Ion Propulsion-Solar Wind Plasma Interactions

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It's well understood that electric thruster plume may induce various environmental interactions. Previous studies of plume interactions have concentrated on charge-exchange ion contamination for ion thrusters, while other aspects of plume interactions, including the effects of an external field and external plasma environment, have not been studied extensively. In this paper, we present a general analysis of ion thruster induced plasma environment for interplanetary spacecraft and characterize the effects of ion propulsion-solar wind interactions.

We show that, in addition to the spacecraft potential, the solar wind electromagnetic field and wave-particle interactions play an important role in ion thruster interactions for an interplanetary spacecraft. From the plasma interaction point of view, the new born ions introduced by an ion thruster fall into two different velocity distributions in the spacecraft reference frame: distribution-1 (formed by the propellant ions) is a cold beam velocity distribution function with drifting energy about 1 KeV and temperature less than 0.1 eV; and distribution-2 (formed by the ionized neutrals) has a more isotropic distribution with temperature of about one to a few eV. The spacecraft potential affect the dynamics of distribution-2 ions. Such interactions, which are electrostatic in nature, determine the near field spacecraft environment. Far away from the thrust exit, where the density of the ion thruster plume becomes sufficiently low, both the distribution-1 and distribution-2 ions can couple with the solar wind protons through collective plasma effects. Several types of electromagnetic instabilities may develop, including the ion cyclotron instability, the Alfven-like turbulence, and the fire hose instability. These instabilities can drive large-amplitude electromagnetic fluctuations, which in turn will scatter the ions originated from an ion thruster. Since the wave length of these instabilities is typically much larger than the dimension of a spacecraft, such interactions determine the far-field spacecraft environment. In this paper, electrostatic and electromagnetic hybrid particle simulation codes are used to analyze both the near-fiels and far-field interactions. Finally, we apply our analysis to predict the effects of the NSTAR ion thruster on the New Millennium Deep Space One spacecraft.