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

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Abstract. An aeroacoustic investigating looking into the effect of changing the inter-spacing of passive self-oscillating trailing edge flaplets has been carried out using a NACA0012 aerofoil. Clear differences can be observed between each of the inter-spacing 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 reduced 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 form of elastic flaps has thus far only studied by the authors [2, 3, 4]. Attached to the trailing edge of a NACA 0010 aerofoil, the rows of individual silicone flaplets clearly showed a reduction in tonal noise [3]. A follow-up study on the flow modification by this type of trailing edge was done by Talboys and Brücker [5] and demonstrated aerodynamic advantages as well. Detailed High-Speed PIV measurements, coupled with simultaneous motion recordings of the flap tips, prove a stabilisation mechanism of the flaps on the boundary layer on the suction side. A lock-in was triggered by tuning the fundamental frequency of the structural bending mode of the oscillator to match with the fundamental frequency of the shear-layer on the suction side, forming regular vortex rollers in the boundary layer. This lock-in delays the growth of non-linear instabilities such as the merging of the rollers, beneficially affecting also the overall aerodynamic performance. A detailed aeroacoustic study was then carried out by Talboys et al. [6], where an untripped NACA0012 aerofoil was tested with the flaplets placed on the pressure and suction sides of the aerofoil separately, across a large range of Reynolds number and angles of attack. It was observed that when the flaplets were placed on the pressure side of the aerofoil, the laminar separation bubble was seemingly modified, due to the severe reduction in the tonal noise components of the acoustic spectra. When the flaplets were on the suction side of the aerofoil, a reduction was still seen.

2 Experimental Arrangement

The aerofoil used in the current study was a NACA 0012 symmetric aerofoil, with a chord length 0.19 m and span 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.

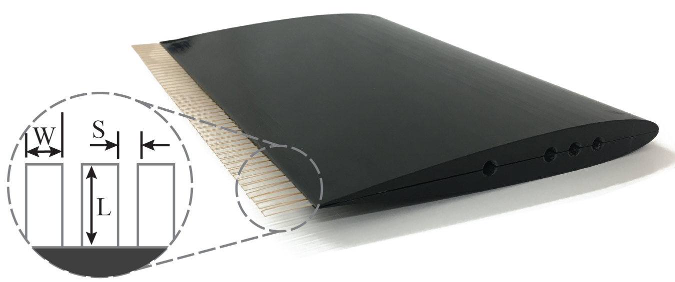


Fig. 1: Photograph of NACA 0012 aerofoil with the trailing edge flaplets attached

Acoustic, hot wire anemometry (HWA) and integral force measurements 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]. The wind tunnel was equipped with a circular nozzle with a contraction ratio of 16 and an exit diameter of 0.2 m. With this nozzle, the maximum flow speed is in the order of 90 m/s and at 50 m/s, the turbulence intensity in front of the nozzle is below 0.1 %. For the present study all

Table 1: Geometric properties and naming convention of the flaplets used within the current study.

Configuration name	Length (L) [mm]	Width (W) [mm]	Inter-spacing (s) [mm]
Large	20	5	7
Medium	20	5	3
Small	20	5	1

measurements were taken at a constant chord based Reynolds number = 200,000 with a varying geometric angle of attack, α_g, from α_g = 0° to 15°. During measurements, the wind tunnel test section is surrounded by a chamber with absorbing walls on three sides, which lead to a quasi anechoic environment for frequencies above 125 Hz.

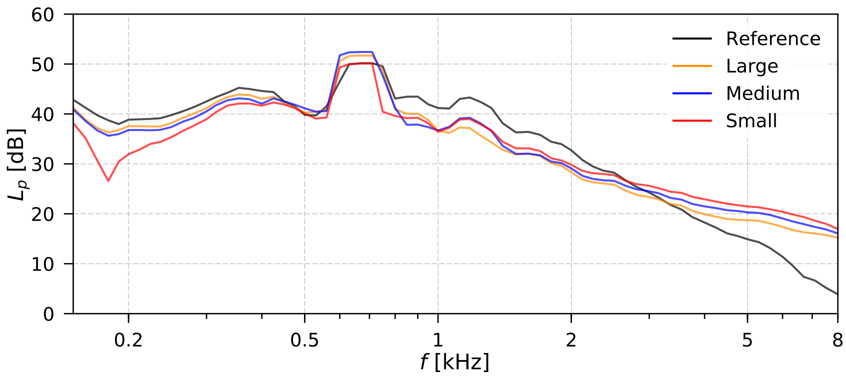
The acoustic measurements were performed using a planar microphone array, consisting of 56 1/4th inch microphone capsules flush mounted into an aluminium plate which is mounted out of the flow, at a distance of 0.71 m above the aerofoil. The data from the 56 microphones was captured at 51.2 kHz for a duration of 60 s.

