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重力加速度が密閉容器内スロッシング現象に与える影響 -ISS 軌道上実験で観測された液体挙動に関する数値解析-

Effect of gravity conditions on Sloshing Phenomena in Sealed Vessel

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Extensive and long-term manned lunar exploration is envisioned in the ARTEMIS program[1)]. To achieve this program, development of a manned pressurized rover equipped with a Regenerative Fuel Cell (RFC) is proceeding. For vehicles equipped with an RFC under reduced-gravity condition, it is essential to control the generated gas-liquid two-phase flow. One of the gas-liquid two-phase flow is the sloshing phenomena. These phenomena have been studied under normal and microgravity conditions[2,3)] as one of the important phenomena in fluid engineering. On the other hand, there is a critical lack of knowledge on sloshing phenomena under reduced gravity. Therefore, in 2022, the Japan Aerospace Exploration Agency (JAXA) conducted a series of rotational swing experiments under reduced gravity on the International Space Station (ISS). Prior to this series of space experiments, we have conducted ground-based experiment and developed a simulation model for prediction of the liquid motion with free surface[4)]. In this study, we will analyze the data obtained from the space experiments in detail and investigate the effects of gravitational acceleration on sloshing phenomena. Furthermore, we will predict and reproduce the liquid behavior obtained from on-orbit experiment using the simulation model.

Figure 1 shows the small rectangular vessel for (a) on–orbit experiment and (b) numerical simulation. The sealed vessel is filled with liquid and gas. **Figure 2** shows that the vessel is rotated side by side around its axis of rotation, which is parallel to the z axis through the centered point in the figure. The maximum angle of rotation θ_{max} was fixed at 10 degrees. The direction of gravity was set to be in the negative direction of the y-axis. Gravitational acceleration was varied under three conditions: normal (on the ground) (G), on the Moon (G/6), and on the Mars (G/3). The vessel was rotated while varying the oscillation frequency, and the motion of the liquid with the free surface were observed. The interFoam solver of OpenFOAM (ver. 9) is used as the numerical simulation solver, which solves gas-liquid two-phase flows using the Volume of Fluid (VOF) method. A moving mesh function is applied to reproduce the reciprocating rotational motion of the vessel around its axis.

Figure 3 shows (a) the first peak amplitude reached for each normalized gravity and (b) the normalized frequency at that time. These findings indicate that in the sloshing phenomena, the amplitude peak and the value of the frequency at which the peak is reached are shifted. In this presentation, we will discuss the gravity dependence on sloshing phenomena through on-orbit experiment and numerical simulation.

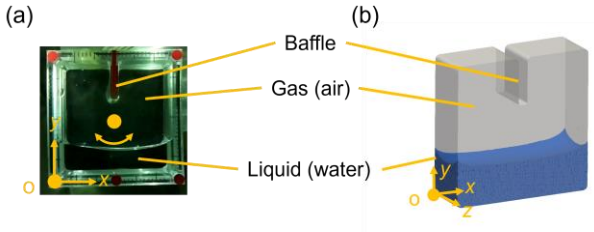

Figure 1. Rectangular vessels for sloshing test (a) on-orbit experiment and (b) numerical model.

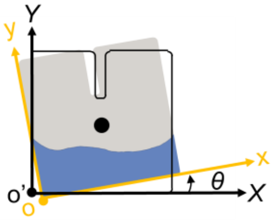

Figure 2. Coordinate systems of target geometry.

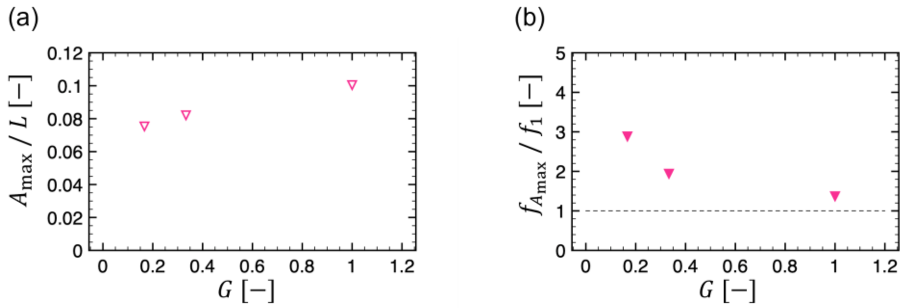

Figure 3. Gravity dependences of (a) normalized first peak liquid-level amplitude of free surface A_{max}/L and (b) normalized frequency at maximum amplitude of free surface $f_{A_{max}}/f_1$.

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