23rd International Conference
ENGINEERING MECHANICS 2017
Svratka, Czech Republic, 15 – 18 May 2017

SOME ENERGY RELATIONS OF THE SELF-EXCITED PROFILE VIBRATION IN FLOWING FLUID

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Abstract: *The aeroelastic measurements on the oscillating NACA0015 profile vibrating as the dynamic system with two degrees of freedom (pitch and plunge) were realized within the interval of Mach numbers M = 0.08 to 0.45 and Reynolds numbers Re = (1 – 5) 10^5 in the wind tunnel of the Institute of Thermomechanics of the CAS. Frequency and amplitude characteristics of the vibrating profile and values of elastic strain energy corresponding maximum pitch and plunge displacements of the studied profile were detected.*

Keywords: Airfoil NACA 0015, Aeroelasticity, Stall flutter, Dynamic stall, Limit cycle oscillation.

Introduction

The effort to reduce energy losses and to increase the reliability of technologies, where aeroelastic phenomena occur, requires obtaining accurate additional supporting data (Dowell, 2015; Fung, 1993). Their completion is one of the goals of this study, which summarizes some experimental results published by the authors earlier (Šidlof, 2016, Vlček, 2016).

1. Experimental equipment

The schema of the experiment is in Fig. 1. Measurements were realized in the vacuum wind tunnel of the laboratory of the Institute of Thermomechanics CAS in N. Knin. Test section has a cross section 210x80 mm and the profile NACA0015 had a chord with a length of 59.5 mm. The effect of seven different values of pitch support stiffness was studied. Modification of the stiffness was realized by using a set of interchangeable springs.

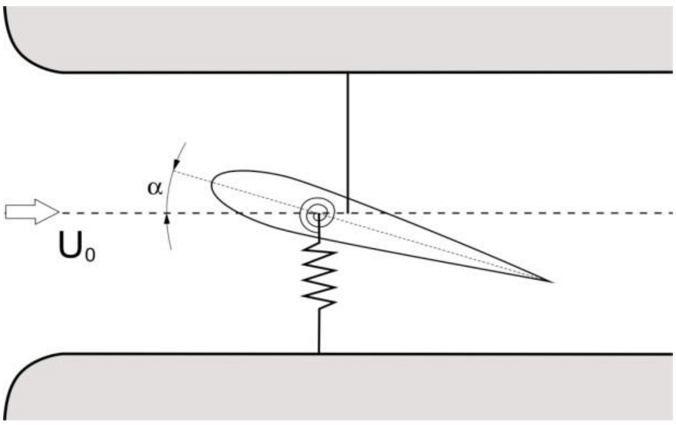

Fig. 1: General schema of the experiment.

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2. Frequency of the self-excited oscillation

The dependence of the frequency of self-excited oscillation to the flow velocity is indicated in Fig. 2 in the form of dimensionless Strouhal number $Sh = f \cdot l / v$, where f is the frequency [Hz], l is the chord of the profile [m] and v is the flow velocity [m / s].

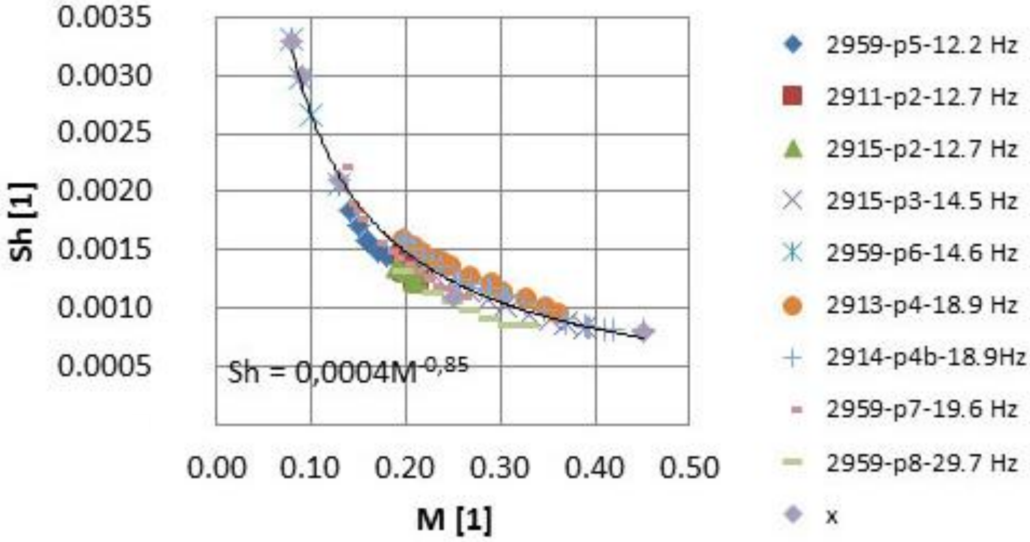

Fig. 2: Dimensionless frequency of the profile oscillation.

A more detailed analysis of this course, including the relationship between the frequency of self-excited profile oscillation and the eigenfrequencies of both degrees of freedom for zero fluid velocity is shown in (Vlček, 2017).

3. Energetic relation between plunge and pitch harmonic vibrations during the self-excited profile

Real waveform of plunge and pitch was not precisely harmonic, therefore the calculation of energy was performed for the case of the maximum amplitude.

Energy of the plunge for one value of the plunge stiffness

First plunge eigenfrequency was found as $f_{0\ plunge} = 16.4$ Hz. Corresponding angular velocity will be

$$\omega_{plunge} = 2\pi\ f_{0\ plunge} = (k_{plunge}/m)^{1/2},$$

where m is the body mass, approximately 1 kg. Then the total plunge stiffness is $k_{plunge} = 10\ 609$ N/m.

