Near-and-Far Field Modeling of Advanced Tail-Rotor Noise Using Source-Mode Expansions

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Long Abstract

Introduction

Analytical modeling of aerodynamic sound generation from rotating-blade technology remains a topic of major interest for the investigation of low-noise criteria at the early design stage. In many situations a rotor is operating in close vicinity of a stator or other stationary bodies, which generates tonal noise because of periodic aerodynamic interactions. The present work addresses the architecture of the shrouded tail rotor of a helicopter as a typical example but the same approach could be applied, for instance, to most low-speed cooling fan configurations. The theoretical basis is the recognition of the modal structure of the tonal noise, according to which the field of each tone can be expanded as a sum of elementary modes of acoustic radiation. The shrouded tail-rotor case involves rotor-noise sources due to the potential interaction with the transmission shaft, on the one hand, and stator-noise sources caused by the impingement of the blade wakes on the vanes. In modern architectures such as shown in Figure 1 the rotor has uneven blade spacing. Furthermore the stator vanes are inclined so that the wake impingement is not simultaneous along the vane span. But because one of the vanes is replaced by the transmission shaft, the stator is not homogeneous. All these particularities induce important modifications with respect to what would be radiated as sound by a “regular” system. On the one hand, uneven blade spacing reduces the levels of the blade-passing-frequency harmonics (BPF) and makes lower-order harmonics of the rotational frequency emerge. On the other hand, removing one vane from a homogeneous stator redistributes the modal structure of the wake-impingement noise and tends to regenerate noise by disturbing destructive interferences. The proposed paper is a substantial continuation of previous works [1,2,3], accounting for three-dimensional design features. It is aimed at demonstrating the ability of simple analytical methods in free field to reproduce the combined effects of aforementioned technological features on the tonal noise. The scattering by the shroud, ignored in the analytical modeling, is assessed by comparing predicted modal radiation patterns with FEM simulations.

Figure 1. Advanced shrouded tail-rotor viewed from downstream. Leaned vanes in grey and unevenly-spaced rotor blades in light blue.

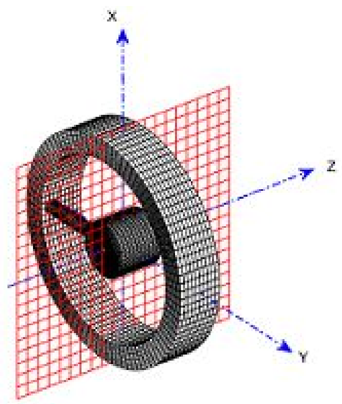
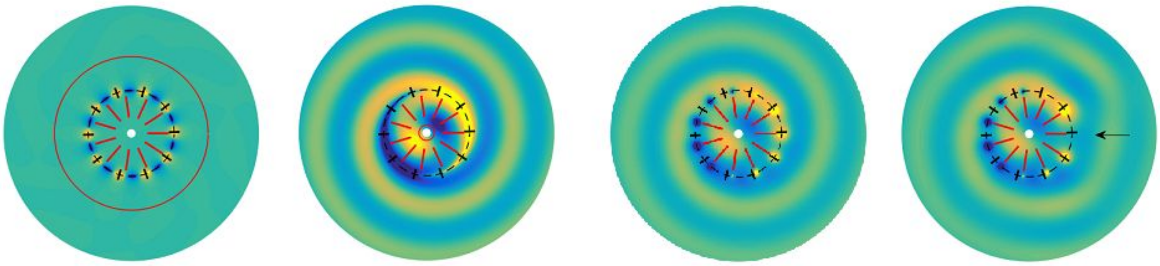


Figure 2. Simplified shroud for scattering computations, transmission shaft, and main axes for the modeling. Meridian cut in red.

1. Methods

The free-field tonal noise generated by periodic blade forces rotating on a circle of radius R_0 can be expanded as a sum of radiation modes. Each mode is characterized by a number of azimuthal periods or lobes n and a rotating phase speed Ω_n. Its field can be reproduced by continuously distributing stationary, phase-shifted dipoles on a circle. For practical implementation this circle distribution, or source-mode, is discretized and the near-and-far field obtained by linear superposition. In the same way the sources of stator noise can be also synthesized by circles of stationary phased sources. This makes the source-modes fundamental patterns to build any field of interest, either in unbounded space or in the presence of scattering bodies. Results representative of a tail-rotor with the same blade and vane numbers B=10 and V=11 as in Figure 1 but with homogeneous rotor and stator (counting the shaft as a vane) are given in Figure 3 (a,b), for the BPF and in the rotation plane (z=0). Here R_0=0.4m (black dashed circle), Ω_n = 4500 rpm. Tyler & Sofrin's rule $n = B\text{-}sV$ (s any relative integer) selects the mode n=-1 as the only efficient one. Indeed only the source modes having a supersonic phase speed contribute significantly (the red circles stand for the circle beyond which the considered mode has a supersonic phase speed). Other efficient modes are regenerated with the heterogeneous system of Figure 1, because of both the removed vane and the uneven blade spacing. As an indication of stator noise at the BPF the field of a set of 10 dipoles corresponding to the vanes in Figure 1 is also plotted in Figure 3, illustrating the different wavefront structure.



(a) (b) (c) (d)

Figure 3. Examples of modal fields synthesized by discretized source modes. *(a),(b)*: modes s=0 and s=1 of the homogeneous stator noise, parameters given in the text. *(c),(d)*: full stator noise of the homogeneous and actual (with 1 vane removed from 11; case of Figure 1) systems.

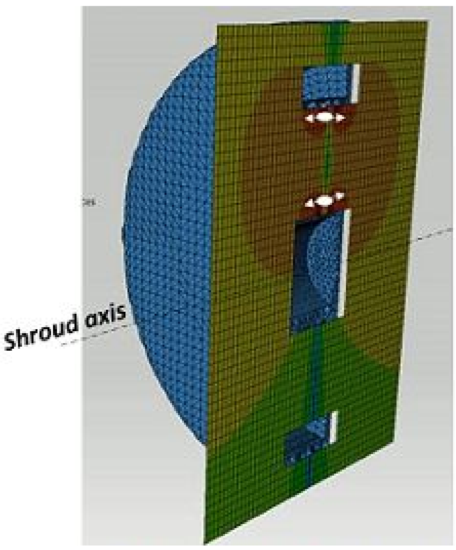


Figure 4. Computed sound-pressure amplitude map in the meridian plane (Figure 2) for two point dipoles in the plane located close to the hub and close to the shroud.

The main effect of the shroud can be inferred from the simplified configuration depicted in Figure 2 where the hub and shroud are axisymmetric bodies. The transmission shaft located close to the exit section can be ignored. In this approach the shroud and hub act as passive scattering surfaces, whereas the blades and vanes are not considered as surfaces because they act as equivalent sources according to the acoustic analogy. As a preliminary test the sound field of two point dipoles located in the meridian cut in Figure 2, as computed using a FEM software, is shown in Figure 4. The red spots indicate the maxima and the green bottom area illustrates the masking by the shroud. In the final paper, complete calculations for discretized source modes will be shown and compared to their free field for a better analysis of advanced-design effects.

References

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