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An Adaptive Cartesian Method for Prediction of the Unsteady Process of Aircraft Ice Accretion

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Abstract. An adaptive Cartesian method combined with the ghost cell method is proposed to solve problems of unsteady aircraft icing simulation in this paper. In the grid generation module, Cartesian method is used to generate the background grids around the clean and iced geometries. Boundary self-adaptive method is developed to update the grids as the ice accumulates and the geometry is changing over time. Besides, local encryption is carried out around the boundary grids in order to improve the prediction accuracy. An improved ray method is used to classify the grids into four types, named fluid grids, solid grids, boundary grids and ghost grids. The flow field is obtained by solving Euler equations, and the ghost cell method is introduced to provide the boundary conditions due to the non-body-fitted feature of Cartesian grids. Droplet trajectories are calculated using Lagrangian method. And a new and efficient droplet location judgment method is proposed to determine whether the droplet impinge on the surface. Besides, the ice accretion behaviors are predicted using Messinger model. With the method proposed in this paper, extensive numerical tests in various icing temperatures are simulated. And, the computational results are compared with test results. It can be seen that the proposed new method can predict the unsteady process of aircraft ice accretion and the compared results also show better agreements for both glaze and rime ice.

AMS subject classifications: 65M08, 76G25

Key words: Ice accretion model, adaptive, Cartesian method, unsteady, ghost cell method.

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1 Introduction

The prediction accuracy for the process of aircraft icing affects the reliability and efficiency of the ice protection system design and the accuracy of the impact assessment on the aerodynamic characteristics due to aircraft icing. Therefore, the ice accretion prediction model and the associated numerical method are important research topics for safety in the field of aircraft ice protection.

Numerical simulation methods of ice accretion prediction have been studied for more than 25 years, and many research institutions have developed their own numerical software or codes, such as LEWICE of NASA [1, 2], FENSAP-ICE of NTI [3, 4], CIRAMIL of Italy [5], and so on. Although there are some differences in the simulation methods employed by these codes, for example, droplet trajectories are predicted using the Lagrangian method for both LEWICE and CIRAMIL, whereas the Euler method is employed for FENSAP-ICE. However, the main simulation procedure and the calculation modules for ice accretion are similar. In general, the prediction of aircraft icing consists of four parts. The first part is the generation of a computational mesh. The second part is the air flow calculation. The third part is the computation of the trajectories and impingement characteristics of super-cooled droplets. The last part is the calculation of the heat and mass transfer behavior on wing surfaces and the consequent prediction of ice shape. As aircraft icing is an unsteady process, ice formed on the leading surface of a wing may change its aerodynamic performance characteristics. Subsequently, the air flow pattern and the droplet trajectories also are affected and eventually accretion of the ice is modified [6]. Therefore, modern CFD methods tend to divide the total icing time into several small freezing time steps, and in each time step the ice accretion procedure is predicted, based upon the hypothesis that there is little effect on the airflow characteristics and droplet field behavior as a result in changes of the shape of the ice deposit. When the accretion time reaches the time step, the iced airfoil geometry is reconstructed, basing on which above four simulation procedures is repeated. The simulation flow diagram of aircraft icing numerical simulation is shown in Fig. 1.

Thus, the current icing prediction codes take the time step as the unit and consider the icing process as multiple quasi-steady process. They always use structured or unstructured grids and require frequent grid regeneration after the wing geometries are changed by ice accretion. This processing method may lead to some deviation between the predicted ice accretion condition and the actual unsteady situation. Furthermore, there are huge costs in computation resources as the time steps are always so large that grid reconstruction and the above four modules need to undergo very many cycles. To overcome these shortcomings, a new ice accretion prediction method, based on an adaptive Cartesian grid, has been developed in the present study.

As the aircraft icing is an unsteady procedure, the geometry is changing over time, so an adaptive grid system is needed, based on which, the flow field and droplet trajectories are update timely. While, both the structured and the unstructured grids do not have the capabilities to quickly adopt new boundaries or inherit former calculation results,