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DETERMINATION OF AERODYNAMIC COEFFICIENTS FOR AIR FLOW AROUND U-PROFILES WITH DIFFERENT FLANGE POROSITIES

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Abstract: *Our contribution presents the comparison of the experimental investigations and of the numerical 2D simulations of the air flow around U –profiles having different flange porosities. The U-shaped beams were exposed to the air flow having a given velocity at different angles of the wind attack for obtaining the curves of the aerodynamic coefficients depending on the impact angle. The numerical simulations of the wind tunnel testing were performed using the Unsteady Reynolds Averaged Navier-Stokes (RANS) method, k-ω SST turbulence model was assumed.*

Keywords: U-shaped beams, Porosity, Wind tunnel, RANS simulation, k-ω SST model.

1. Introduction

Our contribution deals with the study of the airflow around the bluff bodies represented by U-profiles with the side ratio SR=2 and with the inner depth corresponding to ½ of the short side and with the subsequent evaluation of the aerodynamic drag and lift coefficients. The effect of the air flow impact angle α on aerodynamic characteristics needed in evaluation of the proneness of the rectangular body to the galloping was investigated by many authors in last years (cf. Mannini et al., 2017; Patruno et al., 2016; Guissart et al., 2019). The flow around U-profiles with the constant side ratio 2 differing in the inner depth of their vertical sides and the effect of the porosity or their flanges was studied in the wind tunnel by Hračov and Macháček, (2020). Here, we present numerical simulations of the air flow around U-shaped beams with the same geometry and compare our results with their experimental ones.

2. Computational settings

The 2D Unsteady Reynolds averaged Navier-Stokes (URANS) simulations of the airflow around the bluff bodies were performed in this study using k-ω SST model, cf. (Menter, 1994). URANS simulations are based on averaged continuity and Navier-Stokes equations, the k-ω SST model introduces two additional differential equations for the turbulence kinetic energy and the specific dissipation rate needed for the turbulence modelling. Due to the switching function k-ω SST model combines the Wilcox k-ω model suited for modelling of the flow in the viscous sublayer near the walls and the robustness of k-epsilon models in the free air flow. The Comsol Multiphysics software was used in our simulations.

The air flow around the U-profile with SR=2 (30/15cm) with the inner depth D_b equal to 7.5cm at different angles of attack was simulated. The investigated U-profile beam was placed into the larger square computational domain 15x15m in order to suppress the blockage effect. The position of the U-profile in the computational domain is apparent from Fig.1.

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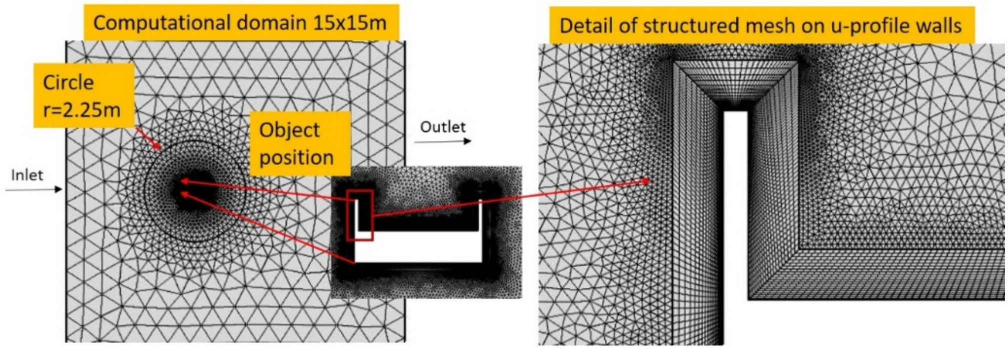

Fig.1: Computational mesh used for URANS simulations (taken from Ledvinková et al., 2021).

