PhD Project: Vortex-Enhanced High-Enthalpy Supersonic Plasma Flows

The School of Engineering and Technology at the University of New South Wales (UNSW) Canberra has an open PhD position in the field of plasma physics and electric propulsion.

Context

Radio-Frequency (RF) Inductively Coupled Plasmas (ICPs) can be used to heat an input gas to temperatures as high as 10,000 K. They consist of an RF coil wrapped around a hollow dielectric tube with neutral gas injected from one end and the opposite end terminated by a subsonic/supersonic nozzle. The RF current in the coil produces a time-varying electric field that can sustain a high-density, partially ionized, plasma that enables significant gas heating and allowing high-enthalpy gas flows to be generated.

The strong gas heating obtained in ICPs makes them useful devices for a number of industrial applications such as materials processing, nano-powder spheroidization and formation, gas conversion, analytical chemistry, and even as high-enthalpy flow generators for hypersonic and aerothermodynamics testing. They have also been proposed as novel electrothermal plasma propulsion systems (see Figure 1) where plasma-gas heating enables much higher temperatures to be obtained compared with combustion in chemical rocket engines. In all of the above applications, ICPs offer several unique advantages as they are essentially electrodeless discharges (with little or no erosion and consequent process contamination or lifetime limitations) and can be used with a wide range of gases.

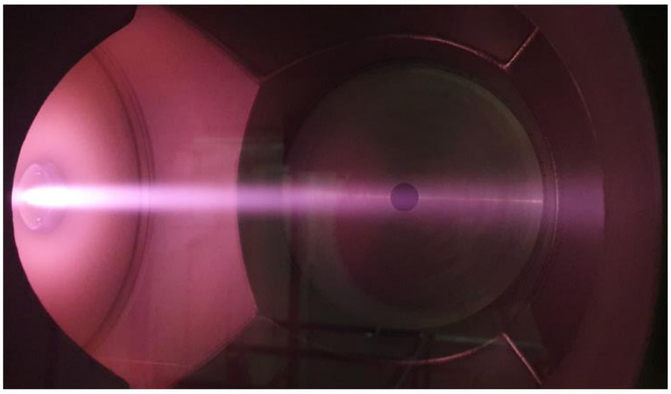

Figure 1: High-temperature plume from a prototype vortex-enhanced electrothermal plasma thruster.

Compared with many low-pressure plasmas, the gas injection configuration in ICPs plays a critical role in the overall stability and performance of the system and a limiting factor in many conventional designs is excessive heat losses to the walls. This is particularly true if a supersonic nozzle is used, since very hot gas must be forced through a relatively small nozzle throat. For some applications, such as space propulsion, heat losses currently represent a technical barrier to further technology development and adoption.

A promising and innovative gas injection technique is the bidirectional vortex, which makes use of counter-propagating vortices. Here, gas is injected tangentially from the *downstream* end of the ICP (just upstream of the nozzle). Due to its initial angular momentum, the gas first spirals up along the inner surface of the ICP tube towards the upstream torch end, before then reversing and spiralling back down towards the nozzle through the center of the tube. In this way, the gas flow field is segmented with a cooler outer vortex flow helping to cool and reduce heat losses to the walls, and a hotter inner vortex flow that allows most of the input gas to pass through the hot central plasma region. Such bidirectional vortex flows have successfully been used in liquid propellant chemical rocket engines and offer a number of advantages including enhanced propellant mixing and heating, reduced heat losses to the walls, smaller engine sizes, and the possibility of using alternative construction materials.

This project will numerically explore vortex-enhanced supersonic ICPs by using multi-physics simulations that couple fluid dynamics, plasma physics, heat transfer, and electrodynamics. This modelling will help to better understand the fundamental operation and physical processes in such systems and will prove vital for practical device development for future ground- and space-based applications.

Project Scope

This is a theoretical/computational project aimed at improving modelling of vortex-enhanced ICPs. The project will make use of an existing simulation code developed at the von Karman Institute (VKI) for Fluid Dynamics, and which will be modified to include supersonic nozzle flows, vortex gas injection, and relevant plasma chemistry.

The primary objective of the project is to better understand the unique bidirectional vortex flow fields and how these fields influence plasma generation and transport, heat transfer, and electromagnetic coupling with the ICP coil. The project will also study important scaling relationships, such as the vortex size relative to the nozzle, and the vortex gas injector geometry: factors which strongly affect system performance and stability.

An important part of the project will also include the comparison of modelling results with existing experimental measurements. This will serve to help validate the numerical simulations and will provide important insight to guide further research and technology development. There is scope for the student to perform some limited experiments with a prototype system to support model development and validation, but this is primarily a theoretical/numerical project.

Project partners

This project will be performed in collaboration with the Research School of Physics at the Australian National University (ANU), and with VKI in Belgium. There is potential for the student to occasionally visit ANU during their PhD and perform experiments to support the validation of numerical modelling results. There is also potential for the student to travel to VKI for several weeks/months to interact with project collaborators.

Candidate Profile

The ideal candidate will have a background in physics and/or engineering with strong mathematical, programming (ideally C++ and Python), and communication skills.

Contact

Express your interest in this project by emailing Dr Trevor Lafleur at t.lafleur@adfa.edu.au. Include a copy of your CV and provide a brief motivation that highlights your research experience.

https://www.unsw.edu.au/research/hdr/our-projects/vortex-enhanced-high-enthalpy-supersonic-plasma-flows

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