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TRANSFORMING ELECTRIC PROPULSION WITH DIGITAL TWINS: GROUNDBREAKING PROMISES AND FOUNDATIONAL GAPS

Abstract

The rapidly evolving market demands due to the emergence of the "New Space Economy" and the "Future Space Ecosystem" paradigms have instigated a revolution in the space industry. Electric Propulsion (EP) serves as one of the key enabling technologies in this new space era, noting the myriad of next-generation space missions and applications that it underpins, from near-Earth constellations and on-orbit servicing to interplanetary exploration. Nonetheless, the EP industry has been struggling for decades with non-concurrent, resource-demanding, time consuming, and largely empirically based development and qualification strategies that are incompatible with the emerging end-user reliability and flexibility requirements.

A digital twin (DT), i.e., a technology capable of providing an accurate and dynamic virtual representation of a physical device, is a game-changing concept beyond the common norm of simulation and modelling. DTs catalyze the transcendence of the EP industry toward streamlined, efficient, and methodical computer-aided design and development processes. They also underpin an automated and robust in-space operation and control of the propulsion system compatible with the full-autonomy requirements of future space missions and spacecraft platforms.

Despite the above revolutionary promises, there are several foundational gaps to achieve fully scalable DTs, which can be transversally applicable across all EP technologies and can represent the full spectra of the complex, multiscale, and multiphysics phenomena occurring during the operation of an EP device. In part, the foundational gaps extend across the simulation capabilities, verification/validation methodologies, and diagnostics/sensing.

In the full article, we will report the vision and the progress of a General Support Technology Programme (GSTP) grant awarded recently by UKSA/ESA to Imperial Plasma Propulsion Laboratory. This project aims to deliver the foundational software building blocks of the DTs, focusing on the Hall thruster technology as a proving ground. The paper will detail the significance of the DTs for EP within the broader framework of ESA's roadmaps and aspirations. It will also discuss the project's approach toward defining a first-of-its-kind computer-aided qualification strategy that features the DT technology at its core.

We will conclude by underlining the crucial role of timely investments to realize fully fledged, fully verified DTs for EP. The necessity for a coordinated effort among the academia, industry, and the decision-

making/regulatory bodies will be highlighted in order to ensure that the DT-enabled computer-aided qualification strategy would be pragmatic and widely accepted.