VISUALIZATION OF UNSTEADY FLOW AROUND A VIBRATING PROFILE

Václav Vlček, Jaromír Horáček, Martin Luxa, Jan Veselý
Institute of Thermomechanics, Academy of Science of the Czech Republic, Prague

ABSTRACT

The contribution presents results of optical measurements of flow field around a vibrating double circular arc (DCA) 18% profile elastically supported in the measurement section of a wind tunnel. The profile can vibrate with two degrees of freedom for translation and rotation. The schlieren and interferometry methods were used for visualization of a two-dimensional flow in different phases of the profile motion.

The measurements were performed in a subsonic wind tunnel above the airflow velocity for loss of the system stability by flutter, thus the vibration amplitudes were relatively large up to about ± 4 mm for vertical translation and ± 6 degrees for angle of rotation around the elastic axis. The images of the flow field were recorded for prescribed phase delays during one oscillation period of the profile from which the pressure and velocity were evaluated in given time instants.

1. INTRODUCTION

For simultaneous measurement of periodic vibrations of a solid body and the optical measurement of surrounding unsteady high speed flow a method of phase shift was used and the measurement of flow fields in selected phases of the oscillation period was carried out.

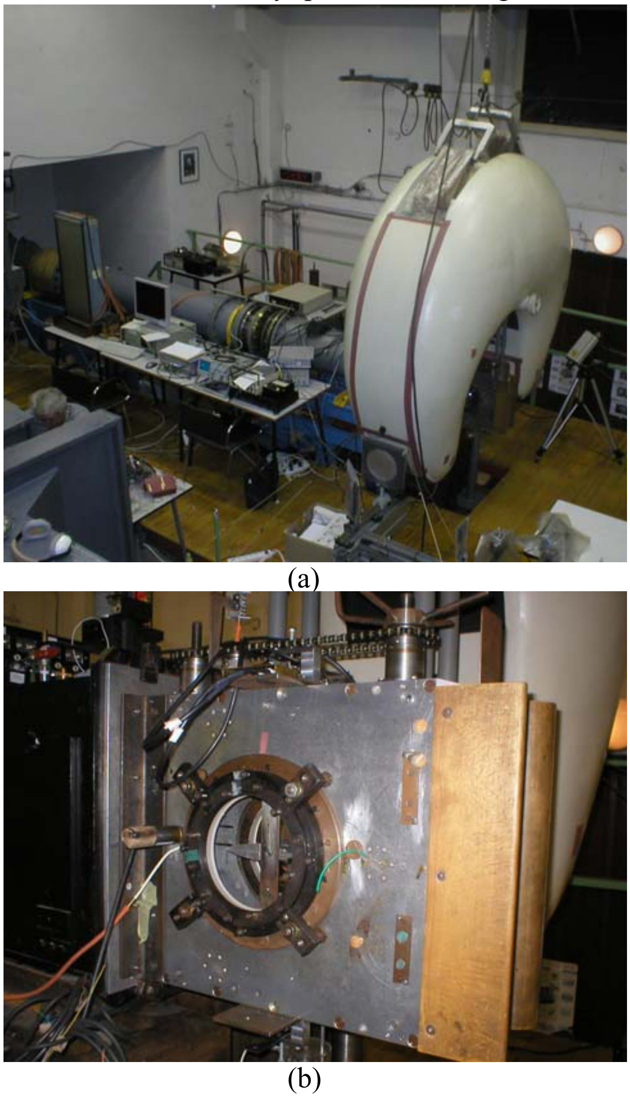
The multiple measurements, performed for the same phase, facilitate the averaging of measurements and thus to evaluate a reproducibility of the whole process. An arbitrary periodic quantity is possible to choose for controlling the image record triggering in a given phase. The pulse source of the light and the digital camera are synchronized with the selected phase of the measured quantity.

The method was successfully verified during schlieren and interferometry measurements of the subsonic flow field around the self-excited vibrating airfoil and behind the self-excited plug of the model of a regulating valve of a steam turbine. Maximum frequencies of the vibrating bodies were about 20-40 Hz in both cases. Using this method, the relations among the flow field, movement of the vibrating body and forces acting on the vibrating body from the flow field can be determined in selected phases of the translating motion of the body.

2. ARRANGEMENT OF THE EXPERIMENT

Vacuum wind tunnel of the Institute of Thermomechanics in Novy Knin was used for the experiments, see Fig.1.

