HIGH PERFORMANCE COMPUTING MODERNIZATION PROGRAM

RESEARCH PROJECT #: HPCMP-HIP-25-029

Sensitivity Analysis of Aero-Optical Distortion in Highly Compressible Turbulent Shear Layers

About U.S. Naval Research Laboratory (NRL):

The Laboratories for Computational Physics & Fluid Dynamics (LCP&FD) at the US Naval Research Laboratory (NRL) develop, implement, and apply multidisciplinary computational physics capabilities to solve critical problems facing the Navy, Marine Corps, DOD, and other programs of national interest. Application areas encompass compressible and incompressible fluid dynamics, reactive flows, fluid-structure interaction, atmospheric contaminant and infectious viral transport and the dynamics of turbulence. This research often leverages complementary subject-matter expertise from collaborators within NRL and throughout the broader research community.

RESEARCH LOCATION: Washington, DC

PROJECT DESCRIPTION:

Highly compressible turbulent structures that develop in hypersonic flow fields can severely distort the propagation of optical signals through the atmosphere. The net effect of these high-frequency aero-optical distortions on optical signal strength and possible boresight errors is not well understood, and fundamental research is required to understand the connection between the turbulent structures and the optical wave aberrations. We aim to ascertain the parameters that affect the distortion the most and quantify the uncertainty associated with each parameter in the numerical simulation.

The effective index of refraction of the atmosphere is locally altered by density changes in the shear layer, leading to bore-sight errors that are characterized by an apparent shift in the target's location. Currently, there are no viable methods for correcting these types of bore-sight errors in hypersonic flows. Furthermore, it is yet unclear how much large- and fine-scale structures contribute to the distortion of aero-optical signals. We aim to make significant advances on the above fronts by performing uncertainty quantifications to ascertain which parameters are most sensitive to aero-optics distortion. We will perform a global sensitivity analysis using Sobol indices to obtain the linear and non-linear contribution of the change in every input parameter to the resulting change in output. Resolving the shocks and vortices of various scales in the hypersonic turbulent simulations require millions of grid points and the computational cost is on the order of hundred thousand hours. We will utilize the modular nature of our DG code to run on CPUs and GPUs on HPCMP machines.

The modeling and simulation of shear layers in high-speed compressible flow is of critical importance for many aerodynamic applications, however, the tight coupling between shock waves and the unsteady flow field makes performing such simulations extremely challenging. In this project, we will consider a simple planar configuration, consisting of supersonic flow over a flat surface with a cavity.

Under the guidance of a mentor, the intern will perform a variety of hypersonic numerical simulations using NRL's in-house DG solver and an open-source code, such as OpenFOAM. The intern will sample a multi-dimensional space of input variables (angle of attack and flow conditions) using Monte-Carlo or Latin Hypercube sampling approaches and model the uncertainty for every quantity of interest using the non-intrusive polynomial chaos model. The intern will have an opportunity to learn a variety of analysis techniques relevant to shock and vortex-dominated flows and help advance the state-of-the-art in simulation technologies. The intern will have the opportunity to publish an NRL Technical report, conference paper, or a journal article based on this work.

This opportunity will help build the intern's professional skills in the use of high-performance computing platforms and will provide exposure to the DOD research community. Most importantly, this program will strengthen the interest of the intern towards pursuing a research career in computational fluid dynamics.

ANTICIPATED START DATE:

May 2025 – Exact start dates will be determined at the time of selection and in coordination with the selected candidate.

QUALIFICATIONS:

The ideal candidate must be pursuing or have recently received a degree in Mechanical, Aerospace, Applied Mechanics, Computer Science, Physics, or relevant degree. The candidate should have taken courses or should have some basic understanding of fluid mechanics, aerodynamics, numerical methods, compressible flow, and high-performance computing.

ACADEMIC LEVEL:

Degree received within the last 60 months or currently pursuing:

- Bachelor's
- Master's
- Doctoral

DISCIPLINE NEEDED:

- Computer, Information, and Data Sciences
- Engineering
- Physics
- Science & Engineering-related