Advanced Thermodynamic Models of High-Pressure Mixing and Combustion for Liquid-Fueled Air-Breathing Engines

About DEVCOM ARL:

The Army Research Laboratory (ARL) is the U.S. Army's leading research institution, committed to delivering scientific discoveries, technological advancements, and innovative solutions that empower the Army to maintain its edge on the battlefield. ARL's research spans multiple disciplines, including materials science, computational modeling, and advanced engineering, with a strong focus on developing cutting-edge weapon systems and propulsion technologies. In the area of weapon development, ARL works on creating more lethal, precise, and adaptable systems that can operate in the most demanding environments. The lab is at the forefront of research in hypersonic weapons, which require advanced propulsion systems capable of withstanding extreme aerodynamic forces and high temperatures. ARL's work in propulsion includes the development of high-speed engines, such as scramjets, that enable sustained hypersonic flight and improve the range, speed, and maneuverability of future military platforms. Through collaboration with industry, academia, and other government agencies, ARL leverages a wide array of high-performance computing resources, experimental facilities, and modeling capabilities to push the boundaries of current technology. By addressing the challenges associated with high-speed flight, ARL plays a pivotal role in advancing the Army's modernization efforts.

RESEARCH LOCATION: Aberdeen Proving Ground, MD

PROJECT DESCRIPTION:

This project aims to enhance the simulation and understanding of high-pressure, high-speed combustion by developing a high-order conservative diffuse-interface method for compressible two-phase flows. It will use high-performance computing to model the injection of long-chain liquid hydrocarbon fuels into a supercritical combustor environment. Through detailed analysis and integration of finite-rate chemistry, the project will improve the accuracy of non-reacting and reacting fluid models. The outcome will be advanced tools for more reliable combustion modeling, ultimately improving combustion efficiency in high-Mach propulsion systems.

This project aims to enhance the simulation and understanding of high-pressure, high-speed combustion by applying advanced high-order conservative diffuse-interface methods to compressible two-phase flows. Using high-performance computing, the focus will be on accurate modeling the injection of long-chain liquid hydrocarbon fuels, such as kerosene, into trans/supercritical combustor environments. Over the course of 10 weeks, the project will use a DNS solver/software currently under development at ARL to simulate both non-reacting and reacting fluid injections, integrating finite-rate chemistry. It will evaluate the accuracy of the Peng-Robinson cubic equation of state (EoS) in capturing real-fluid effects based on the thermodynamic properties of the mixture. The mentor will be involved in all aspects of the project. The outcomes include preliminary results for a journal publication, and validation of the solver with experimental data. Ultimately, the project aims to create more reliable tools for modeling advanced combustion systems, thereby improving combustion efficiency for hypersonic propulsion.

The faculty member will advance the understanding of high-pressure combustion by analyzing liquid fuel injection under supercritical conditions. Using a high-order conservative diffuse-interface method for compressible two-phase flows this project will involve HPC simulations of kerosene injection at subcritical temperatures into a supercritical combustor environment.

Given the faculty's expertise, this 10-week project is both feasible and designed to be a challenging, rewarding experience. It will provide the faculty member with advanced skills and knowledge crucial for leading a novel academic propulsion research program.

- Conduct simulations of non-reacting compressed kerosene trans critical injection using the new high-order compressible diffuse-interface solver. Compare results with experimental or numerical data to evaluate the Peng-Robinson cubic equation of state for real-fluid effects at trans critical states. An implicit method will be used to handle these effects, with an auto-DE aliasing procedure to mitigate spurious pressure oscillations, compared against the standard double-flux method.

- Implement finite-rate chemistry to model chemical source terms and assess kinetic mechanisms for reacting flows. A 33-species reduced mechanism will be used, with the ESDIRK method applied for time integration of stiff chemical source terms.

- Review and analyze data, prepare preliminary results for publication, and identify future funding opportunities. Develop a solver improvement plan based on simulation results to address any new modeling or knowledge gaps.

During the ARL tenure, the faculty member will also participate in APG laboratory tours, HPC/software training, and meetings with ARO program managers to explore extramural research opportunities.

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 faculty candidate for this opportunity should possess a Ph.D. in Mechanical Engineering, Aerospace Engineering, or a closely related field. They should have a strong background in high-speed compressible flows, turbulence, fluid structure interactions, and high-performance computing (HPC) simulations. Proficiency in advanced numerical methods, particularly for high-order flux reconstruction methods, spectral elements, finite elements, unstructured grids, MPI parallelization, and high-performance computing, is essential. Candidates should demonstrate expertise in finite-rate chemistry and reacting flow simulations, with a solid understanding of chemical source terms and kinetic mechanisms. Additional favorable factors include prior experience with high-order numerical techniques, familiarity with the Peng-Robinson cubic equation of state, and a track record of publications in relevant areas. Experience in securing research funding and a demonstrated ability to collaborate with interdisciplinary teams would also be advantageous. Adjunct or visiting faculty are ineligible.

ACADEMIC LEVEL:

- Doctoral

DISCIPLINE NEEDED:

- Engineering