Visualization of Turbulent Structures via Virtual Reality (VR)

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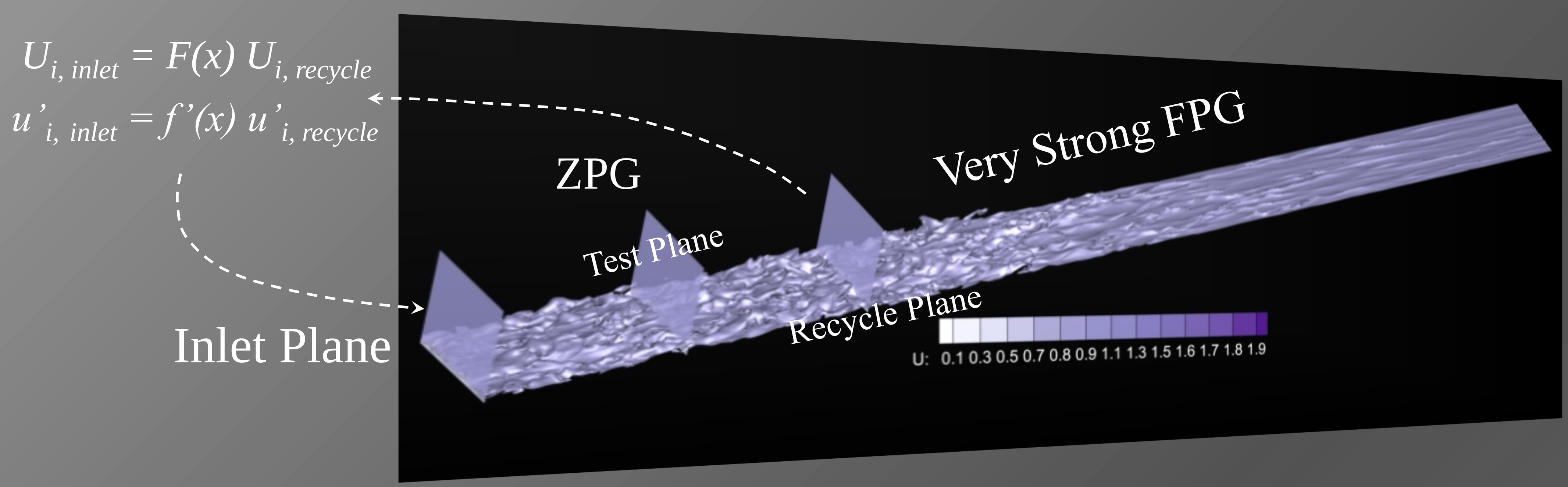
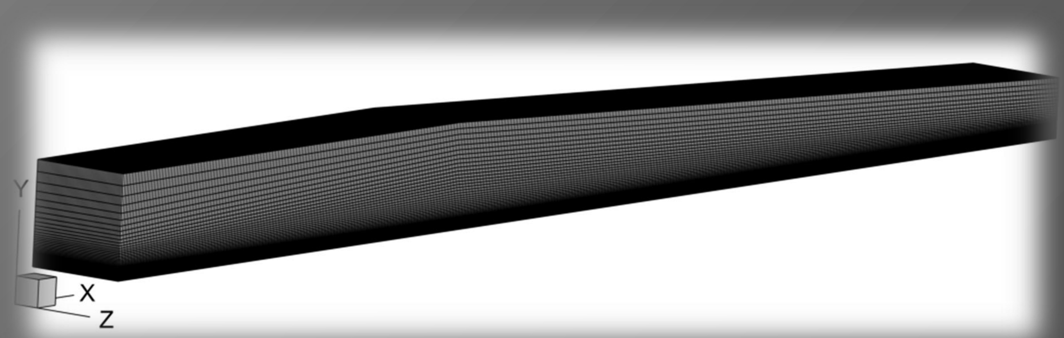
Direct Numerical Simulation (DNS) of a spatially-developing turbulent boundary layer is performed with high spatial/temporal resolution [1]. The initial turbulent flow in a zero pressure gradient (ZPG) boundary layer is subjected to a very strong favorable pressure gradient (FPG). The sudden acceleration imposed to the turbulent flow induces quasi-laminarization. An innovative technique has been developed to visualize the hydrodynamic and thermal (passive scalar) structures present in the combined ZPG-FPG computational domain by means of a fully immersive virtual reality (VR) environment.

