Proceedings of the 46th National Conference on Fluid Mechanics and Fluid Power (FMFP)
December 9-11, 2019, PSG College of Technology, Coimbatore, India

FMFP2019–PAPER NO.183

Trailing Edge Noise Characterisation of Airfoil with Perforated Trailing Edge Extensions

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Abstract

This paper presents the experimental investigation on the trailing edge noise characteristics of a NACA 0012 airfoil with perforate trailing edge extension. The experiment focused on the effect of trailing edge extension in noise abatement and its variation with extension length, angle of attack and its scaling with flow velocity. Results show that noise reduction up to 6dB can be attained with the perforation extension. It is also observed that increase in length of the perforation restricts the noise reduction frequency range and increases noise levels at high frequency. The scaling behaviour of trailing edge showed that the sound power levels scale with 5.1th power of velocity for base airfoil and a 4.6th power dependency for perforated trailing edge. 7dB attenuation in the vortex shedding noise at higher angle of attack can be attained by the perforated trailing edge extension.

Keywords: *Airfoil; Trailing edge noise; perforated plate; scaling; noise reduction.*

I. INTRODUCTION

Noise pollution is one of the primary reasons which limit the expansion of air transport industry. The main sources of aerodynamic noise from aircrafts are airframe noise, engine noise, noise from landing gears etc. The introduction of the modern high-bypass ratio aeroengines resulted in airframe noise being one of the dominating aircraft noise sources during approach and landing. While landing, the airframe noise is the primary source of the noise which is generated by the wings and the control surface such as slats, flaps, winglets, rudders etc.[1] The cross section of all aforementioned components are airfoil and thus the study of self-noise generation from airfoil and its reduction is the need of the hour.

Airfoil self-noise generation mechanisms were classified in to five according to Brooks et al.[2]. Among these five mechanisms turbulent boundary layer trailing edge noise is the most important as far as a flight in real flying condition is concerned [1]. Turbulent boundary layer trailing edge noise is generated when the turbulent eddies developed over an airfoil surface convected over the sharp trailing edge of the airfoil, gets scattered by the sharp trailing edge due the sharp surface impedance variation. [3]. Numerous active [4] and passive [5-7] methods were developed to mitigate the scattering noise by altering the scattering efficiency of the trailing edge.

Noise mitigation by the application of porous materials at the trailing edge has been an interesting topic for researchers ever since Graham et al[7] mentioned the biological reasons for quite flight of owls. Later, Kroeger et al.[8] identified the wing porosity due to the soft weather structure as one of the reasons which helps the silent flight of owl. Inspired by these studies, Hayden [9] used an airfoil with porous trailing edge as a means to reduce the trailing edge scattering noise. He proposed that by gradually changing the surface impedance thereby avoiding considerable surface pressure fluctuations, the trailing edge noise can be reduced. Further, many methods were adopted such as serrations, porous etc. for changing the surface impedance and the turbulent eddy correlation length. Geyer et al.[5] experimentally investigated the noise reduction capacity of a porous airfoil made with different porous materials. They concluded that the noise reduction potential strongly depends on the porosity of the material and up to 6dB reduction was possible in the low frequency range. However, a substantial noise increase is observed at the high frequencies due to surface roughness. Gruber et al. [6] studied the extent of the trailing edge noise reduction using a serrated trailing edge. Here also substantial noise reduction is obtained at the lower frequencies and a hike in the noise levels is observed due to the turbulence at the roots of the serrations. Recently Jiang et al.[10] studied the combination of different flat plate add-ons with perforated and non-perforated serrations of different shapes.

A detailed study of the noise mitigation by varying the surface impedance by using perforated extensions has not yet been reported. This paper presents the aerodynamic noise characteristics of the perforated extension added to the trailing edge of symmetric NACA0012 airfoil. The sound pressure level variation with length of the perforated extension, angle of attack and the noise scaling characterises are presented.

II. METHODOLOGY

A. Experimental Facility

The noise measurements taken in an anechoic wind tunnel facility of 2.5x2.5x2.5 m size ensures a reverberation free environment for frequencies greater that300Hz. A 10 HP motor with variable frequency drive is used to supply air to the wind tunnel facility. The air is supplied to the test section through an acoustically treated matched cubic contoured rectangular nozzle having the exit area 0.2 m x 0.08 m.

