Acoustic characteristics of wavy trailing edged NACA 0012 airfoil

Rahul Narayanan C, *, T. J. Sarvoththama Jothi[2], C K Sumesh[3]

Department of Mechanical Engineering, NIT Calicut, Calicut-673601, India

*Corresponding author email: rahuu.5894@gmail.com, Tel.: 9496989471

ABSTRACT

The acoustic characteristics of wavy trailing edged NACA 0012 airfoil is carried out at velocities ranging from 15 m/s to 45 m/s and geometric angles of attack varying from 0º to 15º.The acoustic data is recorded by ¼" free field condenser microphone having a sensitivity 2 mV/Pa, at a sampling rate of 150 kSa/s. Data acquisition is done by the NI-PCI-6143 DAQ card connected to the computer using LabView software. The power spectrum density, Overall Sound Pressure level (OASPL) graphs are plotted for different sinusoidal wavy trailing edged airfoil models. Comparatively large noise reduction is observed in the wavy trailing edged airfoil having less value of wavelength. The OASPL value increases with increase in velocity for all angles of attacks because major contribution of noise from the airfoil is due to the turbulent boundary layer at the trailing edge and blunt trailing edge.

Keywords - Airfoil, Angle of attack, Power spectrum density, Velocity.

1. INTRODUCTION

The noise, unpleasant, unwanted loud sound generally associated with many engineering applications like gas turbine, aircrafts, household fans, wind mills, jet engines etc. Reducing this unwanted noise is a big challenge for many of the Scientists and Engineers. The main reason for this is the interaction of turbulent flows with solid surface or turbulent flows itself. Such generated noise is referred to as aerodynamically generated noise. Aerodynamic noise can be either tonal or broadband. In tonal noise the acoustic energy is concentrated to a few discrete tones, but in broadband noise the acoustic energy is distributed across a wide range of frequencies. Air foil self-noise is due to the interaction of the airfoil with the turbulence produced within its own boundary layer. Brooks *et al*[1] conducted series of experiments and used semi-empirical methods to quantify the aerodynamic noise from airfoil. According to them, airfoil self-noise is the sound produced while an airfoil encounters a smooth, low turbulent flow during free flight or in quiet wind tunnels. They have classified the airfoil self-noise into five mechanisms. The principal mechanisms are vortex shedding noise from the blunt trailing edge, separation and stall noise, laminar boundary-layer instability noise and tip vortex formation noise, turbulent boundary layer trailing edge noise. Aerodynamically the significance of trailing edge is less as compared to the leading edge and appropriate modification can be done at the trailing edge without effecting the aerodynamic performance if the drag is within the specified limits.

Numerous studies on increasing airfoil lift, improving stall characteristics and reducing the airfoil noise reduction have addressed various active and passive methods to modifying the leading and trailing edge shapes. The active methods include movement of surface elements, heating wall, oscillatory blowing and suction, and synthetic jets, whereas the passive methods include rippling the trailing edge, applying serrated edge or modifying the leading-edge profiles etc.

The accelerated airflow channel on the top side is aligned with the airflow channels on the bottom side. This alignment gives the highest pressure differential between the top and bottom of the airfoil thus reducing noise[2]. The trailing edge vortex shedding mainly grows along the span direction, spanwise trailing edge modifications without adding other devices should be more efficient than the attaching type drag mitigation devices.

For this reason, we propose a new trailing edge shedding vortex mitigation design, which is going to be called as the wavy trailing edge design. The main idea of the newly proposed design is to modify the trailing edge with a sinusoidal wave distribution in the spanwise direction of normal NACA 0012 airfoil.

2. EXPERIMENTAL DETAILS

Experiments are carried out in an in-house fabricated semi-anechoic open-jet wind tunnel facility having the working space of 2.6 m × 2.6 m. The schematic of which is shown in Fig. 1.

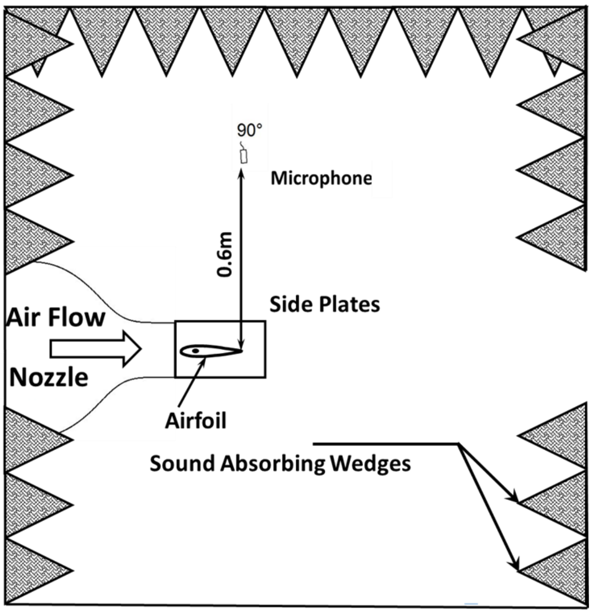

Figure 1. Schematic diagram of the test setup.

