POSTDOCTORAL POSITION

Semiconductor-barrier plasma discharges for electric aerodynamic propulsion

Thrust generation by means of ion acceleration is a well-established mechanism of propulsion for applications in space but much less so in the atmosphere. Electric aerodynamic (EAD) propulsion presents important advantages over thermo-chemical devices. Thrust results purely from an aerodynamic effect of the ionized gas flow, so these new propulsion systems contain no moving parts, thus eliminating friction between solid components. As a result, they are mechanically static with very low noise and mechanical wear, and potentially high reliability. With appropriate design considerations, the onboard electronics can be sufficiently lightweight to achieve fully autonomous flight [1], and significant improvements in thrust-to-weight ratios can be expected with future advances in high-voltage and battery technology. High thrust-to-power ratios are already achievable, leading to the stationary flight of gliders [2], and are expected to increase with further research.

EAD technology is also an intriguing alternative to electric propeller engines for reducing carbon emissions and the environmental impact of aircraft, emitting naturally decaying gases without solid particles because no combustion occurs. The existing and future energy storage and supply systems currently adopted for powering electric motors would be highly compatible with EAD devices. If equipped with solar cells, then renewable energy could in principle power flight indefinitely because only atmospheric air is accelerated through the electrostatic device. The above advantages become particularly relevant for future flying platforms capable of playing the role of satellites while remaining in the high atmosphere. This could lower costs for many services currently reliant on satellites.

The principle of EAD propulsion relies on the generation of an air plasma to act as an ion source or "emitter". The ions then drift in an applied electric field towards an airfoil-shaped ground electrode or "collector", transferring momentum to the surrounding neutral molecules and producing an airstream often termed the ion wind. For aerodynamic reasons, the plasma shape should be long, thin, and uniform. To satisfy this constraint, most studies have employed corona discharges generated in a wire geometry. In one case, a dielectric barrier discharge (DBD) was employed [3]. However, corona discharges and DBDs produce low levels of ionization, resulting in limited thrust produced by ion wind propulsion. Many attempts at improving corona- and DBD-based propulsion, including by densifying emitter arrays [4], have met only limited success because of the electrostatic screening from multiple emitters [5].

Plasmas with higher levels of ionization could greatly increase the thrust achievable by EAD. However, generating such plasmas in high-altitude air while satisfying the constraints of EAD propulsion is challenging. One possibility is to create a glow discharge, which is typically difficult to stabilize in air at sea level, but less so with decreasing gas density at high altitude. There are a number of potentially interesting glows, such as nanosecond discharges [6], but generating the appropriate discharge shape would require electrode configurations that introduce unacceptably large obstacles into the flow.

A new type of surface discharge in a DBD geometry involving semiconducting materials [7], i.e. a semiconductor-barrier discharge, may overcome these drawbacks because the discharge is always homogeneous, unlike standard surface DBDs. Also, the energy coupling to the plasma is potentially much higher, which is indicative of high levels of ionization possibly similar to a glow discharge.

The objective of this project is to apply the semiconductor-barrier discharge to EAD propulsion. This will involve designing and building the plasma reactor, which will entail assembling layers of metal, silicon, and oxide using various film deposition techniques. Uniform plasma generation without streamers will be demonstrated and characterized using plasma diagnostics such as current-voltage measurements to determine the power consumption and the operational stability, fast imaging to confirm plasma uniformity, and optical emission spectroscopy (OES) to measure the electric field. The semiconductor-barrier discharge will be employed as an emitter in an EAD propulsion device. This will entail designing and building an emitter-collector configuration intended for propulsion at high altitude. The produced direct thrust will be measured using suitable load cells. The generated flow field will be characterized using different techniques.

Laser diagnostics of the electric field will be a key tool for evaluating EAD performance. Electric field-induced second harmonic generation (EFISH) [8,9] will be developed specifically for the EAD propulsion device to acquire, for the first time, detailed and time-resolved local electric field measurements in the drift region between the emitter and collector to characterize the charge injection. If possible, EFISH will also be used to measure the electric field in the plasma and compared with OES measurements.

Development and characterization of the semiconductor-barrier discharge will be performed at LPP, as well as development of the EFISH technique adapted to the EAD propulsion device. Development and characterization of the EAD propulsion device will be performed at IMFT and ISAE-Supaéro. This includes using an existing bench for thrust performance evaluation at IMFT but adapting it to the semiconductor-barrier discharge coupled with a static high-potential field, and rebuilding the EFISH diagnostic bench for measurements inside a wind tunnel.

References:

[1] Xu, H., He, Y., Strobel, K.L., Gilmore, C.K., Kelley, S.P., Hennick, C.C., Sebastian, T., Woolston, M.R., Perreault, D.J. and Barrett, S.R.H., (2018). Flight of an aeroplane with solid-state propulsion. *Nature*, 563(7732), pp.532-535.

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[5] Lemetayer, J., Marion, C., Fabre, D. Plouraboué (2022), F., Multi-inception patterns of emitter array/collector systems in DC corona discharge, *Journal of Physics D: Applied* 18, 55, 185203.

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[7] Darny, T., Babonneau, D., Camelio, S., & Pai, D. Z. (2020). Uniform propagation of cathode-directed surface ionization waves at atmospheric pressure. Plasma Sources Science and Technology, 29(6), 065012.

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[9] Adamovich, I. V., Butterworth, T., Orriere, T., Pai, D. Z., Lacoste, D. A., & Cha, M. S. (2020). Nanosecond second harmonic generation for electric field measurements with temporal resolution shorter than laser pulse duration. Journal of Physics D: Applied Physics, 53(14), 145201.

Field of research:
Plasma physics, electroaerodynamics

Background/skills sought:
PhD degree in physics, materials science, or a related discipline with a background in at least one of the following areas: plasmas, optical spectroscopy, and/or semiconductors.

Additional remarks:
Contract duration: 24 months. This position will be funded by the EIC Pathfinder project IPROP "Ionic Propulsion in Atmosphere".

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