Proposed Modifications to Ice Accretion/Icing Scaling Theory

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The difficulty of conducting full-scale icing tests has long been appreciated. Testing in an icing wind tunnel has been undertaken for decades. While aircraft size and speed have increased, tunnel facilities have not, thus making subscale geometric tests a necessity. Scaling laws governing these tests are almost exclusively based on analysis performed over 30 years ago and have not been rigorously validated. The following work reviews past scaling analyses and suggests revision to these analyses based on recent experimental observation. It is also suggested, based on the analysis contained herein, that current ice accretion predictive technologies, such as LEWICE, when utilized in the glaze ice accretion regime, may need upgrading to more accurately estimate the rate of ice buildup on aerodynamic surfaces.

Nomenclature

A_C	= accumulation factor
b	= relative heat factor
C	= chord or characteristic dimension
C_p	= specific heat
d	= cylinder diameter or drop diameter
E	= internal energy
h_c	= convective heat transfer coefficient
h_{fs}	= latent heat of fusion
k	= thermal conductivity
LWC	= liquid water content
ℓ	= mean spacing between drops
M	= mass
R	= drop radius
R_s	= radius of impacted drop
s	= arc length
T	= temperature
T_a	= air temperature
T_f	= freezing temperature
T_s	= surface temperature
t	= time
t_s	= thickness of impacted drop
U_∞	= freestream speed
α	= incidence angle
β	= local collection efficiency
γ	= contact angle
δ	= layer thickness
η	= freezing fraction
θ	= air driving potential
μ	= absolute viscosity
ν	= kinematic viscosity
ρ	= density
σ	= surface tension
τ	= shear stress
ϕ	= water driving potential

Subscripts

a	= air
w	= water
i	= ice

I. Introduction

NASA Lewis Research Center and the Federal Aviation Adminstration (FAA) are currently supporting efforts to develop analytic tools to estimate the rate of ice accretion on aerodynamic surfaces. Concurrently, these efforts are causing a re-examination of the rules under which icing tests are conducted in wind tunnels. Because of the inherent difficulties of documenting icing conditions in the atmosphere in which an aircraft will be flown and the costs associated with flight tests, the use of icing wind tunnels and subscale models is almost a necessity. Yet the basic physics of ice accretion is not readily understood, whereas the problem of ice accretion on aerodynamic surfaces has been known since nearly the earliest days of aviation. To illustrate this lack of detailed understanding, take, for instance, the nature of the ice accretions. Those that occur at atmospheric temperatures significantly below freezing at low speeds and liquid water contents that allow impacting droplets to freeze immediately upon impact with a surface are referred to as rime ice accretion. Conditions where both liquid and ice exist on the surface of the ice are referred to as glaze ice. These definitions of ice accretion types have been in use for some time now, yet there appears to be no quantitative definiton of these ice regimes. For example, what is the functional relationship between ambient temperature and velocity for droplet impact at a stagnation point that separates the rime ice accretion region from the glaze ice regime? To our knowledge, this question has not been answered.

One of several troublesome observations is associated with the actual impact of the supercooled droplets with the surface of the airfoil. Current analyses, and all previous analyses for that matter, assume that the impacting drop sticks to the surface and utilizes the collection efficiency schematically illustrated in Fig. 1. Recently, there has been an interest in the impact of rain with aerodynamic surfaces,[1] and although rain drops are significantly larger than supercooled icing droplets, a large fraction of the droplet mass that impacts the surface is

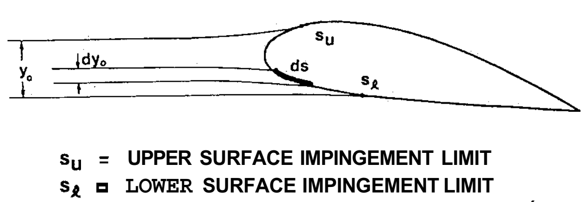

Fig. 1 Definition of local collection efficiency.

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