BLUE WATERS
SUSTAINED PETASCALE COMPUTING

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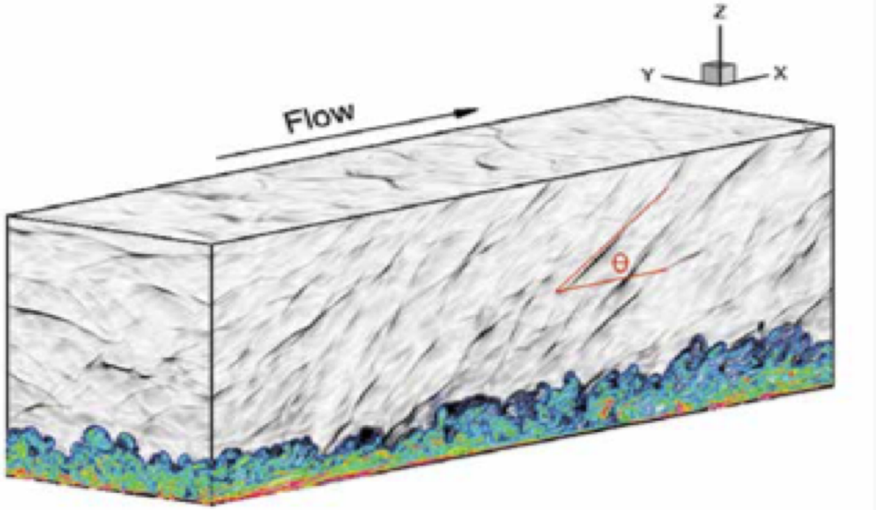

Instantaneous flow visualization for outward-propagating sound waves induced by a Mach 6 turbulent boundary layer. The free-stream acoustic noise is visualized using gray contours of density gradient and the boundary layer is colored by the vorticity magnitude.

PRESSURE FLUCTUATIONS INDUCED BY SUPERSONIC TURBULENT BOUNDARY LAYERS

Research Challenge

The fluctuating pressure on aerodynamic surfaces induced by near-surface turbulent flow of air plays an important role in vibrational loading during atmospheric reentry. The outward-propagating, free-stream sound waves induced by near-wall air flows are related to the genesis of freestream acoustic noise in high-speed wind tunnels. This research aims to advance fundamental understanding of the surface and free-stream pressure fluctuations induced by supersonic boundary-layer flows for developing physics-based models to predict vibratory loading of reentry vehicles and free-stream acoustic noise in supersonic/hypersonic wind tunnels.

Methods & Codes

Direct Numerical Simulations (HyperWENO) solve compressible Navier–Stokes equations. The convective fluxes are computed using a 7th-order weighted nonoscillatory (WENO) scheme with shock capturing and very low numerical dissipation. A 4th-order central difference scheme is used for the viscous flux. A 3rd-order Runge–Kutta scheme is used for time integration. No-slip conditions are applied for the 3 velocity components; an isothermal condition is used for the temperature. Periodic boundary conditions are used in the spanwise direction.

Results & Impact

The work advanced the state-of-the-art of the global pressure field induced by supersonic turbulent boundary layers across a wide range of Mach numbers. This is the first-ever attempt to exploit the advances in HPC to overcome the difficulties in experimental measurements and provide access to both flow and acoustic quantities that are difficult to otherwise obtain. The study led to the 1st successful comparison between numerical predictions and wind tunnel measurements of surface pressure fluctuations underneath hypersonic turbulent boundary layers at Mach 6, 8, and 14.

Why Blue Waters

Direct numerical simulations are used to capture the broadband turbulence field within the boundary layer and the near-field acoustic disturbances radiated by the boundary layer. Extremely fine meshes are required to fully resolve all the turbulence scales in order to obtain the pressure spectra in the high-frequency/large-wave-number range. The simulations need large domain sizes to locate very-large-scale coherent structures. A large number of timesteps are also required for the study of low-frequency behavior of the pressure spectrum. The computational efforts cannot be completed without the world-class capabilities of Blue Waters.