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P03

CBEF を用いた低重力環境下液体挙動に関する ISS 軌道実験 -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-

On-orbit Experiments via CBEF aboard the ISS on Sloshing Phenomena under Normal and Reduced Gravity Conditions

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It is necessary to investigate and develop for future manned space exploration on the Moon and Mars. In particular, elucidation and control of gas-liquid two-phase flow behavior under microgravity and low gravity conditions are important and critical for liquid transport and gas-liquid separation in space. Whereas sloshing phenomena is one of the important problems in fluid mechanics and fluid engineering and have been studied under normal and microgravity[1,2)], the knowledge of sloshing phenomena under low gravity is still fatally limited. The Japan Aerospace Exploration Agency (JAXA) conducted a series of rotationally swinging experiments under low gravity on the International Space Station (ISS) in 2022 using the Cell Biology Experiment Facility (CBEF). Prior to the space experiments, we have conducted ground-based experiments and developed a simulation model for prediction of the liquid motion with free surface[3)]. In this study, we analyze the data from the space experiments in detail and investigate the effect of gravitational acceleration and oscillation frequency on the sloshing phenomena. Additionally, we predict the liquid level amplitude under low gravity condition using the simulation model and compare the results with the experiments.

Figure 1 shows the small rectangular vessel for (a)on–orbit experiment and (b)numerical simulation. The sealed vessel is filled with liquid and air. 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 $\theta_{\max}$ is 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 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 2 shows the normalized liquid-level amplitude of free surface A/L against the normalized oscillation frequency f/f_{1st} under the normal and moon gravity acceleration conditions, respectively. Where f_{1st} is the primary resonance frequency for laterally oscillating rectangular vessel. The results for the moon gravity are plotted up to the higher f/f_{1st} than that for the normal one because f_{1st} decreases with gravitational acceleration. Distinct tendencies exhibit depending on variations in gravitational acceleration. When f/f_{1st} is greater than 1.0, the liquid-level amplitude increases and reaches the peak, and then decreases under the normal gravity. Whereas no significant decrease is observed, and the liquid-level amplitude gradually increases at higher frequencies under the moon gravity. In the presentation, we will discuss the effect of gravitational acceleration on the liquid behaviors in detail.

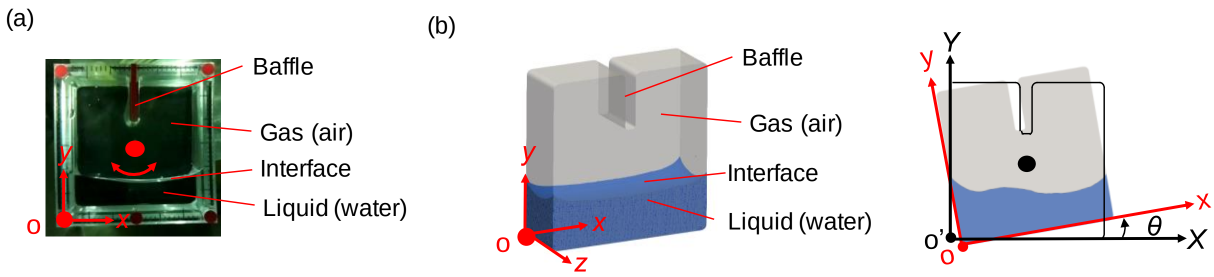

Figure 1. Rectangular vessels for sloshing test (a) on-orbit experiment and (b) numerical model.

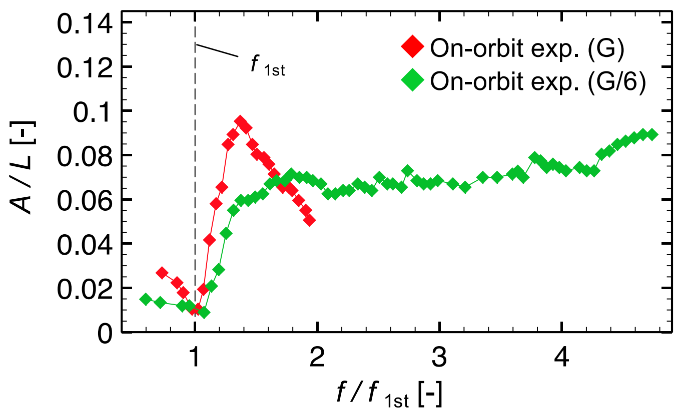

Figure 2. Normalized liquid-level amplitude of free surface A/L against normalized oscillation frequency f/f_{1st} under the normal and moon gravity acceleration conditions obtained by on-orbit experiment.

References

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