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THE EFFECT OF THE PITCH SUPPORT ELASTICITY ON THE NACA0015 PROFILE AEROELASTIC PROPERTIES

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Abstract: *The aeroelastic experiments realized in wind tunnel of the Institute of Thermomechanics with Mach numbers M ~ 0.20-0.22 and with the interval of Reynolds numbers Re = (2.4-2.6).10^5, are presented. These results correspond to the self-excited vibration of the profile NACA0015 with two degrees of freedom allowing the profile rotation in 1/3-chord axis and allowing the vertical displacement of the profile. The dependence of vibration frequency on the wind-flow velocity has been obtained. Comparing with the previous experiments the influence of the pitch support elasticity on the profile aeroelastic properties was determined.*

Keywords: aeroelasticity, self-excited vibration, flutter, subsonic flow.

1. Introduction

The aeroelastic and stability vibration problems of profiles are studied after a long time (Fung, 1993, Blevins, 1990, Dowell, 2015). Nevertheless the problems of self-excited vibration in our experimental configuration and investigated in this paper have not been published yet in detail. The scheme of the NACA0015 profile support is shown in Fig. 1. During the earlier experiments the pitch supports had the eigenfrequencies 14.5 Hz and 18.9 Hz for zero air flow velocity – (Vlček & Zolotarev et al., 2016 and Šidlof et al., 2016). In the current experiments the pitch eigenfrequency of the profile was 12.7 Hz. In these cases the shift eigenfrequency was 16.4 Hz. It means that in present measurements, the eigenfrequency of rotation was lower than shift eigenfrequency and also the lowest within the experiments realized in Institute of Thermomechanics – (Vlček & Štěpán et al., 2016; Zolotarev et al., 2012 and Kozanek et al., 2014).

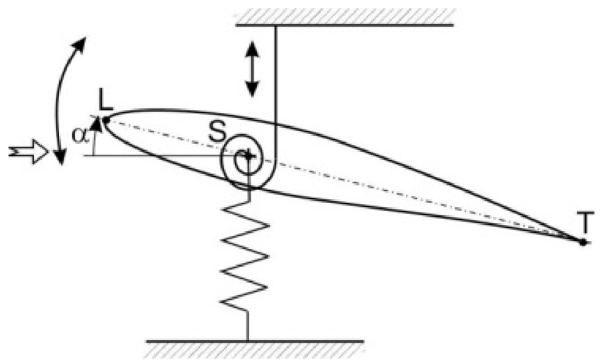

Fig. 1: The scheme of the profile support.

Self-excited aeroelastic vibration of this profile has been studied in lower subsonic speeds. Our aim was to determine the non-stable velocity region of the profile vibration. Attention has been paid to the kinematic behaviour of the profile represented by shift-pitch function.

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2. Experimental results

In figure 2 the results of the experiment are presented in context with other measurements made (see Zolotarev et al., 2012 and Kozanek et al., 2014) in the Institute of Thermomechanics with the same profile, but with the different elasticity of the pitch support.

In the current experiments the pitch eigenfrequency of the profile was 12.7 Hz when air flow velocity M = 0. It was a rare case in the history of similar measurements in Institute of Thermomechanics, when the pitch eigenfrequency was lower than shift eigenfrequency. Other data in Fig. 2 had eigenfrequencies 14.5 Hz and 18.9 Hz for M = 0. In all these cases the shift eigenfrequency was 16.4 Hz. It is evident, that the increase in the pitch-support elasticity corresponding to the pitch-eigenfrequency 12.7 Hz would result in a substantial reduction of the velocity interval with occurrence of the self-excited vibration in the range M = 0.199-0.217.

