# AERODYNAMIC PERFORMANCE AND ASSOCIATED NOISE GENERATION SPECTRA OF AIRFOIL

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ABSTRACT

Noise reduction of turbo-machines is one of the most important targets in the modern technology. This can be achieved by a proper choice of the airfoil which makes a significant reduction in noise level with the best aerodynamic performance. This paper presents an experimental study carried out on a symmetric airfoil with the aim of investigating its performance and associated noise generation. The influence of flow velocity and angle of attack is also presented. The results indicate that the change in flow velocity is accompamed by a variation in the noise spectrum measured. A comparison has been made with other available data and showed that the lowest noise level is obtained in most cases close to the point of the best airfoil aerodynamic performance.

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## INTRODUCTION

Noise reduction of fans is one of the most important targets in the present fan technology. It is essential for our comfortable living and working environments to suppress noise fron, such as, low-pressure small fans in air-conditioning equipment, vehicle engine and radiator coolin fans, large ventilators for cooling towers, and so on. Both manufacturers and users of fans are striving for improving the situation. The aerodynamic performance of airfoils, fans and cascades has been studied by many research workers [1-3]. Such studies generally involve an interaction of the blade cascade and its geometry with different flow conditions on the performance of the cascades. Other studies are dealed with the behaviour of the noise generated by fans airfoils subjected to cross flow [4-6] . These studies showed that the noise generated is due to instability of the boundary layers and the developed vortex shedding which acts as an acoustic sources. Such behaviour is demonstrated according to three different models, namely, the vortex model, the aeroacoustic feed back model, and the unstable boundary layer model.

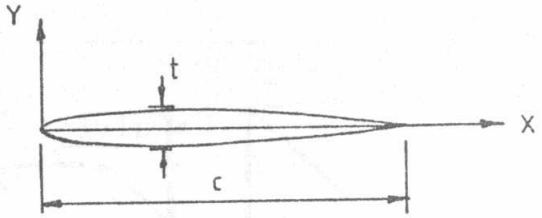
On the other hand, most of the methods taken by turbomachine manufacturers and designers to make quiet turbomachines have been devised from their experience based on the data on performance and noises for a lager number of turbomachines already in operation. In order to obtain a more reliable means, it is desired to establish a quantitative airfoil noise prediction formula, taking the relative physical parameters into account such that an optimum design may be possible on the basis of the formula [7-8] . It is not necessary to say that abundant data on aerodynamic performance and noise are necessary for the above purpose. As formulae for estimating fan airfoil noises, many are in trail use now and efforts are being made to relate airfoil noise level with its performance (its flow behaviour under flow conditions, drag and lift coefficients and turning flow angle with the angle of attack) or airfoil specifications. Most of these evaluation formulae can, however, relate the noise generated by the airfoil with its performance or specifications only roughly. They do not relate it with detailed design parameters, for example, airfoil geometry, angle of attack, etc. and so forth and, therefore, cannot be used quantitatively for designing purpose, particularly that related to the airfoil geometry the most important aerodynamic element among design parameters. In view of these aspects, experiments have been carried out on a symmetric fan airfoil placed in a uniform flow of low velocity range, with the aim of investigating its performance and associated noise generation for the purpose of design.

## EXPERIMENTAL APPARATUS AND METHODS OF MEASUREMENTS

The geometric configuration of tested wooden airfoil with good surface finish is presented in Table 1. This airfoil is set downstream from the wind tunnel nozzle at which a turning mechanism is used to adjust the airfoil at the required angle of attack.

Table 1. Geometrical configuration of the airfoil

| X/C | 0.000 | 0.050 | 0.100 | 0.150 | 0.200 | 0.250 | 0.300 |
|---|---|---|---|---|---|---|---|
| Y/C | 0.000 | 0.070 | 0.094 | 0.108 | 0.114 | 0.120 | 0.126 |
| X/C | 0.400 | 0.500 | 0.600 | 0.700 | 0.800 | 0.900 | 1.000 |
| Y/C | 0.114 | 0.108 | 0.094 | 0.070 | 0.050 | 0.026 | 0.000 |




C = 158 mm
t = 20 mm

The flow characteristics are measured to obtain data on the aerodynamic performance of the airfoil. Such characteristics are obtained by measuring velocity profiles over and along the airfoil by means of a pitot tube of outside diameter of 0.5 mm and a micromanometer. Also, the static pressure along the airfoil is measured using a static pressure tappings. The flow separation is interpreted as given by Waitman, Reneau and Kline [9] by using wool tufts. The noise generated from the airfoil is measured using microphone located at a position not exposed to wind, it is connected to a microphone preamplifier and a narrow band real time analyser works in the real time, and finally the results can be obtained by using X-Y recorder. To correct the background noise, air is blown without the airfoil with other conditions kept unchanged, and hence the noise spectrum is measured. The arrangement of these apparatuses is shown diagramatically in Fig. 1.

Preliminary measurements of air flow, turbulence and noise were performed. Turbulence in air flow is one of the causes for noise and its spectral distribution may serve as an effective basis in the application of experimental data. For the accurate measurement of airfoil noise, it is important to determine the correct position of microphone from this viewpoint, search for a position which would give average noise level has been made by making the microphone traversing measurement over the surface surrounding the airfoil. The location which has been found to be suitable for such investigation is at 0.3 m. above the airfoil.

