aerospace

MDPI

Editorial

Laser Propulsion Science and Technology

John E. Sinko [1,2]

[1] Department of Mathematics and Physics, Saint Cloud State University, Saint Cloud, MN 56301, USA; jesinko@stcloudstate.edu

[2] Institute for Materials, Energetics and Complexity, Saint Augusta, MN 56301, USA

Laser propulsion is an advanced technology that holds promise for use in many aerospace propulsion applications. This Special Issue series provides a snapshot of current activities at the forefront of research on the science and technology supporting laser propulsion applications and potential missions.

The first volume of this 2024 Special Issue is dramatically highlighted by the paper of Ye, Wang, Chang, Hong, Li, Zhou, Xing, Du, and Xie publicly reporting the first-ever data from on-orbit testing of a laser microthruster [1]. This news is a particularly exciting development in the field and may pave the way for future research on orbit. The paper by Ma et al. [2] addresses the significant threat of Earth orbit-crossing asteroids, reporting much-needed data on asteroid simulants. Insightful papers by Keil et al. [3] and Scharring and Kästel [4] address laser propulsion as a technology that may provide useful outcomes in Laser Orbital Debris Removal (LODR). LODR may be able to address some aspects of the long-term growth in the amount of orbital debris around Earth, prolonging our practical use of orbital space. Moving from space to micro-scale laboratory experiments on direct laser ablation of sample materials, Liu, Ye, Li, and Gao [5] explore the morphological characterization of craters from the nanosecond ablation of metals, and Yu et al. [6] explore the nanosecond ablation of copper, focusing on the plasma plume. Moving into the realm of airbreathing laser propulsion, the works of Sagamura et al. [7] and Matsui, Komurasaki, Kanda, and Koizumi [8] explore novel aspects of detonation waves in laser propulsion. The above eight papers represent work ranging in scope from debris removal to thrusters, from remote to onboard applications, and from operation in the ambient vacuum of space to ambient atmospheric air conditions. I hope to attract more reports on additional substantial progress in the field of laser propulsion in the second volume of this series.

The international laser propulsion field was focused for much of its initial decades on inexpensive launch from ground to orbit. With the benefit of hindsight, this goal may well be beyond practical achievability. Nevertheless, the early work in the field laid the groundwork for future progress in many directions and many interesting applications developed from this initial work. A steady development of lasers throughout the years has facilitated tests that move beyond the older gas and chemical laser regimes to more compact and reliable solid state lasers and more recently diode pumped disk lasers, fiber lasers, and other technologies that push the boundaries of efficiency, power, beam quality, etc. The further development of femtosecond and shorter lasers has pushed ablation into previously unknown, higher peak power regimes accompanied by extreme physics. This growth in the technology of lasers has enabled corresponding advances in technologies with applications ranging from basic research and civilian manufacturing to secure long-range communications and warfare. Within this context, laser propulsion continues to serve as one of several inoffensive testbeds for high power and high energy laser technologies.

Although division often reigns in this world, certain problems require a unified international approach to solve them. Laser propulsion is such an international field, connecting researchers in productive collaborations from across the world. Dual-use solutions are necessary to address many international problems, and building and sustaining trust among

Citation: Sinko, J.E. Laser Propulsion Science and Technology. *Aerospace* **2024**, *11*, 806. https://doi.org/10.3390/aerospace11100806

Received: 26 September 2024
Accepted: 29 September 2024
Published: 30 September 2024

the users of orbital space is critical to enable such solutions to be fielded. The ongoing growth in the number of orbital debris objects does not waver or diminish based on international politics. The aerospace community is faced with major challenges in this arena, such as the launch of satellite mega-constellations that have the potential to dramatically increase the amount of debris within future decades even if used responsibly [9]. The field of Laser Orbital Debris Removal is in the process of maturing as a technology that may be useful for countering some orbital debris—some materials, of some sizes, in some situations. It is likely that a broader spectrum of technologies is necessary to fully address the debris problem; for instance, lasers are a poor choice for the removal of the greatest amounts of debris compared to proven alternatives such as grappling arms, attachment of conventional thrusters, or even tethers or drag sails. However, lasers may be an imminently reasonable solution to remove ~10 cm debris particles, or sweep smaller debris from orbital space, assuming certain engineering obstacles and political reluctance can be overcome, and the cost–benefit ratio is realistic [10].