Walls of the semi-anechoic chamber are treated with polyurethane wedges of 30 cm long to absorb the incident sound waves and also act as an insulation for outside noises.

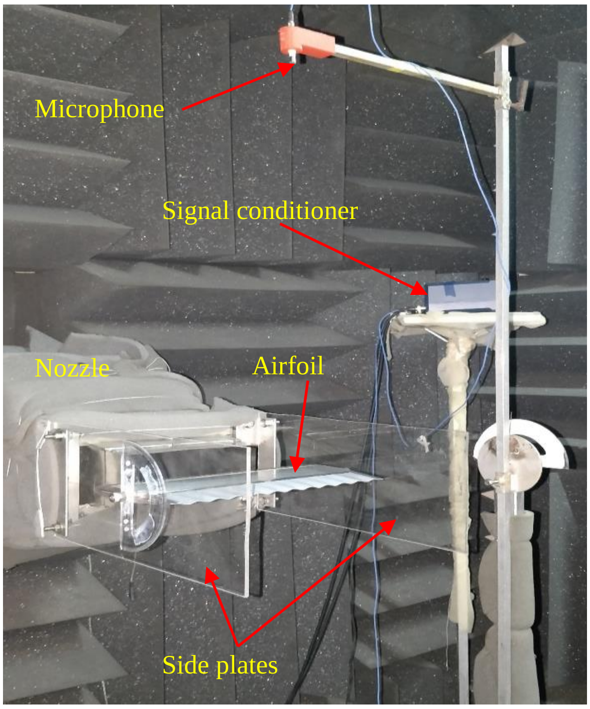

Figure 2. Experimental setup.

The anechoic room provides a reverberation free environment above 300 Hz. Blower is used to supply the air to the test section using a cubic contoured rectangular nozzle with exit dimensions of 200 mm × 80 mm and a contraction ratio of 10:1. The flow velocities are measured using the Pitot-static based digital anemometer probe, and a maximum free stream velocity of 45 m/s can be attained at the test section. In the investigation of acoustic characteristics, the wavy trailing edged airfoil models are placed in the free stream at 5 mm from the nozzle exit plane as shown in Fig. 2. This is to ensure that the noise contribution due to leading edge of the airfoil is insignificant[1] In addition to this airfoil is placed between two side plates for arresting the wing tip flow. Thus, flow over the airfoil can be treated as two dimensional.

Figure 3. Wavy trailing edged airfoil used for experiments.

NACA 0012 airfoil having wavy trailing edge, chord length of 15 cm and span of 30 cm (aspect ratio of 2) is used for the study. The sinusoidal wavy trailing edged airfoil model used for experiments are shown in Fig.3 and the corresponding wave equations are shown in Fig.4.

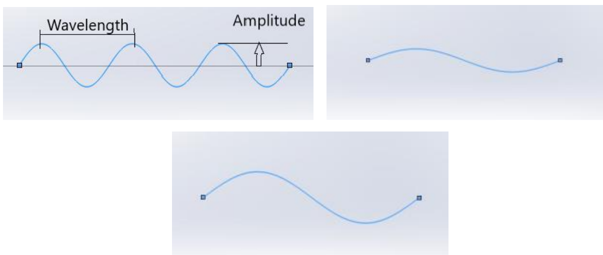

Figure 4. Different sinusoidal wavy forms used for study. (a) 1.5*sin (x), (b) 1.5*sin (0.25x), (c) 3*sin (0.25x)

The free stream velocity is varied in the range of 15 to 45 m/s and the corresponding Reynolds number (defined based on the airfoil chord length, here 0.15m) are from 1.4×10^5 to 4.2×10^5. Noise measurements are carried out using the microphone placed at 90° above the mid-span of the trailing edge at a far- field distance of 0.6 m. The acoustic data is recorded by ¼" free field condenser microphone (PCB make; Model No. 378C01), having the sensitivity of 2mV/Pa, at a sampling rate of 150 kSa/s. The data acquisition is done by the NI-PCI-6143 DAQ card connected to the computer using Lab View software. The narrow band frequency spectra of the acquired time series signal are obtained by the *pwelch* function in the MATLAB with a *Hanning* window and 50% overlap. The acquisition procedure is shown in the Fig. 5.