## RESULT AND DISCUSSIONS

The pressure distribution as the pressure coefficient Cp along the airfoil is shown in Fig. 2. For the airfoil with zero angle

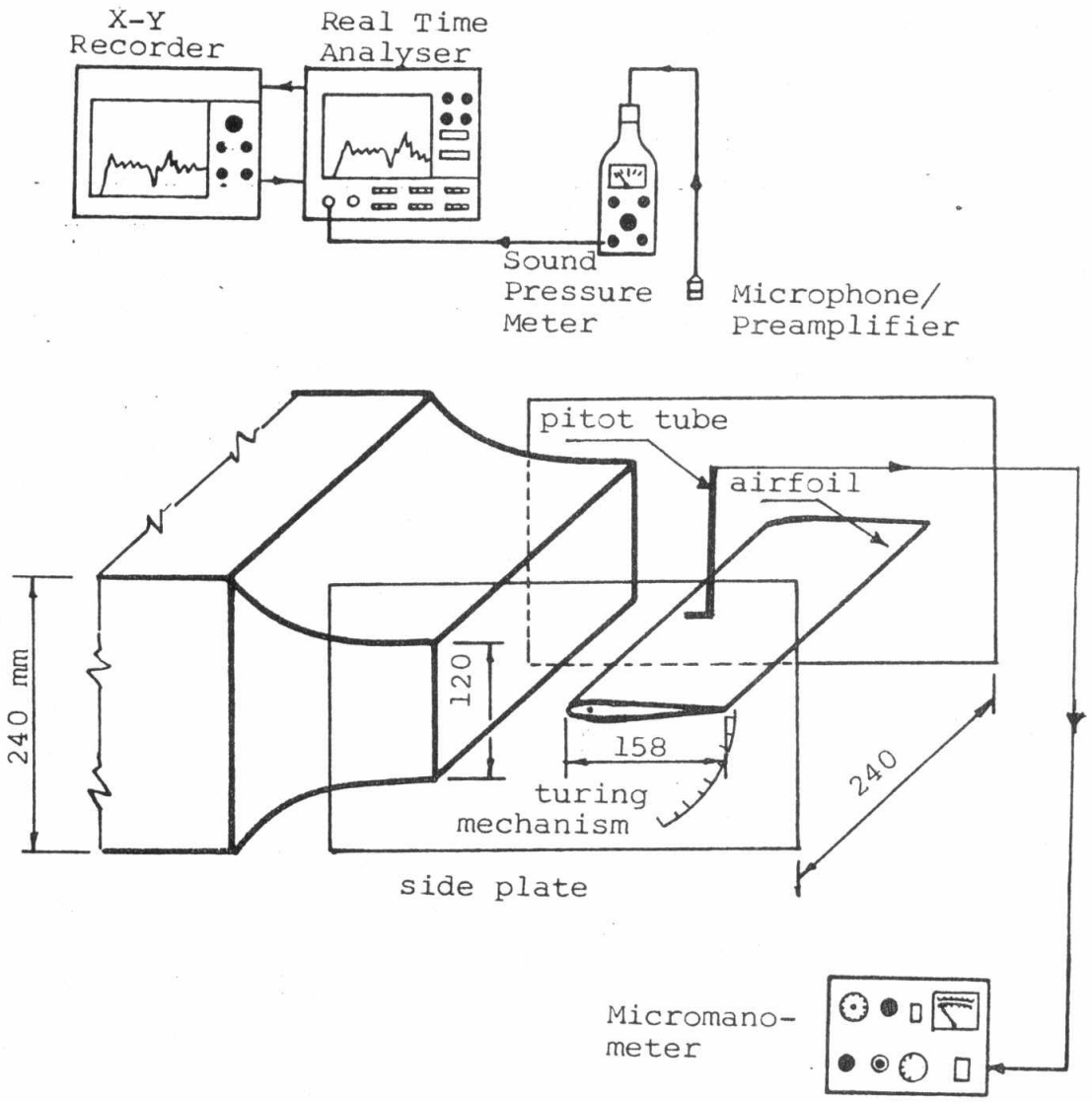



Fig. 1 Schematic diagram of measuring apparatus

of attack, the pressure distribution for both upper and lower surfaces are the same. However, with angle of attack $\alpha$ deg., the fluid accelerates very rapidly from the leading edge over the upper surface, the result is being a large negative pressure coefficient. The fluid then decelerates with increasing $C_p$ to the trailing edge. Over the lower surface, the fluid first accelerates but then flows at a roughly constant rate to the trailing edge. Thus there is a drag and lift forces produced by excess pressure on the lower surface and by suction pressure on the upper surface, with the latter having the greater effect.

