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ADVANCES IN THE DEVELOPMENT OF A 3D MORPHOGENETIC MODEL FOR IN-FLIGHT ICING

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ABSTRACT

Over the last fifty years, a variety of numerical ice accretion models have been developed for a multiplicity of applications, by numerous research groups around the world. The vast majority of these models are based on the solution of conservation differential equations, along with appropriate boundary and initial conditions. While these models have been broadly successful in simulating overall ice accretion characteristics, such as load and general ice distribution, they have been far less successful in predicting the physical details that can influence the aerodynamic and structural properties of the iced component. In addition, the prediction of ice surface roughness remains an elusive goal for traditional models.

The goal of my research over the past decade has been to develop a new paradigm for icing modelling. The essential innovation of my radically new approach to icing modelling, called morphogenetic modelling, is its ability to predict the shape, structural details and physical properties of ice accretions, by emulating the behaviour of individual fluid elements. While existing icing models consider continuous fluxes of impinging supercooled droplets and water flowing along the ice surface, the morphogenetic approach considers the stochastic behaviour of an ensemble of fluid elements, which impinge individually, move along the icing surface following random walk rules, freeze and shed from the surface. Due to the model's discrete formulation, the model is able to simulate the formation of rough and discontinuous ice structures, predict ice accretion density, and predict ice surface roughness. In addition, as a result of the model's intrinsic randomness, it is able to provide measures of the inherent stochastic variability of the ice accretion shape and structure.

The morphogenetic model described here is a descendant of a two-dimensional model, originally conceived by Szilder [1] for freezing rain applications. A more recent, two-dimensional version of the model, designed to simulate in-flight icing conditions [2], is more complex than the original model, being coupled with solvers for the external flow field and heat transfer, and for droplet trajectory and impingement. Using a three-dimensional version of the model, we have also successfully simulated three-

dimensional, discrete rime structures forming on swept wings, under conditions where experiments produce ice structures called “lobster tails” or “scallops” [3].

As an example of the model’s capabilities, we show below two exploratory results, predicting ice formation on the nose and the windshield of a helicopter for cloud droplet diameters of 30 μm and 50 μm. We have chosen heavy icing conditions under forward flight at 50 ms^{-1}, with a liquid water content of 1 gm^{-3}, an icing event duration of 30 min, and atmospheric conditions cold enough for impinging drops to freeze instantly upon impingement (rime ice). The morphogenetic model simulations were performed in a three-dimensional, cubic lattice consisting of 120 × 180 × 400 cells, with a grid size of 2.5 mm. Evidently, increasing droplet diameter leads to an increase in both the extent and thickness of the ice accretion, as a result of the greater collision efficiency of the larger droplets. It may be noted that the ice surface is rough and uneven, with a roughness element scale of the order of ten millimetres. The boundary of the ice accretion is also uneven, as a result of shadowing by the already-accreted ice. In future simulations, we plan to examine cases with glaze ice and runback water.

(a) (b)

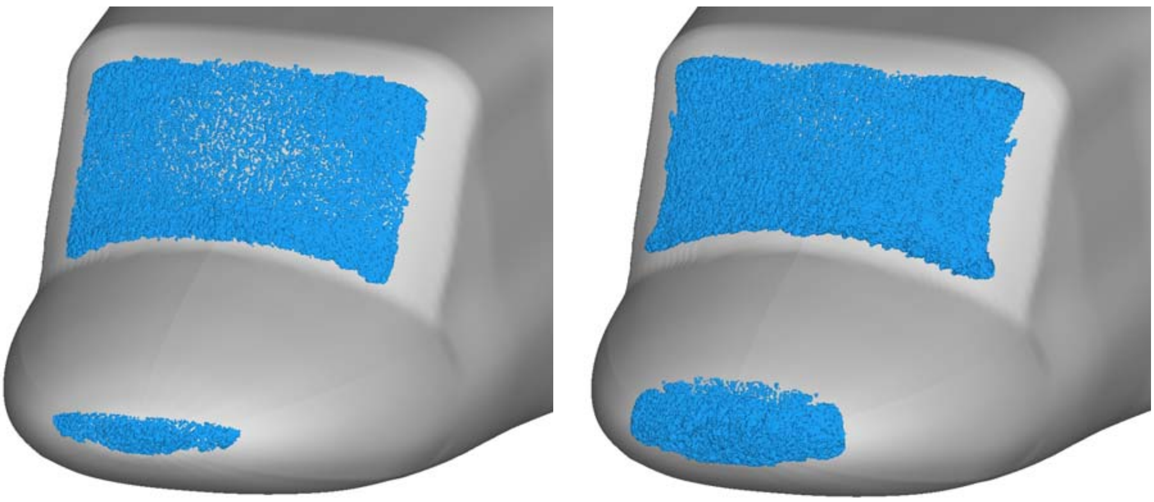

Fig. 1. Predicted rime ice formation on a BELL 412 helicopter nose and windshield for two cloud droplet diameters (a) 30 μm and (b) 50 μm. Other conditions are given in the text.

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