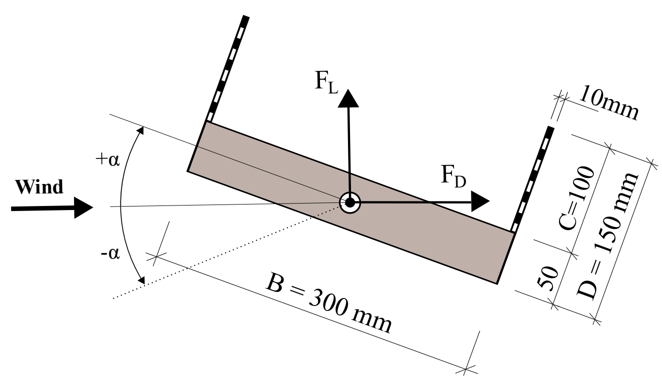

Fig. 1: The geometry of the U-profile.

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This value is non-negligible, considering the recommended maximum blockage ratio of 5% (Koloušek et al., 1983).

The second computational domain, with a width of 7.5 meters, achieves a maximum blockage ratio of 2.8% at a profile rotation angle of 12°, fully complying with the recommended limit. The geometry of the computational domain with a 1.9-meter spacing, along with selected regions of the corresponding computational mesh for the non-porous U-profile, is shown in Fig. 2.

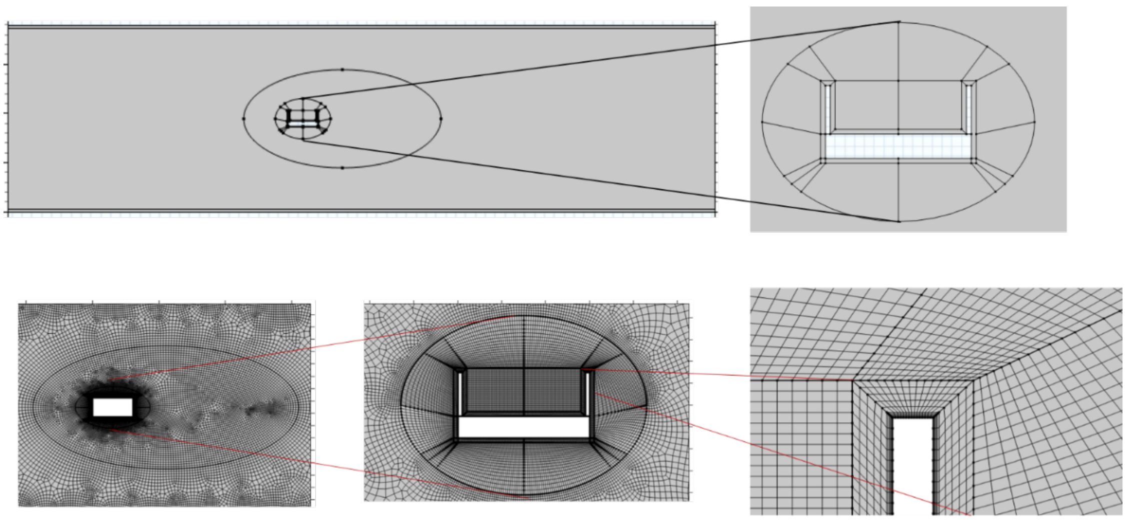

Fig. 1: The geometry and the meshing of the computational domain for non-porous u-profile.

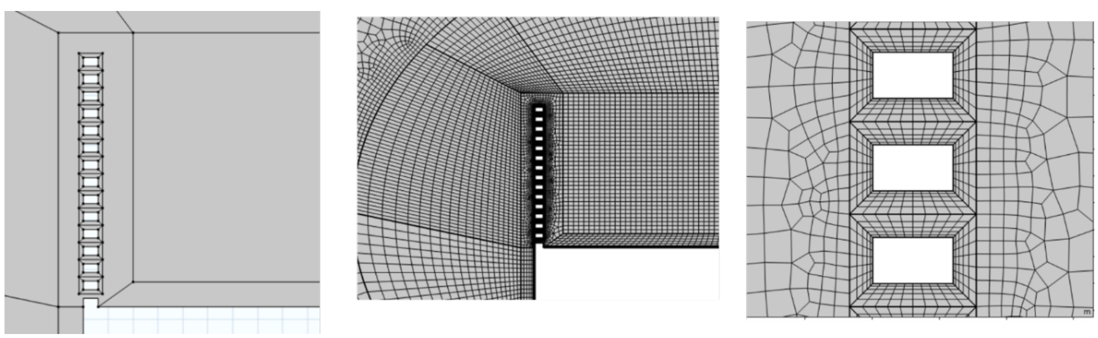

Fig. 2: The geometry and the meshing of the computational domain for U-profile with the flange porosity 50%.