There is also the important question of the form in which a laser would be best deployed to support laser propulsion. Proposed implementations include space-based chaser satellites, an orbital laser platform, a ground-based system, onboard laser thrusters, and more. Laser maintenance in most high-energy terrestrial laboratories is already challenging, and locating the laboratory in space or on a satellite exposed to radiation and atomic oxygen is essentially guaranteed to exacerbate most issues and potentially spawn new ones. Conversely, the size of and challenges associated with a ground-based beam director, to say nothing of the difficulties of propagating a powerful beam through the atmosphere, strain modern engineering limits to achieve a design capable of practical application. Shared control and cooperative sites distributed among partner spacefaring countries may be necessary to make any such laser propulsion system widely powerful enough, precise enough, and palatable enough to field.

Niche applications of laser propulsion have been proposed and sometimes promise to deliver unique aerospace solutions. I would like to highlight a few of those technological applications not yet covered in this Special Issue that I feel are highly worthy of mention for their promise.

One of the more extreme ideas is for relativistic launch to "nearby" star systems, with the idea of sending a hardened chipsat across the void, propelled by a powerful laser array. This application has acquired the moniker 'Breakthrough Starshot' [11]. The engineering, physical, and optical challenges in this endeavor are truly monumental and essentially consist of devoting the entire output of a typical regional electrical power station into a distributed system of many lasers, all focused and phase-locked through the atmosphere onto a single tiny object, all maintained long enough to accelerate it to a fraction of light speed, and without destroying its circuitry or structure via extreme acceleration. The pursuit of this goal is likely to mature various interesting adjacent technologies; however, it is still an open question whether this proposal is achievable in a realistic time span. It may be an aspirational goal, given current human scientific and engineering capabilities.

Another niche application is the cooperative tractor beam, achieved using confined laser ablation to produce thrust. This technology targets a macroscopic structured object that is pulled toward the laser system. This application has been studied in different forms by various researchers including, in alphabetical order, Egorov et al. [12], Phipps [13], Sinko [14], and Yabe et al. [15].

Countless other worthwhile applications no doubt also exist for laser propulsion. It was said sardonically in the first decade after the laser was invented that the technology was a solution looking for a problem [16]. Laser propulsion has struggled to overcome the same sort of stigma, as well as a perceived high risk (e.g., [17]) due to the lack of previously fielded laser propulsion systems, a problem in many developing aerospace technology areas. Demonstration missions such as the one documented in the present Special Issue are therefore critically important to establish actual instead of imagined risks, in addition to corroborating mission-focused metrics such as thrust and delta-V outside of a carefully controlled terrestrial research laboratory. Laudable efforts in this direction were made in the past by a research group in Russia [18]; unfortunately, due to upper-stage rocket failure during launch, the satellite did not reach orbit for testing.

The future of laser propulsion holds great promise. To the author's knowledge, laser propulsion technology remains unfielded as a primary propulsion system in a space mission. Advancements in laser technology continue to improve the key tool for the discipline, and valuable in situ demonstrations help lower the perceived risk of this technology, increasing the chances that it can be practically fielded in the aerospace environment for meaningful testing sometime in the near future.

Acknowledgments: The Guest Editor of this Special Issue extends their thanks to all of the authors for contributing to this volume and making its publication a success. Thanks are also extended to the reviewers and the *Aerospace* Editorial Office.

Conflicts of Interest: The author declares no conflicts of interest.