Model in the test section of the aerodynamic tunnel is schematically presented in Fig. 2. The



(a)

(b)

Figure 1: (a) Wind tunnel with Mach-Zehnder interferometer, (b) test section with the DCA profile.

chord length is 120 mm, thickness of the profile is 21.6 mm, test section is 80 mm wide and 210 mm high. Profile was divided in two parts in the horizontal plane of symmetry. In the cavity inside the model two pressure transducers KULITE were situated for measuring the pressure fluctuations on the vibrating surface of the profile; their front face joint with the model surface. Center of rotation of the profile was at 1/3 of the chord behind the leading edge. The rotational motion of the profile was limited to a maximum in the range of ±11° by mechanical means.

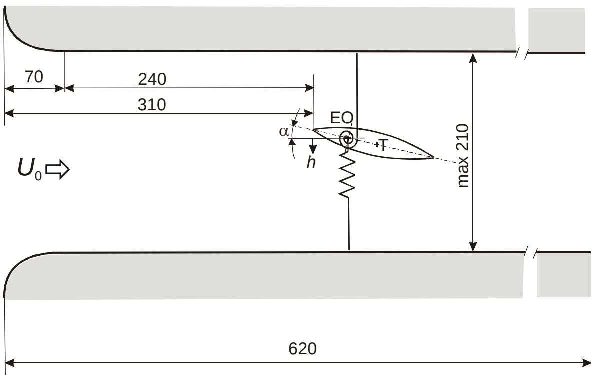


Figure 2: Schematic arrangement of the experiment.

Images were recorded by a digital photo camera, the system triggering and the flash and camera shutter were controlled according to the position of the airfoil using strange gauge signal, which measured the vertical displacement of the profile. Up to now, the interferometry was used mostly for measuring stationary flows, e.g., in fixed turbine or compressor blade cascades (Vlček, Luxa, 2005).

3. DYNAMIC PROPERTIES MEASUREMENT

At first the experiments on dynamic properties of the aeroelastic model were established. For this purpose the system B&K PULSE was used. Mechanical excitation of the model by an electrodynamic exciter was intermediated by side metal strips (see Fig.1b). Random excitation was produced by external generator and the response of the model was indicated at the trailing edge of the profile by the laser-vibrometer POLYTEC. Laser beam was introduced into the test section through the window in the wall of the test section.

The transfer function for U_0=0 m/s is shown in Fig.3 and the dynamic characteristics established by the experimental modal analysis are presented in Tab.I. The first resonance (f_1=18.4 Hz) corresponds mainly to the translational motion of the profile, the second resonance (f_2 =38.1 Hz) to the rotation. The third frequency (149.1 Hz) corresponds to a parasitic resonance of some mechanical detail of the whole construction. This resonance is sufficiently high and therefore it should not substantially affect the experiments.

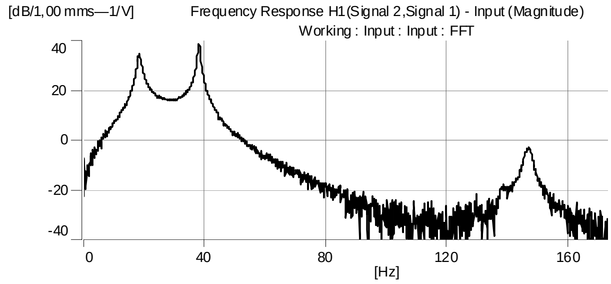


Figure 3: Frequency response of the profile.

Mode No	Natural frequency	Damping ratio	Mode shape
1	18.38 [Hz]	3.22 [%]	translation
2	38.13 [Hz]	0.96 [%]	torsion
3	146.9 [Hz]	0.72[%]	parasitic

Table I: Dynamic characteristics of the model.

Experimentally established eigenfrequencies f_1 and f_2 of the system in relation to the airflow velocity are presented in Fig.4. By increasing the velocity both frequencies converge to the almost same point at the critical velocity for flutter at about Mach number M=0.4. Above this velocity, the system becomes unstable with the rapid increase of vibration amplitudes and the self-excited motion of the profile in a limit cycle oscillation starts.

