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NUMERICAL SIMULATION AND EXPERIMENTS WITH THE PROFILE NACA 0012

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Abstract: *This paper introduces the new model of the airfoil and describes both aeroelastic experiments and numerical simulation with the profile NACA 0012. The aeroelastic is the science which studies the flow-structure interaction. The flow field can cause change of the position of the solid body and the body due to the change of its position influences the flow field. Mathematical description of the interaction has to involve both the equations of the fluid dynamic and the equations of motion of the solid body. The first results will be presented from the measuring in the dynamic laboratory and from the measuring in the wind tunnel. The main aim of the experimental part of this research is to cause a self oscilated motion of the airfoil and to measure the transient flow field during this motion. The numerical part should be identical with the experimental dates.*

Keywords: ***Aeroelastic, flow-structure interaction, identification***

1 Introduction

The interaction of the airfoil and fluid flow belongs to a large group of fluid-structure interaction. This interaction takes place in many technical disciplines, e.g. from civil engineering to human vocal tract computation. It is desirable to be able to describe and compute this field of study. The paper describes first steps with the new model of the airfoil, which is used both for numerical simulation and for the experiments.

2 Structural design

The model of an airfoil NACA 0012 is a symmetrical profile with the length of the chord 100 mm with two degrees of freedom. In comparison to the previous aeroelastic models which have been used in the Institute of Thermomechanics it differs in the solution of airfoil – frame attachment. That models can vibrate vertically and rotate around the elastic axis. It was possible to separate these two motions. In this new stand both degrees of freedom are realized by vertically movement. The combination of two vertical displacements gives the final rotation and translation. The scheme with the basic dimensions is shown in Figure 1. The airfoil (position 1) is fastened to the small beam (position 2) and the beam is fastened to the plate with two leaf springs (position 3). The springs are made from phosphor bronze. The plate is attached to the frame with only one screw in the ways it is possible to change the angle of attack. The small beam (position 2) is equipped with 13 holes, so it is possible to change the position among the wing and the springs. It causes changes in dynamic properties of the wing, moreover the holes allow to add mass which also change the static and dynamic properties. Important part of the stand is rod (position 4) for holding the airfoil in constant horizontal position against the flow.

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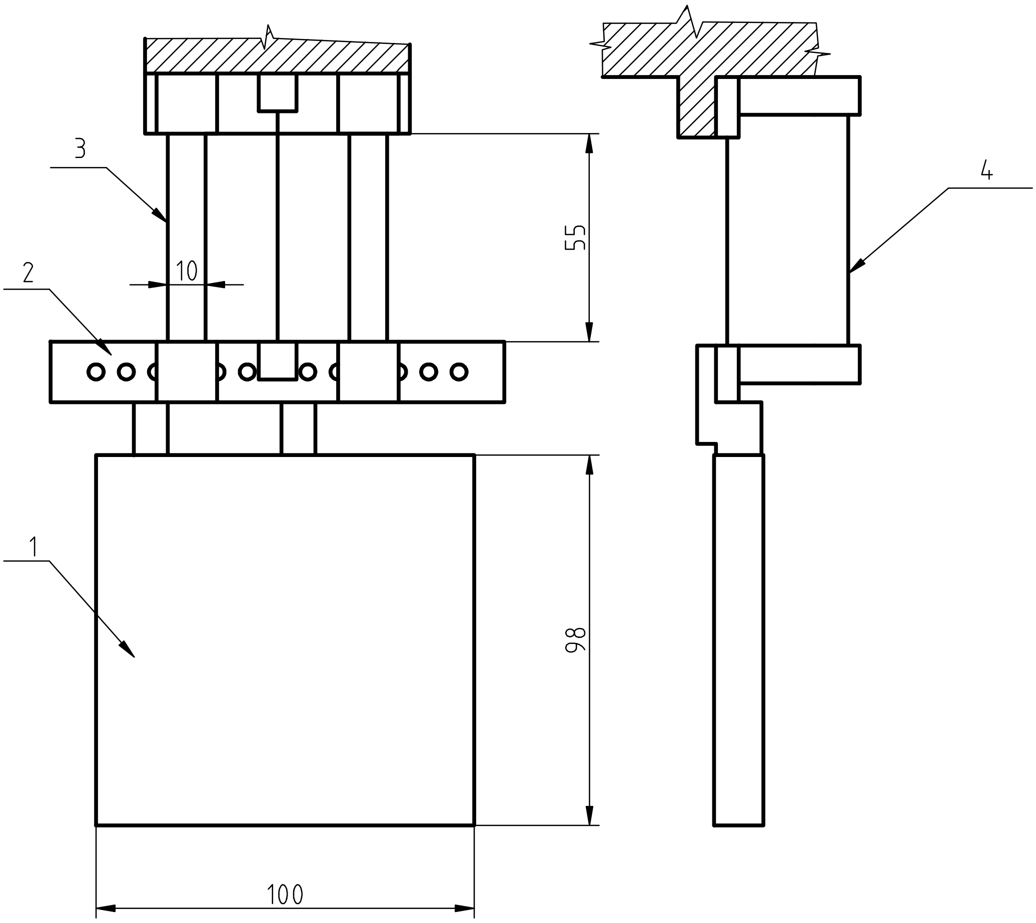


