A first step towards a parametric model for fan broadband and tonal noise

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Motivation

Engine noise is a major concern for the design of future environmentally friendly civil aircraft. As a result the integration of acoustics into the design process - the so called „design-to-noise“ approach - motivates the development of noise prediction tools for the assessment of future aero-engines. This paper presents a first step of a study aiming at developing a tool for fan noise prediction. It is the theoretical continuation of a previous experimental study presented by the authors in ref. [1].

Introduction to the prediction tool

Figure 1 presents the three approaches utilized by the scientific community to develop new engines: experiments, numerical computations and prediction tools. Prediction consists in decomposing the global system - the engine - into elementary sub-systems, which are described by simple models capturing the relevant physical mechanisms. The behaviour of the global system is obtained through the assembling of the sub-systems. The use of simplified models allows for markedly reduced computation time, which in turn makes it possible to perform an integrated evaluation of the global system.

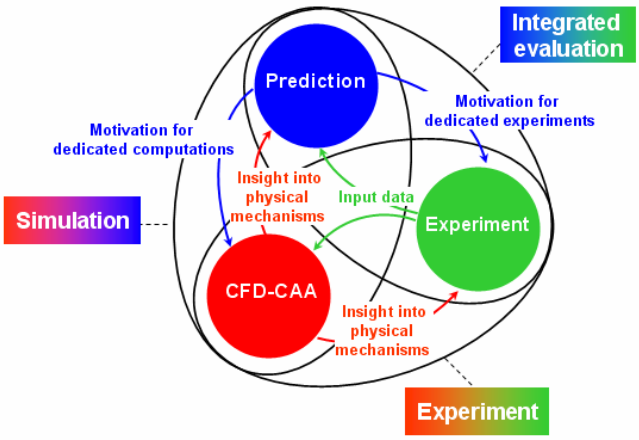

Figure 1: Research strategies for the design of future engines.

Compared to the fan noise model developed previously by Heidmann [2], the investigation of various fan configurations (high-bypass-ratio fan, contra-rotating fan, open rotor) will be possible. The present tool is structured by distinctive modules that can be exchanged and modified depending on the fan configuration investigated. The input data needed for noise generation are modelled and directly related to the aerodynamic parameters. Moreover, an advanced description of the sound field through duct modes will enable the assessment of liner performance and of sound transmission through blade rows.

Description of the fan noise model

As shown in Figures 2 and 3, the tool is structured in separate modules for noise generation, propagation and radiation. Several noise sources are taken into account. Preprocessing modules (“steady aero.” and “unsteady aero.”) provide the acoustic models with aerodynamic input data.

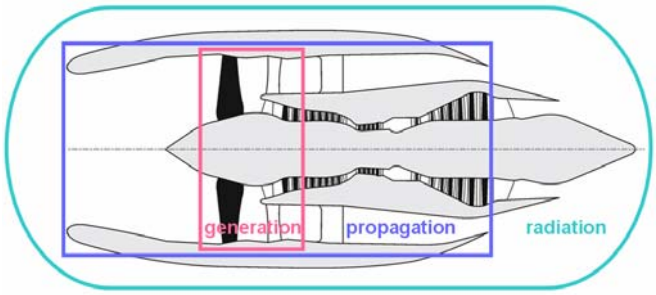

Figure 2: Typical turbofan engine in use on civil aircrafts.

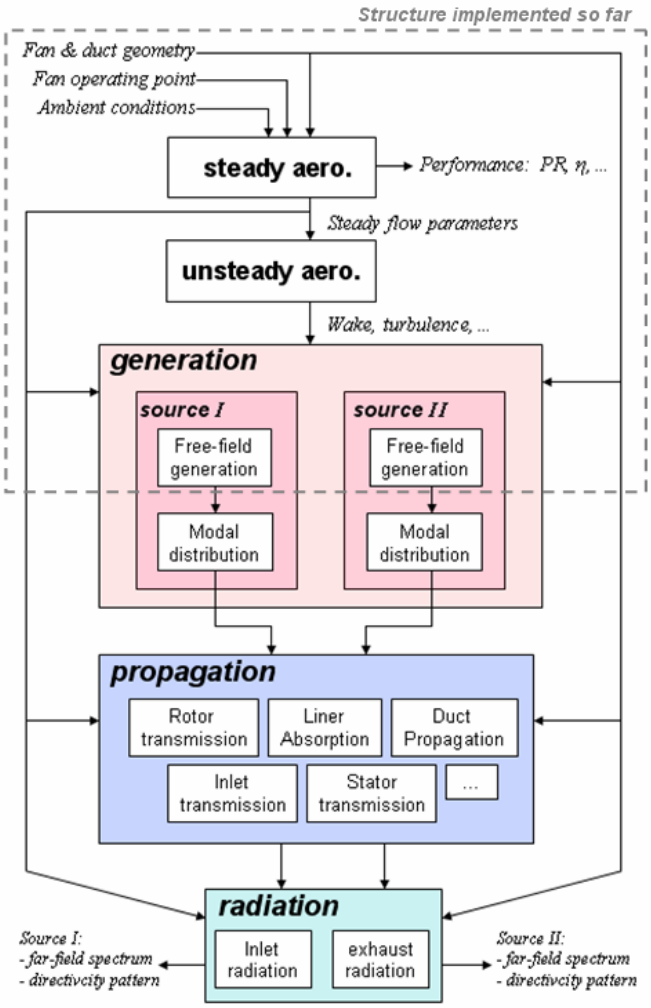

Figure 3: Structure of the DLR fan noise prediction tool.

