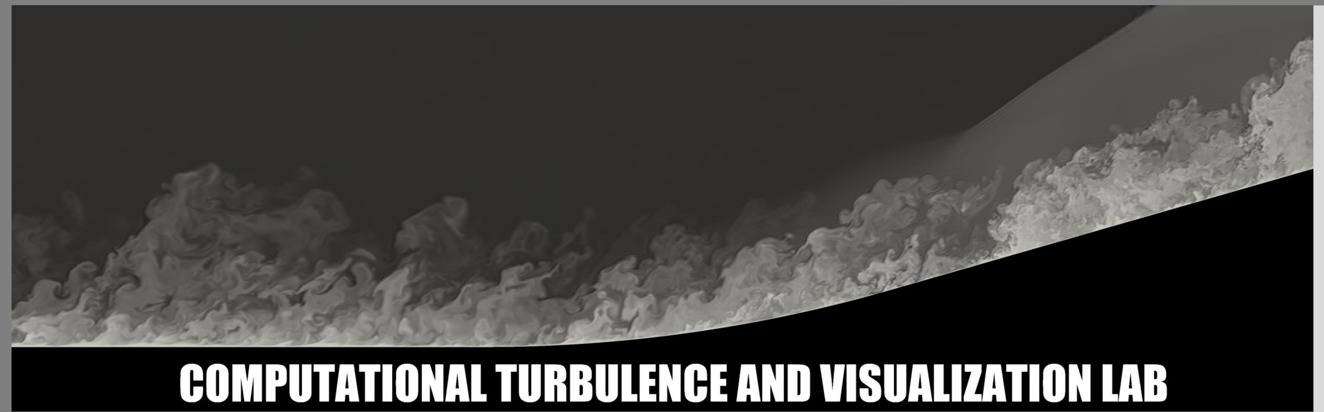

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Setting User Attributes in Virtual Reality for Fluid Dynamics Visualization

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Motivation

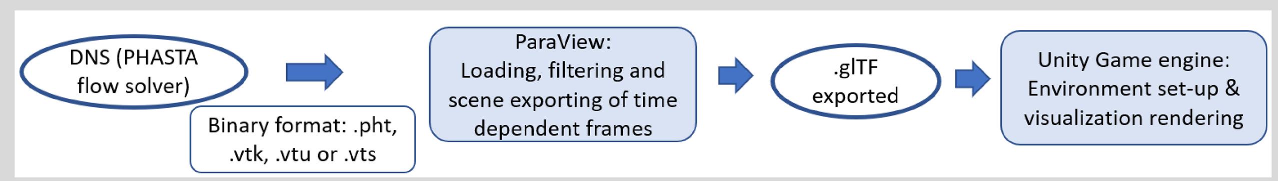
Data visualization is the general and all-encompassing term for everything related to the graphic portrayal of information and data. Information visualization denotes data in an organized visual way to provide meaning [1]. Visualization techniques have substantially evolved along with the world's technology, spanning all disciplines [2]. In recent times, Virtual (VR) and Augmented Reality (AR) have revolutionized the way that visualization is performed. ***VR consists of a digital recreation of a real-life environment or situation, while augmented reality conveys virtual elements as an overlay to the real world*** [3].

Furthermore, high-speed spatially-developing turbulent boundary layers (SDTBL) over curved walls are of crucial importance in aerospace applications, such as unmanned high-speed vehicles, scramjets, and advanced space aircraft. With the help of super computing centers, such as TACC and DoD systems, we are making use of high spatial-temporal resolution numerical simulations (i.e., Direct Numerical Simulation, DNS) of the flow governing equations to study wall-curvature-driven pressure gradient and crossflow-jet problems, but, more importantly their effects on the boundary layer transport phenomena. In this study, we are visualizing DNS data via mixed reality approaches (VR and AR).

