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Response of the temporal turbulent boundary layer to decaying free-stream turbulence. (English) Zbl 07207858

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Summary: The turbulent boundary layer developing under a turbulence-laden free stream is numerically investigated using the temporal boundary layer framework. This study focuses on the interaction between the fully turbulent boundary layer and decaying free-stream turbulence. Previous experiments and simulations of this physical problem have considered a spatially evolving boundary layer beset by free-stream turbulence. The state of the boundary layer at any given downstream position in fact reflects the accumulated history of the co-evolution of boundary layer and free-stream turbulence. The central aim of the present work is to isolate the effect of local free-stream disturbances existing at the same time as the 'downstream' boundary layer. The temporal framework used here helps expose when and how disturbances directly above the boundary layer actively impart change upon it. The bulk of our simulations were completed by seeding the free stream above boundary layers that were 'pre-grown' to a desired thickness with homogeneous isotropic turbulence from a precursor simulation. Moreover, this strategy allowed us to test various combinations of the turbulence intensity and large-eddy length scale of the free-stream turbulence with respect to the corresponding scales of the boundary layer. The relative large-eddy turnover time scale between the free-stream turbulence and the boundary layer emerges as an important parameter in predicting if the free-stream turbulence and boundary layer interaction will be 'strong' or 'weak' before the free-stream turbulence eventually fades to a negligible level. If the large-eddy turnover time scale of the free-stream turbulence is much smaller than that of the boundary layer, the interaction will be 'weak', as the free-stream disturbances will markedly decay before the boundary layer is able be altered significantly as a result of the free-stream disturbances. For a 'strong' interaction, the injected free-stream turbulence causes increased spreading of the boundary layer away from the wall, permitting large incursions of free-stream fluid deep within it.

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