Aeroacoustic study of a wavy stator leading edge in a realistic fan/OGV stage

Damiano Casalino[1], Francesco Avallone and Daniele Ragni
Delft University of Technology

Long Abstract

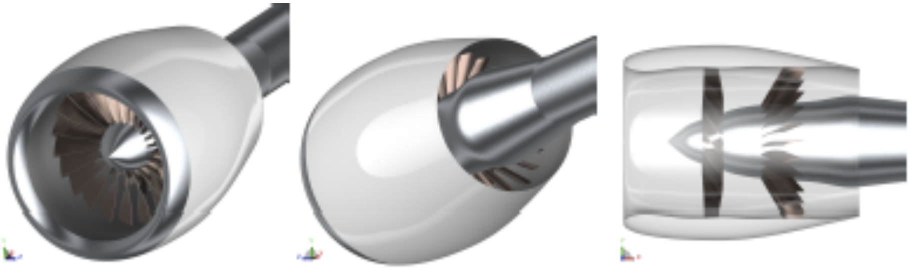
Introduction

The effect of a sinusoidal serration applied to the leading-edge of the vanes of a realistic fan stage is investigated using a high-fidelity numerical simulations. The CFD solver PowerFLOW based on a hybrid Lattice-Boltzmann (LB), Very Large Eddy Simulation (VLES) model is used. The 22-in Source Diagnostic Test (SDT) fan rig of the NASA Glenn Research Center is used as a reference [1]. The computational setup has been extensively validated for the baseline fan/OGV stage (without serration) using wind-tunnel flow and acoustic measurments by NASA. Previous studies in fact have shown that PowerFLOW is able to capture the influence of variations of the OGV configuration on the overall noise levels with an accuracy of less than 1 dB [2]. In the present study the so-called Low-Noise OGV configuration at approach conditions is used as a reference. This configuration consists of 22 fan blades and 26 swept vanes. It is one of three variants of the SDT experimental campaign. Compared to a 54 radial vanes baseline configuration, the Low-Noise OGV results in a lower broadband noise radiation due to the combined effect of lower vane count and sweep angle. However, a conterrotating duct mode of circumferential mode order -4 is cut-on at the first blade passage frequency, and results in a strong far field tonal radiation. The interest of considering the Low-Noise OGV in the present study is therefore to investigate the effect of leading edge serration on both the broadband and tonal noise radiation. Detailed flow analysis are performed in proximity of the leading edge in order to scrutinize the effects of the leading edge serration on the interaction between vortical structures and the blades.

Remark: In the following, an overview of the available numerical results for the Low-Noise OGV configuration is provided. At the current stage of the activity, the numerical simulation for the Wavy Stator Leading Edge (WSLE) OGV is not available. Computational studies of this kind are perfromed on a regular basis and requieres about one week for the CFD computation and one week for the post-processing of the results. We are therefore very confident in the possibility to complete the numerical study in the time due for the final version of the paper.

1. Fan stage configuration and operating condition

Fig.(1) illustrates the Low-Noise configuration of the SDT fan rig. The geometry is perfectly axisymmetric. In order to reproduce the stinger employed in the experiment, a cylindrical prolongation of the centerbody has been added to the CAD model provided by NASA. The rotor radius is 0.2786 m, the bypass exhaust radius is 0.2710 m and the lip intake radius is 0.2962 m.The rotor is constituted of 22 blades with a casing/blade-tip gap of about 0.5 mm. The stator consists of 26 swept blades.



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[1] D.Casalino@tudelft.nl
Aerodynamics, Wind Energy, Flight Performance and Propulsion (AWEP) Department Building 62, Kluyvenweg 1, 2629 HS Delft, The Netherlands.

Figure 1: *Reference SDT Low-Noise configuration*

Among five values of the rotational speed tested by NASA, we consider in this work the one corresponding to the "approach condition" with a fan rotational speed of 7808 RPM. This corresponds to a rotational tip Mach number of 0.669 and a Blade Passage Frequency (BPF) of 2862.93 Hz. The ambient conditions are set to a temperature of 288.15 K and a pressure of 101325 Pa. The engine operates at zero incidence in a free-stream of Mach number 0.1. The Reynolds number based on average conditions in the interstage and the midspan rotor blade chord is 0.8 million.

