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NOISE CONTROL FOR A BETTER ENVIRONMENT

Analysis the correlation of modified edges on acoustic parameters of airfoil.

Kopania, Joanna[1]
Lodz University of Technology
266 Piotrkowska Street, 90-924 Lodz

ABSTRACT

In our everyday life we are surrounded by noise due by ventilation systems, fans and propellers in equipment, from transport processes (aircraft), wind turbines, etc. It has got significant consequence our health and quality of life. All these machines have got the rotor with blades, which interact with streamed fluid. During the turbulent flow the dominant sources of noise is airfoil-turbulence interaction (ATI). It is therefore appropriate to study of ATI noise and its reduction by using varies methods. One of them is modification the geometry of leading edge of airfoil through apply serrated or wavy edges. The another type of noise is the airfoil self-noise which is produced by trailing edge (TE) of blade and may be reduced by brushes or serrated trailing edges of blade or by using the porous surface. In this work experimental studies are performed to investigate the effect of modified leading edges on airfoil noise. Two type of NACA aerofoils with straight and modified edges are studied on special constructed stand test with outlet to anechoic room. The interaction effect between obtained sound pressure level and geometry of studied edges of airfoil is discussed.

Keywords: noise, airfoil, serrated trailing edge,
I-INCE Classification of Subject Number:06.02

1.INTRODUCTION

The efficient airfoil self-noise reduction is a challenge that is studied from years. Airfoil self-noise is mainly associated with the laminar or turbulent boundary layer on the blade surfaces. This type of noise can have tonal or broadband characteristics, and is considered to be caused by several mechanics, such as trailing edge noise, laminar boundary layer vortex shedding noise, tip noise, separated or stalled flow noise, and blunt-trailing-edge noise [1]. According to Brooks et al. [2] the airfoil self-noise mainly is generated by disturbance interaction with the airfoil trailing edge. Turbulent fluctuations in the vicinity of a sharp edge of a solid body scatter more efficiently at low Mach numbers than fluctuations in free-space hence trailing-edge noise is increasingly significant at low Mach numbers.

Trailing edge (TE) noise has been an comprehensive aeroacoustic research topic for more than fifty years, both experimentally and analytically. This time of research seems from the need to understand, predict and control the self-noise from airfoils located within aero-engines, wind turbines, aircraft, and also in ventilation fans, because

[1]joanna.kopania@p.lodz.pl

the research in the area of TE noise prediction are motivated by the desire to incorporate the results of TE noise analysis into design methodologies of airfoil.

In literature reduction of trailing-edge noise is inspired by the silent flight of owls [3,4,5] and the capability of trailing-edge serrations in noise attenuation [6,7,8] in theoretical, experimental and numerical aspect [9,10]. According to them we can assume that a serrated trailing edge attenuates aerodynamic noise through influencing both flow structures and noise scattering patterns. To reduce trailing edge noise several passive methods such as serrated trailing edge [11-15], porous surface [16,17,18] and brushes [19] have been investigated over the past two decades. Serrated trailing edges of airfoil have got of significant interest in future perspective the noise reduction of airfoil in airplanes or blade of fans. Simple modifications of trailing edge such as sawtooth and sinusoidal serrations could reduce the intensity of the trailing edge radiation but the magnitude of reduction depends on the frequency and the length and spanwise spacing of the teeth. Experimental investigation [14, 15] showed that the serrated trailing edge of airfoil may cause a self-noise reduction of up to 2 and 6 dB with significant reduction at high frequencies without the loss of aerodynamic performance. The last works showed that further noise reduction can be achieved by the use of more complex trailing edges such as: slitted edge, sawtooth with hole, slitted-sawtooth edge and randomly serrated trailing edges [20].

Despite the fact trailing edge serrations have proven to be valid means of airfoil noise reduction, the mechanism in which it occurs is not completely understood. The character and level of trailing edge self-noise is highly sensitive to Reynolds number, angle of attack, airfoil geometry and trailing edge bluntness [2]. Trailing edge noise radiated in high Reynolds number flow has got broadband in nature but in low Reynolds number trailing edge noise has a distinctive narrow band character comprising a broadband hump superimposed with a number of high amplitude "tones" [21,22]. In this situation the boundary layer on the airfoil surface is mainly laminar but potentially unstable [23].

The presented paper is a study of the aeroacoustic behaviour of airfoil with and without trailing edge serrations with additional slits on the teeth. Aeroacoustical and aerodynamical parameters has been investigate for symmetric and asymmetric airfoils over at low Reynolds number and two angles of attack.