The velocity profiles traverses across the flow in the boundary layers are carried out at several distances from the leading edge of the airfoil. The aim of such traverses is to obtain the transition zero at which the boundary layer changes from laminar to turbulent characteristics. The velocity traverses

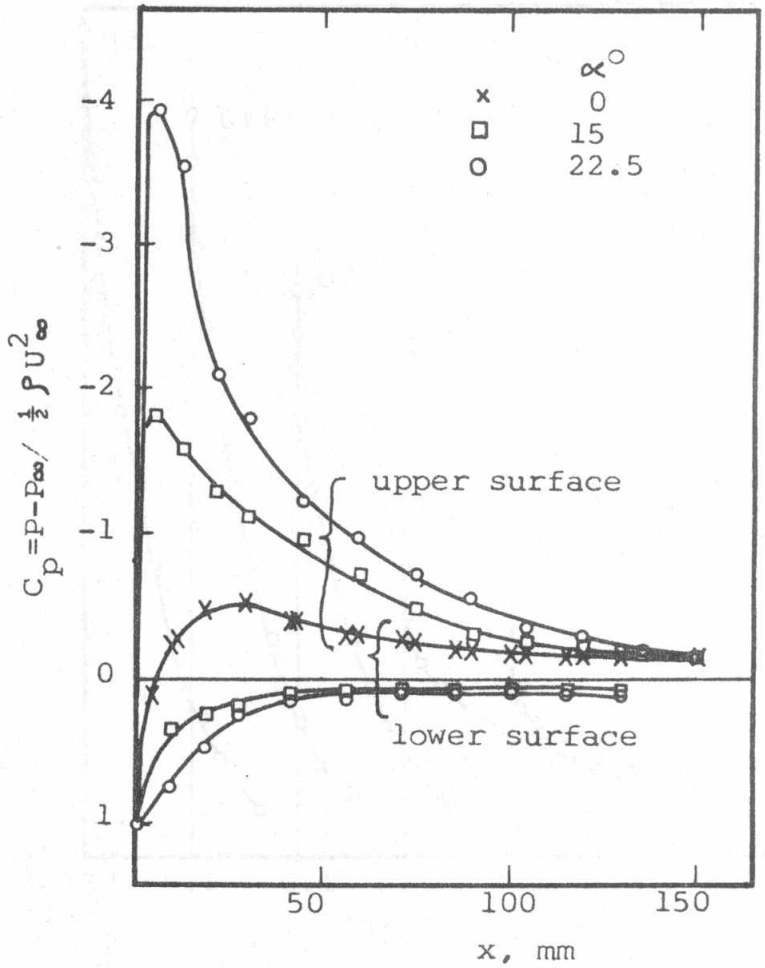



Fig. 2 Pressure distribution on upper and lower surfaces of airfoil

at angle of attack equal to zero are shown in Fig. 3. The boundary layer transition zone is shown to be at about 50 mm from the leading edge of the airfoil.

The above results are used to estimate the drag coefficient of the airfoil which is the sum of the friction-drag coefficient and the pressure drag coefficient

$$D = D_p + D_f$$

$$= \int P \, dA \sin\theta + \int \tau_o \, dA \cos\theta \qquad (1)$$

and the drag coefficient is given by

$$C_D = \frac{D}{\frac{1}{2} U_\infty^2 \rho A} \qquad (2)$$

For small angle of attack the drag coefficient due to friction

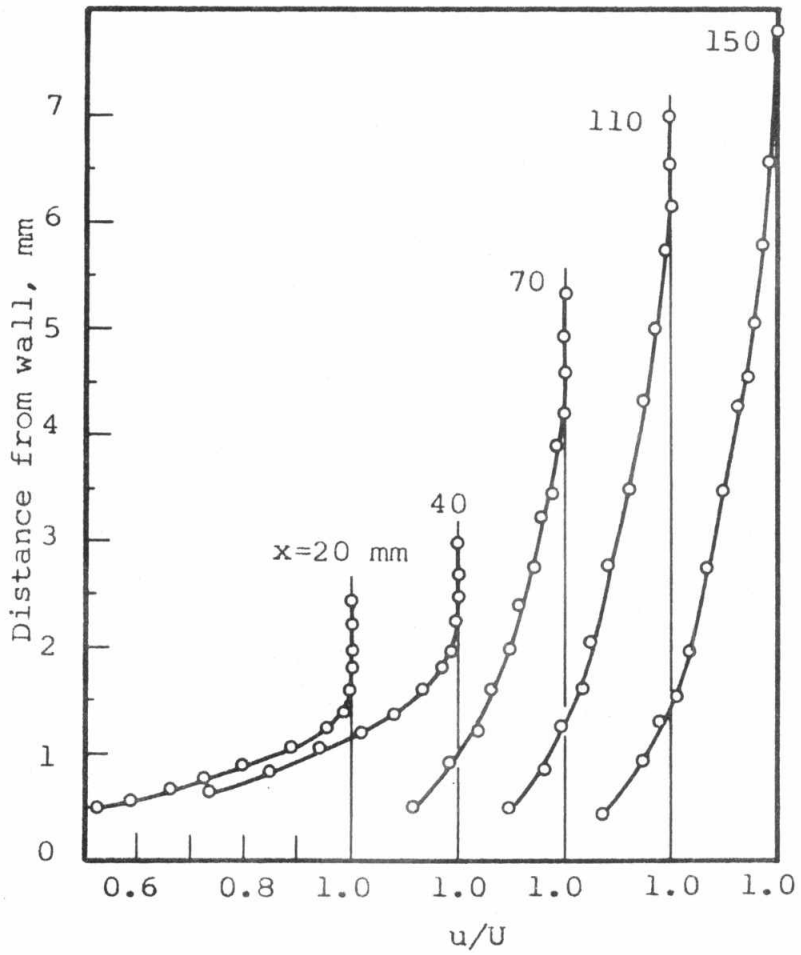



Fig. 3 Streamwise velocity profiles at $\alpha = 0^{\circ}$

is estimated according to the following relation [10] by which the boundary layer along the airfoil is divided into laminar and turbulent

$$D_f = \frac{\rho U_\infty^2 C}{2} \left[ \frac{0.455\ L}{(\log Re_L)^{2.58}} - \frac{0.074\ x_c}{Re_c^{\ 0.20}} + \frac{1.328\ x_c}{Re_c^{\ 0.50}} \right] \quad (3)$$

