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THE SELF-EXCITED VIBRATION OF THE NACA0015 PROFILE

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Abstract: *The two-dimensional flow patterns around the profile NACA0015 vibrating in self-excitation modes were measured in the wind tunnel by optical methods. The profile with two-degree-of-freedom moved in the vertical direction and rotated around the elastic axis in 1/3 of the profile chord. The Mach numbers for the self-excited vibrations were in the interval 0.2 – 0.45. Results of the interferometric measurement and the profile kinematic movements during the self-oscillations are presented.*

Keywords: ***self-excited vibrations, aeroelastic experiment, wind tunnel, flutter .***

1. Introduction

Aeroelastic experiments were realized in the subsonic aerodynamic tunnel of the Institute of Thermomechanics AS CR in Nový Knín with a modified NACA0015 profile. The Mach numbers corresponding to the self-excited vibrations were in the range M = 0.2 – 0.45 and the Reynolds number range was $(0.25 – 0.54)\cdot 10^6$. The detail description of the experimental setup is in Vlček (2009) and a schematic arrangement is in Fig. 1. The flow field was measured by interferometric and pneumatic methods, the profile vertical position was indicated by a mechanical sensor.

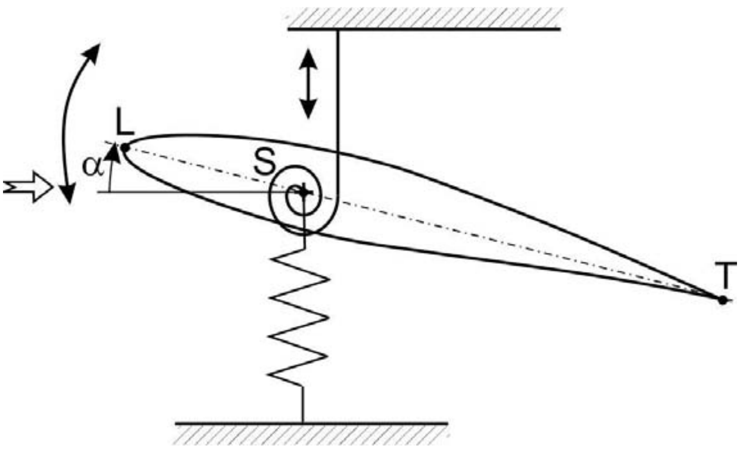

Fig. 1: Schematic arrangement of the experiment.

Eigenfrequencies for M = 0 were 19.0 Hz with 9.3 % damping in translation mode and 21.5 Hz with 11.9 % damping in rotation mode. Measured eigenfrequencies for M = 0 were 16.4 Hz with 2.0 % damping, 19.3 Hz with 9.3 % damping in translation mode, and 24.5 Hz with 1.5 % damping, 21.5 Hz with 11.9 % damping in rotation mode, respectively.

The Table 1 presents a list of data, setting for various experimental trials in the measurements and evaluated flutter frequencies.

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profile (meas. No.)	M [1]	Re [1]	mode	f_o [Hz]	damping [%]	f [Hz] evaluated	film pict/sec
NACA0015	0	0	translat	16.4	2.0		
(for 2510)	0	0	rotation	24.5	1.5		
NACA0015_2510-06	0.43	$0.52 \cdot 10^6$				19.5	1000
NACA0015	0	0	translat	19.0	9.3		
(for 2662,2663)	0	0	rotation	21.5	11.9		
NACA0015_2662-14	0.33	$0.40 \cdot 10^6$				31.2	500
NACA0015_2662-15	0.30	$0.36 \cdot 10^6$				28.5	1000
NACA0015_2662-16	0.28	$0.34 \cdot 10^6$				27.8	1000
NACA0015_2662-17	0.22	$0.27 \cdot 10^6$				21.2	500
NACA0015_2663-01	0.26	$0.31 \cdot 10^6$				22.7	500
NACA0015_2663-02	0.21	$0.25 \cdot 10^6$				21.7	1000
NACA0015_2663-03	0.38	$0.46 \cdot 10^6$				31.8	1000
NACA0015_2663-04	0.40	$0.48 \cdot 10^6$				32.2	1000
NACA0015_2663-05	0.45	$0.54 \cdot 10^6$				32.2	1000

Tab. 1: Experimental value sets.

2. Experimental results

Šafařík, Vlček (1985).The example of measured interferogram is depicted on Fig. 2, where it is possible to see flow separation beside the whole the upper profile surface.

