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Numerical Investigation of Wind Effects on the Perforated Structures

Radomil Král[a], Stanislav Pospíšil[b]

Institute of Theoretical and Applied Mechanics, v.v.i.,
Prosecká 76, CZ-190 00 Prague 9, Czech Republic

[a]kral@itam.cas.cz, [b]pospisil@itam.cas.cz,

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Abstract:. The paper deals with a numerical analysis of wind effects on structures with perforated surfaces. The solution based on FEM model is governed by the stabilized Navier-Stokes equations for incompressible fluid. Special attention is given to perforated screens. Such a partly resistance barrier always introduces considerable numerical difficulties resulting from the complexity of a flow distortion when the fluid is passing through. For simplification, the barrier is assumed as a thin screen with specific resistance parameters where the fluid flow mechanism needs not be resolved. The general influence of a screen on the flow field is a loss in the normal momentum component and the change in flow direction. On the other hand, to simulate the fluid mechanics authentically it requires to specify the relevant input parameters that can be determined by an experiment or by using a corresponding handbook.

Introduction

A great part of scientific and expert reports concerning the wind effects on structures are based on numerical modeling. Generally, in isolated cases when the problem is too complex and/or is of high social importance, the theoretical models are replaced with experimental testings in the wind tunnels. In a case that a structure with perforated surfaces is considered, the tunnel study is recommended provided the model scale is reasonable low. If a large scale is needed for any reason, the perforated surfaces become very complicated from both the similarity requirements and the measurement point of view. Then the numerical analysis prevails, however, relevant boundary conditions and parameters simulating the resistance barrier have to be imposed correspondingly.

In this paper, the overall wind loads with respect to the effect of perforation and wind direction are studied on a civil/architecture engineering structure in the shape of an airship. The wooden structure of more than 42 m length and 9 m in diameter is supported by two slender columns and several guy cables fix the structure horizontally. The external surface is covered by wooden perforated cladding with a regular grid. The upper part of the structure is protected by a pre-tensioned impermeable foil, see Fig. 1 left.

Numerical analysis and resistance barrier specification

The effects of the wind are examined for several loading cases in association with the wind direction. To compare the influence of the perforation, both the porous and the solid surface of the airship cladding are assumed. The acting wind is characterized by a logarithmic velocity profile for an urban terrain type with no turbulence component in the inlet. The mean speed corresponds to category I with a low intensity.

The perforated surface is investigated using a thin barrier to flow at which by solving the relevant boundary conditions the pressures drop and loss in normal momentum velocity component arises. This approach utilizes the method of the step function where two approximation solutions are calculated at each nodal point depending on the screen side orientation to the flow. The unknown velocity $\mathbf{u}$ and

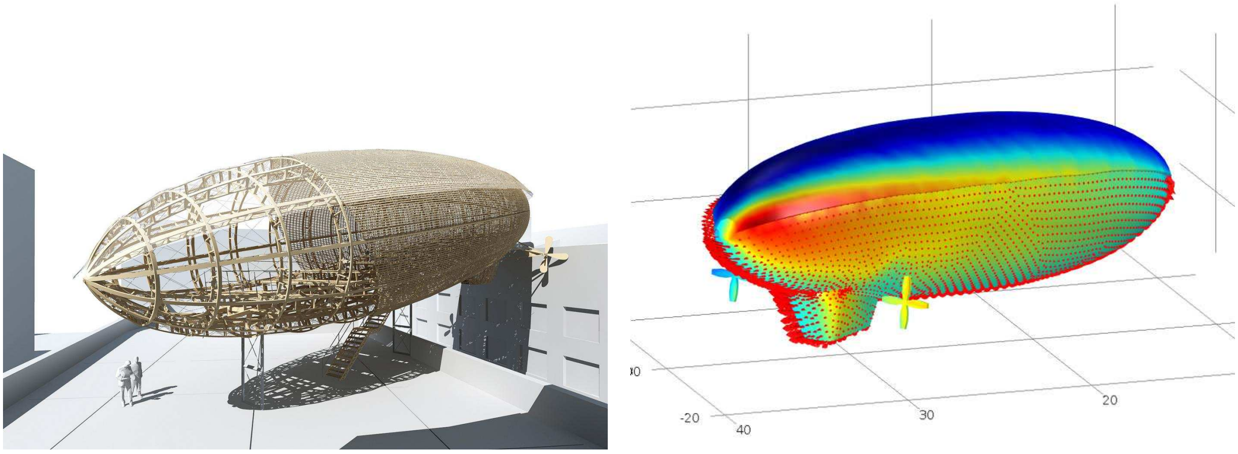

Fig. 1: Architectural visualization by Martin Rajniš© (left) and pressure distribution over the outer surface with velocity vectors (right). The top part is protected by insulating foil.

the pressure p are solved across the screen by imposing the set of conditions:

$$2\Big[\rho\big(\mathbf{u}\cdot\mathbf{n}\big)^2+p-\mathbf{n}^T\Big\{\mu\Big(\nabla\mathbf{u}+\big(\nabla\mathbf{u}\big)^T\Big\}\mathbf{n}\Big]_-^+ = -K\rho(\mathbf{u}_-\cdot\mathbf{n})^2, \tag{1a}$$

$$\mathbf{n}\times\mathbf{u}_+ = \eta(\mathbf{n}\times\mathbf{u}_-), \tag{1b}$$

$$\big[\rho\mathbf{u}\cdot\mathbf{n}\big]_-^+ = 0, \tag{1c}$$

where ρ is the fluid density, μ is the dynamic viscosity and **n** is unit normal exterior vector. The signs $+$ and $-$ refer to the upstream and downstream side of the barrier, respectively, and the operator $[-]_-^+$ indicates the product of the difference between the sides. Eq. (1a) represents quadratic dependency of the pressure loss on the normal velocity component. The Bernoulli's principle is applied taking the dynamic and static pressure and viscous effects into account. The rate of the pressure loss is given by the resistance coefficient K whose value depends on the geometrical properties of the screen and the Reynolds number Re. The coefficient K can be determined by means of an experimental testing, or estimated from relevant handbook, see e.g. [1]. Parameter η stands for the flow refraction expressed in Eq. (1b) in terms of K as $\eta=\sqrt{K^2/16+1}-K/4$. This relation covers a wide range of industrial applications.

In Fig.1, the axonometric views on the perforated structure are shown. The left figure presents the architectural ideas in the final form, while the FEM solution is displayed on the right. This representative image shows the pressure relations over the external surface with velocity vectors when both sides of the perforated screen are considered. The red color indicates the positive pressure, dark blue represents the suction. Integrating the total stress over double-sided surface, component force effects generated by the wind were evaluated and used as the basis for the static design of the guy anchorage and the supports.

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References

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