Some details on the noise model are now given. The flow velocity fluctuations cause the sound generation and therefore are relevant inputs for the noise model. The velocity fluctuations are derived from the steady flow velocities computed at the duct mean radius. Noise generation is computed using a free-field single airfoil model derived from Amiet´s theory [3]. Scattering effects due to blade rows and duct walls are not considered. The only source modelled here is the rotor-stator interaction noise: the wakes of rotor blades impinge onto stator vanes and generate tonal noise at the harmonics of blade passing frequency and broadband noise. This source is known to be the dominant noise generation mechanism for subsonic fans of modern aero-engines. Formulae for the tonal sound power and for the broadband power spectral density are given in equations (1) and (2), respectively.

$$P(h) = a \cdot V \cdot \rho_0 \cdot c_0^3 \cdot S \cdot [k \cdot c]^2 \cdot [M_0^2 \cdot G(\sigma)]^2 \cdot \left[\frac{u_{per}}{U_0}(h)\right]^2 \quad (1)$$

$$\frac{dP}{dSt}(St) = b \cdot V \cdot \rho_0 \cdot c_0^3 \cdot S \cdot [k \cdot c]^2 \cdot [M_0^2 \cdot G(\sigma)]^2 \cdot \left[\frac{u_{turb}}{U_0}(St)\right]^2 \quad (2)$$

a, b: empirical coefficients
St: Strouhal number
h: harmonics of the rotor blade passing frequency
k: acoustic wave number
S: duct section area at stator station
V, c: stator vane count, stator vane chord length
$G(\sigma)$: compressible Sears function (see ref. [3] and [4])
σ: Sears non-dimensional frequency
ρ_0, c_0, M_0, U_0: air density, sound speed, Mach number and velocity magnitude of stator inflow
u_{turb}, u_{per}: turbulent and periodic wake velocities of stator inflow

First results

A simulation was performed for a generic conventional fan with subsonic tip speed. The simulated fan aerodynamic and noise maps are shown in Figures 4 and 5. Relating both maps is part of the "design-to-noise" approach. Figure 6 presents noise spectra for the three colored points identified in Figure 5.

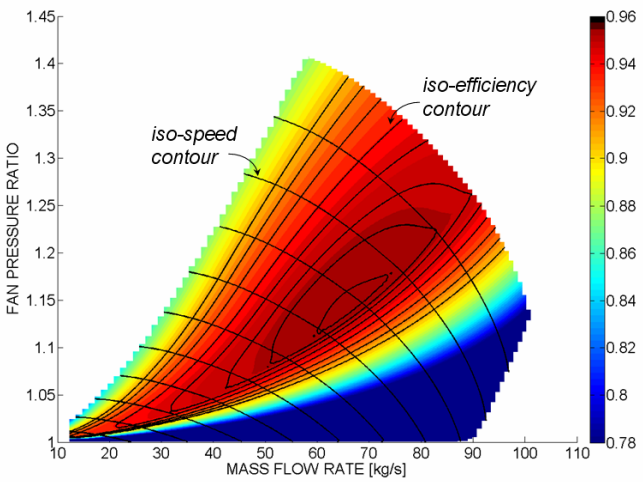

Figure 4: Map of fan aerodynamic efficiency.

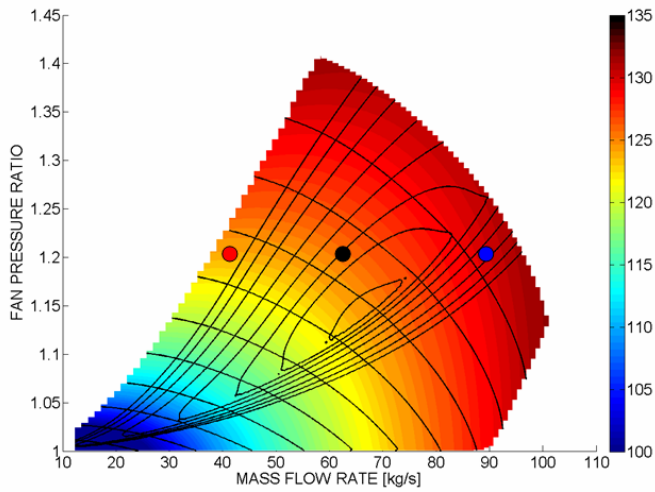

Figure 5: Map of broadband noise level (colorbar in dB).

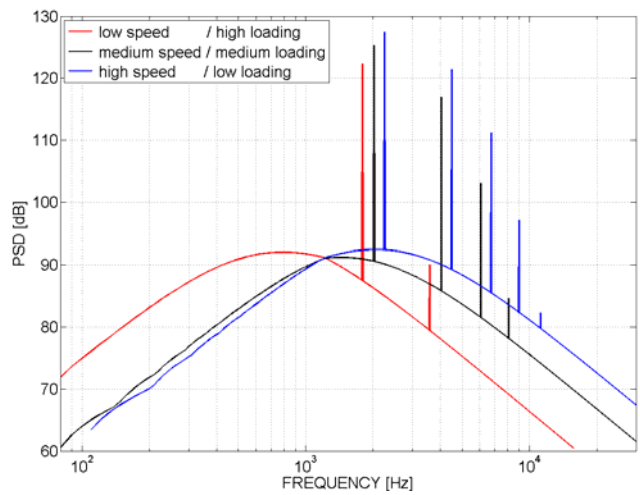

Figure 6: Fan noise spectra at various operating points.

Conclusion

The first version of a new prediction tool for fan noise has been implemented and tested. This tool will be dedicated to the assessment of future engine concepts (contra-rotating fan, open rotor,…). Based on the realistic results obtained so far, the aerodynamic and noise models will be more accurately calibrated by means of experimental data. Duct propagation and radiation will also be modelled.

Literature

[1] Moreau, A., Enghardt, L., Bodén, H.: On the relation between broadband noise and fan aerodynamic performance. Fan Noise Conference., Lyon, 2007.

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