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Multi-Zone Ice Accretion and Roughness Models for Aircraft Icing Numerical Simulation

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Abstract. A mathematical multi-zone ice accretion model used in the numerical simulation of icing on airfoil surface based on three water states, namely, continuous film, rivulets and beads is studied in this paper. An improved multi-zone roughness model is proposed. According to the flow state of liquid water and film flow, rivulets flow governing equations are established to calculate film mass distribution, film velocity, rivulet wetness factor and rivulet mass distribution. Force equilibrium equations of droplet are used to establish the critical conditions of water film broken into rivulets and rivulets broken into beads. The temperature conduction inside the water layer and ice layer is considered. Using the proposed model ice accretion on a NACA0012 airfoil profile with a 4° angle of attack under different icing conditions is simulated. Different ice shapes like glaze ice, mixed ice and rime ice are obtained, and the results agree well with icing wind tunnel experiment data. It can be seen that, water films are formed on the surface, and heights of the films vary with icing time and locations. This results in spatially-temporally varying surface roughness and heat transfer process, ultimately affects the ice prediction. Model simulations indicate that the process of water film formation and evolution cannot be ignored, especially under glaze ice condition.

AMS subject classifications: 76T10, 80A20

Key words: Ice accretion model, multi-zone, film, rivulets, beads, roughness height, heat transfer, temperature conduction.

1 Introduction

Because aircraft icing is a serious threat to flight safety, aircraft must have an efficient anti/de-icing system. No matter which ice protection method is used, the ice accretion

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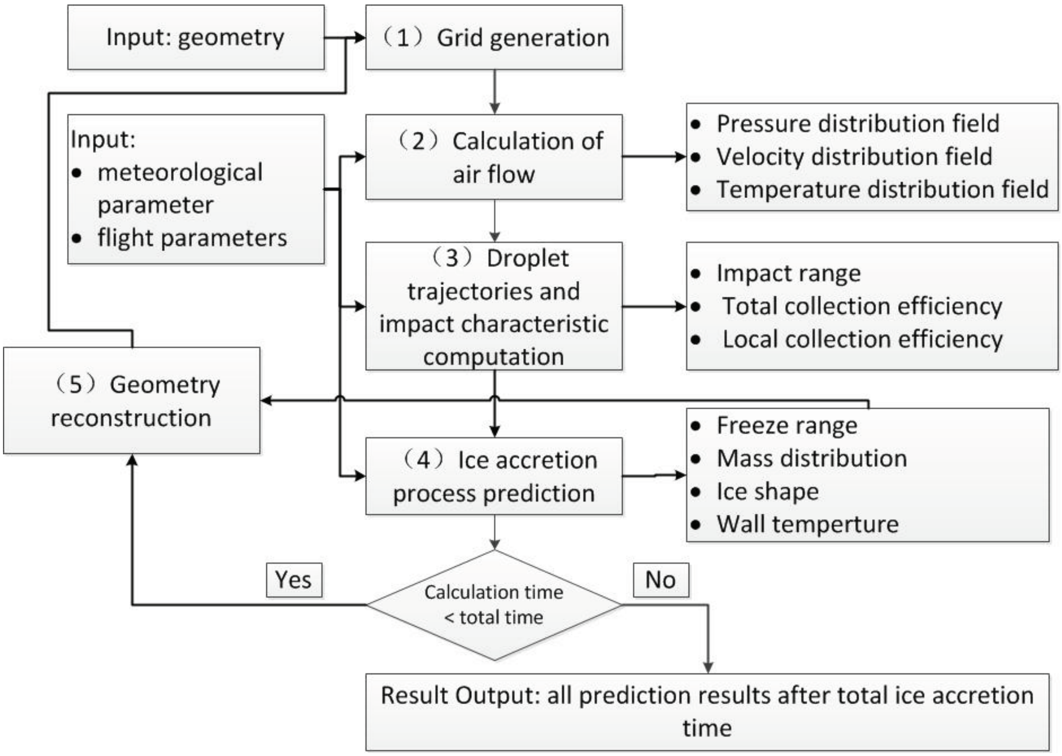

Figure 1: Calculation flow diagram of aircraft icing numerical simulation.

process must be accurately predicted to determine the structure and shape of the ice, its extension and mass distribution, which are important design basis for various ice protection systems.

In general, numerical simulation of icing consists of four modules: (1) generation of computational mesh, (2) calculation of air flow, (3) calculation of water droplet trajectories and impact characteristic, and (4) prediction of ice accretion. Since the aircraft icing is an unsteady process, the ice formed on the leading surface of a wing may change the aerodynamic configuration. Subsequently the air flow and droplet trajectories are also affected, eventually the ice accretion is also influenced. So, a new module: reconstruction of the iced airfoil geometry should be involved in the simulation. Fig. 1 shows the simulation flow chart. As the velocity and pressure of the air flow, and impact droplet mass distribution are obtained from the previous three modules, flowing process and heat and mass transfer of droplet collected by the wall will be determined in the fourth module. The icing extension, ice mass distribution and ice shape will be calculated simultaneously. To obtain accurate and reliable CFD predictions, each module is very important. This paper focuses on a new multi-zone ice accretion and surface roughness model in the fourth module to more accurately simulate the revolutionary process of impact droplet on the wall.