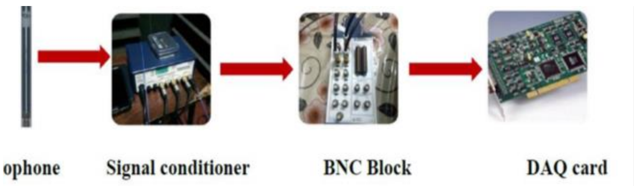

Figure 5. Data acquisition facility

The fabrication of the trailing edge is ensured to be sufficiently sharp. Their values are measured using the *toolmaker*'s microscope and are found to be 0.085 mm. The spectral noise levels analysis is carried in the chosen frequency range of 300 Hz to 10 KHz, since the former value being the cut-off frequency of anechoic chamber, and no dominant noise components are seen beyond the latter frequency value. The background noise is observed to be lesser by around 12 dB compared to the noise from the test models.

3. RESULTS AND DISCUSSIONS

The power spectrum density graphs are plotted at different velocities for 15^o angle of attack as shown in the Fig. 6 The noise components are extracted in between two frequency ranges of 300 Hz to 10 KHz. It is clear that, there is a drastic increase in spectral density is observed with the increase in velocity. It is

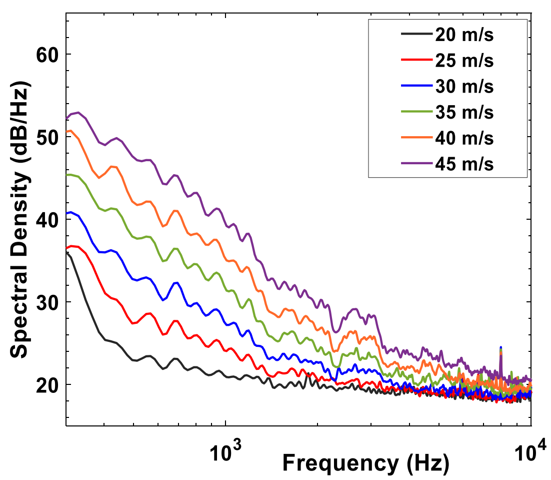

Figure 6. power spectrum density graph

worth mentioning at this stage that the major contribution of noise from the airfoil is due to the turbulent boundary layer at the trailing edge and blunt trailing edge[1].

According to theory as the name implies, the convected turbulent eddies within the boundary layer passes over the sharp trailing edge, scattering of the turbulent eddies will takes place within the boundary layer and noise is produced[3]. The design modification incorporated mostly focus on preventing the strong vortex formation and its development at the trailing edge. The local difference of the trailing edge thicknesses will vary as the local camber steepness and consequently serve as a kind of vortex generator which may interact with the usual vortex formation. By implementing such vortex generators along the span, the span wise growth of the trailing edge vortex should be effectively reduced. In this research, we expect the new design brings significant reductions in the coherence of any trailing edge vortex shedding and thus should result in reduced noise levels while maintaining good aerodynamic performance.

Overall sound pressure level variation (OASPL) with velocity is plotted for base trailing edge (TE), Wavy1 TE and Wavy2 TE as shown in the Fig. 7.

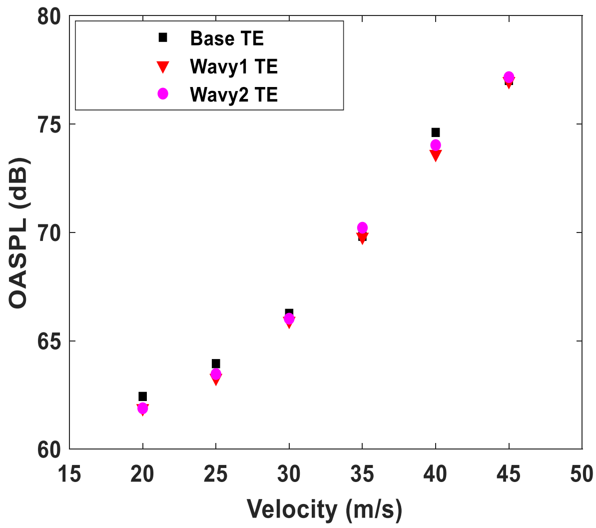

Figure 7. OASPL variation with flow velocity for Base TE, Wavy1 TE and Wavy2 TE.

It is seen that at lower velocity regions, that is from 20 to 40 m/s the wavy TE model 1 (1.5*sin (x)) and wavy TE model 2 (1.5*sin (0.25x)) have less OASPL value compared to base TE. Whereas at 45 m/s wavy TE model 1, wavy TE model 2 and base TE have equal OASPL values. From the OASPL graph wavy TE model 1 having better noise reduction than wavy TE model 2. Thus, it is clear that Noise generation gets reduced with decreasing the wavelength.

5. CONCLUSION

The acoustic characteristics of wavy trailing edged NACA 0012 airfoil is carried out at velocities ranging from 15 m/s to 45 m/s and geometric angles of attack varying from 0^{o} to 15^{o}**.** wavy TE model 1 having better noise reduction than wavy TE model 2. Thus, it is concluded that Noise generation gets reduced with decreasing the wavelength.

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