JASMAC
Conference of the Japan Society of Microgravity Application

OR1-1

惑星表面の柔軟地盤の重力依存性の調査実験運用及び実験結果について

Investigation for gravity dependence of soft terrain on planetary surface (Hourglass mission) : Experiment Operations and Results

黒澤茅広 [1]，大槻真嗣 [1]，尾崎伸吾 [2]，石上玄也 [3]，前田孝雄 [4]，須藤真琢 [1]，小林泰三 [5]，宮本英昭 [6]，和田浩二 [7]，河合優太 [1]，笠原春夫 [8]， 坂下哲也 [1]，土井忍 [1]，内川英明 [1]
Chihiro KUROSAWA [1], Masatsugu OTSUKI [1], Shingo OZAKI [2], Genya ISHIGAMI [3], Takao MAEDA [4], Masataku SUTOH [1], Taizo KOBAYASHI [5], Hirdy MIYAMOTO [6], Koji WADA [7], Yuta KAWAI [1], Haruo KASAHARA[8], Tetsuya SAKASHITA[1], Shinobu DOI[1] and Hideaki UCHIKAWA[1]
[1] 宇宙航空研究開発機構，Japan Aerospace Exploration Agency (JAXA) #1
[2] 横浜国立大学，Yokohama National University#2
[3] 慶応義塾大学，Keio University#3
[4] 東京農工大学，Tokyo University of Agriculture and Technology#4
[5] 立命館大学，Ritsumeikan University#5
[6] 東京大学，The University of Tokyo#6
[7] 千葉技術大学，Chiba Institute of Technology#7
[8] 有人宇宙システム株式会社，Japan Manned Space Systems Corporation (JAMSS) #8

1. Introduction

The Japan Aerospace Exploration Agency (JAXA) has some of future lunar and planetary exploration plans. In the Lunar Polar Exploration mission (LUPEX), JAXA in collaboration with the Indian Space Research Organization（ISRO) plans to obtain the data on the potential water resources on the Moon. The pressurized rover is one of the lunar surface mobilities for human exploration. JAXA is studying the pressurized rover to be able to drive 10,000 km on the lunar surface. Another example of the planetary explorations is Martian Moons eXploration (MMX) . The MMX is the Phobos (one of the moons of Mars) exploration mission. The MMX spacecraft will arrive at the Phobos to collect scientific data and gather samples from the surface. The Mars is also thought as a future exploration destination following the Moon.

The surface of these exploration mission destinations, the Moon, Phobos and Mars, are covered by soft regolith terrain. Characteristics of soft and loose terrain are considered to cause risks affecting the achievement of the exploration mission and the system design, such as lander landing failures and rover stuck. To avoid these troubles, it’s important to understand the interaction between a space craft (footpad, tire etc.) and soft terrain on planetary surface, and reflect the results in the space craft design. The Hourglass mission is studying the gravity-dependent characteristics of regolith under low gravity. This study results can be applied to a numerical analysis for simulating the interaction.

Previous research has investigated how granular materials behave under low gravity, simulated by parabolic flight [1]~[3]. However, the duration of steady low gravity in parabolic flight, is limited to less than 20 s, and the transition from high to low gravity affected the initial conditions of the tests. These studies seem inadequate to reproducing the characteristics of actual regolith under prolonged low gravity. For this reason, the Hourglass mission experiment planned to conduct on the artificial gravity generator in International Space Station (ISS) which can provide the long and static low gravity environment.

2. Hourglass mission method

We used the two experiment hardware, the artificial gravity generator (Figure. 1) and the Hourglass Box (Figure. 2), for the Hourglass mission. The artificial gravity generator was installed in the Cell Biology Experiment Facility (CBEF) in KIBO on the ISS and can be set to provide from 0.06G to 2.0G by ground command. The Hourglass Box is the hardware specially designed for the Hourglass mission. The Hourglass Box, which has Hourglass and Measuring cylinder, was designed to be installed and used at artificial generator. In the mission, eight Hourglass Boxes were developed. Various samples of granular materials were placed in the Hourglass and the Measuring cylinder of each Hourglass Box. For the samples, eight kinds of granular materials were selected, these are Lunar regolith simulant (FJS-1), Phobos simulant, Alumina beads, Mars regolith simulant (MARS-1A), Toyoura sands and Silica sands. The Hourglass and the Measuring cylinder start to automatically reverse every minute by servo motor after the power switch is turned on and installed

