27/28th International Conference
ENGINEERING MECHANICS 2022
Milovy, Czech Republic, May 9 –12, 2022
Paper **#99,** pp. 377–380, doi: 10.21495/51-2-377

EFFECT OF OSCILLATING BLADE ON TONAL NOISE OF BLADE CASCADE WITH FIVE NACA 0010 PROFILES

Šnábl P.*, Pešek L., Radolf V., Antoš P., Procházka P., Prasad C.S.

Abstract: *The airfoil tonal noise is a well known phenomenon which appears on single airfoils in moderate Reynolds numbers at low angles of attack. It can appear on small aircrafts, fans, wind turbines etc. In this paper, it was observed on a blade cascade consisting of five NACA 0010 profiles placed in a closed rectangular channel with hard walls when for given conditions, i.e. flow velocity and angle of attack, the cascade tunes to one single frequency. During the middle blade oscillation, the single tone splits up to several tones with lower intensity modulated by the excitation frequency. Thus, the oscillation of one blade suppresses the tonal noise generation in the cascade.*

Keywords: Aeroacoustics, Blade cascade, Trailing edge noise, Tonal noise, NACA 0010.

1. Introduction

Experimental blade cascade consisting of five NACA 0010 profiles with rotational degree of freedom was built in our institute to study aero-elastic instabilities in the cascade such as flutter. During our research it was observed that high-pitch noise is generated in the flow-field around the cascade and its occurrence and frequency is dependent on the flow conditions, i.e. flow speed and angle of attack (AOA). This phenomenon is known as tonal noise or airfoil self-noise. It is a self-induced discrete frequency noise generated by aerofoils placed in streams at low Mach number with low AOA (McAlpine, 1999). It is supposedly generated by Tollmien–Schlichting waves development in laminar boundary layer on the pressure side of the airfoil that are then amplified by inflectional profiles of separating shear layer at the trailing edge and the sound is radiated as those amplified instabilities pass the trailing edge as described by Nash (1999).

In our experiments on blade cascade we observed vortex trains present on suction side of the profiles that we expected to be responsible for the tonal noise generation. Such vortex train is visible on Fig. 1 where snapshot from particle image velocimetry (PIV) is shown. The illuminated line is lower (suction) side of the fourth blade in the cascade with AOA -10° at velocity 30m/s incoming from the left side and under there are

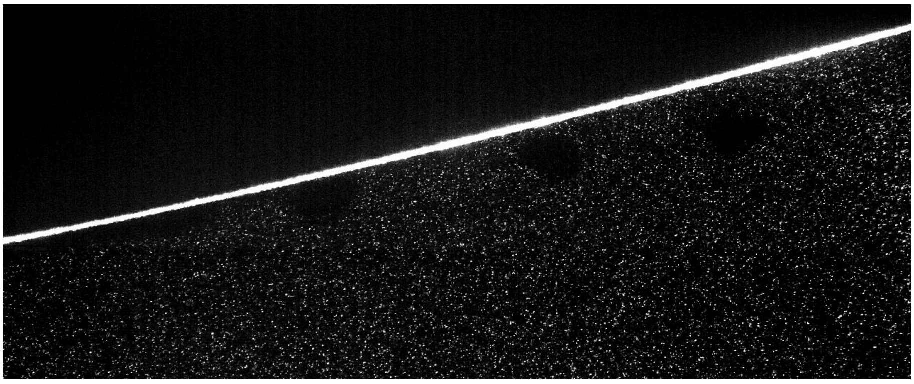

Fig. 1: Vortex train visible on snapshot from the PIV measurement.

---

[*] Ing. Pavel Šnábl: Institute of Thermomechanics of the CAS, v. v. i.; Dolejškova 1402/5; 182 00, Praha 8; CZ, snabl@it.cas.cz

three black circular areas with lower concentration of illuminated particles that visualise the vortices. In this case, the middle blade of the cascade was oscillating and those vortices appeared and vanished periodically with the oscillation.