Fig. 1: Design of the airfoil with important dimensions [mm]

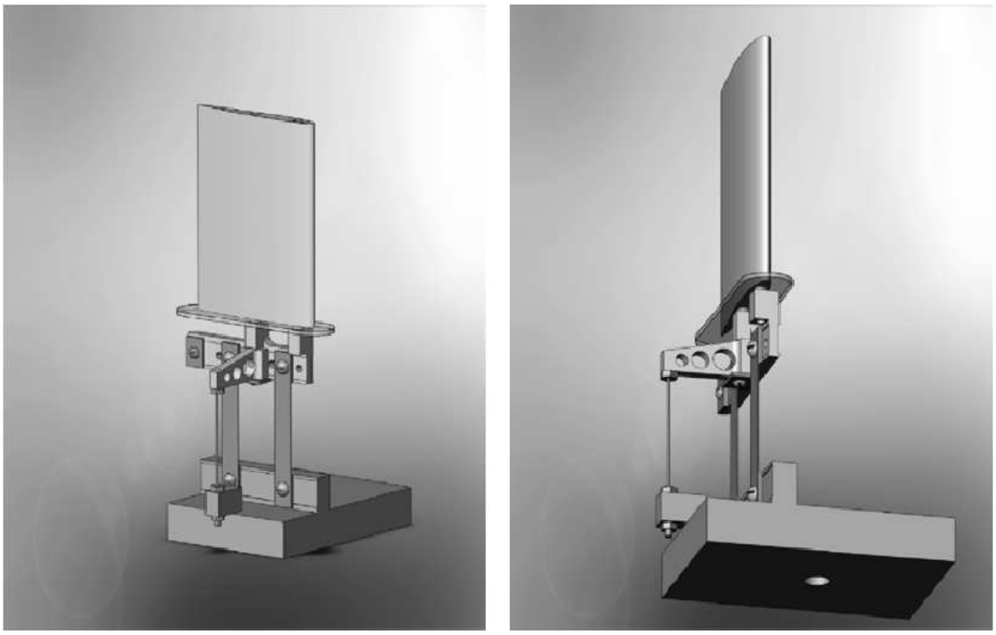


Fig. 2: CAD model of the airfoil stand (from Uruba (2009))

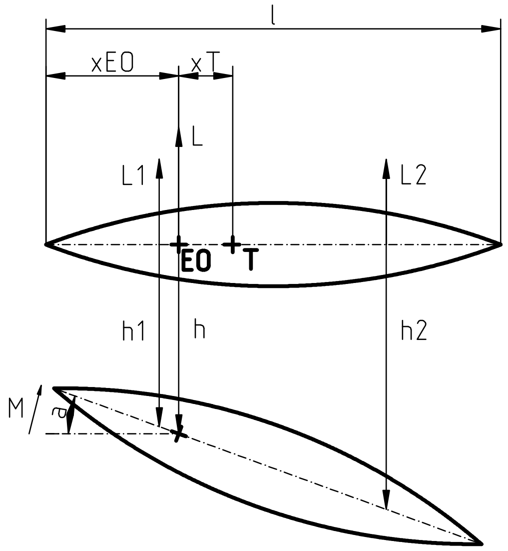


Fig. 3: Basic coordinations and forces acting on the airfoil.

