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EXPERIMENTAL AND NUMERICAL RESEARCH ON ARCH VORTEX

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Abstract: *This paper presents results from research of a structure in a wake of hyperboloid-shaped body. The research was provided in an experimental and a numerical way, and two models with slightly different surface features were used. The experiment was prepared and provided in a Boundary-Layer Wind Tunnel for subcritical Reynolds numbers by means of Particle Image Velocimetry and the numerical calculation was provided in ANSYS Discovery Aim project system. The aim of this research was to find and describe a 3D vortex structure in its wake called an arch vortex and, on top of this, to suggest a numerical way for the development of a computational model of measured phenomena.*

Keywords: Fluid mechanics, Vortex structures, Wake behind bluff body.

1. Introduction

This paper highlights one of the problems belonging to a category of the flow past the bluff bodies. The model for experimental and numerical research was a hyperboloid-shaped model. The shape of the model was derived from a cooling tower. Or more precisely, two models were used. One of them was a model of the cooling tower with 1:400 scale, and the second one was similar with some different surface features.

The researched area was located in a wake of the model. The first measurements, provided on a large area by means of Particle Image Velocimetry system, indicated a large structure which could be a 3D structure known as an arch vortex. The substantial results which came from later complex research, and confirmed in the wake of the model, were already published and presented partly in papers "Barraclough et al., 2016 & 2017" and particularly in paper "Barraclough et al., 2018". A simplified schematic depicting this arch vortex can be seen in Fig. 1. Similar schematic pictures are usually seen in literature (see f. i. Patteden et al., 2005).

The authors followed up the analysis of the found structure, and also continued with the research based on knowledge gained by other researchers. The literature dealing with the wake behind such an object is not rich, but some interesting topics were published in past years (see paper Tanaka, Murata, 1999).

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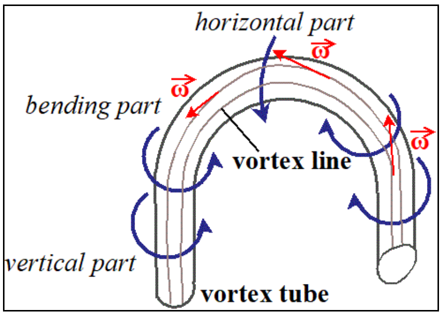

Fig. 1: Simplified detail of the 3D structure found in the wake of the hyperboloid-shaped model. A schema of its shape and a rotational movement.

2. Experimental Equipment

The experimental facility consisted of two Models placed in Boundary Layer Wind Tunnel (BLWT), measured by a system called Particle Image Velocimetry (PIV). The tunnel was designed for simulating atmospheric boundary layer. It is equipped with a special surface helping the development of the boundary layer. This special surface is a foil with regularly placed bumps and this equipment simulates a terrain of the 3rd category, suburbs and unbroken forests, according to the standard for civil engineers. Detailed characteristics of the turbulent boundary layer, its development and other tunnel parameters can be found in Jirsák (2012). The turbulence intensity Tu and Reynolds number of the model used for the experiment are shown in Figs. 2, 3.

The measurements were provided by the PIV system mainly in planes parallel to the ground, in several heights, in the wake area. These measurements provided the results for later vortex filament evaluation.

There were two types of models used for the measurement - both of similar dimensions, but with a few different surface treatments. Model No. 1 (depicted in Fig. 4) is a hollow object, with a so-called vented base. Model No. 2 had the top part and the vented-base covered, so it appeared as a full object. The ratio of the height of the model to the thickness of the modelled boundary layer in the BLWT is $\frac{L}{z_{BL}} = 0.3$. The model blocking of the tunnel ratio was $\frac{S_M}{S} = 0.02$.

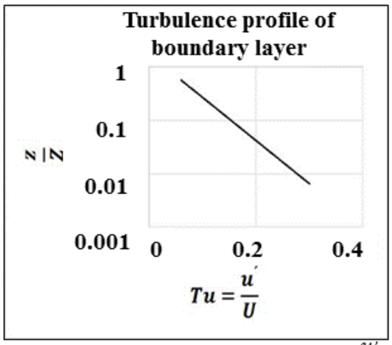

Fig. 2: Level of $Tu = \frac{u'}{U}$ turbulence in the Boundary Layer Wind Tunnel. Data were taken from Jirsák (2012).

