Development of Advanced Plasma Simulation Models for Thruster Applications

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The magnetohydrodynamic (MHD) model has become the incumbent approach to predicting and modeling plasma propulsion systems. While the MHD model has enjoyed great success, particularly for high-conductivity plasmas, there can be cases where other plasma effects (such as violations to charge quasineutrality, electromagnetic wave propagation or species interactions) may be important. These effects could also be important to resolve for new plasma thruster concepts. Since these effects are not directly permitted within the MHD framework, this motivates the development of new physical models and numerical techniques to handle modeling these systems.

An example where the MHD model may break down is in the vacuum region surrounding a space plasma thruster. The high-conductivity plasma plume emerging from the thruster expands into a vacuum region, which is essentially a low-conductivity region. In vacuum, the wave nature of the magnetic field becomes dominant, whereas the MHD model assumes that the magnetic field may only diffuse. This problem has been solved previously by either (a) assuming that the vacuum can be adequately modeled using a low-density gas, (b) injecting field-carrying field into the computational domain, or (c) by applying empirical data from experiments to match the vacuum region. [1]

Motivated by a growing need for understanding and modeling these more complicated effects in plasma thrusters, new plasma models that depict a more physically complete character of the plasma are necessary. Two primary models are of interest: a single-fluid model that retains the full Maxwell equations, and the multi-fluid plasma model, wherein each species retains its own set of Navier-Stokes equations, all coupled through the full Maxwell equations. Both models are capable of capturing the multiscale interactions between the fluid and electromagnetics, and the two-fluid model is also capable of resolving inter-species effects. [1]

This presentation examines the state-of-the-art and current progress in developing new implicit, multidimensional finite volume solvers for plasma thrusters based on these more general physical models. These codes are capable of solving the coupled Navier-Stokes and full Maxwell equations, including multiple fluid models for different species; this allows the full character of the plasma to be resolved even for low-conductivity regions and parts of the domain where net charge or electromagnetic waves may appear. The solvers are implemented in a fast implicit scheme on unstructured meshes, which permits us to investigate the unsteady, full plasma behavior on complex-geometry devices. These new solvers facilitate the study of new propulsion concepts that possess much more complicated plasma effects that are not resolved in the MHD model.

[1] R. Thompson, T. Moeller and C. Merkle. “A Strong Conservation Formulation for Finite Volume Plasma Simulations with Displacement and Conduction Current.” 43rd AIAA Plasmadynamics and Lasers Conference, New Orleans, June 25-28, 2012.