The measured root mean square value (RMS) of the profile translation velocity as a function of the airflow velocity is shown in Fig.5. The exciter was not used in this case and the profile was excited only by chaotic disturbances of the flow field due to the turbulence and vortex shedding. At the flow velocities near the critical velocity for flutter the magnitude of vibrations extremely increases.

4. FLOW MEASUREMENT BY INTERFEROMETRY METHOD

The flow field in the vicinity of the profile was measured by interferometry method at the inflow velocity M=0.4, which is slightly above the stability point of the profile. Individual phases of the flutter cycle are documented in Fig.6. Exposition of each photograph was performed with the time delay approximately of 4 s. This time was required for the recharging of electrical condensers of the flash apparatus.

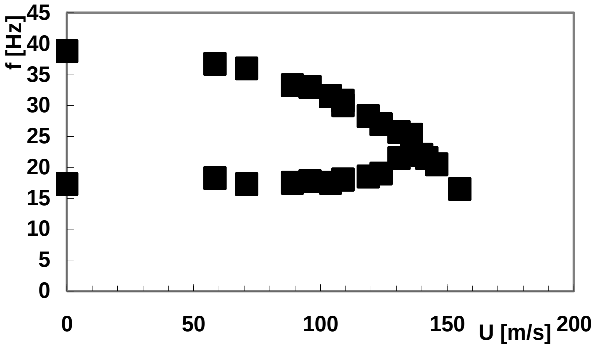


Figure 4: Natural frequencies f_1 and f_2 versus the airflow flow velocity.

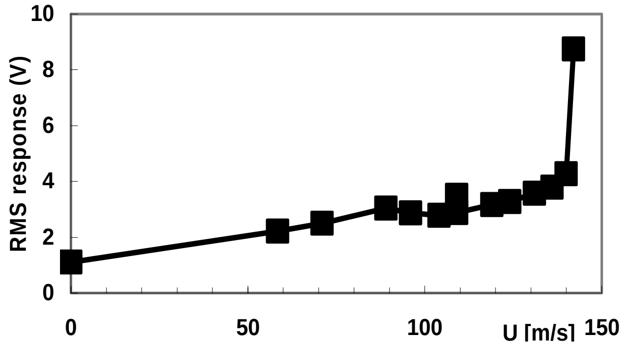


Figure 5: RMS of the profile translation velocity versus the airflow velocity.