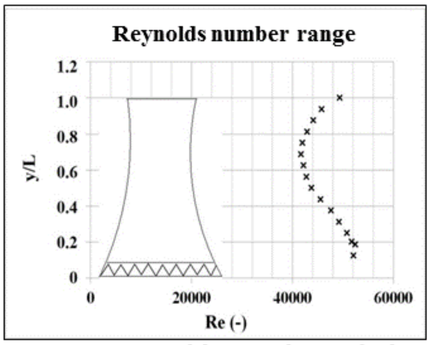

Fig. 3: Reynolds number of the model alongside its height calculated as $Re = \frac{d_z \cdot v_z}{\nu}$, with corresponding diameter and velocity.

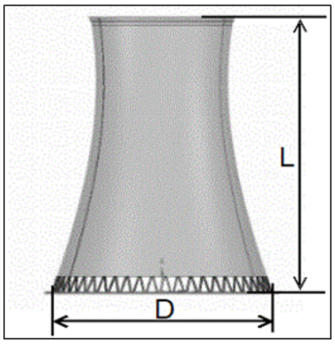

Fig. 4: Model No. 1 with a vented base.

3. CFD

An academic version of ANSYS Discovery Aim project system was used. It allows a user to calculate the number of cells up to 500 000. This limitation leads to a rough solution or probably the failure of a solution, as the flow past such an object might be very complex (especially in the bottom area of Model No. 1). Model No. 1 had to be simplified for CFD because the geometry of puncheons supporting the whole construction was too complicated for use in the academic version of ANSYS. The vented base was left free for flow to go inside the Model, and thus the whole case lost its difficulty in the area close to the bottom. The boundary conditions were as follows: all walls parallel to the flow were set as walls; the Models were set as the wall, both objects with no slip condition. Usual conditions as velocity inlet and pressure outlet were used. Model No. 2, designed for the calculation, corresponds to the measured Model. The mesh was coarse, with the number of cells reaching a maximum of 500000, which made $\frac{yc}{L}$ ratio (cell height to L) large, up to several units of percentage. The boundary conditions were similar to those of Model No. 1. The calculation itself was provided as a steady-laminar case and the $k - \varepsilon$ equations were used. More advanced calculations were done as well, but their solution is not ready for publishing yet.

4. Results and conclusion

PIV measurements provided the results, from which streamlines were calculated and the location of the vortex filament was evaluated. The comparison of the two vortex arches (for Model No. 1 and Model No. 2) showed the significant influence of the Models´ construction on the shape of the arch vortex; the biggest influence can be found at the bottom, caused by the flow through the vented base in the case of Model No. 1. A complicated flow situation caused the bottom part of the arch vortex for Model No. 1 to be locked to the model, while the non-disturbed flow across the bottom part of Model No. 2 with no vented base shifts the ´feet´ of the arch vortex more downstream. This affirmation could be read out from a 3D display of the vortices filaments (Fig. 5).