As the angle of attack increases, the transition point for laminar boundary layer moves forward, therefore the friction-drag coefficient is assumed to be calculated from the turbulent boundary layer on the pressure side using the first part of equation (2). This assumption is reasonable since the flow separates from the suction side of the airfoil as the angle of attack increases. This is associated with the increase of the pressure drag coefficient than that of the friction drag coefficient.

The airfoil noise caused by aerodynamic forces is generally a combination of discrete-frequency noise which attains peaks at

several frequencies. This noise is measured in terms of sound pressure level (SPL), in dB ref $2x10^{-5}$ N/m$^2$. Figs. 4 to 7 show the typical narrow, 1/3 octave and broad bands spectra of the noise for flow velocities of 3, 5, 8 and 10 m/sec respectively. Generally speaking, the SPL in terms of broad band level is reduced as the the outlet flow velocity from the nozzle is decreased. The flow velocity change of this extent do not bring about a remarkable change in the noise spectrum.

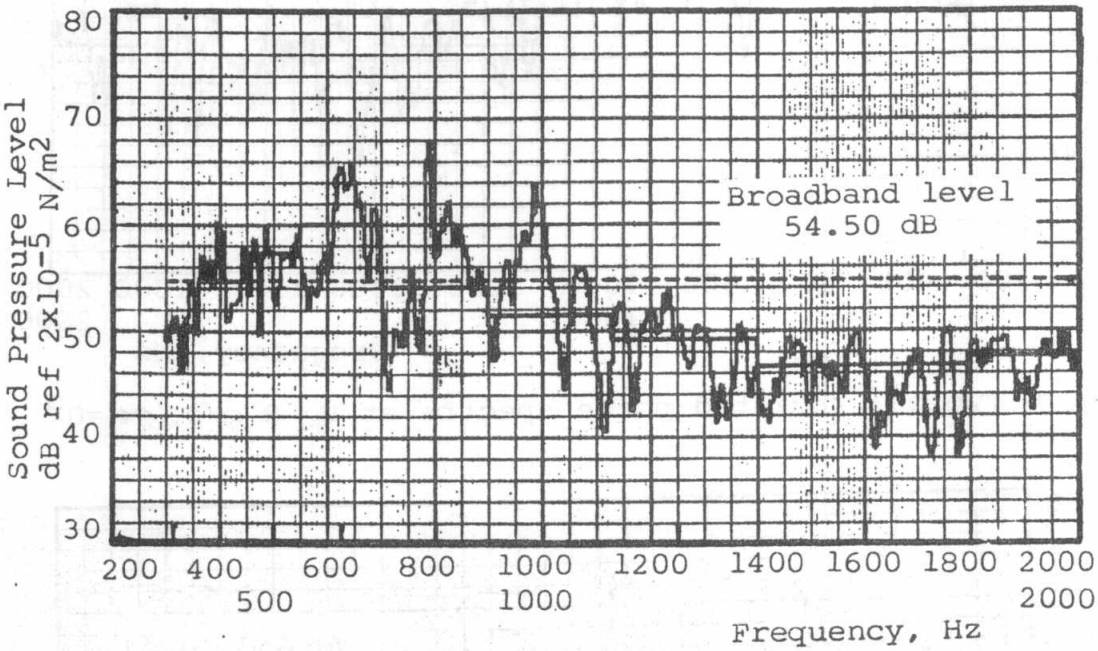



Fig. 4 Typical radiated noise spectra at U= 3 m/s, $\alpha = 0^{\circ}$

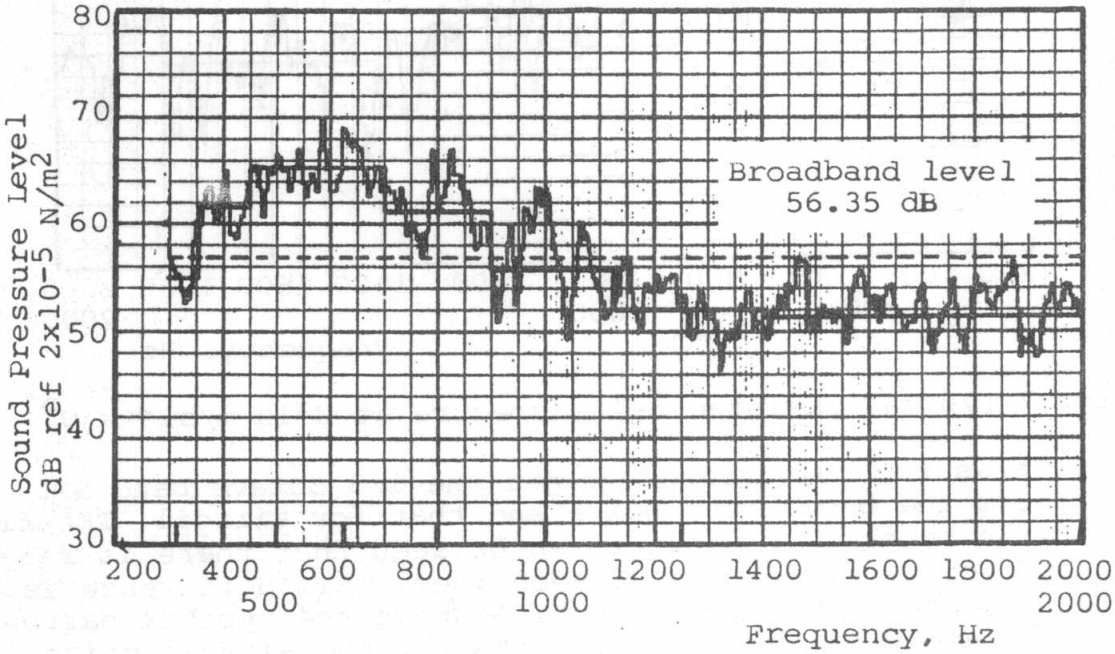



Fig. 5 Typical radiated noise spectra at U= 5 m/s, $\alpha = 0^{\circ}$

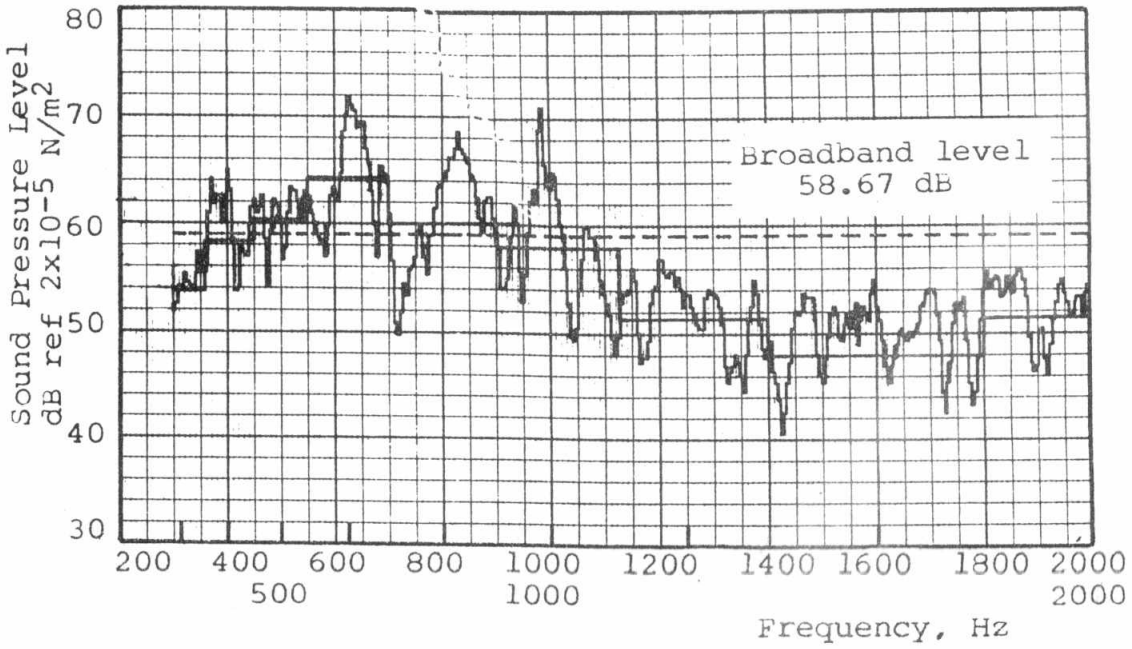



Fig. 6 Typical radiated noise spectra at U= 8 m/s, $\alpha = 0^{\circ}$

