A concept study for sample return mission with touch-and-go sampling probe

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Abstract

This paper describes the consideration of Sample-return missions with Touch-and-go sampling probe. Hayabusa and Hayabusa-2, which successfully returned samples from asteroids, themselves landed on the asteroids. However, the problem with this method is that these spacecrafts had to risk breakdown. If it is possible that only sampling probe lands, collect samples and dock with the spacecraft, we can drastically reduce that risk. The main theme of this paper is what operation forms are effective for target celestial bodies with various size or environment. We conducted trade-off analyses about necessary systems for Touch-and-go sampling from those bodies. In addition to this general discussion, we are thinking to consider concrete operation sequence for some typical target bodies. Through this consideration, we expect that some new questions are found which are not seen in general discussion.

タッチアンドゴーサンプリングプローブを用いた サンプルリターンミッションの検討

要旨

タッチアンドゴー方式サンプリングプローブを利用したサンプルリターンの検討結果について報告する。
小惑星からのサンプルリターンに成功したはやぶさ・はやぶさ２は探査機本体が目標天体へと降下しサンプルを採取しているが、この方法では探査機の故障リスクが高いという問題がある。サンプリングプローブのみが地表に降りサンプルを採取して再上昇したところを探査機が捕獲することができれば、このリスクは大幅に減らせるものと考える。様々な規模・環境の目標天体に対して適切なサンプリングプローブの運用方法はどのようなものであるかが本稿の主題である。天体からのタッチアンドゴーサンプリングに必要なシステムをトレードオフ的に分析した。加えていくつかの典型的な天体に対しての具体的な運用形態も検討し、一般的な議論からは見えにくい課題を発見したいと考えている。

Nomenclature

h	:	altitude, km
μ_c	:	gravitational constant of target body, m^3/s^2
R_c	:	radius of target body, m
m_p	:	payload, kg
F	:	thrust of motors, N
t_f	:	burning duration of motors, s
h_i	:	ignition altitude, m
v_i	:	velocity at ignition, m/s
v_l	:	landing velocity, m/s

1. Introduction

USSR, NASA, JAXA, and CNSA have succeeded in sample-return missions. These missions have great significance, because samples can be stored to be analyzed by latest tools on Earth and compared to prospective outcome. It is also true, however, that Hayabusa or Chang'e 5 couldn't bring the expected amount of samples. Spacecrafts' return to earth is a top priority during sample-return missions, and running a risk to get more samples can not be selected easily. In previous missions sampling on the surface of the target celestial body, spacecrafts landed themselves. One of the most significant risk is the spacecraft's breakdown, so the approaches to the target bodies were performed with caution.

In this paper, we propose a new sampling method using the touch-and-go sampling probe (Fig. 1). Only sampling probes land, collect samples and dock with the spacecrafts to return to earth. This method has two main merits. One is to reduce the spacecrafts' failure risks greatly. Spacecrafts themselves don't need landing, so it will get easier to collect samples even from unfamiliar target bodies. The other main merit is increase of opportunity of sampling. Multiple probes enable sampling many times or from different locations.

We considered operation forms of touch-and-go sampling and the system of the sampling probe. The different operations are needed for the target bodies with different size or environment. The system of the probe is better being simple in order to not increase the spacecrafts' payloads too much.

2. Operation forms and probe's system

Fig. 2 shows the concept of sample-return mission with sampling probe. The spacecraft releases the probe, then the probe descends slowing down by motors to touch down at a low speed. The aim is to land with zero velocity. After touching down and sampling, the probe takes off to dock with the spacecraft waiting at high altitude. The return to earth is realized by the spacecraft.

We think the target bodies can be categorized by operation forms and probe's system suitable for each targets.

2.1. Operation forms

The different operation forms are needed for different target bodies. When releasing the probe, the spacecraft may be hovering or in the orbit around the target body. The movements of spacecraft in this phase would be decided based on the gravity of the target bodies or perturbation. With the phase of waiting until docking, the similar problem exists. Now for the phase of probe's descent and rising again, the timing of motor's ignition may be controlled by a timer or an altimeter. The ignition using only a timer can make probe's system very simple, but the slight deviation of timing would generate a great landing velocity in case of descending from high altitude toward a target body with large gravity.

2.2. Probe's system

The simple system of probe is desirable. It roughly consists of sampling device, motors and a timer or an

