Analytical Study of the Unsteady Aerodynamic Noise Radiated by Distributed Electric Propulsion Systems

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Introduction

Innovative Urban Air Mobility (UAM) electric aircraft are developed to meet future noise and gas emissions requirements. The UAM is likely to lead to new sources of community noise because of the interactions between propulsive units and airframe **[1]**. One of the most prominent UAM propulsion concepts is the Distributed Electric Propulsion (DEP) system, which relies on thrust generation by multiple fans or propellers installed close to the airframe. The main challenges inherent to DEP systems include the effects of inflow distortions on propeller efficiency and noise. Within this context, resorting to analytical models at the preliminary-design stage is an attractive approach, as for the steady loading noise **[2,3]**. However, for subsonic installed rotors, steady-loading noise is most often of secondary importance compared to unsteady-loading noise because of the higher radiation efficiency of blade-loading harmonics induced by the azimuthal mean-flow distortions. In the present investigation of a generic configuration, unsteady-loading noise is assessed by combining some simplifications in the analytical model with numerical inputs.

Propeller-Wing Configuration

The modelled configuration is primarily dealing with the scattering of propeller noise by a wing, for an over-the-wing installation and a pair of 0.2 m diameter side-by-side propellers. The configuration is a reduced arrangement mimicking DEP systems. Because the tonal noise, considered as of major interest, is interferential in essence, the sound field is explored in three dimensions, varying its main parameters. The dual propeller system is defined by the axis-to-axis distance d. Its positioning with respect to the wing is defined from the wing trailing edge point at mid-wetted span, by the streamwise distance to the edge D and the normal-to-wing distance h. Because the blades are unswept and radially aligned, the mid-chord plane of the propellers and the plane containing the propeller axes are taken as reference for the definition of these distances as seen in Fig. 1. The isolated single propeller is also addressed as a reference test case.

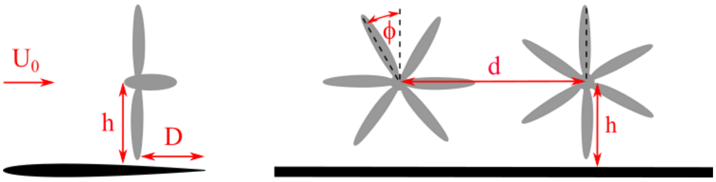

Fig. 1 Configuration and modelled parameters. Lateral view (left) and frontal view (right).

Analytical Tonal Noise Prediction

The analytical approach, previously validated **[3]**, consists in combining a source model, which determines the blade forces acting as equivalent dipoles, and a propagation model, based on the acoustic analogy and a simplified Green's function. Accompanying Large-Eddy Simulation (LES) of the pylon-mounted propeller configuration

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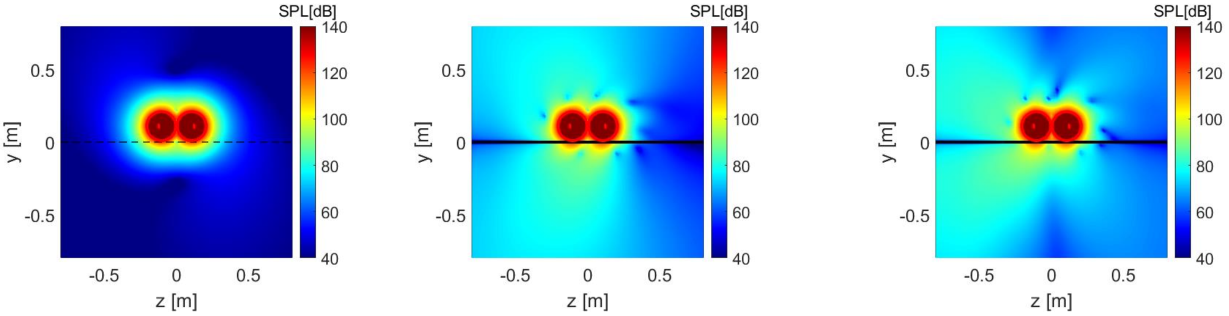
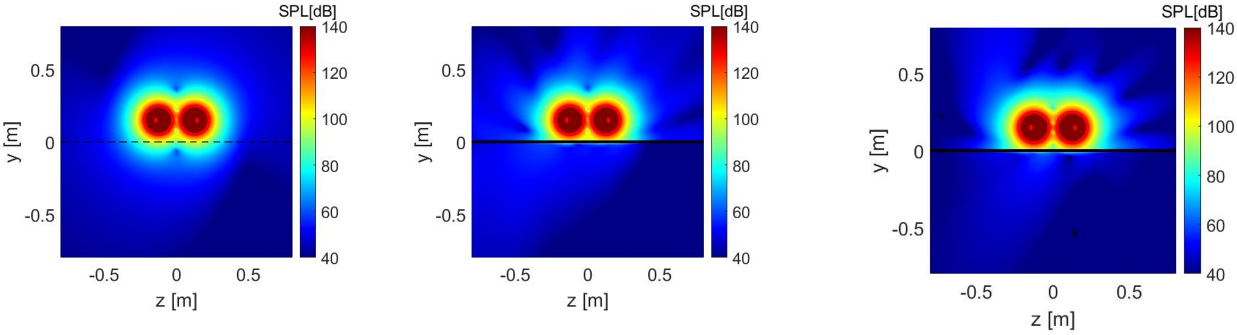
was carried out in CFD commercial software Simcenter STAR-CCM+ **[4]** in order to compute the time-averaged velocity fields upstream and downstream of the propeller as well as the unsteady blade pressure.

Preliminary Results

Sound-pressure maps for the rotor-locked mode associated with steady-loading noise at the BPF, are shown in Fig. 2. for the most critical cases where the distance parameters D, h, and, d are at their maximum (Max) and minimum (Min) positions with respect to each reference. This mode only generates evanescent waves in the free-field because of the low tangential phase Mach number. Significant amplification is found in all cases of the Min configuration in the presence of the wing, because of the vicinity of the scattering edge. However, the amplification is reduced above and below the wing in the case of zero phase clocking ϕ0. The same can be seen in the Max configuration but without amplification.



a. Free-field ϕ30 **b. Scattering-field Min-ϕ30** **c. Scattering-field Min-ϕ0**



d. Free-field ϕ0 **e. Scattering-field Max-ϕ30** **f. Scattering-field Max-ϕ0**

Fig. 2 sound-pressure maps of different configurations of contra-rotating propellers for steady-loading noise (n = 6)

Further Developments

Further results will include sound-pressure maps of the unsteady loading noise resulting from the numerical results, which will produce sound in additional modes, different from the steady-loading noise mode.

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