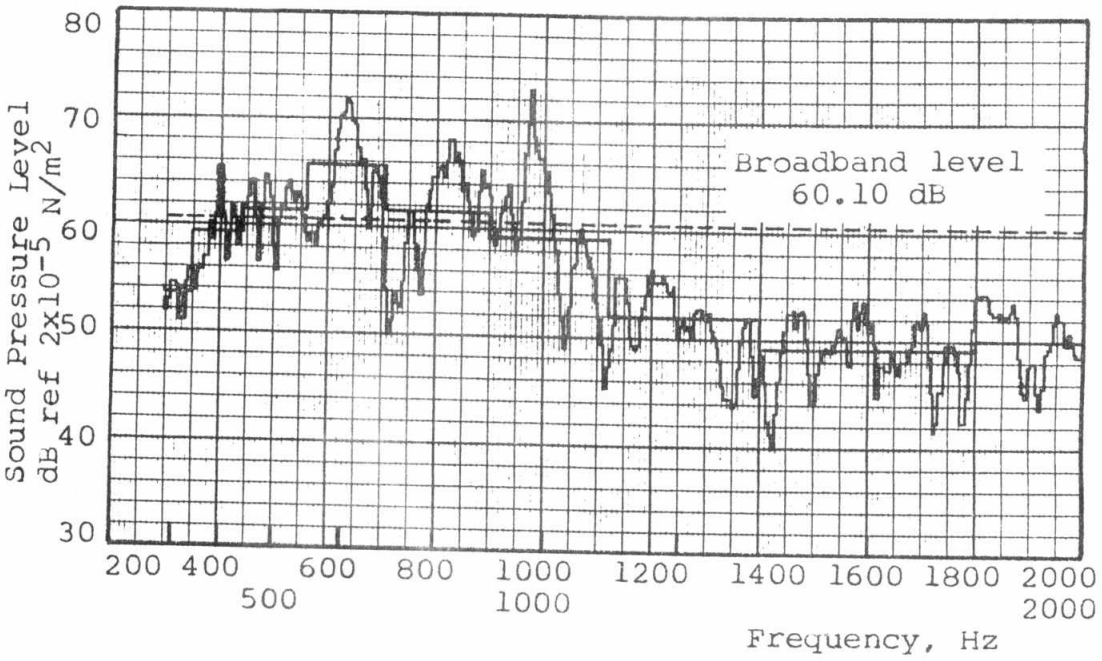



Fig. 7 Typical radiated noise spectra at U=10 m/s, $\alpha = 0^{\circ}$

Fig. 8 shows the comparison between the 1/3 octave band SPL spectra for the background noise and that for airfoil. The flow velocity is being 10 m/sec. It can be seen that there is relatively sufficient difference between them. This difference is estimated to be within 10 dB. Fig. 9 shows the typical narrow, 1/3 octave and broad band SPL spectra for the airfoil noise measured at flow velocity of 10 m/sec with angle of attack ($\alpha$) of 7.5 deg.

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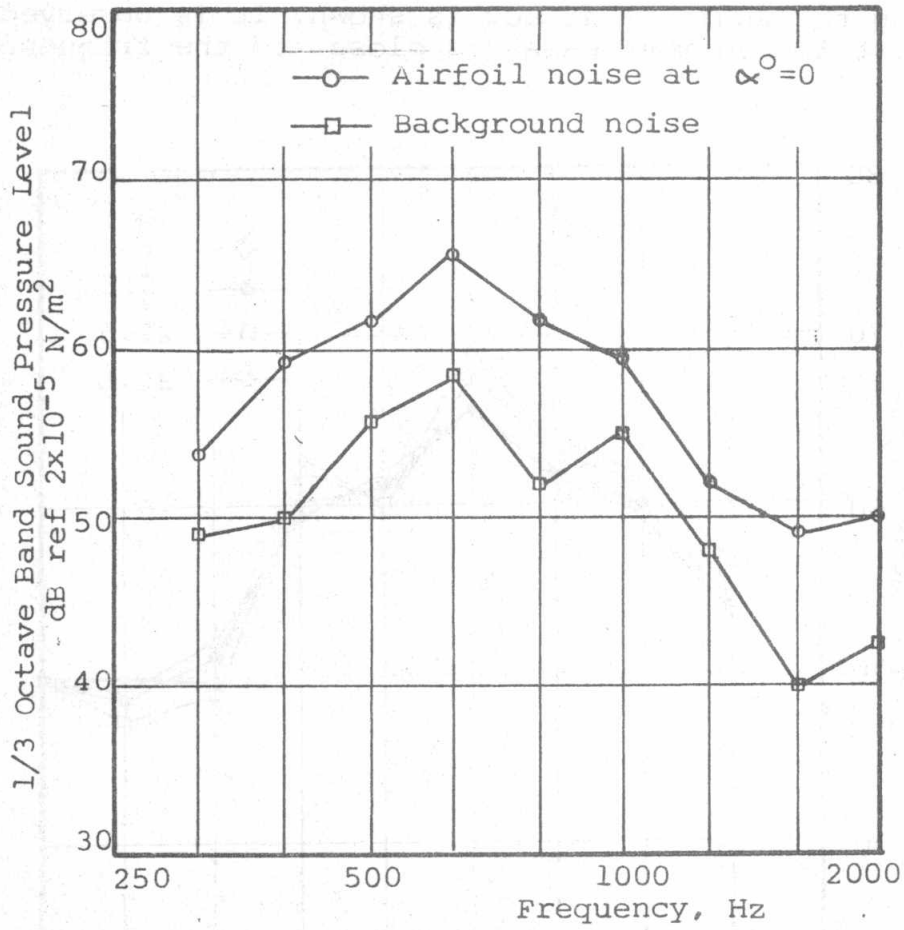


Fig. 8 Effect of background noise on airfoil noise at U= 10 m/s.

