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Semi-empirical Investigation of Trailing Edge Noise by Measuring Unsteady Surface Pressures

A. Afshari, A. A. Dehghan , M. Farmani

Department of Mechanical Engineering, Yazd University, Yazd, Iran

ABSTRACT: Aerodynamic noise reduction requirement from airplanes, wind turbines blades and fans have resulted in the identification of noise sources of such equipment in many research works. Turbulent boundary layer trailing edge noise is one of the main sources of aerodynamic noise and extensive studies have been devoted to trailing edge noise identification during the past decades. In the present study, for measuring the main parameters affecting the far-field trailing edge noise including the surface pressure spectra, the spanwise length scale of the Surface pressure fluctuations and eddy convection velocity in the trailing edge region, a flat-plate model equipped with several streamwise and spanwise surface pressure transducers is designed and built. The spanwise length scale and eddy convection velocity are calculated by simultaneously measuring of unsteady surface pressure in both streamwise and spanwise directions. The experimental results, including the surface pressure spectra, longitudinal and lateral coherences and eddy convection velocity provide many information regarding the flow field structure in the turbulent boundary layer. The results also show that the best collapses in the surface pressure spectra at low frequency and mid to high frequencies can be obtained by using outer and inner layer scales respectively. Furthermore, the longitudinal and lateral coherences can provide adequate information about the lifespan (or, inversely, the decay) of the turbulent eddies and their physical size. Finally, the far-field trailing edge noise induced by the turbulent flow over the flat plate has been predicted by using the Amit-Roger model and results show the effectiveness of this model for prediction of far-field turbulent boundary layer trailing edge noise.

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1. Introduction

Airfoil self-noise is produced due to interaction of unsteady flow, with the surfaces of the airfoil. There are a variety of noise generating mechanisms associated with airfoil self-noise that are concisely summarized in Ref. [1]. Turbulent Boundary Layer Trailing Edge (TBL-TE) broadband noise is one of the most important airfoil self-noise mechanisms [1]. Over the recent decades, trailing edge noise has received considerable attention in the form of theoretical, computational and experimental research works. This is due to the importance of the subject in a wide range of applications such as aircraft, underwater vehicles, wind turbines, fans, etc. [2]. Numerous theoretical trailing edge noise models have been developed over the past decades, a summary of which can be found in Ref. [2]. There are two basic approaches for prediction of far field trailing edge noise: formulations based on the Lighthill [3] acoustic analogy that need hydrodynamic velocity field around the TE, or based on linearized hydroacoustic methods that use the induced hydrodynamic pressure field at some distance upstream of the TE. The majority of noise prediction methods for trailing edge have been formulated based on surface pressure fluctuations. According to Amit-Roger model [4], the frequency dependent spanwise length scale of the Surface Pressure Fluctuations (SPFs) defining the efficiency of scattering at the TE, and convection velocity in the TE region are crucial quantities in predicting the far-field trailing edge noise.

In the present study, the Amit-Roger model [4] has been used for prediction of the far-field trailing edge noise induced by the flow over a flat plate. The spanwise length scale and the convection velocity of the turbulent eddies are calculated by measuring the unsteady surface pressure in both spanwise and streamwise directions. The experimental layout is described in section 2 and the main outcomes of the investigation are presented in section 3.

2. Experimental Setup

The experiments were carried out in the open subsonic wind tunnel of the Yazd University. The flat plate used in the present work has a chord length of 580 mm, a span of 456 mm and a thickness of 8 mm. The experiments were carried out at three free stream velocities, U_∞=10, 15, and 20 m/s. The model was tripped by a step with 5 mm height block which was positioned at ten percent of the chord length downstream of leading edge. The detailed CAD view of the flat plate model is shown in Fig. 1.