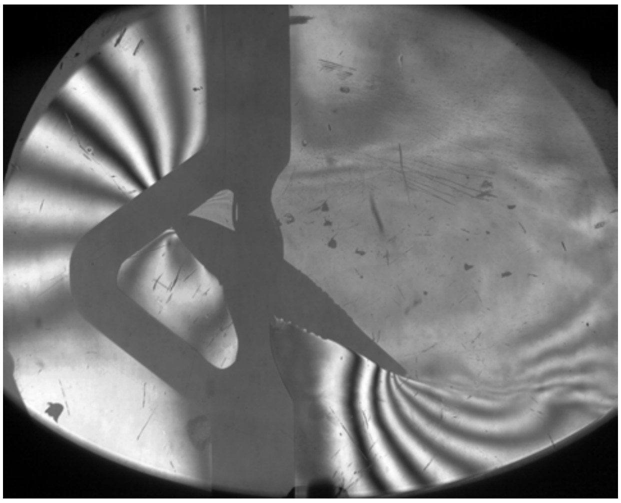

Fig. 2: Interferogram of a studied profile.

The arrangement of the system with different eigenfrequencies (corresponding to the translation and rotation motion of the profile) influenced the properties of the flow-field and the mechanical structure interaction. As it is depicted in Fig. 3 by increasing the inflow velocity higher than M = 0.26, the separation area is larger and the vibration frequency rises above the both eigenfrequencies identified for M = 0. The couple mode flutter found between M = 0.21 and M = 0.26 is changed to the stall flutter for the bigger Mach numbers. The increase of the vibration level was so high, that at M = 0.45 the experiment had to be finished due to the danger of system destruction. The flutter frequency of the vibration in this process increased 1.6 times and the optical measurements showed that the area-wide separation appears during 25% to 50% of the vibration period. In this case we can observe so-called stall flutter Dowell (1995). The evaluation of interferograms is described in Vlček (2010).

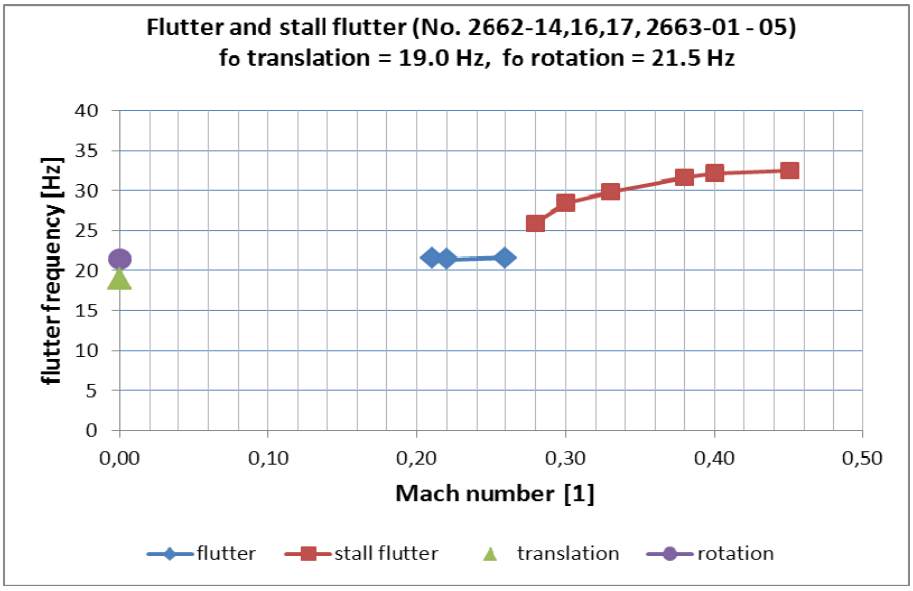

Fig. 3: The eigenfrequency changes of the self-excited vibration as a function of the Mach number.

In case of the bigger difference between the eigenfrequencies for translation and rotation modes for M = 0 no stall flutter was observed. Fig. 4 illustrates this result: original translation frequency was 16.4 Hz and the rotational frequency was 24.5 Hz, i.e. the difference in this case was 8.1 Hz (about four times more than in previous case shown in Fig. 3). The flutter frequency 19.9 Hz (M = 0.44) lies between original profile fequencies measured for M = 0. It means that the origin of the aeroelastic instability was in the classic coupled mode flutter with two-degrees of freedom.

