1. Introduction

Since micro-perforated panel (MPP) absorber has been put forward by Maa in 1975\textsuperscript{1}, which is getting increasingly applications in areas such as architecture acoustics\textsuperscript{2,3}, environmental noise abatement\textsuperscript{4} and acoustic window systems\textsuperscript{5}, but mostly used in motionless objects or environment. In the last couple of decades, with the number of aircrafts and airports rapidly growing to satisfy the requirements of passengers. Inevitably, this leads to a strong rise of the aircraft noise disturbing the neighborhood of airport. Thus, noise reduction of airplanes has become one major issue to airports and the design of future aircraft\textsuperscript{6}, making it necessary to develop new strategies to sufficiently reduce the emission of noise by airplanes.
One important noise mechanism is the interaction between boundary layer turbulence, which forms on the surface of the wings, with the airfoil trailing edge. It has long been recognized that airfoil trailing edge noise may be reduced by modifying the trailing edge geometry or material, such as the trailing edge serrations, brush-type trailing-edge and porous airfoils, all of which turned out to be effective means for airfoil noise reduction. Meanwhile considering the successful applications of MPP absorbers in various areas and some good examples of effective noise emission are in fighter cockpit and fan. A passive noise control system to some fighter cockpit by using Micro-perforated panel absorber has realized by Sun Yafei and the control effect was notable. In addition, Fang Kaixiang showed a sound reduction of fan model with holes up to 8 dB compared with the original fan in the middle-high frequency by numerical simulation. Therefore, it will be realizable and advisable to develop an innovative airfoil with the MPP absorber for trailing edge noise reducing.

In the following, a micro perforated airfoil is proposed, and the surfaces are punched with perforations in the range of several millimeters on single or both sides. The aerodynamic performance and acoustic properties of the perforated airfoils will be simulated with finite element method (FEM). Subsequently, the experimental setup in a small wind tunnel is described and the results are presented and analyzed. The intention of this study is the identification of the influence of the micro perforated airfoils on the sound reduction and the lift of airfoils that can be achieved compared to a non-perforated reference airfoil.

2. Validation of simulation condition

2.1 Physical model and computational grid

For simulation, the original airfoil model is done in Pro/E, which has a 40mm chord length (c) and a 220mm span (L) as illustrated in figure 1(a, b) and a perforated airfoil with some parameters of the perforation diameter d, the distance between centers of adjacent perforations b, as shown in figure 1(c). The numerical solutions are conducted on four cases which are airfoils with surface perforation on single or both sides and the base airfoil. Then these models are imported in Workbench for meshing.

![Airfoil model](image)

**Figure 1.** Airfoil model.

2.2 Turbulence model validation boundary conditions

For the current research, the standard k-ε model was chosen for the validation studies. The “standard” k-ε model is a two-equation model which was developed by Launder and Spalding in 1974. In this model, the eddy viscosity is computed based on the turbulence kinetic energy k, and the turbulence dissipation rate ε via the turbulent viscosity relation:
\[ \mu_f = C_c \rho \frac{k^2}{\varepsilon}. \] (1)

Where \( C_c \) was obtained using experiments and computer optimization with a standard value of 0.09\(^{19}\).

And Transport Equations for the standard k-\( \varepsilon \) Model are\(^{20}\):

\[ \frac{\partial (\rho k)}{\partial t} + \frac{\partial (\rho U_j k)}{\partial x_j} = \frac{\partial}{\partial x_j} \left( \frac{\mu_t}{\sigma_k} \frac{\partial k}{\partial x_j} \right) + \rho (P + G) - \rho \varepsilon. \] (2)

\[ \frac{\partial (\rho \varepsilon)}{\partial t} + \frac{\partial (\rho U_j \varepsilon)}{\partial x_j} = \frac{\partial}{\partial x_j} \left( \frac{\mu_t}{\sigma_\varepsilon} \frac{\partial \varepsilon}{\partial x_j} \right) + C_{1\varepsilon} \frac{\varepsilon}{k} \rho (P + G) \left( 1 - C_{3\varepsilon} R_j \right) - C_{2\varepsilon} \rho \frac{\varepsilon^2}{k}. \] (3)

In these equations, \( P \) is the production of turbulent kinetic energy due to shear, \( G \) is the production of turbulent kinetic energy to buoyancy, \( \hat{R}_j \) is the flux Richardson number, \( C_{1\varepsilon} \), \( C_{2\varepsilon} \), \( C_{3\varepsilon} \) are constant.

In this study the flow is assumed to be steady, incompressible and 2D, the inlet of computational domain is velocity and the outlet is pressure.

### 3. Acoustic results

Considering the effects of inlet velocity of fluid and punching position on airfoil noise, different surfaces were chosen to perforate respectively, as listed in table 1. And the simulation were performed for different flow velocities \( \nu \) (10, 20, 30, 40, and 50m/s) at a 0-deg angle of attack.

