



Use of local-flow conditions for calculation of roughness-particle height in transition strips on wings

Associated software: **ecrit2**



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USE OF LOCAL-FLOW CONDITIONS FOR CALCULATION OF ROUGHNESS-PARTICLE HEIGHT IN TRANSITION STRIPS ON WINGS

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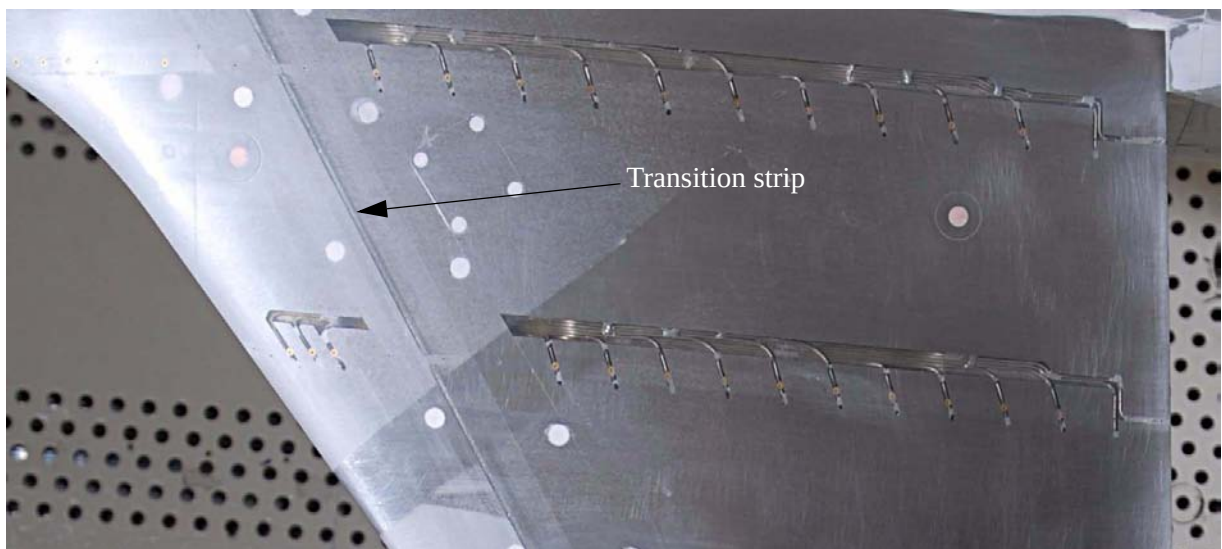
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USE OF LOCAL-FLOW CONDITIONS FOR CALCULATION OF ROUGHNESS-PARTICLE HEIGHT IN TRANSITION STRIPS ON WINGS

1. INTRODUCTION

The use of transition (or roughness) strips (or bands) to induce transition in wind-tunnel testing is well established. An example of such a strip, which typically consists of roughness elements (such as carborundum particles) locally glued to the surface, is shown in Sketch 1.1. When using this technique it is important that the roughness height, in the transition strip, is sufficient to establish transition fully at the desired location. However, use of excessive roughness height will thicken the turbulent boundary layer, resulting in excessive drag.



Sketch 1.1 Transition strip in transonic wind-tunnel test (courtesy ARA Ltd.)

In transonic wind-tunnel testing, at Reynolds numbers significantly below the full-scale value, it is important to control boundary-layer conditions at locations where high pressure gradients are anticipated, such as in the region of a shock wave or close to the trailing edge on a wing upper surface¹. Because of this “aft-fixing” may be employed², in which tests are made with a transition strip located downstream of the expected full-scale transition location (which is usually close to the wing leading edge for a swept wing). This results in a reduced turbulent boundary-layer thickness downstream of the strip, simulating a Reynolds number that is higher than the actual test Reynolds number. The use of this technique is described more fully in Reference 2.

The roughness height required to ensure transition depends on the state of the laminar boundary layer at the position of the transition strip. When aft-fixing is used, this requires knowledge of the laminar boundary-layer state at the particular location on the surface at which the transition strip is located. Because a single transition strip will usually be required to cover a range of conditions (such as different incidence settings), the strip is sized to ensure transition under all test conditions. Allowance may then be made for “over-fixing” where appropriate.