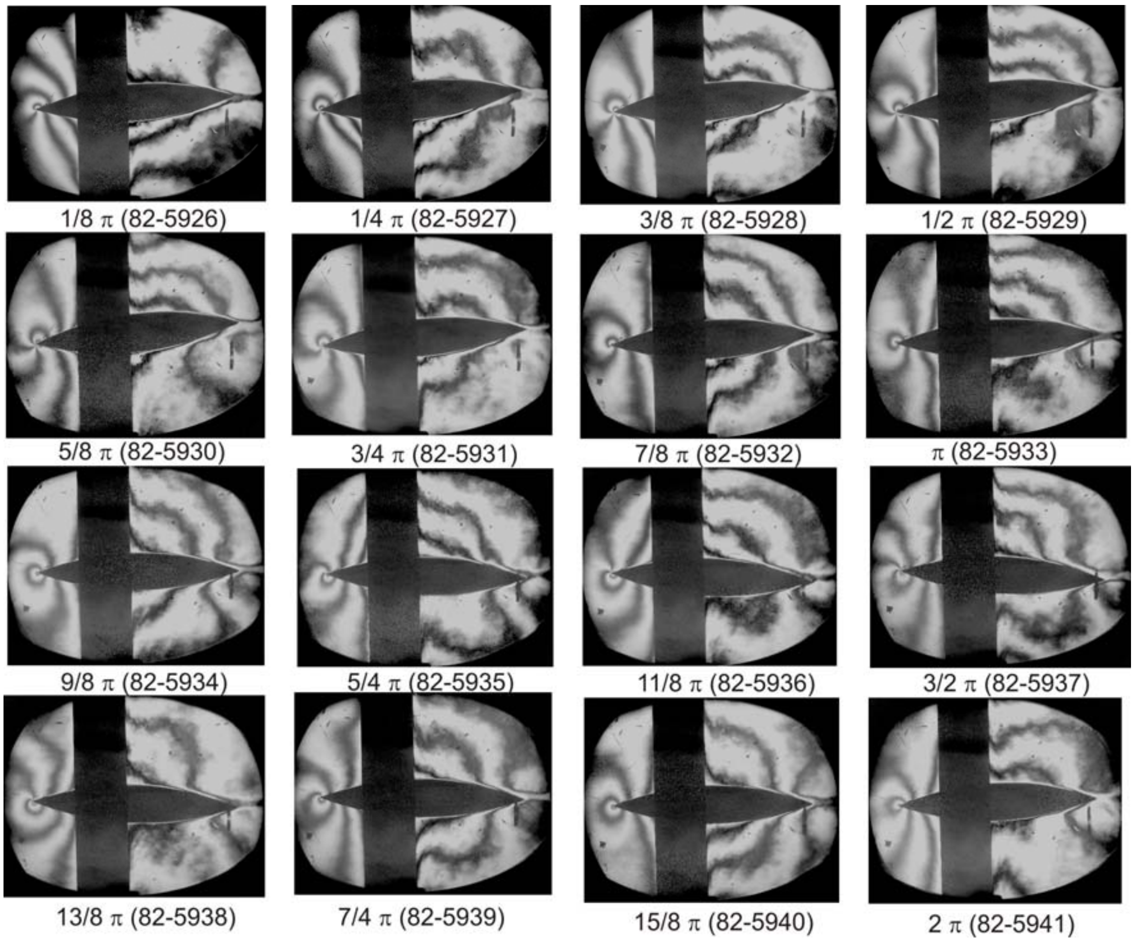


Figure 6: Interferogrammes of the flow field around vibrating DCA profile for one period of the self-oscillations after the lost of stability by flutter.

A hysteresis of fringes between the images for the motion of the model up and down can be identified on the interferogrammes. It is associated with the direction of the profile translation; see e.g. the difference between the phases ¼ π (movement down) and ¾ π (movement up).

The airflow velocities along the surface of the profile evaluated from the interferogrammes are presented in Fig.7 in eight phases of one vibration period. However, the interpolation of interferometry fringes in the non-visible region of the flow field, covered by metal strips carrying the profile, was problematic.

5. FLOW FIELD MEASUREMENT BY SCHLIEREN METHOD

For a better representation of the shear layers and of the separated flows, the schlieren method of visualization was also used. The schlieren images taken during one oscillation cycle are presented in Fig 8.