2.1 Mathematical model of the structure

The mathematical model of the profile consists of system of ordinary differential equations (ODE) of motion. These equations can be derived for example using Lagrange equations and from the law of total energy conservation. They are generaly nonlinear, but for small motion they can be linearized. The profile can vertically vibrate with two degrees of freedom. Let us denote $y = (h_1, h_2)^T$ a position vector which describes the vertical translation at the points of connection among the springs and the airfoil and $\mathbf{M}, \mathbf{B}, \mathbf{K}$ the mass, damping and stiffness matrices. Then we can write the equation of motion in the form (1)

$$\mathbf{M}\ddot{\mathbf{y}}(t) + \mathbf{B}\dot{\mathbf{y}}(t) + \mathbf{K}\mathbf{y}(t) = \mathbf{f}(t) \tag{1}$$

Vector $\mathbf{f}(t) = (-L_1(t), -L_2(t))^T$ contains the lift forces acting on the leaf springs. In many aeroelastic applications there are considered instead of two lift forces just one lift force, which acts on the elastic axis and one torsional moment. The vector of forces looks like then $\tilde{\mathbf{f}}(t) = (-L_1(t), M(t))^T$. It is possible to use basic geometrical transformation to transform equation (1) to the equation of motion with the position vector in the form $\tilde{y} = (h, \alpha)^T$. If we know the transformation matrix R, we can express the coordition like (2)

$$\tilde{y}(t) = \mathbf{R}y(t), \mathbf{R} = \frac{\mathbf{1}}{\mathbf{x_{EO2}} + \mathbf{x_{EO1}}} \begin{pmatrix} \mathbf{x_{EO2}} & \mathbf{x_{EO1}} \\ -1 & 1 \end{pmatrix} \tag{2}$$

If is used the transformation relation (2) and the corresponding derivation to the equation (1), after few modification it will be obtained

$$\mathbf{R^T M R}^{-1}\ddot{\tilde{\mathbf{y}}}(t) + \mathbf{R^T B R}^{-1}\dot{\tilde{\mathbf{y}}}(t) + \mathbf{R^T K R}^{-1}\tilde{\mathbf{y}}(t) = \mathbf{R^T f}(t) \tag{3}$$

With the following substitution $\tilde{\mathbf{M}} = \mathbf{R^T M R}^{-1}, \tilde{\mathbf{B}} = \mathbf{R^T B R}^{-1}, \tilde{\mathbf{K}} = \mathbf{R^T K R}^{-1}$ a $\tilde{\mathbf{f}}(t) = \mathbf{R^T f}(t)$ it can be written the final equation

$$\tilde{\mathbf{M}}\ddot{\tilde{\mathbf{y}}}(t) + \tilde{\mathbf{B}}\dot{\tilde{\mathbf{y}}}(t) + \tilde{\mathbf{K}}\tilde{\mathbf{y}}(t) = \tilde{\mathbf{f}}(t) \tag{4}$$

The very important factor for next computation is the identification of static and dynamic properties of the model.

Table 1: Dynamic characteristics of the model from the experiment

Mode No.	Natural frequency $[Hz]$	Damping ratio [%]
1	31.75	2.04
2	40	1.74

3 Mathematical fluid flow model

The problem is solved using finite volume method in the commercial software Fluent. Numerical code has been prepared for the fluid-structure interaction problem and nowadays it will be created a structural mesh of the channel with the airfoil. It is considered viscous laminar incompressible flow, which is modelled in Fluent by the Navier-Stokes equations. Considering the character of the task it has to be dealt with the mesh motion. It is solved using spring - based smoothing method, where edges between any two nodes are idealized as a springs. Any motion at a given boundary disturbes an equilibrium of the mesh and it is used an iterative algorithm to find a new position of all nodes to setup new equilibrium again. Of course, this solution is useful for only small motions.

4 Dynamic properties of the model

The aim of the measurement in the laboratory of dynamic and vibration is to gain both the basic idea about the system properties and the data for the system identification.

