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A Review on Airfoils with Serrated Trailing edge

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Abstract — *This Review paper gives a brief introduction the effects of providing the serration in airfoils. Few experimental procedures have been presented in this review paper in order to understand the effect of introducing serration. Major factor affecting by serration is the noise emission due to turbulence and boundary layer separation. The Acoustic levels are found to be decreasing by the use of serration and the aerodynamic properties like lift force drag force remains same. Presently all conclusion are based on the experimental work and empirical derivation.*

Keywords- *Airfoils, Serration, Leading Edge, Trailing edge, Acoustic Emission*

I. INTRODUCTION

Aerodynamic properties of airfoils are very unique and have been topic of interest for many of the researchers. Airfoil is been used extensively in fan blade, wind turbine i.e. to convert the kinetic energy of the wind into mechanical energy in terms of drag force and lift force and visa versa. Whenever the fluid flows over the airfoil several phenomena such as, Flow separation Turbulence, Wake development, takes place that is to be considered while analyzing the aerodynamic properties of the airfoil. Due to all this Noise is generated in the leading edge and trailing edge of the airfoil Researcher have developed many theories and conducted experiments by optimizing the design of leading edge and trailing edge that can attenuate the generation of the noise. Several experiments are performed on different types of the airfoils to reduce the noise generated without compromising the aerodynamic properties of the airfoil.

II. METHODOLOGY

M. S. Howe discussed the radiation noise over Trailing Edge of Flat Plate Airfoil by deriving the Mathematical model. His model is based on the assumption that the noise generated over the trailing edge is primarily due to Turbulence created due to the instability of the boundary layer. The Airfoil considered for this study is modeled by a Flat Plate set at a zero angle of attack. The Flow is considered to be Low Mach number high Reynolds Number. The Frequency of the generated Noise is considered Large enough so that the Wavelength is small compared to the chord length of the Airfoil. (1)

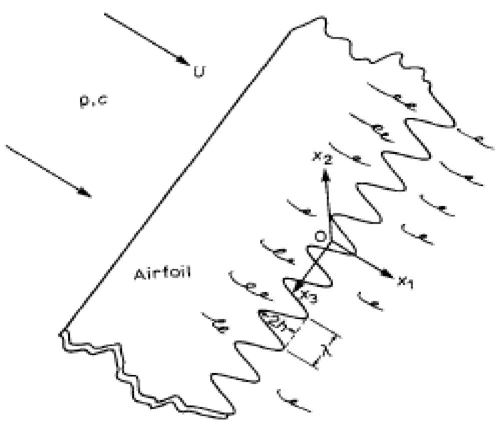

Figure 1. Turbulent flow over an airfoil with a serrated trailing edge (1)

S Narayanan et al adopted the experimental method to investigate Noise reduced by providing the serration in the leading edge. The Airfoil considered for this study is NACA-065. The Broadband Noise is generated due to the interaction of the leading edge of an airfoil with the turbulence. The experiment is done with Flat Plate Airfoil with serration in Leading Edge in the open Jet Wind Tunnel. The main objective of the paper is a parametric Study of reduction in the Attenuation of the noise with respect to the serration parameters, amplitude (2h) and wavelength (λ). (2)

For Acoustic measurement, an Array of 11 Microphone is distributed over the circular arc of the radius of 1.2m. The array covered a range of emission angles (θ) between 40◦ and 140◦ measured relative to the downstream jet axis. (2)

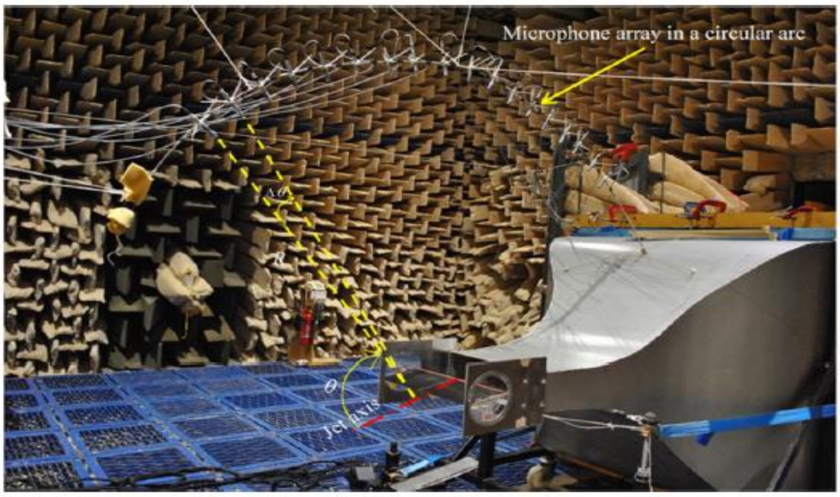

Figure 2. Photograph of the jet nozzle and the test setup inside the ISVRs anechoic chamber (2)

