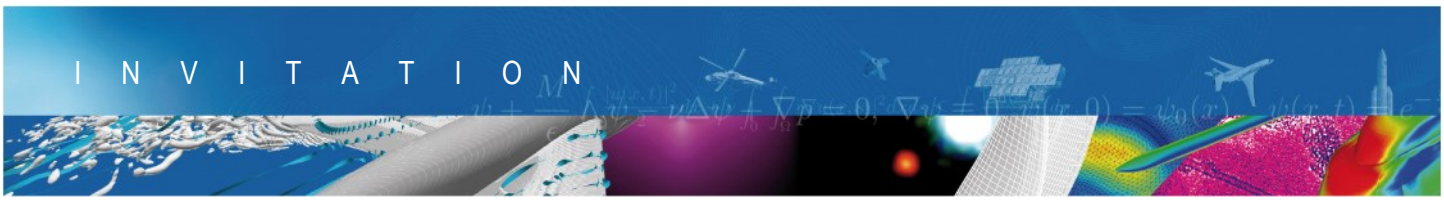

Numerical modeling of microwave plasma actuators for aerodynamic flow control.

Soutenance de thèse – Emanuele ARCESE
Vendredi 5 Juillet 2019 à 10h
Amphi 4 – ISAE-SUPAERO – 10 av. Edouard Belin – Toulouse

Devant le jury composé de :

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Résumé

In recent decades, microwave discharge plasmas have attracted increasing attention of aerospace scientific community to the subject of aerodynamic flow control because of their capability of substantially modifying the properties of the flow around bodies by effective energy deposition. The design and optimization of these plasma actuators as flow control technique require a comprehensive understanding of the complex physics involved that the sole experiments are incapable to provide. In this context, we have interest in the numerical modeling of the mutual interaction of electromagnetic waves with plasma and gas in order to better understand the nature of microwave discharges and their applicability. A challenging problem arises when modeling such phenomena because of the coupling of different physics and therefore the multitude of spatial and temporal scales involved. A solution is provided by this thesis work which addresses both physics and applied mathematics questions related to microwave plasma modeling. The first part of this doctorate deals with validity matters of the physical model of microwave breakdown based on the local effective field concept. Because of large plasma density gradients, the local effective field approximation is questionable and thus a second-order plasma fluid model is developed, where the latter approximation is replaced by the local mean energy approximation. This modeling approach enables to take into account the non-locality in space of the electron energy balance that provides a more accurate description of the energy deposition by microwave plasma leading to the shock waves formation into the gas. A dimensionless analysis of the plasma fluid system is performed in order to theoretically characterize the non-locality of the introduced electron energy equation as function of the reduced electric field and wave frequency. It also discusses other approximations related to the choice and method of calculation of electron transport coefficients. Concerning the mathematical aspects, the thesis work focuses on the design and the analysis of a multiscale method for numerically solving the problem of electromagnetic wave propagation in microwave plasma. The system of interest consists of time-dependent Maxwell's equations coupled with a momentum transfer equation for electrons. The developed approach relies on a Schwartz-type domain decomposition method, based on a variational formulation of the standard Yee's scheme, using two levels of nested Cartesian grids. A local patch of finite elements is applied to calculate in an iterative manner the solution in the plasma region where a better precision is required. The proposed technique enables a conservative local and dynamic refinement of the spatial mesh. A theoretical analysis of the convergence behavior of the iterative algorithm combined with an explicit or implicit time marching is then carried out.
In the last part of the doctorate, a series of numerical simulations of microwave breakdown and the filamentary plasma array formation in air are performed. The consequences of the different types of physical approximations adopted in the plasma fluid model are analyzed in depth. The numerical experiments then demonstrate the accuracy and the computational efficiency of the proposed patch correction method for the problem of interest.
Lastly, a numerically investigation of the effects of gas heating on the formation and sustaining of the filamentary plasma array in atmospheric-pressure air is conducted. For doing this, the developed microwave-plasma model is coupled with unsteady Navier-Stokes equations for compressible flows. The simulations provide interesting features of the plasma array dynamics during the process of gas heating, in close agreement with experimental data.

Mots-clés

microwave discharge, electromagnetic wave-plasma interaction, plasma fluid model, FDTD method, domain decomposition, multiscale spatial refinement, gas heating effects.

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