4.1 Experiment

It was needed to measure the frequency spectrum of the airfoil. This measurement gives an idea about the model properties. It has been used for a modal testing the devices from the company Brüel & Kjær. The actuator was modal hammer B&K 8230-002 and the sensor was accelerometer B&K 4519-002. It has been measured in the frequency range $(0, 200)$ Hz and there are two important peaks, see Figure 4. The values of natural frequencies and damping ratios from the experiment are presented in Table 1.

Further, it has been was changed the position among the airfoil and the leaf springs and it was measured the natural frequencies of the system. The results are shown in the Figure 5. Considering the graph could be concluded: when changing the airfoil-frame position, its two natural frequencies change significantly. As mentioned above, in the case of self-feeding oscillation is necessary to keep the natural frequencies as close as possible at a flow speed $v = 0 m.s^{-1}$. The ideal configuration should be either position 3 or position 4, where the number denotes the hole of the beam (Figure 1, position 2).

4.2 System identification

Very important process is the identification of the system. The identificated model is an input not only to the fluid-structure interaction but also to the predictive algorithm for flutter onset. For the identification process it has been used the following experiment. The airfoil was attached to frame at two points and in these two points were measured in four combination (position of actuator vs. position of sensor) the complex frequency transfers. From these transfers were computed the eigenvalues of the model, for more information see Horacek (2005). The eigenvalues of the system are listed in Table 2.

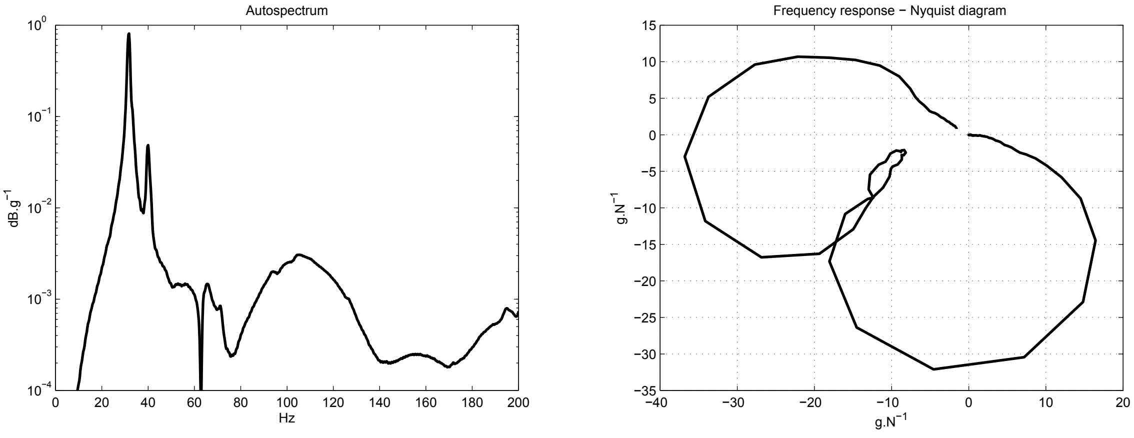
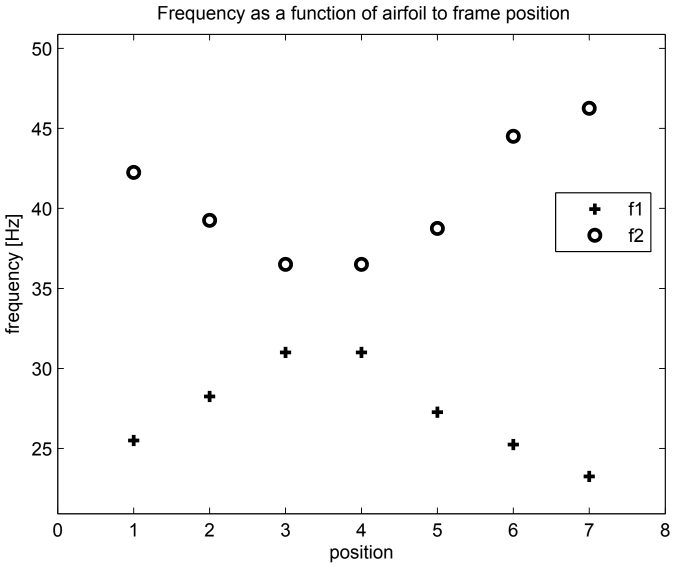


