Comet capture mission

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Abstract

A mission to construct a permanent manned base on the lunar surface is being planned in many countries in the world. Water is the most necessary resource for such a manned base. Water is useful for daily life, fuel, propellant valves, etc. Moreover, it is a convenient resource that can be preserved in a permanent shadow on the surface of the moon as ice. Unfortunately, the cost to carry water from the earth to the moon is high. This study examines a mission to divert a small comet to a lunar orbit as a means to acquire water resources from space. From a scientific perspective, obtaining a small comet would be an important achievement. This report presents recent comet orbital data and assesses the capability of orbital control from the perspective of comet eccentricity.

彗星捕獲ミッションの小検討

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月面に恒久的な有人基地を建設するミッションが各国で計画されている．月面有人基地で最も必要とされる物資の一つに水が挙げられる．水は生活用水の他、燃料、推薬などに利用できる．また、氷として月面上の永久影に保存できる便利な資源でもある．地球から月へ水を運ぶにはコストが掛かる．本稿では地球外から水資源を調達するミッションとして彗星の欠片を月軌道へ投入するミッションについて小検討を行う．資源としての利用の他、小さな彗星の入手は科学分野において非常に貴重な試料となる．本稿では最近の彗星の観測データを示す．また、彗星軌道の離心率の観点からミッションの議論を行なう．

1. Introduction

In this text, the following contents are described for quick examination.

1) First we assess the demand for water for manned space activity and describe an investigation of water transport costs.
2) Next, uses of water resources in a manned lunar base are illustrated.
3) Then, we explain comet compositions and propose the mission to capture a comet for acquiring water resources in space.
4) Recent and planned comet investigations are presented.
5) Comets that are likely targets are examined.
6) Finally, we discuss technical problems.

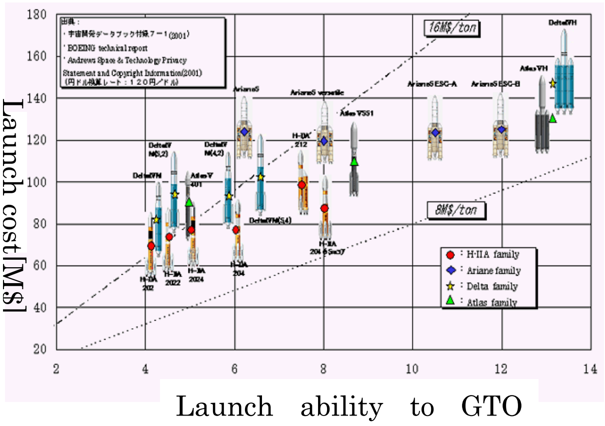
2. Demand and costs of water in space

Four-year water replenishment has been shown in results of ISS(International Space Station) activity. The amount of drinking water that must be transported is shown in Table 1-1: for minimum manned activity of space, a half-ton of water would be needed for each person. Russian data imply that spaceship transport costs to the GTO would be two billion yen per ton. Figure 1-1 shows Transport cost to GTO in western countries. Consequently, if a manned lunar base were in operation, hundreds of billions of yen per year would be the cost merely for transport water.

Table 1-1 Value of a water supply for the ISS

year	number of stayer	water supply of the year
2004	3persons （long period 2persons short period 1person）	1370[kg/year]
2005	3persons （long period 2persons short period 1person）	1454[kg/year]

*2004, 2005 data show only the replenishment by Progress of Russia. Water from STS and fuel-cell replenishment during STS docking are inferred from 2006 (From JAXA HP).



Launch ability to GTO

Fig.1-1 Transport cost to

3. Water usage at a manned lunar base

Water is useful for some lunar base resources. Examples of water uses are listed below.

· Uses as storage
  Radiation shield material
  Heat shield material
· Uses for recycling
  Fuel battery
  Oxygen resource
  Heat pump fluid
· Uses as a consumable resource
  Propellant

There are many uses of water at a lunar base. The supply of water must therefore be great to support lunar base operations.

