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A Method of Trajectory Design for Manned Asteroid Explorations† ⋆

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Abstract A trajectory optimization method for the nuclear-electric propulsion manned asteroid explorations is presented. In the case of launching between 2035 and 2065, based on the two-pulse single-cycle Lambert transfer orbit, the phases of departure from and return to the Earth are searched at first. Then the optimal flight trajectory is selected by pruning the flight sequences in two feasible regions. Setting the flight strategy of propelling-taxiing-propelling, and taking the minimal fuel consumption as the performance index, the nuclear-electric propulsion flight trajectory is optimized using the hybrid method. Finally, taking the segmentally optimized parameters as the initial values, in accordance with the overall mission constraints, the globally optimized parameters are obtained. And the numerical and diagrammatical results are given at the same time.

Key words celestial mechanics—Earth—space vehicles—asteroids: general—methods: numerical

1. INTRODUCTION

Asteroids belong to an important objective in the 21th century campaign of deep space explorations, the asteroid exploration relates closely with the Earth, and has important scientific significance. Reference [1] has analyzed comprehensively the meanings and values of the asteroid exploration as follows: (1) to study the evolution of asteroidal orbits for preventing the potential collision events; (2) the effect of asteroid collision on the terrestrial

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lives; (3) the formation and evolution histories of asteroids in the solar system; (4) the internal fusion and dissociation mechanisms of parent asteroids; (5) to establish a direct relation between asteroids and meteorites; (6) to explore the new primordial matter of the solar system; (7) to explore the relation of the terrestrial life origin with the asteroids; (8) to provide clues for the planet formation and stellar evolution; (9) the acquisition of space resources; and (10) to experiment on and develop the space techniques.

The activity of asteroid exploration is now in the ascendant. 1991, Galileo detected Gaspra in the journey flying to the Jupiter, then flied by Ida in 1993, it measured precisely the rotational periods, shapes, and sizes of the two asteroids, as well as the situations of their surface meteorite craters. In 1996, the launch of the probe Near Earth Asteroid Rendezvous (NEAR) opened a new era of deep space asteroid exploration, beginning from 14th Feb. 2000, the spacecraft NEAR made the fly-around exploration for 12 months on 433 Eros, and measured the size, shape, mass, mass distribution, gravity, magnetic field, chemical composition, and other properties of the asteroid Eros. In 2005, the Japanese Hayabusa probe rendezvoused with the asteroid Itokawa, and returned successfully to the Earth after sampling. In September of 2007, the United States launched the probe Dawn to explore especially the asteroids Ceres and Vesta. The project of Autonomous Nano-Technology Swarm (ANTS) of USA planed to launch multiple main-belt asteroid probes around 2020. On 13th Dec. 2012, the Chinese CE-2 satellite flied closely by the asteroid Toutatis, and made the optical imaging observation[2], it founded the technical base for the deep space asteroid exploration in our country. In the aspect of research work, Xia Y., et al.[3−4] studied the feasibility and the approaches to the multi-object multi-task main-belt asteroid explorations; Cui et al[5] suggested the first exploration mission of small celestial bodies in our country, and proposed an one-for-three exploration project; for the near-Earth asteroid exploration Chen Y. et al.[6] proposed the candidate objects of near-Earth asteroids, and designed the optimal electric propulsion orbits.

In recent years, the American and European astronautic departments have planned the manned Mars exploration and other manned space flights, the manned asteroid exploration will be possible, and because of the existence of human, the exploration mission should take the basic necessity of life, the return course, short period, and other factors into consideration. The thrust of conventional electric propulsion is rather small, can not afford the spacecraft with a weight of several ten tons, thus the nuclear-electric propulsion arouses again the people's attention. In the end of the 19th century and the beginning of the 20th century, in his work Tsiolkovskii suggested to realize the manned space flight by using the nuclear energy as the rocket power. 1963, in his work "An Introduction to Space Flight" Dr. Qian Xuesen described systematically the structure of atomic energy rockets (nuclear propulsion), analyzed the superiority of atomic energy rockets over the electric rockets (electric propulsion), and pointed out the advantage of nuclear-electric propulsion in speed, and that in the aspect of effective payload, it is more superior to the electric propulsion