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Interactions Between Spacecraft and Thruster Plumes

WHEN in orbit, spacecraft require on-board or secondary propulsion systems to perform orbit transfer, orbit maintenance, and attitude control maneuvers. An important issue in the use of any secondary propulsion system involves the assessment and reduction of any effects caused by interaction between the host spacecraft and the thruster plume. The interaction effects fall into a number of categories that vary in their significance with thruster type and task. Potential interaction effects that apply to any thruster system involve direct surface impact or the scattering of part of the plume from one spacecraft surface to another. Direct surface impacts by the thruster plume can generate turning moments on the spacecraft that must be corrected and that can cause localized heating of the spacecraft. The adsorption of propellant effluents on spacecraft surfaces can also create several operational concerns. The adsorption of molecules on solar arrays and thermal control surfaces can lead to decreased power production and increased spacecraft temperatures.

Most of the satellites that have been launched and operated have employed chemical systems using hydrazine propellant for secondary propulsion. A key spacecraft interaction effect for these thrusters is the potential deposition of highly condensible ammonia (an abundant product of hydrazine decomposition) onto solar cells. A significant layer of ammonia can accumulate over the 10- to 15-year lifetime of communications satellites, causing significant degradation in the power subsystem. In recent years, the advantages of electric propulsion have been incorporated, such as in the Xenon Ion Propulsion System (XIPS) developed by Hughes. For the main electric propulsion systems (ion thrusters such as XIPS and the NSTAR thruster used on NASA's Deep Space-1 mission, and Hall thrusters), one of the main integration issues concerns impacts of high-energy ions on spacecraft surfaces that can lead to direct sputtering of the surface materials. Sputtering can adversely affect the nominal thermal, electrical, and optical properties of materials.

Although there have been few reported incidents of spacecraft failing because of spacecraft interaction effects from the secondary propulsion system, the tighter margins of contemporary spacecraft operation require improved optimization of all spacecraft systems. Improved assessment of the interaction potential of a thruster may also allow propulsion systems on spacecraft that are extremely sensitive to contamination concerns. Accurate prediction of plume interaction effects is technically challenging. It is very difficult and expensive to recreate the in-orbit environment within a ground-based laboratory facility. In terms of modeling, the flow physics associated with chemical and plasma propulsion systems is complex, requiring the development of advanced numerical techniques. In the past, due to the lack of detailed information, the prevention of the plume effects described here has been achieved primarily using very conservative spacecraft design. In the past few years, significant advances have been made in terms of both experimental facilities and numerical methods for the measurement and computation of the plumes of spacecraft secondary propulsion systems.

Therefore, this is an appropriate time to provide a summary of the present state of the art in this important area of spacecraft design. The papers included in this summary include investigations on chemical and electric propulsion systems. Results are presented from flight experiments, laboratory experiments, and numerical simulations. As new thruster technologies are developed, investigations of spacecraft-thruster interactions will continue, and as new spacecraft technologies are developed, these studies will become increasingly important.

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