SCALING LAWS FOR TESTING OF HIGH LIFT AIRFOILS UNDER HEAVY RAINFALL

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Abstract

Subscale test data has shown that airfoils operating in a simulated heavy rain environment can experience significant performance penalties. The physical mechanism which results in this performance penalty has yet to be conclusively identified. Therefore, the extrapolation of subscale data to fullscale conditions must be undertaken with extreme caution since complete scaling laws are unknown.

This paper discusses some of the technical issues which must be addressed and resolved prior to extrapolating performance of fullscale airfoils from subscale test data. A set of scaling laws is suggested based on the neglect of thermodynamic interactions between the droplets and the air/water vapor phase.

Nomenclature

a	isentropic acoustic speed
c	airfoil chord
C_d	drag coefficient
C_L	lift coeffient
c_v	specific heat at constant volume
D	drop diameter
h_{fg}	latent heat of vaporization of water
ℓ	mean distance between droplets
m	mass
M	Mach number
n(D)	raindrop size spectrum
n_o	$8 \times 10^3 m^{-3} mm^{-1}$
N	aerodynamic force
ND	droplet number density
p	pressure
R	rainfall rate (mm/hr) or gas constant
T	temperature
u_i	velocity vector
U_∞	flight speed
V	volume or droplet impact velocity
V_T	drop terminal velocity
W_L	liquid water content (gm/m^3)
We	Weber number
x,y,z	Cartesian coordinate system
α	angle of attack
β	impact angle
Λ	reciprocal of rain spectrum scale
γ	ratio of specific heat
ρ	density
Φ	velocity potential
σ	surface tension
ν	kinematic viscosity
τ	shear stress
θ	contact angle
μ	absolute viscosity

subscripts

fs	fullscale
ss	subscale
s	solid
w	water
a	air
v	vapor

I. Introduction

The National Aeronautics and Space Administration (NASA) and other agencies are currently conducting studies on the performance penalties which might occur when airfoils operate under heavy rain conditions. The studies to date are primarily of an experimental nature and for practical reasons are conducted at subscale. Since incorrect extrapolation of test results to fullscale could seriously impact performance predictions, it is critical to have in hand detailed scaling laws. These laws will assure that tests conducted at subscale are relevant to the performance of aircraft.

The effect of rainfall about aircraft has received considerable attention in the literature. However, the bulk of this work is concerned with rain erosion resulting from high speed droplet impacts with the aircraft surface.[1] The first reported investigation of the effect of heavy rain on the performance of aircraft was published in 1941 by Rhode.[2] In this report, the

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