Wei Jun et al has considered the LES(Large Eddy Simulation) of the turbulent flow. This mathematical model is used for the numerical study of noise generated on the NACA-0015 airfoil. This is used to compare the airfoil for both conditions i.e unserrated trailing edge and serrated trailing edge. The purpose of this study is to correlate the aerodynamic pressure with the trailing edge noise. The extended length of the serration (from its root to tip) is 5% of the airfoil chord length and the span of the serration is 10% of the chord. The pressure signals obtained from original airfoil and from the serrated airfoil are compared with each other to observe dependency of pressure fluctuations with the noise attenuation. (3)

Figure 3. A photograph of LE serrated flat plate and jet nozzle inside the ISVR's anechoic chamber and a photograph of the LE serrated airfoil showing all the parameters (2)

M.Gruber et al. have compared the measurement self-noise generated by NACA-651210 with the measurement obtained by providing the sawtooth serration in the same. By using the Howe's Trailing edge noise model in reference and by taking the similar assumption as Howe's model.

The experiment is conducted in open jet wind tunnel with the microphone array (4)

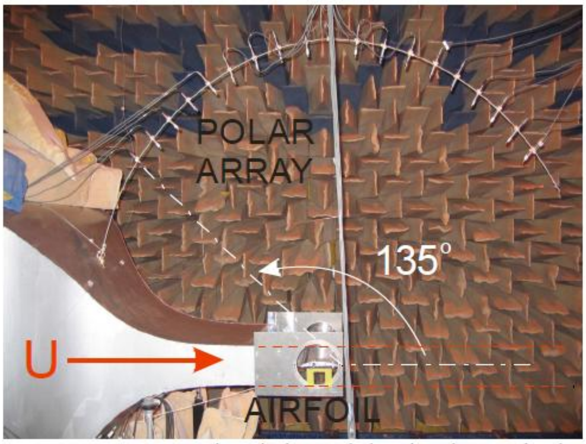

Figure 5. ISVR open-jet wind tunnel showing the nozzle, the airfoil model and the polar array (4)

Figure 4. Picture of the NACA6512 airfoil (4)

A. Finez et al has experimented the noise reduction of Airfoils arranged in linear cascade manner with trailing edge serration. The cascade shown on Figure is made of 7 NACA 6512-10 blades: the original chord is c = 100 mm and their span is L = 200 mm, the pitch is s = 70mm. (5)

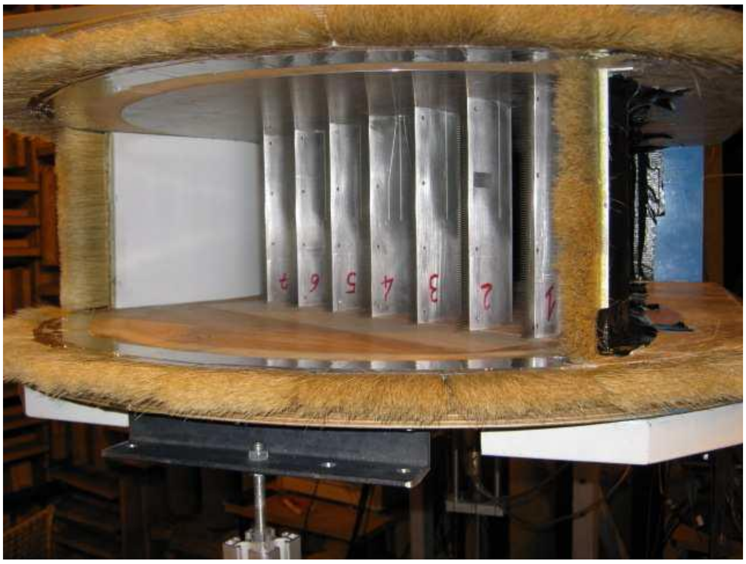

Figure 6. Picture of the cascade test rig (5)