2.EXPERIMENTAL METHOD

2.1 Test model

In this work two airfoils have been investigated using a symmetrical NACA 0012 and a cambered asymmetrical NACA 6412. Symmetrical airfoils, like NACA 0012, are used in where very low drag for high speeds is needed. NACA 0012 airfoil is used in many airplane (B-17 Flying Fortress, Cessna 152 and the helicopter Sikorsky S-61 SH-3 Sea King) and also in horizontal and vertical axis wind turbines so this airfoil is under extensive research. NACA-6412 is good standard section for models operating under slow speed or high lift conditions. This airfoil is best used for sport models and gliders that are not super fast but need to slow down quite well for landings. The parameters of both airfoils are shown in Table 1.

The airfoils were manufactured by 3D printing using PLA material. Both airfoils have 4.0 mm blunt trailing edge with a 25mm deep and 2.0 mm thick slot cut through the trailing-edge along the span in order to allow flat plate serration inserts to be fitted to the airfoil, as shown in Figure 1.

Table 1. The parameters of studied airfoils.

PARAMETERS	Profile	
	NACA 0012	NACA 6412
Thickness	12.0%	12.0%
Camber	0.0%	6.0%
Trailing edge angle	21.3^o	21.3^o
Lower flatness	5.4%	26.8%
Leading edge radius	2.6%	3.0%
Efficiency	34.8	41.8

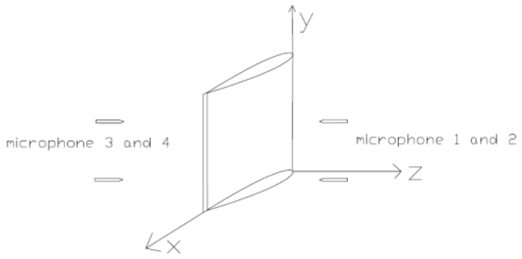
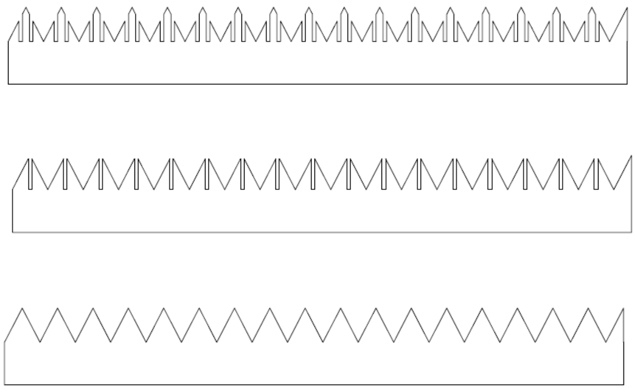


Figure 1. Studied airfoils and locations of microphones around the airfoils.

The flat plate and serrated plates were used in this experiment as a additional trailing edge. Each of them have a chord of c = 45 mm, a span of s = 350 mm and a thickness of d =2,0 mm. The airfoil with straight unserrated trailing edge (baseline) was used as a reference model for airfoil with serrated plates. The geometries serrated plates added to airfoils are presented on the Fig.2 and Table 2.

The serrated plates have got high of teeth 20mm, with distance between the tip of teeth also 20mm. The slotted-sawtooth plate 1 has got one has got one 2mm thin slit, and slotted-sawtooth 2 has got two 2mm thin slits. The height of slits (H) is different as shown in Table 2. The airfoils were held by a special adjustable handle with the possibility of angle of attack regulation.



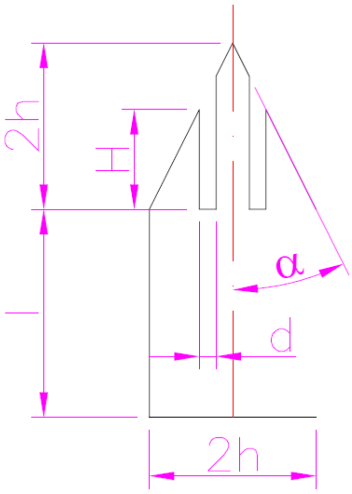


Figure 2. The geometries serrated plates added to airfoils (at the bottom – sawtooth plate; in the middle – slotted-sawtooth 1; at the top – slotted-sawtooth 2)

Table 2. The parameters of serrated plates.

	Parameters of serrated plates					
Model of airfoil	l [mm]	2h [mm]	i_d [-]	d [mm]	α_s [°]	H [mm]
Baseline	25	-	-	-	-	-
Sawtooth	25	20	-	-	26,6	-
Slotted-sawtooth 1	25	20	1	2	26,6	18
Slotted-sawtooth 2	25	20	2	2×2	26,6	2×12

2.2 Aeroacoustical measurement

The measurements were performed on the special constructed test stand with the outlet to the anechoic room – Figure 3. The outlet was circular with a diameter of 350 mm. Airflow was induced by a fan mounted on the inlet of the stand and regulated by the power inverter. The outlet of test stand was in the anechoic room at the Institute of Power Energy in Lodz. The anechoic test chamber is cubic, approximately 350m^3 in size and has walls that are acoustically treated with foam wedges providing a reflection free environment.

