

Adjoint-based optimisation of wake-vortex flows at high Reynolds number

PARTENAIRES

AIRBUS

LATECOERE

Key words: optimisation, stability, adjoint, URANS

Department: DAEP (Aerodynamics, Energetics, and Propulsion Department)

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.

JOB DESCRIPTION:

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].

The interaction of wake vortices with the outgoing jets from an 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].

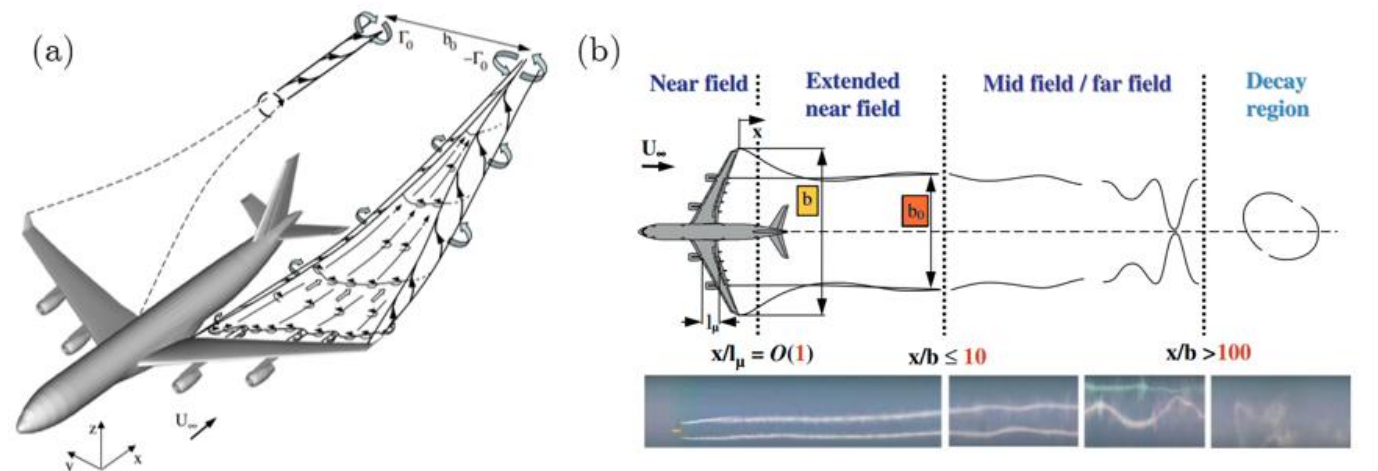


Figure 1: Evolution of the vortex sheet and winding process (a) [2]. Determination of the wake vortex evolution regions as a function of the downstream position (b), figure adapted from [3].

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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.

MISSIONS:

The aim of this internship is to determine the optimal perturbations which would lead to the greatest deviation in the dynamics of trailing vortex flows. With a view to designing new strategies for controlling such vortices, the idea is to employ the adjoint method in the Reynolds-Averaged Navier Stokes (RANS) framework to obtain not only the optimal perturbations but also the associated sensitivity [9].

The first part of the internship will be devoted to familiarising with the adjoint methods and our numerical solver, DALSA. This code, written in the C programming language and parallelised using OpenMP (Open Multi-Processing), has been developed within the DAEP and enables the simulation of instabilities arising around a high-Reynolds-number wake vortex (Navier-Stokes and RANS) through a local approach [10]. Recently, the code has been provided with both nonlinear and linear RANS equations using a k-epsilon turbulence modelling. As far as the numerical methodology is concerned, the code is characterised by a pseudo-spectral method with Chebyshev collocation for the discretisation of the radial direction, while time integration is performed in spectral space using a third-order Runge-Kutta (RK3) scheme, which includes a projection method for handling the pressure term. By the end of this first phase, the candidate will have acquired fundamental knowledge of both adjoint and spectral methods. The first objective of the internship will be to compute the RANS adjoint equations in cylindrical coordinates, corresponding to the specific phenomenology under investigation, namely the wake vortex, whose base flow is assumed to be parallel and axisymmetric. Once the RANS adjoint equations have been derived, it will be necessary to validate them by comparing the stability properties of the adjoint with those of the corresponding direct mode. After validation, the adjoint method will be used to perform temporal optimisation and sensitivity analysis.

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

- Getting to grips with the adjoint methods and our solver DALSA (stored in our internal GitLab).
- Deriving the RANS adjoint equations for the problem under study.
- Validating the RANS adjoint by comparing its stability properties with those of the corresponding direct mode.
- Performing optimisation and sensitivity analysis.

REQUIRED PROFILE:

The student should have a particular aptitude for linear algebra, numerical methods, and programming. Knowledge of C programming is highly appreciated.

COMPENSATION: 4,35€ /hour – 35 hour-per-week

DURATION: 6 MOIS

LOCATION: TOULOUSE

RESPONSIBLE OF THE SUBJECT:

NOM : NASTRO

E-MAIL : gabriele.nastro@isae-supaero.fr

TÉL. : 05 61 33 87 89

APPLICATION PROCESS:

Applications (CV and transcripts) should be sent to gabriele.nastro@isae-supaero.fr and jerome.fontane@isae-supaero.fr

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