S.Oerlemans et al experimentally demonstrated the noise emission of the wind turbine rotor through optimized shape and trailing edge serration. The airfoil blade used for this purpose is NACA-64418 and a model scale rotor with a two-blade 4.5 m diameter rotor and for the acoustic measurement the array of 136 microphones the speed of the tunnel is between 11 and 16 m/s (6)

D.Moreau et al have presented the experimental study on the noise reduction potential of a NACA-0012 airfoil with trailing edge serration at low-to-moderate Reynolds number 1.6×10^5 < R <4.2×10^5, based on chord) the noise reduction is measured in wind tunnel setup. Two different serration geometries are compared in this study, both with root-to-tip amplitude of 2h = 30 mm: one with a wavelength of ƛ= 3 mm (ƛ /h = 0:2, termed narrow serrations) and the other with ƛ =

9 mm (ƛ /h = 0:6, termed wide serrations). Experiments were conducted at free-stream velocities between U = 15 and 38 m/s (7)

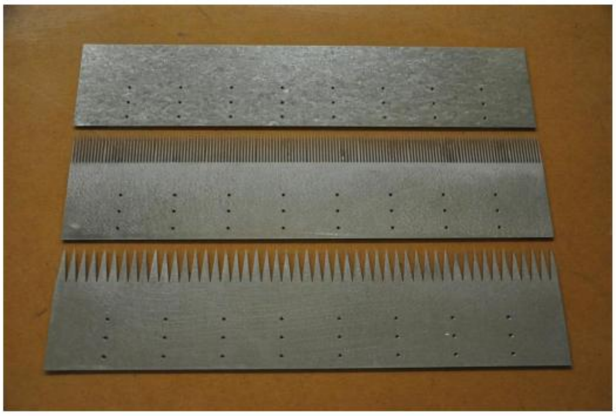

Figure 8. Trailing edge plates. Top: straight unserrated trailing edge (reference), middle: narrow serrations with ƛ = 3 mm, bottom: wide serrations with ƛ = 9 mm. (7)

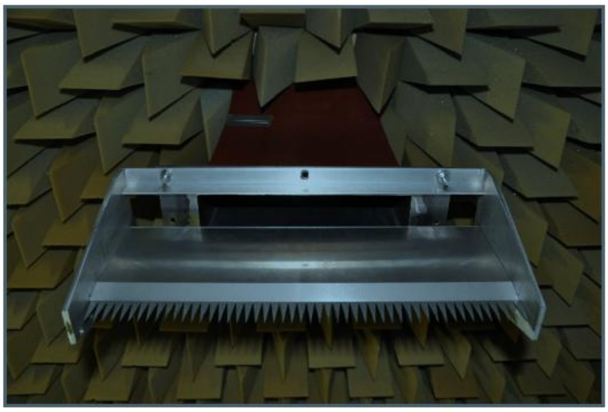

Figure 7. The flat plate model with wide trailing edge serrations (7)

F.Zenger et al conducted the experiment to study noise reduction by providing the leading edge serration in axial fan the airfoil of the fan blade is NACA-4510 and the serration provided on leading edge were sinusoidal such that the wavelength of the serration decrease from hub to blade tip design volume flow rate V = 1.4 m^3/s and at V = 1.8 m^3/s along with the acoustic parameters the fan parameter such as Pressure rise and Efficiency is also compared with respect to the serrated airfoil (8)

J. Madadnia et al have conducted an experimental study of aerodynamic performance from the trailing edge and leading edge of the blade of the co-axial double shaft fan of the blower. The model was operated in fan mode and air velocity, shaft-revolution; electric-fan-power, acoustic noise amplitude (dB) and Centre frequency (CF in Hz) were measured for a number of spacing and serrations. Coefficients of Performance (COP), dB, CF were plotted against tip speed (TS) (9)

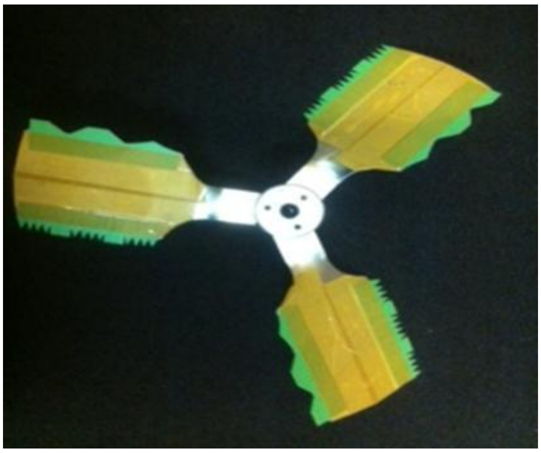

Figure 10. Serrated Fan Blade (9)

