NASA SBIR 2020 Phase I Solicitation

Z7.06 Diagnostic tools for high enthalpy and high temperature materials testing and analysis

Lead Center: ARC

Participating Center(s): LaRC

Technology Area: TA9 Entry, Descent and Landing Systems

Scope Title

Optical imaging diagnostics for validation of conventional instrumentation and simulation used to characterize high enthalpy, arc-heated ground test facilities

Scope Description

Advances and new technologies are sought for optical-spectroscopic imaging techniques for NASA's high enthalpy aeroheating test facilities, specifically the Ames Research Center's Arc Jet Complex and Langley Research Center's Hypersonic Materials Environmental Test System (HyMETS). These facilities are used for evaluation of entry system thermal protection materials and structures. Experimental methods for arc jet facility characterization strive to quantify thermodynamic and gas dynamic properties of arc jet flows and serve multiple purposes, such as verification of test conditions (facility operations), validation of arc heater and flow field simulations, and measurement of incident/boundary conditions for material response simulations.

Foremost among these methods are instrumented stream probes and shaped test articles. They are routinely used to measure local heat flux and surface pressure and are tightly integrated with facility operations. Concerns over systematic errors in heat flux measurements have, to date, not been adequately addressed due to a lack of relevant data for validation of the underlying metrology principle – namely the interpreted response of a heat flux sensor to a nominally stable, but unsteady and highly dissociated, gas stream. Development of specialized diagnostic tools which can acquire these validation data, in situ, is the goal of this subtopic scope.

References

Entry Systems Modeling Project: https://gameon.nasa.gov/projects/entry-systems-modeling-esm/

1. G. Palmer, et al., "The Effect of Copper Calorimeter Surface Catalycity on the Predicted Recession of TPS Materials", AIAA 2018-0496
2. O. Chazot, "Experimental Studies on Hypersonic Stagnation Point Chemical Environment", RTO-EN-AVT-142, Experiment, Modeling and Simulation of Gas-Surface Interactions for Reactive Flows in Hypersonic Flights, pp. 13-1 – 13-32
3. A. Nawaz, et al., "Surface Catalysis and Oxidation on Stagnation Point Heat Flux Measurements in High Enthalpy Arc Jets", AIAA 2013-3138
4. A. Gülhan, "Heat Flux Measurements in High Enthalpy Flows", RTO EN-8, Measurement Techniques for High Enthalpy and Plasma Flows, April 2000

5. J. Grinstead, et al., “Consolidated laser-induced fluorescence diagnostic systems for the NASA Ames arc jet facilities”, AIAA 2016-4159
6. J.A. Inman, et al., “Nitric Oxide PLIF Measurements in the Hypersonic Materials Environmental Test System (HYMETS)”, AIAA Journal Vol. 51, No. 10, pp 2365-2379, October 2013

Expected TRL or TRL range at completion of the project: 3 to 6

Desired Deliverables of Phase II

Prototype, Hardware

Desired Deliverables Description

Phase I: Assessment study of potential diagnostic techniques
Phase II: Prototype instrument demonstration in relevant environment with hardware delivery to NASA

State of the Art and Critical Gaps

Heat flux is undoubtedly the most critical measurement of every arc jet test program as it is used for facility operations, flow field simulation validation, and materials response analyses. Diminished – or unwarranted – confidence in conventional heat flux gauge measurements influences uncertainty in test results and ultimately adds risk to TPS (Thermal Protection System) qualification programs.

In highly dissociated arc jet flows, convective, catalytic, and radiative heat fluxes simultaneously contribute to a heat flux gauge’s response. However, response interpretation may not properly account for the microscopic thermodynamic and spatiotemporal characteristics of the incident stream and gas-surface interactions that ultimately govern the response. Potential sources of error and bias are incident flow property unsteadiness and catalytic efficiency uncertainties.

Perturbations and instabilities within the arc heater can persist through nonequilibrium expansion within the nozzle and into the test chamber, possibly resulting in fluctuating flow properties, gradients, and atom fluxes at article surfaces. As flow property gradients are the driving potentials for catalysis, property fluctuations could influence the magnitude of catalytic heat flux. Departures from modeled interpretation cannot be discerned without direct observation, potentially resulting in unknown error and bias in heat flux measurements.

Also contributing to error and bias is the uncertainty in the sensor’s catalytic efficiency. A reduction or augmentation from an assumed value creates an undetectable bias in heat flux measurements with consequences that may not be conservative. Coupled with the potential influence of property gradient fluctuations on catalysis, the modeling assumptions of heat transfer to catalytic surfaces in dissociated flows cannot be validated without additional, independent data sources.

Time-resolved gas property measurement along the stagnation streamline would enable evaluation of the key assumptions of NASA’s heat flux measurement approach. Quantities of particular interest are atomic and molecular species concentrations and temperature. The profiles and statistical variations could verify the conformance to, or reveal the departure from, the modeled theories. The ultimate benefit will be greater confidence in NASA’s use of heat flux gauges.

The above requirements strongly indicate the use of kHz rate, species-selective, ultrafast pulsed laser spectroscopic imaging techniques to advance the state-of-the art. NASA’s current nanosecond laser-induced fluorescence capabilities are inadequate due to insufficient sensitivity for quantitative planar imaging in the highly luminous shock layer ahead of a test model.