2. Computational setup

The same computational setup used in Ref. [2] is adopted in the present study. A sketch of the computational setup is shown in Fig.(2) . The rotor and the spinner are encompassed by a volume (red) that defines the rotating mesh region. The center body is extended with a solid cylinder. As in the experiments, no primary jet is included in the simulation. The green surface depicts the location of the interstage hot-wire measurements, which have been performed by NASA, referred to as station #1. The Ffowks-Williams and Hawkings (FW-H) integration surface is shown in the right image (orange). It is used to compute the acoustic far-field and it consists of three parts: a spherical sector around the intake, a cylindrical connector and a conical surface in the exhaust region. The cone is opened at its downstream extremity in order to avoid contamination of the acoustic signals due to integration of jet shear-layer hydrodynamic fluctuations. The downstream extension of the cone is however sufficient to recover the bypass duct radiation over the angular range of interest.

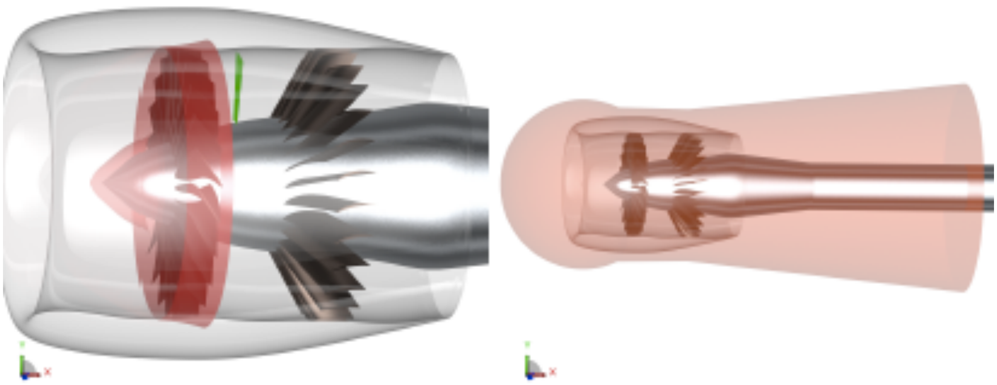

Figure 2: Computational setup of the reference SDT Low-Noise configuration

3. Flow results

The unsteady flow solution in the stage has been validated by comparing hot-wire measurements at station #1 with the numerical results for a baseline OGV configuration (radial vanes). A subset of the results is presented in Fig.(3) where the narrow-band spectra of the three components of the velocity spectra are compared to the hot-wire measurements. Both broadband and tonal components are accurately predicted. Since the rotor and the computational setup are the same for the Low-Noise OGV, it is reasonably expected that the same accuracy is achieved for the present study.

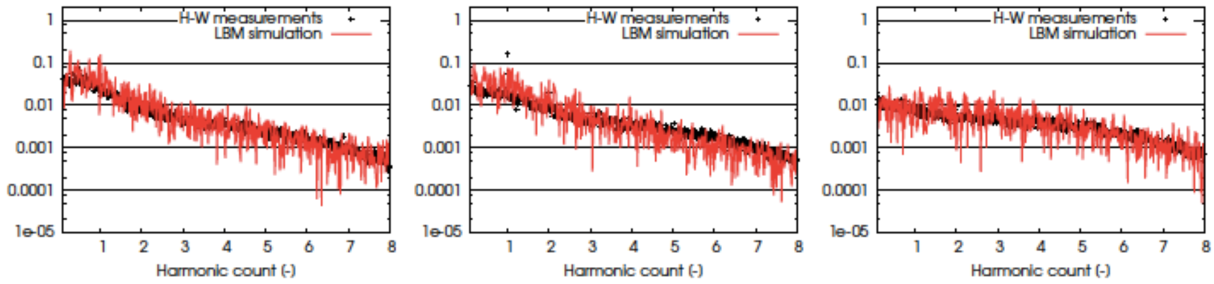

Figure 3: Velocity spectra at station #1 and r/R=98.97%. Axial, radial and azimuthal velocity in the left, middle and right columns, respectively (in m/s). Comparison between hot-wire measurements (symbols) and PowerFLOW.

