Axial Sloshing of Liquid Hydrogen in Cylindrical Containers with Superheated Walls in Weightlessness

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Abstract

The most powerful rocket upper stages use liquid oxygen (LOX) as oxidizer and liquid hydrogen (LH2) as propellant. By shutting down the engine, the spacecraft enters microgravity and the fluid free surface is now dominated by capillary forces. Since liquid hydrogen is a perfectly wetting fluid with the contact angle $\gamma_s = 0°$ an axial sloshing motion is initialized.

First technical investigations of the reorientation period were performed by Siegert et al. [1] in the context of the Apollo program in the 1960s. They used a small drop tower to examine the reorientation of different liquids at room temperature, liquid Nitrogen and LH2 ($T_{\mathrm{sat}} = 20.3$ K at $p_{\mathrm{sat}} = p_0 = 101325$ Pa). In contrast to storable liquids, LH2 is kept under saturation conditions and the surrounding walls are superheated. During the rise at the wall the meniscus travels through a wide range of superheat temperatures and the motion of the meniscus is disturbed by the evaporation and its recoil. The influence of these effects on the sloshing motion of liquid argon and methane was investigated scientifically by Kulev et al. [2, 3] and Schmitt and Dreyer [4] using LH2 in the drop tower in Bremen, Germany.

The actual experiments were performed at the same drop tower at the University of Bremen. It provides microgravity for an experiment duration of $t_1 = 4.74$ s with acceleration residuals of $g_{\mathrm{res}} < 10^{-5} g_0$ by dropping down an experiment capsule a 110 m tall evacuated drop tube.

The experiment is built up inside a cryostat that contains liquid helium (LHe, $T_{\mathrm{sat}} = 4.2$ K at p_0) as coolant and is thermally insulated from the environment by vacuum and multiple radiation shields. The experiment vessel is placed inside this cryostat and is made from glass, which allows an optical observation by an endoscope. Its inner radius is $r = 26.2$ mm, and it is filled with LH2 up to $h = 42$ mm from the bottom. The system is a single species hydrogen system with two phases which is hermetically sealed.

Temperature sensors are bonded to the outside of the cylinder wall to determine the temperature distribution in the height axis. The temperature is regulated by two heating foils on the glass cylinder and the connecting flange respectively. A third heating foil is applied on the bottom of the vessel to manipulate the thermal stratification of the bulk liquid. With exception of the temperature sensors the measuring equipment is assembled outside the cold area.

The influence of two parameters on the sloshing motion and the pressure evolution were investigated, so the temperature gradient at the wall above the free surface $\Delta T/\Delta z =$

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-5 K/m $\cdots$ 690 K/m and the temperature difference in the liquid from the free surface to the liquid bulk $\Delta T_{\mathrm{sub}} = 0.12$ K $\cdots$ 2.24 K.

Three regimes of superheating were identified. In regime A, the liquid and the wall are quasi-isothermal, no nucleation occurs. In regime B, the wall is that much superheated to create nucleate boiling in a retarded manner. This is in contrast to regime C where nucleate boiling occurs immediately after wetting the surface.

References

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