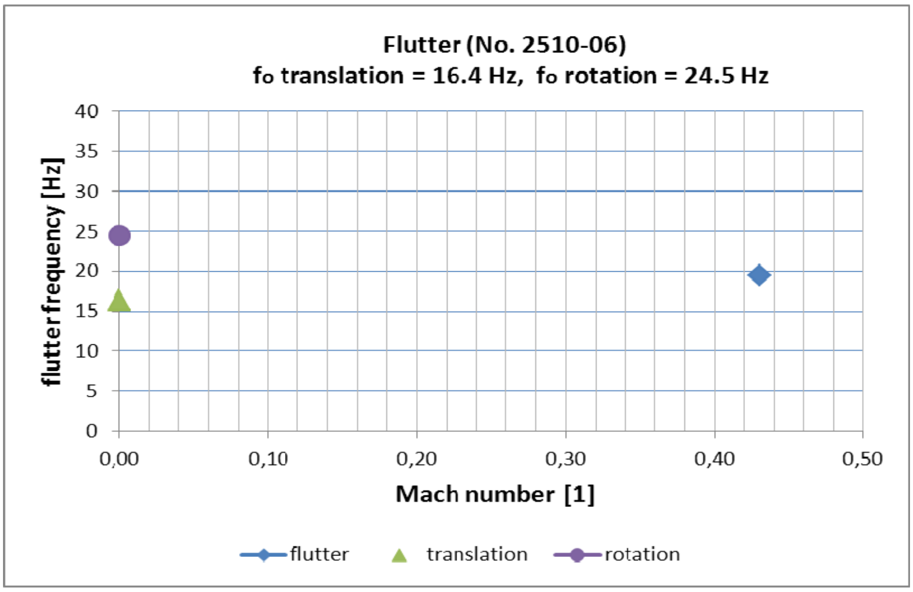

Fig. 4: The eigenfrequency changes of the self-excited vibration as a function of the Mach number for the case of bigger difference between the profile eigenfrequencies.

The kinematics of the airfoil motion during one period of the self-excitation is presented in the next Figures 5a) – 5e) for several Mach numbers in increasing order. There is interesting that in Figure 5c), 5d) and 5e) zero angle of attack was achieved at the value 80-85% of the maximal amplitude of the rotation center motion. This was found in the case of the profile with the eigenfrequencies 19,0 Hz without flow (M = 0) for translation mode, and 21,5 Hz for rotation mode. On the all figures, the red points inside denote the trajectory of motion of the profile rotation center.

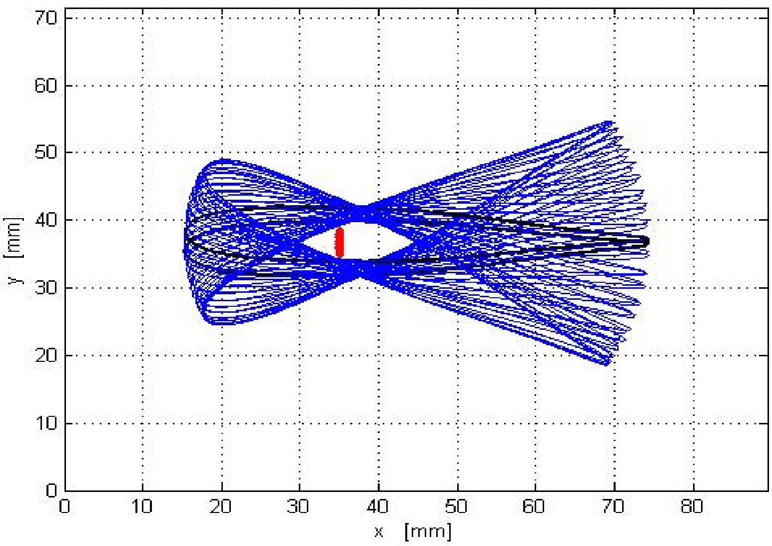

Fig. 5a): Profile motion during one period of its self-excited vibration by flutter for M = 0.21 (2663-02).

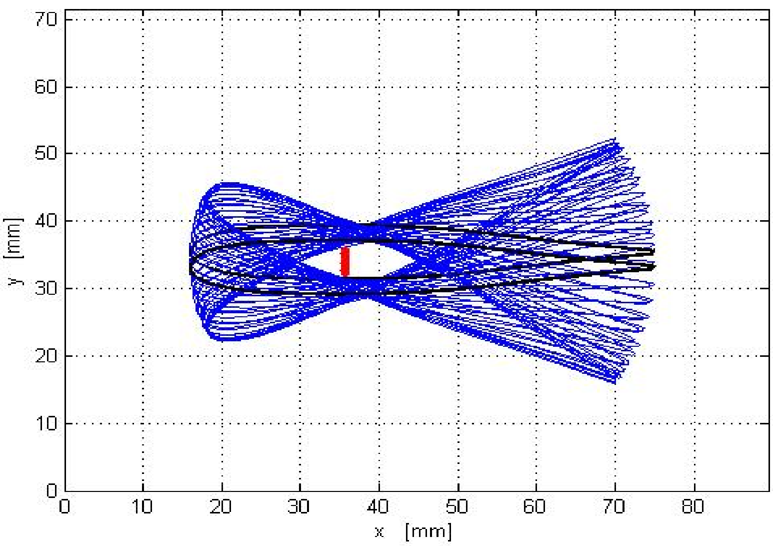

Fig. 5b): M = 0.22 (2662-17).