Figure 9. Testing of Caxial Double Fan (9)

D. Deb Nath et al conducted an experimental study on the effect of serration on axial flow fan blade of compressor rotor The serrated blade considered here has 4 triangular shaped serrations with a serration period of 18 mm and the serration depth of 10% of the maximum chord. The definitions of serrations in this experiment the wakes generated by two axial impellers, one with the serrated blades and other with baseline blades are compared.(13)

Figure 11. Baseline and Serrated blades (13)

III. RESULT AND DISCUSSION

Serrations can reduce low Mach number edge noise provided That the edges are inclined at an angle less than about 45° to the mean flow direction over a significant portion of the edge. Sawtooth serrations whose edges satisfy this condition are predicted to give substantial reductions in radiated Sound levels Predictions for an edge with teeth of spanwise Wavelength λ and root-to-tip distance 2h indicate that the spectrum of trailing edge noise is about $10*\log[1+\left(\frac{4h}{\lambda}\right)^2]$dB below that for an unserrated edge when λ/h < 1 (θ <45°).For serrations of the smooth, sinusoidal form of the same wavelength and root-to-tip distance 2h is about $10*\log(\frac{6h}{\lambda})$ dB below that for an unserrated edge (1)

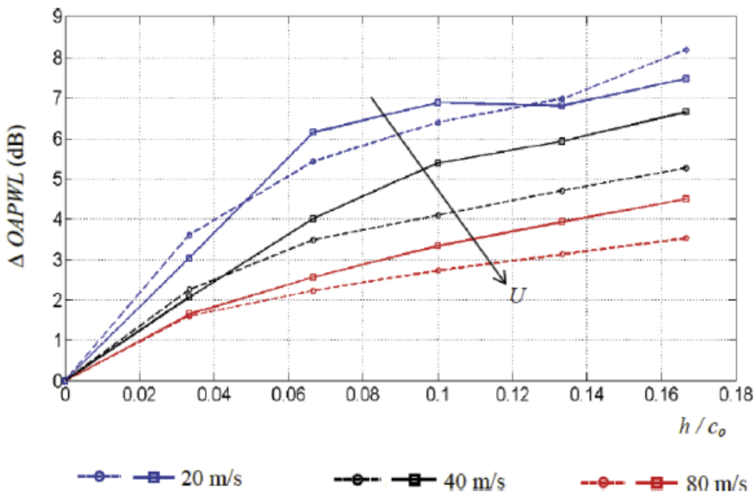

Figure 12. Variation of ΔOAPWL (overall sound power level) with h/co(Co=mean Chord Length) (2)

Noise attenuation is more significant in flat plate airfoil than compare to the conventional airfoil with serrated trailing edge. The noise reduction was of 9 dB. for the flat plate as compared to 7dB for the airfoil it is observed that sound power reduction level (ΔPWL) is sensitive to the amplitude, 2h of the LE serrations but less sensitive to the serration wavelength, λ (2)

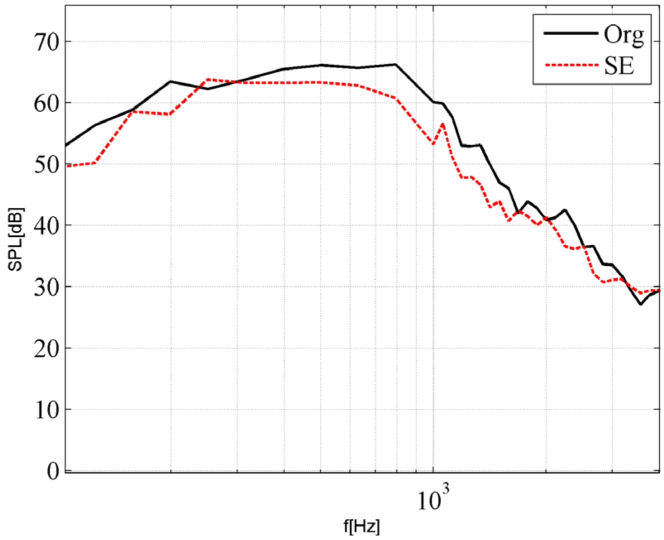

Figure 13. Sound pressure level in 1/3 octave band: comparison with original airfoil and airfoil with TE serration. (3)