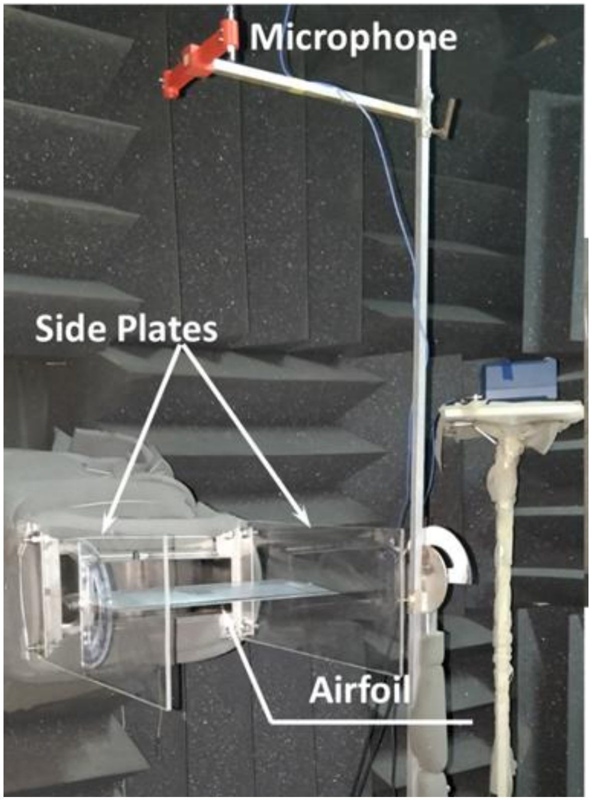

Figure 1: Experimental setup with airfoil held between the side plates.

The maximum flow velocity of the free stream jet attained by the wind tunnel facility is 47 m/s and at this velocity the turbulence intensity at the potential core is estimated to be less than 0.2%, while the background noise is kept low. The airfoil is kept 25mm in front of the nozzle which helps to minimize leading edge noise due to the interaction of the side wall boundary with leading edge of the airfoil as shown in Fig. 1. The nozzle width decides the extent of the potential core of the jet and is generally assumed to be four to five times of the jet widths.[11] Thus, it is confirmed that the airfoil is kept within the jet potential core.

A NACA0012 airfoil with chord (*c*) 0.15 m and span of 0.3m is used for the present study. The airfoil model is placed in the potential core of the free jet flow by holding it in between two side walls attached to the nozzle lip as shown in Fig.1. These side walls are used to arrest the wing tip flow and to make the flow over the airfoil two dimensional. Moreover, since the airfoil span is greater than the nozzle width, the side plates are kept away from vertical side wall of the nozzle which avoids the development of boundary layer over the side plates. This arrangement helps to circumvent the contamination by background noise level as well as by the leading-edge noise[12]. To study the turbulent boundary layer interaction noise, laminar boundary layer development over the airfoil surface is important. To ensure the turbulent boundary layer, both sides are artificially tripped using strip of sandpaper of width 0.01m on both sides of the airfoil at a distance 20% of the chord downstream of the leading edge as shown in figure 2.

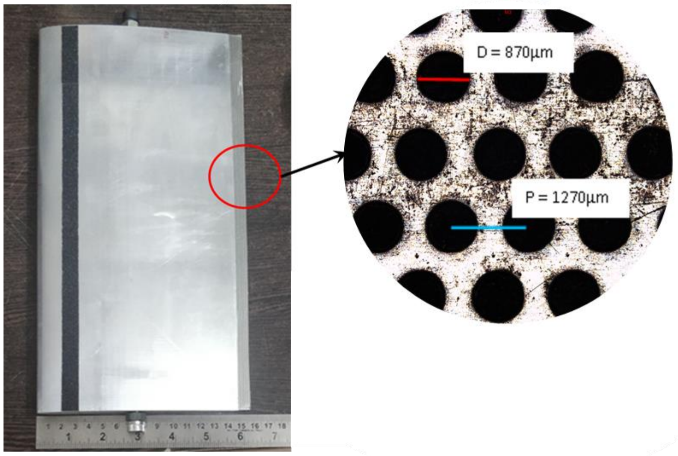

Figure 2: NACA 0012 airfoil with perforated extension

The perforated extension is attached to the trailing edge of the airfoil. To retrofit this extension plate to the airfoil, a 0.5 mm slit is made along the span of the airfoil as shown in Fig. 2. The perforated plate has a 60º staggered perforation pattern with hole diameter (D) 870 µm and pitch (P) 1270µm. The perforation ratio is measured as 43%. The 2D microscopic image of the perforated plate is shown in the Fig.2 The jet velocities considered for the experiment are between 20 m/s to 45m/s and corresponding Reynolds Numbers based on the chord length varies from 1.89 $\times 10^5$ to 4.3 $\times 10^5$.

The far field noise measurements were taken by a single ¼” PCB - 378C01 condenser microphone at a distance of 0.6m perpendicular to the mid span of the aerofoil trailing edge at polar angles of 90^0. The microphone signals were passed on to a National Instruments PCI- 6143 DAQ card through NI BNC-2110 noise rejecting, shielded BNC Connector Block. The noise data was acquired at a sampling frequency of 150 kHz as successive samples of duration of 2s. Five sets of 2s data were then combined to form a 10s data. This time domain signal is then converted to frequency domain using *pwelch* function with 50% overlap and 2^{12} point FFT with hanning window function. The resulting frequency resolution of the spectrum is 36.62 Hz.

