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MODELLING AND CHARACTERISATION OF PLASMADYNAMIC DRAG ON GRIDDED ION ENGINE PROPELLED SPACECRAFT IN VERY LOW EARTH ORBIT

Abstract

This work presents particle-based kinetic simulations of Gridded Ion Engine (GIE) plasma plumes, in an analysis of the modified spacecraft drag profile, resultant of plume interactions with ambient thermosphere, in Very Low Earth Orbit (VLEO). VLEO is a highly appealing region for spacecraft operations, as reducing the operational height of remote sensing payloads improves radiometric performance, whilst reducing size, mass, power, and costs required of the unit. VLEO operation therefore offers high-performing economical spacecraft platforms, but the mission lifetime is very limited owing to high drag from the residual atmosphere. Detailed characterisation of plume dynamics is vital in exploring the feasibility of Electric Propulsion (EP) as means of continuous drag compensation at such altitudes and mitigating thruster-self-induced drag mechanisms. This research considers the previously undocumented interactions between EP plumes and onset plasma flow, while also extending on the detailed studies of in-orbit drag by including interactions of EP operation. Investigations were conducted for orbital altitudes of 150-400km, where the highest concentration of ionosphere free electrons and ions was assumed to cause most critical influence on the flow regime, modelling a prograde firing T5(UK-10) GIE. The plume expands into a rarefied environment of both neutral and charged particles, which required implementation of the hybrid 'Direct Simulation Monte-Carlo' - 'Electrostatic Particle-in-Cell' (DSMC-ESPIC) method, with density and species compositions obtained from the International Reference Ionosphere IRA-2012 and NRLMSISE-00 Atmospheric Model. It is shown that the flow profile is affected by a combination of collisional and indirect electrostatic field mechanisms. In the immediate aft region of the spacecraft, the interaction is driven by pick-up of freestream ions within the charge-exchange cloud. The main effect of the plume is to simply deflect the thermosphere freestream as freestream ions collide with primary beam propellent and accelerate under the thruster potential. Unbounded ion jets form from collisional exchange at the primary beam edge, and where the energy of freestream ions was enough to penetrate the main plume, it was found that the plume ions may couple with the freestream to form collective electrostatic instabilities. The plume and freestream mix into an isotropic structure, which raises the possibility that far-field interactions beyond the scale investigated here may occur. The consequences of the observed plasmadynamic mechanisms on the spacecraft drag profile are theorised, and it is shown that effects of EP plume plasma in VLEO should be included in future analyses, to ensure drag models are complete.