AERODYNAMIC FORCES MEASURED ON A FLUTTERING PROFILE

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The study presents evaluation of optical measurements of the air flow field near the fluttering profile NACA0015 with two-degrees of freedom, Mach number of the flutter occurrence were $M = 0.21$ and $M = 0.45$. Aerodynamic forces (drag and lift components) were evaluated independently on the upper and lower surfaces of the profile. Using the mentioned decomposition, the new information about mechanism of flutter properties was obtained. The forces on the upper and lower surfaces are phase shifted and are partially eliminated as a result of the circulation around the profile. The cycle changes of these forces cause the permanent energy contribution from the airflow to the vibrating system.

Keywords: *aeroelastic experiments, self-excited vibrations, wind tunnel, interferometry*

1. Introduction

Published experimental studies on fluttering systems are rare and mostly are based on PIV method, see e.g. Hodges D.H. et al. [1], Bernal L.P. et al. [2] and Heerenbrink M. [3]. This contribution add some experimental results based on interferometric visualization of the air flow field in the vicinity of the self- excited pitching-plunging airfoil.

2. Measurement setup

The detailed arrangement of the experiment is shown in Vlček et al. [4]. The flow field near the vibrating NACA0015 profile was visualized by the interferometry in the flutter regime. Interferograms were recorded by the high-speed camera using 1000 fps. During the flutter, the profile, as two degrees of freedom dynamic system, oscillated by the coupled translational and rotational motion with large amplitudes. Two cases (No 2663-02: $M = 0.21$, $\mathrm{Re} = 0.25\times10^6$ and No 2663-05: $M = 0.45$, $\mathrm{Re} = 0.54\times10^6$) were evaluated. The eigenfrequencies of this system corresponding to zero flow velocity were close to the frequencies 19.0 Hz (translation) and 21.5 Hz (rotation). In flutter regime, the flutter frequencies were 21.6 Hz ($M = 0.21$) and 32.3 Hz ($M = 0.45$). The experiments were performed in the wind tunnel of the Institute of Thermomechanics in Nový Knín.

Schematic configuration of experimental model is depicted in Fig. 1. Profile NACA0015 with the chord length 61 mm was used. The axis of rotation was situated in 1/3 of the chord, measured from the leading edge.

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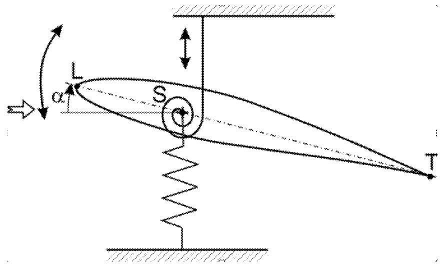

Fig.1: Schematic configuration of the experiment

3. Experimental results

The experimental results, discussed in this paper, are based on the evaluation of the interferograms of the non-stationary flow field in the vicinity of the self-excited profile. We suppose the isentropic flow in the evaluation of the interferograms. This simplification was compensated by the possibility of the evaluation of the forces acting separately on different parts of profile surfaces, in this case devided on the upper and lower surfaces.

3.1. The kinematics of the profile

The self-excited vibrations were studied here at the Mach numbers 0.21 and 0.45 in the ranges of the angles of attack ±30° and ±40°, respectively. An overview of the selected positions of the profile during one oscillation period is shown in Fig. 2. The case $M = 0.21$ (Fig. 2a) is characterized by a small translation trajectory relatively to the angle of attack, on contrary, in the case $M = 0.45$ the translation is greater and the highlighted profile positions with zero angle of attack are farther away, see Fig. 2b.

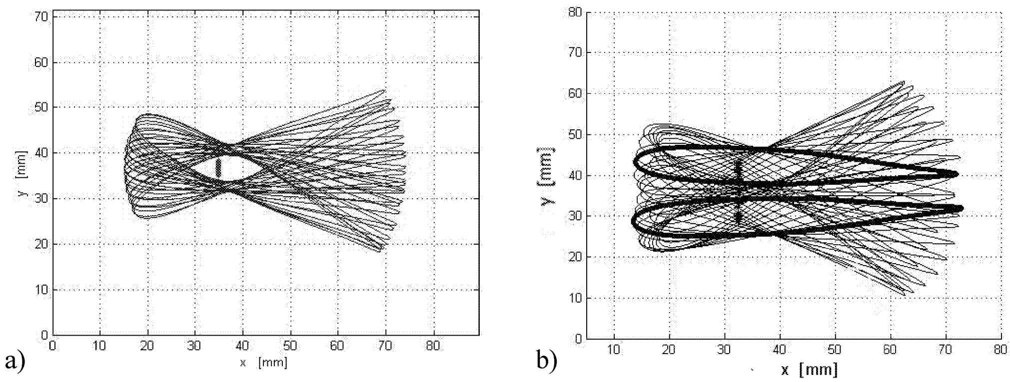

Fig.2: Profile positions during one period of flutter: a) $M = 0.21$; b) $M = 0.45$

