11th World Congress on Computational Mechanics (WCCM XI)
5th European Conference on Computational Mechanics (ECCM V)
6th European Conference on Computational Fluid Dynamics (ECFD VI)
July 20 - 25, 2014, Barcelona, Spain

NUMERICAL INVESTIGATION ON FREEZING PROCESS OF SUPER-COOLED DROPLET

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Key Words: *Multi-physics CFD, VOF Method, Ice Accretion, Multi-phase Flow*

Icing is a phenomenon that super-cooled water droplets impinge on a solid surface and accrete on it. There are serious problems with the icing on aircraft – for example, a degradation of the aerodynamics performance caused by the deformation of the airfoil shape due to the accreted ice and a mechanical damage on engine core components due to the shed ice from the jet engine fan. Therefore, it is important to investigate the effect of icing on the flow field and to predict icing areas in the design phase. Icing wind tunnel tests should be conducted under various weather conditions in the development process of an airplane. However, it is difficult to reproduce the weather conditions by the experiment repeatedly because icing phenomena are very complicated, and thus the icing experiment needs huge cost. Therefore, the numerical investigation using CFD which can reproduce various icing conditions is desirable.

In our laboratory, we have developed the icing models [1] which can be applied at various conditions. There are a lot of existing researches on the ice shape on a main wing, a tail wing and engine fans. However, the detailed mechanism of the super-cooled droplet freezing has not been clarified. Therefore, in this study, we simulate the behaviour of a super-cooled droplet when the droplet freely falls on a flat plate.

In the present study, continuity and Navier-Stokes equations are used as the governing equations and MAC method is employed for the pressure computation

$$\nabla \cdot \boldsymbol{u} = 0 \tag{1}$$

$$\frac{\partial \boldsymbol{u}}{\partial t} + \frac{1}{\rho}\left(\boldsymbol{u} \cdot \nabla\right)\boldsymbol{u} = -\frac{1}{\rho}\nabla p + \nu \Delta \boldsymbol{u} + K \tag{2}$$

where K in Eq. (2) is body forces which are the gravity and the surface tension. Continuum Surface Force (CSF) model [2] is applied to the surface tension f_v

$$f_v = \sigma \kappa \nabla F \tag{3}$$

where σ is the surface tension factor and κ is the curvature. The curvature is represented by the next equation with the unit normal vector $\boldsymbol{n}$

$$\kappa = -\nabla \cdot \boldsymbol{n} \tag{4}$$

The computational target in this study is the three phase flow, which consists of air, water and ice. We use VOF (Volume of Fluid) method [3] to simulate the free interface

$$\frac{\partial F}{\partial t} + u\frac{\partial F}{\partial x} + v\frac{\partial F}{\partial y} = 0 \tag{5}$$

where F is the fluid filling ratio in VOF method. Moreover, the heat conductive computation is conducted by use of the Extended Messinger model [4]

In this study we simulate behaviour of a super-cooled droplet and the freezing process when the droplet is dropped to the plate as shown in the Fig. 1. The computational conditions are summarized in Table 1.

Table 1 Computational Condition

Initial Temperature of Vapor Phase T_G	[K]	253.15
Initial Temperature of Droplet T	[K]	265.15
Initial Heght of Droplet H	[m]	0.002
Initial Diameter of Droplet$D$	[m]	0.002

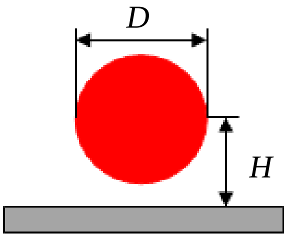
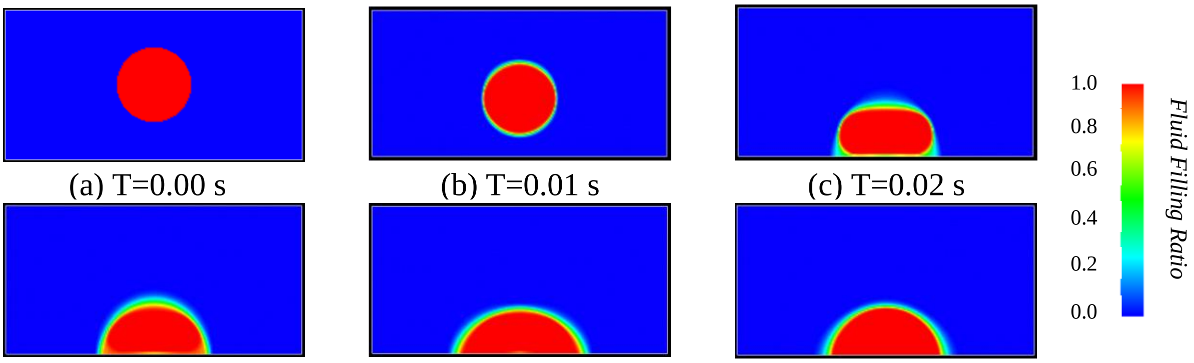


Fig. 1 Initial Condition of droplet

We conducted two simulations in the present study, which are without freezing and with freezing cases. First, we show shows the falling motion of the droplet in the case without freezing in Fig. 2. The droplet oscillated up and down after it impinges on the plate in 0.02 seconds. This was caused by the gravity force acting on the droplet and the surface tension keeping the droplet shape as sphere. In the final paper, we will compare this result with the freezing case, and our results are validated by using the experimental data measured by Tanaka et al. [5]



(a) T=0.00 s (b) T=0.01 s (c) T=0.02 s

(d) T=0.03 s (e) T=0.04 s (f) T=0.05 s

Fig. 2 Droplet Behaviour

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