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PROSPECTS OF SPACE TUGS IN INTERSTELLAR DEVELOPMENT AND THEIR SOLUTIONS

Abstract

Over the years, the application of high-performance upper stages has been a crucial means for launching deep space exploration spacecraft. However, the current upper stages have inherent limitations in their capabilities, with restrictions on the mass that can transport. Typically, the ΔV provided by hydrazine-based fuels is limited, and the available coasting time with LH2 upper stages remains insufficient. By improving existing technological levels in energy supply, propulsion methods, and orbital design, a novel class of spacecraft, known as space tugs, has been developed to address the transportation challenges. This approach leverages a temperature difference of up to 200°C on the spacecraft surface and employs higher energy density nuclear fusion to extend on-orbit operational time.

Recent research has explored various propulsion methods, including solar sails, beam propulsion, and nuclear saltwater propulsion, offering high specific impulse (Isp). For instance, under nuclear saltwater propulsion conditions, the total engine exhaust power can reach 427,000 MW, with an Isp of 6730s. Dynamics effects of solar radiation have been analyzed to obtain thrust density data for solar sails under operational conditions. Functional methods have been employed to derive the neutron flux formula along the longitudinal direction in the nuclear reaction chamber, enabling the determination of the required fuel flow rate to prevent thermal neutron reflux. In these operational modes, the transportation time between Earth and gas giants is significantly reduced.

Appropriate trade-offs between time and fuel consumption can be achieved through suitable orbital design. The advancement in computational capabilities in recent years has facilitated the emergence of nonlinear orbits accommodating multiple body gravitational calculations, such as the dual lunar flyby trajectory. Cycler orbits demonstrate exceptional potential, allowing for the permanent presence of large spacecraft and enabling normalized and routine space tug transportation.

This work aims to propose potential concepts for future space tugs through computational analysis, focusing on energy, propulsion, and orbital aspects. Various workload magnitudes with valuable utilization methods are analyzed and evaluated. A brief overview is provided, envisioning performance data for an independent space tug working model within a specific workload magnitude and task scope.