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NOVEL COUPLING METHODS FOR FLUID AND KINETIC SOLVERS IN THE NUMERICAL MODELING OF HELICON PLASMA THRUSTERS

Abstract

Helicon Plasma Thrusters (HPTs) are electric propulsion systems that offer many advantages over other systems, such as simplicity, flexibility, longer operational lifetime, and the ability to produce high-density plasma. Accurate modeling of plasma transport throughout the HPT is crucial to improve the understanding of physical phenomena within the plasma flow, optimize HPT design, and enhance thruster performance.

However, existing models for helicon sources and magnetic nozzles are separate, and coupling the two accurately is challenging. The plasma flow behaves differently in the source chamber and the magnetic nozzle, and the transition between these regimes is not well understood. To improve the accuracy of HPT modeling, a study is conducted to evaluate different coupling methods between fluid and Particle-In-Cell (PIC) solvers, with a focus on the 3D-VIRTUS numerical suite [M. Magarotto, S. Di Fede, N. Souhair, S. Andrews, F. Ponti, Numerical suite for cathodeless plasma thrusters, Acta Astronautica, Volume 197, 2022]. Two methods are investigated for mapping the transition between the fluid and kinetic regimes:

1. The first method involves finding the transition surface by analyzing the behavior of specific transition parameters, such as the plasma density and potential, which may vary depending on the particular HPT design and operating conditions. This method requires pre-modeling the entire thruster in the fluid model and mapping the transition surface to minimize the computational cost of applying the PIC model downstream of it.
2. The second method involves creating an artificial buffer region around or near the throat of the nozzle, where both fluid and kinetic regimes are solved simultaneously. This method requires iterative runs of the models with an updated plasma profile in the buffer zone.

Numerical simulations of plasma profiles of a real HPT thruster will be compared to experimental measurements for the different coupling approaches and analysed in terms of accuracy and computational

burden. Finding the best coupling method will not only improve the 3D-VIRTUS numerical suite's capability to simulate HPTs in an accurate yet computationally efficient fashion, but it will also provide insight into coupling other RF or microwave source chambers with magnetic nozzles in general.