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密閉容器内スロッシング現象に対する封入流体初期液位の影響

Effect of initial liquid height on sloshing in closed vessel

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For technological developments in spacecraft and Environmental Control and Life Support System (ECLSS) used in manned space exploration to Moon and Mars, it is necessary to unveil the gas-liquid two-phase flow behavior under micro- and low-gravity conditions. Sloshing phenomena in rectangular tank have been widely investigated under normal gravity conditions[1-3]. It is of great importance to accumulate knowledge on liquid behavior within a closed vessel under various gravitational conditions and in various motions. Japan Aerospace Exploration Agency (JAXA) conducted a series of experiments on sloshing phenomena under low gravity environments assuming not only the earth gravity but also the moon and Mars on the International Space Station (ISS) in 2022 using a Cell Biology Experiment Facility (CBEF). Because the on-orbit experiments happened to be conducted with undesignated lower liquid volume within the vessel, a series of ground experiments and numerical simulation are conducted to elucidate the effect of initial liquid height after the on-orbit experiments.

Target geometry is illustrated in **Fig. 1**: (a) the front view of the vessel for the ground experiments, (b) the bird-eyed view of the model used in the numerical simulations, and (c) the coordinate system of the swinging vessel. The test liquid and gas enclosed in the vessel are n-Hexane and air, respectively. The apparatus is the same as introduced in the previous research[3]. The vessel is swung back and forth to the left and right about an axis passing through the center of the vessel. The maximum oscillation angle is set at 10 deg to examine the on-orbit experiments. The liquid behavior is observed through the front transparent wall. Numerical simulation is performed by solving the equations of continuity, Navier-Stokes, and advection of volume fraction by applying the Volume of Fluid (VOF) method. The surface tension is treated as the body force by applying the Continuum Surface Force (CSF) method. The dimensions of the vessel in the numerical simulation are the same as those used in ground experiments. To swing the vessel, a sinusoidal wave with a designated frequency is applied. The governing equations are solved by employing InterFoam solver of OpenFOAM (ver. 9).

Figure 2 shows a typical example of the liquid behavior obtained by the experiment with the initial liquid height (h_0) of (a) 7.34 mm and (b) 9.33 mm. The former corresponds to the undesignated condition in the on-orbit experiment, whereas the latter designated condition that was investigated[3] in prior to the on-orbit experiment. The excitation frequency for each case is the value closest to the first-order resonance frequency[4] $f_1^{(\mathrm{pre})}$ among the excitation frequencies in the experiments. The first-order resonance frequencies at $h_0 = 7.34$ mm and 9.33 mm are $f_1^{(\mathrm{pre})} = 4.10$ Hz and 4.42 Hz, respectively. The time $t - t_1$ represents the time elapsed since the vessel is most inclined to the right. The angle θ in $\theta - \theta_0$ is the oscillation angle of the vessel, and θ_0 is the average of the maximum and minimum oscillation angles of the vessel in the experiment. In the case of $h_0 = 7.34$ mm, the liquid-gas interface is not vigorously deformed despite that the vessel is swung at the first-order resonance frequency. In the case of $h_0 = 9.33$ mm, on the contrary, the interface deformed significantly in an asymmetrical manner, confirming the characteristics of the first-order resonant behavior. In the poster session, we will discuss the induced behaviors by varying the exciting frequency through the on-ground experiments and numerical simulation.

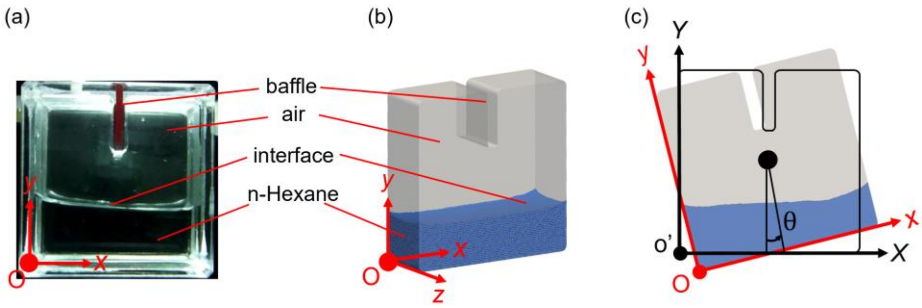

Figure 1. Target geometry: (a) front view of vessel for ground experiments and (b) bird-eyed view of model for simulations. The coordinate system of oscillating vessel is illustrated in Panel (c).

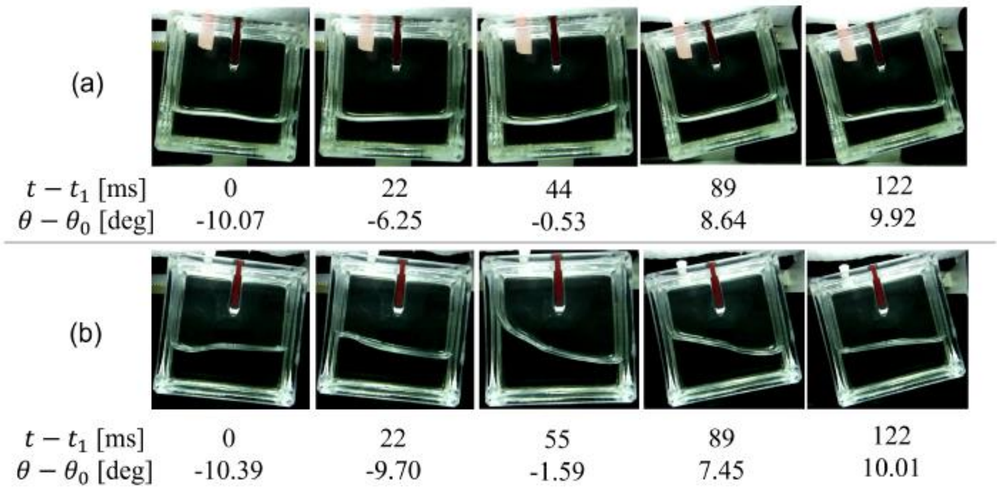

Figure 2. Liquid behavior obtained by on-ground experiments under different initial liquid height h_0 with oscillation frequency f: (a) $(h_0, f) = (7.34\ \mathrm{mm},\ 4.00\ \mathrm{Hz})$ and (b) $(9.33\ \mathrm{mm},\ 4.42\ \mathrm{Hz})$.

References

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