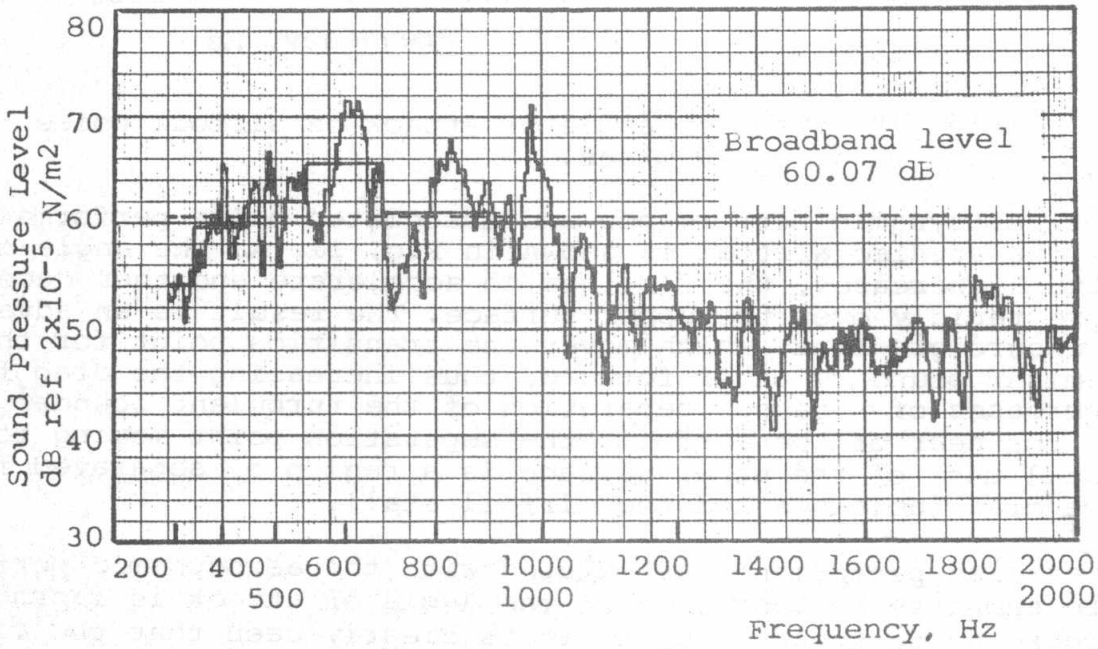


Fig. 9 Typical radiated noise spectra at U=10 m/s, $\alpha$ =7.5$^{o}$

In Fig. 10, the change in 1/3 octave SPL for the airfoil noise by changing the angle of attack is shown. It is observed that the hightest SPL in most cases is close to the frequency of 630 Hz.

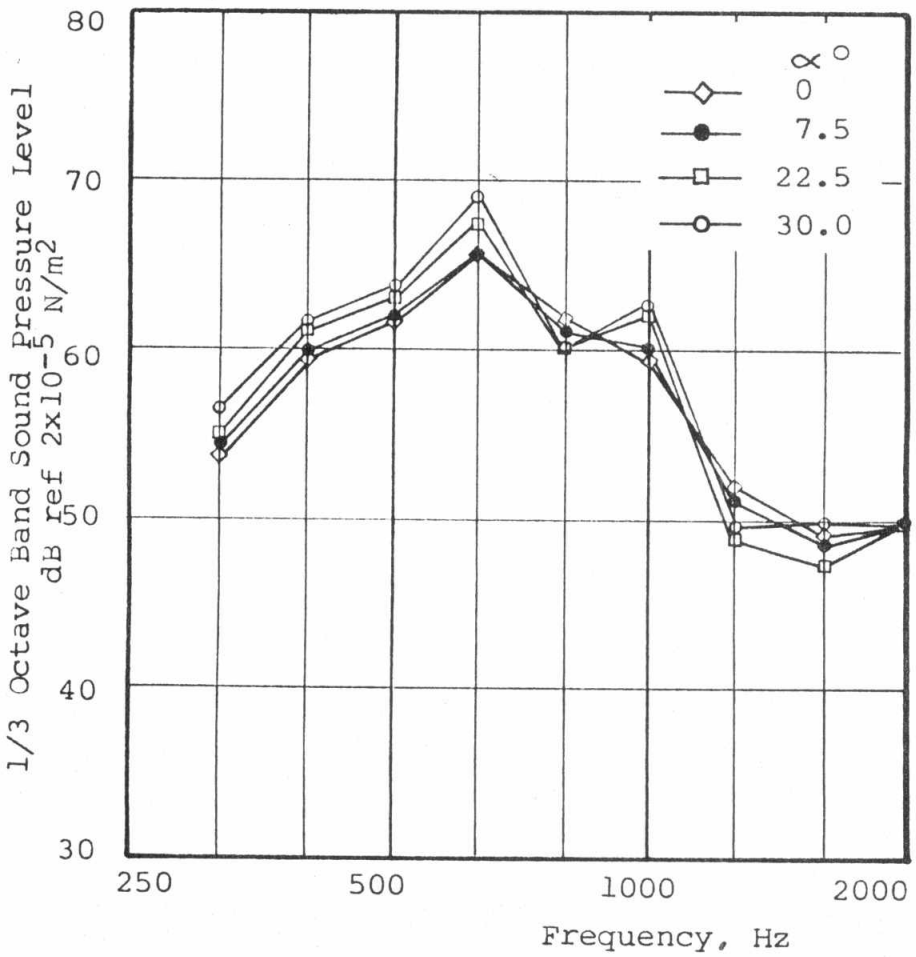


Fig. 10 Effect of angle of attack on airfoil noise at U= 10 m/sec.

The aerodynamic performance and associated noise performance of the studied airfoil is shown in Fig. 11. As the angle of attack increases, the flow has to accelerate and then decelerate more rapidly over the upper surface. The result is an adverse pressure gradient, which moves the transition point for the laminar boundary layer forward, thus increasing the drag, further increases of ∝ causes separation of the turbulent boundary layer at the near of the airfoil, the separation point moving forward until most of the upper surface is a region of separated flow. The drag increases and the airfoil stall.