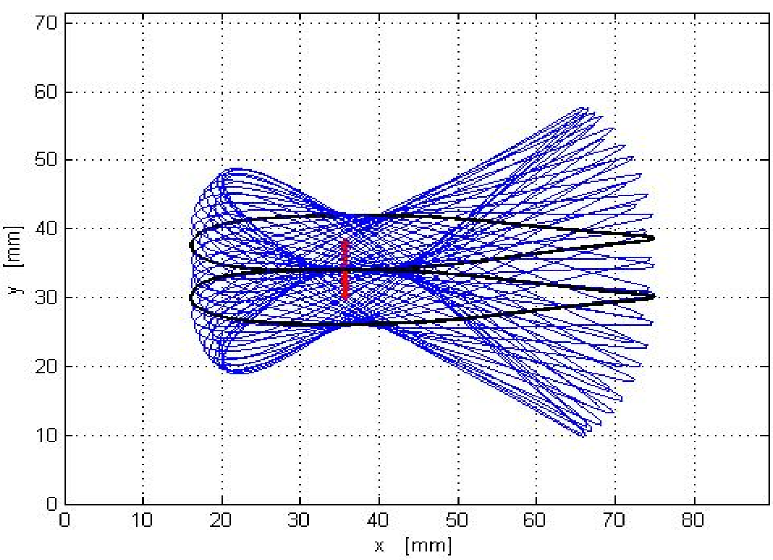

Fig. 5c): M = 0.28 (2662-16).

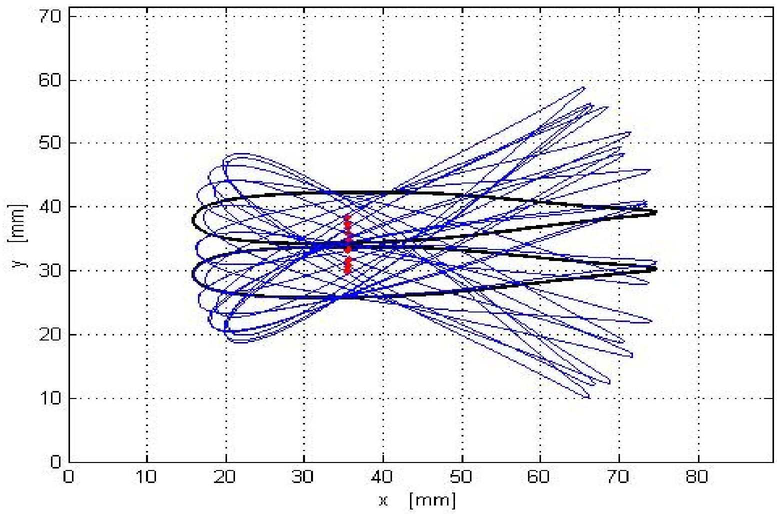

Fig. 5d): M = 0.33 (2662-14).

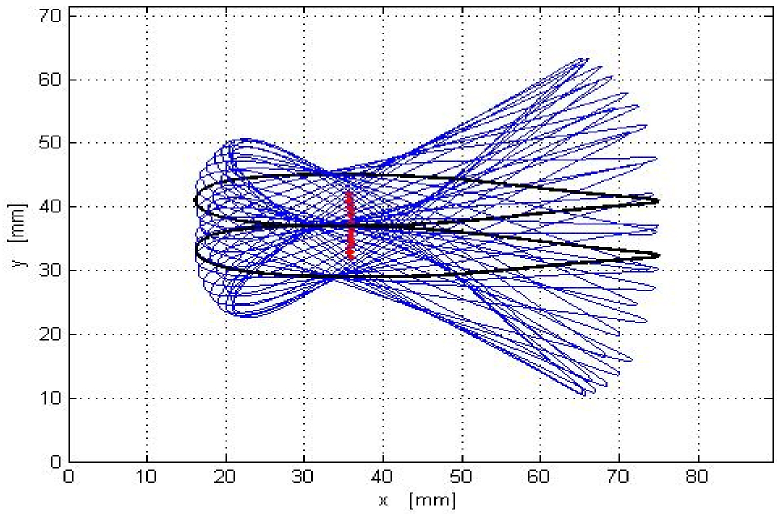

Fig. 5e): M = 0.45 (2663-05).