This Item describes a method (implemented as the accompanying program **ecrit2**) that can be used to estimate the roughness height required to ensure transition on a wing, using the simple correlation method suggested by van Driest and Blumer³, and investigates its performance in the transonic range. An advantage

of this method is that it can easily be applied to local-flow conditions and, in this Item, the Viscous Garabedian and Korn (VGK) two-dimensional aerofoil program⁴ is used to derive required input parameters.

The present method is validated against an alternative method, due to Braslow and Knox⁵. A spreadsheet implementation of the Braslow and Knox method, which is tailored to the ARA transonic wind tunnel (TWT)⁶ is used for this validation. In the spreadsheet method (which is not included in this Item) the wing is replaced by an equivalent flat plate and local-flow conditions are not taken into account.

2. NOTATION

C	constant (Equation (A1.8))
C_L	lift coefficient
c	local chord length of wing or aerofoil
$\bar{c}$	mean chord of wing
e_{crit1}	roughness height below which boundary layer is not affected
e_{crit2}	roughness height which triggers sustained transition
H	shape parameter ($= \delta^*/\theta$)
M	Mach number
M_δ	local Mach number at edge of boundary layer
M_∞	freestream Mach number in wind tunnel
p_s	wind-tunnel freestream stagnation pressure
R	gas constant
Re	Reynolds number
Re_c	Reynolds number based on freestream conditions and c ($= U_\infty c/\nu_\infty$)
$Re_{\bar{c}}$	Reynolds number based on freestream conditions and $\bar{c}$ ($= U_\infty \bar{c}/\nu_\infty$)
$Re_{e_{crit2}}$	Reynolds number based on e_{crit2} ($= u_\delta e_{crit2}/\nu_\delta$)
$Re_{x_{strip}}$	Reynolds number on flat plate at transition strip location ($= u_\delta x_{strip}/\nu_\delta$)
Re_{δ^*}	Reynolds number based on δ^* ($= u_\delta \delta^*/\nu_\delta$)

Re_θ	Reynolds number based on θ ($= u_\delta \theta / \nu_\delta$)
Re_{θ_i}	Reynolds number based on θ_i ($= u_\delta \theta_i / \nu_\delta$)
r	$Re_\theta / Re_{\theta_i}$
T_{ref}	reference temperature (Equation (A1.8))
T_s	wind-tunnel stagnation temperature
T_w	aerofoil surface temperature
T_{wr}	adiabatic recovery temperature at surface
T_δ	local temperature at edge of boundary layer
U_∞	freestream speed in wind tunnel
u	local velocity in boundary layer
u_δ	local velocity at edge of boundary layer
x	distance from leading edge, measured along aerofoil chord line
x_{plate}	distance from leading edge of flat plate
x_{strip}	x at transition strip location
y	distance normal to surface
δ	local boundary-layer thickness
γ	ratio of specific heats
δ^*	local boundary-layer displacement thickness $\left(= \delta \int_0^1 \left(1 - \frac{\rho u}{\rho_\delta u_\delta} \right) d \frac{y}{\delta} \right)$
θ	local boundary-layer momentum thickness $\left(= \delta \int_0^1 \left(\frac{\rho u}{\rho_\delta u_\delta} \left\{ 1 - \frac{u}{u_\delta} \right\} \right) d \frac{y}{\delta} \right)$
θ_i	local boundary-layer momentum thickness in incompressible flow
μ_{ref}	dynamic viscosity reference value (Equation (A1.8))
μ_δ	local dynamic viscosity at edge of boundary layer
μ_∞	freestream dynamic viscosity in wind tunnel

ν_δ	local kinematic viscosity at edge of boundary layer ($= \mu_\delta/\rho_\delta$)
ν_∞	freestream kinematic viscosity in wind tunnel ($= \mu_\infty/\rho_\infty$)
ρ	local density in boundary layer
ρ_s	wind-tunnel stagnation density
ρ_δ	local density at edge of boundary layer
ρ_∞	freestream density in wind tunnel