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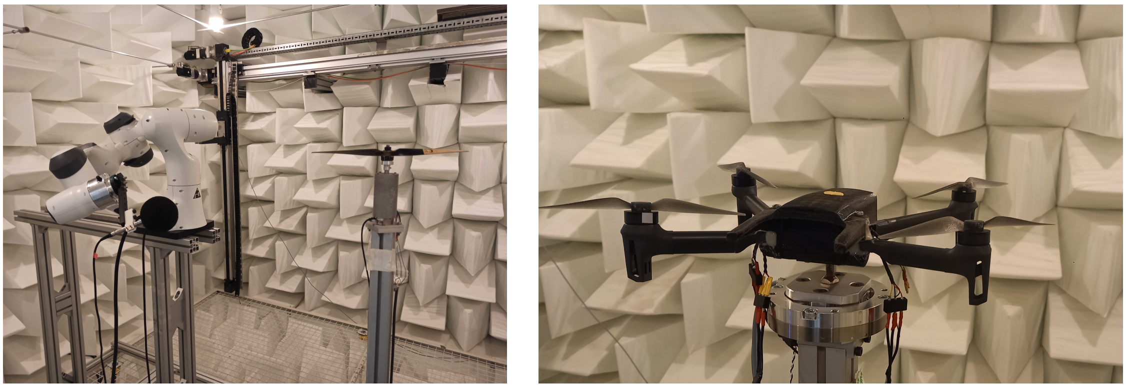
Institute of Mechanical Sciences and Industrial Applications

PhD position in aeroacoustics: modeling and simulation of aerodynamic and acoustic installation effects of a small-size quadcopter drone

Context

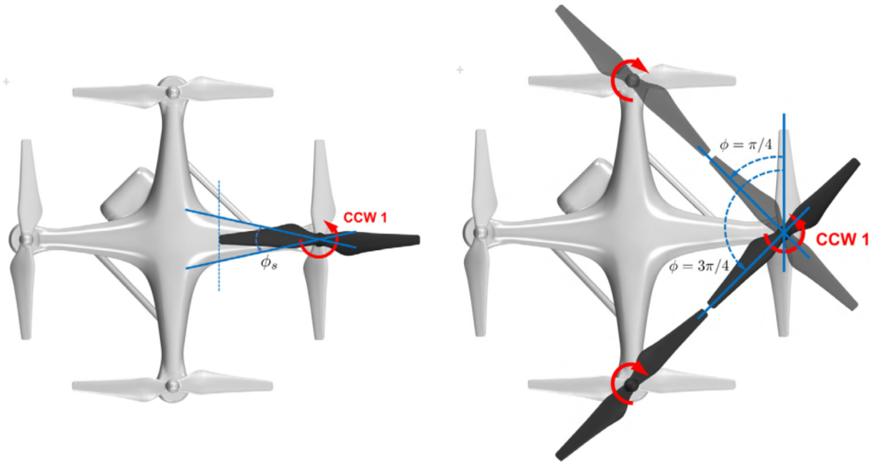
Multicopter drones are increasingly being used for civil and military applications such as delivery, building inspection, or monitoring. The objective of the project *Aeroacoustics for drone PROpulsion* (APRO) is to better understand and model the noise-generating mechanisms in multicopter drones in order to reduce their noise impact and to improve their social acceptability. During the first part of the project, experimental setups have been built in the anechoic chamber of ENSTA Paris in order to characterize the aerodynamic performance and acoustic radiation of isolated propellers and of a small-size quadcopter drone in hover, as can be seen in Figure 1.



(a) (b)

Figure 1: Experimental setups in the anechoic chamber of ENSTA Paris: (a) isolated propeller with robotic arm [1] and (b) quadcopter model mounted on a force balance.

In a quadcopter drone architecture, several aerodynamic and acoustic installation effects are present that will modify the radiated noise spectrum and directivity with respect to an isolated propeller configuration [2, 3]. Aerodynamic installation effects are associated to aerodynamic interactions that cause an increase in tonal noise (unsteady loading noise) and potentially in broadband noise too. As shown in Figure 2, these installation effects can be associated with the interactions between propellers and their supporting struts, on one side, and the interactions between rotors, on the other side. Acoustic installation effects are associated with the scattering of the propeller noise by the fuselage or other components of the drone, that can yield to amplification or shielding of the noise. Predicting drone noise is thus a complex challenge, especially for small-size drones that operate at relatively low Reynolds numbers, corresponding to transitional regimes on the propeller blades [4].



(a) Tip-on-strut interaction.

(b) Tip-on-tip interaction.

