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MODELLING AND DESIGN OF EARTH AND MARS ATMOSPHERE-BREATHING ELECTRIC PROPULSION SYSTEMS (ABEP) USING A CATHODE-LESS RF THRUSTER

Abstract

Atmosphere-breathing electric propulsion (ABEP) is a concept that could transform space missions by using atmospheric air as a propellant source, eliminating the need for stored reservoirs. This sustainable technology has the potential to enable Very-Low Earth Orbit (VLEO) mission scenarios, providing a clean and efficient propulsion system for spacecraft. These missions offer a series of advantages, such as higher resolution communications and imagery, and shorter orbital periods. Moreover, the use of this technology may be extended to Mars orbit applications as well, by changing the gas combination in the design and optimization phase from nitrogen and oxygen to carbon dioxide. Due to the significant change of atmospheric composition with altitude, which decisively affects the performance of the ABEP system, accurately simulating ABEP plasma chemistry plays a crucial role in the mission design. However, achieving a correct estimation of the propulsive performance represents a challenging task, as a result of the highly complex plasma dynamics. This is due to the presence of both atomic and molecular particles as well as the large number of species interactions to be taken into account. In this study, a series of numerical tools have been developed with the aim of estimating the performance of an ABEP system using a cathode-less radiofrequency (RF) plasma thruster. First, a Direct Simulation Monte-Carlo (DSMC) simulation of the intake is carried out at different altitudes and atmospheric compositions; the resulting flow properties (e.g. mass flow rate and velocity) are then used as input to a 0D Global Source Model (GSM) that evaluates the generation of plasma inside the ionisation chamber. Lastly, the plasma expansion in the magnetic nozzle is simulated by means of a fully-kinetic 2D3V Particle-in-Cell model. The modelling of the background neutral density of the atmosphere and its interaction with the plasma plume has been included as well; this negatively affects the performance of the magnetic nozzle. Different intakes designs (e.g. diffuse and specular) are considered, in order to design an inlet that is robust to changes in the atmospheric conditions. To achieve this goal, several scenarios of altitude and chemical composition are simulated, both for a terrestrial and a Martian environment. The operating power required by the cathode-less RF thruster to achieve a break even condition (i.e. thrust fully compensating the atmospheric drag) is then evaluated and used as input to estimate the overall performance and efficiency of the thruster.