4.12 Coupling of Potential Flow and Boundary Layers

4.12.1 Classical solution

The classical boundary layer problem is schematically shown in Figure 4.26. An inviscid (potential) flow problem is first solved with the displacement effect ignored. This then provides the edge velocity $u_e(s)$ distribution which is the input to one of the boundary layer solution methods presented in this chapter. The outputs are the various viscous variables of interest, $\theta(s)$, $\delta^*(s)$, $c_f(s)$, etc.

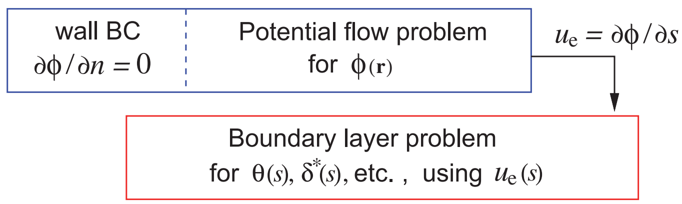

Figure 4.26: One-way coupling from the potential flow problem to the classical boundary layer problem. The boundary layer solution fails if separation is encountered.

Although conceptually simple, this solution approach has two shortcomings:

1. The potential flow solution ignores the viscous displacement effect. Hence it cannot predict the gradual loss of lift as stall is approached, which is illustrated in Figure 3.8. Also, if the displacement effects are large, then the specified $u_e(s)$ is inaccurate and the resulting boundary layer solution and predicted profile drag are suspect.
2. If the specified $u_e(s)$ leads to separation, the boundary layer solution will fail at that point, and subsequent downstream integration is impossible. This behavior was already observed for self-similar laminar flows, which have no solution for $a < -0.0904$ which is the incipient-separation case. For a general (not power-law) flow, there is also no solution at the first streamwise location where separation is encountered. This occurs with finite-difference and two-equation integral methods, and is known as the *Goldstein separation singularity* [28]. The consequence is that the boundary layer solution cannot proceed downstream into the separated flow region. Ironically, the simpler one-equation methods do not have this singularity, essentially because their physics modeling is too inadequate to represent it. This is not really an advantage, since they become wildly inaccurate or problematic in other ways once separation is indicated. For example, if $\lambda < -0.09$ in Thwaites's method, which roughly indicates separation, its closure functions become undefined.