The FG-23329-P07 microphones are employed for the measurement of the unsteady surface pressure. The microphones are embedded in the flat plate under a pinhole

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*Corresponding author's email: adehghan@yazd.ac.ir

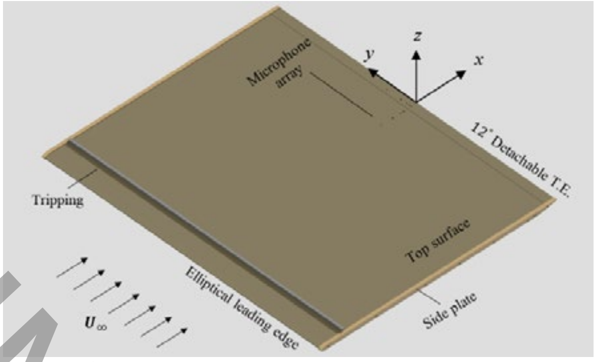

Fig. 1. Model, trip's position and microphone array.

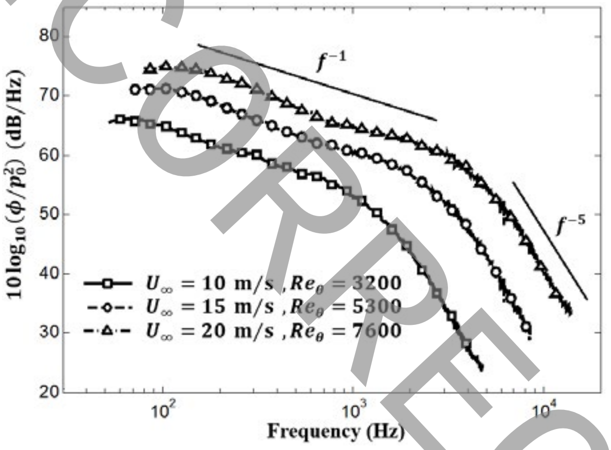

Fig. 2. Surface PSD at *x/c* = 0.976 at various velocities.

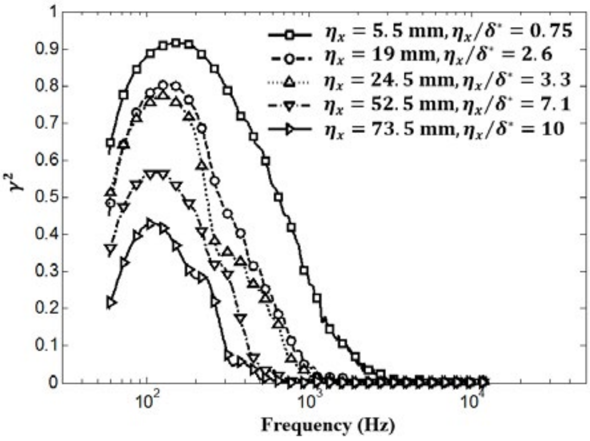

Fig. 3. Longitudinal coherence variations for various streamwise microphones spacing at 20 m/s.

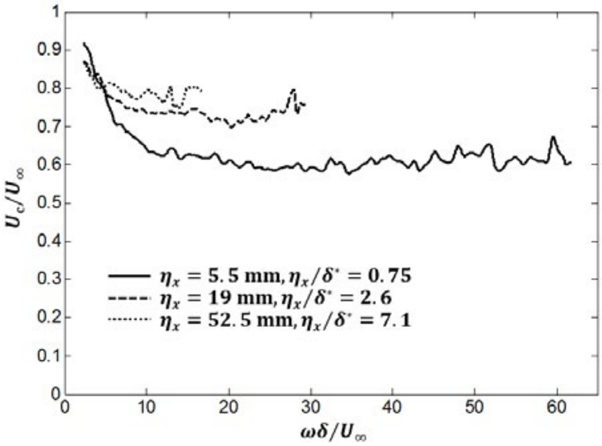

Fig. 4. Variation of convection velocity at 20 m/s.

mask of 0.4 mm diameter in order to decrease attenuation effects at high frequencies due to the finite size of the microphones sensing area. A total number of 10 microphones are arranged in the form of L-shaped array on the surface of flat plate, Fig. 1. A set of microphones are distributed in the streamwise direction from *x/c* = 0.85 to 0.976 to provide information on the convection velocity of the turbulent eddies. Another set of microphones are distributed along the span to measure the spanwise length scale. The microphones were powered by a 10-channel power module and the data were collected by a 16-channel NI PCI-6023E data acquisition system. The sampling frequency was $f_s = 40$ kHz, and a total of 800,000 samples were recorded over 20 seconds. The spectral analysis of the data is done using the pwelch power spectral density function in MATLAB with a Hamming window function, 50% overlap and a reference pressure of 20 μPa. Reliable and repeatable measurements are achieved for all microphones.