The 2D RANS computations are less computationally demanding compared to 3D LES simulations, where a simplified pressure jump model is often employed to represent the resistance of the porous barrier, enabling acceptable computation times. In our 2D simulations, the geometry and mesh of the U-profile with 50% porosity accurately represent the detailed structure of the porous barrier, as illustrated in Fig. 3. A no-slip boundary condition was applied to the walls of both the modeled body and the wind tunnel's top and bottom walls. Zero pressure was imposed at the outlet, while the turbulence intensity at the inlet was set to 1% and 6%, corresponding to the turbulence levels observed in the experiments (Hračov and Macháček, 2023).

Due to the relatively long computational times required for simulations at each individual angle of attack, with an inlet velocity of v = 14 m/s—matching the velocity used in the wind tunnel experiments by Hračov and Macháček (2023)— an additional study was conducted to assess whether reducing the inlet velocity would significantly affect the aerodynamic characteristics of the investigated body.

3. Results

The aerodynamic characteristics of the non-porous U-profile were calculated at inlet velocities of 14 m/s and 2.8 m/s in a computational domain corresponding to the actual wind tunnel dimensions, for selected angles of attack of -9°, 0°, and 5°. The simulations were set to model 25 seconds and 5 seconds of flow development for inlet velocities of 2.8 m/s and 14 m/s, respectively. As shown in Fig. 4, the reduction in velocity—and consequently in Reynolds number—does not significantly affect the aerodynamic characteristics of the non-porous U-profile. Therefore, to reduce computational time, an inlet velocity of 2.8 m/s was used in subsequent simulations investigating the blockage effect.

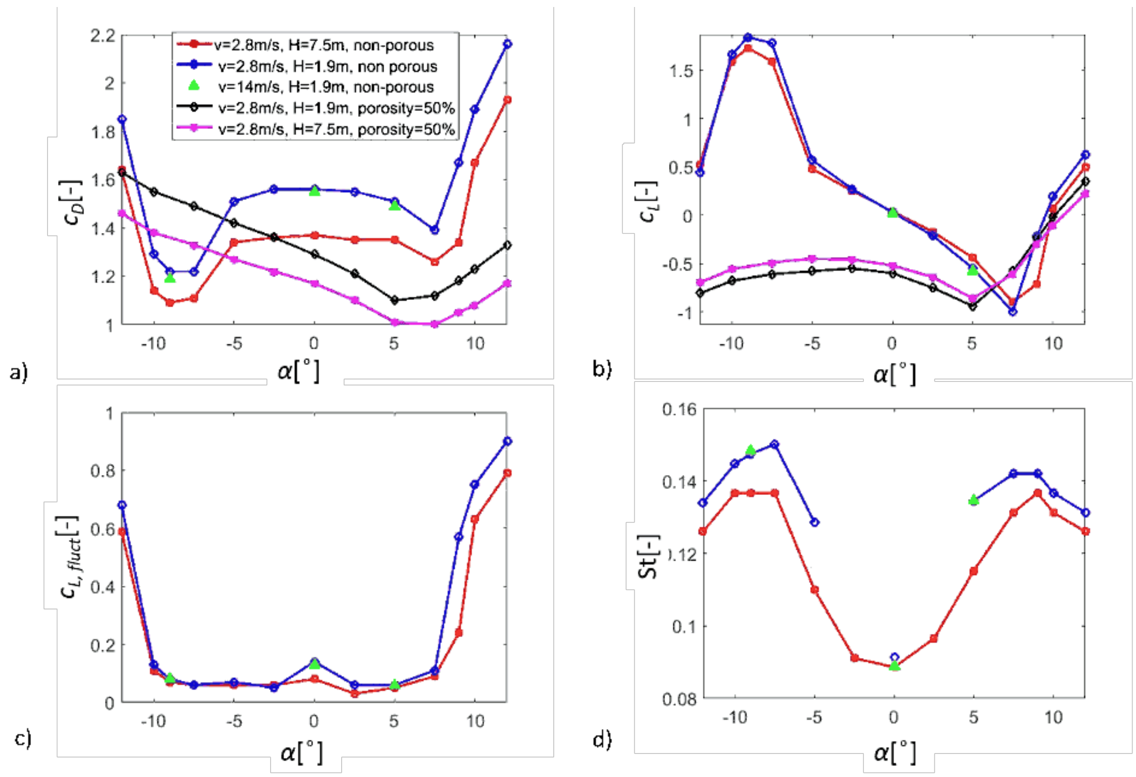

Fig 4: The dependence of the mean drag coefficient (a), the mean lift coefficient (b), the fluctuating lift coefficient (c) and Strouhal number (d) on the distance of confined walls for the flow around the non-porous and porous u-profile.