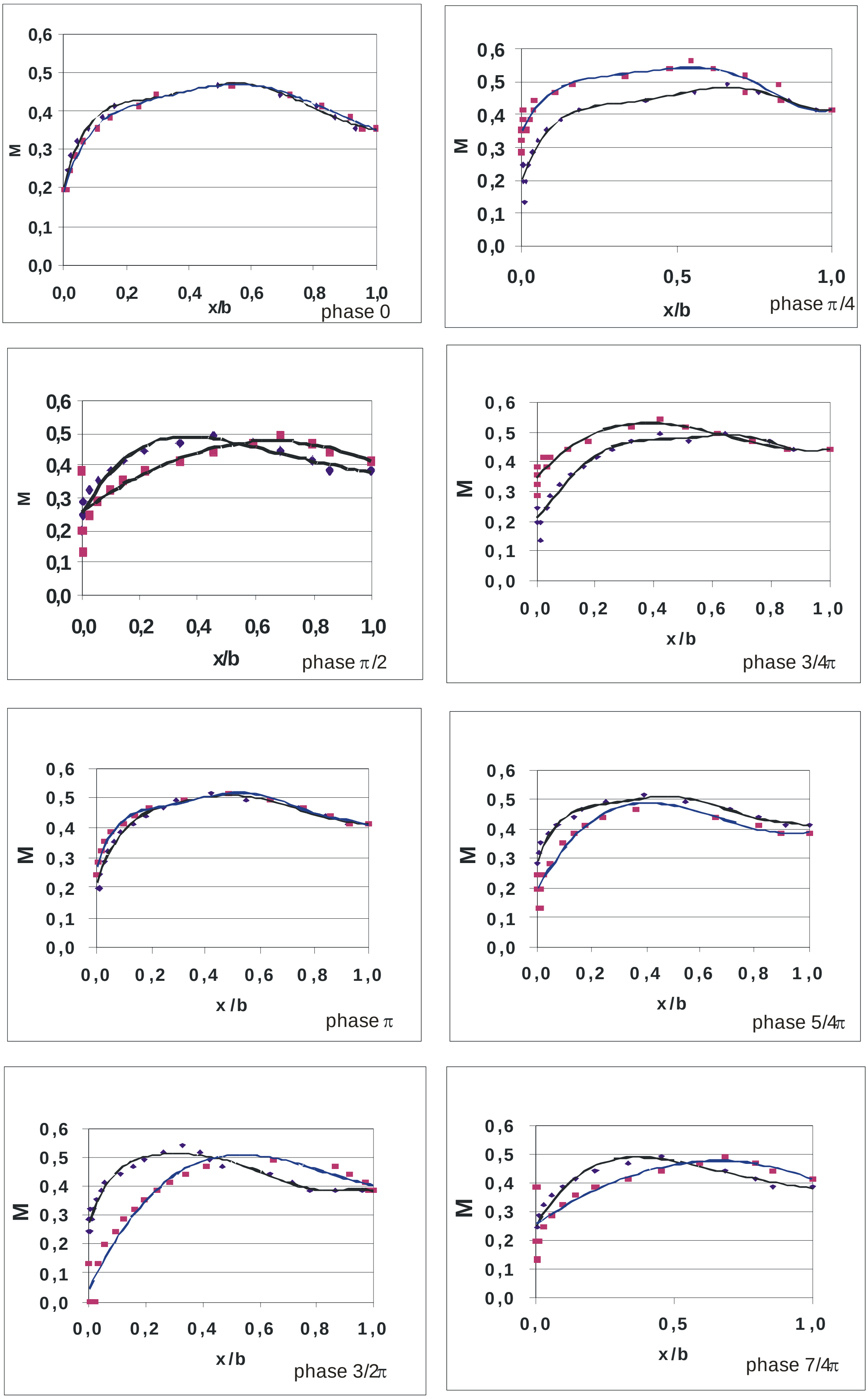


Figure 7: *Mach number of the flow field on the upper (♦) and lower (■) surfaces of the vibrating DCA profile during different phases of the self-oscillations related to the translation motion.*

