Center for Environmental & Applied Fluid Mechanics

"Analysis of Nonequilibrium Turbulent Boundary Layers – Adverse Pressure Gradients and Swept-like Conditions"

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Abstract: Nonequilibrium turbulent flows are ubiquitous in industrial applications, yet most wall-bounded turbulent studies focus on canonical configurations, like zero pressure gradient (ZPG) turbulent boundary layers (TBL) or channels. The flow over an airplane wing can experience both adverse pressure gradients (APG) and wing sweep, introducing effects that cause the turbulent statistics to significantly deviate from their canonical counterparts. This presentation will show that the APG effects on the turbulent statistics can be predicted from linear amplification using only the mean flow field while swept-like conditions are simulated for a compressible flow allowing for a characterization of the turbulent and thermal transport.

The effects of the APG on the turbulent structures are studied with resolvent analysis, an equation-based scale-dependent decomposition that identifies the most linearly amplified flow structures as response modes and their linear gain from the linearized Navier Stokes equations. From only the mean flow field, this approach predicts various features in APG TBLs such as near-wall self-similarity of the small-scales, energization of large-scales with increasing Reynolds number and APG strength. In addition, this approach analytically characterizes the influence of upstream APG history effects on the intensification of the turbulent statistics. From these insights, a new self-similar scaling is presented that incorporates the upstream APG history, collapsing the APG turbulent statistics onto the ZPG statistics.

Swept wings are common in high-speed aircraft introducing statistically 3D flow to compressible turbulence but are sparsely studied in the literature. Here, swept-like conditions on compressible wall-bounded turbulence are studied through direct numerical simulations where fully developed canonical channels experiences a suddenly imposed spanwise body force. This creates a transient period where the channel experiences 3D effects as the flow responds to the sudden spanwise acceleration, observing effects seen in swept wing experiments like a mismatch between the mean velocity and Reynolds shear stress directions and a drop in turbulent kinetic energy despite the net increase in acceleration. Compressible velocity transformations are presented for the 3D mean flow that account for the transport property variations, mapping regions of the flow to the incompressible counterparts. The response of the energy-containing eddies to the spanwise acceleration are characterized through structure identification. Finally, a prediction for the temperature statistics is presented using the mean velocity.

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