

# DIRECT NUMERICAL SIMULATION OF SELF-NOISE OF AN INSTALLED CONTROL-DIFFUSION AIRFOIL

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## 1. INTRODUCTION

Recent improvements have led to a strong reduction of tonal noise in rotating machines. Broadband noise contribution is therefore becoming more and more important. One of the main broadband noise source is the sound produced at the blade trailing edges. Even in undisturbed incoming flows, the boundary layer development on any lifting surface generates pressure fluctuations and vorticity distortions that diffract at the trailing edge and produce acoustic waves.

Many numerical studies have tried to analyze the flow around airfoils to isolate the trailing-edge (TE) noise mechanisms. In the present study the compressible flow around a controlled diffusion (CD) airfoil is investigated in a full anechoic open-jet facility. The chord based Reynolds number of the configuration is  $1.5 \times 10^5$  and the Mach number is 0.05, characteristic of low speed fan systems. This configuration has become an excellent test case for trailing-edge noise as extensive aerodynamic and acoustic data have already been obtained both experimentally and numerically [1-4]. In the present study, the trailing edge noise sources of the CD airfoil and their propagation in the anechoic wind tunnel are simulated in a single step for the first time, using the Lattice Boltzmann Method (LBM) implemented in the PowerFlow solver 4.3a.

## 2. NUMERICAL METHODOLOGY

The LBM solves the time and space evolution of a discrete particle distribution function on a lattice grid. The method is naturally transient and compressible, and has been successfully applied to aeroacoustics problems at similar Reynolds number [5,6].

As shown in [3], the open-jet facility has a major effect on the flow around the airfoil. Therefore the jet shear layers are also simulated in the present computational domain. Moreover the high Reynolds number of the flow based on the airfoil chord length and the turbulent transition on the airfoil surface that is triggered by a thin laminar recirculation bubble at the leading-edge, require a very fine mesh achieving DNS resolution in the vicinity of the airfoil. Cell sizes are  $15 \mu\text{m}$  on the profile surface achieving a dimensionless wall distance  $y^+$  of 1 on the airfoil. The mesh has 640 million cubic elements or voxels. The simulation has been initialized by a 2D field which has been duplicated in the span-wise direction. The computation has been run on 512 processors Intel Xeon X5560 @ 2.80GHz for 255 hrs to simulate 15 through-flow times, statistics are acquired on the last 10 through-flow times. Further details of the numerical methodology are provided in [7].

## 3. RESULTS

### 3.1. Flow field around the airfoil

An instantaneous velocity field around the airfoil in the region achieving DNS resolution is shown in Fig. 1. At the leading edge a laminar recirculation bubble appears. Close to the reattachment point a turbulent boundary layer develops. When the curvature changes, the adverse pressure gradient leads to an increase of the boundary layer thickness. At the trailing edge, the laminar boundary layer coming from the pressure side destabilizes into a small vortex-shedding. This Von Karman street then interacts with the fully turbulent vortical structures coming from the suction side turbulent boundary layer.



Figure 2. Instantaneous velocity field.

### 3.2. Mean flow analysis

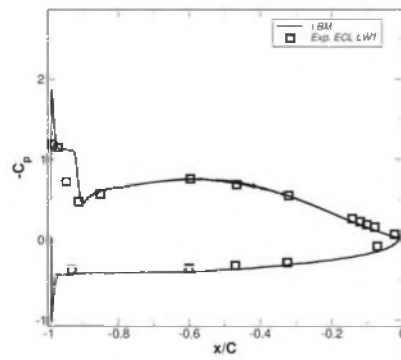


Figure 2. Mean pressure coefficient along airfoil

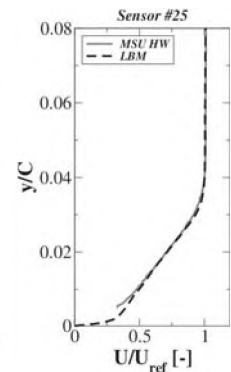


Figure 3. Mean boundary layer profile before the trailing-edge

The mean pressure coefficient along the airfoil is in excellent agreement with the experiments as shown in Fig. 2. Compared to previous incompressible LES results [4], this LBM simulation, due to the finer resolution at the surface, provides a closer agreement with experiment, especially the favorable pressure gradient after the reattachment point is well captured. The boundary layer

evolution along the suction side is also well predicted especially at the last location near the trailing as shown in Fig. 3. This is a key point to precisely predict the trailing-edge noise mechanism.