Translation of the elastic axis as the function of the angle of attack during one period of flutter are depicted in Fig. 3 for the cases $M = 0.21$ and $M = 0.45$, respectively. The different behaviour of the system is also well observable from Fig. 5, where both cases are depicted in the same scale. For better illustration of the evolution of the vibration process the numbers besides the points of curves in Figs. 3, 4, 5 are presented, which means the number of interferogram and simultaneously the time evolution in miliseconds.

3.2. Forces acting on the profile

The starting point for the experimental determination of the unsteady aerodynamic forces acting on fluttering profile from the air flow field was the evaluation of the force distribution around the profile surface at discrete time instants during one oscillation period. Here, two cases with different Mach numbers are presented. The one flutter period was evaluated for $M = 0.21$ and for $M = 0.45$ with the help of the 45 and 31 interferograms, respectively. The frequency of the fluttering profile was in the first case 21.6 Hz and 32.3 Hz in second one.

a)

b)

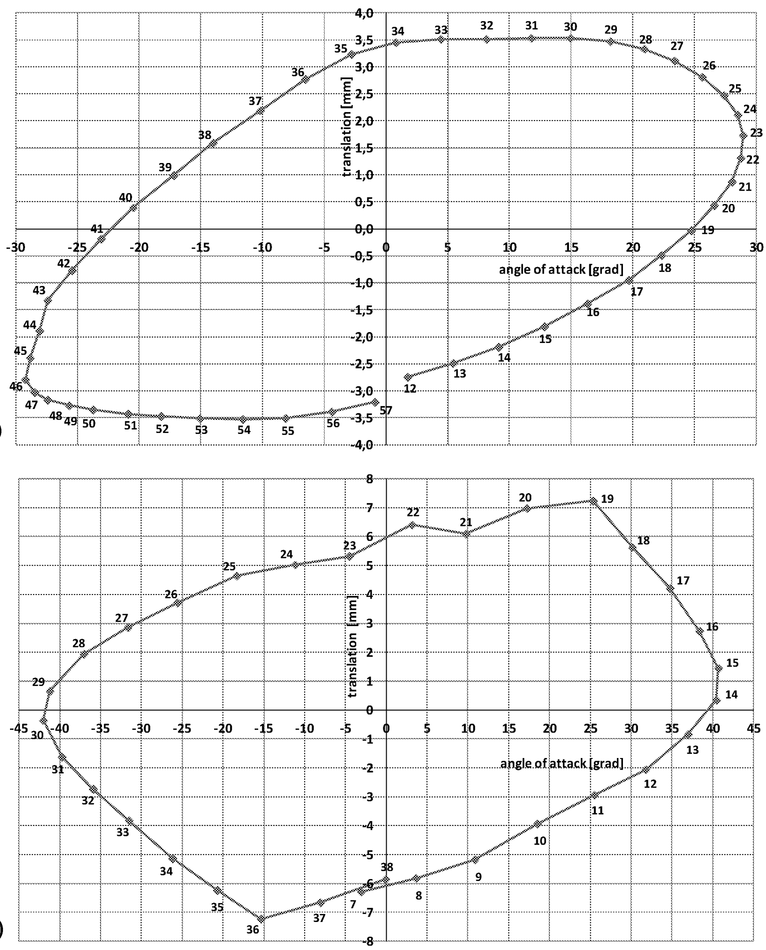

Fig.3: Translation as the function of the angle of attack during one period of flutter: a) $M = 0.21$; b) $M = 0.45$

For understanding of the energy flow from surrounding airflow to the vibrating structure it is useful to study the relations between the lift forces and the profile motion (see Fig. 4). The area enclosed by the curved lines in Fig. 4 is proportional to the energy obtained from lift forces. For example, as an approximate estimation, from Fig. 4b, it follows, that the average power supplied to the vibrating profile from the flow is about 50 W.

Earlier published papers of the authors show that the direction of the energy flow (from the structure to the airflow or the opposite) depends on the flow velocity and very markedly on the mode of vibrations (see e.g. Zolotarev I. [5]). In the presented experiment for the case described by Figs. 2a and 4a for $M = 0.21$ the corresponding energy goes from the flow to the structure, i.e. destabilising the structure. In the second case (see Figs. 2b and 4b for $M = 0.45$) the positive energy transfer of the rotational mode could prevail the negative transfer found for the translation mode.