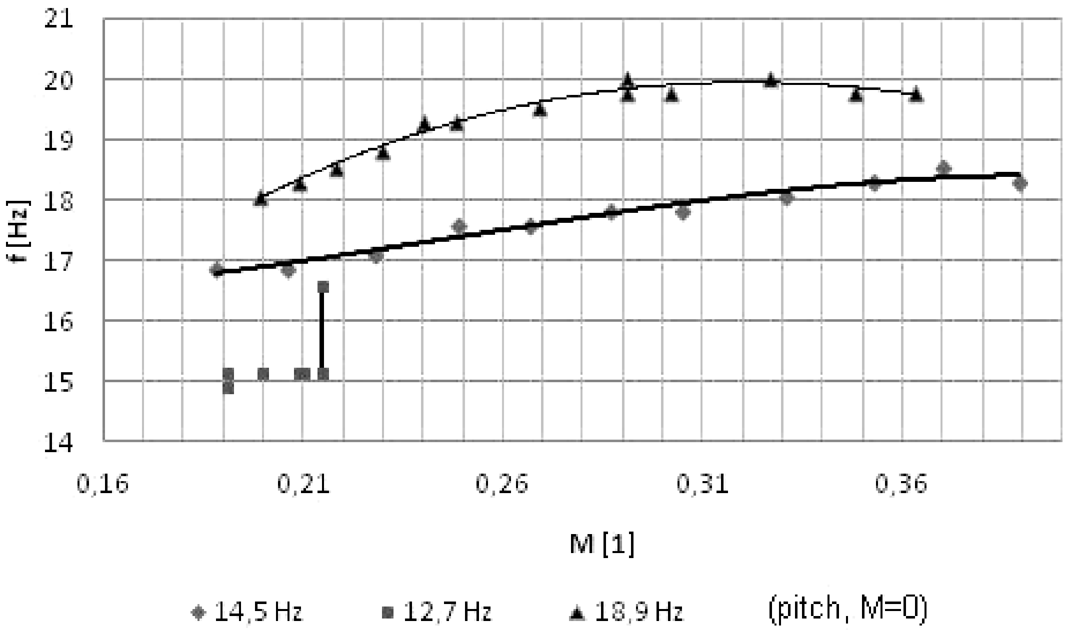

Fig. 2: Frequencies of the profile self-excited vibration.

2.1. Amplitude modulation of the pitch time vibration and the profile instability

The decreased stiffness of the pitch support has resulted in the amplitude modulation of the pitch time vibration (e.g. Fig. 3, Vlček & Zolotarev et al., 2016). This phenomenon for 12.7 Hz initial pitch eigenfrequency (M=0) appeared in the narrow velocity interval M =0.199-0.217, where the self-excited vibration occurred. This vibration is shown in Fig. 4 as the relationship between pitch and shift parametric time function. The shape of this curve has the form of a double-loop. The time evolution of circulation in both loops is in the counter-clockwise direction. The right loop is centered towards the origin of coordinates and the left one has an eccentric position.

At the bottom of the Fig. 3 there are depicted the results of the FFT analysis. The left side of the picture is dedicated to the pitch vibration and the pair of non-zero significant frequencies was determined. In this case, 15.1 Hz is related to the centered loop frequency, the 7.8 Hz corresponds to the eccentric loop frequency.

The amplitude of the pitch vibration and shift vibration are different time functions. The upper amplitude of vibration in the pitch alternates on two levels, while lower amplitude remains constant. On the other hand the shift vibration has only one significant frequency 15.1 Hz with the amplitude almost constant. This common value explains the connection of both loops in Fig. 4.

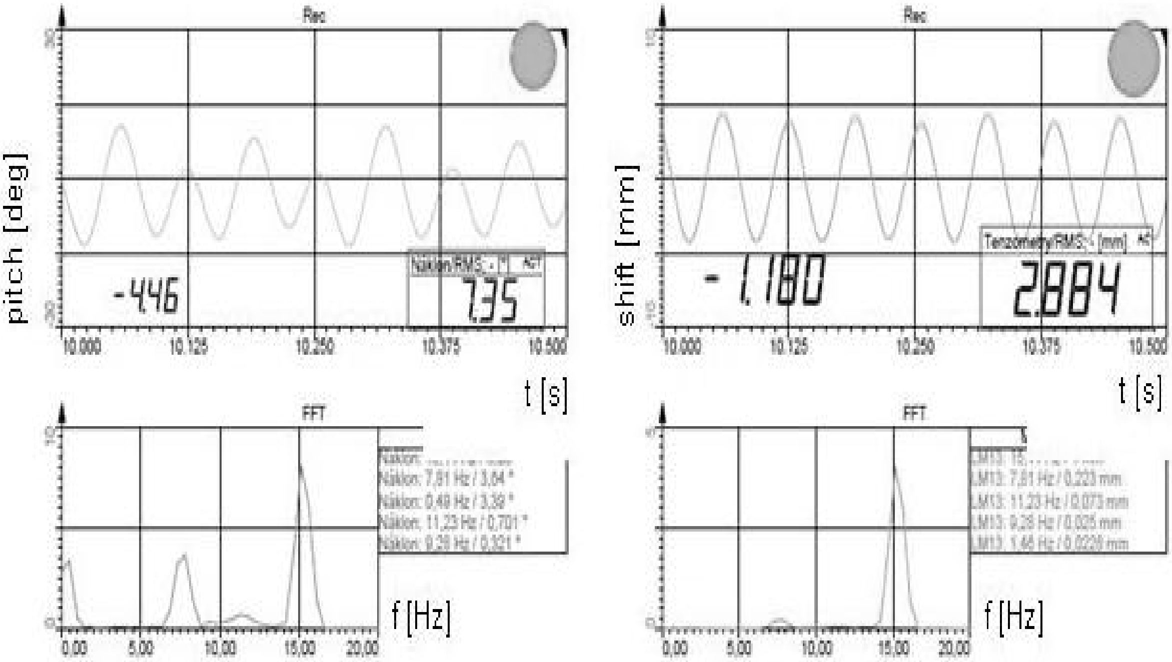

Fig. 3: Pitch vibration (left part) and shift vibration (right) of the profile in the case of the two-loop regime.

