Wu, Xiaohua; Moin, Parviz
Direct numerical simulation of turbulence in a nominally zero-pressure-gradient flat-plate boundary layer. (English) Zbl 1181.76084
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Summary: A nominally-zero-pressure-gradient incompressible boundary layer over a smooth flat plate was simulated for a continuous momentum thickness Reynolds number range of $80 \leq Re_\theta \leq 940$. Transition which is completed at approximately $Re_\theta = 750$ was triggered by intermittent localized disturbances arising from patches of isotropic turbulence introduced periodically from the free stream at $Re_\theta = 80$. Streamwise pressure gradient is quantified with several measures and is demonstrated to be weak. Blasius boundary layer is maintained in the early transitional region of $80 < Re_\theta < 180$ within which the maximum deviation of skin friction from the theoretical solution is less than 1%. Mean and second-order turbulence statistics are compared with classic experimental data, and they constitute a rare DNS dataset for the spatially developing zero-pressure-gradient turbulent flat-plate boundary layer. Our calculations indicate that in the present spatially developing low-Reynolds-number turbulent flat-plate boundary layer, total shear stress mildly overshoots the wall shear stress in the near-wall region of 2-20 wall units with vanishing normal gradient at the wall. Overshoots as high as 10% across a wider percentage of the boundary layer thickness exist in the late transitional region. The former is a residual effect of the latter. The instantaneous flow fields are vividly populated by hairpin vortices. This is the first time that direct evidence (in the form of a solution of the Navier-Stokes equations, obeying the statistical measurements, as opposed to synthetic superposition of the structures) shows such dominance of these structures. Hairpin packets arising from upstream fragmented Λ structures are found to be instrumental in the breakdown of the present boundary layer bypass transition.

MSC:

76F40 Turbulent boundary layers
76F65 Direct numerical and large eddy simulation of turbulence

Full Text: DOI

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