#### Table 1. Four kinds of airfoil structures chosen for simulation.

<table>
<thead>
<tr>
<th>No. of airfoil</th>
<th>Airfoil structure</th>
<th>Hole arrangement</th>
<th>( d )(mm)</th>
<th>( b )(mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Base airfoil</td>
<td>4*6</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>upper-surface perforation airfoil</td>
<td>4*6</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>lower-surface perforation airfoil</td>
<td>4*6</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>4</td>
<td>upper-lower-surface perforation airfoil</td>
<td>4*6</td>
<td>2</td>
<td>6</td>
</tr>
</tbody>
</table>

(a) \( \nu=20\)m/s

(b) \( \nu=30\)m/s
Simulations of sound pressure level (SPL) versus frequency for each set of structures were made with ACTRAN Acoustics at different velocities of flow, as shown in figure 2 (a), (b), (c) and (d), the results are analysed in one-third-octave band spectra.

The effects of noise reduction of the lower-surface perforation airfoil is the most remarkable than other airfoils as presented in figure 2. It also indicates the noise performance is closely related to flow speed. Therefore the parameter should be taken into account in designing perforated airfoils structure to reduce noise in actual situation. In order to show the noise performance of each airfoil structure more significantly, figure 3 indicates the overall dB (A) value ($I_A$) under different speeds. It is calculated by the equation, namely

$$I_A = 10 \times \lg \sum_{i=1}^{n} \left[ 10^{-0.1 \times (p_i + \Delta a_i)} \right]$$

(4)

Where $p_i$ is the SPL of each of the center frequency of one-third-octave band, and $\Delta a_i$ is the SPL attenuation value of A-weighting at the corresponding center frequency.

The $I_A$ of base airfoil increases with an increasing flow velocity, but the slope of the curve of perforated airfoil is changed in 20m/s and 40m/s as displayed in figure 3. Comparing the lower-
surface perforation airfoil and base airfoil, the noise reduction value can up to 20dB over the whole range of frequencies. For the shape of the perforated airfoil changed significantly, the effect of perforation on the airfoil lift should be noted in the research.

4. Aerodynamic performance analysis

![Model of lower-surface perforation airfoil and pressure nephogram.](image)

**Figure 4.** Model of lower-surface perforation airfoil and pressure nephogram.

![Simulation results of the perforated airfoils.](image)

**Figure 5.** Simulation results of the perforated airfoils.

Figure 4(a) gives the wind tunnel simulation of the lower-surface perforation airfoil, and the pressure nephogram was obtained from the simulation as observed in figure 4(b). The influence of the perforation on the aerodynamic properties of the airfoils shall be characterized here by the simulated lift ($F_l$). When the velocity increases from 10m/s to 50m/s, the value grows from 0.1N to 2.1N and the four curves were found almost to be similar in figure 5(a), please note that figure 5(b) was the relationship between $F_l$ and velocity squared, which is linear and consistent with the following equations:

$$F_l = \frac{1}{2} \rho v^2 s c_l.$$  \hspace{1cm} (5)

Where $\rho$ is the air density, $v$ is the flow speed, $s$ is the wing area and $c_l$ is lift coefficient.

The influence of the holes on the lift of airfoils is rather uninvolved, however, it has a positive effect on the magnitude of SPL. In order to validate the conclusion, the lift of airfoil mock-ups (see
figure 6(a)) is measured in a wind tunnel (see figure 6(b)). The flow velocity is from 5m/s to 35m/s at a 0-deg angle of attack. Experimental data are given in figure 7. For comparison, simulation results are shown in both figures, which basically corresponds with the conclusion of testing. Figure 7 also illustrates the lift force of perforated airfoils changing with varying flow speed, which is consistent with the simulation data. This is probably caused by the flow of air through the perforation from the pressure to the suction side of the airfoils. Here in, the holes has little impact on lift of the airfoils.

![Figure 6. Airfoil for testing and wind tunnel](image)

![Figure 7. Testing results of the perforated airfoils](image)

### 5. Conclusion

Three perforated airfoils were chosen to model and simulate, the aeroacoustic and aerodynamic simulation results reveal that noise reduction depends on the velocity, furthermore, lower sound pressure level could be achieved while without sacrificing the aerodynamic performance of the airfoils by punching holes at the airfoil surface. In a wind tunnel, the aerodynamic parameter is measured which shows the value of the lift force increases with an increasing flow speed and the influence of the holes on the lift of airfoils is rather uninvolved, which gives a good agreement with the simulation.

Both the aeroacoustic and the aerodynamic results encourage further simulation and experiments with optimized parameters of punch perforations and even scaling down the perforation diameter $d$ to micros. This work will become our future research focus and direction, especially the optimization of parameters of micro-perforated panel on the surface of the wing.
ACKNOWLEDGEMENTS

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REFERENCES

