ISROMAC 2017
International Symposium on Transport Phenomena and Dynamics of Rotating Machinery
Maui, Hawaii
December 16-21, 2017

[Extended Abstract]

Aerodynamic and acoustic analysis of an optimized low Reynolds number rotor

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Introduction

The demand in Micro–Air Vehicles (MAV) is increasing as well as their potential missions. Whether for discretion in military operations or noise pollution in civilian use, noise reduction of MAV is a goal to achieve. Aeroacoustic research has long been focusing on full scale rotorcrafts. At MAV scales however, the hierarchization of the numerous sources of noise is not straightforward, as a consequence of the relatively low Reynolds number that ranges typically from 5, 000 to 100, 000. Reducing the noise generated aerodynamically in this domain then remains an open subject. This contribution describes a low–cost, numerical methodology to achieve noise reduction by optimization of MAV rotors. The optimized rotors are further analyzed using higher–fidelity numerical approaches, including Unsteady Reynolds Averaged Navier–Stokes (URANS) simulations and Large Eddy Simulations using Lattice Boltzman Methods (LES–LBM), as well as experimental measurements. That strategy will give insight on the flow features around the optimized rotors yielding solutions to achieve higher noise reduction and guideline for the most suitable acoustic model in the optimization tool for low Reynolds number rotors.

1. Numerical tool for the optimization process

The optimization consists in the systematic evaluation of a parameter space defined by chord and twist laws as a function of the blade radius and rotor rotation speed with the same thrust as objective. Airfoil section optimization will be introduced in the final paper. For each set of parameters, the blade loading is obtained using Blade Element Momentum Theory (BEMT) [1]. In turn, the acoustic prediction is achieved following two steps. The main acoustic program consists in a Wave Extrapolation Method (WEM) in the time domain based on the Ffowcs–Williams and Hawkings (FW–H) equation, known as Formulation 1A as expressed by Farassat [2]. As it takes as input the aerodynamic steady loading on the blade surface (without quadrupole contribution), it yields the sole tonal noise at the blade passing frequency, as a consequence of a Doppler effect caused by the rotation of that steady loading to a fixed observer. However, the high frequency, broadband part of the acoustic spectrum is believed to be non negligeable [3] at low Reynolds number. A comparison between several broadband noise models will be presented in the final paper with experimental measurements and numerical simulations to justify the use of specific models that account for the most dominant noise sources at low Reynolds number. The optimization process described above is achieved for two-, three-, four- and five-blade rotors.

Optimized rotors are $3D$ printed for experimental measurements.

2. Experimental measurements

The aerodynamic forces are retrieved from a five–components balance that is validated with literature [4] and compared with numerical tools including BEMT, U–RANS and LBM. The noise measurements are carried out in a regular room following the guideline set by ISO 3746 : 1995 (in french). Measurements in an anechoic chamber currently under construction at ISAE Supaero will be available for the final paper. ISO 3746 : 1995 specifies five measurement points and compute the sound power level L_{wA}. Following that guideline has proven that a 4 dB(A) reduction from the reference blade APC7x5 in acoustic power is achieved by the optimization process for the three-blade optimized rotor (figure 1). Note that the 20 dB(A) in tonal noise reduction is hidden by the broadband part in the total noise, then justifying the need for appropriate broadband models.

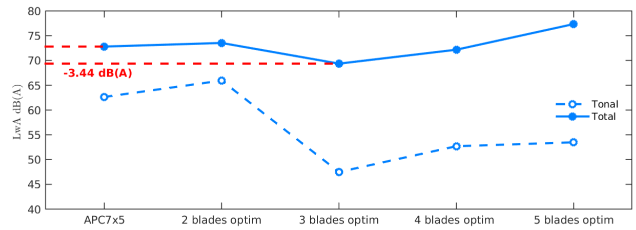

Figure 1. L_{wA} for the reference and the optimized blades

3. Detailed analysis

That optimized rotor is investigated in more details through numerical simulations. Valuable can be obtained such as the presence of boundary layer transition and ingestion informations of tip vortex by the following blade, stall phenomena or vortex merging as can be seen in figure 2. Such analysis gives access to suitable strategies to reach higher noise reduction and to identify the most dominant noise source that, in turn, allows selection of appropriate acoustic models in the low–cost optimization tool. Acoustic waves are retrieved from the numerical simulations by a WEM based on the porous FW–H integrals in the frequency domain as expressed by Gloerfelt *et al.* [5]. The need to accurately design boundary conditions in the computation procedure is highlighted in order to avoid spurious sound wave reflections.

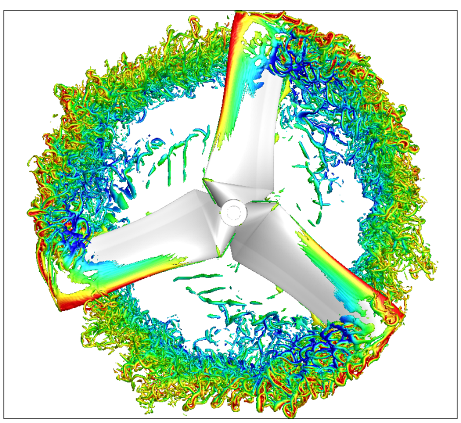

Figure 2. Iso–surface of the Q–criterion on the optimized blade.

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