The comparison of curves calculated for the non-porous U-profile in computational domains with different wall distances and an inlet velocity of 2.8 m/s, as shown in Fig. 4, indicates that the presence of confined walls in the wind tunnel increases the mean drag coefficient, the fluctuating lift coefficient, and the Strouhal number. Moreover, the lift coefficient curve exhibits more pronounced extrema. These findings are consistent with results obtained for a U-profile of different geometry, with dimensions C = D = 75 mm (Ledvinková et al., 2024).

For the U-profile with 50% porosity, the drag coefficient exhibits a significant increase in the computational domain with a wall distance of 1.9 meters compared to the domain with a wall distance of 7.5 meters across all angles of attack. An increase in the lift coefficient was also observed for both negative and positive angles of attack up to 5°. Since the fluctuating lift coefficient approached values close to zero, the curves for the fluctuating lift and Strouhal number are not presented for the porous U-profile in Fig. 4.

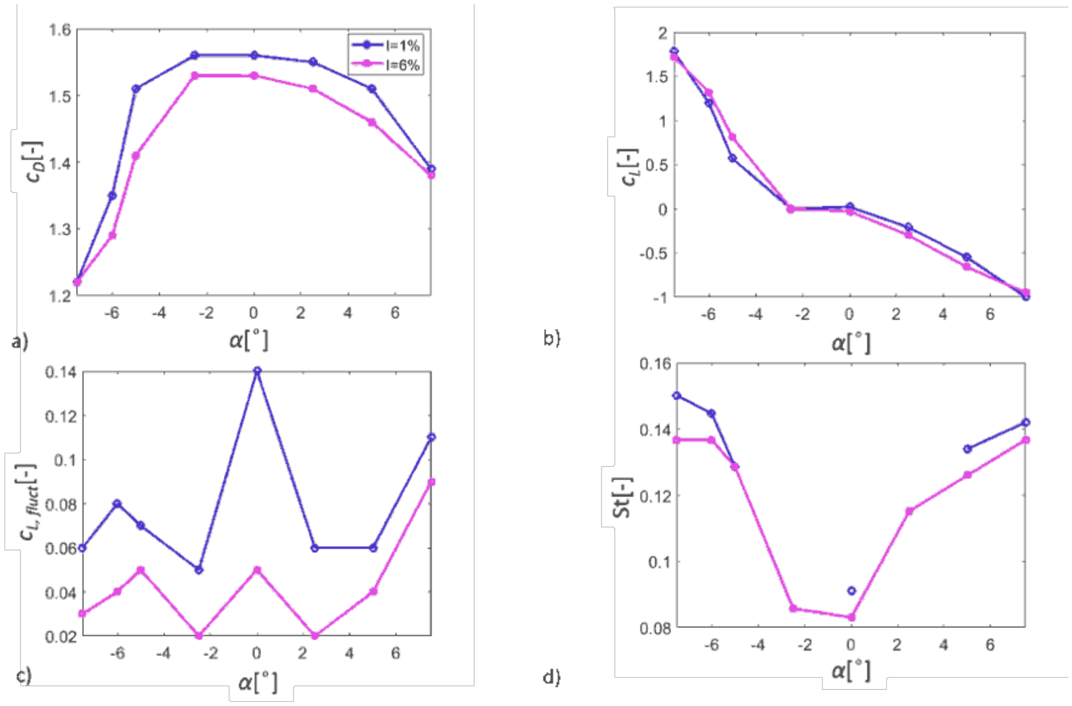

Fig 5: The dependence of the mean drag coefficient (a), the mean lift coefficient (b), the fluctuating lift coefficient (c) and Strouhal number (d) on the turbulent intensity for the flow around the non-porous u-profile in the domain with wall distance 1.9m.

Fig. 5 presents the results of simulations for the flow around the non-porous U-profile in the computational domain with a wall distance of 1.9 meters and an inlet velocity of 2.8 m/s, for turbulence intensities of 1% and 6%. The results clearly demonstrate that an increase in turbulence intensity reduces the drag coefficient and Strouhal number while suppressing lift fluctuations.

4. Conclusions

The influence of the blockage effect and turbulence intensity on the aerodynamic coefficient of porous and non-porous U-profiles was numerically evaluated. The obtained data will be further compared with experimental results to derive appropriate correction factors for the measured data.

Acknowledgements

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