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Full PIC simulations on plasma electromagnetic disturbance in the vicinity of spacecraft

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Space exploration has been rapidly increasing, and a strong demand arises regarding comprehensive understanding of spacecraft-plasma (SP) interactions [1]. This is clearly required to ensure survivability and proper operations of space-based systems, and also for correct interpretation of measurements and other information collected in situ by scientific spacecraft.

In space environments, spacecraft are electrically charged due to plasma contact to spacecraft surface and its floating potential is basically determined by the current balance at spacecraft surface. The current consists of incident background plasma, emission of photoelectrons/secondary electrons from spacecraft surface as well as active emission of plasma beam in electric propulsion system such as ion engine. Due to the spacecraft charging, plasma environment near spacecraft is influenced. Non-uniform plasma distributions such as sheath and wake structures are formed near spacecraft surface and in the downstream region with respect to the solar wind, respectively. Field components near spacecraft can be also disturbed by the plasma response to spacecraft. Understanding of the SP interactions is important from a view point of spacecraft observation of plasma environment as well as its data analysis. To discriminate plasma phenomena artificially disturbed by spacecraft from observational data, quantitative understanding of SP interactions is necessary. In designing science instruments such as electric field sensor, plasma disturbance near spacecraft has to be minimized as much as possible to obtain reliable and valuable data. To obtain self-consistent solution of these plasma disturbances near spacecraft, we perform plasma simulations including spacecraft body in a simulation domain.

For solving SP problems, we have developed the EMSES plasma particle simulation code [2]. EMSES is based on the standard electromagnetic PIC method, and also has the capability to include the conducting bodies of a spacecraft, based on the capacitance matrix method. In addition, a number of crucial physics such as the photoelectron emission and the secondary emission are modeled numerically in the latest version of EMSES. The code has been applied so far to some specific spacecraft, e.g., Geotail, Cluster, BepiColombo/MMO, and Solar Probe Plus.

In this talk, first we will briefly explain the numerical treatment of spacecraft in EMSES. Then we will show a few examples of EMSES applications to scientific spacecraft. One of such applications is an enhanced wake formed behind the Cluster satellite in tenuous streaming plasma [3]. In the simulation we have included the conducting surfaces of very thin (in an order of mm) wire booms by using the fictitious surface technique. We found that even the extremely thin wire booms can contribute substantially to the formation of an electrostatic wake because of highly positive spacecraft charging in the tenuous plasma environment. We will also show a recent research topic on the SP interactions in the near-Sun environment. Large photoelectron emission current caused by an intense solar flux forms a negative potential barrier on the spacecraft surface, leading to negative charging of the spacecraft. Electromagnetic environments around these specific spacecraft will be presented in the talk.

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[2] Y. Miyake and H. Usui, A new electromagnetic particle code for the analysis of conductive spacecraft-plasma interactions, Physics of Plasmas 16, 062904, 2009.

[3] Y. Miyake, C. M. Cully, H. Usui and H. Nakashima, Plasma particle simulations of wake formation behind a spacecraft with thin wire booms, Journal of Geophysical Research: Space Physics, Volume 118, Issue 9, pages 5681-5694, September 2013.

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