Using Howe's idea to predict the far-field noise radiation for the low-frequency range. M. Gruber et al predicted theoretically that for high frequency the sawtooth serrations show a potential noise reduction of about 30 to 35 dB. But in practice, experimental data shows that noise reduction is efficiently up to 5 dB (4)

A..Finez et al conducted an experiment on the cascade arrangement for the serrated airfoil to analyze the effect on noise reduction but experimentally there is no change in the noise reduction but from the aerodynamic point of view the cascade arrangement increase the drag coefficient by 14 % (5)

Experiments performed on the Wind turbine by providing the serration on the trailing edge show that there is no significant change in the aerodynamic performance of the airfoil blade and the serration gives the noise reduction of 2-3 Db. (6)

The trailing edge serration in NACA-0012 reduces up to 3 dB. of noise and it goes up to 13 dB. for high velocities and high Frequencies (7)

Serrations on the leading edge of a single haft fan have reduced sound up to 10% and have increased the efficiency Leading edge serration are more effective than trailing edge serration and serration are more effective at increase tip speed (9)

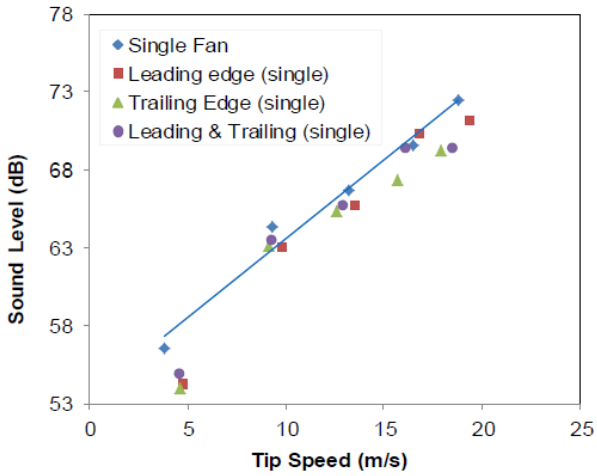

Figure 14. Efficiency vs. Blade Tip Velocity (m/s) of experiment on single fan with serration in leading edge and trailing edge and both (9)

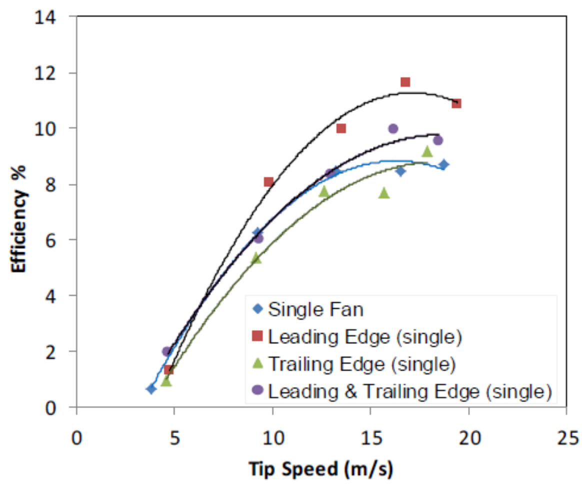

Figure 15. Sound Pressure Level (dB) vs. Blade Tip Velocity (m/s) of experiment on single fan with serration in leading edge and trailing edge and both (9)