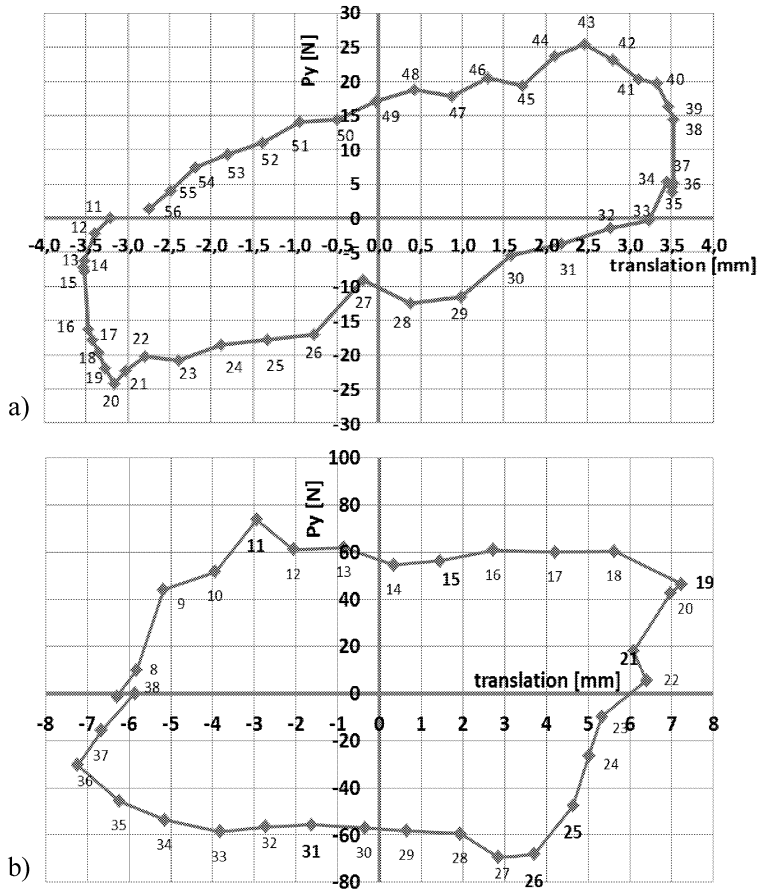

Fig. 4: Total lifting force as a function of profile translation : a) $M = 0.21$; b) $M = 0.45$

In Fig. 5 and Fig. 6 the components of lift force acting on the lower and upper surfaces during one cycle of the self-excited vibration are depicted. In Fig. 5 results for the flutter regime and in Fig. 6 results for the stall flutter are presented.

Flutter regime ($M = 0.21$), see Fig. 5 :

- The elliptical curve situated in the middle of the figure represents the cycle with negative (counter clockwise) rotation, see Fig. 4a,
- In the upper and lower part of the diagram there are trajectory loops – the additive components of the middle elliptical curve. These loops are going in the same sense and represent variable forces existing separately on the upper and lower surfaces. The forces are interconnected by means of the circulation.