4. Acoustic results

Far-field noise results have been validated by comparing the Overall Sound Pressure Level (OASPL) measured along a sideline linear array and to source Power Level Results derived by perfroming an integration of the acoustic intensity flux on a sphere surroinding the engine, both for the simulation and the expriments. In order to show the capability of PowerFLOW to capture the effect of OGV changes on the radiated noise, results are shown for the three available OGV configurations. Fig.(4) show absolute levels. OASPL is overpredicted by about 3 dB along the complete arc, whereas the PWL spectra exhbit a slight underestimation. This is quite unexpected, since both results are obtained from the same pressure signals at the microphone locations. We guess an inconsistency of the spectral analysis applied to the numerical and experimental data. Fig.(5) illustrates the same quantities but in terms of differences with respect to the baseline OGV. The relative accuracy is clearly below 1 dB. Interestingly, the Low-Count and Low-Noise OGVs are characterized by the presence of a strong tone at BPF1 that is also quite well preidcited by the numerical simulation.

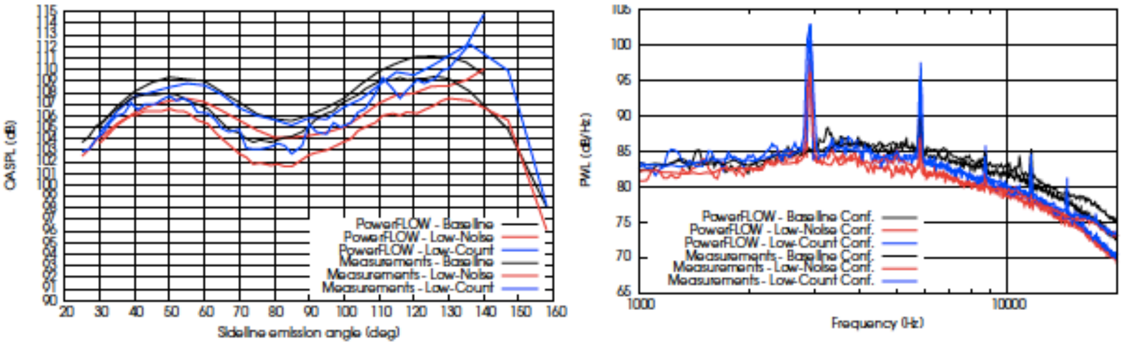

Figure 4: absolute OASPL (left) and PWL (right) for three variations of the SDT OGV.

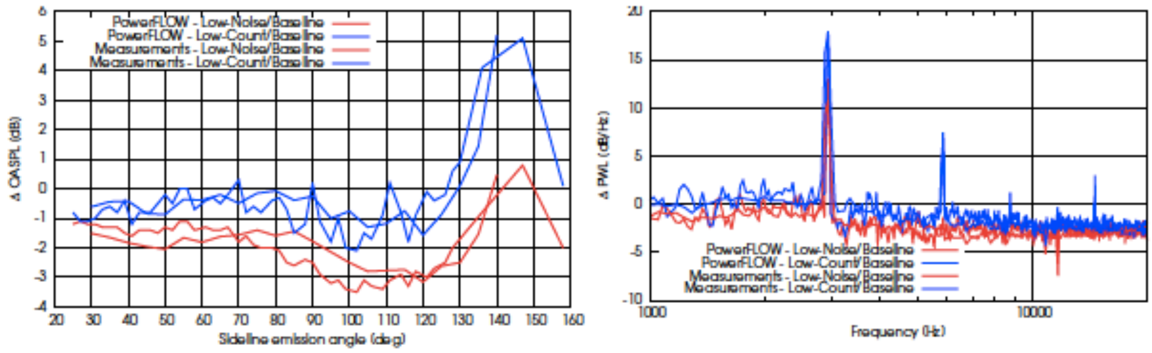

Figure 5: relative OASPL (left) and PWL (right) for three variations of the SDT OGV.

References

[1] Woodward, R.P., Hughes, C.E., Jeracki, R.J., and Miller, C.J., "*Fan Noise Source Diagnostic Test – Far Field Acoustic Results*," AIAA-2002-2427, 2002.

[2] Casalino, D., Hazir, A., and Mann, A., "*Turbofan Broadband Noise Prediction using the Lattice Boltzmann Method*", AIAA-Paper 2016-2945, 2016.