Figure 2: Types of interaction on a quadcopter drone. Taken from Zarri *et al.* [3]

Objectives and workplan

The objectives of this PhD position are to study numerically and theoretically the aerodynamic and acoustic installation effects of a small-size quadcopter drone. This will be used eventually to build a simplified source model in order to to optimize its shape and its trajectory. The workplan is divided into two main work packages:

1. **Numerical investigation of aerodynamic and acoustic installation effects**

   In order to understand the interaction mechanisms between propellers and supporting struts, on one side, and between propellers, on the other side, high-fidelity large eddy simulations will be perform using the Lattice Boltzmann Method (LBM). This numerical method has been shown to provide accurate predictions of tonal and broadband noise for low-Reynolds number propellers [5]. The aerodynamic installation effects will also be predicted using a low-fidelity method based on surface panels of vortex lattice methods. Finally, it can be envisaged to predict the acoustic diffraction effects associated with the drone body and supporting struts using a Boundary Element Method (BEM).

2. **Semi-analytical modeling of aerodynamic and acoustic installation effects**

   Several analytical models have been proposed in the literature to predict the rotor-strut interaction [6, 7]. Several mechanisms are involved, namely sound generation by the rotor operating in the potential distortion of the strut, noise generation by the strut because of impinging wakes from the rotor blades, and scattering of each emitted sound by the other solid surfaces. Modeling of the noise sue to the interaction between rotors is quite difficult, and generally relies on numerical aerodynamic calculations [8, 9]. Constructive and destructive interference effects between the different propellers can be observed, and some modulations in time can be present since the different propellers have slightly different rotational frequencies.

Practical information

- **Profile**: the candidate must hold a Master degree or equivalent in Acoustics or Fluid Mechanics.
- **Supervision**: Benjamin Cotté, Associate Professor at ENSTA Paris.
- **Duration and location**: the 3-year PhD program will take place at ENSTA Paris in Palaiseau (20 km south of Paris). The candidate will be registered at the IP Paris graduate school (`https://www.ip-paris.fr/en/`).
- **Salary**: net salary of approximately 2000 euros per month, with possibility to add a teaching assistantship (up to 64 hours per year).
- **To apply**: send a cover letter and a resume with a list of references to benjamin.cotte@ensta-paris.fr.

References

[1] Y. Beausse, B. Cotté, C. Pascal (2024). Towards a controlled roughness for improved aerodynamic and acoustic performance of propellers at low Reynolds number, 30th AIAA/CEAS Aeroacoustics Conference, 4-7 June, Rome, Italy, `doi.org/10.2514/6.2024-3266`.

[2] M. Roger and S. Moreau (2020). Tonal-Noise Assessment of Quadrotor-Type UAV Using Source-Mode Expansions *Acoustics* 2, pp. 674–690.

[3] A. Zarri, E. Dell'Erba, W. Munters, C. Schram, Aeroacoustic installation effects in multi-rotorcraft: Numerical investigations of a small-size drone model, Aerospace Science and Technology, Vol. 128, 2022, p. 107762.

[4] E. Grande, G. Romani, D. Ragni F. Avallone, D. Casalino, Aeroacoustic investigation of a propeller operating at low Reynolds numbers, AIAA Journal, Vol. 60, No. 2, 2022, pp. 860-871.

[5] E. Grande, G. Romani, D. Ragni F. Avallone, D. Casalino, Aeroacoustic investigation of a propeller operating at low Reynolds numbers, Aerospace Science and Technology, Vol. 125, 2022, 107086.

[6] J. Rendon, S. Moreau, M. Roger (2024). A Numerical and Analytical Approach of the Sound-Scattering Effects in Rotor-Strut Interaction Noise of Small-Size Drones, 30th AIAA/CEAS Aeroacoustics Conference, 4-7 June, Rome, Italy, `doi.org/10.2514/6.2024-3047`.

[7] E. Vella, R. Gojon, H. Parisot-Supuis, N. Doué, T. Jardin, M. Roger (2024). Mutual Interaction Noise in Rotor-Beam Configuration, 30th AIAA/CEAS Aeroacoustics Conference, 4-7 June, Rome, Italy, `doi.org/10.2514/6.2024-3318`.

[8] H. Lee, D.J. Lee (2020). Rotor interactional effects on aerodynamic and noise characteristics of a small multirotor unmanned aerial vehicle, Phys. Fluids 32, 047107 `doi.org/10.1063/5.0003992`

[9] F. de Prenter, A. Zarri, D. Casalino (2024). Low-Cost Computational Modeling of Aeroacoustic Interactions between Adjacent Propellers, 30th AIAA/CEAS Aeroacoustics Conference, 4-7 June, Rome, Italy, `doi.org/10.2514/6.2024-3069`.