The computational mesh consists of the structured and unstructured parts. The circle surrounding the U-profile in Fig. 1 is filled with the unstructured mesh with finer resolution and the remaining computational domain with the unstructured mesh having the coarser resolution. The neighbourhood of the walls of the U-profile walls consists of the structured mesh. The width of the first cell layer centre adjacent to the U-profile wall needs to be placed in log-law region in order to obtain correct results. This requirement is fulfilled when the value of the wall resolution $y^+ \approx 1$ for the most of the cells on the walls of the investigated body. This arrangement was used for the simulation of limit cases when the porosity of flanges $\varepsilon = 0$ corresponding to the “filled” U-profile and $\varepsilon = 1$ corresponding to the rectangle with side ratio SR=4 (30x7.5cm).

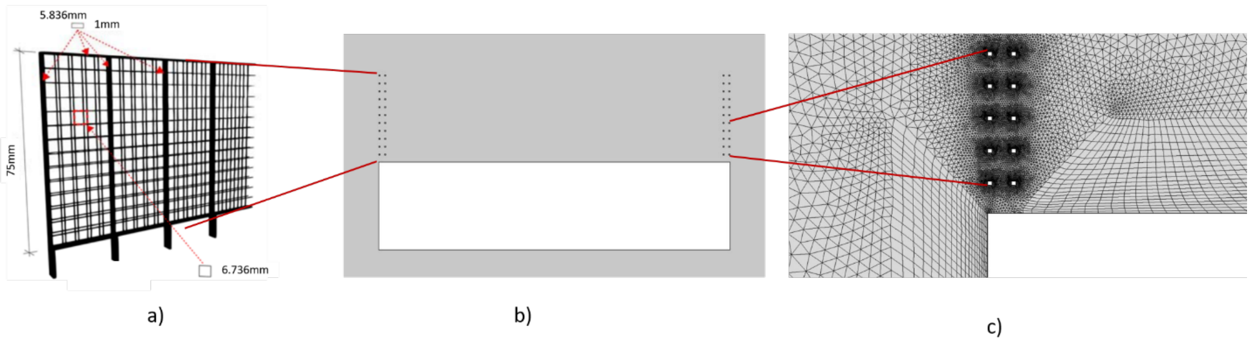

Fig.2: a) Porous plastic net used in wind tunnel testing (porosity ε=0.75), b) geometry of porous flanges used in 2D simulations, c) detail of the mesh surrounding porous flanges.

In experiments the porous flanges of the U-profile beam were built from two plastic nets glued on frontal and rear sides of a tiny plastic frame in order to secure a sufficient stiffness of the flanges see Fig.2a. For the purposes of our 2D simulations, the arrangement of porous nets was projected into 2D space. The 2D cut through the original net results in the barrier consisting of the system of small solid rectangles corresponding to the plastic net as seen in Fig2.b. The vertices of small rectangles corresponding to the plastic net are slightly rounded in order to enable meshing software to generate sufficiently fine unstructured mesh in such a way that $y^+ \approx 1$.The details of the mesh are apparent from Fig.2c. The dimensions of the porous net were initially set according to those used in experiments for the porosity $\varepsilon = 0.75$ (cf. Fig.2a), but due to the projection of 3D net into 2D computational space, the porosity in 2D calculations was $\varepsilon = 0.86$ and thus didn’t correspond to this used in 3D experiments. Therefore, the new net dimensions corresponding to the porosity $\varepsilon = 0.75$ in 2D was proposed.

Due to the time demanding computations for the inlet flow velocity 14m/s used in the wind tunnel experiments (Hračov and Macháček, 2020), the velocity of the inlet flow was chosen in our simulations to be 2.8 m/s corresponding to Reynold’s number Re = 2.7e4. This value is similar in other URANS simulations of the air flow around bluff bodies available in literature, cf. (Mannini et al., 2017; Patruno et al., 2016; Guissart et al 2019).

The value of the turbulent intensity was considered to be 1% corresponding to the moderate turbulence level and the value of the turbulent length scale was set equal to 8.2e-4m corresponding to the turbulence eddy viscosity ratio 1. The no slip boundary condition was assumed on the walls of the modelled body and

the zero pressure was imposed at the outlet. The freestream was inclined at the range α = 0-9° in order to obtain the dependence of aerodynamic coefficients on the angle of wind attack, therefore the boundary condition at the top and the bottom wall of the computational domain was set to the open boundary.
The values of the drag and the lift forces were evaluated by the integration of the *x*-and *y* components of the total stress force over all the walls of the investigated body, the effect of the angle of the attack was taken in the consideration.

