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Fluid-Structure Interaction Analysis with Slippery Mucus Skin

Masao Yokoyama[1], Kohei Murotani[2], Genki Yagawa and Osamu Mochizuki[3]

[1] Meisei University, 2-1-1 Hodokubo, Hino, Tokyo, 191-8506, Japan,
masao.yokoyama@meisei-u.ac.jp
[2] University of Tokyo, 7-3-1 Hongou, Bunkyou, Tokyo, 113-8656, Japan
[3] Toyo University, 2100 Kujirai, Kawagoe, Saitama, 350-8585, Japan

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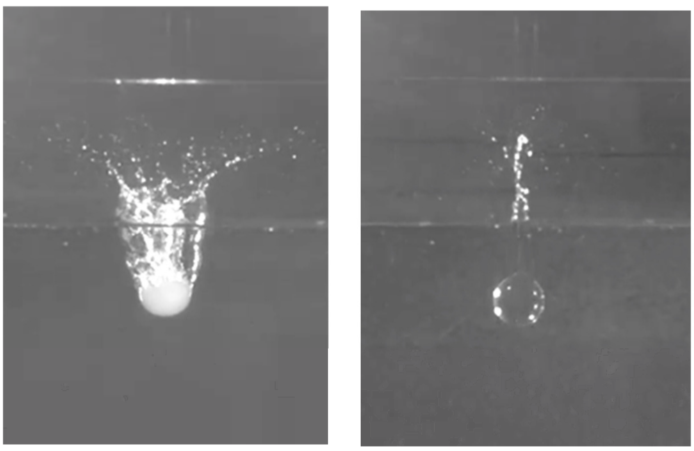
The Fluid-Structure Interaction (FSI) is one of the most popular topics in the computational mechanics. It covers a wide range of phenomena of scientific and engineering fields such as vehicle, medicine, civil engineering and construction, agriculture, forestry, disaster prevention, music, sports, etc. The vibration of structure caused by the Kármán's vortex street has been studied for many years, which is a locking phenomenon caused by the vortex street behind a spherical cylinder [1].

It is well known that the surface condition, the roughness of surface or the uneven shape of the solid surface gives some influence on the flow fields and the movement of the solid as seen in the case of the dimple of a golf ball [2]. In the most of the FSI studies, however, the wall of the solid or the structures is assumed to be as non-slip condition in numerical simulation. It is not a realistic assumption. For example, creatures living in water such as fish and amphibians have a slimy mucus skin, whose principal ingredient is a hydrogel known as mucin [3]. Furthermore, since the inner wall of the digestive organs or the blood vessel has a slippery surface, it seems important to take the characteristics of such slippery surface into consideration in numerical simulation.

The experimental results which we have observed by a high-speed camera of a splash formed by a sphere impinging on water surface are shown in Fig. 1, comparing the primary splash formed by a hydrogel sphere (Fig. 1A) with that by an acrylic sphere (Fig. 1B), where the primary splash means the splash, which rises right after an object plunging. The primary splash formed by the hydrogel sphere is a kind of the crown-type. On the other hand, the acrylic sphere creates the column type primary splash.



(A) Hydrogel (Agar) (B) Acrylic resin

Fig. 1 Comparison of splash patterns between hydrogel and acrylic resin (Radius of sphere=10mm and Impact velocity=2.21m/sec).

This experimental observation suggests that the numerical simulation should take into consideration the various surface conditions or the interaction between the solid object and the water.

Let us discuss here how we can introduce the influence of the slippery wall seen, for example, in the case of the skin of a frog into the calculation in a heuristic manner. We take a diving sphere made of agar as the hydrophilic material, which consists of cross-linked structure by polymer called agarose and plenty of water molecule between the polymer structures, which makes the solid surface slippery.

Thus, we discuss in this paper focusing on the treatments of the interface between the solid and the fluid and propose a calculation method with the slip effect on the surface of a slimy material. An engineering model to express the slimy surface, which the creatures living in water such as fish or frogs have, is proposed, where the slip ratio α, which is the reduction ratio of the shear stress near a solid wall obtained through the experiment, is introduced in the shear term of the Navier-Stokes equation. The splash pattern calculated by the proposed method is in good agreement with the experimental result. The above method for calculating the splash is applied to the large scale parallel computing in 3D, which depicts the more detailed splash patterns. As the future work, a larger scale computing and a modelling of the surface tension are needed to observe the finger or the spike as seen in the case of the milk-crown.

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