4. Water supply plan for a lunar base

This paper presents the new water supply plan for a lunar base. A comet is put into a circular orbit around the moon by correcting the comet orbit. Then, a lander waiting in a lunar orbit guides the comet to a soft landing on the lunar surface. For these discussions, the comet is inferred to be a very small comet or comet fragment with mass of about 5000–1000 [ton] and diameter of about 25–15 [m] by Figure 4-1.

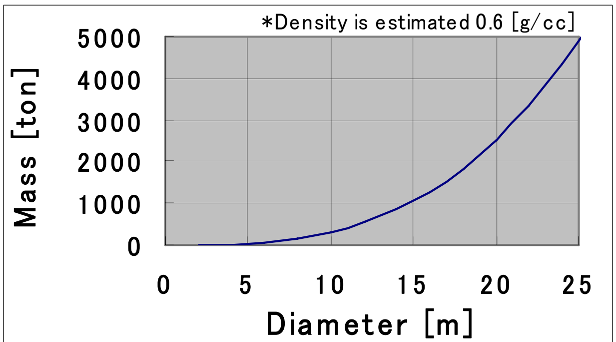


Fig.4-1 Mass apploximation of comets

5. Composition distribution of comets

Figure 5-1 presents reference data from “Comets and interstellar matter” from Shin Yabushita p.106 Table 3.6.

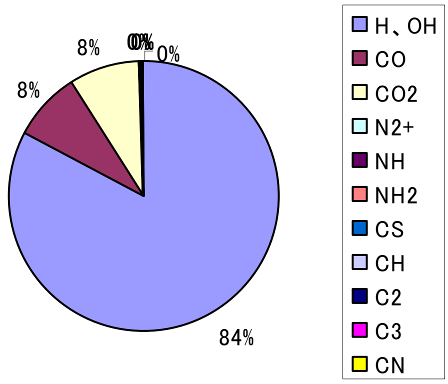


Fig.5-1 Ratio of presumption moleculre of comets

The formation rates of H and OH are almost equal; the rate is about 10 times higher than those of other molecules. This figure shows that comets consist mainly of water. Therefore, we can obtain large amounts of water from comets.

6. Recent comet explorer missions

Recent comet exploration missions are listed below.

・Deep Impact (NASA)
  9P/Tempel 1 Semi-major axis 3.1 [AU]
・Stardust (NASA)
  81P/Wild 2 Semi-major axis 3.5 [AU]
・Rosetta space probe (ESA)
  67P/Churyumov-Gerasimenko
  Semi-major axis 3.5 [AU] (2014)

The Deep Impact mission shot a projectile into the Tempel 1 comet to investigate its internal structure. In addition, an orbit is corrected and fly-by of 85P Boethin is planned. Dust particles of 81P/Wild 2 comet were returned by Stardust. Rosetta, which is intended to land on the comet in 2014, is underway now. At present, no mission to use the water of the comet as a resource is planned. It is necessary to plan this mission immediately to contribute to the manned lunar base development in the near future.

7. Comet orbital period and semimajor axis

Comet data must be investigated to narrow the field of target comets for a capture mission. The first point to be considered is the orbital period. The target should not be an overly long period. Figure 7-1 shows the number of short-period comets according to the orbital period. Many comets pass in seven cycles of the year. Figure 7-2 shows the relation of the orbital period and the semimajor axis. The figure shows that, in comets of seven-year cycles, the semimajor axis is about 3.5 [AU]. Figure 7-3 shows the number of comets according to the semi-major axis. It shows the semimajor axis of target comets of 3.5–4.5 [AU].

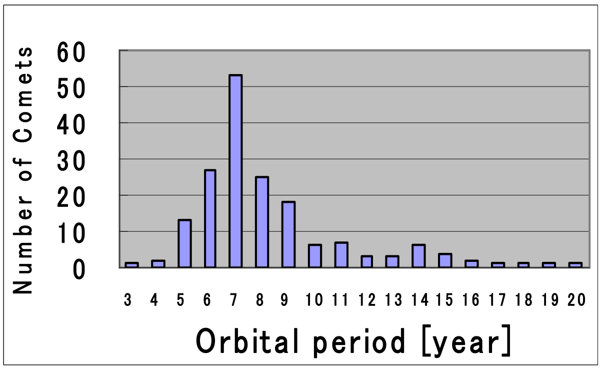


Fig. 7-1 Number of comets every period of Short-period comets. Data from Minor Planet Center (MPC), 2007.7.20.