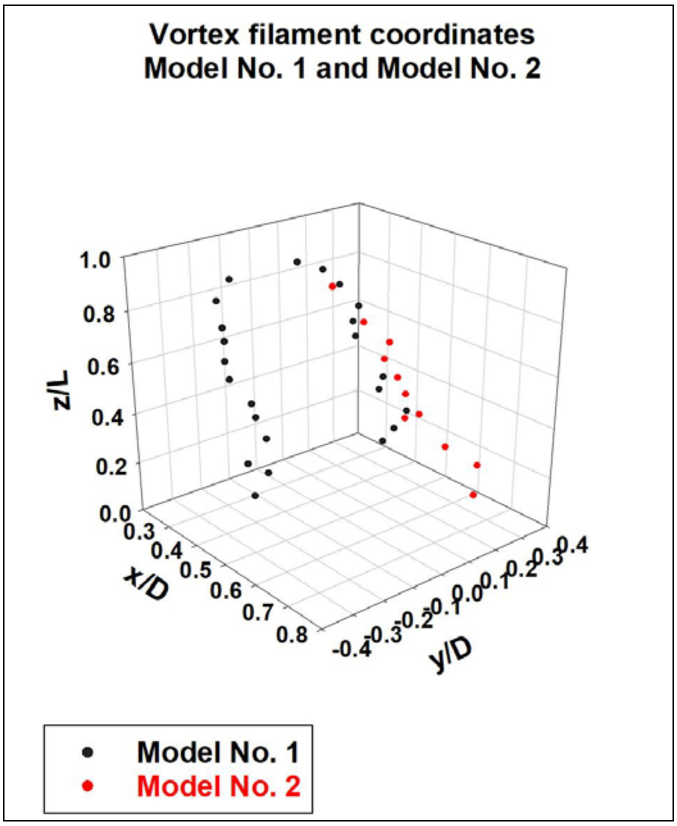

Fig. 5: A 3D display of the vortices filaments coordinates. Two black branches belong to the Model No. 1, one red branch belongs to the Model No. 2.

CFD results indicated some structure in the wake for both cases. For comparison with the experimental data, the CFD solution needs more advanced calculation and post-processing. But the first results look promising. For validation, a circular cylinder was calculated first and according to these results, the setup was considered as appropriate to start with (the cylinder results are not part of this paper).

Pathlines depicted for Model No. 1 (Fig. 6) provide a rough idea about the interface between an undisturbed outer flow and a core with the vortex structures. The blue pathlines show the particles copying a complicated 3-dimensional trajectory. For better evaluation of this result, an averaged-velocity field similar to the PIV results would be needed.

Streamlines displayed for Model No. 2 correspond to the experimental findings. The structure behind the model would need an averaging, so as the CFD results could be more in detail compared to the experimental ones. From existing investigations it is possible to claim, that the structure forming in the wake reaches up to the z/L=0.92, which corresponds to experimental findings. The primary finding confirms the legitimacy of the used model, the correctness of the model and rightness of the mesh.

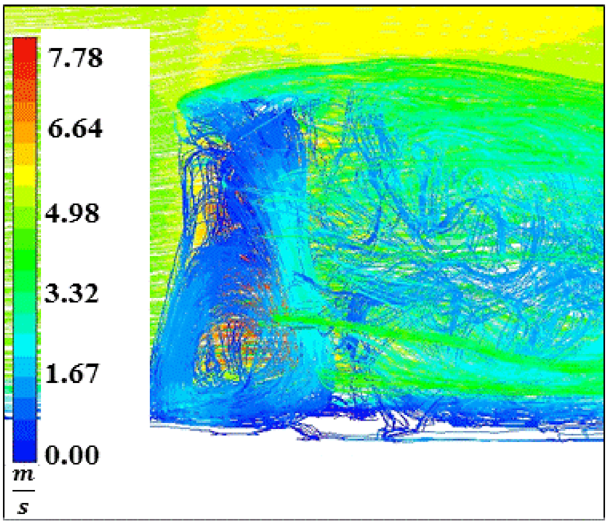

Fig. 6: Pathlines of velocity depicted in cut led through Model No.1's axis.

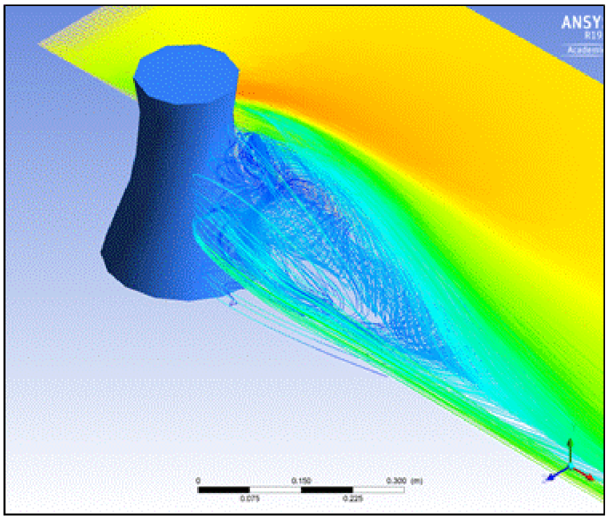

Fig. 7: Streamlines around Model No. 2. The detailed view indicates a complicated structure in the wake.

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