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低重力環境下での液体落下挙動およびスロッシング現象に関する数値流体解析

Numerical Simulation on Liquid Falling Behavior and Sloshing Phenomena under Low Gravity Environment

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Toward the development of Environmental Control and Life Support System (ECLSS) for the on-orbit and on-planet/satellite habitation facilities, it is essential and indispensable to understand and control the interfacial thermal fluid behaviors including the dynamic wetting micro- and low-gravity conditions. Japan Aerospace Exploration Agency (JAXA) plans to conduct two types of fundamental experiments on the dynamics of fluids with free surface in a closed vessel under low-gravity environment realized in the International Space Station (ISS) in 2022: (1) Liquid migration test in between reservoirs (so called 'half-hourglass' vessel) and (2) Sloshing test in a rectangular vessel. We focus on the fluid behaviors accompanying with the movement of the solid-liquid-gas interface (contact line) and deformation of the liquid-gas interface (free surface) in each closed vessel after the variation of the system orientation. In this study, prior to these experiments, we develop computational models to investigate the effect of the gravity level on the fluid motions.

Figure 1 shows a calculation model of the half-hourglass vessel. The designated gravitational acceleration is given in the y direction, and the test liquid is enclosed in a reservoir of the vessel as the initial condition. The rest of the space is filled with the test gas. As soon as the simulation starts, the gravity direction gradually changes to the opposite direction in y within 0.5 s, and the test liquid starts moving through the junction to the opposite side of the vessel. The vessel rotates around the x axis to simulate the on-orbit experiments. **Figure 2** shows the temporal variation of the movement of the test liquid under the gravity of G/6, where G is the gravitational acceleration on the ground (1G = 9.81 m/s^2). One finds that most of the liquid is driven to the opposite reservoir along the wall. In particular, the interior corner flow, which the liquid flows ahead of the corners of the vessel due to surface tension[1)], occurs as shown in a region (A) at t = 0.8 s. We will discuss the effects of the gravitational acceleration, the geometry such as the junction width, and the fluid properties such as the liquid viscosity on the fluid motion.

Figure 3 show the calculation models for the sloshing test. In the operation for the on-orbit experiment, the vessel is swinged like a pendulum system around a single central point in the x-y plane. We establish two types of rectangular vessel models: (a)_the three dimensional (3D) model with a baffle for observing the deformation of the gas-liquid interface when the liquid flows over the baffle, and (b) the 2D model without the baffle for investigating the amplitude of the liquid level when the vessel is oscillated at a value close to the resonance frequency[2,3)]. The predicted resonance frequency is determined from the size of the vessel and the initial liquid level, and is independent of the physical properties of the liquid. We perform a series of simulation by varying the oscillation frequency and the swing angle of the vessel. When the oscillation frequency is close to the resonance frequency of the system, a large amplitude of the liquid level is observed for any gravitational acceleration. The deformation of the gas-liquid interface is smaller at low gravity acceleration, and the absolute value of the amplitude are different depending on the gravity. We will discuss the effect of the gravity on their characteristics in detail.

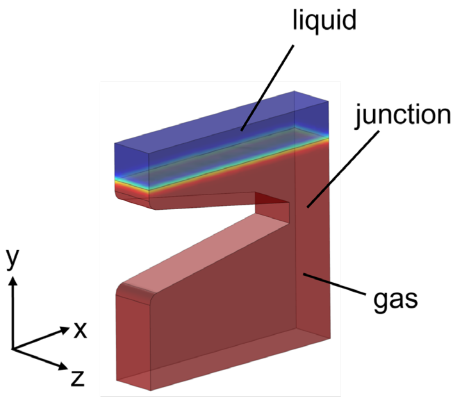

Fig. 1 Calculation models: half-hourglass vessel

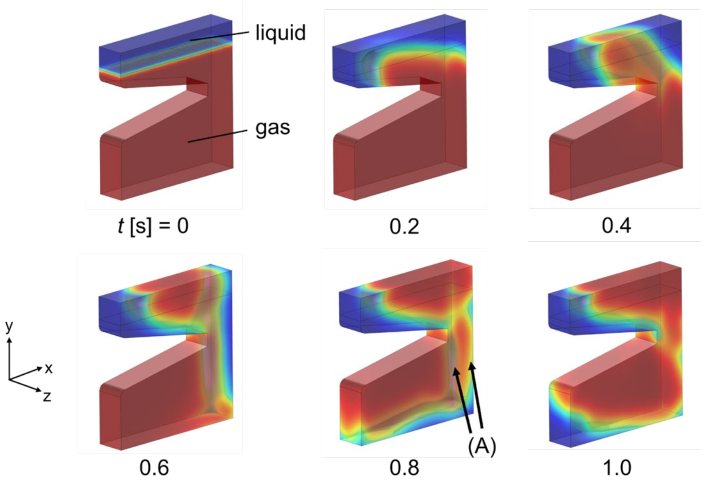

Fig. 2 Temporal variation of water movement in half-hourglass vessel for w = 10 mm at G/6.

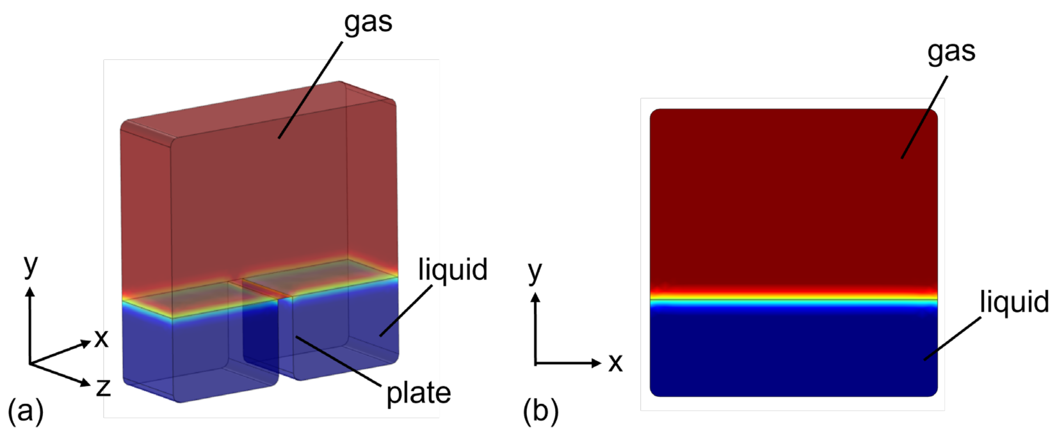

Fig. 3 Calculation models: (a) 3D rectangular vessel with plate as baffle, and (b) 2D rectangular vessel.

References

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