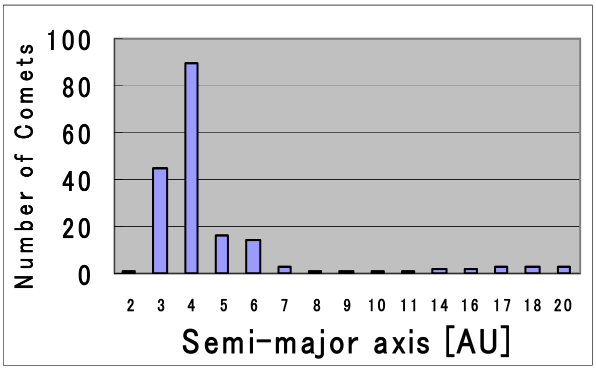


Fig. 7-2 Relation of orbital period and semimajor axis.

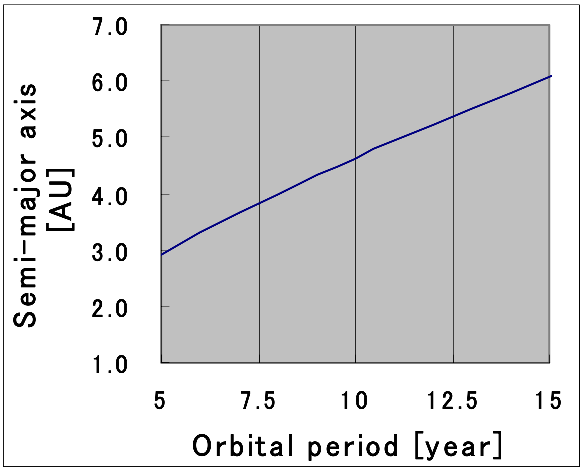


Fig. 7-3 Number of comets on every semimajor axis.

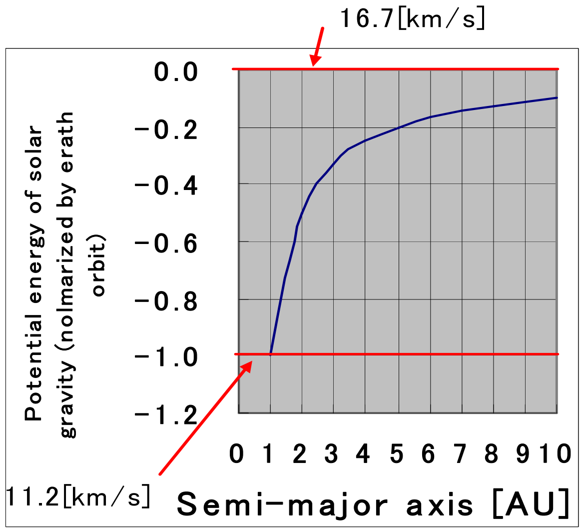


Fig. 7-4 Relation of semimajor axis and the potential energy of solar gravity.

Figure 7-4 shows the potential energy of solar gravity. Where the semimajor axis is one, the orbital velocity is 11.2 [km/s] as the second cosmic velocity. Therein, the potential energy is zero; the orbital velocity is 16.7 [km/s] as the third cosmic velocity. This figure shows that the velocity of a comet capture satellite should increase about 15 [km/s] at 7 [au]. It seems difficult to increase the velocity 15 [km/s] and decrease the comet velocity using the satellite's chemical fuel jet alone.

8. Minimum fuel exploration

For comet exploration, the problem is controlled acceleration to change its vector. To transport as much propellant as possible, the use of electric propulsion is effective. One study has reported the minimum fuel inquiry orbital characteristics considering the influence of eccentricity in the asteroid orbit of the earth neighborhood.

