Turbulent Marginal Separation: A Novel Triple-Deck Problem for Turbulent Flows

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Abstract:
A new rational theory of incompressible turbulent boundary layer flows having a large velocity defect is presented on basis of the Reynolds-averaged Navier–Stokes equations in the limit of infinite Reynolds number, here denoted by Re. The approach is essentially based on the assumption, strongly supported by dimensional reasoning and an asymptotic investigation of all commonly employed shear stress closures, that the Reynolds equations admit a further limit apart from the pure Eulerian one. This then implies the existence of a non-dimensional small parameter, denoted by α, which measures the slenderness the turbulent boundary layer in the formal limit $1/Re = 0$. The resulting wake-type formulation of wall-bounded shear flows for $\alpha \to 0$ allows for, among others, the prediction of singular solutions of the boundary layer equations under the action of a suitably controlled adverse pressure gradient which are associated with the onset of marginally separated flows. Increasing the pressure gradient locally then transforms the marginal-separation singularity into a weak Goldstein-type singularity occurring in the slip velocity at the base of the outer wake layer. Interestingly, this behaviour is seen to be closely related to (but differing in detail from) the counterpart of laminar marginal separation where the skin friction replaces the surface slip velocity. Most important, adopting the concept of locally interacting boundary layers gives rise to a closure-free and uniformly valid asymptotic description of turbulent boundary layers which exhibit small closed reverse-flow regimes. The according non-trivial eigensolutions of the underlying triple-deck problem which govern the mildly separating flow to leading order have been found numerically, see figure 1. For a more extensive outline of this theory the reader is referred to [1].
The main emphasis of the present investigation is on the effect of finite values of Re. As a highlight of the theory, it is demonstrated how the logarithmic law of the wall is gradually transformed into the well-known square-root variation with distance from the surface of the streamwise velocity on top of the viscous wall layer close to the locations of both separation and reattachment.

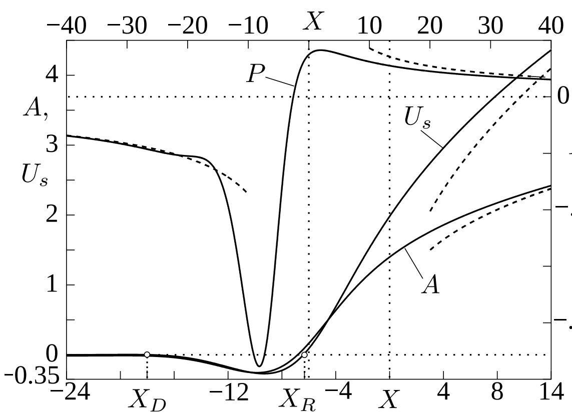

Figure 1: *Typical solution of the interaction problem using suitably rescaled variables: The streamwise coordinate and the points of flow detach- and reattachment are denoted by X, X_D, and X_R, respectively. The top abscissa refers to the induced pressure P, the one at the bottom to the surface slip velocity U_s and the local boundary layer displacement $-A$. The asymptotes $U_s = O(X^{1/2})$, $A = O(X^{1/3})$ as $X \to \infty$, and $P = O(X^{-2/3})$ as $|X| \to \infty$ are plotted dashed.*

References

[1] Scheichl B. and Kluwick A. (2005): Turbulent Marginal Separation and the Turbulent Goldstein Problem, *AIAA paper #2005-4936*