The HWA measurements were taken in separate experiments to the acoustic measurements, to insure no additional noise from the HWA and associated traverse system was measured in the acoustic spectra. The probe used was a Dantec X wire probe (55P64), where the data was taken at a sampling frequency of 25.6 kHz. The data for the wake profiles were taken for 10 s at each point and the turbulence spectra was sampled for 60 s to obtain greater statistical accuracy. For all cases the probe was kept at a constant distance of 0.25c from the solid aerofoil trailing edge. A full description of the experimental set-up can be seen in [6].

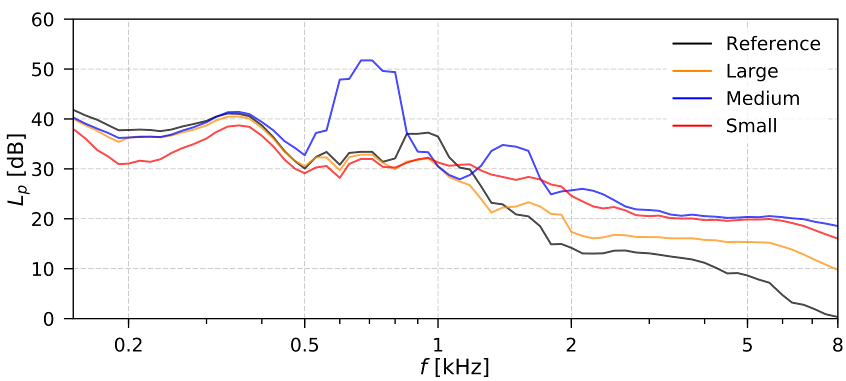
3 Results

Figure 2 shows the sound pressure levels for each of the different flaplet geometries at different geometric angles of attack. At $\alpha_g = 0°$ (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], [9]), 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 $\alpha_g = 10°$, 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 increase at the higher frequencies is also observed. A similar trend can also be seen at $\alpha_g = 15°$. 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 effect coupled with the shear-layer stabilisation, leads to the low frequency noise noise reduction and the scattering of the noise to higher frequencies.

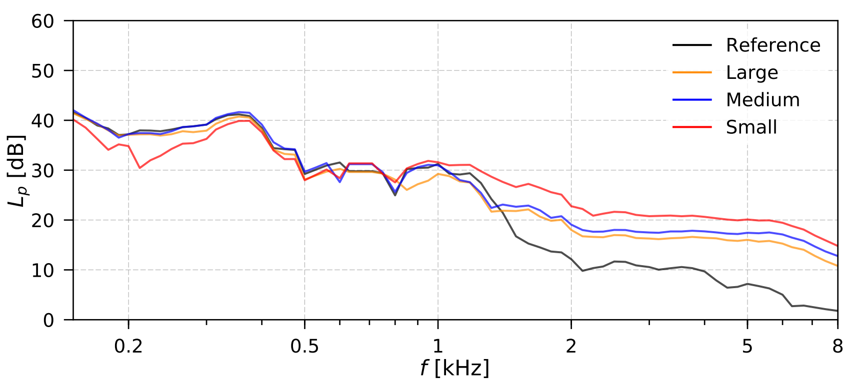
As the wake profiles were taken from a set distance from the aerofoil solid trailing edge, the normalisation proposed by Wygnanski et al. [10] has been used such that the reference and flaplet aerofoils can be compared. Figures 3a-c-e, show that the streamwise velocity component for all cases and at all three test angles, collapse well on to each other and at $\alpha_g = 0°$, the theoretical solution [10] (fig. 3a). Positive values of ξ indicate the suction side of the aerofoil, therefore it can be seen that as the angle of at-