To measure the far-field noise was made by SVAN 958. The four microphones was located above and below the trailing edge (perpendicular to the direction of the flow) positioned at a distance 500mm from the edges. The experimental setup for NACA 0012 is shown in Figure 4. The microphone was calibrated before commencing the acoustic test. The signals from microphone nr 1 and 2 and from microphones 3 and 4 were averaged accordingly.

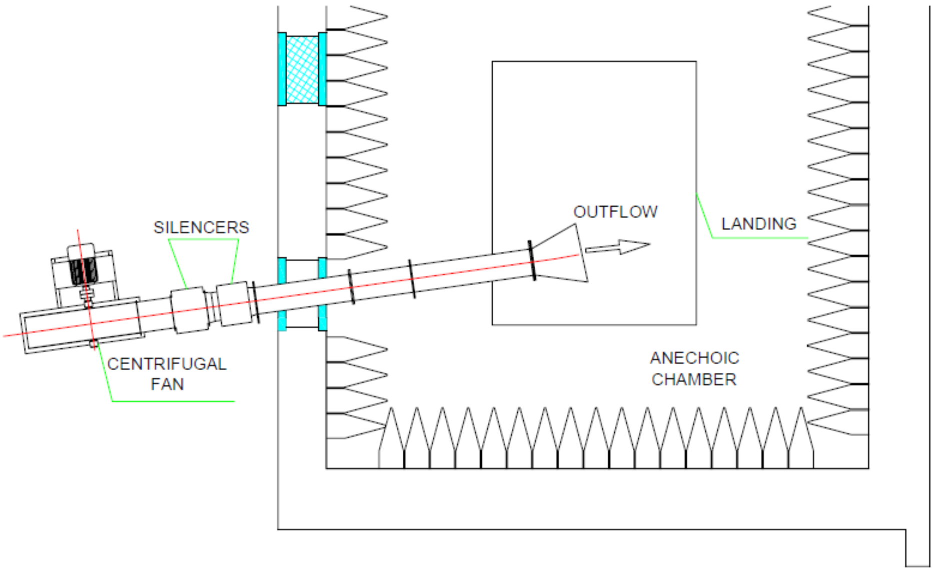


Figure 3. Construction of test stand with outflow to anechoic room.

The aeroacoustical and aerodynamical parameters were studied at two angles of attack: 0°, 10° wherein the zero angle was in level at x-axis. The measurements were taken at five flow velocities: 1,7m/s; 3,2m/s; 5,0m/s; 6,5m/s - what constitute range 4×10^4 – $1,6\times10^5$ of Reynolds number. The velocities distribution in outlet of the stand test were measured by using a Pitote probe and calculated by using log-Chebyshev method. For these investigations a small single probe was used to this with a diameter of 2 mm by using data acquisition station - SAD-2, equipped with the ADAM modules 4000+, an integrated PC with the application GeniDAQ equipped with a Visual Basic language.

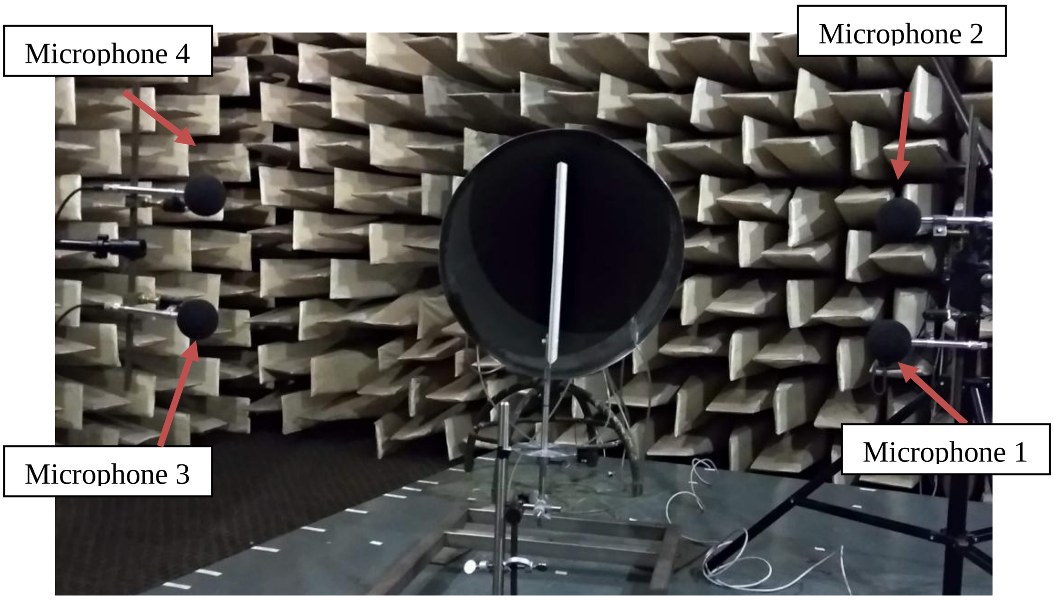


Figure 4. The photograph of NACA 0012 during the measurements.

3. EXPERIMENTAL RESULTS

The knowledge about aerodynamic and acoustic parameters of airfoil in low Reynolds number is important for learning its physical nature. Most of the flight animals (insects, birds) fly at Reynolds number of 10^3-10^5 due to their low speed and small length scales [24]. Current trend "inspiration on nature" to improved the areodynamical of flight and reduce flight's noise parameters requires knowledge in this aspect. In recent times appeared important experimentally and numerically work about vortex formation around a NACA 0012 airfoil at low Reynolds number [22,23,25,26].

In this work the acoustic measurements of NACA 0012 and NACA 6412 airfoils as the baseline and serrated configurations were carried out for a two angles of attack (0° and 10°) and Reynolds numbers Re = 4×10^4 to $1,6 \times 10^5$, corresponding to flow velocities of u=1,7m/s to u= 6,5 m/s. The main goals of this work was to determine the impact of plates steel, cut as serrated and serrated with slits, added to trailing edges of two studied airfoils, to emitted noise. In these studies the same cut system of teeth were used (geometrical parameters) but additional the one or two slits were cut in two cases. The spectra of the acoustic pressure level in the 1/3 octave bands were determined for tested airfoils. It was important to understanding, how different serrated and slits cuts added to trailing edges of tested airfoils influence on the noise of these airfoils in regard with the airfoils with straight trailing edge. Therefore only differences in the sound pressure level between airfoils with serrated and straight trailing edges were determined ("differential SPL"). That allowed to define the bands in which the added plates reduce the noise.

The difference of measured SPL between serrated and straight airfoils depending to velocities for the two configurations of for NACA 0012 airfoil are presented in Figure 5 and Figure 6 as a colour maps. As is seen from the Figure 5 and Figure 6 the maximum noise reduction value, depending on the frequency and also depending on the suction and pressure side of airfoil, does not exceed 2dB (blue fields on the maps) for all studied serrated airfoils. In each case (Figure 5) for studied airfoils at 0° angle of attack, on the suction and pressure side, above 6,5m/s at range 500-1000Hz is observed reduction of noise approximately 2 dB. For these airfoils on the pressure side in the area

3 kHz reduction of noise is also observed. But for the sawtooth-slotted 2 airfoils on pressure side noise reduction is observed at around 8kHz.

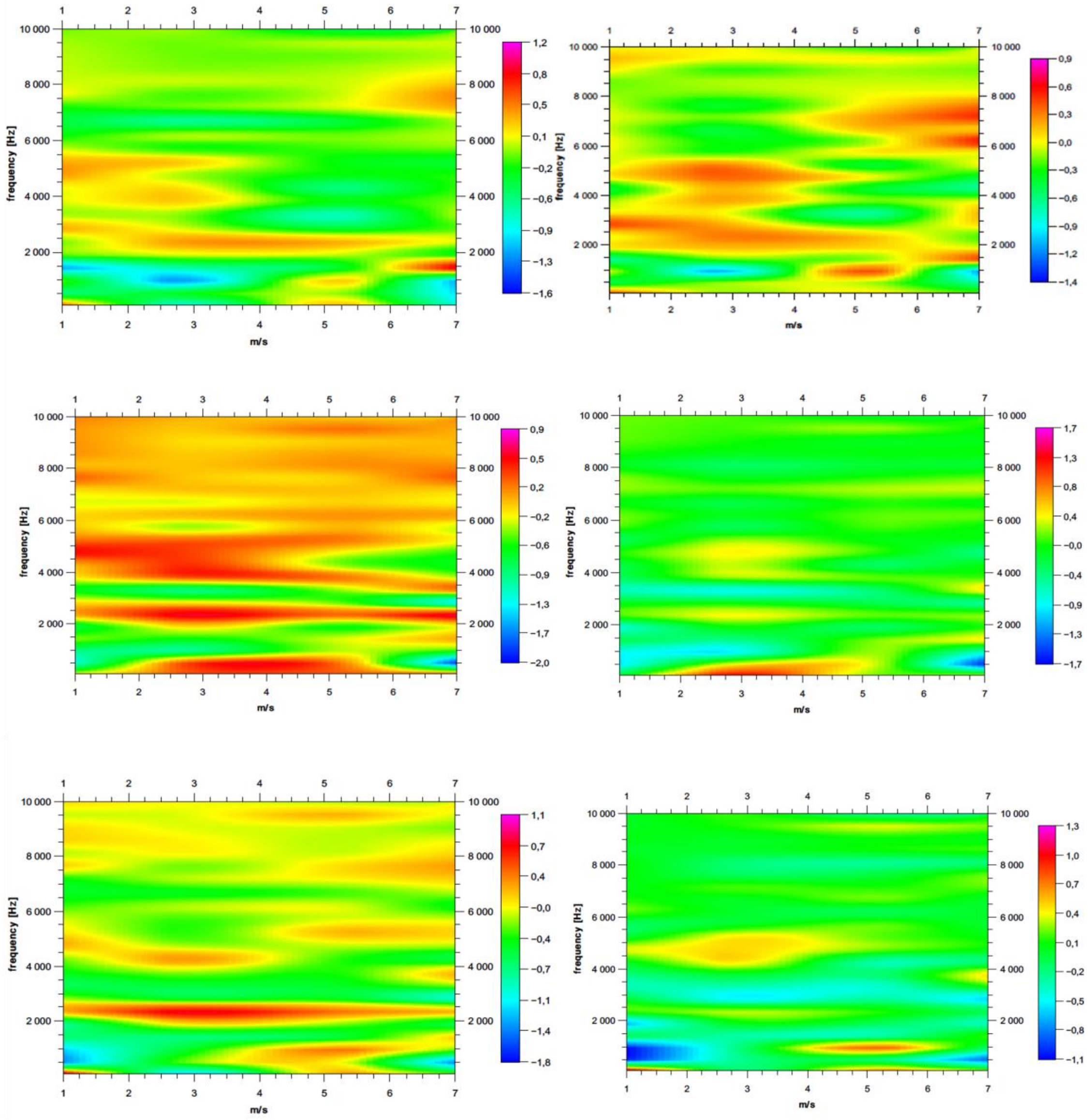


Figure 5. Colour-maps of relationship difference sound pressure level between serrated airfoils and straight airfoil depending on velocities, dB (ref 20 μPa), for NACA 0012, above (left side) and under (right site) the airfoil, for the case of = 0°. At the top – sawtooth plate; in the middle – slotted-sawtooth 1; at the bottom – slotted-sawtooth 2.

Generally the noise reduction of studied airfoils have got a resonance character, what mean that we observed the increase and decrease of differential SPL depended on frequencies.

Colour-maps of differential SPL are a little distinct when the airfoils were studied at 10° angle of attack. For sawtooth-slotted 1 and sawtooth-slotted 2 airfoils on the suction and pressure side, noise reduction is observed at approximately 500Hz, above 2kHz, around 4kHz, and above 5,5kHz depending on flow velocity. In this case, colour-maps have got more of the blue area what may suggest impact positive angle of attack of airfoil on increase of noise reduction.