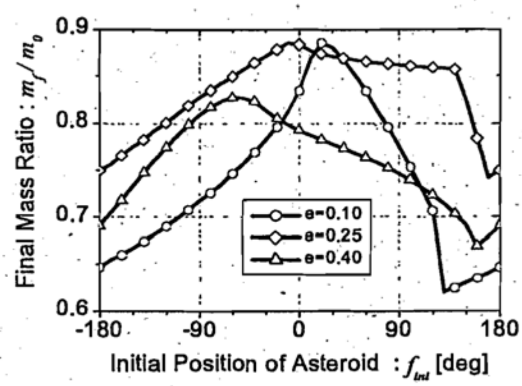


Fig. 8-1 Final mass of transfer orbit : $a = 1.3$

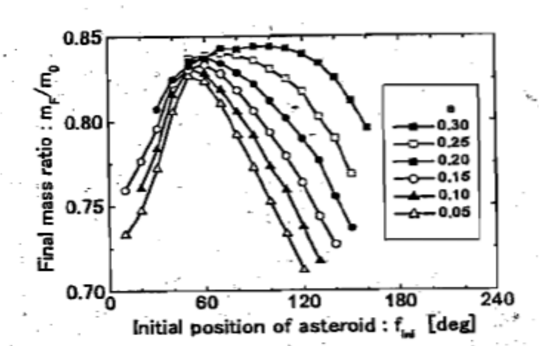


Fig.8-2 **Final mass of optimal trajectories** **a = 1.3, f_{ex} = 0.0[deg]**

Figure 8-1 exhibits specific fuel consumption in the impulse approximation of chemical propulsion.

Fig. 8-1 and Fig. 8-2 Ueno, Kobayashi, Koga, "Eccentricity of an Asteroid's Orbit for the Minimum Fuel Exploration" Proceedings of 15th Workshop on Astrodynamics and Flight Mechanics, ISAS, 2005

Figure 8-2 shows the fuel remainder rate with electric propulsion. For the latter, the higher the eccentricity, the less the decrease of fuel remains. For impulse approximation, a kick in the best position is available. Therefore, the remaining fuel is greater than that of electric propulsion. Moreover, the optimality changes according to the comet eccentricity. In this report, the semimajor axis of asteroid is assumed as a=1.3 AU. Consequently, it is necessary to examine the orbits of the semimajor axis of 3.5–4.5 [AU].

9. Comet data according to eccentricity

Figure 9-1 presents the distribution of eccentricity using comet data of 1986. Figure 9-2 shows a distribution of eccentricity using comet data observed as of July 2007. Compared to data of 1986, Fig. 9-2 shows that observation capabilities have increased greatly, merely judging from the number of comet data. Results show that comets with much remaining moisture can be discovered by improving observation capabilities of planetoids. That figure shows a tendency of near normal distribution except that eccentricity=1. When it approaches the sun, the comet produces a dust tail and becomes classified as a comet. In an orbit near the sun, the volatile element of the comet dries up, thereby becoming classified as an asteroid. This might explain that the eccentricity of the comet causes the near normal distribution. Moreover, its brightness of luminescence might be related to the distribution. Figure 9-3 depicts the relation between the semimajor axis and eccentricity. Comets do not exist near the origin.

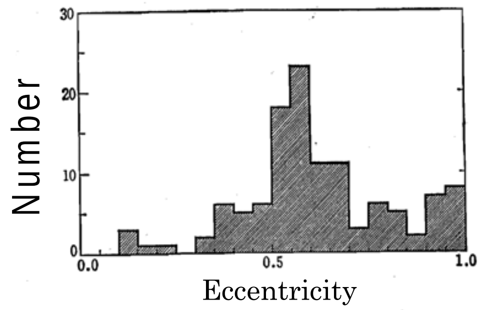


Fig. 9-1 Eccentricity of comets from "Comets and interstellar matter", Shin Yabushita P.63 Fig. 2.8

