Prediction of Fan Broadband Noise including rotor shielding effects and swirling mean flow effects in a lined annular duct

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1. Context of the study:

The acoustic signature of present high bypass ratio engines can be dominated by turbomachinery noise at approach condition and even sometimes at cut-back condition. This turbomachinery noise is mainly caused by the interaction of the fan wake with the downstream Outlet Guiding Vanes (OGV) yielding both tonal and broadband noise. To decrease or eliminate some of this sound, the engine nacelle is often lined upstream and downstream of the fan-OGV system. Yet in future Ultra High-By-pass Ratio (UHBR), the nacelle will become even shorter limiting the possibility of lining upstream of the fan. For this reason, engine manufacturers are considering including liners between the fan and the OGV. The present study must then include the effect of the liner on the noise generated on the OGV.

A detailed analytical model of fan broadband noise caused by both the interaction of ingested turbulence with a fan rotor blades and the rotor-wake impingement on downstream stator vanes was proposed by Posson et al. [1-3]. It is based on a strip theory and a formulation of the three-dimensional unsteady blade loading for a rectilinear cascade caused by the impingement of three-dimensional vorticity waves accurately describing the impinging turbulence or the rotor wakes. This three-dimensional cascade response applied in each strip combined with an acoustic analogy in an annular duct in a uniform axial flow (Goldstein’s analogy) yielded the upstream and downstream broadband acoustic power spectral densities. The model was compared with NASA’s experimental Source Diagnostic Test (SDT) fan rig results for two OGVs at approach condition, showing a very good agreement upstream, whereas an underestimate of 3-5 dB was observed downstream in the middle frequency range [3].

Yet, the rotor-stator noise propagating upstream of the stator is partially transmitted and partially blocked by the rotor before radiating outside the engine inlet. Posson & Moreau [4] proposed again an analytical model for the rotor scattering based on a strip theory and a formulation of the three-dimensional unsteady blade loading for a rectilinear cascade caused by the impingement of acoustic waves [5]. Specific treatment is introduced to address the behavior around the cut-on frequency of the duct modes both in the noise generation and in the noise scattering. The acoustic power spectral densities and the sound pressure levels at the duct wall were studied for the NASA SDT test case. The rotor scattering was then shown to be a potential source for the downstream under prediction mentioned above. Finally, a simple effect of the
swirl between the rotor and the stator was considered using a Doppler shift in frequency. It was shown to have a strong effect.

The effect of swirling mean flow and liner was then studied in detail by Posson and Peake. First they derived an extension of Ffowcs-Williams & Hawkings’ acoustic analogy in a medium at rest with moving surfaces, of Goldstein’s acoustic analogy in a hardwall circular duct with uniform mean flow (used in the above initial model) to a swirling mean flow in an annular rigid duct, and derived the associated tailored Green’s function [6]. The acoustic analogy has been applied in the context of fan trailing-edge broadband noise (or fan self-noise) [7]. Second, this work has been extended to account for lined walls [8], namely, an acoustic analogy in an annular duct with liner and swirling mean flow has been derived together with the tailored Green’s function, extended Rienstra & Tester’s Green’s function in an annular duct with uniform mean. Again, a rotor trailing-edge noise model accounting for both the effects of the annular duct with lined walls and the swirling mean flow was developed and applied to a realistic fan rotor with different swirling mean flows (and as a result different associated blade stagger angles). The swirling mean flow was again found to have a strong effect on the absolute noise level. The overall liner insertion loss was little changed by the swirl in the studied cases.

The aims of the proposed PhD thesis are twofold. First it aims at developing a tool to predict the rotor-stator interaction noise accounting for the effect of the swirl, lined interstage walls and rotor shielding effect. The stator shielding effect may also be introduced in an additional step. Second, it aims at enhancing the understanding on the role of the interstage liner and its link to the swirl, the geometry and source content.

It will extend the study of swirling mean flow and liner to the wake-interaction noise mechanism. The shielding effect of the rotor will also be introduced in this context. The general sketch of the rotor shielding effect with the swirling effect in the interstage is shown in Figure 1 (the rotor blades and stator vanes are represented by cascades of flat plates). A specific investigation on the liner behavior with swirl will be performed. The final goal will be to provide a complete semi-analytical model that will combine all effects that will become important in a UHBR configuration, and to compare with available data (SDT and Airbus). Comparisons with direct LES computations will also be performed. A particular attention will be put on the speed of the code and asymptotic formula will be considered at high frequencies. Moreover a parametric study will be achieved on the different parameters of UHBR fans (diameter, rotor-stator distance for instance).

References:


2. Preliminary statement of work:

This PhD thesis aims both at

A) Developing a tool to predict the rotor-stator interaction noise accounting for the effect of the swirl, lined interstage walls and rotor shielding effect. The stator shielding effect may also be introduced in an additional step.
B) Enhancing our understanding on the role of the interstage liner and its link to the swirl, the geometry and source content