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The aeroacoustic effect of different inter-spaced self-oscillating passive trailing edge flaplets.

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Abstract. An aeroacoustic investigation looking into the effect of changing the inter-spacing of passive self-oscillating trailing edge flaplets has been carried out using a NACA 0012 aerofoil. Clear differences can be observed between each of the different cases. Where a reduction in low frequency noise, an increase in high frequency noise and a reduction in turbulence intensity in the wake can be seen for each case. As the inter-spacing is reduced, the differences become more prominent, when compared to the reference aerofoil.

Keywords: Passive oscillators, aeroacoustics, trailing edge flaplets, fluid structure interaction

1 Introduction

Bio-mimicking is a topic of increasing interest within the aeroacoustic community, where many different strategies have been tested and implemented in order to reduce perceived noise levels from either aircraft, wind turbines or compressors; to name a few examples. Many of these strategies are inspired from the well-known ‘silent’ flight of the owl [1].

In the present study, a novel configuration of a flexible trailing edge is used, consisting of an array of individual elastic flaplets mimicking the tips of bird feathers aligned along the span of the wing. This type of trailing edge modification with arrays of individual mechanical oscillators in the form of elastic flaps has thus far only been studied by the authors [2,3,4,5,6].

2 Experimental Arrangement

The aerofoil used in the current study was a NACA 0012 symmetric aerofoil, with a chord length of 0.19 m and a span width of 0.28 m. The aerofoil was 3D printed in two halves such that the flaplets could be adhered on the centre plane of the aerofoil and extended out of the trailing edge of the aerofoil, as seen in Figure 1. The flaplet arrays were laser cut from a 180 μm thick polyester film. For the present study, the inter-spacing (s) between flaplets was altered in accordance to the specification in Table 1.

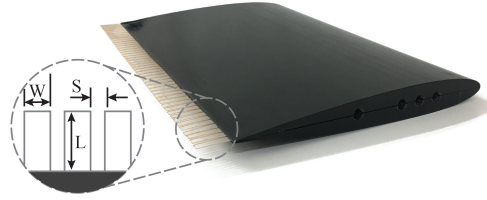


Fig. 1: Photograph of NACA 0012 aerofoil with the trailing edge flaplets attached

Acoustic and hot wire anemometry (HWA) took place in the small aeroacoustic open jet wind tunnel [7] at the Brandenburg University of Technology in Cottbus, with a setup similar to that used in [8] and in [6], where a full description of the experimental set-up can be seen.

For the present study, all measurements were taken at a constant chord based Reynolds number $Re = 200,000$ with a varying geometric angle of attack, α_g , from $\alpha_g = 0^\circ$ to 15° .

3 Results

Figure 2 shows the sound pressure levels for each of the different flaplet geometries at different geometric angles of attack. At $\alpha_g = 0^\circ$ (Fig. 2a), all cases show a clear tonal peak between 0.6 – 0.8 kHz, with no real discernible difference between the cases. In the low frequency range, a clear reduction can be seen for all of the flaplet cases and is particularly evident in the small spacing case. This low frequency effect has been seen in previous studies [6] and has been attributed to a modification of the large scale structures in the flow. In the mid-frequency range (0.9 – 2 kHz) a reduction can also be seen, prior to a noise level increase at frequencies beyond this point. As the angle increases to $\alpha_g = 10^\circ$, there is a stark difference between the medium spacing and the rest. A large tonal peak is present at 0.7 kHz and is not observed amongst the other cases. This is believed to be due to the flaplets, at this testing condition and this specific geometry, damping the non-linear instabilities within the boundary layer sufficiently enough to cause the formation of a laminar separation bubble on the pressure side of the aerofoil, a necessary feature required for tonal noise. The decrease at low frequencies and the increase at the higher frequencies are also observed. A similar trend can also be seen at $\alpha_g = 15^\circ$. It can be clearly seen across all the angles, that as the inter-spacing is increased, any differences that have been observed tend towards the reference case. This is thought to be due to the flaplets acting as a ‘filter’ for large scale structures. This

Table 1: Flaplet properties and naming convention used within the current study.