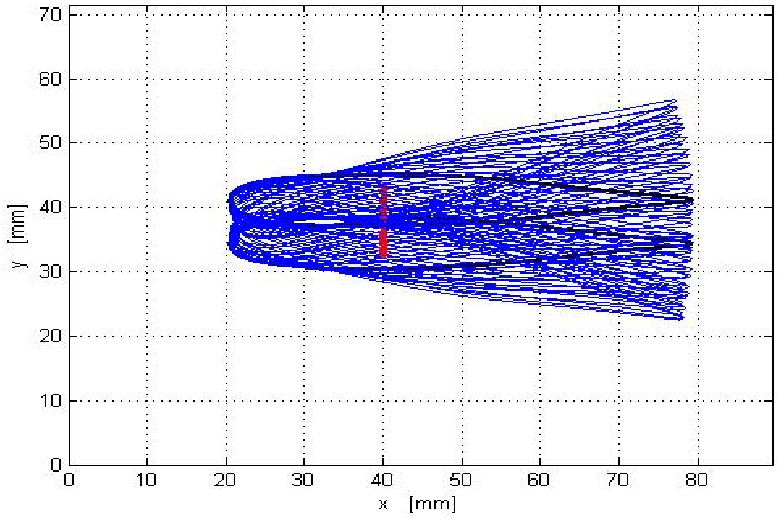

Fig. 6: The profile NACA0015, M = 0.43.

Figure 6 shows the kinematics of the airfoil motion of the profile for the case bigger difference between profile eigenfrequencies: translation mode – 16.4 Hz (damping 2.0 %), rotation mode 24.5 Hz (damping 1.5 %).

Figures 7a) – 7c) explain the stall flutter arise during the flow velocity increase. On the presented results it is possible to see the jumping between the flutter frequencies with increasing the flow velocity in the interval of Mach numbers 0.25 – 0.35. Outside of this velocity interval the system has properties as follows: unstable by coupled mode flutter is for M < 0.25 and by stall flutter for M > 0.35.

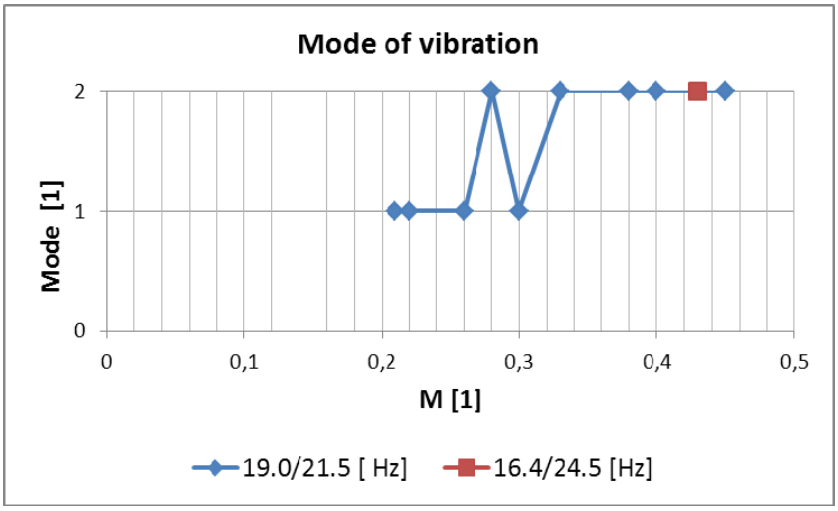

Fig. 7a): Mode of vibration.

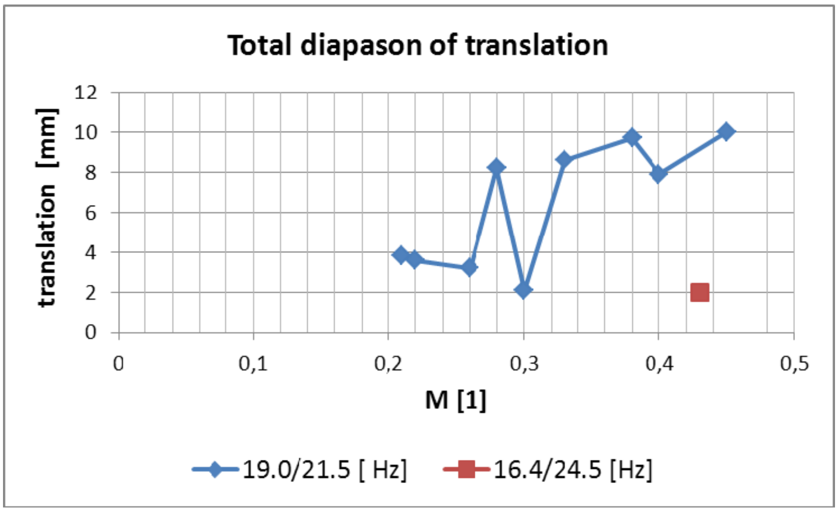

Fig. 7b): Total diapason of translation.