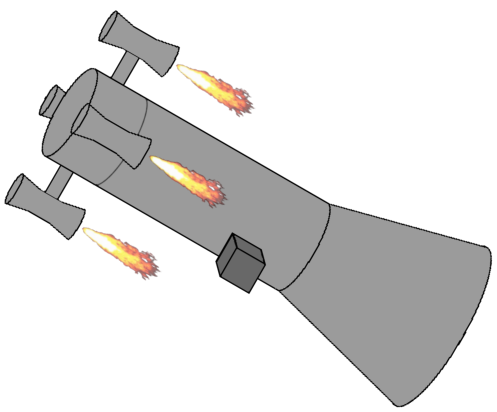

Fig.1 Touch-and-go sampling probe

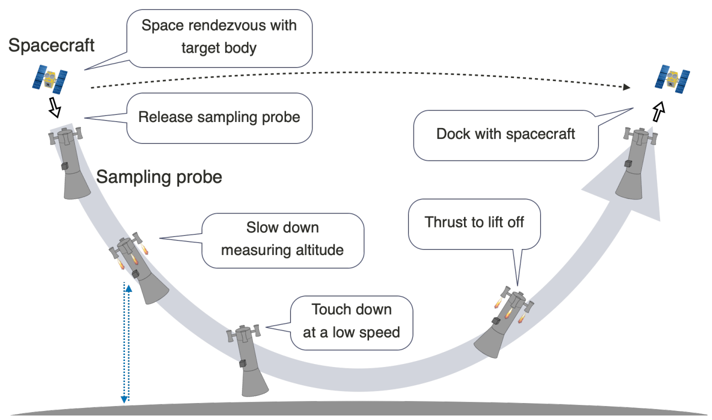

Fig.2 Concept of sample-return with sampling probe

altimeter. As the propulsion system, the solid rocket motor is simpler than the liquid rocket motor or the other system. One of the difficult point of the solid rocket motor is the inability to regulate its thrust after ignition. Because of this, it might not suitable large target bodies requiring thrusting for a long time and competent amount of deceleration, but devising control of thrusting direction of multiple motors could make it possible to land on also moderately-sized target bodies, not only small ones.

Therefore, the first consideration is how large or small target body is the limit to be able to realize touch-and-go sampling by the probe with simple system using solid rocket motors.

3. Sizing of solid rocket motor

Suppose that the probe has four motors, its terminal mass at landing is 15 kg, and it's released from infinity. We calculated combinations of the burning duration, the altitude of ignition, and the thrust of one motor in the case that the target body is the moon (Fig.3(a)), then estimated the diameter and length of one motor based on the motor of OMOTENASHI (Fig.3(b)). Specific impulse, diameter, length, average thrust and burning duration of OMOTENASHI's motor are 270 s, 110mm, 300mm, 500N and 16s. Accordingly, the diameter and length of sampling probe's motor is given as follows.

$$\text{Length} : 300 \times \frac{t_f}{16},$$

$$\text{Diameter} : 110 \times \sqrt{\frac{F}{500}}.$$

At the moment of ignition, the velocity of the probe is given by conservation of energy, that is

$$v_i = -\sqrt{\frac{2\mu_c}{R_c + h_i}}.$$

The condition for landing zero velocity is the velocity and altitude become aero at the same time just after burning duration t_f.

$$v(t_f) = 0 \text{ and } h(t_f) = 0,$$

where the acceleration from motors' thrust is constant on the assumption that the total mass of the probe is constant, but it is variable when the mass flow rate of motors is considered. Fig.3 shows that whether we consider the probe's variable mass or not has considerable effects on the motor's size.

However, the size of motors can not be decided freely. It should have structural limits. What is more, if we control the thrust of these four motors, enough control time is required. Discerning these limits to categorize the target bodies based on the realizable size of solid rocket motor is the future task.

4. Conclusion

The sample-return mission with touch-and-go sampling probe has some option of the operation form or the system of the probe. Among them, the simple probe using solid rocket motors has the possibility of probe's landing on not

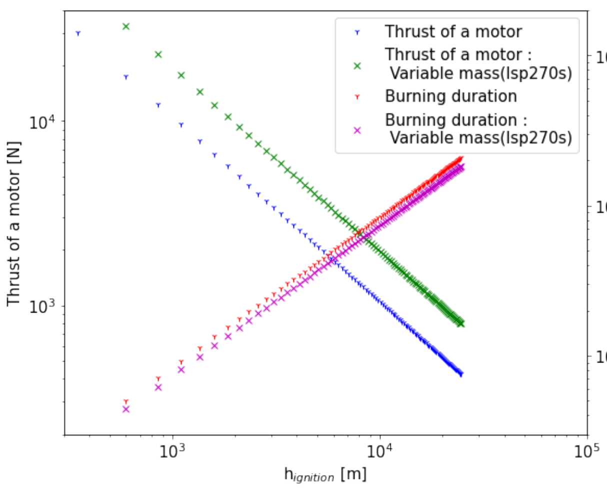

Fig.3(a) Thrust and burning duration vs ignition altitude

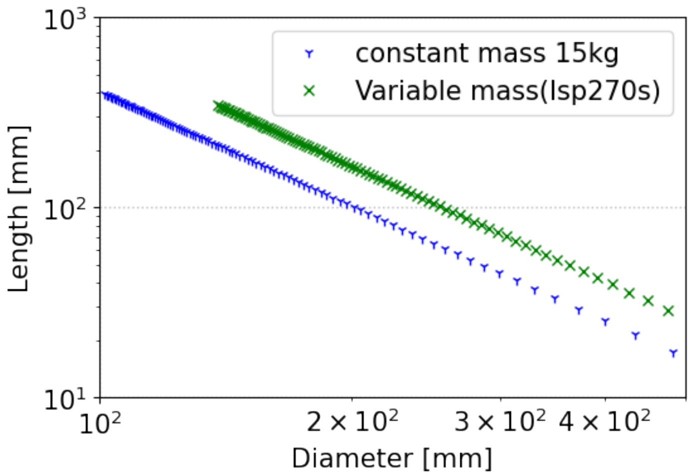

Fig.3(b) The sizing of a motor

Fig.3 Motor's sizing to land on the moon only small target bodies but also moderately-sized ones like the moon.

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