Optimization of casing contours in an aero-engine fan stage with emphasis on rotor—stator interaction noise.

Long Abstract

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Introduction

Continuous efforts are being made to improve the performance of aero-engine fans. As new designs get closer to the aerodynamic optimum, reductions in noise emission become less pronounced and must rely on incremental steps that need to be carefully assessed in a multi-disciplinary context.

The present study focuses on the aerodynamic and acoustic impact of an axisymmetric modification of the outer-casing contours in the vicinity of the fan rotor tip. The noise generated in relation to the tip region of a fan is governed by various mechanisms and sources. Here, we concentrate on the contribution of the rotor tip flow to the rotor—stator interaction noise, both tonal and broadband components.

A hybrid theoretical approach has been chosen to assess and optimize the impact of the casing contours. This approach combines the calculation of the steady mean flow and the statistically-averaged turbulence from a RANS simulation with an analytical fan noise model. The objective of the paper is to show on that particular application if significant noise reductions can be achieved along with an improved aerodynamic performance.

1. Methods

Modern computational capabilities make it possible to explore a vast design space based on realistic simulations and automated optimization. The process chain applied in the present study results from a joint development within the DLR Institute of Propulsion Technology.

The Department of Fan & Compressors has acquired a substantial experience in the domain of aerodynamic design and multi-disciplinary optimization [1]. The basic in-house tools supporting this are the RANS flow solver TRACE [2] and the optimization framework named AutoOpti, which combines evolutionary, gradient-based, and neural-network strategies to locate rapidly optimal members in the design space.

The prediction tool PropNoise developed in the Department of Engine Acoustics consists of a number of analytical models dedicated to several fan noise broadband and tonal sources [3]. As shown in Figure 1, this tool exists in a stand-alone version and in a RANS-informed one, which is the mode adopted for the study. In the RANS-informed version, the flow quantities are extracted and pre-processed prior to PropNoise to feed the acoustic models [4].

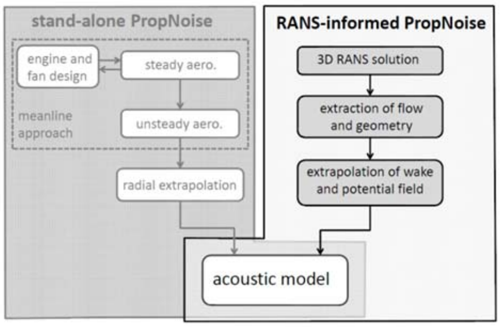

Figure 1. Structure of the acoustic prediction tool

The optimization is conducted by AutoOpti, whereby TRACE and PropNoise deliver the aerodynamic and acoustic cost functions for each calculated member, respectively.

2. Preliminary study : characteristics of the baseline fan

The application selected for the study is the so-called UFFA fan owned by the company AneCom AeroTest GmbH and kindly shared with the project partners. The fan is composed of a 20-blade rotor and 44-vane bypass stator. The fan stage generates a pressure ratio around 1.5 for a relative tip Mach number of 1.2 at design conditions.

This section will focus on the description and analysis of the main acoustic characteristics of the baseline geometry of the fan in terms of broadband and tonal interaction noise (see Figure 2). In particular, the relative importance of the tip region will be detailed.

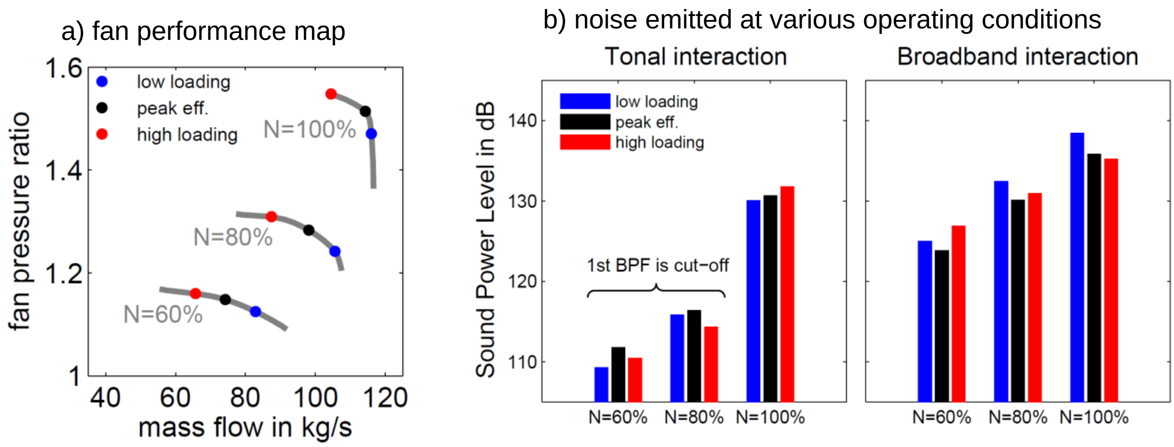

Figure 2. Assessment of the baseline fan performance a) and acoustic characteristics b)

3. Optimization of the casing contours

The shape of the axisymmetric casing contour will be modified in the vicinity of the rotor tip trailing edge, as shown exemplarily in Figure 3. The modification of the casing contour affects the mass flow distribution [5] and may locally enhance flow acceleration to decrease the magnitude of the pressure gradient that the blade and wall boundary layers have to sustain. Moreover, the contour may affect positively the tip vortex, by reducing the turbulence produced in that region.

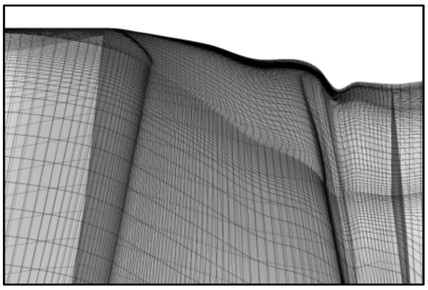

Figure 3. Typical casing contour to be optimized near the rotor tip

The optimization objectives are to maximize the fan isentropic efficiency at the cruise operating point while minimizing the noise emission at approach conditions, under the constraint that the design fan airflow and pressure ratio must remain constant. The impact of considering the tonal or the broadband component in the acoustic cost function will be discussed, respectively.

A companion study based on the same approach but focusing on the optimization of serrations for low tonal noise emission from a CROR is also submitted to ISROMAC 2016 (see Ref. [6]).

References

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