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PREDICTION OF LEADING-EDGE TRANSITION AND RELAMINARIZATION PHENOMENA ON A SUBSONIC MULTI-ELEMENT HIGH-LIFT SYSTEM

by

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Abstract

Boundary-layer transition and relaminarization may have a critical effect on the flow development about multi-element high-lift systems of subsonic transport jets with swept wings. The purpose of my research this summer is to study these transition phenomena in the leading-edge region of the various elements of a high-lift system. The flow phenomena studied include transition of the attachment-line flow, relaminarization, and crossflow instability and transition. The calculations are based on pressure distributions measured in flight on the NASA Transport Systems Research Vehicle (Boeing 737-100) at a wing station where the flow approximated infinite swept wing conditions. The results indicate that significant regions of laminar flow can exist on all flap elements in flight. In future flight experiments (planned for January-February, 1994) the extent of these regions, the transition mechanisms and the effect of laminar flow on the high-lift characteristics of the multi-element system will be further explored.

Project Background and Results

The aerodynamic design of an effective high-lift system remains as challenging today as it was twenty years ago when A.M.O. Smith wrote his enlightening papers on high-lift aerodynamics.[1,2] Modern jet transports require complex multi-element high-lift systems to meet stringent performance criteria during takeoff and landing. In the current competitive market place, new transport-jet designs are driven to simpler, more efficient high-lift systems that provide improved aerodynamic performance in terms of increased maximum lift coefficient, $C_{L_{max}}$, increased L/D, or increased lift coefficient, C_L, for a given angle of attack and flap setting.[3] Solving the aerodynamic design problem of high-lift systems has been a difficult task primarily because of the limited understanding of the flow physics associated with such systems.

The flow field around a high-aspect-ratio swept wing with its multi-element high-lift system deployed is characterized by a number of aerodynamic phenomena which are highly interrelated and complex in nature. Smith[1,2] concentrated in his papers on the aerodynamic processes that occur in flows past two-dimensional multi-element airfoils at high-lift conditions. These phenomena include inviscid- and viscous-flow interactions between the various elements, boundary-layer transition, and flow separation. Currently many of these flow phenomena can be analyzed fairly accurately with two-dimensional computational methods based on the full Navier-Stokes equations[4,5,6] or a reduced set of these equations (e.g., Euler equations coupled with boundary-layer equations[7]). Unfortunately our understanding of these phenomena in three dimensions is less extensive than of the two-dimensional phenomena; the main reasons being a lack of detailed flow measurements for three-dimensional high-lift flows and a lack of computational methods that can adequately compute (separated) viscous flows past wings with deployed multi-element high-lift systems. Three-dimensional flow phenomena such as (1) transition of the attachment-line boundary layers, (2) relaminarization of turbulent flow in the leading-edge regions of the elements and (3) crossflow instability and transition of the laminar flow downstream of the attachment lines, among others can be significant in the aerodynamic design and analysis of a high-lift system.[8]

The influence of the boundary-layer state in the leading-edge region on high-lift performance is illustrated for a single-element swept lifting surface in Fig.1. Loss of laminar flow due to attachment-line contamination at high Reynolds numbers can result in a noticeable drop in maximum lift as shown in Fig.1. This adverse scale effect on lift makes it difficult to extrapolate maximum-lift data from low (wind-tunnel) Reynolds-number to high (flight) Reynolds-number conditions. In addition, note that even at full-scale flight conditions the smaller elements of the high-lift system may be operating at low (chord) Reynolds numbers where their flows are dominated by laminar bubbles. Therefore, determining the transition location and understanding the mechanisms that govern transition are crucial to the accurate prediction of high-lift system performance.

As part of the subsonic transport high-lift research program, a flight experiment is being conducted using the NASA Langley Transport Systems Research Vehicle (TRSV) to obtain detailed high-lift flow measurements at full-scale high-Reynolds-number conditions. The purpose of my efforts this summer is to study leading-edge transition and relaminarization phenomena for this typical subsonic transport high-lift system using flight-measured pressure distributions. The results of this study are being used to define transition instrumentation on future flights planned for January-February 1994. The results indicate that significant regions of laminar flow can exist on all five elements of the high-lift system at full-scale flight conditions and indicate the importance of measuring the state of the boundary layer in the leading-edge region of the various elements because of its dominant role in determining the high-lift performance characteristics.Many of the results are reported in the paper that was presented at the AIAA Fluid Dynamics Conference.[9]

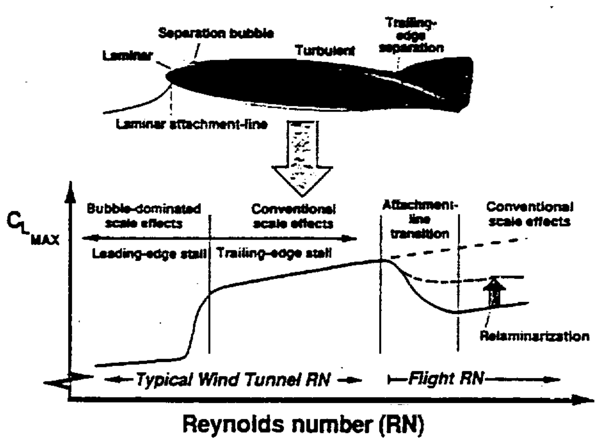

Fig.1 Effect of attachment-line transition and relaminarization on maximum lift coefficient for a single-element lifting surface.

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