High-fidelity thermal radiation models and measurements for high-pressure reacting laminar and turbulent flows

Project Summary
Thermal radiation, chemical kinetics, and turbulence individually are among the most challenging fundamental and practical problems of computational science and engineering. However, little attention has been paid to date to accurate modeling of radiative heat transfer in combustion systems, in spite of the fact that radiation is often the dominant mode of heat transfer (being ignored or treated with simplistic “optically thin” and “gray” models). In chemically reacting turbulent flows, radiation, kinetics, and turbulence are coupled in interesting and highly nonlinear ways, leading to interactions between turbulence and chemical kinetics (turbulence–chemistry interactions: TCI) and between turbulence and thermal radiation (turbulence–radiation interactions: TRI). Both have profound influences on flame behavior but, while turbulence–chemistry interactions have received a great deal of attention over the years, the TRI have essentially been ignored, even though TRI can be just as or even more important than TCI. Numerical simulations treating radiation simplistically and/or neglecting TRI yield inaccurate predictions of temperature (by as much as several hundred degrees Kelvin) and pollutant emissions (especially soot and NOx). Significant progress in physical understanding and modeling of radiation and TRI has been made by the PI over the past several years. The proposed research will extend this work to the high pressures encountered in modern propulsion systems, including extensive experimental verification and measurements of heretofore unknown radiation properties of high-temperature, high-pressure combustion gases. The work will advance fundamental understanding of thermal radiation in chemically reacting flows, including complex interactions between turbulence and radiation. The specific objectives are to measure, develop, validate, and apply models for spectral radiation properties of the most important combustion gases, with particular emphasis on radiation effects in high-pressure combustion, including the effects of TRI. As a result high-end models for spectral thermal radiation and TRI will be advanced to a level that is more consistent with their importance in chemically reacting flows.

The starting point for the proposed research will be the high-fidelity physical models for thermal radiation and for turbulence/chemistry/radiation interactions that have been developed under the PI’s earlier NSF- and NASA-sponsored research. AFRL/RZSA at Edwards Air Force Base has committed to make their EC-1 test cell available for the project, and will provide the personnel, the test article and the consumable materials necessary to conduct the experiments. Four specific research areas will be targeted: 1) extend our spectral radiation models for combustion gases to the elevated pressures relevant to propulsion systems, 2) carry out high-temperature, high-pressure measurements to determine required gaseous absorption coefficients, 3) obtain radiometric heat transfer measurements in high-pressure combustion environments for relatively simple reacting flows, and 4) perform a systematic and detailed validation of existing models against experimental measurements.