III. RESULTS AND DISCUSSION

This section describes the variation in noise reduction potential of the perforated extensions at trailing edge with length and angle of attack. The results are indicated as frequency spectrum, the power spectral density (PSD) plotted against corresponding frequencies. The power spectral density has been expressed in dB/Hz, normalised by reference pressure Pref = 20 µPa.

Figure 3 represents the far field acoustic Power Spectral Density (PSD) spectrum of the base trailing edge and perforated extension at different lengths at velocity 45m/s. The figure demonstrates that the add-on extension to the trailing edge has substantial effect on the Power Spectral Density Spectra. The length of the extension (l) is represented as normalised length by dividing with the chord length(c). The *l/c* values varied from 0.06 to 0.2. From the figure 3 it is clear that the noise levels of the perforated extension with lower *l/c* value shows a noise reduction in a wide frequency range from 360 Hz to 2200Hz. But the maximum attainable reduction is 6dB. The extension with *l/c* = 0.13 provides noise reduction in the frequency range 300Hz to 1500Hz while the higher length plate gives reduction in 300Hz to 700 Hz only. However, the second extension (*l/c*=0.13) can provide up to 8dB reduction in the lower frequency range. Another important observation is that the use of perforated extension causes an increase of high frequency noise levels. This is due to the roughness offered by the perforated extension. The same was observed in the study of Geyer et al.[5]

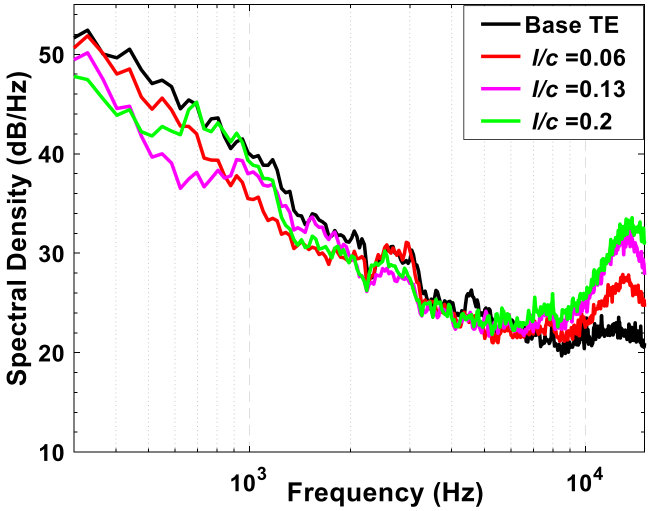

Figure 3: Spectral comparison of airfoils with different trailing edge extensions length at α=0^O^ and U = 45m/s.

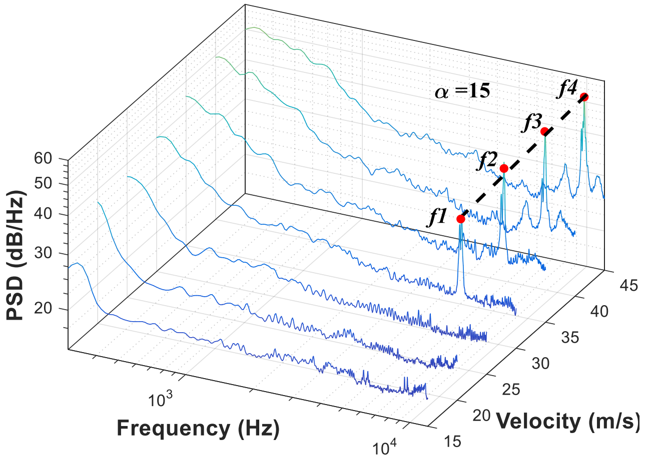

Figure 4: Waterfall spectra of base trailing edge at α = 15^O^

The variation of power spectral density of the base trailing edge noise is shown in the Fig 4. In the figure it is observed that a tonal noise peak is observed at higher frequencies for velocities greater than 30m/s. In order to find the nature of the tonal noise, the frequencies were plotted against velocity as shown in the Fig.5. It is observed that the frequency varies with 0.87th power of the velocity. This depicts that the tones are due to the vortex shedding at the trailing edge [13].

