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Regularization modeling for large-eddy simulation of turbulent separated boundary layer flow

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We focus on a separated turbulent boundary layer over a flat plate using direct and large-eddy simulation. Particular attention will be given to so-called regularization subgrid modeling. The quality of the Leray and NS-α models [1] in near wall flows and under separated flow conditions will be assessed by comparison with DNS and dynamic subgrid modeling.

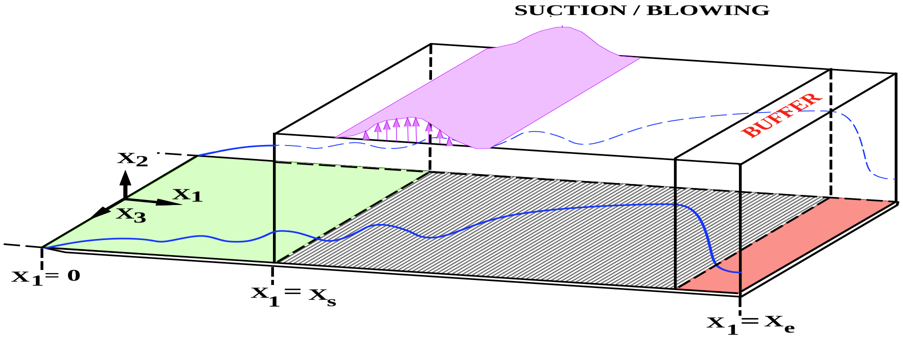


Figure 1: Sketch of the computational domain.

A suction-blowing velocity distribution is prescribed along the upper boundary of the computational domain, as shown in Figure 1. This creates a pressure gradient distribution that produces an unsteady separation bubble. The Reynolds number based on inlet free-stream velocity and momentum thickness is 330 and the Mach number is 0.2. Characteristic is the rapid transition to turbulence near separation and the gradual recovery of a zero-pressure gradient turbulent boundary layer. An impression of the spanwise vorticity is contained in Figure 2.

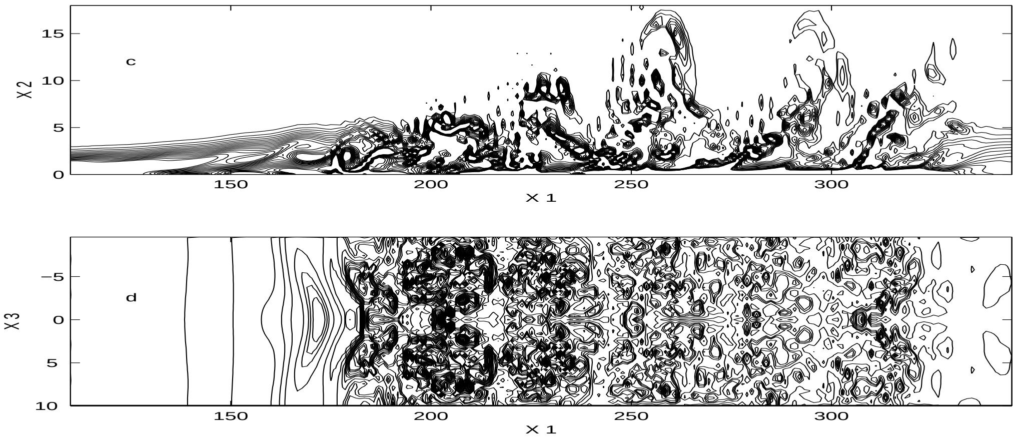


Figure 2: Instantaneous spanwise vorticity in the plane $x_3 = 0$ (peak plane) and total vorticity ω_t in the plane $x_2 = 3.54$. Flow-calming near out-flow corresponds to the numerical buffer layer.

This flow problem was studied by a number of researchers in the past [2, 3, 4]. The combination of separated shear layers, transition and a turbulent boundary layer make this a complex test-problem for large-eddy simulation. In figure 3 snapshots of the spanwise vorticity are compared, including the Smagorinsky model with van Driest damping, and the dynamic model. Evidently, the streamwise inhomogeneities in this flow result in an incomplete transition process when the Smagorinsky model is adopted. The dynamic model provides a better qualitative capturing. The dynamic eddy-viscosity was shown to display a scaling with $(y^+)^3$ in the wall-normal direction. In the laminar region ahead of the separation, the dynamic coefficient is close to zero. In the separated and turbulent regions this coefficient rapidly assumes values close to 0.1.

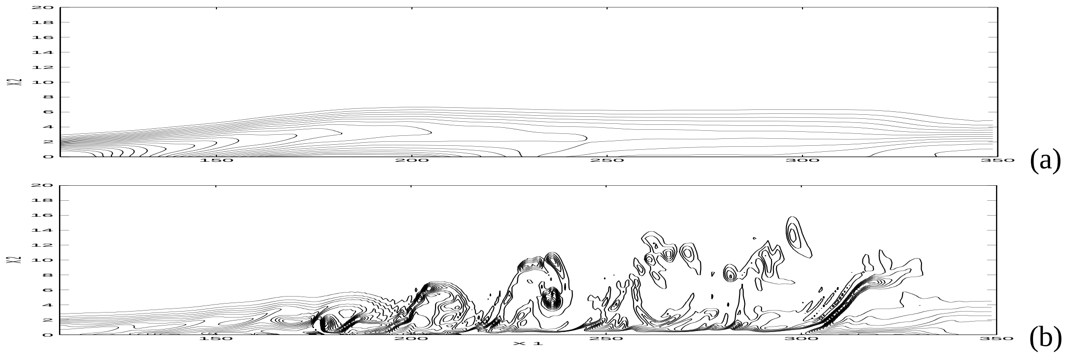
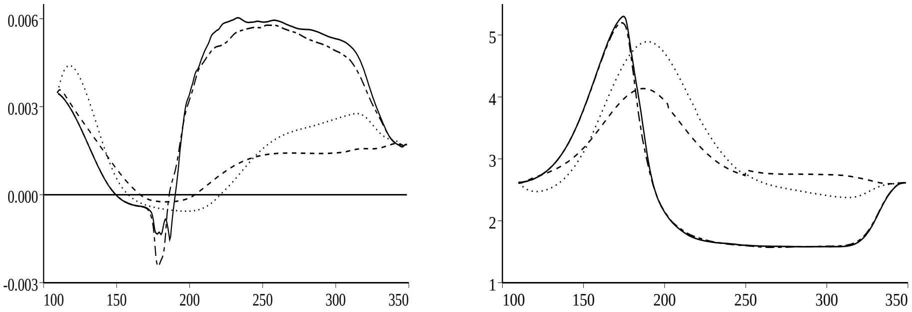


Figure 3: Instantaneous spanwise vorticity in the plane $x_3 = 0$: Smagorinsky model plus van Driest damping (a); dynamic eddy-viscosity model (b).

Some mean flow predictions corresponding to these subgrid models are compiled in Figure 4. The skin-friction and shape factor are quite well predicted by the dynamic model. The qualitative differences between the DNS solution and the results obtained on the basis of the Smagorinsky model also show up in significant errors in these flow properties.



(a) (b)

Figure 4: Predicted skin-friction (a) and shape factor (b): DNS (solid lines), dynamic model (dash-dotted), Smagorinsky (dotted), Smagorinsky with van Driest damping (dashed).

In the final contribution, the application of the Leray and NS-α subgrid models will be included. Moreover, attention will be given to effects of curvature, which necessitates the extension of the regularization modeling to curvilinear coordinates.

References

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