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Numerical study of the air flow around the U-profile

B. Ledvinková[a], S. Hračov[a], M. Macháček[a]

[a] *Institute of Theoretical and Applied Mechanics, Czech Academy of Sciences, Prosecka 809/76, 190 00 Prague 9, Czech Republic*

Our contribution deals with the 2D numerical study of the airflow around the bluff bodies represented by U-profiles and by rectangles having side ratios 2 and 4 and with the subsequent evaluation of the aerodynamic drag and lift coefficients needed for the determination of their proneness to the self-excited transverse galloping. Transverse galloping is a kind of the aeroelastic instability occurring at bluff cross-section bodies characterised by the large amplitude oscillations with the low frequency, perpendicular to the direction of the air flow. These oscillations emerge after the critical wind velocity is exceeded. The susceptibility of rectangles and U-profiles to the galloping was evaluated on the basis of the quasi-steady theory with the help of the den Hartog instability criterion in the proximity of the zero impact angle [1]

$$\left(\frac{dC_L}{d\alpha} + C_D\right) < 0, \tag{1}$$

where C_D is the drag coefficient, C_L is the lift coefficient and α is the angle of the attack.

The effect of the air flow impact angle α on aerodynamics characteristics needed in evaluation of the proneness of the body to the galloping was investigated by many authors. The dependence of the drag and lift coefficients for the rectangle with the side ratio SR=5 was measured by Mannini et al. [4]. Patruno et al. [6] investigated the effect of the impact angle on the drag and the lift coefficient for values α=0.1° and 4° both experimentally and by the Unsteady Reynolds averaged Navier-Stokes (URANS) and Large Eddy simulations (LES) for the rectangle with the same side ratio. Guissart et al. [3] presented experimental results and the results of URANS and DDES (Delayed Detached Eddy) simulations for the dependence of aerodynamics coefficients on the angle of attack for rectangle having side ratio SR=4. The flow around U-profiles was investigated experimentally and by CFD simulations by Strecha et al. [7].

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 [5]. 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 rectangles with side ratios SR=B/D =2 (30/15cm) and SR=4 (30/7,5cm) and 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 see Fig 1. Subsequently, the drag and lift coefficients needed for den Hartog instability criterion were evaluated.

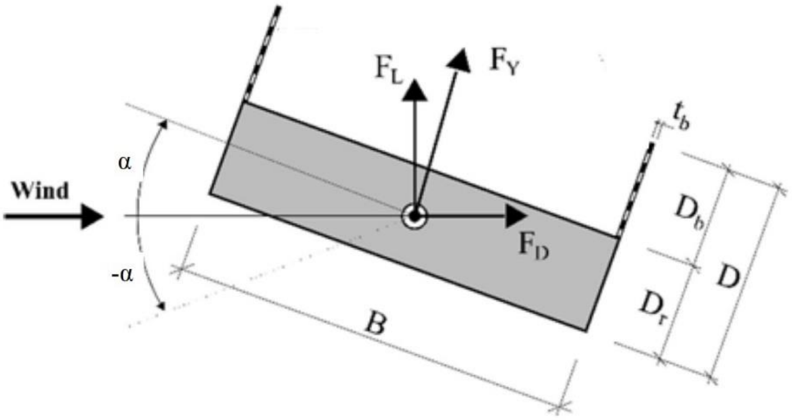

Fig. 1. U-profile layout (taken from [2])

The rectangles and the U-profile were placed into the larger square computational domain 15x15m in order to supress the blockage effect. The position of the rectangle/U-profile in the computational domain is apparent from Fig.2. The computational mesh consists of the structured and unstructured parts. The circle surrounding the rectangle/U-profile in Fig. 2 is filled with the unstructured mesh with finer resolution and the remaining computational domain with the unstructured mesh having the coarser resolution, cf. Fig. 2. The width of the first cell adjacent to the rectangle/U-profile wall was set to a value providing wall resolution $y^+ \approx 1$ for the most of the cells on the walls of the investigated bodies.

Due to the time demanding computations for the inlet flow velocity 14m/s used in the wind tunnel experiments [2], 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 was also used in similar studies [3,6]. 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 $\alpha = 0\text{-}9°$ 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.

