width and shape of cross-section. The characteristics of the model channel are defined on the basis of a topographic map of the corresponding avalanche bed. The motion of avalanche snow is modelled by the flow of an incompressible "liquid" subjected to the action of gravity, internal resistance, and external friction. Destruction and capture of undisturbed snow by an avalanche from the slope is accounted for by introducing into the equations of motion distributed sources of mass the intensity of which depends on the sought characteristics of the problem and which is defined while solving the problem.

On the basis of simple physical considerations connected with the finite shear stress in the snow, it is shown that for sufficiently large avalanches the specific friction force becomes inversely proportional to the thickness of the flow. The proposed mechanism of friction explains the abnormally high mobility of catastrophically large avalanches.

The adopted model possesses a number of properties agreeing qualitatively with the observational data for avalanches. Computer solutions have the form of rather prolonged flows with the shape of the front part typical for avalanches and with characteristic wave formations in the flow which sometimes result in pulsating regimes of motion. The report concludes with results of comparison of predicted and observed characteristics of motions of avalanches for some real avalanche beds demonstrating possibilities of the proposed model.

A NUMERICAL ICE-ACCRETION MODEL

By S. F. Ackley

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Abstract. A numerical model is developed for calculating the rate and total amount of ice accretion under atmospheric conditions. The principal application of the numerical approach is to aircraft icing and more specifically, helicopter icing problems. These problems are best solved using numerical techniques because of three factors: (1) the dependence of the ice accretion rate on the amount of ice previously deposited, (2) the existence of two different ice growth regimes, the "dry" and "wet" growth regimes, determined by the surface temperature of the accreting surface, and (3) variable velocities (e.g. along rotor blades) which affect the rate of capture of swept-out water droplets and the amount of heat generated by the flow on the accreting surface. These three factors cause feedback in the two governing equations for determining the mass rate of ice accumulation.

The first of these equations is for the mass rate of water captured, and the second equation is for the heat balance of the accreting interface. For the numerical calculation, the object, such as a helicopter rotor blade, is broken down into elements of constant velocity, and for each time step the resulting ice thickness is used to recompute new cross-sectional and surface areas which are then used as input to the next time step. Changes in the cross-sectional and surface areas caused by ice build-up affect both the mass rate (directly through the cross-section and indirectly through a change in collection efficiency) and the heat balance (directly through the cross-sectional and surface areas and indirectly through changes in the collection efficiency and Reynolds number). An additional instability in the ice growth rate develops when the transition between wet and dry growth occurs, enhancing the feed-back that already exists between the mass rate of ice accumulation and the thickness previously deposited. Numerical icing simulations using various helicopter configurations and the icing conditions they typically encounter are presented.

DISCUSSION

S. C. Colbeck: It is encouraging to see that you understand the physics of the problem. Do you have any suggestions for practical solutions to the problem at this time?

S. F. Ackley: This is obviously a leading question by a well-known provocateur at these meetings. We are continuing with our investigations. We are particularly interested at this time in the shedding problem.

R. List: The applied heat-transfer equation is for slowly rotating cylinders with quasi-symmetric accretion and transfer. The situation for helicopter blades is quite different. Further, J. N. Carras and W. C. Macklin's data on shedding are for situations without the high angular accelerations observed for blades. Higher angular accelerations will enhance shedding considerably. The distinction between wet and dry growth is quite academic because even at surface temperatures below 0°C parts of the surface will be liquid at any one time. I agree with the author that the heat transfer (through conduction) from the part of the blade without deposit to the part covered by ice could be crucial. In general, however, I feel that the phenomenon of helicopter blade icing is better described by empirical equations than by modelling on the basis of an unsatisfactory theory.

Ackley: In reference to the use of the shedding data from lower velocities, I should point out that we have not used the quantitative values but only the implied dependence as given by Carras and Macklin, I feel there is a need for more experimentation but am encouraged by the qualitative similarity between the "extended prediction" using Carras and Macklin's results and the observed ice thickness from our experiments. There may not be the strong angular acceleration dependence for shedding that Dr List has stated but not proven. A similar reply may also apply for the use of the heat-transfer equation, i.e. there is reasonable agreement, here more quantitative, with the prediction of the heat-transfer equation and the transition from dry to wet growth. Therefore the heat-transfer equation we use may be more valid than Dr List would care to admit.

The wet and dry growth transition is not academic because it seems uniquely to define whether water is shed or not. I would concur that there is probably a temperature rise to 0°C as a droplet impinges, however, if the heat transfer is adequate we may assume that it is completely frozen without shedding. This leads to a linear dependence of ice thickness with velocity in the dry-growth regime and a non-linear dependence on velocity in the wet-growth regime. The transition also appears to be well defined by ice structure and is fairly predictable from the assumptions in the heat transfer causing a surface temperature of 0°C.

The dialectic between modelling and experiments is the guts of any scientific advance and is crucial to the understanding of the process so I am in complete disagreement with Dr List in his emphasis on empiricism rather than theory.

A STUDY OF SEVERAL PRESSURE RIDGES AND ICE ISLANDS IN THE CANADIAN BEAUFORT SEA

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Abstract. The environment conditions in the southern Beaufort Sea are described with special emphasis on pressure ridges and ice islands. Techniques for determining the geometric