3. Results and Discussion

Fig. 2 shows the surface pressure Power Spectral Density (PSD) near the trailing edge for different free stream velocity. As may be seen, PSD increases and shifts to the higher frequencies with increasing Reynolds number. Furthermore, all the spectra decays as f^{-1} and f^{-5} in the mid and high frequency ranges, respectively. The longitudinal coherence measured between the streamwise microphones at 20 m/s are depicted in Fig. 3. As can be seen, by increasing the streamwise spacing between microphones, η_x, the lower coherences are observed due to the structures have more distance and time to evolve and change their identity from one microphone to the other one. Also, the maximum values of the longitudinal coherence are seen in lower frequencies which means that the larger structures have longer life spans.

Fig. 4 shows the eddy convection velocity ratio for various streamwise spacing at 20 m/s. As can be seen, the eddy convection velocity increase with increase of streamwise spacing between the sensors. Finally, the far-field spectra predicted by analytical Amiet–Roger model [4] at *z*=580 mm is presented in Fig. 5. Results show that although there is a deviation up to 7 dB from direct experimental results [5] at mid frequencies, however, the model adequately predicts magnitudes and general trend of the far-field noise.

4. Conclusions

In the present study a long flat-plate model, equipped with several streamwise and spanwise surface pressure microphones have been designed and built for measuring the surface pressure PSD, the spanwise length scale of the SPFs and eddy convection velocity in the TE region. The experimental results, including the surface pressure

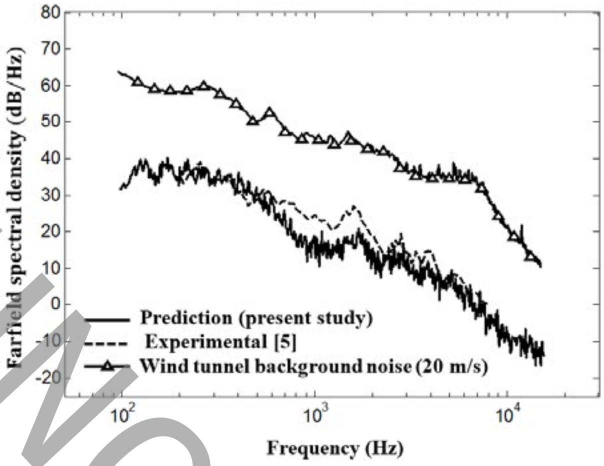

Fig. 5. Comparison of the far-field spectra predicted by analytical Amiet–Roger model [4] with results of reference [5] at 20 m/s at z=580 mm.

spectra, the longitudinal and lateral coherences and eddy convection velocity provided many information regarding the flow field structure in the turbulent boundary layer. Furthermore, the results show the effectiveness of the Amit-Roger model for prediction of far-field turbulent boundary layer trailing edge noise.

References

[1] T. F. Brooks, D. S. Pope, M. A. Marcolini, Airfoil self-noise and prediction: National Aeronautics and Space Administration, Office of Management, Scientific and Technical Information Division, 1989.

[2] M. Roger, S. Moreau, Trailing edge noise measurements and prediction for subsonic loaded fan blades, AIAA paper, Vol. 2460, 2002.

[3] M. J. Lighthill, on sound generated aerodynamically. I. General theory, Mathematical, Physical and Engineering Sciences. Vol. 211. No. 1107, 1952.

[4] M. Roger, S. Moreau, M. Wang, An analytical model for predicting airfoil self-noise using wall-pressure statistics, Annual Research Brief, Center for Turbulence Research, Stanford University, pp. 405-414, 2002.

[5] D. J. Moreau, L. Brooks, C. J. Doolan, Experimental investigation of broadband trailing edge noise from sharp-edged struts, 17th AIAA/CEAS Aeroacoustics Conference, Portland, Oregon, 05-08 June, 2011.