3. Results

The dependence of the drag and the lift coefficients (c_D and c_L) for the limit case of the U-profile with the porosity ε=1 (corresponding to the rectangle with the side ratio 4) obtained by simulations (sr4) and by the wind tunnel measurements (sr4_exp) is shown in Fig.3. These results are compared with curves published in literature (Guis_exp, Guis_urans, Guis_ddes) (Guissart et al, 2019). As evident the curves show qualitatively same trends, the curves of the drag coefficient are all slightly increasing with the increasing impact angle and on the curves of the lift coefficient occurs maximum, but its position differs for various curves.

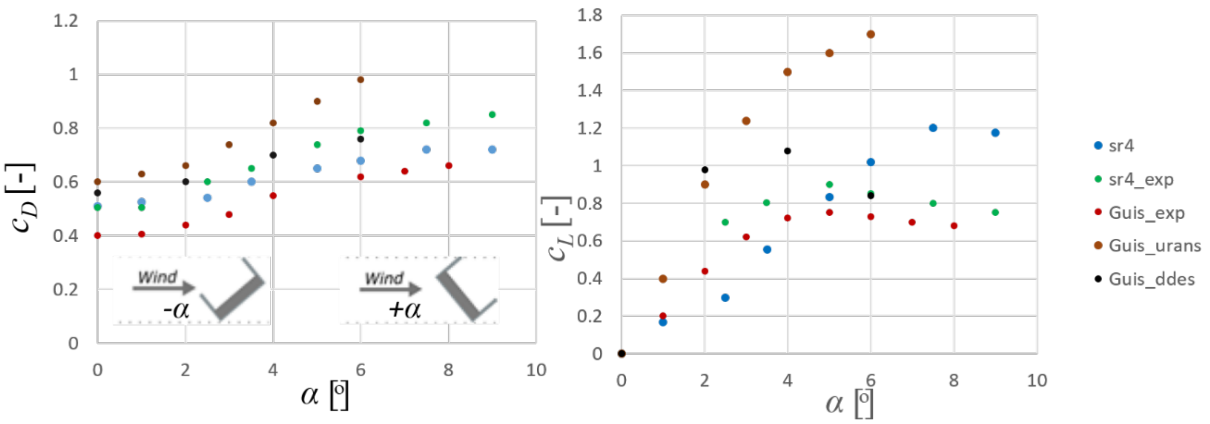

Fig.3: Drag and lift coefficient for the rectangle having side ratio 4- comparison of results obtained by our simulations (sr4), in wind tunnel (sr4_exp) and from literature (Guissart et al., 2019).

The results of simulations of the air flow around U-profile beam with the porosities of the flanges ε=0, ε=0.75, ε=0.86, ε=1 (corresponding to the rectangle with side ratio 4) and around the rectangle with side ratio 2 can be seen in Fig 4.