Configuration name	Length (L) [mm]	Width (W) [mm]	Interspacing (s) [mm]	Eigen frequency (f) [Hz]
Large	20	5	7	111
Medium	20	5	3	104
Small	20	5	1	107

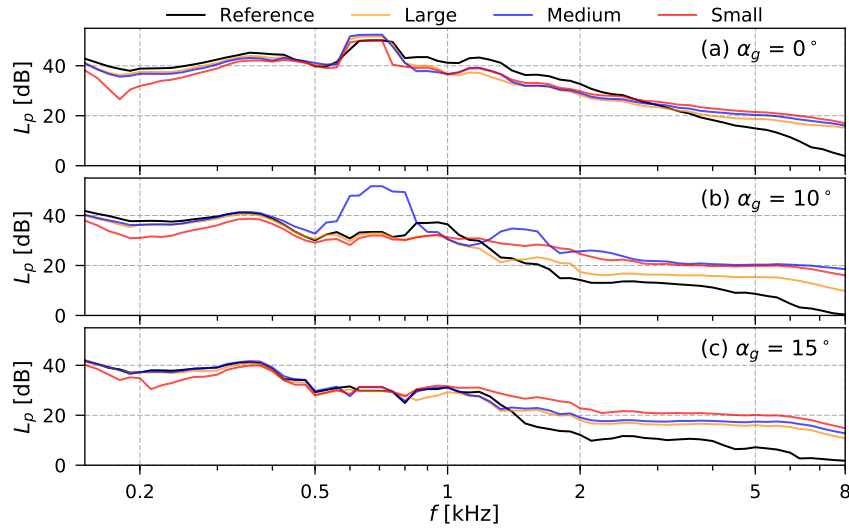


Fig. 2: 12th Octave band acoustic spectra at the three different geometric angles of attack. L_p is the sound pressure level normalised with $20 \mu\text{Pa}$,

effect, coupled with the previously observed shear-layer stabilisation [5], leads to a low frequency noise reduction and a scattering of the noise to higher frequencies.

Wake profiles were taken from a set distance, $0.25c$, downstream of the aerofoil solid trailing edge. Such that the results for the reference and flaplet aerofoils can be compared, the normalisation proposed by Wagnanski et al. [9] has been used. Figures 3a-c-e show that the streamwise velocity component for all cases and at all three test angles collapse well on to each other, and at $\alpha_g = 0^\circ$, onto the theoretical solution [9] (Fig. 3a). Positive values of ξ indicate the suction side of the aerofoil, therefore it can be seen that, as the angle of attack increases, the deficit profile becomes positively skewed due to the thickening of the boundary layer on the suction side of the aerofoil at increasing angles. Figures 3b-d-f show the turbulence intensity in the v velocity component normalised with the respective reference maxima. At $\alpha_g = 0^\circ$, there is little difference between the three flaplet cases, but they are significantly reduced compared to the reference case. At $\alpha_g = 10^\circ$, all three cases are still reduced in comparison to the reference case, with the small spaced case lower than both other cases. Further increasing the angle shows a clear difference between all cases, where there is a clear and distinct level of reduction dependent on the spacing. This further shows that the large scale structures are less present with decreasing flaplet inter-spacing.

Figure 4 shows the turbulence spectra from the pressure side of the aerofoil. At $\alpha_g = 0^\circ$, multiple peaks can be seen for all cases within the same frequency range where the tonal noise component is observed in Fig. 2a. As α_g is increased to 10° , the reference case shows none of these multiple tones but rather one clear distinct peak followed by subsequent harmonics. This dominant peak can also be observed within the acoustic spectra at this frequency. The large spaced flaplets show a similar peak, but it is much reduced with a few small peaks at the tonal noise frequency seen in Fig. 4a. The