The noise performance associated with the aerodynamic performance are shown to be increased as the angle of attack is increased. According to these results, it is clearly seen that the airfoil exhibits similar trends of aerodynamic and noise performance

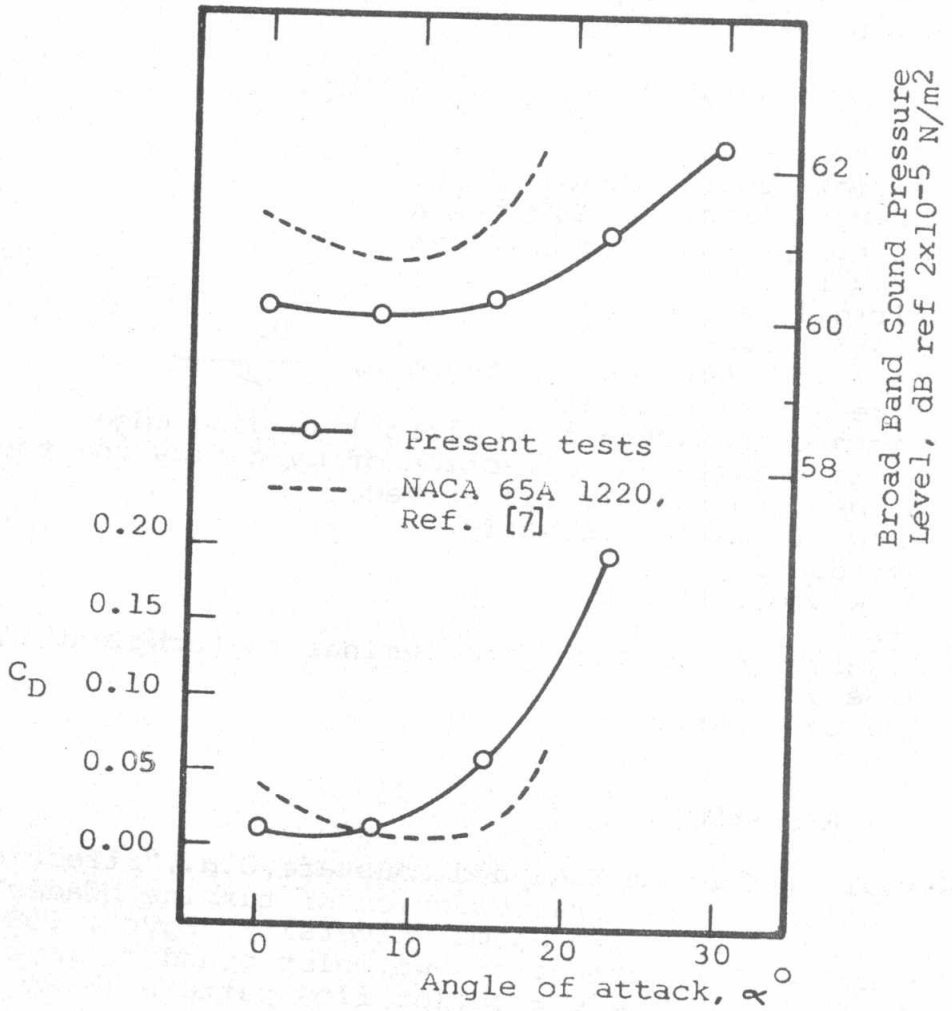


Fig. 11 Aerodynamic performance and aerodynamic noise.

with the angle of attack. These changes in aerodynamic performance and noise characteristics are shown also in Fig. 11 but for unsymmetric airfoil studied by Yanaguchi et al [7] . The obtained lowest level of noise is close to the point where the airfoil displays the minimum drag coefficient, i.e., to the point of best aerodynamic performance.

## CONCLUSIONS

1. Measurements aerodynamic performance of airfoil and its noise behaviour have been carried out at low flow velocities under different angle of attack.

2. The change in air flow velocity is shown to be associated with the change in noise specrum. Also, the noise level is increased as the angle of attack is increased.

3. The aerodynamic performance and noise characteristics have been presented the same trend. The obtained lowest level of noise is close to the point where the airfoil displays the best aerodynamic performance.

## NOMENCLATURE

| | |
|---|---|
| A | Surface area |
| C | Airfoil chord length |
| $C_D$ | Drag coefficient, $D/\frac{1}{2}\rho U_\infty^2 A$ |
| $C_p$ | Static pressure coefficient |
| D | Drag force |
| L | Airfoil length |
| P | Static pressure |
| $Re_x$ | Reynolds number at distance x, $\frac{U_\infty A}{\nu}$ |
| U | Free stream velocity |
| x | Distance measured from airfoil leading edge |
| $\theta$ | Angle between the direction of main flow and the tangent to the airfoil surface |
| $\nu$ | Flow kinematic viscosity |
| $\rho$ | Air density |
| $\tau_o$ | Flow shear stress |

Subcripts

| | |
|---|---|
| c | Transition distance from laminar to turbulent flow. |
| $\infty$ | Free stream |
| p | Due to pressure |
| f | Due to friction |

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