Boundary Layer Transition: Low Speed, High Speed, and Control

Solkeun Jee

Department of Mechanical and Robotics Engineering, Gwangju Institute of Science and Technology, Gwangju, 61005, South Korea

†Email address for correspondence: sjee@gist.ac.kr

Abstract

Recent efforts towards high-fidelity simulation of turbulent transition in boundary layer will be reviewed in this talk. An innovative method which combines eddy-resolving simulation and flow stability theory allows to achieve both high fidelity and computational efficiency in simulating transitional boundary layers across the speed regime including subsonic, supersonic and hypersonic speeds. Natural transition scenarios starting with a few dominant instability modes are well captured with the current simulation method. Three canonical cases will be discussed briefly: (1) sub-harmonic resonance with Tollmien-Schlichting instability in subsonic flow, (2) oblique-mode breakdown in supersonic flow, and (3) fundamental resonance with the Mack second mode in hypersonic flow (Fig. 1a). Improved understanding of intrinsic transition mechanism helps to design effective strategies for transition control. Phase modulation of two dominant instabilities delays the transition significantly as shown in Fig. 1b. A recent effort to delay hypersonic turbulent transition with porous surface will be discussed as well in this talk.

Keywords: turbulent transition, boundary layer, eddy-resolving simulation, stability theory, transition control

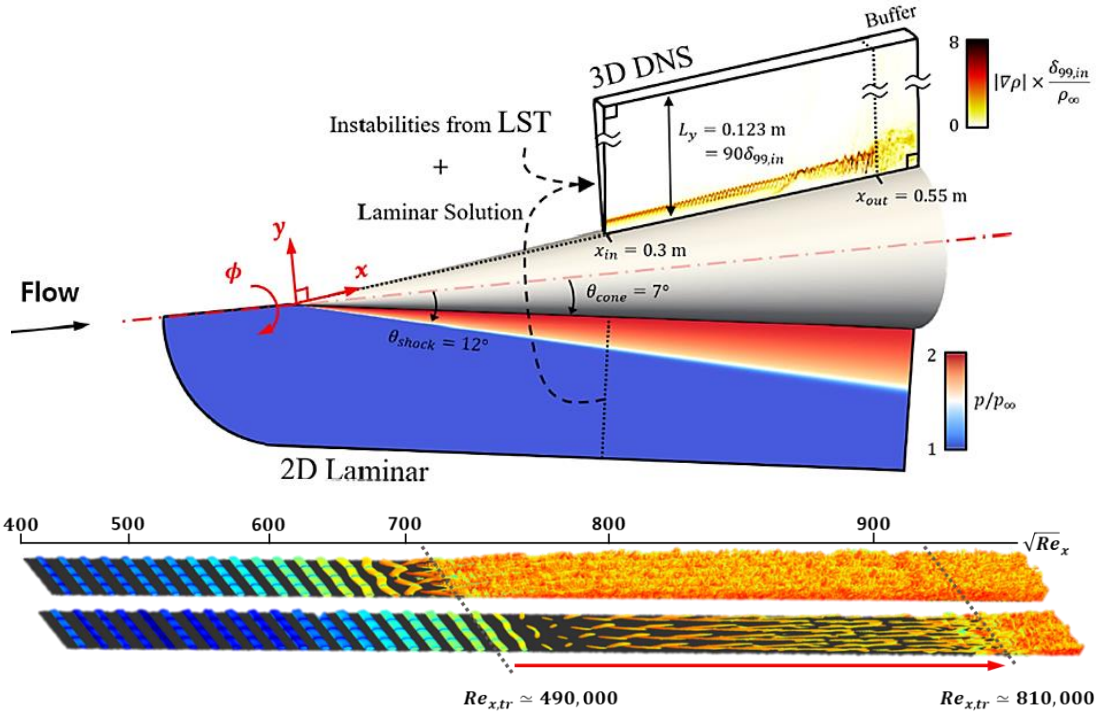

Figure 1. (Top) Eddy-resolving simulation framework combined with stability theory applied for transitional boundary layer on a cone in hypersonic flow (image from M. Jeong et al. PoF, 2025, 37 (3): 034120); (Bottom) Transitional boundary layer with and without a transition control (image from M. Kim et al. JFM, 2021, 927:A14).

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