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 DROPLET TEMPERATURE OF ICE CRYSTAL ACCRETION

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Key Words: *Multiphysics-CFD, Jet Engine Core Icing, Super-cooled Water Droplets.*

Ice accretion is a phenomenon that super-cooled water droplets in the atmosphere impinge on a body and form ice layer. When it occurs in a jet engine, the shape change of iced blades makes aerodynamic performance worse, and the ingestion of shedding ice flakes can cause serious mechanical damages to the fan and the compressor components. Engine components such as a splitter, a nose cone, fan blades and fan exit guide vanes have been considered as the icing areas in a jet engine. However, in recently years, it is known that the ice accretion occurs in the engine core such as the low pressure compressor and the first stage of the high pressure compressor [1], where the temperature is about 30 °C. The ice accretion in the engine core is called as “ice crystal accretion”. Some scenarios are given for the ice crystal accretion, one of which is super-cooled water droplets, but the mechanism has not been sufficiently clarified yet. Moreover, the current icing model is not available in the environment where the temperature is above the freezing point. In our previous study, we developed a new icing model which is applicable to a warm environment by computing the heat conduction inside a computational target [2]. In this study, we apply our new icing model to an actual compressor blade with various initial temperature of super-cooled water droplets and research whether the ice crystal accretion occurs by only super-cooled water droplets or not.

Our computational approach consists of four procedures, which are grid generation, flow field, super-cooled water droplets trajectory and thermodynamics. First, the flow field around a compressor blade is computed. Then, properties of super-cooled water droplet trajectory, such as impact position and mass, are predicted by a Lagrangian method. At last, temporal changes of the surface and the inside temperature of the blade are estimated by the thermodynamics computation. In the thermodynamics computation, we use the Extended Messinger model [3] based on the Stefan problem. Moreover, in order to estimate the temporal change of the temperature within a blade, the heat conduction equation is employed in the thermodynamics computation.

In the present study, we select NACA65-210 airfoil as a compressor blade. Computational domain is shown in Fig. 1. Computational grid system has two sub grids based on the overset grid method to analyze the detail of the boundary layer flow around the blade and the heat conduction within the blade. The total number of the grid points is about 300,000. Computational conditions are exhibited in Table 1. 1,000,000 droplets whose median volume diameter (MVD) is 20.0 μm are put on the inlet boundary. The temperature of super-cooled water droplets is varied from -10.0 to -40.0 °C, because super-cooled water droplets can be found more than -40.0 °C. Then, the collision mass on the surface is computed by liquid water content (LWC) and the thermodynamics computation is performed till 3.0 sec.

Internal blade temperature distributions are shown in Fig. 2. This figure indicates that the internal blade temperature decreases as super-cooled water droplets temperature decreases. When the temperature of super-cooled water droplets is -40.0 °C, it is obvious that the surface temperature decreases under the freezing point and the ice crystal accretion can occur there. The ice shape of -40.0 °C droplet temperature case is shown in Fig. 3. Ice shape looks like the glaze icing which has a horn. This study indicates that the ice crystal accretion occurs by only super-cooled water droplets if the temperature of super-cooled water droplets is low enough. The future prospects include that MVD and the attack angle are varied in order to clarify the cooling effect of super-cooled water droplets.

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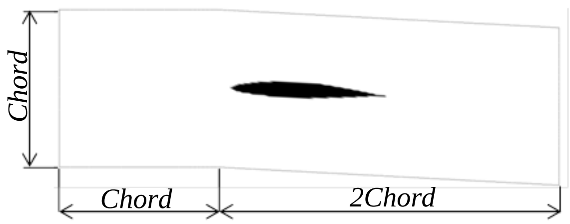

Fig. 1 Computational Domain and Size

Table 1 Computational Condition

Chord Length	[m]	0.1
Angle of Attack	[deg.]	3.0
Inlet Velocity	[m/s]	244.3
Inlet Mach Number		0.7
Inlet Total Pressure	[MPa]	0.1497
Inlet Total Temperature	[K]	332.85
LWC	[g/m^3]	8.0
Inlet Droplet Temperature	[°C]	-10.0, -20.0, -30.0, -40.0
MVD	[μm]	20.0
Exposure time	[s]	3.0

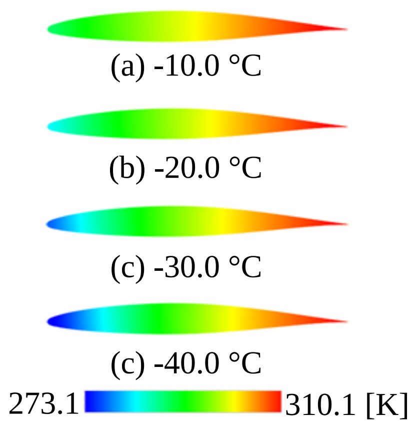

Fig. 2 Blade Temperature

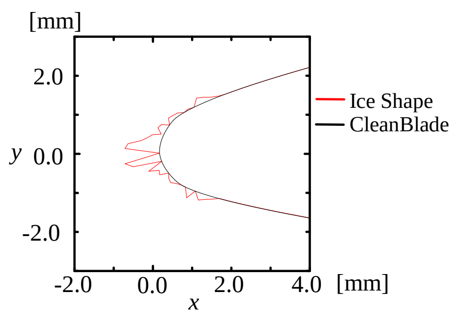

Fig. 3 Ice Shape