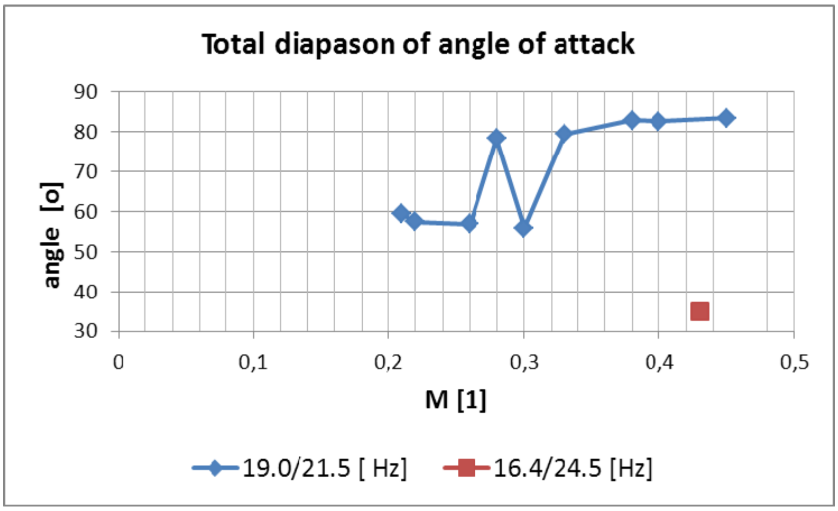

Fig. 7c): Total diapason of angle of attack.

The relations between axis rotation center shift of the profile and approach angle are presented on the Fig. 8a) – i) for Mach number from interval 0.21 – 0.45.

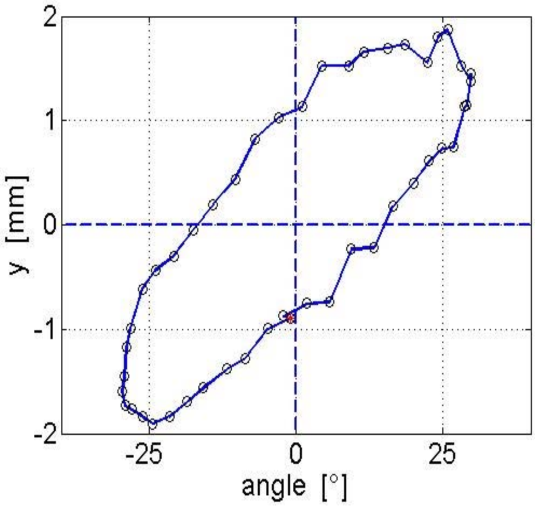

Fig. 8a): M=0.21 for measure No. 2663-02.

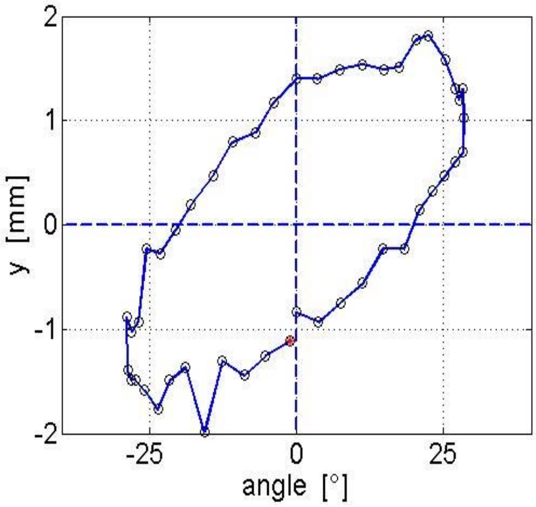

Fig. 8b): M=0.22 for measure No. 2662-17.

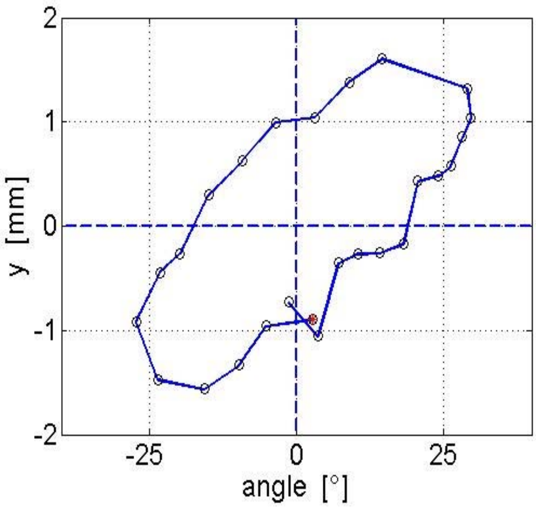

Fig. 8c): M=0.26 for measure No. 2663-01.

