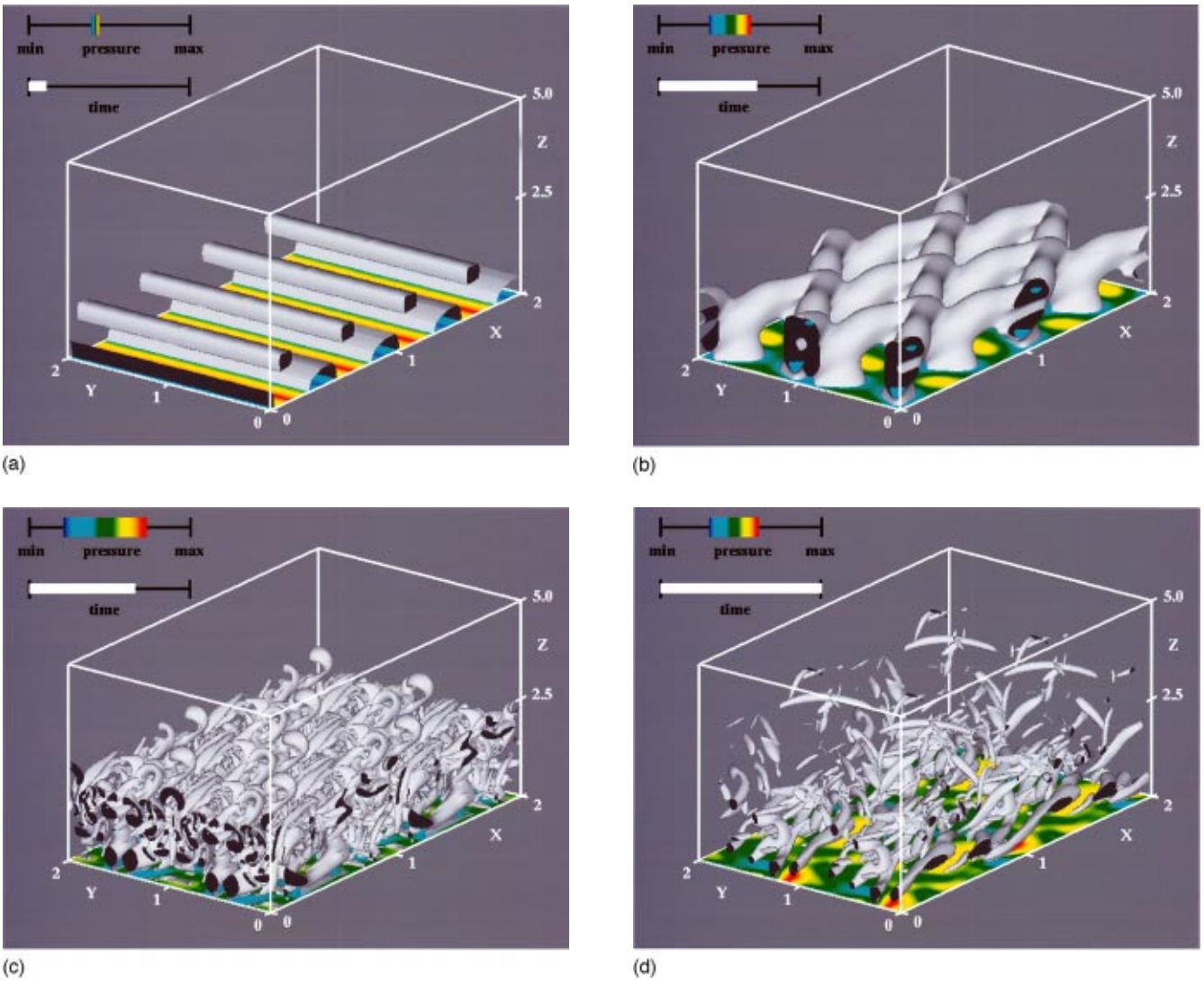

FIG. 1. Visualization of formation and decay of vortical structures during the laminar–turbulent transition process. (a) 2D travelling instability waves. (b) 3D Λ-vortices. (c) Breakdown into small-scale structures. (d) Turbulent stage.

LAMINAR–TURBULENT TRANSITION IN A SUPERSONIC BOUNDARY LAYER

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A direct numerical simulation employing the temporal model has been performed to simulate the subharmonic laminar–turbulent transition process in a two-dimensional Mach 4.5 boundary layer over a flat plate.[12,13] The evolution of vortical structures together with the wall-pressure distribution is shown at four different stages. For visualization the computational domain is doubled in streamwise (x) and spanwise (y) direction. Low static pressure, Figs. 1(a) and 1(b), and the positive second invariant Q of the velocity gradient tensor ∇u, Figs. 1(c) and 1(d), are used for vortex identification (see also Ref. 13).

The second mode primary instability forms travelling spanwise vortical structures, Fig. 1(a). Secondary instability evolving from background noise deforms the two-dimensional vortices to a staggered pattern of Λ-vortices as shown in Fig. 1(b). These decay to form new intermediate structures. The boundary layer grows rapidly and fills up with vortical structures during the final breakdown to turbulence. The dynamically most important structures are staggered systems of hairpin vortices located near the outer edge of the boundary layer and strong streamwise-oriented near-wall vortices, counterrotating in pairs,[13] see Fig. 1(c). Figure 1(d) shows vortices at a fully developed turbulent state.