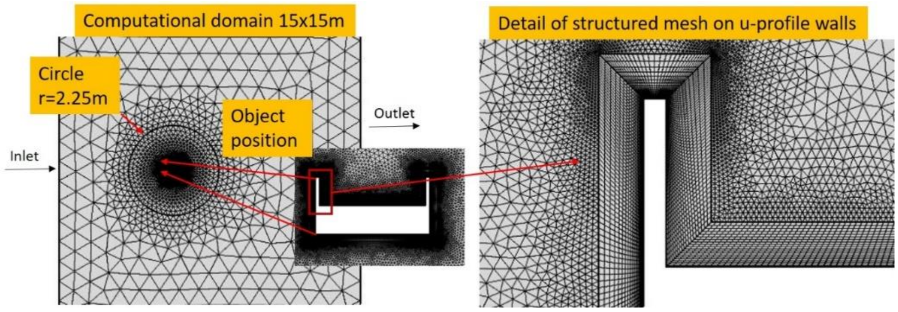

Fig. 2. Computational mesh used for URANS simulation

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 coefficients. The drag and lift coefficients were calculated according to equations.

$$C_D(\alpha) = \frac{2F_D(\alpha)}{\rho U^2 D} \ , \tag{2}$$

$$C_L(\alpha) = \frac{2F_L(\alpha)}{\rho U^2 D} \quad , \tag{3}$$

where F_D and F_L are the drag and lift forces, ρ is the air density, U is the mean air velocity and D is the cross wind dimension.

The results of our simulations mapping the dependence of the drag and lift coefficients on the impact angle were compared with the experimental ones obtained by the static measurement in the wind tunnel [2] as demonstrated in Fig. 3.

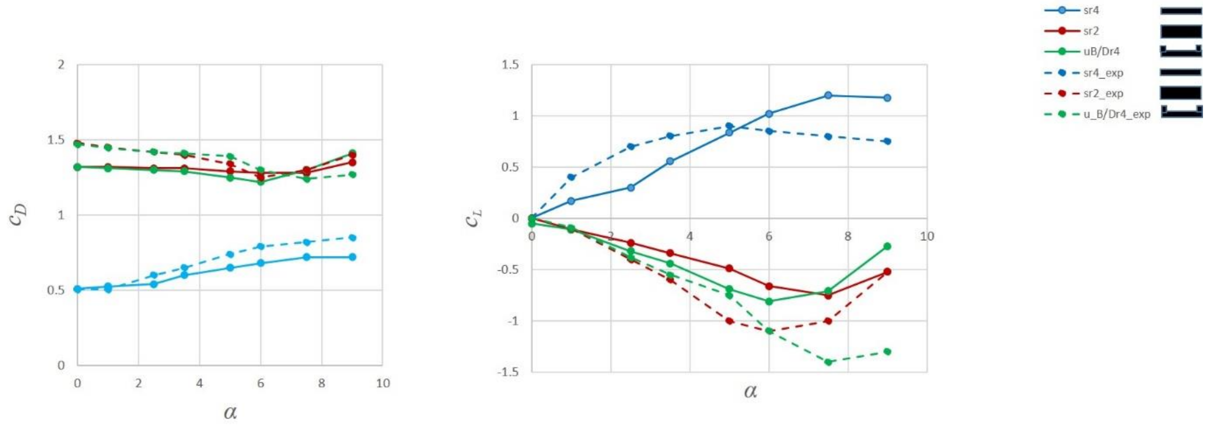

Fig. 3. Drag and lift coefficients- comparison of the results calculated by the k-ω SST model and values measured in the wind tunnel

The results of our simulations show qualitatively same trends for the drag and the lift coefficients depending on the impact angle for all analysed cross-sections as the experimental results obtained by the static measurement in the wind tunnel [2]. The calculated values of the drag coefficient have more monotonous character compared to measured ones. The calculated lift coefficient corresponds to its experimental value for all bodies with SR=2 only at small angles of wind attack. For angles higher than 5° the difference between experimental and numerical results is evident and is increasing with the increasing impact angle. The slope of the lift coefficient near the zero angle is positive or negative according to the experimental data, but for obtaining its more precise value needed for the evaluation to the proneness to the transversal galloping the simulations with smaller angle step near zero and with negative angles have to be done. The possible effect of the different Reynolds number used in measurements in the wind tunnel and in our simulations should be also taken in account.

The simulations of the U-profiles with porous barriers and their comparison with measured results are planned as the next step needed for the understanding of the proneness of U-profiles to the galloping.

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