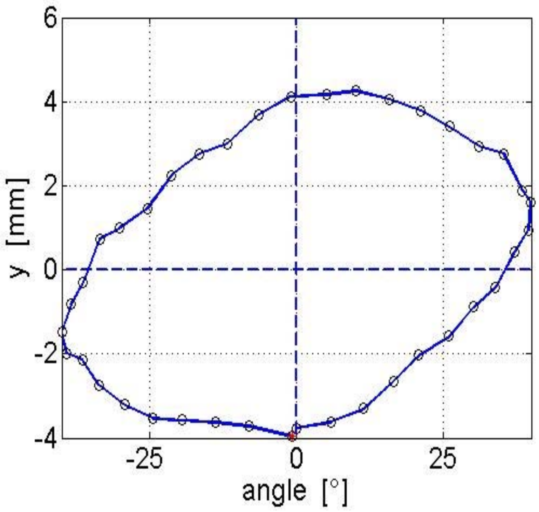

Fig. 8d): M=0.28 for measure No. 2662-16.

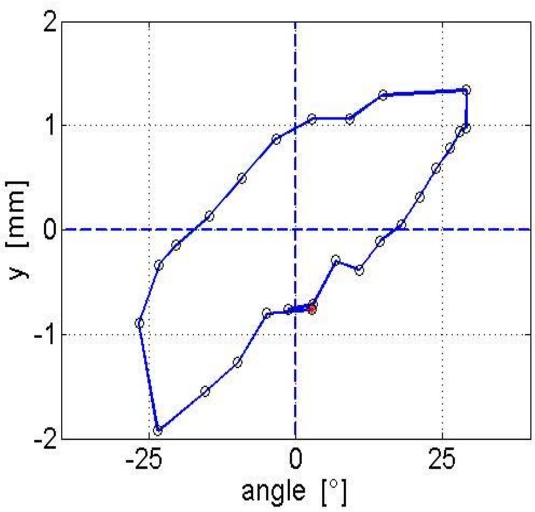

Fig. 8e): M=0.30 for measure No. 2662-15.

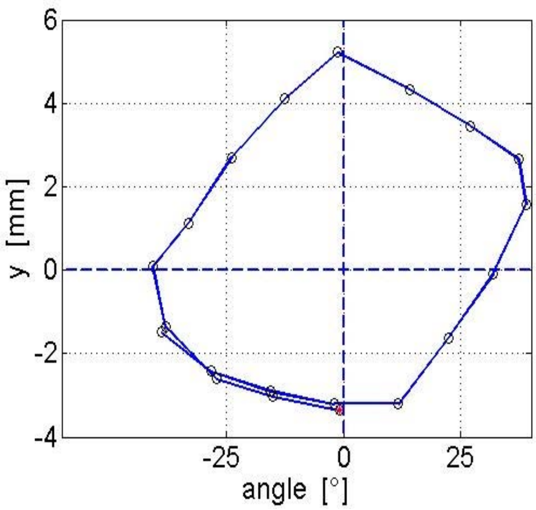

Fig. 8f): M=0.33 for measure No. 2662-14.

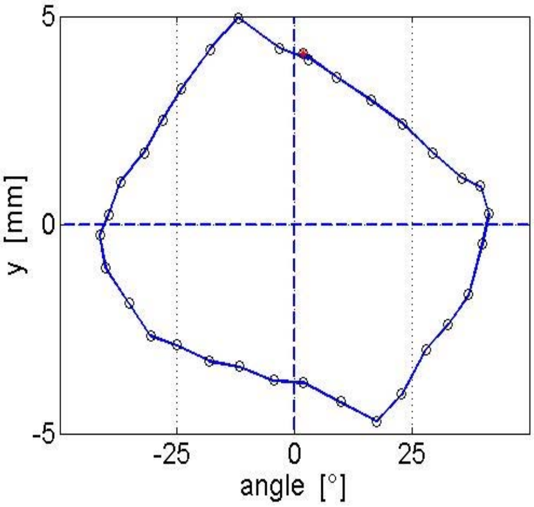

Fig. 8g): M=0.38 for measure No. 2663-03.

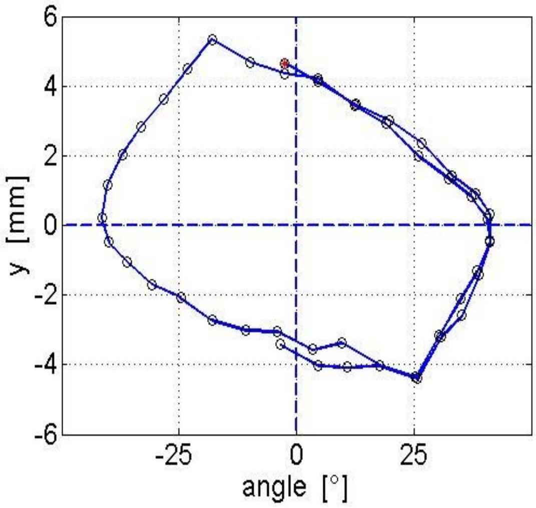

Fig. 8h): M=0.40 for measure No. 2663-04.

