

Diffraction and refraction effects in trailing-edge noise free-jet experiments

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Self-Noise Background

The reliable measurement of airfoil self-noise in open-jet wind-tunnel experiments requires to make the investigated model airfoil as independent as possible of the nozzle providing the necessary air flow and to include it in a large quiet environment. The wind tunnel has to ensure both a low background noise and a low residual turbulence level (<1%). Furthermore, the far-field microphones are located away from the air stream tube to avoid measurement problems and control the accuracy of the experimental acoustical data. All the above criteria tend to show that a free-jet anechoic wind tunnel provides the best experimental compromise. One such a facility is the ECL low-speed anechoic wind tunnel shown in fig. 1. In this set-up, a thin cambered CD airfoil developed by Valeo is placed in the potential core of the nozzle jet between two side plates connected to the nozzle lips. The latter mock-up shown in fig. 1 is equipped with sets of flush-mounted Remote Microphone Probes (RMP) [1] measuring the wall-pressure field both along the streamwise direction at mid span and in the spanwise direction at the trailing edge. These probes provide the mean and fluctuating pressures which characterize the trailing edge noise sources whereas the far field microphone measures the emitted sound simultaneously. Similar measurements have been repeated with a NACA12 airfoil and a flat plate. In [2], several flow regimes obtained by varying the angle of attack were identified for the CD airfoil. The transition between the different regimes was shown to strongly depend on the jet width impinging on the airfoil [3]. Indeed, the airfoil load causes a flow deflection due to the induced lateral momentum injection.

In parallel, an analytical model has been derived that provides the fan self-noise from a statistical description of the wall pressure field near the blade trailing edge [2,4]. More precisely, the power spectral density (PSD) of the far-field pressure S_{pp} is related to the power spectral density of wall pressure fluctuations close to the trailing edge ϕ_{pp} , a spanwise correlation length, l_y , and an acoustical radiation integral, $|I|^2$. The latter is derived analytically. According to the theory, the true airfoil shape can be assimilated to a flat plate and the measured quantity $S_{pp}/(\phi_{pp} l_y)$ must be an invariant. Yet, as shown in [2], remaining discrepancies up to 5 dB between measured and predicted values can be attributed to directivity accidents coming from the experimental set-up.

Jet-Width Effect

The mean flow deflection [3] is an important issue as most experiments are devoted to a comparison with numerical

computations (LES simulations of [5, 6] for instance) often assuming that the airfoil is embedded in an infinite flow. Up to that point the net effect of the wind-tunnel flow deflection is a modified load on the airfoil with respect to the expected value for the same angle of attack [7]. Similarly the turbulent boundary layer growth is affected and the induced sources of aerodynamic noise at the trailing edge are modified. As a result the comparison with LES may fail if the installation effect is not accounted for in the computations. A minimum requirement is to match the mean pressure coefficient on the airfoil as accurately as possible, rather than the angle of attack.

Wind-Tunnel Scattering Effects

The other effects are of acoustical nature. One is the scattering of the noise emitted by the airfoil at the nozzle lips. It is more severe in the upstream direction because trailing-edge noise is known to radiate preferentially upstream as frequency increases. This has been verified in a flow regime with Tollmien-Schlichting (TS) waves in the unstable laminar boundary layers formed on an airfoil with negligible mean loading. In this case an almost perfect spanwise coherence is observed at the TS wave frequency. The radiated field has been computed using the SYSNOISE software with and without the nozzle, a dipole source being put at the airfoil trailing edge (fig. 2). The diffraction effect is defined by the difference between both computations. It has been reintroduced in the analytical calculations to compare with the measurements. As shown in fig. 3, the diffraction effect is indeed responsible for an additional lobe. The resulting good agreement validates the analytical model.

The second acoustical effect is related to sound refraction at the shear layers encountered on the installation. The acoustic wave fronts propagating in the flow are deviated when crossing the shear layer separating the flow from the quiescent air where the microphone is located. In [8], a correction for this effect is derived assuming a perfectly thin shear layer. The correction is applied in most wind-tunnel measurements referred to in the literature. However, if the measurements are to be compared with analytical modeling based on wall-pressure input data, the sound refraction in the airfoil boundary layers, generally ignored, must be accounted for too. Combined refraction effects at both layers tend to cancel each other, at least at high frequencies. This results in just a displacement of the apparent acoustic source with no necessary angular correction.

Conclusion

The combined effects of the jet width and the set-up scattering can be significant in any self-noise experiment and they must be accounted for in any comparison with theoretical or numerical results.