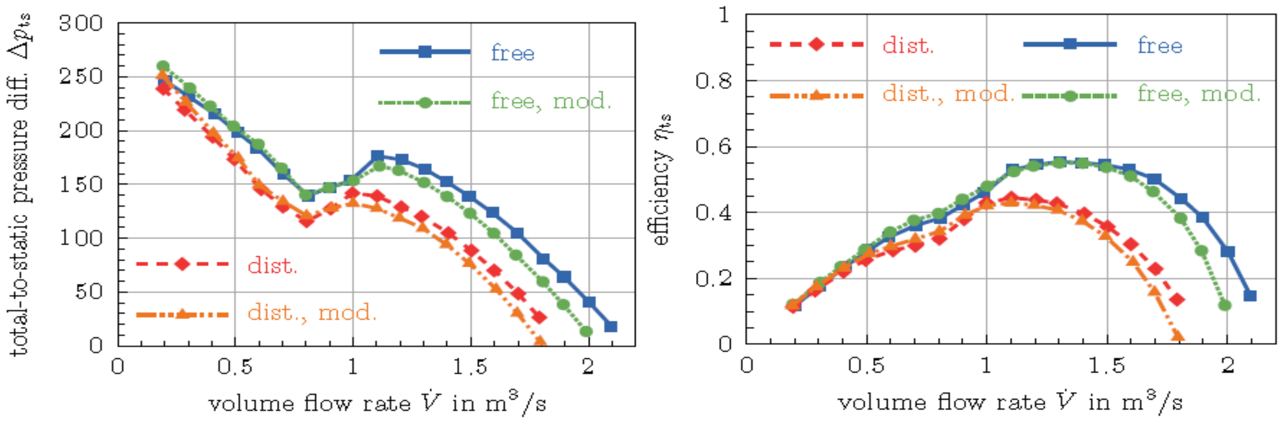

Figure 16. Fan aerodynamic characteristic curves of the total-to-static pressure difference (left) and total- to-static efficiency (right). (8)

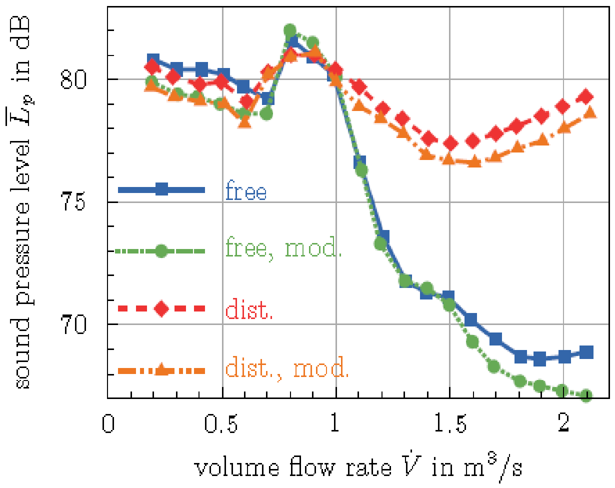

Figure 17. Fan acoustic characteristic curves. (8)

From Figure, it is obvious that the fan with straight LEs has better aerodynamic properties, i.e. a higher pressure rise and efficiency, than the fan with modified LEs, at volume flow rates of $V \geq 1 \frac{m^3}{s}$.

In above figure, the fan with modified LEs has lower overall averaged sound pressure levels Lp than the fan with straight LEs. The differences Lp between the fans with straight and modified LEs are fairly constant under distorted in flow conditions (8)

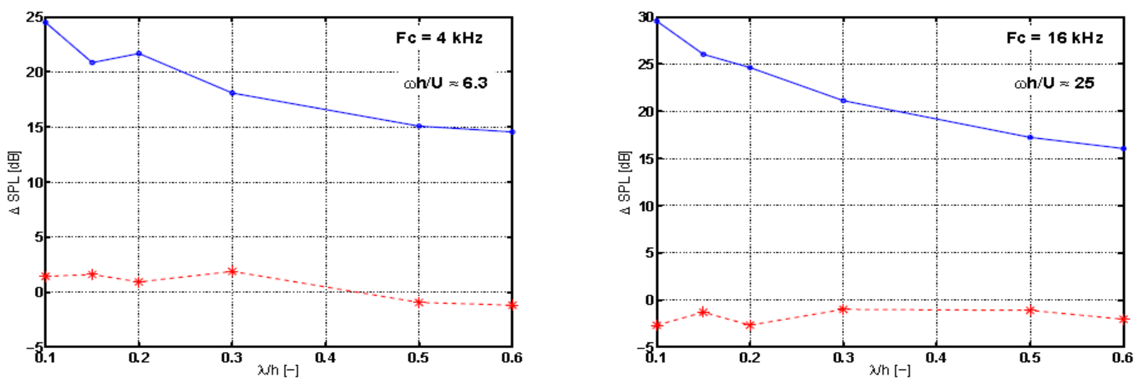

Figure 18. Overall noise reduction averaged over third-octave bands as a function of h, predicted by Howe (Solid) and measured experimentally (Dashed) - Experimental data with airfoil at 5oAoA and U= 40 m/s (10)

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