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STATUS AND FUTURE OF RESEARCH ON PLUME INDUCED CONTAMINATION

Abstract

Spacecraft typically rely on chemical propulsion systems for active attitude and orbit control during cruise stage, and for entry, descent and landing on planetary surfaces. Besides thruster performance parameters, spacecraft and mission designers must account for thruster plume impingement on adjacent surfaces (on the flight system or on planetary surfaces). Plumes of chemical thrusters invariably interact with spacecraft surfaces, as the vacuum environment allows them to expand to well upstream the nozzle exit plane. Thruster plumes are thus a source of parasitic forces, moments, heat loads, and particularly of contamination and surface erosion. Plume contaminants may be gaseous, liquid or solid and have been demonstrated to severely degrade functional surfaces on spacecraft, affecting power and thermal budgets, as well as scientific payloads and mission design. Plume induced contamination can also impact mission science objectives since contaminants contains both organic and inorganic compounds, and current missions have highly sensitive instruments targeting detection of organics and life markers. It is thus mandatory to conduct plume contamination analyses when designing a space mission. As mission science objectives and evolving scientific instrumentation put ever more challenging constraints on contamination control, this paper reviews the existing plume induced contamination and erosion measurements on which current models rely. The data available from both, ground-based chamber tests and on-obit flight experiments, is very limited. Most of the measurements obtained in ground-based vacuum facilities were conducted in the decades of the 1970s and 1980s, in vacuum environments that did not allow for prolonged free thruster plume expansion, and most of the data was taken near plume centerline. Shuttle-borne on-orbit experiments SPIFEX and PIC provided measurements of plume induced contamination as well as droplet impact damage, but give only integral account of liquid phase contamination at coarse spatial resolution. From the reviewed data, we identify several unexplored aspects pertaining to plume induced contamination, such as the impact of thruster start-up and shutdown on the production and distribution of droplets and particulates, the spatial, temporal and size distribution of droplets and particulates in the plume during start-up, steady-state and shutdown phases, the chemical composition of plume effluents, such as partial combustion/decomposition reaction products and the previously observed non-volatile residue, and the optical properties of plume deposits. We identify the need for further development in thruster plume modelling as well as ground-based and on-orbit testing, and propose a road map to improve plume induced contamination predictive capabilities by lowering model uncertainties.