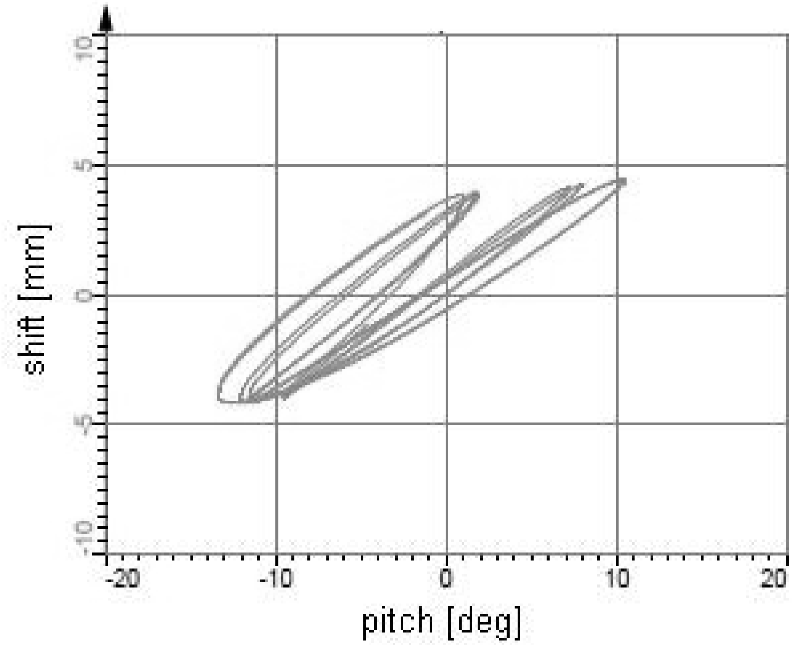

Fig. 4: The shift as a function of the pitch corresponding to Fig. 3.

The above double loop regime for small stiffness of the pitch support was specific. In almost all other experiments in Institute of Thermomechanics realized for higher stiffness the one loop vibration occurred – see e.g. Vlček & Zolotarev et al., 2016. However, in one of these cases already existed frequency of vibration, corresponding to the left eccentric loop in Fig. 4, but its amplitude was significantly lower than dominant one.

3. Conclusions

- The self-excited vibration of the 2D profile was studied (see also Vlček et al., 2015) and its dependency on the Mach number for one combination of the pitch and the shift elastic supports was obtained.
- The experiments indicate a possibility to suppress or increase self-excited oscillation of such profile. Using appropriate relationship between the elasticity of supports of both degrees of freedom it is possible to replace the stable „one-loop“ vibration by less stable „double-loop“ vibration or vice versa and by this way the occurrence of the self-excited vibration substantially suppress or increase.
- This changes of the vibration character are connected with the modulation either of the pitch or shift time course. The shift modulation was observed in previous experiments (Vlček et al., 2016) and pitch modulation is described here.

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References

Fung, Y. C. (1993) An Introduction to the Theory of Aeroeleasticity, Dover Publications, Inc, Mineola, New York.

Blevins, R. D. (1990) Flow-Induced Vibration, Van Nostrand Reinhold, Amsterdam.

Dowell, E. (2015) A Modern Course in Aeroelasticity, Springer, Switzerland.

Vlček V., Zolotarev I., Kozánek J., Štěpán M. (2016) Some atypical flutter characteristics of the NACA0015 profile. Colloquium DYMAMESI 2016, Prague, March 1-2, 2016.

Vlček, V., Štěpán, M., Zolotarev. I., Kozánek. J. (2016) Innovation of the experimental facility for the study of flutter in the Institute of Thermomechanics AS CR and some results obtained from initial experiments. Applied Mechanics and Materials, Vol. 821 (2016), pp. 141-151.

Šidlof, P., Štěpán, M., Vlček, V. (2016) Experimental investigation of flow-induced vibration of a pitch-plunge NACA 0015 airfoil under deep dynamic stall. Preprint submited to Journal of Fluids and Structures.

Zolotarev, I., Vlček, V., Kozánek, J. (2012) Experimental results of a fluttering profile in the wind tunnel. Flow-induced Vibration, School of Engineering Trinity College, Dublin, (eds. Meskell, C., Bennett, G.), 2012, pp. 677-680.

Kozánek, J., Vlček, V., Zolotarev, I. (2014) Vibrating Profile in the Aerodynamic Tunnel — Identification of the Start of Flutter, Journal of Applied Nonlinear Dynamics 3(4), 2014, pp. 317–323.

Vlček, V., Štěpán, M., Zolotarev, I., Kozánek, J. (2015) Experimental Investigation of the Flutter Incidence Range for Subsonic Flow Mach Numbers, Proc. of the 21-st International Conference ENGINEERING MECHANICS 2015, Svratka, Czech Republic, 2015, pp. 350-351.