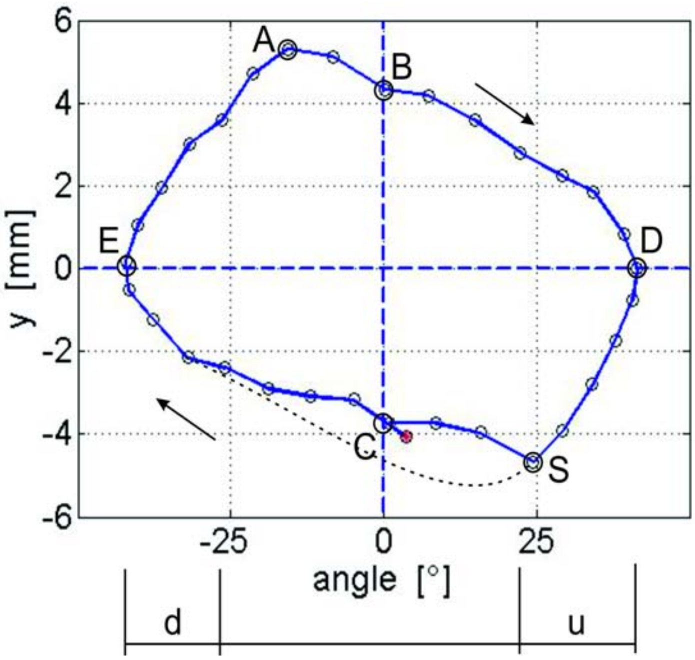

Fig. 8i): Relation between axis rotation center shift of the profile (vertical, [mm]) and approach angle (horizontal, [°]) for measure No. 2663-05, M=0.45, translation frequency for M = 0 is 19.0 Hz and rotation frequency is 21.5 Hz.

The motion of the profile during the stall flutter is shown in more detail on Fig. 8i) for the highest Mach number M = 0.45. The point B in the diagram denotes zero angle of attack, the point A denotes the maximal translation and precedes the point B in time. In the point S the profile impacts to some artificial mechanical barrier; a point-line represents the profile trajectory that could be realised in the system without impacts. The points A and C correspond to the maximal translation deplacement in positive and negative direction, respectively. The intervals denoted by letters **u** and **d** correspond to the regimes when the whole break of the flow appears on the upper (**u**) and lower (**d**) profile surface, respectively. The maximal positive (point D) and negative (point E) angles of attack correspond to zero profile translation.

An example of the phase shift between the translation and rotation of the profile demonstrated in Figure 9.

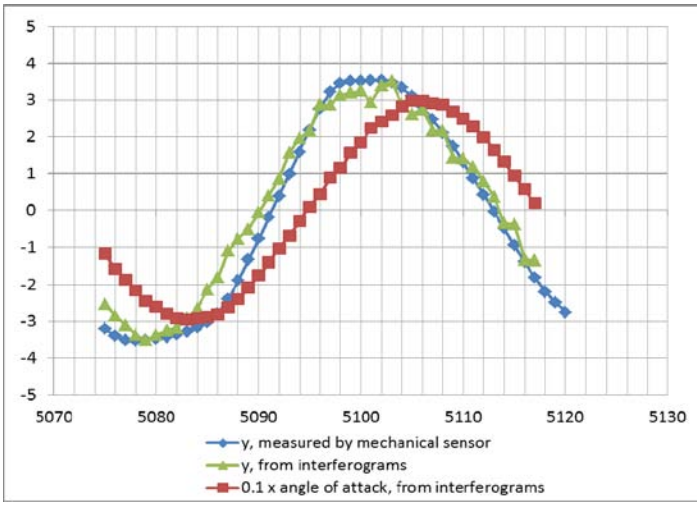

Fig. 9: The angle of attack (in [°]) and vertical translation (in 10 time scale, [mm]) on the vertical axis versus the time (horizontal, [ms]) during one period of the self-excited vibrations, for measurement No. 2663-02, M=0.21.

3. Conclusion

Several combinations of experimental parameters were realized during aeroelastic measurements of the self-excited profile vibrations in the Mach number range M=0.21 – 0.45. The influence of Mach number on the coupled mode flutter and stall flutter in relation to the difference between the eigenfrequencies corresponding to the translation and rotation motion of the profile was determined.

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