Denis Packan
(ONERA)
Research Scientist, Plasmas Applications and Electric Propulsion, Physics and Instrumentation Department

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Plasmas for Aeronautics

The potential of plasmas for aerodynamics and combustion has been known for many years, but a dedicated research domain has only started to significantly develop over the past 20 years (Ref. [1]). Based either on new technological advances, on enhanced numerical capabilities, or on new needs created by the aeronautical industry's quest for higher performance, the development of plasma actuators has now reached a point where an industrial application is within grasp. This tenth issue of the Aerospace Lab journal will present an overview of the research in this field. Due to the great diversity of the plasmas and of the applications studied in laboratories around the world, this overview is necessarily limited in its scope, but the main research areas will nevertheless be illustrated.

Plasmas are generally created by causing an electrical current to flow through a gas. The energy deposited results in effects such as chemical reactions, radiation, forces or heating in the gas, which can combine in different ways depending on the physical conditions and on the electrical discharge parameters. Numerical simulations are still challenging nowadays, because of the non-equilibrium nature of the physics involved. Indeed, the electrons are the main vector for the interaction with the gas (they excite, dissociate, heat-up, etc.), yet they are very complex to model: they generally are much hotter than the heavy species and their temperature is sometimes even not defined when they do not follow a Boltzmann distribution. This complexity also renders experiments difficult to interpret. However, distinct advantages of plasmas for aerodynamics and combustion have long been observed and are being studied.

For aerodynamics, plasma actuators have the unique capability of injecting momentum into an air flow without any mechanical movement. Beyond the cost / reliability advantage, this enables the use of high pulsed repetition rates, which can be tuned to a physical frequency of the flow, in order to achieve a resonant enhancement. Both supersonic (Ref. [2], [3], [4]) and subsonic flows (Ref. [5], [6]) are targeted, with plasmas that can vary widely in nature, from cold plasma such as coronas and Dielectric Barrier Discharges or DBDs, which act as "momentum injectors" mostly in subsonic flows (Ref. [5], [6]), to thermal plasmas used as "energy injectors" (Ref. [2], [3], [4], [6]). Plasma actuators are being developed to tackle important issues, such as aerodynamic instabilities, drag reduction (and hence fuel efficiency), or sonic bang attenuation, and the variety and complexity of the physics and of the experiments is a challenge that will be illustrated in all of the contributions to this issue.

Combustion is also a crucial issue in aeronautics, as jet engines seek ever higher combustion stability, fuel efficiency or startup flexibility, and plasmas have specific properties that make them well suited to address these issues. Whether plasmas are used for ignition or flame stabilization, several phenomena are at play. Combustion processes can be affected in particular by chemical kinetics enhancement, due to the creation of reactive species (Ref. [7], [9]) or by heating of the gas (Ref. [8]). In parallel, the actuations on the flow can improve fuel mixing or create stabilizing recirculation zones. These effects are often difficult to distinguish experimentally and even more difficult to model, which explains why maturity has not arrived yet. However, mastering all of them with plasma actuators could potentially lead to a breakthrough in such hot topics of jet engine combustion as lean combustion stabilization (for pollution reduction), supersonic combustion (for high speed transportation), low temperature ignition (for reliable in-flight restart) or even pulsed detonation engines (new technologies) ■

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