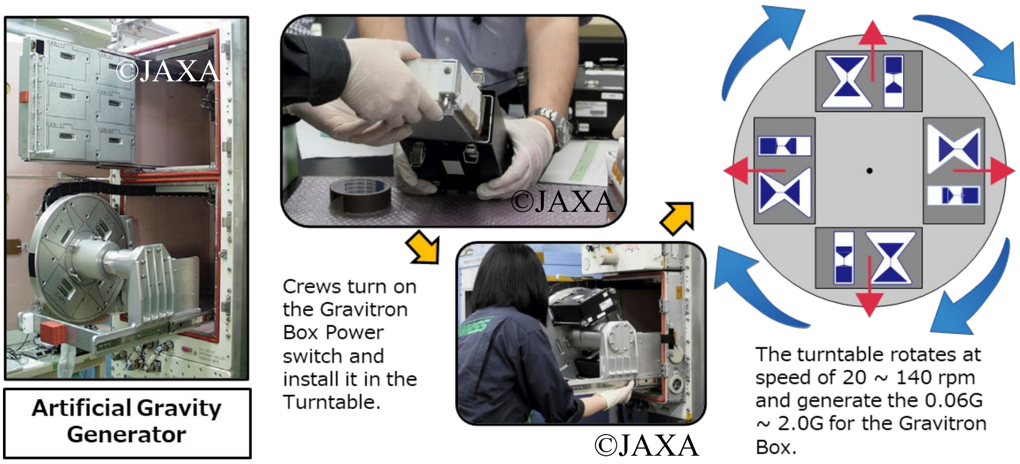


Figure 1. Artificial Gravity Generator and procedure of the

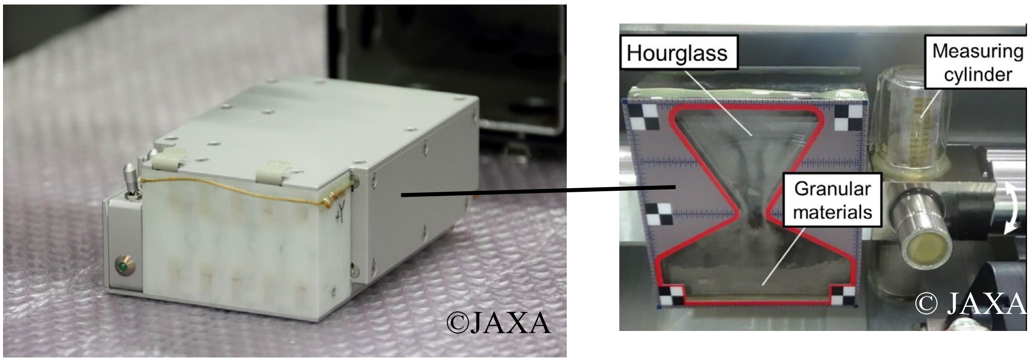


Figure 2. Hourglass Box (left) and inside of Hourglass Box

at artificial generator by a crew. We can observe the behaviors of granules, flow velocity and volumetric state with a camera inside the Hourglass Box under various artificial gravity conditions from 0.06G to 2.0G, which changes every 13 minutes. The lunar gravity (0.17G) and The Mars Gravity (0.38G) are included in the gravity conditions, the artificial gravity is measured by the accelerometer which is installed in the Hourglass Box.