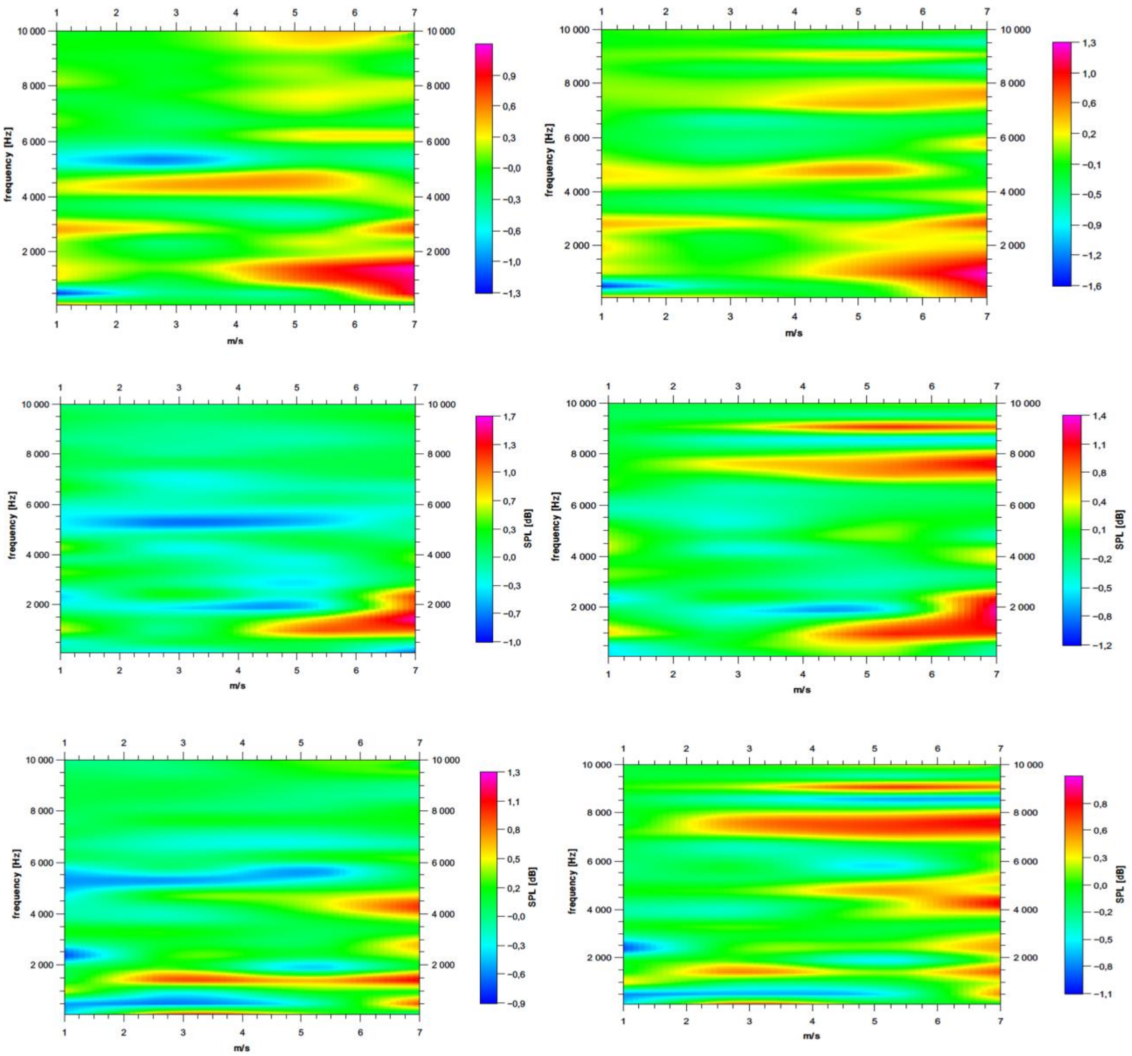


Figure 6. Colour-maps of relationship difference sound pressure level between serrated airfoils and straight airfoil depending on velocities, dB (ref 20 μPa), for NACA 0012, above (left side) and under (right site) the airfoil, for the case of = 10°. At the top – sawtooth plate; in the middle – slotted-sawtooth 1; at the bottom – slotted-sawtooth 2.

The differential SPL between serrated and straight airfoils depending to velocities for the two configurations of for NACA 6412 airfoil are presented in Figure 7 and Figure 8 also as a colours maps. As is seen from the Figure 7, when the airfoils were studied at 0° angle of attack, the maximum noise reduction value is around 1,5-2dB, depending on the frequency and also depending on the suction and pressure side of airfoil. For all studied airfoils on suction side at 0° angle of attack, strong noise reduction between 4-5,5kHz is observed regardless of flow velocity. Additional for these objects, at around 2kHz above 6,5m/s noise reduction is also observed. However, for sawtooth-slotted 1 and sawtooth-slotted 2 airfoils on suction side at 0° angle of attack, noise reduction around 1kHz is observed but for velocity above 5 m/s.

Slightly different colour maps are observed for the pressure side of studied airfoils at 0° angle of attack. For all studied airfoils on pressure side at 0° angle of attack, strong noise reduction between 6kHz at flow velocity above 4,5m/s is observed. For sawtooth-slotted 2 airfoil more of blue area is observed then for other airfoils, what might suggest that this system of cutting in more acoustical friendly - makes lower trailing edge noise.