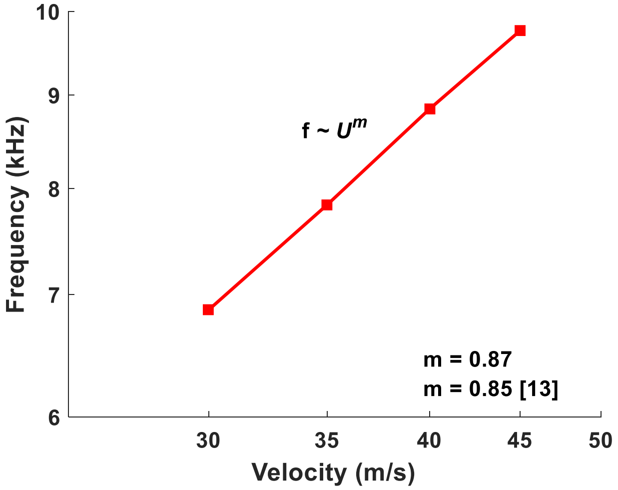

Figure 5: Variation of frequency with increase in velocity.

Figure 6 shows the spectral comparison of the base trailing edge and perforated extension of *l/c* = 0.6 at 15° angle of attack and 45m/s. From the figure it is evident that, in addition to the low frequency broadband noise reduction, the trailing edge vortex shedding noise, which occurs at high angle of attack, can also be reduced by the use of perforated extension. 7dB reduction at 10kHz is obtained by this perforated plate at 45m/s. The presence perforated extension alters the surface impedance at the trailing edge which causes change in the pressure fluctuation at the trailing edge.[5]

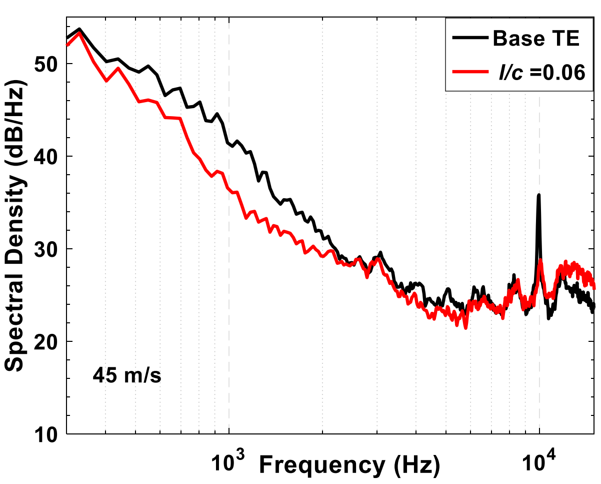

Figure 6: Noise spectra of base trailing edge and perorated trailing edge at α=15º and U = 45m/s.

The Overall Sound Pressure Level (OASPL) was calculated by integrating sound pressure levels over the frequency range of 300Hz to 15kHz. The OASPL are given in terms of free stream velocity in Figure 7. The best fit to the base trailing edge noise is found to conform with a $U^{5.1}$ dependency which is in good agreement with Howe's [3] prediction. The perforated extension shows a 2dB reduction and follows $U^{4.6}$ dependence.

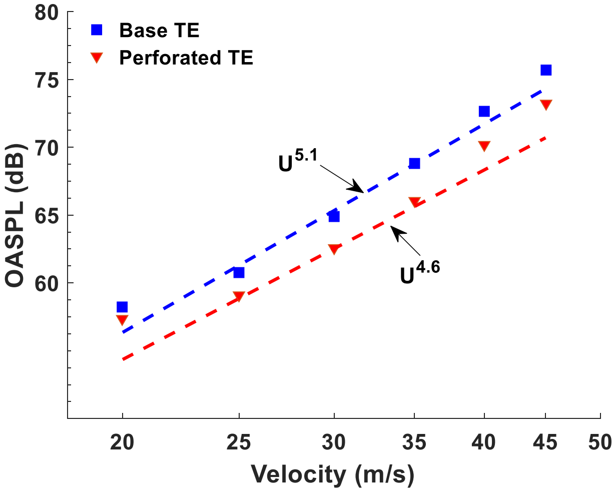

Figure 7: Variation of OASPL with mean flow velocity at α=0º.

IV. CONCLUSIONS

This paper presented the experimental results of the effect of add-on type perforated extension at the trailing edge on aerodynamic noise characteristics of a symmetrical NACA0012 airfoil. The acoustic study focused on the turbulent boundary layer trailing edge noise. The results show that up to 6dB reduction in low frequency broad band noise is possible in a wide frequency range with an extension length of 1cm.The vortex shedding tonal noise at higher angle of attack also can be attained by using this passive approach. By carefully optimising the add-on type perforated extension, substantial reduction in trailing edge broadband noise, as well as the boundary layer separation noise can be attained.

Acknowledgements

The authors gratefully acknowledge the research funding from the Department of Science and Technology (DST) – Science and Engineering Research Board (SERB) vide Project No. SB/FTP/ETA-0137/2013.

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