Fig. 4: Autospectrum



Fig, 5: Natural frequencies as a function of the airfoil to frame position

Table 2: Eigenvalues of the airfoil from the identif cation

Eigenvalue	Real part	Imaginary part
s1	-2.55	201.4
s2	-1.72	250

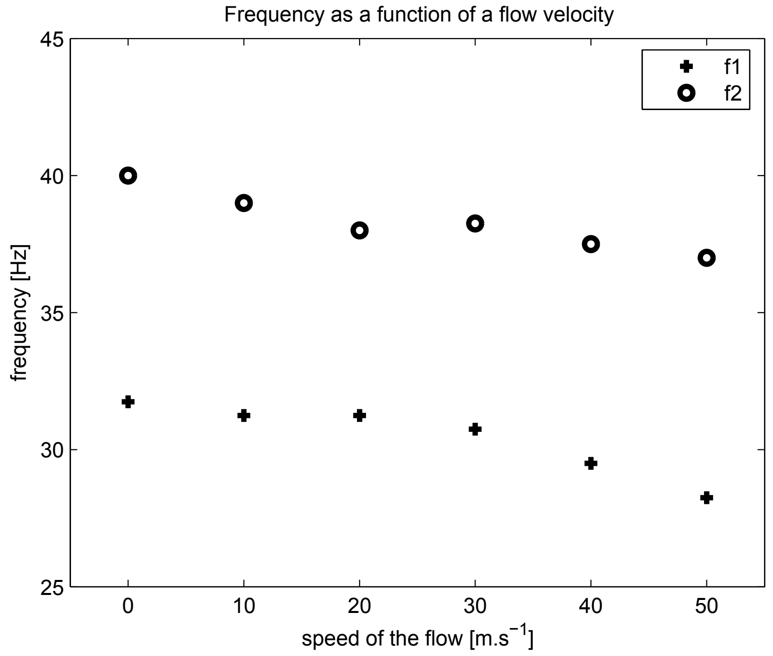


Fig. 6: Natural frequencies of the airfoil as a function of the flow speed

5 Measurement in the wind tunnel

It has been measured in the wind tunnel in the Institute of Thermomechanics with this profile. It has been used the wind tunnel operating at highest velocity of the flow approximately $50\,m.s^{-1}$. The flow speed was not set up directly, but it was calculated from the pressure difference. This measurement has prooved also a feasibility of the experiment. The configuration of the experiment has been tested with good results. The airfoil can be excited with a modal hammer, moreover there is a space for vibrator in a case of need.

During the first experiment it has been measured the frequency spectrum of the profile as a function of the flow speed. The angle among the flow and the airfoil was set to $\alpha = 0\,rad$. It has been changed the flow speed with the difference $\Delta v = 10\,m.s^{-1}$ in the range $v \in (0, 50)\,m.s^{-1}$. It has been used the same devices Brüel & Kjær as in the laboratory of dynamics. The results are shown in the Figure 6.

It has not been reached the flutter during this first measurement with the limit speed of the flow $u_\infty = 50\,m.s^{-1}$. It was not possible to increase the flow speed, moreover the method, which will be used for the flow field mapping, PIV (particle image velocimetry) needs for correct results speed of the flow no more than $30\,m.s^{-1}$. It should be done some structural changes on the stand to change its modal properties, either to replace the leaf springs with another type or to add some mass.

6 Conclusions

This paper describes current situation about the new profile NACA 0012 in the Institute of Thermomechanics. There are two parallel parts of research, one focuses on the experiments both in the laboratory of dynamics and vibration and in the wind tunnel, the second one concentrates on the numerical simulation. One of the global aim of the experimental branch is to set up self-feeding oscillation (flutter) and to measure the transient flow field during this motion. The numerical part consists of correct identification and fluid-structure interaction problem simulation. The mathematical model ot the wing is in good agreement with the measurement.

Acknowledgement

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