Flow transition over surface gaps in incompressible laminar boundary layers

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Aircraft wings are not perfectly smooth; they often have spanwise gaps due to manufacturing tolerances, structural components, or control surface discontinuities. These geometric irregularities can significantly influence boundary layer transition, potentially affecting aerodynamic performance and efficiency. In this study, we investigate the interaction between such gaps and the transition process, with a particular emphasis on the enhanced amplification of Tollmien-Schlichting waves and bypass mechanisms. Specifically, we examine the role of gap-induced modes in triggering or enhancing natural boundary layer instabilities [1]. The analysis is conducted at low Mach number under incompressible flow conditions at a Reynolds number of $Re_{\delta^*} = 1000$, where δ^* denotes the displacement thickness measured at the upstream edge of the gap on a smooth surface free of discontinuities. The depth of the gaps considered lies in the interval $d / \delta^* = 1$-4, while the width is varied within the range $w / \delta^* = 10$-30 to assess the onset of global instability. High-fidelity numerical simulations are performed using the spectral/hp element method implemented in the open-source framework Nektar++ [2]. The results provide new insights into the transition mechanisms induced by geometric discontinuities, contributing to the design of more aerodynamically efficient wings. Future work will extend the study to compressible flow regimes and three-dimensional configurations to account for sweeping effects.

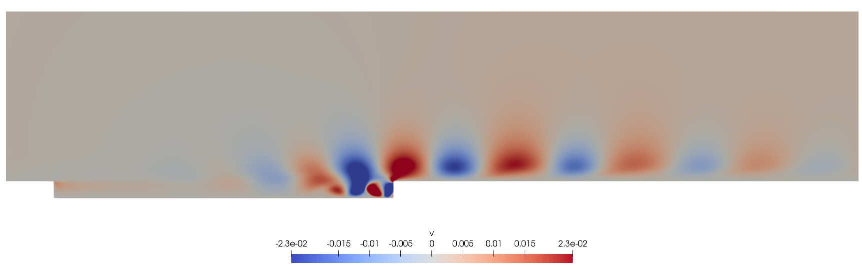

Figure 1. v-component of the flow field illustrating an absolute instability near the downstream edge of a gap of dimensions d = 2δ and w = 40δ*, where δ* denotes the displacement thickness of the boundary layer.*

References:

[1] Crouch JD, Kosorygin VS, Sutanto MI, Miller GD. Characterizing surface-gap effects on boundary-layer transition dominated by Tollmien Schlichting instability. Flow. 2022;2:E8. doi:10.1017/flo.2022.1

[2] Nektar++. https://www.nektar.info/. Accessed: 29/05/2025.