Characterizing High-Fidelity Numerical Simulations in the Supersonic and Hypersonic Flow Regimes for Aero-Optical Applications

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 characterize these vortical structures using high-order numerical simulations to understand the source of the aero-optical distortion.

Density fluctuations in the shear layer locally alter the effective index of refraction of the atmosphere, causing bore-sight errors which are characterized by an apparent shift in the location of the target. Currently, there are no viable methods for correcting these types of bore-sight errors in hypersonic flows. Furthermore, the contribution of large-scale and fine-scale structures in the distortion of aero-optical signals is not fully understood yet. NRL aims to make significant advances on the above fronts using the following approach: 1) Generate a database of wavefront distortions using high-order accurate DG simulations and compare it with finite-volume simulations. 2) Perform reduced order modeling to understand the correlation between the distortion with different vortex sizes. 3) Perform uncertainty quantifications to ascertain which parameters are most sensitive to aero-optics distortion. 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. NRL will utilize the modular nature of their 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, NRL will consider a simple planar configuration, consisting of supersonic flow over a flat surface with a cavity.

Under the guidance of mentors, the intern will generate appropriate computational grids using third-party meshing packages, such as GMSH or the HPCMP CREATE tool, Capstone, taking care to properly resolve shock, boundary, and shear layers throughout the flow. The intern will then vary the angle of attack of the flow over the cavity and 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. Various analysis techniques such as Proper Orthogonal Decomposition (POD) and Spectral POD (SPOD) will be used by the intern to process the simulation data. 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 2024 – 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