Analysis of the Atomic Propulsions for Space Mining Inspiring by PSYCHE Mission: Historic Rich Project for Space Gold Rush (SGR)

Tae Ho Woo[1,*], Hyo Sung Cho[2], Kyung Bae Jang[1], Chang Hyun Baek[1]

[1]*Department of Mechanical and Control Engineering, The Cyber University of Korea, Seoul 03051, Republic of Korea*
[2]*Department of Radiation Convergence Engineering, Yonsei University, Wonju 26493, Republic of Korea*
[*]*Corresponding author: thwoo@cuk.edu, thw_kor@hotmail.com*

***Keywords* :** Space mining, Nuclear thermal propulsion (NTR), Space Gold Rush (SGR)

1. Introduction

The Psyche mission has launched for a journey to the metal-rich asteroid which is orbiting the Sun between Mars and Jupiter [1,2]. Space mining is tested for catching the nickel-iron core where it has gotten attention for useful resources such as the space gold rush (SGR). The capture spacecraft is designed with the orbiting mechanics and the power source where the momentums of the target asteroid and the spacecraft show a different feature compared to conventional chemical propulsion. In this work, the atomic propulsion for the spacecraft is investigated for the possibility. Fig. 1 shows the configuration of capturing a target asteroid. In addition,

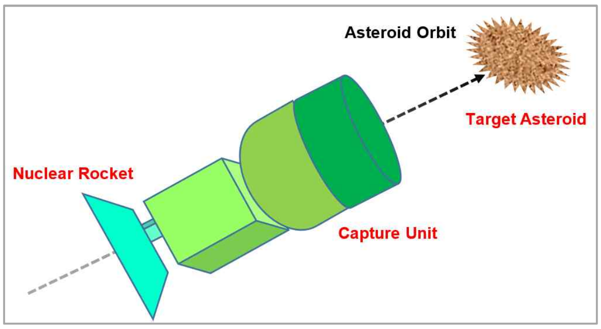

Fig. 1. Capturing a target asteroid.

there are three main types in Table 1 [3,4]. In Table 2, there are economic classifications [5]. Most asteroids

Table I: Type of resources asteroids [3,4]

Type	Meaning
C	Carbonaceous asteroids contain high concentrations of carbon compounds and silicate compound rocks (Abundant frozen water and about 75% asteroids)
M	Higher concentrations of metals (Very interested asteroids)
S	Dense and rich in silicate minerals and metals, including iron and magnesium (Most common)

Table II: List of space mining market [5]

Classification	Content
Phase	Launch, Thrust, Operation and Space Vehicle
Asteroid	C, M, S Types
Nations	USA, EU, RUSSIA, Asia Pacific etc.

present between Mars and Jupiter are called the main asteroid belt. Until now, there are counted 1,300,542 asteroids [4]. Usually, the velocity of impacting on the Earth is about 11.2 km/s in minimum, an average velocity is 18 km/s, and higher impact velocities are averaging about 30 km/s [6].

To catch this asteroid, the spacecraft is faster to exceed its speed. So, powerful nuclear propulsion is more effective in that the payload is lighter compared to the chemical power sources. Space mining would be successful by rocket launching, target catching, nuclear propulsion, and so on. Furthermore, the return to Earth is another important issue. There are some previous studies in space mining. Dallas et al. worked on the sustainable concept for space resources [7]. Regarding the space economy, Steffen studied the space mining architectures [8].