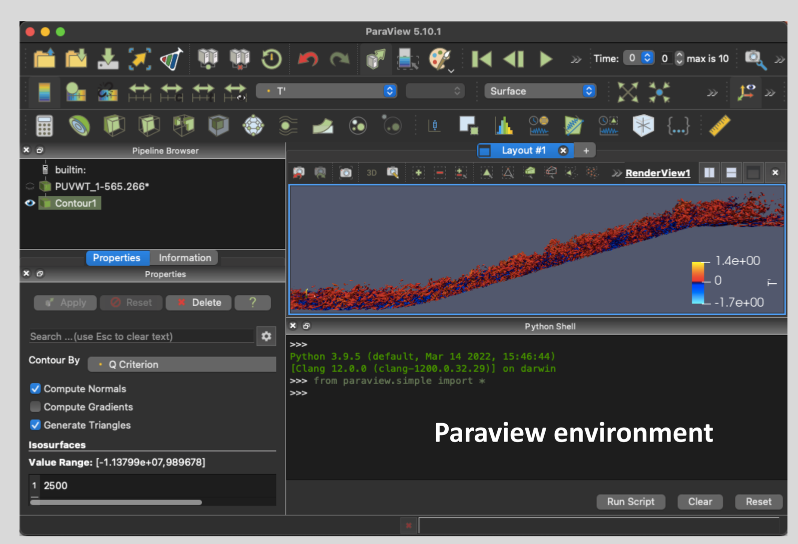
Goals

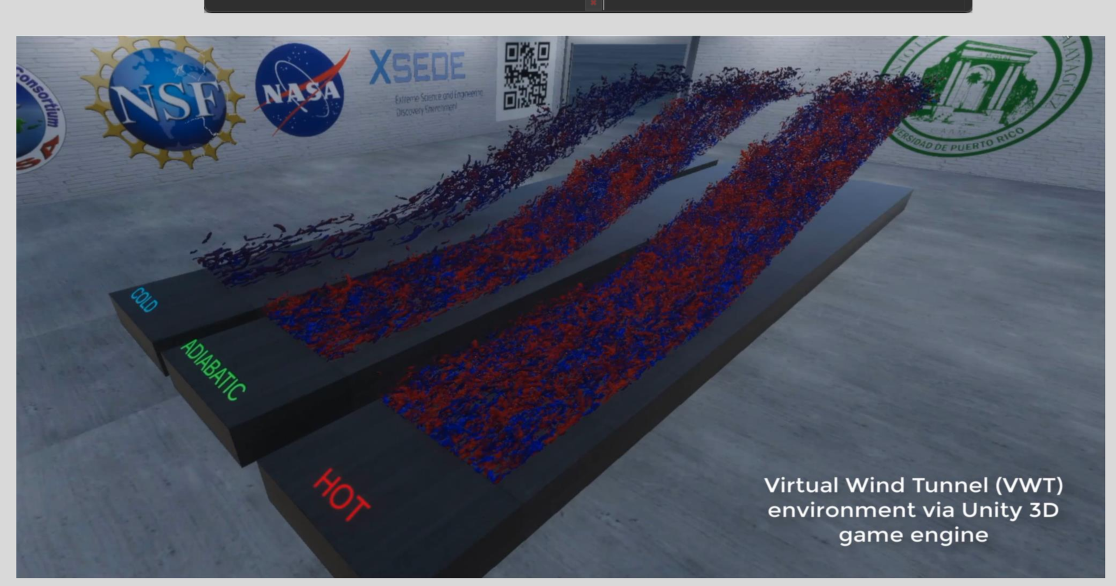
We are performing fully immersive visualization of high-fidelity numerical results of supersonic SDTBL under strong concave and concave curvatures and Mach = 2.86. The comprehensive DNS big-data is filtered and converted to file format readable by the Unity gaming software. Transient flow visualization also sheds important light on the transport phenomena inside boundary layers subject to strong deceleration or Adverse Pressure Gradient (APG) caused by concave walls as well as to strong acceleration or Favorable Pressure Gradient (FPG) caused by convex walls at different wall thermal conditions (i.e., cold, adiabatic and hot walls). Another fluid dynamics example to be visualized is the high-speed crossflow-jet problem. We are mainly extracting vortex core iso-surfaces via the Q-criterion. However, other flow parameters, such as flow velocity, temperature, etc. can be extracted and visualized.

Scientific Visualization: From DNS results to 3D Virtual Objects



The procedure starts with the open-source scientific visualization software ParaView. The DNS data (binary format) generated by the PHASTA flow solver [4] are loaded to apply the desired data post-processing or filter. In this example, the DNS files (restart.* files) are loaded and filtered to Paraview via .pht format (PHASTA reader) to compute Q-criterion parameters. With a Python script, it is possible to automate all process (around 500 frames or more) with the purpose of a flow movie development in the Unity game engine: loading, filtering, and "scene" exporting as .glTF file format [5,6].