### 3.3. Unsteady flow analysis

The instantaneous contours of dilatation, provided in Fig. 4, show the acoustic waves propagation around the airfoil. The main acoustic source is the TE, which radiates as a dipole source. The non compactness of the source can be seen by the cardioid radiation pattern in the anechoic room (more radiation toward the leading edge). The waves reflect on the corners of the nozzle lips. As in the NACA12 study of [8] a secondary source, at higher frequency (closer wave fringes) appears on the suction side, near the leading edge, close to the reattachment point of the recirculation bubble.

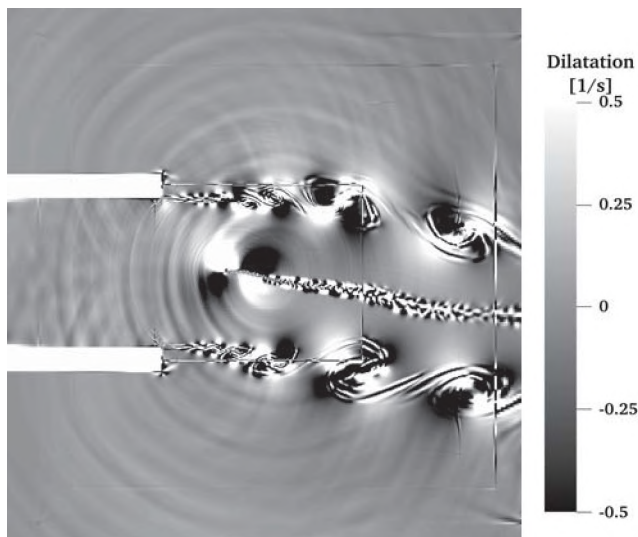


Figure 4. Instantaneous dilatation field in the anechoic chamber.

The wall pressure spectral density near the trailing-edge of the profile provides an excellent agreement with experimental data [8]. A better frequency roll-off is even predicted than in previous incompressible LES.

The acoustic radiation at 90° with respect to the main flow direction is compared to experimental measurements recorded at 2m from the profile in Fig.5. The simulation captures the correct levels above 200 Hz. The noise decay at high frequency is not seen in the measurements as the background noise in the anechoic room is reached.

## 4. CONCLUSIONS

Both trailing-edge noise and fully resolved turbulent flow have been numerically investigated with a Lattice Boltzmann Method on the installed Controlled-Diffusion airfoil at a high Reynolds number based on the chord length of  $1.5 \times 10^5$  including the wind tunnel environment. The present study focuses on the configuration at 8° angle of attack, and is compared to experimental data.

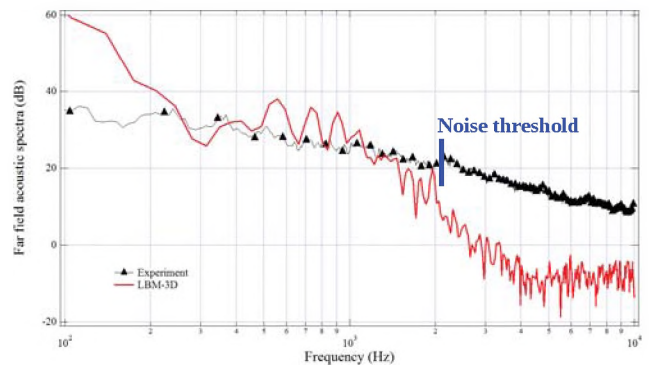


Figure 5. Sound pressure levels at 90° and 2m from the airfoil.

The laminar recirculation bubble at the leading-edge of the CD profile has been successfully captured by simulating the full jet width of the mock-up and using a DNS resolution in the vicinity of the profile. This laminar recirculation triggers a turbulent transition of the boundary layer on the suction side. Turbulent structures are scattered at the trailing-edge as non-compact sources of the self noise mechanism. Mean pressure loading on the airfoil and mean boundary layer profiles are in good agreement with experiments. The noise propagation is directly simulated by the LBM in the full computational domain, thanks to a fine discretisation.

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