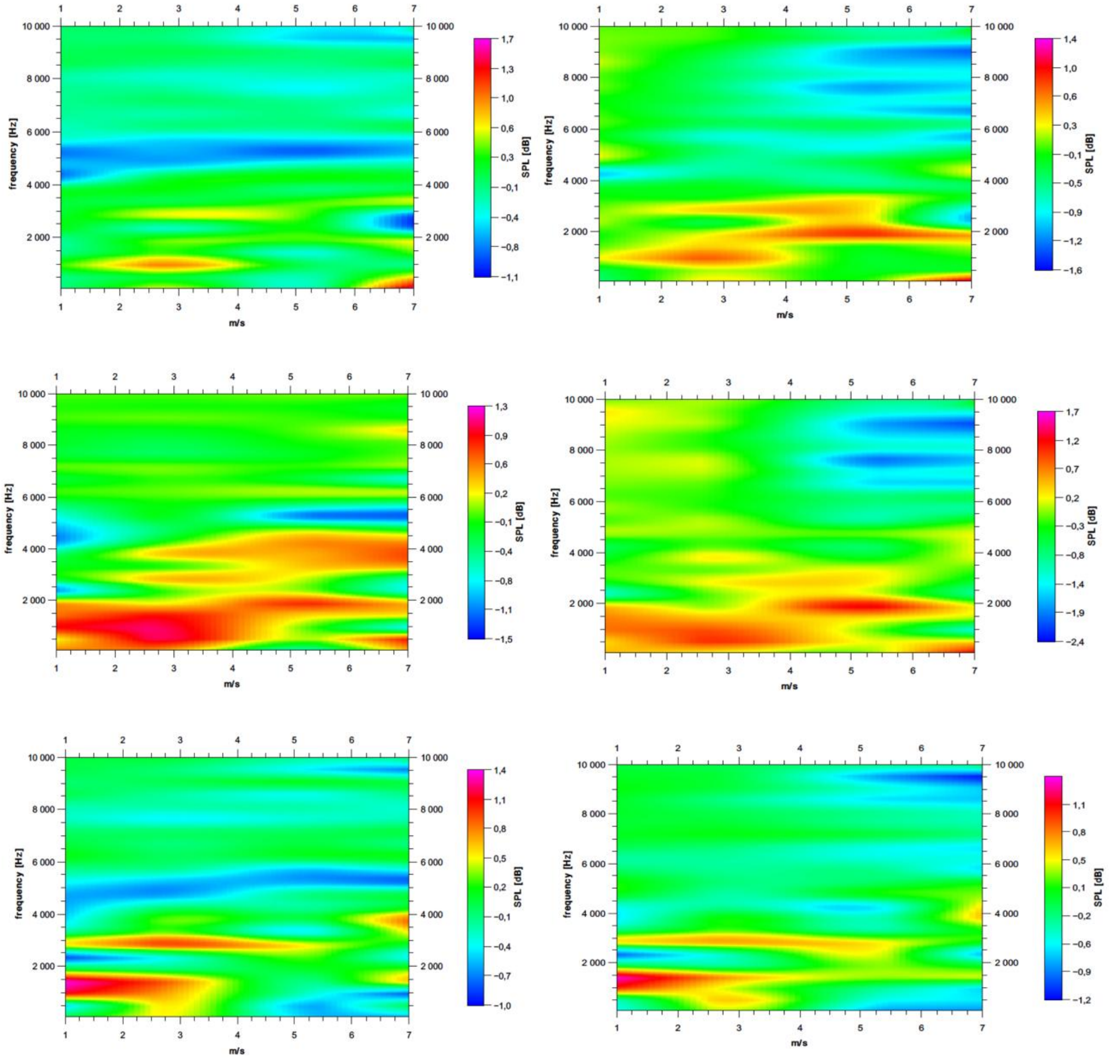


Figure 7. Colour-maps of relationship difference sound pressure level between serrated airfoils and straight airfoil depending on velocities, dB (ref 20 μPa), for NACA 6412, above (left side) and under (right site) the airfoil, for the case of = 0°. At the top – sawtooth plate; in the middle – slotted-sawtooth 1; at the bottom – slotted-sawtooth 2.

The differential SPL between serrated and straight airfoils depending to velocities for NACA 6412 airfoil at 10° angle of attack are presented in Figure 8. The slightly differences between pressure and suction side of studied airfoils are observed. As is seen noise reduction values depending on the frequency and also depending on flow velocity around the airfoil. For all studied airfoils on suction side at 10° angle of attack, noise reduction is observed: above 7,5Hz; between 4-5,5kHz and around 1kHz, depending upon flow velocity.

On pressure side at 10° angle of attack for sawtooth and sawtooth-slotted1 airfoils, strong noise reduction above 6kHz at flow velocity above 4,0m/s is observed (intensive blue area). Colour-maps have got alternating character - there are intensive blue area and alternately intensive red area, which may inform about ranges of frequencies where studied serrated airfoils influence on decrease of noise, but also make increase on noise parameters. However, compared with sawtooth airfoil, the slotted-sawtooth airfoils (especially sawtooth-slotted 2) show a various colour-map of differential SPL, with characteristic bigger area of noise reduction, as green and blue region.

