A Consistent Kinetic Plasma Solver for the Computational Modeling of 2D Conductive Structures in Flowing Ionospheric Plasmas

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1 Background and Motivation

Current-collecting conductive objects in flowing, collisionless, unmagnetized plasmas are found in several applications, such as plasma diagnostic devices (Langmuir probes, Mach probes), in spacecraft charge control, and for bare electrodynamic space tethers. Space electrodynamic tethers offer the opportunity for propellantless propulsion of near-earth orbiting spacecraft, based on the conversion of the geomagnetic force on an electric current along a tether into a propulsive force. One of the key parameters affecting thrust is the current level flowing through the tether, which in turn is limited by the level of ionospheric electron collection. It is desirable to assess how the electron collection capability of various tether cross-section geometries, immersed in a flowing plasma, departs from that predicted by the Orbital Motion Limit, which is only valid in the case of thin wires in non-flowing plasmas.

2 Proposed Kinetic Computational Model

Existing models for the round cylindrical probe in flowing plasmas have assumed a symmetrical sheath potential. In this paper, we present a novel electrodynamic computational model based on kinetic theory that fully accounts for the sheath potential asymmetries induced by plasma flow effects. The model numerically solves, self-consistently, the Poisson and Vlasov equations for arbitrarily-shaped 2D conductive bodies in collisionless, unmagnetized, flowing 2-species plasmas(ions and electrons). The resulting solver allows representation of the complete, non-equilibrium arbitrary velocity distribution of both species within the computational domain, given Maxwellian populations at infinity. It provides an adaptive, unstructured meshing strategy and allows simulation of very large computational domains. Finally, it has a parallel implementation, such that it could be run on either a single host, a parallel architecture, or a scattered network of workstations.

The implementation of the solver consists of successive linearizations of the non-linear Poisson-Vlasov operator, within a Newton iterative process stabilized using the Tikhonov regularization procedure, which handles the numerical instabilities introduced by the use of large grid spacings. The Finite Element Method is used for the Poisson solver, while the inside-out trajectory tracking procedure, also known as the method of characteristics for partial differential equations, is used for the Vlasov solver.

3 Theoretical and Experimental Validation

The proposed model was validated against known 1-D results in the non-flowing case, existing approximate models for ion collection in flowing plasmas, published Mach probe simulation and measurements, and experimental data obtained as part of vacuum chamber tests on long collecting probes in a flowing plasma (Gilchrist *et al*, IEEE Trans. on Plasma Science, **30** (5), Oct. 2002).