(a) $\alpha_g = 0^{\circ}$

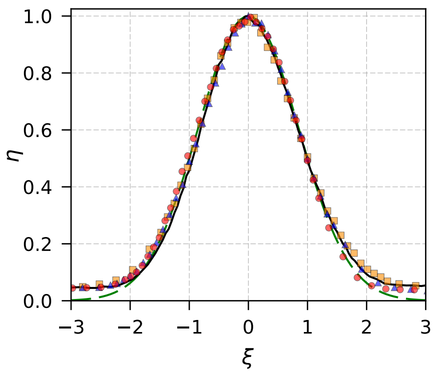


(b) $\alpha_g = 10^{\circ}$

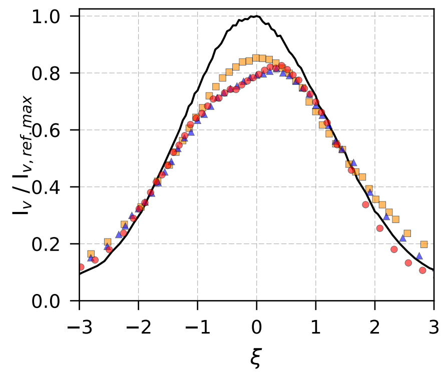


(c) $\alpha_g = 15^{\circ}$

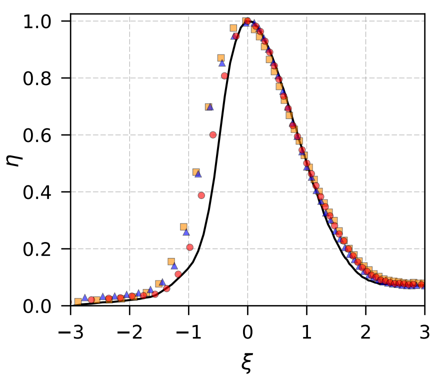
Fig. 2: 12$^{\text{th}}$ Octave band acoustic spectra at the three different geometric angles of attack. L_p is the sound pressure level normalised with 20 μPa,



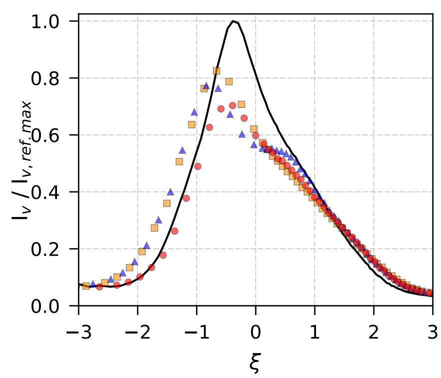
(a) $\alpha_g = 0^\circ$



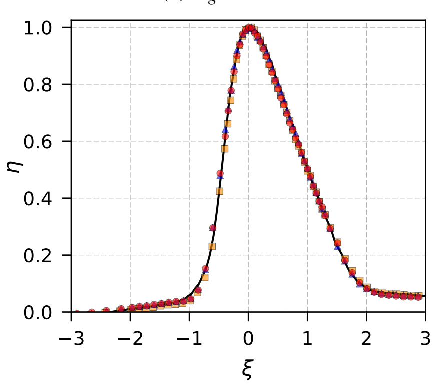
(b) $\alpha_g = 0^\circ$



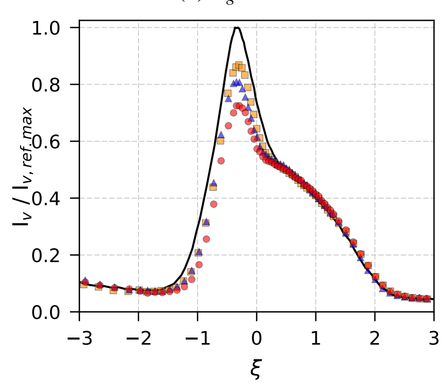
(c) $\alpha_g = 10^\circ$



(d) $\alpha_g = 10^\circ$



(e) $\alpha_g = 15^\circ$



(f) $\alpha_g = 15^\circ$

Fig. 3: Normalised wake profile measurements. (a-c-e): Streamwise velocity component normalised using the formulation proposed by Wygnanski et al. [10] and (b-d-f): v component turbulence intensity, normalised with respect to the maxima of the reference cases at the corresponding angle of attack. Where: — is the reference case; - - is the theoretical solution [10] and is only plotted in (a); ■ is for the large spacing; ▲ is for the medium spacing and ● is for the small spacing.

tack 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 $\alpha_g = 0°$, there is little difference between the three flaplet cases but they are significantly reduced compared to the reference case. At $\alpha_g = 10°$, 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 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 a position 0.25c behind the solid trailing edge. At $\alpha_g = 0°$, 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 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 is can be concluded that that the small spacing damps out the instabilities more extensively than the medium spacing overcoming some sort of threshold which prevents the formation of the laminar separation bubble, hence tonal noise. At the highest test angle, $\alpha_g = 15°$ (fig. 4c), the dominant peak observed for the reference case at $\alpha_g = 10°$ 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 anenometry wake measurements. A low frequency reduction and a high frequency noise increase is 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.