Since the acquisition frequency of the PIV was not high enough to identify the frequency of the vortex separation, it was decided to use hot-wire anemometry in the area of the vortex presence and to place a microphone behind the cascade to measure far field noise.

2. Experimental Setup

Five NACA 0010 airfoil profiles with cord length $c = 73$ mm and span $l = 100$ mm are placed in a closed channel test section with cross-section 100×250 mm and length 420 mm that is connected to open-loop wind tunnel. The geometry of the cascade is shown in Fig. 2. The blades of the cascade are fixed except the middle one that can be either hinged freely on torsional springs so it can oscillate freely along its axis in the flow or it can be excited by electromagnetic shaker with chosen frequency and amplitude. More detailed description of the blade cascade design can be found in Šnábl (2021). “HW” in Fig. 2 shows the position of hot-wire near the lower surface of the fourth blade where the vortices appear and are affected by the motion of the middle blade. A hot-wire probe *Dantec 55P11* was used for HW measurement. The probe has a tungsten wire of 0.005 mm diameter of and the 1.2 mm length. It was operated by constant temperature anemometer (CTA) *Dantec Streamline* at a sensor temperature of 200°C. A *B&K 2239 Sound Level Meter* microphone was placed 30 cm behind the outlet of the channel aside from the outcoming flow and a laser vibrometer *Polytec OFV 505* was used to measure the motion of the middle blade. In the results shown in this paper, the blades were parallel to the incoming flow (AOA 0°) and the flow velocity was 30 m/s.

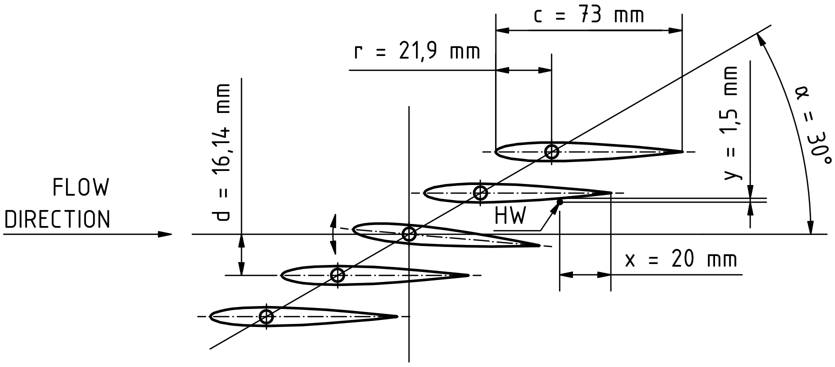

Fig. 2: Schematic picture of the blade cascade.

3. Results

At first, the measurement was performed without forced excitation of the middle blade. In this case, the middle blade exhibits only small amplitudes of flow-excited vibrations (around 0,1° in peaks). Fig. 3 shows autospectra of the measured signals for this measurement. In all measured signals there is significant resonance peak at frequency 2720 Hz. Not only the tonal noise measured by microphone corresponds to the frequency of vortex separation measured by hot wire, also the movement of the middle blade shows this frequency. This finding seemed suspicious because the cascade is not periodic, i.e. each blade is subjected to different flow conditions, and the possibility that vortices under the middle blade would have exactly the same frequency as those under the fourth blade seemed unlikely. We suppose that the vortices of all blades locked-in with the fourth acoustic resonant frequency of the closed channel that is theoretically 2744 Hz (for the speed of sound 343 m/s and channel height 250 mm). Such behaviour was also observed for single profile in hard-wall channel by Nash (1999).

In the next experiment, the middle blade was excited by electromagnetic shaker with frequency 40 Hz and amplitude 3° and the autospectra of all measured signals are shown in Fig. 4. During this measurement, no single tone was heard which is also visible in the autospectrum from the microphone. The tonal noise at 2720 Hz is not present in this case but, however, several smaller peaks appeared in the spectrum in the range from 2500 to 3000 Hz. These peaks are 40 Hz apart which corresponds to modulation by oscillation

