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Editorial

Editorial for Special Issue: Recent Advances in Space Debris

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The near-Earth space debris environment represents an existing hazard for human activities in space. The increasing number of man-made objects resident in orbit leads to a growing risk of collisions involving active spacecraft, which could cause anything from the loss of important functionalities to vehicle break-up and, in parallel, the fragmentation of satellites that are no longer operational. The scientific community worries that such a process may lead to large fragmentation events and a cascade effect that would prevent the safe access and exploitation of entire orbital regions.

Addressing the space debris problem and finding potential mitigation solutions is a challenge that requires a holistic approach and the collaboration of all involved stakeholders. It is of paramount importance to clarify the mechanisms that lead to the generation of space debris and their distribution at different altitudes, especially in crowded orbits, and to find strategies by which to remove potential sources of novel debris (e.g., end-of-life satellites, spent rocket stages). In this Special Issue, three of the main investigative lines concerning space debris are presented: (1) understanding the physical processes behind in-orbit fragmentation; (2) assessing the in-orbit population of space debris; and (3) developing mitigation strategies and enabling technologies by which to remove end-of-life satellites and large relicts from non-operational spacecraft.

The direct observation of space debris collisions in space is extremely difficult; for this reason, on-ground impact testing and numerical simulations are the most frequently employed methods by which to investigate the relevant fragmentation physics and to evaluate the survivability of space shields and structures. In this context, in the Special Issue's feature paper [1], the authors present a review of the experimental and simulation activities performed in a research laboratory, describing the main findings and underlining the importance of such activities for better understanding the space debris problem. The importance of experimental facilities is also addressed in [2], where the authors introduce advances in the technologies currently employed in hypervelocity testing. Both the complexity and the advantages of numerical simulations are well addressed in [3]; the authors describe the analysis of heterogeneous materials subjected to impacts and present the simulation of single- and multiple-space-debris impacts. To quantitatively assess the survivability of spacecraft structures after impact, ballistic limit equations are often employed; these represent a fundamental tool in the risk assessment and design of spacecraft protection. In [4], the authors present the extension of BLEs for foam-filled dual-wall systems, showing how the comparison between test data and numerical simulations can lead to a marked improvement in the prediction capability of such a useful tool.

Understanding the physics of space debris generation can help in defining and modeling the future trends of the space debris environment; however, the investigation and cataloguing of the current population is a fundamental step in assessing risks and suggest mitigation strategies. Observations can be performed both from large ground facilities and via distributed in-orbit systems. In [5], the authors provide an improved method for determining the orbital parameters of space objects obtained via very short arc observations from a ground telescope; it is shown that this method has a high success rate and can be employed for the rapid assessment of fragmentation events. With respect to in situ observation, in [6], a model for designing and assessing the efficiency of a constellation for space debris observation is presented; through long-term continuous observation, these constellations could maintain an orbit catalogue of the majority of the objects in LEO, and they could also provide up-to-date information for space situational awareness.

In addition to collision modeling and population cataloguing, active ons shall be taken in order to mitigate the risk of further pollution in Earth's orbit. Removing spacecraft at the end of their operational life, or when otherwise malfunctioning, requires state-of-the-art technologies and complex mission architectures. First, cooperative or non-cooperative targets shall be safely approached and observed in order that we might assess their structural integrity, status, and attitude. In [7], an architecture based on binocular and time-of-flight cameras is implemented to reconstruct the pose of an uncontrolled target, and experimental results indicate good accuracy in reconstructing the pose, with position errors within 1 cm and angular errors below 1 deg for low-speed tumbling. Another complex task is the creation of a mechanical joint between the target and a servicing or deorbiting module. In [8], a versatile interface that can also be fit in CubeSat-sized vehicles is presented, and it effectiveness in performing soft-capturing with uncooperative targets is assessed. The removal of space objects requires the performance of orbital maneuvers, which can be performed by active and passive systems. In [9], a comparison of existing strategies is performed, indicating the strength and the limit of the different approaches. In addition, the author suggests that for LEO satellites, low-thrust propulsion combined with drag augmentation systems could be an effective and low-cost solution for both drag compensation during operations and controlled re-entry at end of life. Among drag augmentation devices, drag sails already represent the state of the art. In [10], the authors present an in-orbit demonstration performed by a micro-satellite equipped with a sail that, despite a few subsystem failures, was still capable of lowering the spacecraft altitude from 500 km to 400 km.

The collection of papers in this Special Issue represent the state of the art in space debris research. Addressing this issue with competent and effective strategies is a complex challenge for all of the involved stakeholders; as editors of this Special Issue, we hope that the works published herein will increase public awareness of, and stimulate further research on, this captivating and crucial topic.

Acknowledgments: We wish to thank the authors contributing to this Special Issue. Their effort in presenting state-of-the-art works was paramount to the success of this Special Issue, and the high quality of the submitted works underlines the importance of researching the physical processes of space debris generation and the mitigation strategies necessary to maintaining safe access to Earth's orbits.

Conflicts of Interest: The authors declare no conflicts of interest.

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