2. Methods

The mechanics of the target asteroid capture, the gravitational acceleration, and the power source of the nuclear thermal propulsion (NTR) need to be considered. The conventional Newtonian is used to operate the asteroid catch spacecraft in which the captured spacecraft and the target asteroid move in a head-on collision. In Fig. 2, the configuration for the mechanics of capturing a target asteroid is shown. The moment

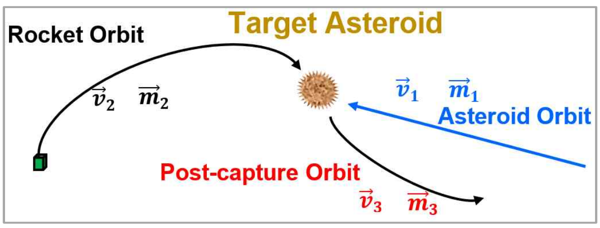

Fig. 2. Mechanics of capturing a target asteroid in space mining.

conservations between the target asteroid and rocket are described by basic mechanics [9],

$$\vec{p}_3 = \vec{p}_1 + \vec{p}_2 \quad (1)$$

where $\vec{p}_1$ is the asteroid momentum, $\vec{p}_2$ is the capture spacecraft momentum, and $\vec{p}_3$ is the post-capture momentum. The velocity is,

$$\vec{v}_3 = \vec{v}_1 + \vec{v}_2 \quad (2)$$

where $\vec{v}_1$ is the asteroid velocity, $\vec{v}_2$ is the capture spacecraft velocity, and $\vec{v}_3$ is the post-capture velocity. For energy conservation,

$$E_1 - E_2 = \left(\frac{1}{2}m_1\vec{v}_1^2 + \frac{1}{2}m_2\vec{v}_2^2\right) - \frac{1}{2}m_3\vec{v}_3^2 \quad (3)$$

where $\vec{m}_1$ is the asteroid mass, $\vec{m}_2$ is the capture spacecraft mass, and $\vec{m}_3$ is the post-capture mass. The energy difference shows the squared velocity difference graph in Fig. 3 where the minimum value is on the 18 km/sec. Then,

$$E_1 - E_2 \propto \frac{m_1 m_2}{2(m_1+m_2)} \quad (4)$$

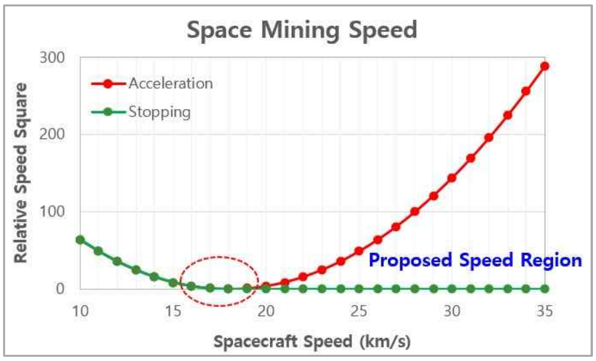

Fig. 3. Calculation of the relative speed square.

which is shown in Fig. 4. The proportional energy is shown where the spacecraft mass is assumed as 1.0. The

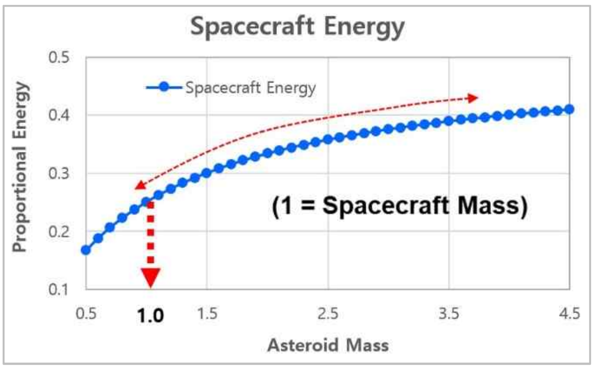

Fig. 4. Proportional energy in space mining.