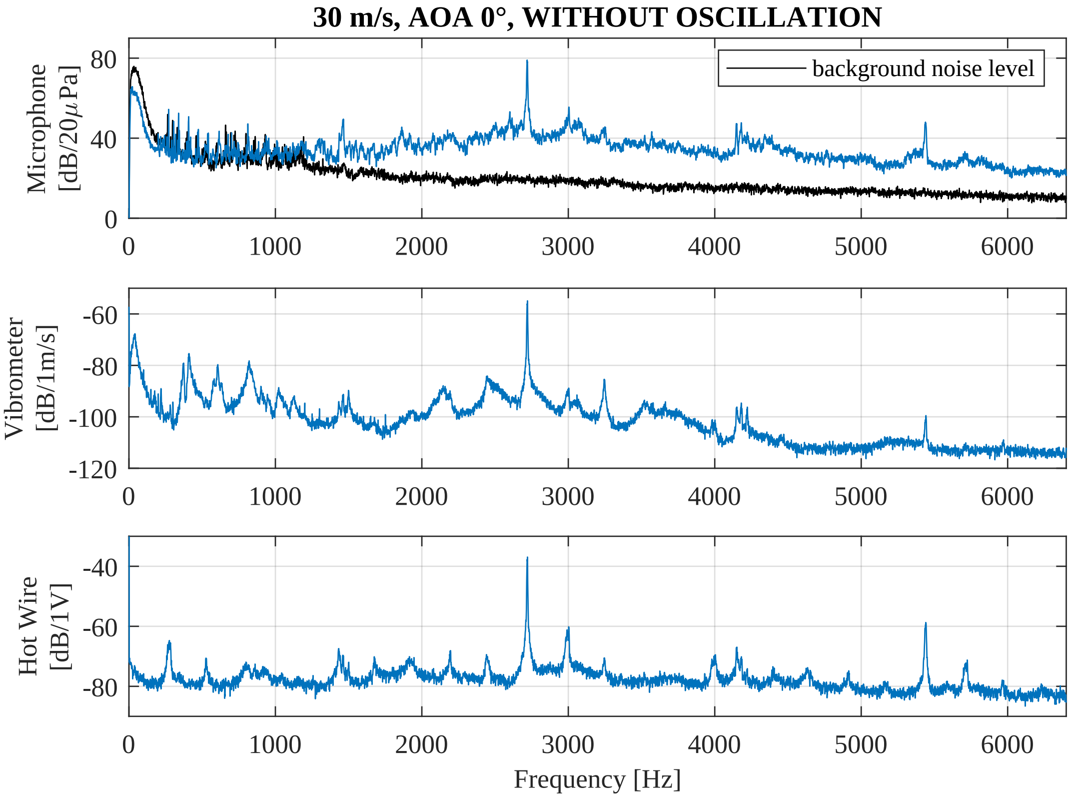

Fig. 3: Autospectra of the measured signals without middle blade oscillation.