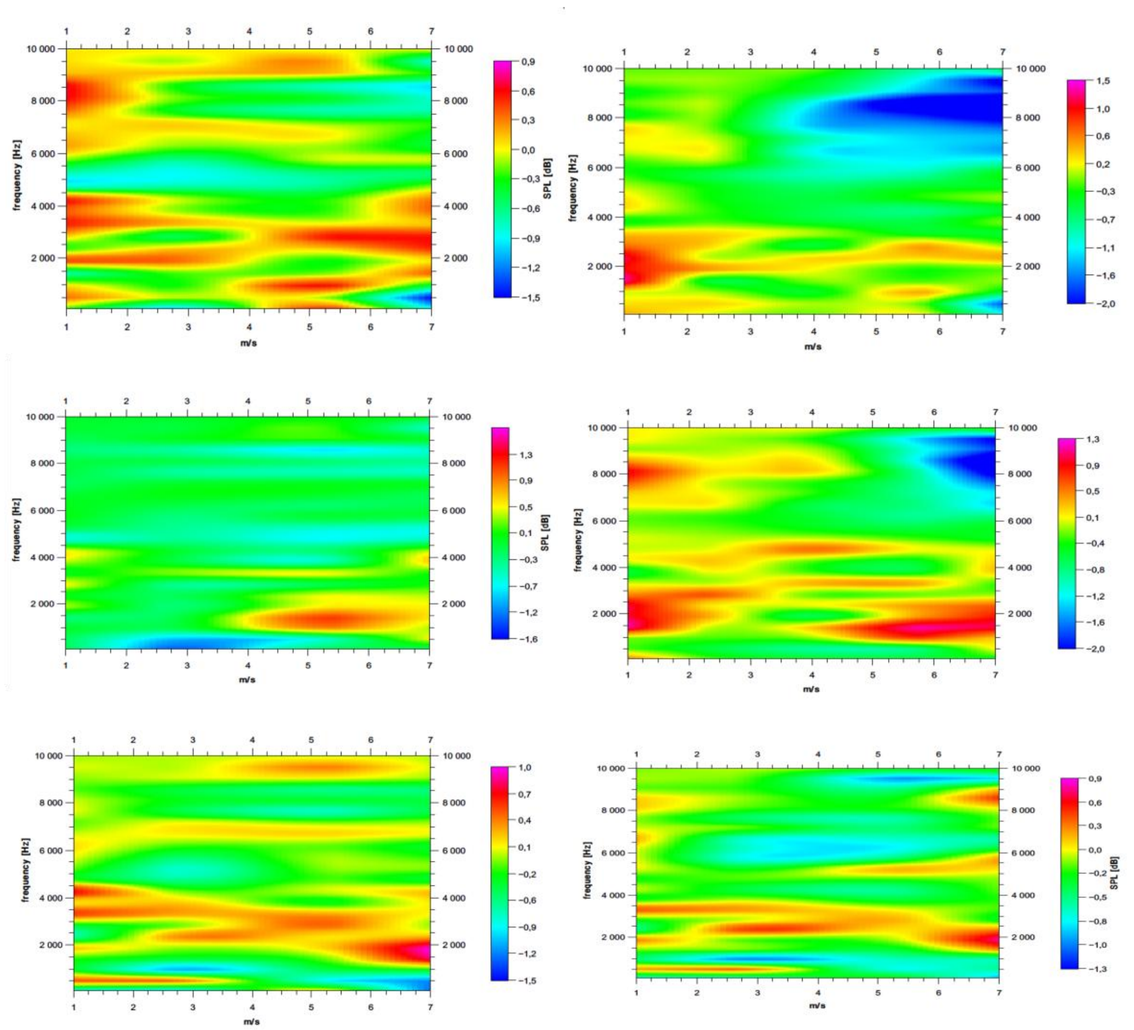


Figure 8. Colormaps of relationship difference sound pressure level between serrated airfoils and straight airfoil depending on velocities, dB (ref 20 μPa), for NACA 6412, above (left side) and under (right site) the airfoil, for the case of = 10°. At the top – sawtooth plate; in the middle – slotted-sawtooth 1; at the bottom – slotted-sawtooth 2.

4. CONCLUSIONS

The aeroacoustic parameters of airfoils with trailing-edge serrations and slit-serrations has been studied. Experimental study on NACA 0012 and NACA 6412 in anechoic room at low Reynolds number have been carried out. The experimental results show that the trailing edge serration can influence on noise reduction parameters. The properties of noise reduction depends on the type of geometrical characteristics of the serration. For all studied serrated airfoils the differential sound pressure level were determined by compared to baseline (with straight plate on trailing edge). For serrated airfoils in studied range of flow velocities, similarities are observed. Regardless of type of serrated trailing edge, noise reduction in the same or similar range of frequencies are observed; around 1kHz, 4-5,5kHz, above 6-7,5kHz, but they have got various intensity of reduction. The present study also shows that slitted configurations could be more effective as a noise reduction solution especially in combination with serrated geometry. The research of airfoils with serrated trailing edge, in low Reynolds number are very interesting because of flow is laminar then and prone to separate even under a mild adverse pressure gradient. In this case the development of coherent structures in the airfoil are waked also due to structural vibrations and noise generation. These studies are "not perfect" and require improvement, for example on setting airfoil in a holder. Additional the aerodynamic parameters should be measure, what could give the information about flow field around studied airfoils.

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