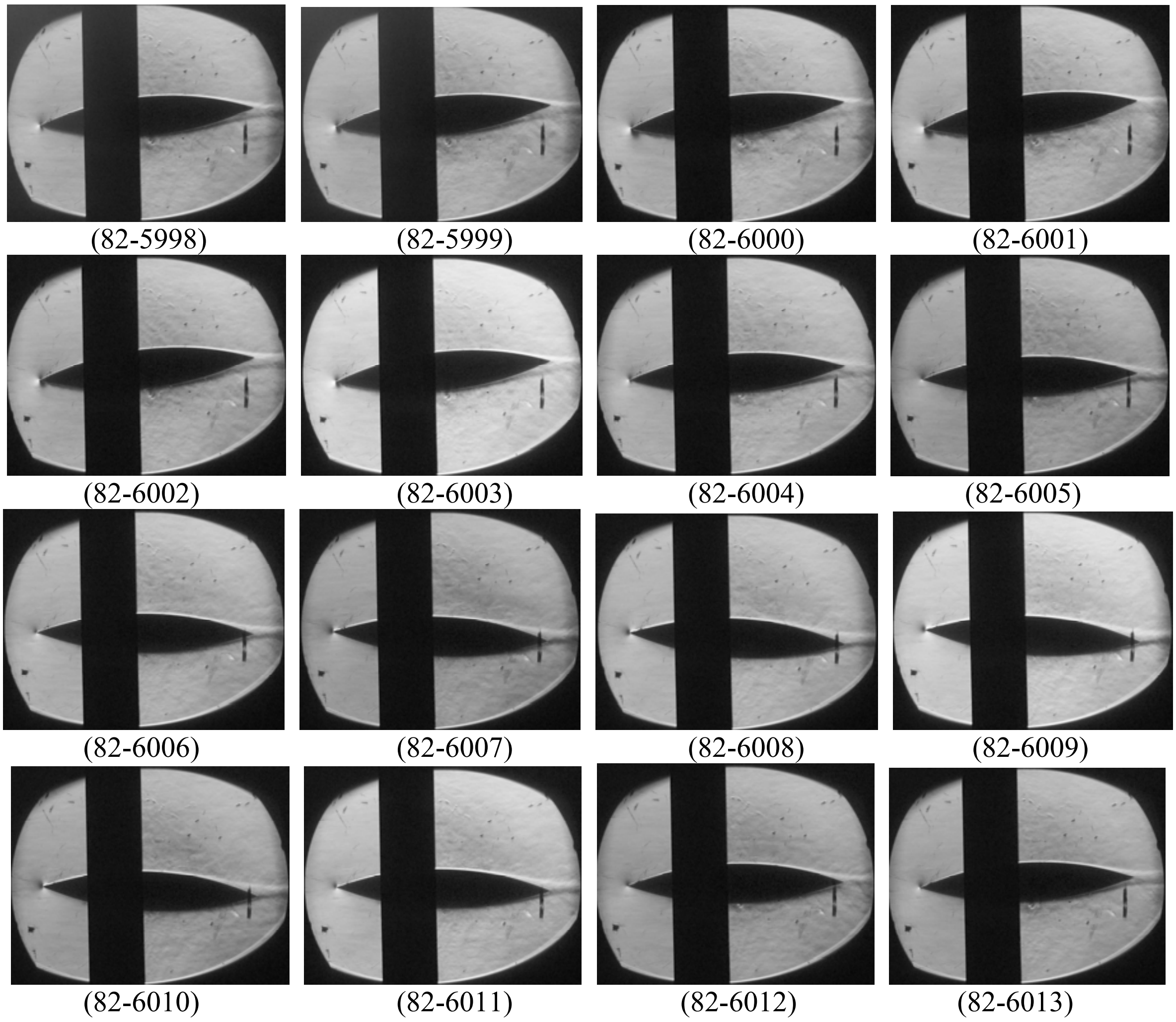


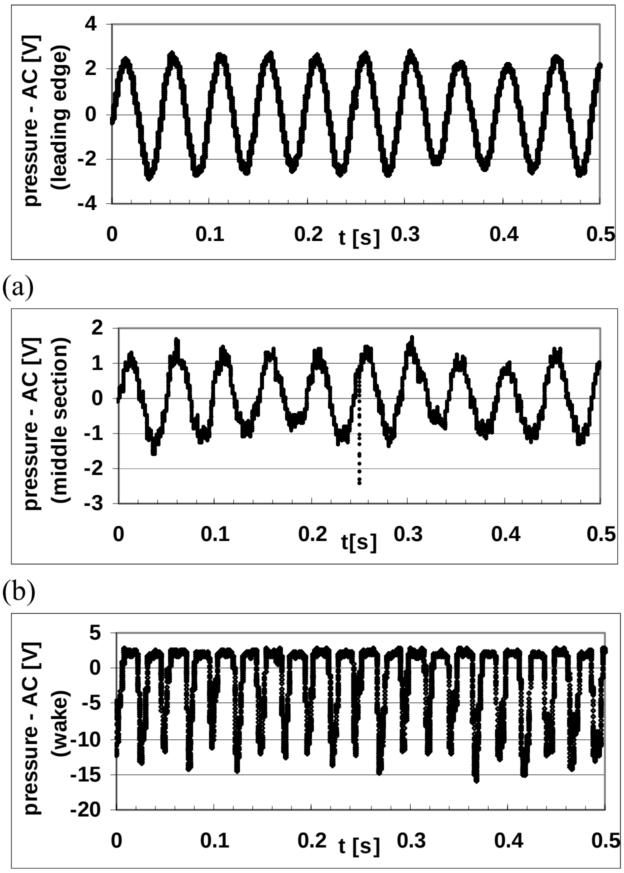
Figure 8: Schlieren images taken for the inlet airflow velocity M = 0.4 in 16th time instants during one self-oscillation period. (The phases of the profile motion do not correspond to the Fig. 6.)

6. PRESSURE MEASUREMENTS

Fluctuating part of the pressure signals measured during self-excited motion of the profile by the KULITE transducers is presented in Fig. 9. The static pressure on the upper surface of the vibrating profile is presented in Fig. 9a for the position of the transducer 20 mm behind the leading edge and in Fig, 9b for the position in the middle of the chord. The dynamic pressure in the wake of the profile is shown in Fig. 9c. The fundamental frequency of static pressure fluctuations on the profile was two times higher than the frequency of the dynamic pressure in the wake. The pressure signal at the middle of the chord is more noisy than the signal at the leading edge, probably caused by a higher turbulence level. The impulse disturbance due to the condenser discharge for the flash can be seen in the instant when the interferometry image at the time delay $\pi/8$ was taken.

