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Advanced Electric Propulsion Concepts for Fast Missions to the Outer Solar System and Beyond

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Abstract

Electric Propulsion (EP) comprises all types of space propulsion in which a certain amount of propellant is ionized and then accelerated by electric or magnetic fields, or both. This propulsion technology allows for much higher specific impulses ($I_{sp} > 2000$ s) than conventional chemical propulsion ($I_{sp} < 500$ s), resulting in a major reduction of the propellant mass or a considerably higher final speed for a certain space mission. Hence, EP can enable very challenging space missions as DAWN has clearly shown. Furthermore, an EP system coupled with an advanced nuclear reactor could enable fast manned missions to Mars (one-way travel times less than 4 months). This propulsion technology can be scaled up to even higher specific impulses ($I_{sp} > 5000$ s). However, the power needed for the same thrust is also increasing. An Oberth maneuver performed very close to the Sun could provide the additional power to a high- I_{sp} Solar Electric Propulsion (SEP) system in order to reach the needed Δv for challenging interstellar precursor missions. A breakthrough in power source specific mass is needed in order to enable missions with ultra-high specific impulses ($> 10,000$ s) ; this breakthrough could be realized having the power source not on-board, as with Laser-powered Electric Propulsion (LEP), where the needed power is beamed to the spacecraft from an external laser source. In this case the on-board power source is limited to a light-weight photovoltaic receiver/converter. The development of ultra-high I_{sp} ion thrusters powered by an external laser source could enable the most challenging interstellar precursor missions up to the Oort Cloud and beyond. This paper gives an update on the status of these advanced propulsion concepts, and provides some examples of interstellar precursor missions enabled by advanced EP systems which could be launched before 2040.

Keywords: Interstellar, Electric Propulsion, Oberth, Laser

Nomenclature

Variables

| | |
|------------|---|
| I | = irradiance [W/m^2] |
| I_{sp} | = specific impulse [s] |
| \dot{m} | = mass flow rate [kg/s] |
| P | = power [W] |
| r | = distance [AU] |
| T | = thrust [N], temperature [K] |
| v_{ex} | = exhaust velocity [m/s] |
| α | = absorptivity [-], specific mass [kg/kW] |
| ϵ | = emissivity [-] |

Constants

| | | |
|----------|-----------------------------|-----------------------------|
| AU | = astronomical unit | = $1.496e+11$ m |
| I_0 | = solar irradiance at 1 AU | = 1362 Wm^{-2} |
| σ | = Stefan-Boltzmann constant | = $5.67e-8$ $Wm^{-2}K^{-4}$ |

Indices

| | |
|-----|---------|
| f | = front |
| r | = rear |

Acronyms/Abbreviations

AF-MPDT Applied-Field Magnetoplasma-

| | |
|--------|--|
| AU | Astronomical Unit |
| EP | Electric Propulsion |
| GIT | Gridded Ion Thruster |
| HET | Hall Effect Thruster |
| IIS | Initiative for Interstellar Studies |
| JGA | Jupiter Gravity Assist |
| JIMO | Jupiter Icy Moon Orbiter |
| LEO | Low Earth Orbit |
| LEP | Laser Electric Propulsion |
| LISM | Local Interstellar Medium |
| NEP | Nuclear Electric Propulsion |
| NEXIS | Nuclear Electric Xenon Ion Thruster System |
| NIAC | NASA Innovative Advanced Concepts |
| REP | Radioisotope Electric Propulsion |
| RIT | Radiofrequency Ion Thruster |
| SEP | Solar Electric Propulsion |
| SERT | Space Electric Rocket Test |
| TAU | Thousand Astronomical Unit |
| TRL | Technology Readiness Level |
| VASIMR | Variable Specific Impulse Magnetoplasma Rocket |

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Table of Contents Advanced Propulsion Concepts Symposium No 4

1. Understanding the eBook Advanced Propulsion Concepts Symposium No 4
 - The Rise of Digital Reading Advanced Propulsion Concepts Symposium No 4
 - Advantages of eBooks Over Traditional Books
2. Identifying Advanced Propulsion Concepts Symposium No 4
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an Advanced Propulsion Concepts Symposium No 4
 - User-Friendly Interface
4. Exploring eBook Recommendations from Advanced Propulsion Concepts Symposium No 4

- Personalized Recommendations
 - Advanced Propulsion Concepts Symposium No 4 User Reviews and Ratings
 - Advanced Propulsion Concepts Symposium No 4 and Bestseller Lists
5. Accessing Advanced Propulsion Concepts Symposium No 4 Free and Paid eBooks
 - Advanced Propulsion Concepts Symposium No 4 Public Domain eBooks
 - Advanced Propulsion Concepts Symposium No 4 eBook Subscription Services
 - Advanced Propulsion Concepts Symposium No 4 Budget-Friendly Options
 6. Navigating Advanced Propulsion Concepts Symposium No 4 eBook Formats
 - ePub, PDF, MOBI, and More
 - Advanced Propulsion Concepts Symposium No 4 Compatibility with Devices
 - Advanced Propulsion Concepts Symposium No 4 Enhanced eBook Features
 7. Enhancing Your Reading Experience
 - Adjustable Fonts and Text Sizes of Advanced Propulsion Concepts Symposium No 4
 - Highlighting and Note-Taking Advanced Propulsion Concepts Symposium No 4
 - Interactive Elements Advanced Propulsion Concepts Symposium No 4
 8. Staying Engaged with Advanced Propulsion Concepts Symposium No 4
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers Advanced Propulsion Concepts Symposium No 4
 9. Balancing eBooks and Physical Books Advanced Propulsion Concepts Symposium No 4
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection Advanced Propulsion Concepts Symposium No 4
 10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
 11. Cultivating a Reading Routine Advanced Propulsion Concepts Symposium No 4
 - Setting Reading Goals Advanced Propulsion Concepts Symposium No 4
 - Carving Out Dedicated Reading Time
 12. Sourcing Reliable Information of Advanced Propulsion Concepts Symposium No 4

- Fact-Checking eBook Content of Advanced Propulsion Concepts Symposium No 4
 - Distinguishing Credible Sources
13. Promoting Lifelong Learning
- Utilizing eBooks for Skill Development
 - Exploring Educational eBooks
14. Embracing eBook Trends
- Integration of Multimedia Elements
 - Interactive and Gamified eBooks

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