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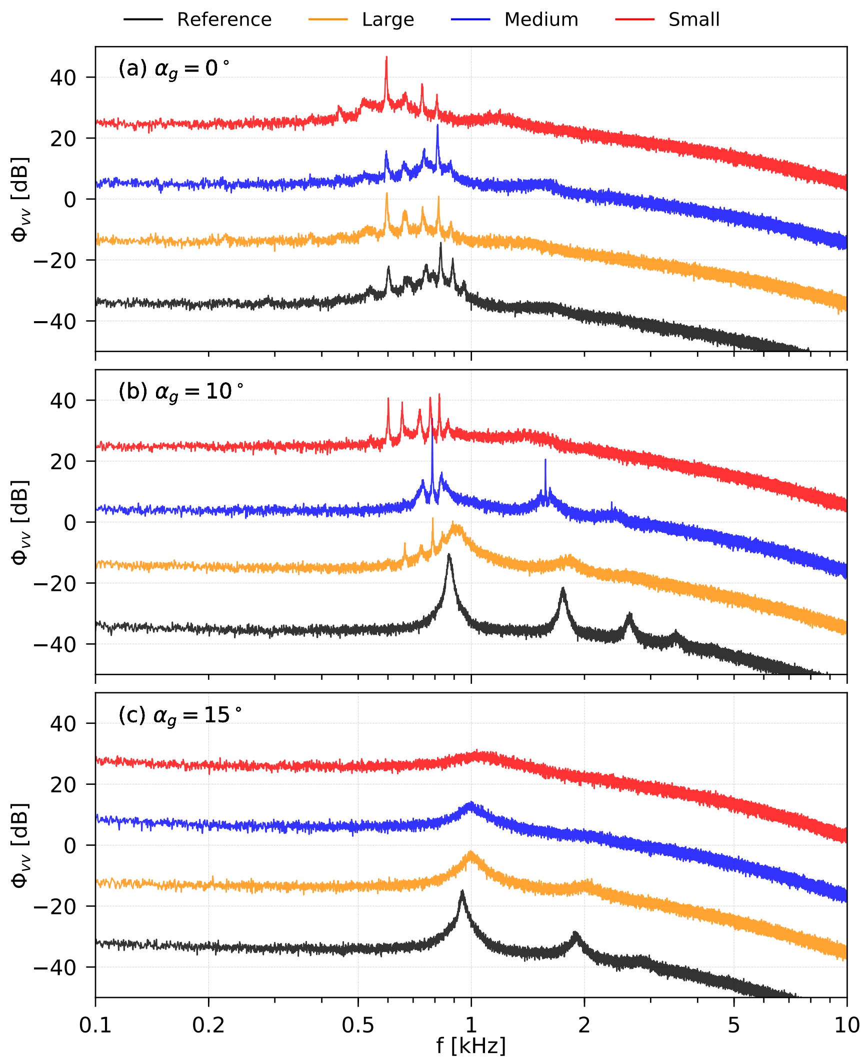

Fig. 4: v turbulence spectra from the pressure side of the aerofoil at 0.25c behind the solid trailing edge. Each spectra is offset by 20 dB from each other, for clarity.

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Bibliography

[1] R.R Graham. The silent flight of owls. *Aeronaut. J.*, 38(286):837–843, 1934.

[2] Laura Kamps, Thomas F. Geyer, Ennes Sarradj, and Christoph Brücker. Vortex shedding noise of a cylinder with hairy flaps. *J. Sound Vib.*, 388:69–84, 2016.

[3] Laura Kamps, Christoph Brücker, Thomas F. Geyer, and Ennes Sarradj. Airfoil Self Noise Reduction at Low Reynolds Numbers Using a Passive Flexible Trailing Edge. In *23rd AIAA/CEAS Aeroacoustics Conf.*, number June, pages 1–10, Reston, Virginia, jun 2017. American Institute of Aeronautics and Astronautics.

[4] Thomas F. Geyer, Laura Kamps, Ennes Sarradj, and Christoph Brücker. Vortex Shedding and Modal Behavior of a Circular Cylinder Equipped with Flexible Flaps. *Acta Acust. united with Acust.*, 105(1):210–219, jan 2019.

[5] Edward Talboys and Christoph Brücker. Upstream shear-layer stabilisation via self-oscillating trailing edge flaplets. *Exp. Fluids*, 59(10):145, oct 2018.

[6] Edward Talboys, Thomas F. Geyer, and Christoph Brücker. An aeroacoustic investigation into the effect of self-oscillating trailing edge flaplets. *J. Fluids Struct.*, (xxxx):1–13, feb 2019.

[7] Ennes Sarradj, Christoph Fritzsche, Thomas F. Geyer, and Jens Giesler. Acoustic and aerodynamic design and characterization of a small-scale aeroacoustic wind tunnel. *Appl. Acoust.*, 70(8):1073–1080, 2009.

[8] Thomas F. Geyer, E. Sarradj, and C. Fritzsche. Measurement of the noise generation at the trailing edge of porous airfoils. *Exp. Fluids*, 48(2):291–308, feb 2010.

[9] Edward Talboys, Thomas F Geyer, and Christoph Brücker. Influence of self-oscillating trailing edge flaplets on turbulent boundary layer – trailing edge noise . In *23rd Int. Congr. Acoust.*, Aachen, 2019.

[10] I. Wygnanski, F. Champagne, and B. Marasli. On the large-scale structures in two-dimensional, small-deficit, turbulent wakes. *J. Fluid Mech.*, 168(-1):31, jul 1986.