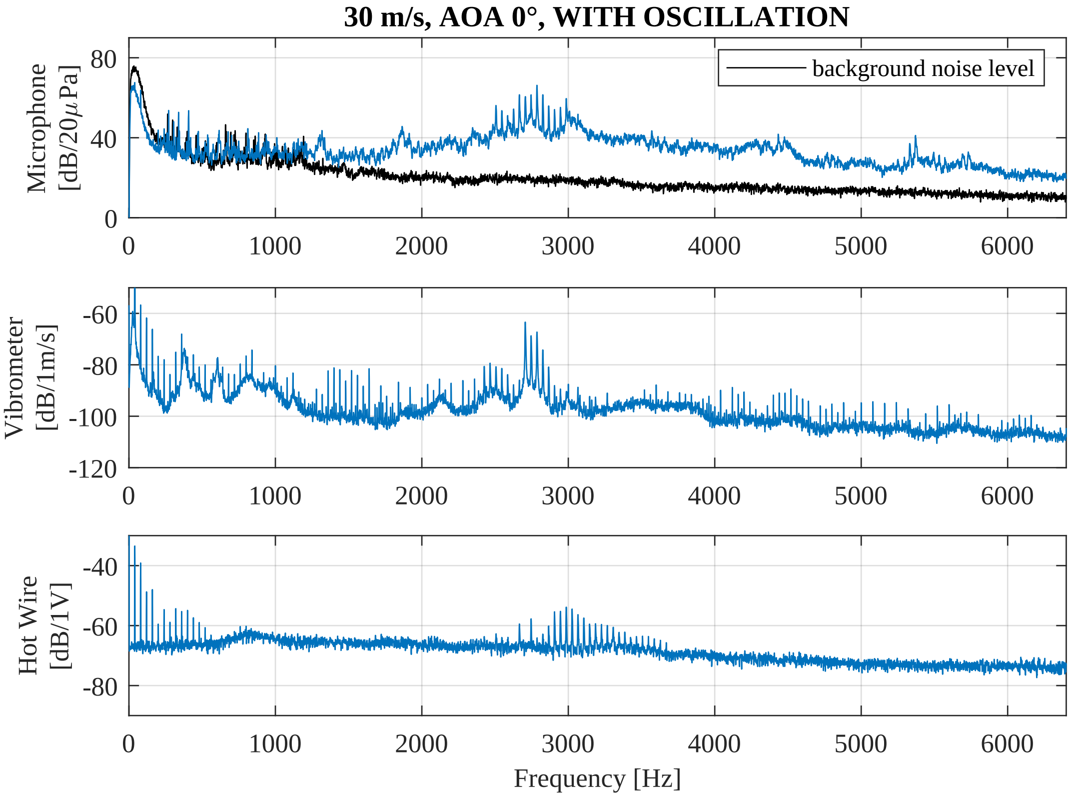

Fig. 4: Autospectra of the measured signals with middle blade oscillation.

frequency of the middle blade. In the autospectra of vibrometer and hot-wire signals the modulation by 40 Hz frequency appears in the whole spectrum. In vibrometer autospectrum, besides the most dominant 40 Hz frequency, the peaks are most amplified around the original tonal frequency 2720 Hz. On the other hand, hot-wire autospectrum shows the biggest amplification of modulated peaks around 3000 Hz which does not correspond with any resonant frequency of the channel. It seems that the oscillation of the middle blade disturbed the lock-in of vortex separation frequency with the inner channel resonance.

4. Conclusions

In this paper we showed that airfoil tonal noise, often present on single airfoils in moderate Reynolds numbers and low angles of attack, appears also in the blade cascade. Because the cascade is placed in closed hard-wall channel the frequency of the noise as well as vortex separation frequency and high-frequency blade vibrations are locked in with the resonant frequency of the channel. Such behaviour was also observed for single airfoil in the literature. When the middle blade starts to oscillate with specified frequency, this frequency lock-in is suppressed and more peaks with lower intensity that are apart by the value of oscillation frequency appear in the noise spectrum. The paper brings the first important results of our aero-acoustic noise observation in the blade cascade. It shows how complex is an initiation and production of the acoustic sources on the aerofoils. Therefore, the next experimental research will be aimed at getting more detailed flow field dynamics in the vicinity of the aerofoils at different motion and flow conditions.

Acknowledgments

This research is supported by the research project of Czech science foundation No. GA20-26779S "Study of dynamic stall flutter instabilities and their consequences in turbomachinery application by mathematical, numerical and experimental methods".

References

McAlpine, A., Nash, E. C. and Lowson, M. V. (1999), On the Generation of Discrete Frequency Tones by the Flow around an Aerofoil, *Journal of Sound and Vibration*, Vol. 222, pp. 753-779.

Nash, E. C., Lowson, M. V. and McAlpine, A. (1999), Boundary-layer instability noise on aerofoils, *Journal of Fluid Mechanics*, Vol. 382, pp. 27-61.

Šnábl, P., Pešek, L., Prasad, C. S., Bula, V. and Cibulka, J. (2021), Experimental setup and measurement for evaluation of blade cascade stall flutter instability, In: Carletti, E., Crocker, M., Pawełczyk, M. and Tuma, J. , eds., *Advances in Acoustics, Noise and Vibration 2021*, International Institute of Acoustics and Vibration, p. 172047.