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Editorial

From Satellite Systems Design, Verification, and Testing to Spacecraft Operations

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1. Introduction and Scope

In contemporary space missions, spacecraft design, verification and validation, and operations can no longer be regarded as separate phases addressed in isolation. As space systems become more capable, more autonomous, and increasingly software-intensive, the path from concept development to in-orbit deployment requires engineering approaches that are rigorous, integrated, and operationally aware. In this context, the connection between system design choices, testing strategies, and operational readiness becomes a central issue for both large spacecraft and smaller satellite platforms.

Lifecycle-oriented model-based systems engineering has been proposed to maintain consistency of spacecraft information across project phases and to support integrated engineering processes beyond early concurrent design studies [1]. Related work on model-driven environments for on-board satellite software further shows how structured digital artifacts can support configuration control and deployment during development and validation activities [2]. In parallel, recent contributions on digital twins in aerospace engineering have emphasized both the constituent elements of these approaches and their lifecycle value for development, validation, risk reduction, and sustainment [3,4]. Representative hardware-in-the-loop facilities remain equally important for experimentally validating guidance, navigation, and control strategies in proximity operations and formation flying [5]. At the same time, research on the automated operations of distributed satellite systems and recent reviews on trusted autonomous satellite operations underline the growing need for scalable, trustworthy, and increasingly automated operational concepts [6,7]. Taken together, these studies strengthen the rationale for considering design, verification, testing, and operations as tightly coupled elements of a single engineering continuum.

It is therefore my pleasure to introduce the *Aerospace* MDPI Special Issue “From Satellite Systems Design, Verification, and Testing to Spacecraft Operations”, which was conceived as a forum for contributions spanning the spacecraft lifecycle, from system and subsystem design to verification, testing, and operational use. Its scope intentionally includes analytical, numerical, experimental, and application-oriented studies on spacecraft modeling, subsystem integration, on-board software, digital twins, hardware-in-the-loop environments, mission analysis, autonomy, and operational methods. The papers collected in this issue reflect this breadth: they address digital-twin-based development and testing, hardware-in-the-loop validation, model-based systems engineering, preliminary mission and trajectory design tools, onboard artificial intelligence, and advanced positioning methodologies with clear operational relevance.

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2. Contributions

Seven high-quality papers were submitted to this Special Issue, covering several topics across the broad spectrum of the addressed themes. Read together, they suggest a clear message: spacecraft engineering is best understood not as a strictly sequential chain of isolated phases, but as a set of tightly coupled activities in which design choices, validation environments, and operational concepts continuously inform one another.

The first theme emerging from this Special Issue is the effort to reduce the distance between what is assumed during development and what can be demonstrated during verification. In [8], a digital-twin framework is proposed for spacecraft on-board software development and testing, with real-time execution and fault injection used to assess software behavior in both nominal and contingency scenarios. At the subsystem level, Casado et al. [9] present a digital twin of a 6U CubeSat electrical power system, showing how real-time models can support both control-hardware-in-the-loop and power-hardware-in-the-loop activities while also reproducing orbital operating conditions. These virtual assets are complemented by the work of Governale et al. [10]. In this work, a compact tip-tilt flat-table facility for hardware-in-the-loop testing of spacecraft relative dynamics and tethered satellite systems is described. Considered together, these contributions show that the value of a digital or experimental test environment lies not only in fidelity but in its ability to become a practical engineering instrument early enough to guide design choices before they are frozen.

The second theme concerns structured mission and system design under tight constraints. Nardi et al. [11] discuss the BOREALIS 6U CubeSat mission and show how model-based systems engineering can support the transition from mission concept to design trades, requirement management, and configuration assessment. Their case study is especially relevant because it links a compact scientific mission to ambitious orbital transfer objectives, illustrating that even comparatively small platforms benefit from a disciplined, model-centered engineering process. Fan et al. [12] address another early-phase design problem, namely the initial trajectory design of multi-target electric-sail missions. By proposing a fast optimization framework that incorporates gravity assists, they highlight the importance of preliminary design tools that can screen mission opportunities efficiently before moving toward more detailed analyses. Although these papers address different mission classes, both underline the importance of keeping early design connected to downstream feasibility, implementation, and operational realism.

This Special Issue also reflects the progressive shift from conventionally operated satellites to platforms that must process more information on board and respond more rapidly to changing environments. Yu et al. [13] tackle this issue in the context of dynamic LEO satellite networks by accelerating CNN inference for DQN-based routing on GPU-enabled embedded hardware. Their contribution is valuable not only because it improves computational performance but because it addresses the practical question of whether advanced decision-making methods can actually run within the constraints of spaceborne systems. From a different but complementary perspective, Yu et al. [14] examine long-baseline real-time kinematic positioning using combined BDS, GPS, and Galileo observations, together with Kalman filtering and partial ambiguity resolution. Their results point to the continuing importance of robust estimation and multi-constellation integration for high-precision operations. Together, these contributions indicate that spacecraft operations are increasingly shaped by the interplay of onboard computing, communications, and navigation performance.

Finally, the collection reminds us that spacecraft engineering remains inseparable from mission purpose. The paper by Fan et al. [12] extends the Special Issue toward deep-space architectures, while the BOREALIS mission study [11] and the CubeSat power-system digital twin [9] keep the focus on small-satellite practice and development constraints. This coexistence of large conceptual questions and highly practical validation problems is, in many respects, one of the strengths of the field. Spacecraft engineering advances not only through new mission ideas, but also through the steady refinement of the methods that make those ideas verifiable, testable, and operable.

3. Conclusions

No Special Issue can cover the full breadth of a domain as wide as spacecraft design and operations. Nevertheless, the diversity of the papers gathered here is itself instructive. Across different mission scales and technical emphases, three needs recur: representative models, credible validation assets, and operational intelligence that can run within real mission constraints. The collection therefore suggests that the most useful future advances will likely come from tighter continuity across phases—from design models that remain meaningful during testing, from verification environments that inform operational preparation, and from operational concepts that are considered already in the earliest design trades. In this sense, the main lesson of the Special Issue is less about any single method than about the quality of integration among systems engineering, software, guidance and navigation, testing, and operations.

I would like to sincerely thank all authors who contributed to this Special Issue for the quality of their work and for the trust they placed in this initiative. I am equally grateful to the reviewers for their careful assessments and constructive suggestions, which helped to strengthen the published papers. Finally, I wish to thank the *Aerospace* Editorial Office for its consistent support throughout the organization and completion of this Special Issue.

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