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Selfsimilar turbulent boundary layer in pressure gradient. The phenomenon of hysteresis in near-separating flow

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ABSTRACT

Studying the turbulent boundary layer in pressure gradients is one of the main problems in boundary layer theory. Meanwhile, this problem, particularly for the case of strong adverse pressure gradients giving rise separation, has not had at present a satisfactory theoretical solution. The turbulent models, which serve as a main practical tool, give no correct description of turbulent separation.

Selfsimilar flows in the turbulent boundary layer when the free stream velocity is specified as a power function of the longitudinal coordinate are investigated in the paper. The problem is solved by the method of matched asymptotic expansions for large values of the logarithm of the Reynolds number based on the boundary layer thickness.

It is shown that in the case of the adverse pressure gradient when the exponent $-1/3 < m \leqslant -0.228$, the problem has the two solutions with different values of the boundary layer thickness and skin friction which points out to the possibility of a hysteresis in near-separating flow. Correspondingly, the state of the flow — the profiles of the mean velocity and Reynolds-stress-tensor components and the skin friction — depends on two different similarity parameters one of which is the well-known Clauser equilibrium parameter and the second one is determined for the first time. Separation occurs on the second curve of the solution, not at the minimal value of m which corresponds to the strongest adverse pressure gradient but at $m = -0.228$.

A new velocity defect law for the outer region of the boundary layer which is true for the entire range of pressure gradients from favorable to adverse values giving rise separation and the corresponding representation for the turbulent shearing stress are established.

The results of the theory are in a good agreement with experimental data.

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