Internship proposal
Dynamics and stability of wake vortices

Supervisors: Gabriele NASTRO, Jérôme FONTANE, Jérémie GRESSIER

The proposed internship is part of a project called DESTINS, which aims to study the *dynamics of vortices* downstream of aircraft using *direct numerical simulation tools* and *global stability*, accompanied by tests on our department's bench. This internship will be devoted to the *theoretical* and *numerical aspects* and therefore to the *implementation of the numerical tools* that will help the future experimental campaigns.

Context

Vortex dynamics has always been a subject of great interest to the scientific community because of its involvement in many engineering applications.

These vortices are induced by the generation of lift on wings of finite span and contribute to induced drag (see figure 1a). Even with the presence of winglets, their formation is unavoidable, and their presence can be very dangerous for following aircraft due to the induced rolling moment. This aspect plays an important role in the configuration of UAVs in formation or swarms of UAVs, as well as in the imposition of limitations on take-off and landing frequencies between two consecutive aircraft, limitations which are essential for air traffic control [1].

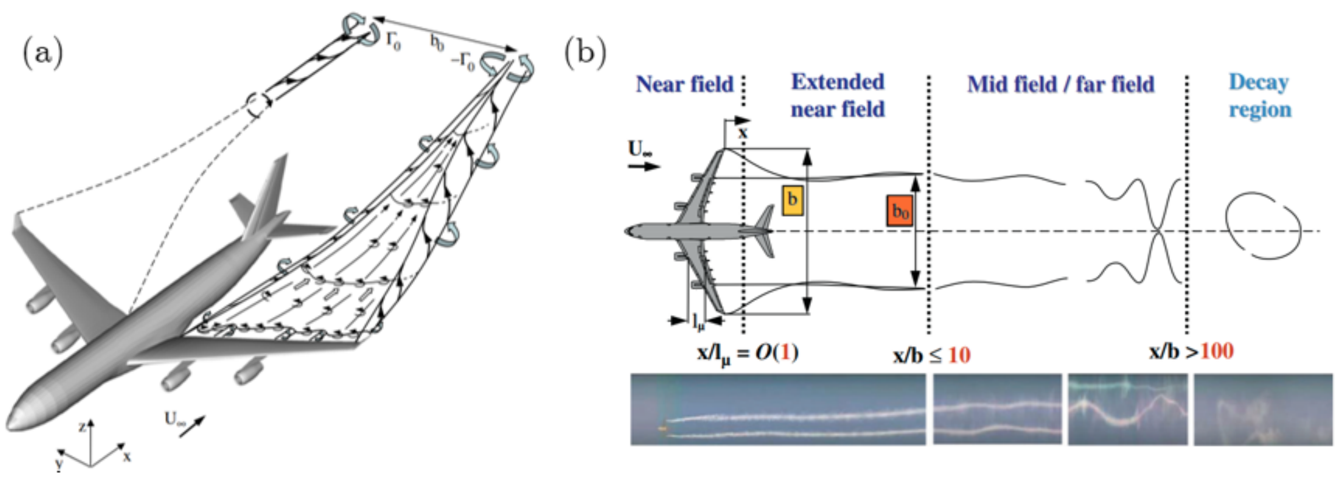

Figure 1: Evolution of the vortex sheet and winding process (a) [2]. Determination of the wake vortex evolution regions as a function of the downstream position (b), figure adapted from [3].

The interaction of wake vortices with the outgoing jets from a hydrogen engine, for example, is the basis for the formation of contrails, which have a significant influence on radiative forcing under certain atmospheric conditions (see figure 1b). This is why their persistence at flight altitude has been identified as the main effect of the climatic impact of aviation [4-5].

In addition to these critical issues, it should also be emphasised that vortex dynamics also give rise to acoustic problems. For example, in the aeronautical industry, in take-off/landing flight configurations, the vortices generated by the deployment of the trailing edge flap are a source of noise [6].

For all these reasons, a scientific effort to improve our understanding of their dynamics and design control strategies is necessary. One of the control strategies relies on the excitation of three-dimensional instabilities [7-8], which need to be studied using fully global approaches in order to gain a detailed understanding of the physical mechanisms.

Internship objectives

The aim of this internship is to study the dynamics of different flow configurations involving one or more wake vortices using direct numerical simulation tools and global stability analysis that can provide quantitative information on their intensity, the frequencies involved and their lifetime.

The first part of the internship will be devoted to getting to grips with our numerical solver, namely IC3 which is the department's massively parallel code. The first step will consist of carrying out global stability analyses on simple cases (i.e., 2D cylinder) using spectral difference methods (SD). The first objective of the internship will be to verify the validity of the calculations carried out using the spectral formulation by comparing them with the reference cases obtained using the finite volume formulation (VF). Secondly, a mesh around a wing using commercial mesh generators (such as ICEM and AutoGrid) will be carried out. The second objective will therefore be to perform global stability analysis computations at low Reynolds numbers using the spectral formulation, which has already been validated on simpler cases in the first part of the internship.

Therefore, the goals of this internship can be summarised as follows:

- Getting to grips with the department solver IC3.
- Performing global stability analysis via SD on a reference case (for example, the cylinder).
- Creating a mesh around a complete wing.
- Global stability analysis around the meshed wing and physical analysis.

Applications should be sent to: gabriele.nastro@isae-supaero.fr

Important

Possibility of continuing the present work in the framework of a PhD thesis after the internship.

References

[1] Spalart, P.R. Airplane trailing vortices. *Annu. Rev. Fluid Mech*, 30(1), 107–138 (1998).
[2] K. Huenecke. Structure of a transport aircraft-type near field wake. *AGARD CP-584*, 1996
[3] C. Breitsamter. Wake vortex characteristics of transport aircraft. *Progress in Aerospace Sciences*, 47(2) :89–134, 2011.
[4] Lee, D.S., Fahey, D.W., Skowron, A., Allen, M.R., Burkhardt, U., Chen, Q., Doherty, S.J., Freeman, S., Forster, P.M., Fuglestvedt, J., Gettelman, A., De León, R.R., Lim, L.L., Lund, M.T., Millar, R.J., Owen, B., Penner, J.E., Pitari, G., Prather, M.J., Sausen, R.,Wilcox, L.J. The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018. *Atmos. Environ*, 244, 117834 (2021).
[5] Noppel, F.G. Contrail and cirrus cloud avoidance technology. *Ph.D. thesis*, Cranfield University (2007).
[6] Streett, C., Lockard, D., Singer, B., Khorrami, M., Choudhari, M., Macaraeg, M. In search of the physics: the interplay of experiment and computation in airframe noise research, part 1. In: *41st Aerospace Sciences Meeting and Exhibit*, p. 979 (2003).
[7] Crouch, J. Airplane trailing vortices and their control. *Comptes Rendus Physique* 6(4), 487–499 (2005).
[8] Edstrand, A.M., Sun, Y., Schmid, P.J., Taira, K., Cattafesta, L.N., III. Active attenuation of a trailing vortex inspired by a parabolized stability analysis. *J. Fluid Mech*, 855, R2 (2018).