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PROPOSITION DE SUJET DE THESE

Intitulé : DYNAMICS OF TURBULENCE IN JET / VORTEX WAKE INTERACTION

Référence : **MFE-DAAA-2022-06**
(à rappeler dans toute correspondance)

Début de la thèse : 01/10/2022	**Date limite de candidature :** 20/5/2022

Mots clés

Turbulence, jet, vortices, wind tunnel, simulation

Profil et compétences recherchées

Fluid Mechanics, physics, applied mathematics

Présentation du projet doctoral, contexte et objectif

The interaction of jets and vortex wakes is a problem of fundamental interest that lies at the heart of one of the most important issue that aviation faces today with regards to global warming, namely contrails (Fig. 1). Indeed recent researches [1] suggest that contrails could contribute more than 50% of aviation impact on climate. However this figure needs refinement, as its uncertainty is currently high, as a consequence of the complex and multiscale physics at play, and of the insufficiency of available models.

Fig. 1 Condensation trails in the wake of a 4 engine commercial aircraft

From an aerodynamics point of view**, the underlying problem is that of the interaction between the jet that generate the contrails and the vortex wake formed by the aircraft wing and that evolves in the jet surroundings.** Specifically the nature of the turbulence that takes place in this interaction dictates the mixing and dispersion of the jet exhaust and contributes to the properties (size, content) of the contrails far downstream of the aircraft, where they may evolve into artificial cirrus with high radiative impact. Today the numerical simulations that are carried out to estimate contrail properties [2] for flight Reynolds configurations are hindered by the capability of turbulence models to capture this complex interaction flow. These models already have weaknesses for the simpler flows of jet or wake alone (see [3] and references to wakes therein). Therefore their reliability for the full flow complexity and, hence, capacity to deliver good prediction of contrail and thus estimates on their effect on climate are in question.

In this context, the **goal of the proposed PhD project is to investigate the nature of the turbulent processes within the jet / vortex interaction and to explore the modifications to the jet and wake dynamics due to their coupling**. The motivation is to increase physical understanding, describe the leading physical mechanisms of the coupling and provide the necessary data to improve modeling capacities of current turbulence models.

The PhD work is based on a wind tunnel experiment of a jet / vortex wake interaction at the LMFL main facility, with an original experiment made of a rectangular wing equipped with two jets underneath, similar to the one described in [4]. The PhD will make use of this set up for a variety of high quality PIV measurements, including small fields of view in highly zoomed sectors of the flow but also large fields of view for large-scale properties (such pairs of different PIV measurements have recently been carried out in [5]). In preparation to these experiments, the first 15 months of the PhD will be devoted to DNS (using an appropriate highly parallelized DNS code for use on HPC platforms) and theory of jet/wake turbulent flows. This will make it easier to decide on the details of the PIV measurements and diagnostic analyses which will be carried out during the second 15 months of the PhD thesis, the final 6 months being devoted to writing the PhD thesis and journal publications.

The state of knowledge on the problem remains low but gives the overall directions of research. Low Reynolds number numerical simulations, allowing LES [6], as wells as integral models [7] have shown how jets diffusion and entrainment are controlled by the wake vortices depending on **relative initial position** of the jet within the wake. The proximity of the jet to the vortex core leads to highly non homogeneous mixing, as a result of the shearing effect imposed by the vortex, and, the other way around, can disturb the vortices, causing larger momentum diffusion and instabilities [6]. Furthermore, the turbulent time scale may be on order of the microphysical time scale of water vapor condensation, indicating that wrong modeling of turbulence can result in a bad prediction of ice content [8] and thus of the contrails final content and size. A puzzling physics also takes place in the trailing vortices, as these generally tend to a laminar state, prone to not yet fully understood low frequency oscillations, that the jet could favor [9].

In the PhD, both the DNS (or perhaps QDNS or LES) and the PIV will be concerned with the turbulence within the jet/wake interaction flow for various **jet-to-vortex strengths**, various **jet-to-vortex distances** and various **Reynolds numbers**. This is a case of turbulence-turbulence interactions where a significant turbulence-turbulence interface could exist depending on parameters. Such interfaces may or may not involve significant jumps in vorticity, as in the case of turbulent/non-turbulent interfaces. It will be important to investigate the nature of this interface as it is critical to entrainment (itself a central aspect of the jet/wake interaction and the way that the jet may be ingested into the vortex depending on parameters) and can also affect the pressure field (itself important for condensation leading to contrails). Such interfaces are particularly challenging aspects of turbulence inhomogeneity and inhomogeneous mixing and represent a challenge for turbulence models. Other aspects of the flow which will need to be investigated include the presence/absence of self-preservation of various turbulence property profiles because self-preservation very significantly simplifies momentum and energy budgets [3]. The specific properties of turbulence in question which are at the heart of turbulence prediction and modeling methods include turbulence dissipation, integral scales and turbulent kinetic energy. In particular, these are turbulence properties which, in conjunction with entrainment, contribute to the determination of jet/wake growth and decay with streamwise distance. It will be important to determine the rate of growth and decay of the jet/wake flow. Possibly, as a side objective, the influence of the jet on the vortex dynamics will also be detailed, following recent work that describe the receptivity of wake vortices to external perturbations [9,10].

As mentioned above, the leading objective is to provide inputs (data, understanding) to correct turbulence model for the prediction of the early stage of the evolution of a complete aircraft wake so as to allow for better contrail assessment. Discussions with research engineer conducting research on contrails simulation will be favored to evaluate the current state of modeling, considering the results and analysis of the experiments as basis.

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Collaborations envisagées

LMFL

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