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Simulation of Electric Thruster Plumes and Spacecraft Interaction with Hybrid Particle Codes

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Electric propulsion is gradually becoming the de-facto standard propulsion technique onboard modern satellite platforms. At the same time, this increasing popularity is demanding more and more accurate analyses of the expansion of electric thruster plumes into vacuum. Firstly, their interaction with sensitive S/C surfaces, such as onboard sensors and solar panels, has to be carefully evaluated, as the main plume ions and the secondary ions (generated by charge-exchange collisions) can hit and damage them through sputtering or deposition. Secondly, refined plume models are necessary in the design of a new contactless technique for active debris removal missions, named ion beam shepherd, in which the target object is relocated to a different orbit by means of the ion push of a plasma plume directed towards it. This technique, whose feasibility is being studied by the European Union LEOSWEEP project [1], clearly requires the knowledge of the spatial and time evolution of the plume properties, as well as other phenomena such as the target erosion and the back-sputtering towards the satellite (due to eroded target particles). For what concerns the plume simulation, this can be achieved by means of either fluid or kinetic models. The former can be applied with good results only in the far region of the plasma plume, sufficiently far away from the thruster exit [2] and their major limitation consists in the difficulty of modelling the lateral plume and the detailed energy distribution functions (strongly influenced by charge-exchange collisions). Kinetic models, on the other hand, do not present such limitations but generally require a much larger computational power. In order to study the plume expansion with reasonable computational power, while covering the above described phenomena and the particularities of a rapidly-expanding plasma into vacuum, we are developing 2-D and 3-D hybrid particle codes. An arbitrary number of heavy species populations (variable charge ions or neutrals of different species) can be simulated as in conventional PIC codes, while the “neutralizing” electrons are treated as a fluid. Heavy species particles are moved with a conventional particle mover and collisions are simulated with dedicated Montecarlo techniques. The electron fluid properties and the electromagnetic fields necessary to move the heavy particles and close the loop, are obtained, on the other hand, by imposing quasi-neutrality and by either assuming a simplified electron behaviour (Boltzmann or polytropic) or by solving the electron conservation equations. While the 2-D code can provide quicker simulation results, the 3-D code enables the study of interesting non-axially symmetric problems, such as plumes with a neutralizer (typically on one side of the thruster and emitting neutral atoms), different non-axisymmetric S/C shapes and also the effects of an oblique magnetic field (such as the geomagnetic field) on the plume expansion. This paper presents the development status and some results of both codes and benchmarks one against the other, through the simulation of the expansion of a collisionless and axisymmetric plasma plume. References [1] M. Ruiz, U. Urdampilleta, C. Bombardelli, E. Ahedo, M Merino, and F. Cichocki, “The FP7 LEOSWEEP Project: Improving Low Earth Orbit Security With Enhanced Electric Propulsion”, Space Propulsion Conference [2] M. Merino, F. Cichocki, and E. Ahedo. “Collisionless plasma thruster plume expansion model”, Plasma Sources Science and Technology, 24

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