graph slope goes lower as the asteroid mass increases. The gravitational acceleration between the asteroid and spacecraft is described as,

$$\vec{F} = G\frac{M\,m}{R^2}\hat{R} = m\,g \quad (5)$$

where $\vec{F}$ is the gravitational force of vector form, G is the gravitational constant, M is the asteroid mass, m is the spacecraft mass, and $\hat{R}$ is the unit vector. So, new gravitation $\boldsymbol{g'}$ is obtained as,

$$\boldsymbol{g'} = g + g' = G\frac{M}{R^2}\hat{R} + g' \quad (6)$$

where g is the asteroid acceleration and g' is the capture spacecraft acceleration. For a constant acceleration linear motion,

$$\vec{v} = \vec{v}_o + gt = 18\ km/s + G\frac{M}{R^2}\hat{R}t \quad (7)$$

where $\vec{v}$ is the capture spacecraft velocity, t is the period to impact, G is 6.67430 $\times 10^{-11}$ N·m^2/kg^2 and the asteroid velocity, $\vec{v}_o$, is assumed as the average value of 18 m/sec. It is possible to consider the asteroid's velocity addition term to be negligible because the spacecraft can break the asteroid's movement by fixing to the inner cabin.

3. Results

It is assumed as quadrillions of dollars in space mining. There are acceleration and stopping movements of spacecraft where the possible cases of post-catching are shown between two graphs. If the speed is lower than 18 km/sec, the direction is the opposite way. If the speed is higher than the acceleration case, the efficiency of the operation could be lower. Additionally, the energy of the spacecraft is represented by the mass of the asteroid and spacecraft. Considering the gravitational acceleration of the asteroid, the asteroid's velocity addition term is negligible, because the spacecraft can break the asteroid's movement by fixing to the inner cabin. Possible operations of spacecraft after asteroid catching are described.

4. Conclusions

The importance of space mining is to catch the valuable materials in the vast universe. The mechanics of momentum and energy have been evaluated for the operations of the spacecraft. The SGR is proposed by the atomic power-based spaceship. There are some serious matters to consider. Some materials can be radioactive if the asteroids have a radioactive substance. Therefore, it is needed to check the safety of the rocks and any contents of the asteroids. In the case of a larger asteroid, it is possible to drag it instead of containing it in the cabin. The operation of the catching spacecraft should be done cautiously for safe driving.

Acknowledgments

This study was supported by the Ministry of SMEs and Startups grant (RS-2023-00266376).

REFERENCES

[1] J. Carter, Space Mining: Scientists Discover Two Asteroids Whose Precious Metals Would Exceed Global Reserves. Forbes, Jersey City, USA, 2021.

[2] NASA, Psyche, Jet Propulsion Laboratory, Pasadena, USA, https://www.jpl.nasa.gov/missions/psyche.

[3] An Underground Miner 2022. Beginner's Guide to Asteroid Mining, An Underground Miner, 2024, https://anundergroundminer.com/blog/beginners-guide-to-asteroid-mining.

[4] NASA, Asteroids, NASA’s Jet Propulsion Laboratory for NASA’s Science Mission Directorate, National Aeronautics and Space Administration (NASA), Washington DC, USA, 2023, https://solarsystem.nasa.gov/asteroids-comets-and-meteors/asteroids/in-depth/.

[5] Fortune Business Insights, Space Mining Market Size, Share & Industry Analysis, By Phase (Spacecraft Design, Launch, Operation), By Asteroid type (Type C, Type S, Type M, Others), By Application (Construction, Resource Harvesting, 3D Printing, Others) and Regional Forecast, 2023-2030, Fortune Business Insights Pvt. Ltd., Maharashtra, India, 2022.

[6] USRA, Impact Cratering Mechanics, Lunar and Planetary Institute, Universities Space Research Association (USRA), Washington DC, USA, 2023, https://www.lpi.usra.edu/exploration/training/illustrations/craterMechanics/.

[7] J. A. Dallas, S. Raval, J. P. A. Gaitand, S. Saydam, A. G. Dempster, Mining beyond earth for sustainable development: Will humanity benefit from resource extraction in outer space? Acta Astronaut, Vol. 167, pp. 81–188, 2020.

[8] Steffen, Explore to Exploit: A Data-Centred Approach to Space Mining Regulation, Space Policy, Vol. 59, p. 101459, 2022.

[9] Serway and Vuille, College Physics, 11^{th} Ed., Cengage Learning, Boston, USA, 2017.