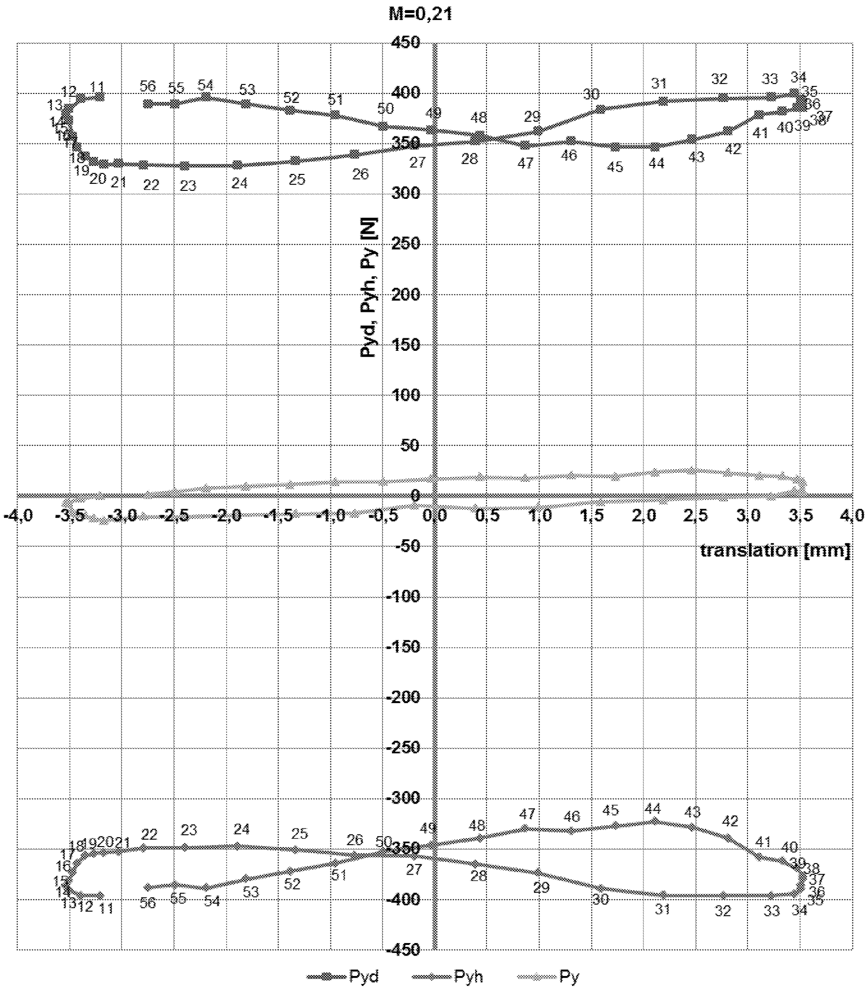

Fig.5: The lift as the function of the translation ($M = 0.21$, P_{yd} *– lower,* P_{yh} *– upper surface of the profile)*

Stall flutter regime ($M = 0.45$), see Fig. 6 :

- The elliptical curve situated in the middle of the figure represents the cycle with positive (clockwise) rotation (see Fig. 4b),
- Loops in the upper and lower part of the diagram are going in opposite sense.

4. Conclusions

The interferometric measurements of unsteady aerodynamic forces acting on the profile NACA 0015 surface were evaluated during one period of flutter vibration, for the flow velocity $M = 0.21$ and $M = 0.45$. The decomposition of the lifting forces into two parts (loading the upper and lower surfaces) enables to obtain original results that describe the dynamical behaviour of the system after the loss of aeroelastic system stability in the flutter and stall-flutter regime.

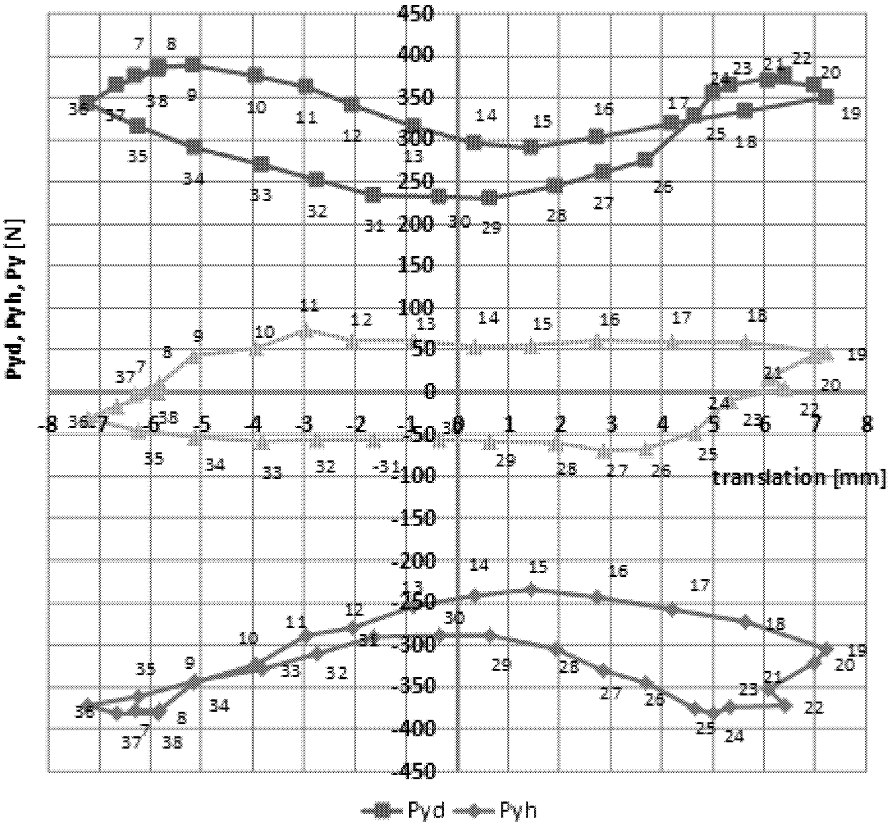

Fig.6: The lift as the function of the translation ($M = 0.45$, P_{yd} – lower, P_{yh} – upper surface of the profile)

Acknowledgement

The authors gratefully acknowledge the Grant Agency of the Czech Republic for supporting this work under Grant No. 13-10527S 'Subsonic flutter analysis of elastically supported airfoils using interferometry and CFD'.

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Received in editor's office: August 14, 2013
Approved for publishing: December 16, 2013