Relevance / Science Traceability

Several potential future missions, outlined in decadal surveys, crewed exploration mission studies, and other supporting analyses, have Entry and Descent (ED)/ Entry, Descent and Landing (EDL) architectures: Mars sample return, high speed crewed return, high mass Mars landers, Venus and gas/ice giant probes. With few exceptions, entry vehicle TPS for these missions will be composed of materials currently under development and without certification heritage. Arc jet testing at conditions relevant for certification will invariably be required for each of these proposed missions. Ground testing at more extreme environments for future missions will challenge existing capabilities. There is a compelling need now to bring research-level diagnostic technologies forward to ensure that facility operations can credibly demonstrate required performance to TPS technology projects.

Conventional instrumentation will continue to be the primary source of facility characterization data. The purposes of the advanced techniques are to provide validating evidence for the conventional instrumentation, reveal error and bias in interpretation of heat flux measurements, and ultimately reduce uncertainty in facility performance data provided to test programs.

NASA planetary exploration programs supporting ED/EDL missions are the intended beneficiaries of this subtopic. The first-line project is STMD’s (Space Technology Mission Directorate) Entry Systems Modeling Project.

Scope Title

Advanced instrumentation for NASA's shock tube and ballistic range facilities

Scope Description

NASA is seeking innovative imaging and spectroscopic measurement techniques for NASA’s two specialized-use impulse facilities: the Electric Arc Shock Tube (EAST) and the Hypervelocity Free Flight Aerodynamic Facility (HFFAF). The EAST facility replicates shocked gas environments encountered by entry vehicles transiting planetary atmospheres at hypersonic velocities. Spectroscopic instrumentation is used to characterize the absolute radiance and gas kinetics behind a traveling shock wave. The HFFAF is used for the study of dynamically similar supersonic and hypersonic aerodynamics, transition to turbulence, and laminar and turbulent convective heat transfer. Optical imaging instrumentation is used to characterize aerodynamic forces and moments of scaled models launched through the range. Thermographic and spectral imaging instrumentation is used to characterize spatially resolved heating rates to scaled models.

New electro-optic products and methods enable measurement of quantities beyond current capabilities and improve current practices.

References

Entry Systems Modeling Project: https://gameon.nasa.gov/projects/entry-systems-modeling-esm/

ADEPT Project: https://gcd.larc.nasa.gov/projects-2/deployable-aeroshell-concepts-and-flexible-tps/

Many journal papers, conference proceedings, and technical reports describing the NASA Ames EAST and HFFAF test facilities and research are available in the open literature.

Expected TRL or TRL range at completion of the project: 3 to 6

Desired Deliverables of Phase II

Prototype, Hardware

Desired Deliverables Description

Phase I: Assessment study of potential diagnostic techniques or technology upgrades
Phase II: Prototype instrument demonstration in relevant environment (preferably w/hardware delivery to NASA)

State of the Art and Critical Gaps

The EAST facility’s instrumentation acquires data for shocked gas phenomenology and facility performance characterization. Measurements of radiance, absorbance, electron density, and temperature are used for validation of comprehensive radiation transport simulations of planetary atmospheres. Those measurements are primarily acquired using calibrated optical-spectroscopic instruments with sufficient temporal and/or spatial resolution to correlate observed magnitudes with localized, spectrally resolved absolute radiant fluxes or columnar property densities (including electron densities). Ancillary instrumentation is used to measure shock arrival times and transient pressures at the tube wall to establish shock speeds adjacent to the science instruments.

Measurement techniques that correlate observables to atomic and molecular state populations and radiance magnitudes enable validation of radiance models. Emission spectroscopy techniques, which capture the transient characteristics of excited atomic and molecular state populations, have reached a high degree of maturity and efficacy.

However, post-shock electron and ground or other dark state population dynamics also influence shock radiance. Measurement of these states rely on more complicated absorption, induced fluorescence, or scattering (spontaneous and coherent) techniques. The lack of light sources and/or detectors with suitable spectral and temporal characteristics or the challenges of implementation in impulse facilities have limited opportunities for such measurements. Techniques that enable measurement of these states would greatly expand opportunities for radiation transport model validation, particularly for conditions in which self-absorption would influence emission spectroscopy measurements.

For the HFFAF, shadowgraph and schlieren photography are used to provide time-resolved imagery for aerodynamic force and moment analyses of scaled flight vehicles in free flight. A high-speed shutter (40 ns duration) and a spark-gap light source enable images to be captured without motion blur. The shuttering system relies on Kerr cells filled with benzonitrile and a 35 kV pulse shaping and switching network. Advances are sought for the eventual replacement of the 32 heritage light source/shutter systems with components that offer equal or greater performance as well as improved safety and reliability.

Relevance / Science Traceability

Several potential future missions, outlined in decadal surveys, crewed exploration mission studies, and other supporting analyses, have ED/EDL architectures: Mars sample return, high speed crewed return, high mass Mars landers, Venus and gas/ice giant probes. Entry vehicles to these destinations will encounter radiative heating to varying degrees. Radiative heating of a vehicle’s back shell has been recognized as a significant concern, so ensuring a full range of diagnostic techniques for expanding flows has become a high priority for the EDL (Entry, Descent, and Landing) community.

Characterizing the aerodynamic stability of emerging deployable drag devices for entry vehicles is also of high importance for future high-mass lander missions. The HFFAF will be a key ground test facility for acquiring crucial free-flight aerodynamic data for study and simulation validation.

NASA planetary exploration programs supporting ED/EDL missions are the intended beneficiaries of this subtopic. Technology development projects supporting these programs are potential beneficiaries of new instrumentation for the EAST and HFFAF.