References

1. Ye, J.; Wang, S.; Chang, H.; Hong, Y.; Li, N.; Zhou, W.; Xing, B.; Du, B.; Xie, C. Development of a Laser Micro-Thruster and On-Orbit Testing. *Aerospace* **2024**, *11*, 23. [CrossRef]
2. Ma, Y.; Chang, H.; Zhou, W.; Jian, Z. Experimental Investigation of Impulsive Coupling Characteristics of Asteroid Simulants Based on Laser Ablation Propulsion. *Aerospace* **2024**, *11*, 388. [CrossRef]
3. Keil, D.; Scharring, S.; Klein, E.; Lorbeer, R.-A.; Schumacher, D.; Seiz, F.; Sharma, K.K.; Zwilich, M.; Schnörer, L.; Roth, M.; et al. Modification of Space Debris Trajectories through Lasers: Dependence of Thermal and Impulse Coupling on Material and Surface Properties. *Aerospace* **2023**, *10*, 947. [CrossRef]
4. Scharring, S.; Kästel, J. Can the Orbital Debris Disease Be Cured Using Lasers? *Aerospace* **2023**, *10*, 633. [CrossRef]
5. Liu, H.; Ye, J.; Li, M.; Gao, H. Experimental Investigation on Morphological Characteristics and Propulsion Performance of Typical Metals Ablated with Multipulse Nanosecond Laser. *Aerospace* **2023**, *10*, 690. [CrossRef]
6. Yu, C.; Ye, J.; Chang, H.; Zhou, W.; Han, X.; Li, M.; Gao, H. Experimental Research on Characteristics of Impulse Coupling and Plasma Plume Generated by Laser Irradiating Copper Target with Nanosecond Pulsed Laser Propulsion. *Aerospace* **2023**, *10*, 544. [CrossRef]
7. Sugamura, K.; Kato, K.; Komurasaki, K.; Sekine, H.; Itakura, Y.; Koizumi, H. Hugoniot Relation for a Bow-Shaped Detonation Wave Generated in RP Laser Propulsion. *Aerospace* **2023**, *10*, 102. [CrossRef]
8. Matsui, K.; Komurasaki, K.; Kanda, K.; Koizumi, H. Observation of Oblique Laser-Supported Detonation Wave Propagating in Atmospheric Air. *Aerospace* **2024**, *11*, 327. [CrossRef]
9. Boley, A.C.; Byers, M. Satellite mega-constellations create risks in Low Earth Orbit, the atmosphere and on Earth. *Sci. Rep.* **2021**, *11*, 10642. [CrossRef] [PubMed]
10. Colvin, T.J.; Karcz, J.; Wusk, G. *Cost and Benefit Analysis of Orbital Debris Remediation*; HQ IPA-PNNL; NASA OTPS Report: Washington, DC, USA, 2023.
11. Parkin, K.L.G. The Breakthrough Starshot system model. *Acta Astronaut.* **2018**, *152*, 370–384. [CrossRef]
12. Egorov, M.S.; Rezunkov, Y.A.; Repina, E.V.; Safronov, A.L. Laser corrective propulsion plant for spacecraft. *J. Opt. Technol.* **2010**, *77*, 159–164. [CrossRef]
13. Phipps, C.R.; Seibert, D.B., II; Royse, R.; King, G.; Campbell, J.W. Very High Coupling Coefficients at Low Laser Fluence with a Structured Target. In Proceedings of the High-Power Laser Ablation III, Santa Fe, NM, USA 24–28 April 2000; Volume 4065, pp. 931–938.
14. Sinko, J.E. Laser Ablation Propulsion Tractor Beam System. *J. Prop. Power* **2010**, *26*, 189–191. [CrossRef]
15. Yabe, T.; Nakagawa, R.; Yamaguchi, M.; Ohkubo, T.; Aoki, K.; Baasandash, C.; Oozono, H.; Oku, T.; Taniguchi, K.; Nakagawa, M.; et al. Simulation and Experiments on Laser Propulsion by Water Cannon Target. In Proceedings of the First International Symposium on Beamed Energy Propulsion, Huntsville, AL, USA, 5–7 November 2002; Volume 664, pp. 185–193.
16. *Developer of the Laser Calls It 'A Solution Seeking a Problem'*; New York Times: New York, NY, USA, 1964; p. 69.
17. Beiting, E.J. Orbital Debris Removal by Ground-based Laser Ablation: An Overview. *Aerosp. Rep.* **2010**, TOR-2010(1189)-1.
18. Gurin, A.V.; Kuvaev, K.Y.; Loktionov, E.Y.; Protasov, Y.S.; Sirenko, K.N.; Zakharov, V.I. First attempt of a laser thruster space flight test: Lost at launch. *Opt. Laser Tech.* **2019**, *120*, 105656. [CrossRef]