Numerical details:
As strongly accelerated boundary layers become thinner, the necessary mesh resolution coupled with the need for long computational domains, makes direct simulations challenging. Furthermore, the prescription of accurate turbulent inflow boundary conditions in spatially-developing boundary layers is not a trivial task. For that reason, the methodology proposed in [2] is employed in this investigation [1]. The method prescribes time-dependent turbulent information at the inlet plane based on the transformed flow solution downstream (mean flow and fluctuations) by using scaling laws from a downstream plane called recycle (rescaling-recycling approach [3]). There is no need to use an empirical correlation in order to compute the inlet friction velocity, such information is deduced dynamically by involving an additional plane, the so called test plane located between the inlet and recycle stations.

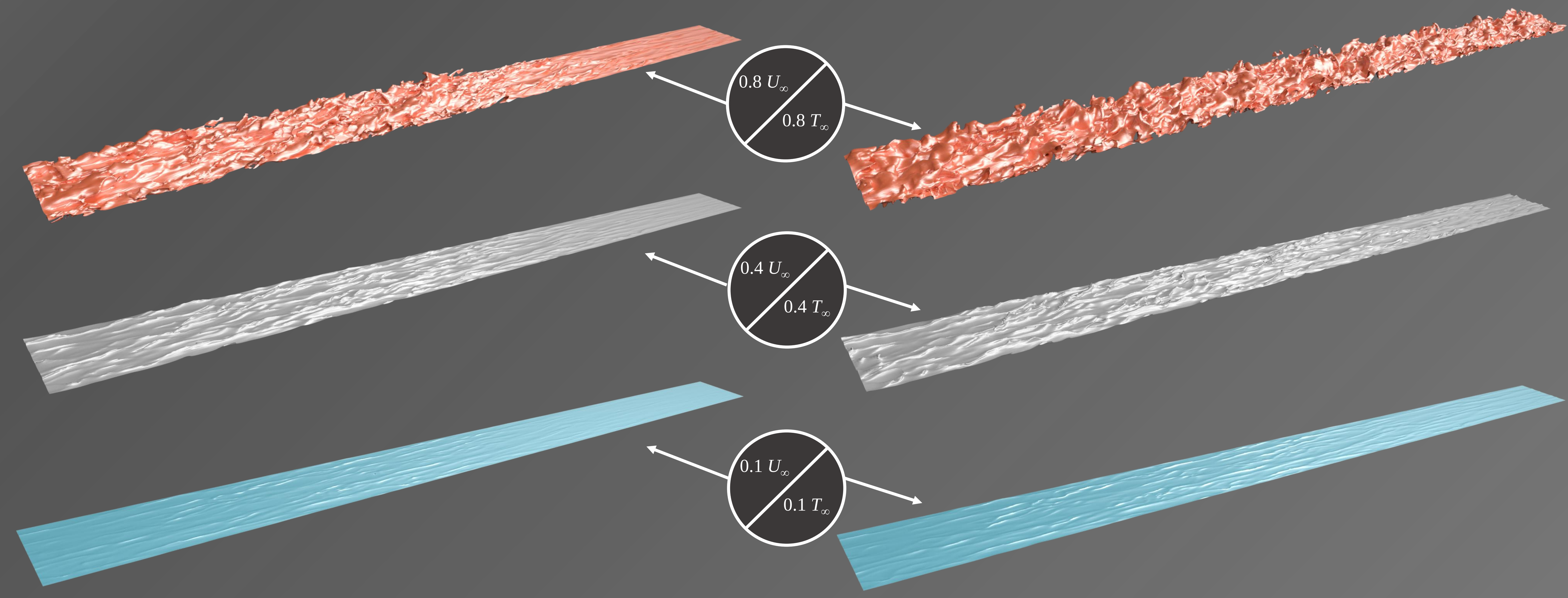




Computational domain

The images below show iso-surfaces of the instantaneous velocity and thermal fields based on the inlet freestream velocity and temperature, respectively. The strong flow acceleration in the FPG zone is manifested by energy extraction of the pressure gradient forces from the Reynolds shear stresses [1], which attenuates turbulence intensities. However, the flow does not completely laminarize due to the presence of streamwise velocity fluctuation residuals. Furthermore, the thermal field is not equally affected by the pressure gradient, which represents a source of strong dissimilarity. Thermal fluctuations develop more appropriately in the outer 'inviscid' part of the boundary layer.

Hydrodynamic iso-surfaces: Thermal iso-surfaces:



The technique extracts iso-surfaces from the hydrodynamic and thermal fields to be transferred into a game engine with virtual reality capabilities. The final result is an experience in which the user can be immersed into the DNS results. Iso-surfaces of velocity fluctuations being viewed in Unity Game Engine with the Oculus Rift headset.

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