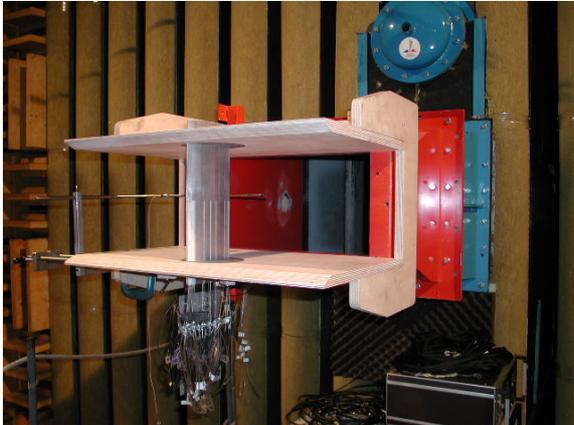


Figure 1: Experimental set-up in the open-jet anechoic wind tunnel at ECL, showing the instrumented airfoil and horizontal side-plates.

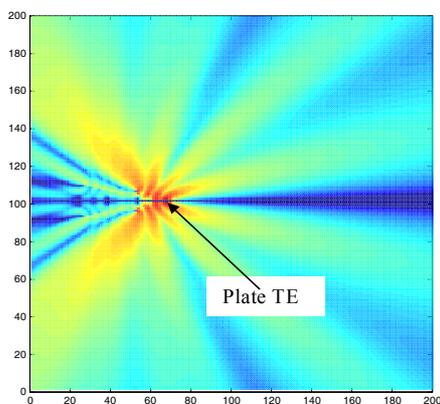
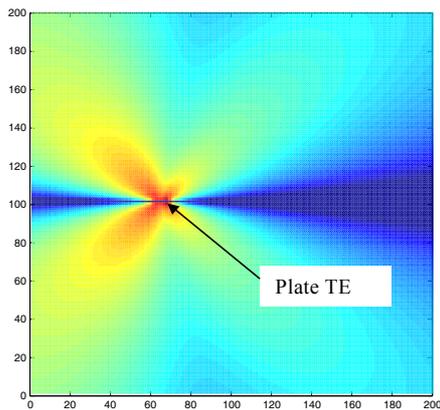


Figure 2: Computed trailing-edge noise directivity patterns in mid-span plane for a flat plate: free field (top); nozzle scattering included (bottom); $k c = 4.88$. Flow from left to right.

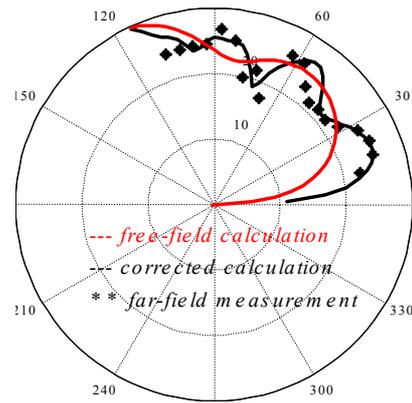


Figure 3: Measured directivity of a Tollmien-Schlichting tone on a NACA 0012 airfoil at zero angle of attack compared to theoretical results assuming free-field and corrected for nozzle scattering. dB-scale ; $k c = 4.88$ (k wavenumber, c chord length).

References

- [1] "Aerodynamic Noise of a Two-dimensional Wing with High Lift Device," S. Pérennès, and M. Roger, AIAA98-2338 paper, July 1998.
- [2] "Trailing Edge Noise Measurements and Prediction for Subsonic Loaded Fan Blades," M. Roger, and S. Moreau, AIAA2002-2460 paper, Breckenridge, June 2002, *Accepted for publication in the AIAA Journal (2004)*.
- [3] "Effect of Airfoil Aerodynamic Loading on Trailing Edge Noise Sources," S. Moreau, and M. Roger, AIAA2003-3177 paper, Hilton Head, May 2003, *Submitted for publication in the AIAA Journal*.
- [4] "Towards Airfoil Self Noise Prediction using Wall-pressure Statistics from LES and an analytical Acoustic Model," M. Roger, and S. Moreau, Annual Research Briefs-2002, Center for Turbulence Research, Stanford Univ./NASA Ames Research Center, 2002.
- [5] "Trailing Edge Noise Prediction Using Large-Eddy Simulation and Acoustic Analogy," E. Manoha, B. Troff, and P. Sagaut, *AIAA Journal* **38**(4), pp. 575-583, 2000.
- [6] "Computation of Trailing-Edge Flow and Noise Using Large-Eddy Simulation," M. Wang, and P. Moin, *AIAA Journal* **38**(12), pp. 2201-2209, 2000.
- [7] "Analysis of Flow Conditions in Free-Jet Experiments for studying Airfoil Self-Noise," S. Moreau, M. Henner, G. Iaccarino, M. Wang, and M. Roger, *AIAA Journal* **41**(10), pp.1895-1905, 2003.
- [8] "Refraction of Sound by a Shear Layer," R.K. Amiet, *J. Sound Vib.* **58**(4), pp.467-482, 1978.