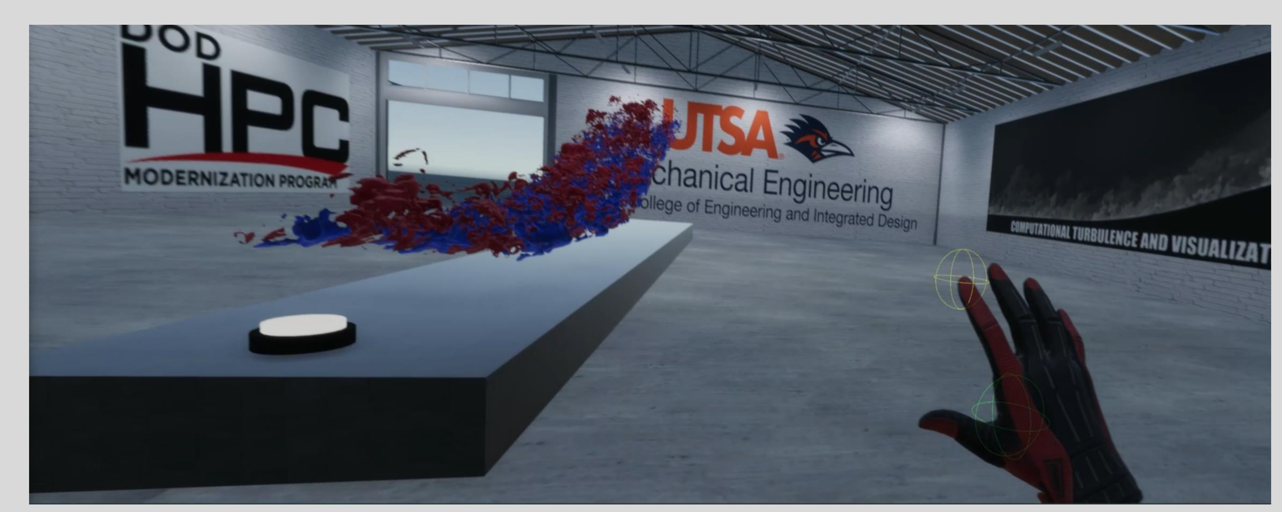


The image below depicts the hardware used: (left) HTC VIVE Pro 2 VR Kit; (center) Varjo XR Headset; (right) Dell Alienware computer desktop.

Most Relevant Results

Present study of high-speed SDTBL (Mach numbers up to 5) via DNS at high Reynolds numbers has contributed to a better understanding of supersonic/hypersonic SDTBL under the influence of concave/convex curvature, which can lead to the determination of appropriate flow control tools and design optimization in high-speed aerodynamics [7]. It has also been developed an efficient in-house post-processing library with GPU-CPU capabilities: AQUILA-CFD, AQUILA-LCS and Particle Advection [8]. Both, the in-house flow solver (PHASTA) and in-house postprocessing tool (AQUILA) have been run in up to 32,768 CPU cores and 64 Tesla V100 GPUs in Frontera and DoD supercomputers.

The figure below displays a VR user in the Virtual Wind Tunnel (VWT) examining vortex cores. This image exhibits iso-surfaces of Q-criterion colored by static temperature at adiabatic wall thermal condition and Mach 2.86. It was observed that, as the wall temperature decreases (cold wall), vortex cores become more organized and elongated. With recent improvements of the User Interface (UI), the user can analyze the flow from various angles and move in all six senses (up/down, forward/back, left/right).



We are expanding the capabilities of our VWT via the HTC Vive Pro2 VR toolkit. The figure below shows a user visualizing the startup process of the subsonic crossflow-supersonic jet problem (iso-surfaces of Q-criterion colored by local the Mach number).

Lessons Learned

This work presents a state-of-the-art methodology for the immersive visualization of virtual objects with mixed reality (i.e., virtual and augmented reality). Whereas the specific application has been focused on flow visualization, extension of the acquired knowledge to other disciplines is straightforward. Unity and ParaView allow the data conversion, model creation, and scene animation to be automated, a big help for DNS database containing multiple files corresponding to each time step solution (unsteady flow). Future work will involve "remote visualization" and "real-time visualization", as part of our VWT enhancement campaign.

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