3. Hourglass mission result

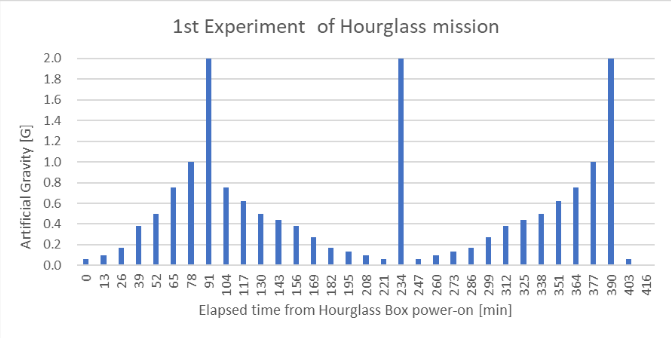
3.1. Overview

The eight Hourglass Boxes were launched by H-2B rocket and transferred to the ISS by HTV-8 in November 2019. The Hourglass mission experiment were conducted in two separate sessions. In each mission, four Hourglass Boxes were tested. The first experiment was conducted in January 2019 and the Hourglass Boxes with Alumina beads, Toyoura sands, Silica sands and Lunar regolith simulant were used. The second experiment was held in May 2020 with the Hourglass Boxes having Phobos simulant, Mars and lunar regolith simulants, and Silica sands. In the second experiment, Lunar regolith simulant and Silica sands with different size distribution from the first experiment were used. From the investigation after the experiments, we confirmed that the planned artificial gravity was generated during the experiments from the acceleration data of Hourglass Box accelerometers. We also confirmed that all Hourglass Boxes worked normally for the planed eight hours experiment and over 3000 flipping the Hourglass and the Measuring cylinder images were recorded. As the results, for each material tested, we successfully obtained more than 3000 datasets showing their motion behaviors in various gravity environments.

3.2. Experiment operations

The above two experiments were operated from the Tsukuba Space Center. Preferred artificial gravity conditions was determined based on remaining battery capacity and communication conditions between the ISS and ground station while proceeding with the experiments.

The experiment result data was recorded on the SD Card which were installed to each of Hourglass Boxes. The crew inserted the SD Card to Payload Laptop Terminal (PLT) in ISS and the data was downlinked after the experiments. Although the experiments were conducted in 2019 and 20220, there was initially a possibility that both experiments would be conducted within a few days or weeks. For this reason, to quickly check the effectiveness of the gravity conditions selected, the results of the Alumina beads in the first experiment were handed over to our investigation team within a few days after the first experiment. After the investigation on this result, the team determined the artificial gravity conditions for the second experiment. The other data were obtained within one month after the experiments. The final artificial gravity conditions selected are showed in Figure 3.



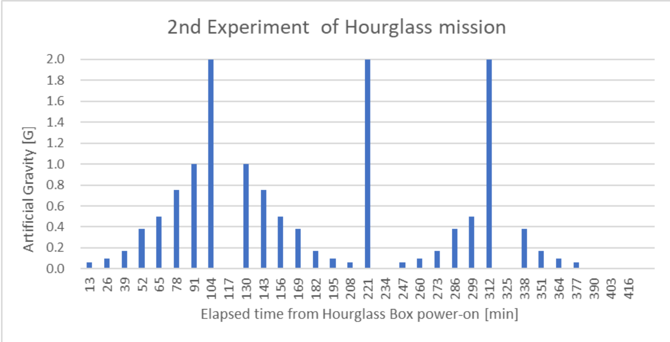


Figure 3. Artificial Gravity conditions in the 1st / 2nd Experiment

4. Summery

This document outlines the experimental methodology and results obtained from the Hourglass mission. JAXA is analyzing the images and acceleration data acquired in the experiment to investigate the gravity dependence the flow velocity and volumetric state. These results are expected to be used for designing and development of space probes in the future lunar and planetary exploration missions.

References

1) T. Kobayashi, H. Ochiai, Y. Suyama, S. Aoki, N. Yasufuku, K. Omine : SOILS AND FOUNDATIONS, Vol. 49, No.1, 115-134, Feb. (2009)
2) T. Kobayashi, Y. Fujiwara, J. Yamanaka, N. Yasufuku, K. Omine : J. Terramechanics, (2010), 261-274.
3) H. Nakashima, Y. Shioji, T. Kobayashi, S. Aoki, H. Shimizu, J. Miyasaka and K. Ohdoi, K: