LECTURE 3
ON THE NOISE FROM OPEN ROTORS

I INTRODUCTION

I-1 General features

It is remarkable that, in spite of the great variety of existing rotating blade technologies in aeronautics, wind energy and in air-conditioning, the physical mechanisms responsible for the sound are nearly the same, and so the radiated noise exhibits the same basic properties. More precisely, the noise spectrum of a rotor contains a broadband part and a discrete-frequency part at the blade-passing frequency (number of blades times rotational frequency) and harmonics. The latter is generally referred to as the rotational noise or tonal noise and is due to all periodic interactions between the rotor and the flow, whereas the former is due to random interactions with turbulence. Apart from this, the various shapes of spectra simply involve differences in blade number and rotating speed. The characteristic rotational Mach number at blade tip is also an important parameter, high velocities inducing more complicated sources with higher convective amplification. Roughly speaking, rotating machines, ducted as well as non ducted, can be arbitrarily classified by inspecting three parameters: the number of blades $\boldsymbol{B}$, the rotation speed $\boldsymbol{\Omega}$ and a characteristic tip radius $\boldsymbol{R_0}$. This suggests that the way a machine can be investigated depends on the corresponding areas in the planes of coordinates $(\boldsymbol{\Omega}, \boldsymbol{B})$ and $(\boldsymbol{\Omega}, \boldsymbol{R_0})$. For instance, the main rotor of a helicopter is characterised by small blade number and rotating speed, thus a very low fundamental frequency. This kind of rotor exhibits a strong rotational noise, perceived like a pulsation and the time-domain approach mentioned in the next sections is well suited. It would be irrelevant to a turbofan engine, for which the major noise currently heard is a high-frequency tone superimposed on a broadband spectrum. In another context, cooling fans are subsonic machines with low characteristic Mach numbers; this certainly allows for special assumptions that cannot be made in the case of aeronautic rotors, and leads to a different competition of sound sources, according to the general scaling laws with flow velocity. Typically, in this case, the blades can be best considered as compact sources essentially determined by the unsteady loads.

In all cases, the need for noise reduction depends on the subjective nuisance, which in turns depends on two points:

- the relative levels of discrete-frequency and broadband contributions,
- the position of the blade-passing frequency within the range of human hearing.

The present lecture is not only devoted to the aeronautic applications, for which aeroacoustic phenomena are more crucial. The general equations apply to any less sophisticated subsonic machine as well. The emphasis is on rotor noise and rotor-stator wake-interaction noise radiating in free space, thus ignoring the effect of a duct. The simplification provides a better understanding of the basic noise-generating mechanisms without additional complexity and can help to develop methods of noise control at source. The effect of the duct for turbomachinery applications will be introduced later on.

I-2 Prediction methods

For many years, the noise from rotating blades has been predicted by the acoustic analogy, using more or less accurate flow predictions as input data. Modern methods can be developed following two strategies. Again, a long term strategy is to think of solving the full fluid dynamics equations by extending pure CAA methods, which will be possible only if the expected future growth of computation resources remains at the same rate as what has been achieved in the past decades. Another one, more dedicated to short-and middle term purposes, consists in developing hybrid methods coupling efficient CFD tools and some acoustical post-processing based on the acoustic analogy. Finally, for the pre-design and parametric studies, the pure analytical techniques based on a very simplified description of the system of interest are well suited. Only the approaches related to the acoustic analogy are considered below.