LECTURE 4
DUCT ACOUSTICS AND TURBOMACHINERY NOISE

I PRELIMINARIES

I-1 Introduction

Even if reduced to the simple case of an equivalent finite-length cylindrical duct, the question of the effect of a casing or a duct on the noise radiated by rotors and stators strongly depends on three different length scales, namely the duct length L and diameter D and the acoustic wavelength λ. An intuitive classification can be proposed in terms of the non-dimensional parameters L/λ and D/λ. A short duct, in the sense that $D<\lambda$ and/or $L<\lambda$, acts as a diffracting screen but the radiation properties of the sources are not strongly modified with respect to free-field radiation, especially if the sources remain 'directly visible' from the observation point in the far field. A stronger modification is expected in the case of a long duct, for which $L>D$ and $L>>\lambda$. Long ducts are currently encountered in turbomachinery, this justifying the main assumption made in this lecture. In that case, duct effects are twofold:

1 - The duct causes a re-organisation of the natural acoustic field of the sources by successive reflections on the walls, producing special guided waves.

2 - Those waves radiate outside in the far field through the duct terminations, due to a complicated diffraction mechanism.

Both effects can be separately modelled using analytical methods, as long as the coupling between terminations is weak. The duct is said a wave-guide. In intermediate situations between long and short ducts, or when some details such as the thick inlet geometry of a turbofan engine are to be taken into account, no analytical approach is available. Numerical techniques based on boundary elements methods or finite elements methods must be used, at the price of much higher computation time and cost.

The modal approach detailed below, by which the sound field is expanded on a set of modes of propagation inside the duct, is theoretically exact and uniformly valid in the wave-guide range. However, different approaches are more or less suited depending on the value of D/λ. At low frequencies, in the sense that $D/\lambda<<1$, sound propagates only as plane waves and the duct is seen as an acoustic circuit with reflections and transmissions at discontinuities. Specific methods using transfer matrices are developed. Applications are found in acoustics of wind instruments, car-engine exhaust ducts, and so on. The modal approach is best suited to the duct of a turbofan, for instance, and, generally speaking, to a class of applications in turbomachinery defined as the high-frequency range. At even higher frequencies, the ray theory applies and can be a palliative to the questionable use of a very large number of modes.

In the present lecture, the complete approach using the modal theory and related to a semi-infinite hard-walled duct with zero thickness and uniform flow is rapidly outlined, in order to emphasise on the basic physical mechanisms. This provides a necessary theoretical background. Extensions to more complicated and realistic configurations (non-uniform flow, absorbing walls, varying cross-section) will be just mentioned.