PHD THESIS PROPOSAL

Title : Numerical modelling of a plasma actuator for supersonic flow control

Reference : **MFE-DAAA-2023-19**

PhD start date : 10/01/2023	**Deadline to apply :** 07/31/2023

Keywords

Flow control, plasma actuators, boundary layer transition, drag reduction, high performance computing

Profile and skills expected

Knowledge of fluid mechanics, electromagnetism, plasma physics.

Numerical modelling, applied mathematics, high performance computing.

Good programming skills.

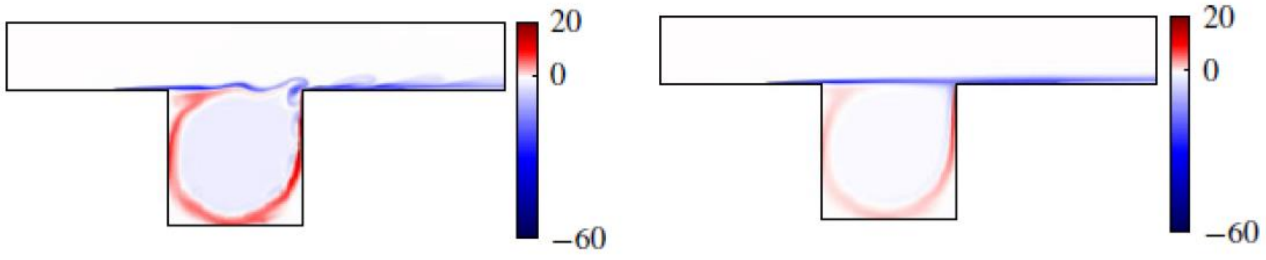
Writing skills. Fluency in English.

The candidate must be a citizen of the European Union, the United Kingdom, or Switzerland.

Presentation of the PhD project, context and objectives

ONERA has been considering for a long time plasma actuators for flow control applications [1-3], including plasma synthetic jets (JSP), Dielectric Barrier Discharges (DBDs), or high intensity laser discharges. One generally aims at reducing drag, suppressing and/or reducing aerodynamic instabilities, flow detachment, or noise. Plasma actuators are a great candidate for airflow control applications, since they do not require mobile parts, exhibit a relatively short time response, are light, and can be relatively smoothly embedded on an aerodynamic profile. Besides, plasmas may allow to reach thermal non-equilibrium between electrons and heavy-species [6] which can be beneficial for hypervelocity applications, where high temperatures must be avoided. However, current performances of plasma actuators are not sufficient so far, in particular for supersonic applications.

These physical limitations have led researchers to consider closed-looped flow control as a possibility to optimise the effect of plasma actuators [7]. Indeed, closed-looped control algorithms are known to require less energy than open-looped ones. Closed-looped flow control by plasma actuators has proven efficient at low, subsonic, speeds, but is still under development for higher velocities. One particular requirement at supersonic velocities, is a relatively high actuation frequency, in the range ($\sim 100\ \mathrm{Hz} - 10\ \mathrm{kHz}$), which may be attained with AC driven or pulsed plasma actuators.



Flow vorticity before the iteration process (Left) and after five iterations (Right) [7]

The aim of this thesis is to evaluate the effect of plasma actuators with respect to the fluid receptivity to forcing disturbances. This thesis will consider academic configurations, such as supersonic cavity flow, which is a two-dimensional configuration that poses serious difficulties for control of aerodynamic instabilities.

Given the range of actuation frequencies required ($\sim 250\ \mathrm{Hz} - 5\ \mathrm{kHz}$ for a Mach 1.6 cavity flow), it is probable that the actuation signal must be modulated. This is generally done using a carrier frequency much higher than the actuation frequency, in order to uncouple plasma generation from control signal. For that reason, in this thesis we will consider using nanosecond DBD discharges (ns-DBD), which can be driven with modulation frequencies in the range $0{,}1 - 10\ \mathrm{kHz}$ [8].

COPAIER is a plasma solver [9-10] which solves for the charged species densities and electric potential, and allows to compute the source terms experienced by the flow. COPAIER can be used to characterize the forcing and to derive the actuator transfer function. Obtaining the transfer function is complicated due to the strong time scale disparity between the plasma (ions, electrons) and the modulation signal. A naïve temporal integration might reveal too expensive. Therefore, we consider developing multi-time-scale numerical methodologies, so as to get rid of the fast (carrier) time scale. Two approaches are envisioned : a data-based approach (e.g. : time spectral method) and a physics-based approach (e.g. : temporal homogenization). The transfer function will then allow optimising the main actuator parameters (geometry, materials, etc.) with respect to the fluid receptivity to forcing.

One of the most crucial aspects of the thesis will be the study of saturation. Saturation happens when the forcing is not sufficient to obtain a tangible effect on the flow. This problem can be tackled numerically through CFD simulations accounting for physical constraints limiting the actuators' capabilities.

The PhD candidate will work in the team "Design and production of software for fluid flows" in the Aerodynamics, Aeroelasticity, Acoustics (DAAA) Department. The team is developing elsA software, which is an industrial CFD solver developed in partnership between ONERA and the French company Safran.

References :

[1] Applications of Dielectric Barrier Discharges and Plasma Synthetic Jet Actuators at ONERA, F. Chedevergne, G. Casalis, O. Léon, M. Forte, F. Laurendeau, N. Szulga, O. Vermeersch, and E. Piot, *Aerospace Lab Journal*, 10-06, **2015**

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Collaborations envisioned

Collaboration with CORIA Laboratory, Rouen, France.

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