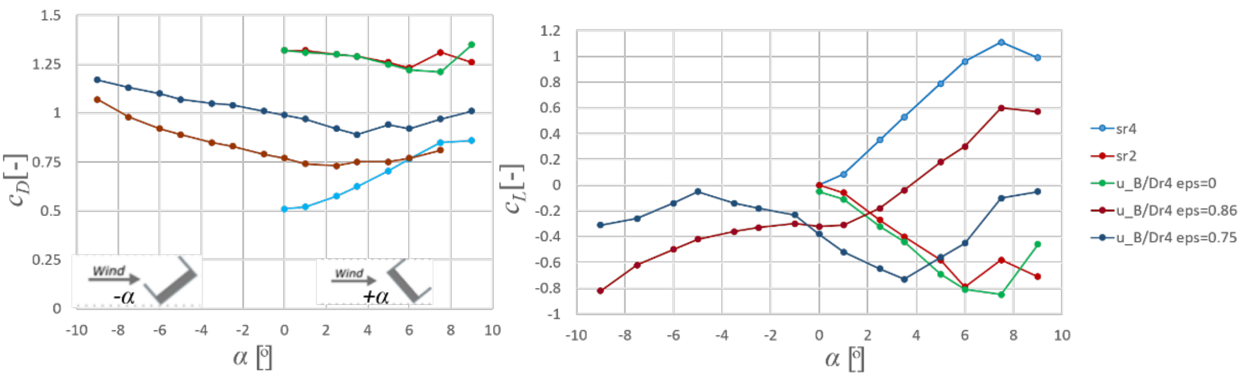

Fig.4: Drag and lift coefficient- the results calculated by the URANS simulations using k-ω SST model for different values of flange porosities.

Fig. 5 shows the comparison of the numerical and experimental results for selected values of U-beam porosities. The values of aerodynamic coefficients for rectangles and U-profile with zero porosity were calculated only for positive angles of attack due to assumption of their symmetric values in the case of rectangles and due to the high computational time for the non-porous U-beam. As evident, the simulation and experimental curves in Fig.5 are predominantly in a good agreement, the worse correspondence was detected for both aerodynamic coefficients for the porosity ε=0.9 in 3D measurements compared with ε=0.86 in 2D simulations. The possible reason of the worse correspondence should be the effect of different values of Reynolds number used in simulations and in experiments.

The increasing flange porosity causes the decrease of the value of the drag coefficient, this effect is more pronounced in simulation results, while there is only small difference in experimentally measured values of the drag coefficient for porosities ε=0.75 and ε=0.9. The values and the slope of the lift coefficient curve for ε=0.86 calculated by numerical simulation differs from that one for ε=0.9 obtained by measurement and also from the numerical results for ε=0.75. In case of experimentally measured curves the difference between values of lift coefficient curves for ε=0.75 and ε=0.9 is smaller.

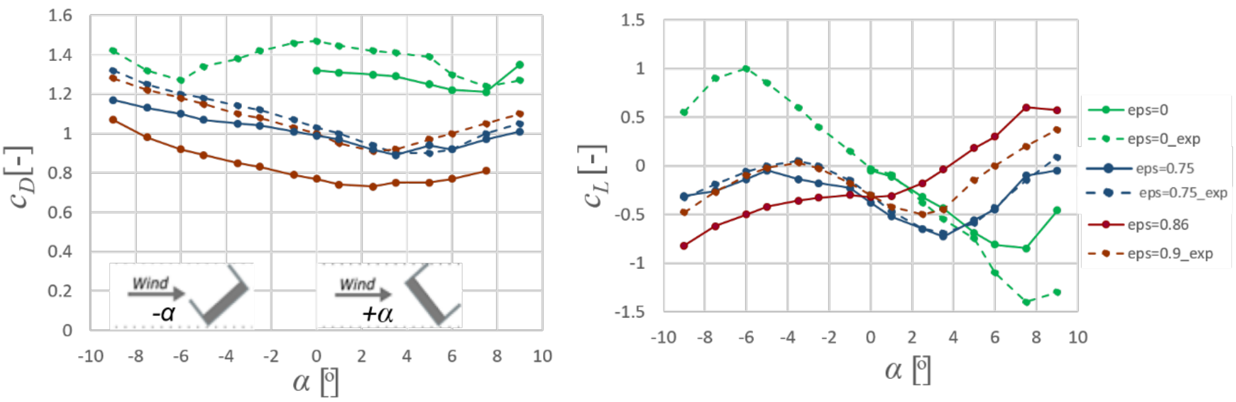

Fig.5: Drag and lift coefficient- comparison of simulation results and values obtained by static measurements in the wind tunnel for different flange porosities.

4. Conclusions

The results of our simulations show qualitatively same trends for the drag and the lift coefficients depending on the impact angle for the most of the analysed U-profile cross-sections as the experimental results obtained by the static measurement in the wind tunnel.

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