PROPOSITION DE SUJET DE THESE

Intitulé : Impact of Formation Flight Aerodynamics on Condensation Trails: Coupled Wake Dynamics, Stability and Sensitivity Studies

Référence : **MFE-DAAA-2026-14**
(à rappeler dans toute correspondance)

Début de la thèse : 01/10/2026	**Date limite de candidature :**

Mots clés : Wake vortices, vortex vortex and vortex wing interactions, condensation trails, formation flight, instability, experiment, simulation

Profil et compétences recherchées

Engineer diploma or second year Master specialized in aerospace engineering, fluid mechanics, or experimental aerodynamics.

Data analysis & programming skills (Matlab / Python).

Teamwork & collaboration, Fluency in English (scientific writing & communication), Autonomy, dynamism, determination.

Présentation du projet doctoral, contexte et objectif

The project aims to elucidate how aerodynamic interactions in formation flight (FF) influence the formation and evolution of condensation trails (contrails). While FF can reduce fuel burn through induced-drag reduction, its impact on wake dynamics and exhaust thermodynamics remains poorly understood. The coupled vortices of two aircrafts modify the local flow, mixing, and available moisture that determine contrail formation and persistence. The question is whether FF is also interesting from a contrail point of view. Early studies on this matter indicate that FF lead to contrail reduction [1].

FF is of interest to both civilian and military aviation (see figure 1 below). Today, military operations account for approximately 8% of total aviation emissions [6]. Long-haul military transport aircraft could benefit from FF by reducing fuel consumption and, possibly, contrail formation—thus lowering their overall climate impact while simultaneously enhancing stealth through reduced optical visibility [7]. In the civil aviation sector, FF, which is often labelled as the concept of Wake Energy Retrieval (WER), is currently being investigated in several research projects [8,9], aiming to achieve similar gains in aerodynamic efficiency and environmental performance.

Figure 1 Formation flight. Demonstration of formation flight of A400M aircrafts (left), illustration of the condensation behind the turboprop engine of an A400M during a fighter refueling operation (middle), tests of formation flight in Airbus Fello'fly project (right)

To question the interest of the aerodynamics of FF for contrails, the PhD will carry out a **fundamental investigation on a generic problem of two wings flying in FF, looking first at the coupled wing aerodynamics and then investigating the impact on contrails**.

A two-wings wind tunnel experiment will first be carried out, in dry air, to characterize the coupled wake that results from a pair in FF, using Particle Image Velocimetry (PIV), multi-hole pressure probes, and, where appropriate, force balances. At this stage, the focus will be solely on the aerodynamic of the wakes, with the aim of analyzing vortex–wing and vortex–vortex interactions. The resulting database will form the foundation for physical analyses aimed at identifying the dominant mechanisms governing these interactions and the resulting vortex structures [2,3,4]. Subsequent stability and modal analyses, possibly based on a simplified flow model, will be conducted to better characterize these mechanisms, the associated perturbation modes, their growth potential. The goal is to evaluate the fate of the wake in the far-field, as it won't be available in the experiment.

In a second phase, microphysical simulations of contrail formation—using the two-wing configuration as a reference—will quantify the sensitivity of contrail properties to the relative offset between the upstream and downstream wings, as well as, if appropriate, to ambient atmospheric conditions. The experimental data obtained in the first phase will serve to validate the numerical simulations.

Finally, by combining the understanding of aerodynamic drag and contrail sensitivity with respect to transverse wing spacing, a global optimum under the double constraint of minimizing induced drag and contrails, will be sought and identified. This outcome will provide practical guidance for contrail-mitigation strategies in future FF operations.

The PhD will be conducted at ONERA Meudon research center, in collaboration between two teams, one specialized in vortex dynamics (DAAA/AMES, Meudon) and the other in contrails microphysics, modeling and simulation (DMPE/CMEI, Palaiseau).

Bibliographical references:

[1] Unterstrasser, S. (2020). The contrail mitigation potential of aircraft formation flight derived from high-resolution simulations. Aerospace, 7(12), 170.

[2] Inasawa, A., Mori, F., & Asai, M. (2012). Detailed observations of interactions of wingtip vortices in close-formation flight. Journal of aircraft, 49(1), 206-213.

[3] Barnes, C. J., Visbal, M. R., & Huang, P. G. (2016). On the effects of vertical offset and core structure in streamwise-oriented vortex–wing interactions. Journal of Fluid Mechanics, 799, 128-158.

[4] Chen, C., Wang, Z., & Gursul, I. (2018). Vortex coupling in trailing vortex-wing interactions. Physical Review Fluids, 3(3), 034704.

[5] McKenna, C., & Rockwell, D. (2016). Topology of vortex–wing interaction. Experiments in Fluids, 57(10), 161.

[6] Gössling, S., & Humpe, A. (2020). The global scale, distribution and growth of aviation: Implications for climate change. Global Environmental Change, 65, 102194.

[7] Kapur, V. (2014). Stealth technology and its effect on aerial warfare (p. 33). New Delhi, India: Institute for Defence Studies and Analyses.

[8] https://www.sesarju.eu/projects/GEESE

[9] https://www.airbus.com/en/innovation/future-aircraft-operations/air-traffic-management/fellofly-and-geese

Collaborations envisagées

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