NASA SBIR/STTR Technologies

A2.06-9878 - Electron Kinetics in Hypersonic Plasmas

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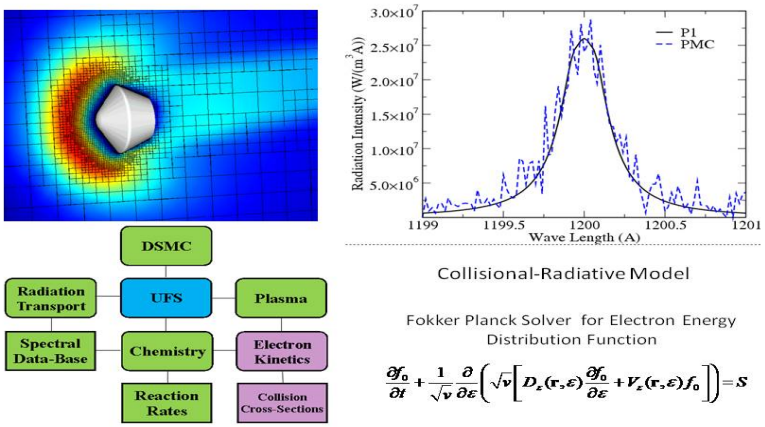
Identification and Significance of Innovation

- Development of hypersonic flight vehicles for space exploration poses severe design challenges associated with limited understanding of the aerothermal environment at extreme Mach numbers.
- The proposed addition of high-fidelity kinetic models for electrons will advance the state of the art in computations of hypersonic flows. Our models will decrease uncertainty in calculations of ionization processes and enhance predictive capabilities of collisional-radiative models, especially in the poorly understood vacuum ultraviolet part of the spectrum.

- INNOVATIONS:
a) kinetic models for electrons based on the Fokker-Planck equation for rarefied and continuum flow regimes;
b) adaptive modeling of the electric fields using both the quasi-neutrality assumption and the Poisson equation,
c) smart selection of appropriate models for electron transport for multi-resolution, multi-physics, adaptive modeling of hypersonic plasmas.

Estimated TRL at beginning and end of contract: (Begin: 1 End: 3)

Electron Kinetics for Predicting Radiation Signature of Hypersonic Plasmas



Collisional-Radiative Model

Fokker Planck Solver for Electron Energy Distribution Function

$$\frac{\partial f_0}{\partial t} + \frac{1}{\sqrt{v}}\frac{\partial}{\partial \varepsilon}\left(\sqrt{v}\left[D_\varepsilon(\mathbf{r},\varepsilon)\frac{\partial f_0}{\partial \varepsilon} + V_\varepsilon(\mathbf{r},\varepsilon) f_0\right]\right) = S$$

Technical Objectives and Work Plan

OBJECTIVES:
- Develop adaptive multi-scale model for electrons applicable for hypersonic flows in rarefied and continuum regimes
- Incorporate this model into UFS framework coupled to plasma, chemistry, and radiation transport modules
- Assess predictive capabilities of the new model for reducing uncertainty for calculations of vacuum ultraviolet radiation

WORK PLAN: In Phase I: 1) Develop a framework for simulation electron kinetics in our existing Unified Flow Solver.; 2) Illustrate the feasibility of adaptive multi-scale simulations of electrons using kinetic-fluid models for rarefied and continuum flow regimes.; 3) Demonstrate improved predictive capabilities of the models for calculations of vacuum ultraviolet radiation spectra.
In Phase II: fully develop and validate the new models versus laboratory experiments for the shock layer radiation in the vacuum ultraviolet part of the spectrum, demonstrate increased predictive capabilities of computational models for hypersonic vehicles with realistic 3D geometries, illustrate effects of electric fields generated by the plasma and externally applied electric and magnetic field on plasma dynamics and MHD interactions, simulate the extreme entry environment at Earth and Mars.

NASA Applications

Technology development programs related to access to space and planetary entry. Predicting heat load and design of thermal protection systems for space vehicles, such as Orion spacecraft and the proposed Space Launch System. Predictive models for plasma radiation signature in the ultraviolet spectral range. Communication blackout problems and hypersonic flow control by electromagnetic fields. Simulating extreme entry environment at Earth, Mars and other planets.

Non-NASA Applications

Ballistic missile and hypersonic vehicles (X-51 waverider, Falcon). Radiation signature for plumes, expanding nozzle flows, plasmatrons and other high enthalpy flow systems. Communication blackout and plasma flow control, electric propulsion, shock wave propagation through plasmas. High-speed plasma jets for material processing and biomedical applications, plasma assisted ignition and combustion.

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NON-PROPRIETARY DATA