Total lift force loading the profile in vertical direction was also evaluated from the interferogrammes and the results are shown for one vibration period in Fig.10. We suppose that the irregularity of the graph is due to the above mentioned necessity of interferometry fringes interpolation on approximately 25% of the profile surface.

Evaluated translational and rotational displacements of the profile during one cycle of the self-oscillations are shown in Fig. 11. Comparing Figs. 10 and 11, it can be concluded that the rotation, translation and lift force were all vibrating nearly in phase.



(c)

Figure 9: Fluctuating part of pressure on the upper surface of the profile at the leading edge (a), at the middle of the chord (b), in the wake (c).

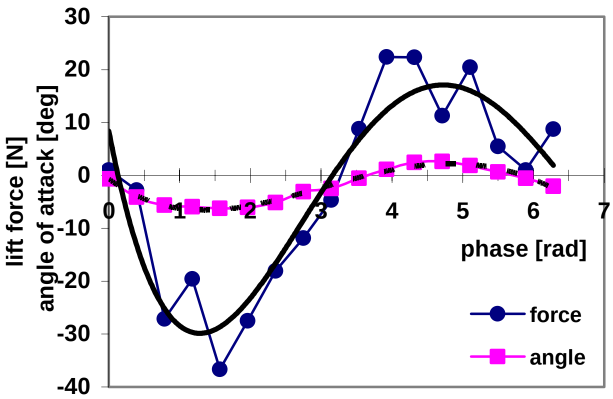


Figure 10: Lift force acting on the profile during one period of the self-excited motion.

7. CONCLUSIONS

Aeroelastic model with a double arc circle profile was constructed and investigated in wind tunnel in the regime of flutter instability at the Mach number *M*=0.4. Interferometry and schlieren methods were used for visualization of the airflow around the vibrating profile during the whole oscillation cycle, which was divided into 16 phases. From the interferogrammes, the flow velocity and the pressure distribution on the profile was determined. The accuracy of the evaluation was decreased due to the necessity of extrapolation of interferometry fringes in the part of the test section, where the flow field was shielded by the support construction of the model, and where the flow field was not visible.

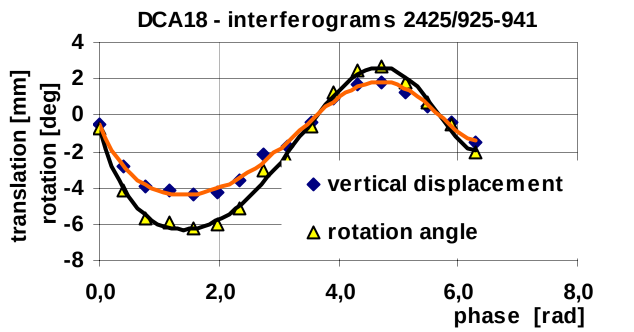


Figure 11: Angle of attack and vertical translation of the profile during one period of the self-excited motion.

ACKNOWLEDGEMENTS

The research was partially supported by the project of Ministry of Industry and Trade of the Czech Republic No. FT-TA/026 FOREMADE part T13 and by the project No. IA200760613 of the Grant Agency of Academy of Sciences of the Czech Republic. The authors also acknowledge the help of our colleagues: *Ing. Rudolf Dvořák, DrSc.* and *Prof. Ing. Pavel Šafařík, CSc.* from the Institute of Thermomechanics.

8. REFERENCES

Vlček, V., Luxa, M., 2005, Preliminary aeroelastic experiments on the profile with two degrees of freedom, In: *Engineering Mechanics 2005*, Svratka 9.-12.5.2005, (eds. Fuis.V, Krejčí P., Návrat T.), Institute of Thermomechanics, Prague 2005, 343-344 and 7 pp. on CD ROM – ISBN: 80-85918-93-5.

Horáček, J., Kozánek, J., Veselý, J., 2005, Dynamic and stability properties of an aeroelastic model, In: *Engineering Mechanics 2005*, Svratka 9.-12.5.2005, (eds. Fuis.V, Krejčí P., Návrat T.), Institute of Thermomechanics, Prague 2005, 121-122 and 12 pp. on CD ROM – ISBN: 80-85918-93-5.