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Author: Mr. Mario Merino
Universidad Politécnica de Madrid, Spain

Prof. Eduardo Ahedo
Universidad Politécnica de Madrid, Spain

ADVANCED PLASMA PROPULSION WITH MAGNETIC NOZZLES

Abstract

Advanced plasma thrusters are opening the way for exciting new missions and activities in space, such as efficient interplanetary travel based on optimized trajectories, economic station-keeping of Earth-orbit satellites, and lean deorbiting of space debris. The highly energetic plasma beams they produce, however, tend to erode and damage the materials of the thruster and can also affect the rest of the spacecraft, usually becoming the limiting factor for the thruster durability and the life of the mission.

An axisymmetric, slowly-diverging magnetic field can be used to confine and harness the hot plasma, keeping it away from sensitive surfaces and accelerating it into a high-velocity, well-collimated plume. In this manner, a "magnetic nozzle" can be produced, that mimics the behavior of a solid de Laval nozzle, with the advantages of reducing wall erosion and plasma losses, and allowing fine in-flight thrust and specific impulse control (by varying the intensity and geometry of the field). Several new plasma thrusters utilize magnetic nozzles for acceleration, including the Helicon Thruster (HT), the Variable Specific Impulse Magnetoplasma Rocket (VASIMR), or the Applied-Field MagnetoPlasmaDynamic thruster (AF-MPD). Magnetic nozzles are still novel devices, though, and many aspects of the physics of the plasma expansion and subsequent detachment from the magnetic field remain to be clarified.

In this contribution we will study the expansion and acceleration of the plasma to obtain the performance of these devices under different operating conditions, and investigate various physical mechanisms that are relevant for propulsion. Using an updated version of our DIMAGNO 2D fluid code for magnetic nozzles, we will analyze thrust gain, plume efficiency (divergence losse2s), force transmission to the thruster, and the balance between confinement and detachment downstream. The influence of electron thermodynamics, the relevance of the plasma profile upstream and the influence of non-negligible electron inertia will be discussed. The formation of electric currents in the plasma, both azimuthal and longitudinal, is recovered in the simulations. These currents play a central role in the electromagnetic interactions with the nozzle generator and produce their own magnetic field. Finally, we will comment on the axial torque delivered by the nozzle.