Tab. 1: Calculation of the plunge energy.

№	M	y_{max} [mm]	f [Hz]	E_{plunge} [J]
2959-46	0.14	0.9	14.90	0.0043
2959-47	0.15	0.6	14.90	0.0019
2959-48	0.16	1.7	14.60	0.0153
2959-49	0.16	2.6	14.60	0.0359
2959-50	0.17	3.6	14.60	0.0687
2959-52	0.19	6.3	15.10	0.2105
2959-42	0.20	7.7	15.40	0.3145

Potential energy E_{plunge} [J] of the plunge at the maximum deflection is

$$E_{plunge} = \tfrac{1}{2}\ k_{plunge} \cdot (y_{max})^2,$$

where y_{max} is maximum plunge amplitude determined from measurements. Data № 2959-46 up to 52 has values denoted in Tab. 1, M is the Mach number of the fluid flow, f is the self-excited frequency.

Energy of the pitch for different pitch stiffness corresponding of variable elasticity support

Potential pitch energy E_{pitch} [J] for one vibration period is defined by relation

$$E_{pitch} = ½\, k_{pitch} \cdot (\varphi_{pitch})^2,$$

where k_{pitch} [N·m/rad] is the pitch stiffness and φ_{pitch} [rad] is maximum pitch angle amplitude, both determined from experiments.

Numerical values of the pitch energy are calculated in Tab. 2.

Tab. 2: Calculation of the pitch energy.

№	M	φ_{pitch} [rad]	k_{pitch} [N.m/rad]	E_{pitch} [J]
2959-46	0.14	0.03	0.305	0.000137
2959-47	0.15	0.02	0.431	0.000086
2959-48	0.16	0.06	0.400	0.00072
2959-49	0.16	0.09	0.622	0.0025
2959-50	0.17	0.43	0.7905	0.0731
2959-52	0.19	0.88	1.991	0.7709
2959-42	0.20	0.91	0.030	0.1242

The pitch eigenfrequency for the case 2959-47: $f_{0\ pitch}$ = 14.9 Hz.

The calculation of the moment of inertia I from the equation

$$\omega_{pitch} = 2\,\pi\, f_{pitch} = (k_{pitch} / I)^{1/2}.$$

For pitch stiffness k_{pitch} = 0.431 [N·m/rad], determined from measurement, the profile moment of inertia is

$$I = k_{pitch} / (2\,\pi \cdot f_{pitch})^2 = 5.2 \cdot 10^{-5}\ kg \cdot m^{-2}.$$

We note, that the above energy calculations concern the individual plunge and pitch maximum energy which are not realized at the same time.

The illustration of the ratio of the maximum plunge and pitch potential energy E_{plunge} / E_{pitch} is given in Fig. 3.

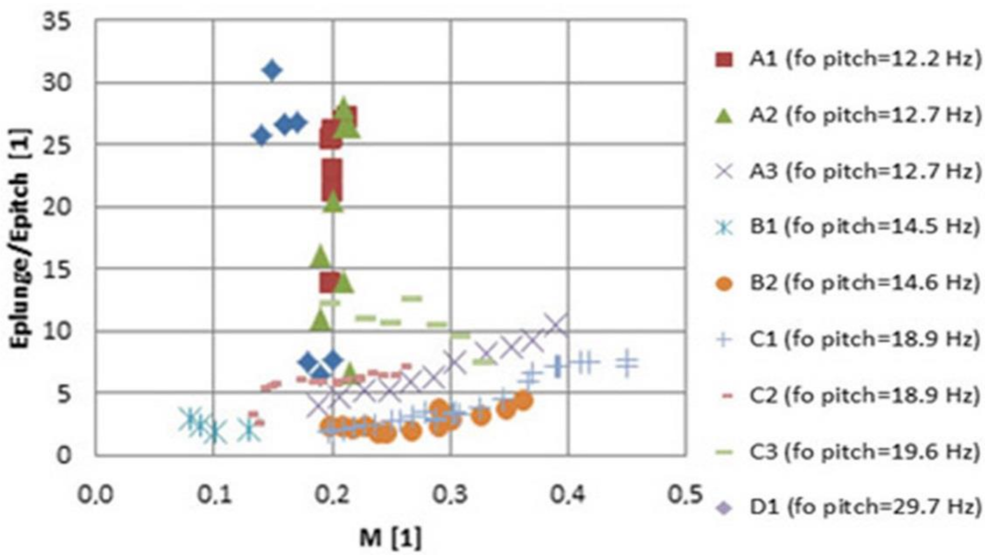

Fig. 3: The energy ratio of the plunge and pitch elastic support deformation for different flow velocity.

4. Conclusions

The paper is concerned with the aeroelastic energy in the self-excited vibration of the profile in fluid flow and follows the results published in (Vlček, 2017) devoted to the frequency of this vibration.

The relationship between the plunge and pitch support elasticity deformation energy changes with a specific form with the pitch stiffness or with the flow velocity (see Fig.4). We can expect connection of this character with attributes of the origin and attributes of the periods of the self-excited oscillations of the profile. The potential energy was evaluated in the plunge and pitch mode separately.

The calculation of the total plunge and pitch deformation for one case was shown. For future calculation of the total energy deformation their phase shift must be considered.

Acknowledgement

The authors have been sponsored by the Pilot project of the Institute of Thermomechanics AS CR, v. v. i. № 903101 and Strategy AV21 № 3 "Effective transformation and storage of the energy" of the Academy of Sciences of the Czech Republic. The paper was created in cooperation with J. Horáček, M. Luxa and D. Šimurda.

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