24. Leading-Edge Contamination and Relaminarization on a Swept Wing at Incidence

D. Arnal and J.C. Juillen

1. Introduction

The infinite swept wing represents the simplest example of three-dimensional flow. Two coordinate systems are usually introduced (Fig. 1): one \((X, Z, y)\) is linked to the wing, the other \((x, z, y)\) is linked to the external streamline. In both cases, the \(y\)-direction is normal to the wall and the other two coordinates are defined on the wing surface: for instance, \(X\) represents the curvilinear abscissa measured from the geometrical leading edge, in the direction normal to it. The mean velocity components are denoted as \((U, W, v)\) in the \((X, Z, y)\) coordinate system and \((u, w, v)\) in the \((x, z, y)\) coordinate system. \(u(y)\) is the streamwise velocity profile, \(w(y)\) is the cross flow velocity profile.

Over swept wings, turbulence may appear through three mechanisms: leading edge contamination, streamwise instability and cross flow instability, see review papers [519,520] and [581]. In this paper, attention is focused on the problem of leading edge contamination along the attachment line of a swept wing at incidence.

The attachment line is a particular streamline, which divides the flow into one branch following the upper surface of the body and another branch following
the lower surface. It is sketched on Fig. 2 for the simple case of a swept cylinder. For an infinite span, constant chord body, the \( x \) and \( Z \) axes are confounded; the streamwise mean velocity profile \( u(y) \) does not vary in the spanwise direction and self-similar solutions indicate that it looks like the Blasius profile.

When a swept wing is in contact with a solid surface (fuselage, wind tunnel wall, ...), it has been observed that the attachment line can be contaminated by the large turbulent structures coming from the wall to which the model is fixed; this phenomenon was studied by many authors, who observed that the leading edge contamination cannot be explained in terms of linear stability theory: it is an example of "bypass" (Morkovin, [582]). An important parameter is the Reynolds number \( R\theta_{11} \) defined as:

\[
R\theta_{11} = W_\infty \theta_{11} / \nu
\]

\( W_\infty = Q_\infty \sin \phi \) is the free stream velocity component in the spanwise direction (see Fig. 1, where \( \phi \) is the angle of sweep), \( \nu \) represents the kinematic viscosity and \( \theta_{11} \) is the momentum thickness of the streamwise mean velocity profile along the attachment line. The characteristic length \( \eta \) and the Reynolds number \( \tilde{R} \) are also often used; they are defined as:

\[
\eta = (\nu/k)^{1/2}, \quad \text{with} \quad k = (dU_e/dX)_{X=X_p}
\]

\[
\tilde{R} = W_\infty \eta / \nu
\]

\( X_p \) is the attachment line abscissa. For infinite swept wing conditions, it can be demonstrated that:

\[
\theta_{11} = 0.404 \eta, \quad \text{or} \quad R\theta_{11} = 0.404 \tilde{R}
\]

Previous studies ([462, 583–587]) have shown that if \( \tilde{R} \) is lower than 245, the turbulent structures are damped as they are convected along the leading edge; if \( \tilde{R} \) is greater than 245, they become self-sustaining; they develop and the whole wing can be contaminated. When expressed in terms of \( R\theta_{11} \), the critical value for leading edge contamination is 100.

The purpose of this paper is to describe experiments in which leading edge contamination is induced by the turbulent boundary layer developing along the wind tunnel floor to which the model is fixed. The second objective of this investigation is to analyse the development of the boundary layer on both sides.