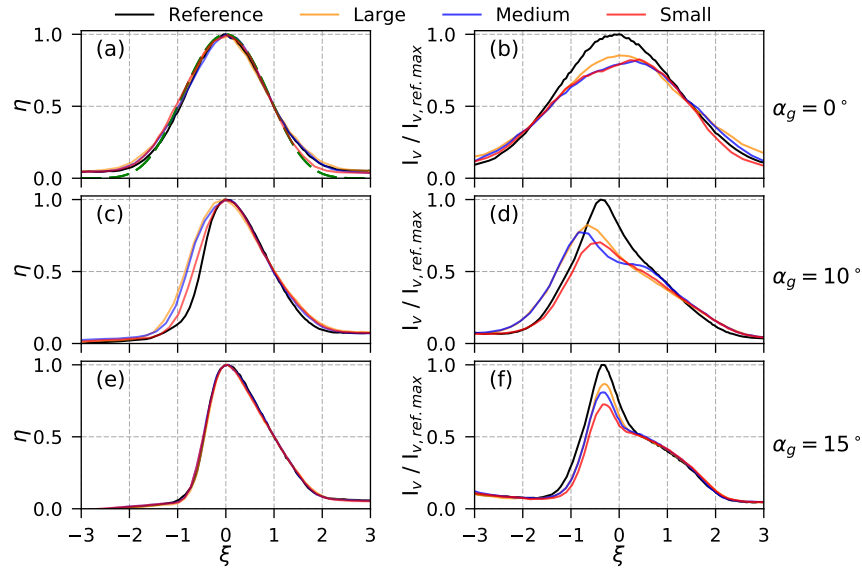


Fig. 3: Normalised wake profile measurements. (a-c-e): Streamwise velocity component normalised using the formulation proposed by Wygnanski et al. [9] and (b-d-f): v component turbulence intensity, normalised with respect to the maxima of the reference cases. Note that the theoretical solution [9] is only plotted in (a) as (---).

most interesting observation is at the medium spacing, where a clear singular peak is observed. The frequency at which this peak occurs is in agreement with the tonal noise seen in Fig. 2b and the conclusion of sufficient instability damping. When the spacing is further reduced, it can be seen that the singular peak of the medium spaced flaplets and the dominant peak of the reference and large spaced flaplets has been damped out and a series of multiple, smaller peaks are present. Here it can be concluded that the small spacing damps out the instabilities more extensively than the medium spacing, overcoming some sort of threshold that prevents the formation of the laminar separation bubble, hence tonal noise. At the highest test angle, $\alpha_g = 15^\circ$ (Fig. 4c), the dominant peak observed for the reference case at $\alpha_g = 10^\circ$ is seen in all cases. But crucially, as the spacing is reduced, the peak reduces in amplitude and almost completely for the small spacing.

4 Conclusion

The effect on the inter-spacing of self-oscillating trailing edge flaplets has been investigated using both a 56 microphone array and hot-wire anemometry wake measurements. A low frequency reduction and a high frequency noise increase are seen in all of the flaplet cases when compared to the reference case. Both of these noise level differences increase in magnitude as the flaplet inter-spacing is reduced, showing that the flaplets could be acting as some sort of a large structure filter. The turbulence intensity wake profiles also agree with this finding, as it can be seen that as the inter-spacing is reduced, the maximum turbulence intensity also reduces.

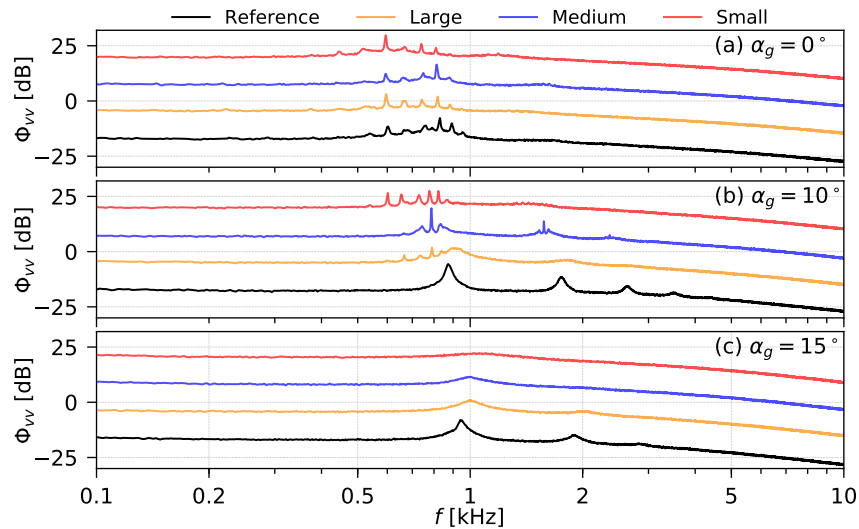


Fig. 4: v turbulence spectra from the pressure side of the aerofoil at $0.25c$ behind the solid trailing edge. Each spectra is offset by 12.5 dB from each other, for clarity.

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