Airfoil Boundary Layers in High Intensity Free-Stream Turbulence: Analysis of Intermittency Factor from PIV Measurements

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Knowledge of how freestream turbulence affects the location of boundary layer transition is required for the prediction and control of aerodynamic loads on lifting surfaces, especially those that operate at aerodynamically low chord Reynolds numbers. The objective of this work is to develop a robust method for discriminating laminar and turbulent regions within a transitional boundary layer from particle image velocimetry (PIV) measurements that does not require the flow to be temporally resolved.

A method of transition detection using the entropy of proper orthogonal decomposition (POD) modes [1] is used to quantify the intermittency factor. This approach to laminar-turbulent discrimination has previously been applied to data from numerical simulations of internal flows. In this work, we show that a similar method can also be used for experimental data from external flows. The method involves performing POD separately on the velocity measurements at each x location of the PIV vector field. The spatial entropy (S_s) is then computed from the POD modes at each x location of the PIV vector field. The spatial entropy is 0 when the velocity profile at a given x location is exactly represented by a single POD mode, and the spatial entropy is maximised when the kinetic energy is distributed equally among all POD modes. Because transition involves an increase in disorder of the flow, S_s increases as the flow transitions from laminar to turbulent states.

This method of transition detection is applied to PIV data from the boundary layer on a NACA 0018 airfoil in high-intensity free-stream turbulence at a chord Reynolds number of 7.0×10^4 (figure 1). A transition threshold of $S_s = 0.06$ is defined from the entropy measured at the location of separated shear layer transition in the laminar separation bubble forming on the airfoil at the baseline free-stream turbulence intensity of 0.1%. Application of the entropy-based transition detection method at a free-stream turbulence intensity of 9% reveals intermittent laminarisation of the airfoil boundary layer and large variations in the location of transition. The full presentation will compare the entropy-based transition indicator to other indicators, including those based on time-resolved velocity field measurements, and demonstrate how coherent structures in the oncoming flow lead to variations in transition location.

[1] Abouelmagd Abdelsamie, Gábor Janiga, and Dominique Thévenin. Spectral entropy as a flow state indicator. *International Journal of Heat and Fluid Flow*, 68(September):102–113, 2017.

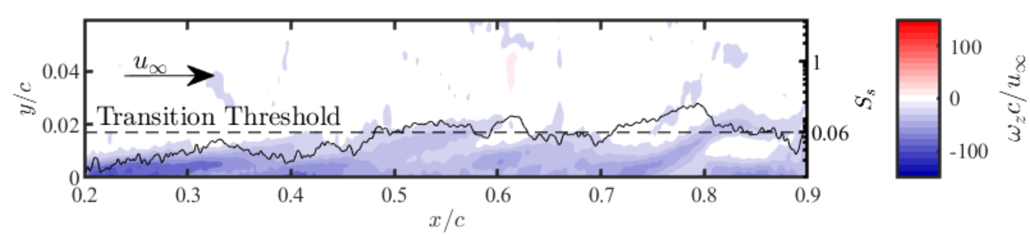

Figure 1: Spanwise vorticity field of boundary layer from PIV measurements at a free-stream turbulence intensity of 9%. Solid lack line: S_s, dashed black line: transition threshold.

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