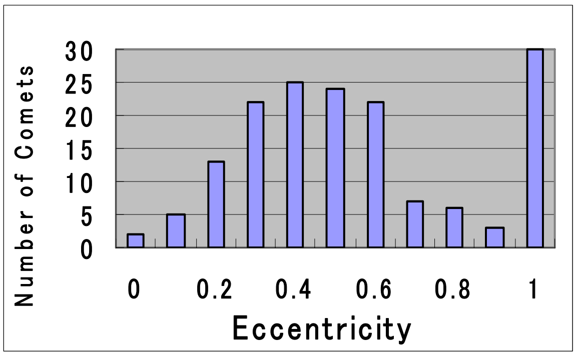


Fig. 9-2 Number of comets every period of Short-period comets. Data from Minor Planet Center (MPC) 2007.7.20.

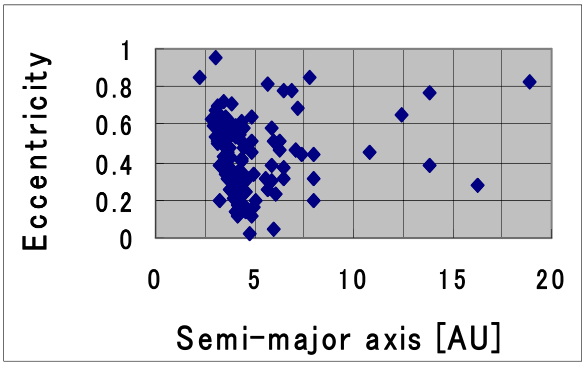


Fig.9-3 Eccentricity of every semi major axis

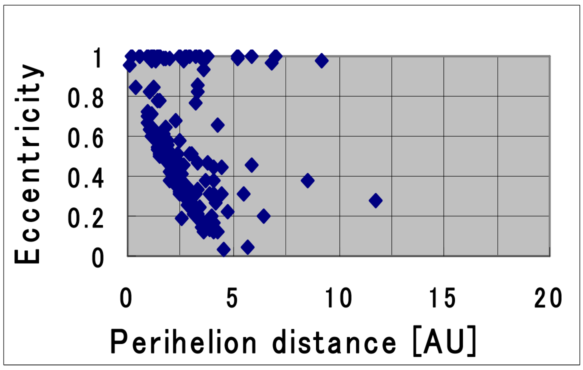


Fig.9-4 Eccentricity of every Perihelion distance

No comet with small eccentricity exists in an orbit with a small semimajor axis. Comets with small eccentricity remain near the sun too long: water tends to evaporate. Existence areas of comets are vaguely suggested by this figure.

A plot of comets is depicted in Fig. 9-4 according to the perihelion distance to present this tendency more clearly. The left boundary of the plot is almost a line. From this figure, the comet existence area is readily apparent. Generally, a comet with large eccentricity and large semimajor axis is expected to have a high residual ratio of moisture. Many such comets with a small dust tail are shown in the figure. Thereby such comets can be discovered even if they are not easy to find. A target should be selected from among these comets that is able to make an orbital transition to the moon. The standard can be found by reference to Chapter 8.

10. Conclusion

Comet capture mission guidelines were presented in this report. Results indicate that a comet capture mission is suitable for advanced support of manned activity for a lunar base. Moreover, results show that comets that have retained much moisture can be discovered by improving observation capabilities of planetoid, as they have in recent years. Future tasks are summarized as follows. For the comet capture mission, some technologies should be developed. Here are matters that are consider to be necessary.

1. A means to identify target comets.
2. A means to capture comets.
3. Estimating energy for guidance to a lunar orbit and reorientation of the comet's attitude.
4. Guidance control of comet orbit that is arranged by out-gassing vector control from the comet.

Control of the vector of gas blowing from the core is executed by maneuvering the comet attitude, and controlling of amount of gas blowing according to temperature control on the comet surface.

A comet-capture mission should be initiated immediately.

References

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[3] Minor Planet Center HP, http://cfa-www.harvard.edu/iau/mpc.html

[4] Ueno, Kobayashi, Koga, "Eccentricity of an Asteroid's Orbit for the Minimum Fuel Exploration" Proceedings of 15th Workshop on Astrodynamics and Flight Mechanics, ISAS, 2005