ARCTRON: A Rapid Experimental Proving Ground for TPS Experiments and Arcjet Technology Development

Magnus Haw[a,*], Sebastian Colom[b], Arnaud Borner[b]

[a]*NASA Ames Research Center, Moffett Field, CA, USA*
[b]*AMA, Inc. at NASA Ames Research Center, Moffett Field, CA, USA*

Abstract

Innovation in high-enthalpy facilities is fundamentally limited by the cost and risk of experimentation. New concepts for plasma control, diagnostics, facility components, and plasma-material interaction often require repeated iterations that are impractical to perform in production arcjets. As a result, promising ideas may remain unexplored or reach operational facilities only after significant development effort.

ARCTRON is being developed as a rapid experimental proving ground where new ideas in plasma science, arcjet engineering, diagnostics, and material response can be conceived, tested, and quantitatively evaluated before transition to large-scale facilities. The platform combines radio-frequency (RF) and DC arc plasma generation, externally applied magnetic fields, configurable gas composition, reduced-pressure operation, laser heating, electrical biasing, and modular diagnostic access. These capabilities permit the plasma source, applied forcing, test article, and measurement configuration to be modified independently, allowing individual physical mechanisms to be isolated more readily than in a traditional test environment.

One class of investigations addresses fundamental plasma-surface interaction physics. Conventional material tests often expose a specimen simultaneously to convective heating, reactive species, pressure, shear, radiation, and surface-current effects. The resulting material response may be measured accurately, while the contribution of each mechanism remains difficult to identify. ARCTRON is designed to vary these effects selectively. Plasma chemistry can be changed independently through configurable gas mixtures; magnetic fields and electrical biasing can modify charged-particle transport; laser heating can provide a non-plasma thermal input; and pressure, flow, and discharge mode can be varied over a broad operating space. This enables controlled tests of hypotheses involving surface catalycity, reactive-species transport, plasma-assisted oxidation, electromagnetic effects, shear, and the relative contributions of thermal and chemical loading.

A second class of investigations enabled by this approach concerns the engineering of high-enthalpy facilities themselves. Arc-heated facilities are limited by electrode erosion, unstable arc attachment, localized heating, and damage to nozzles and other plasma-facing components. ARCTRON provides a lower-cost environment for testing concepts intended to mitigate these limitations. Candidate investigations include the use of applied magnetic fields to alter current paths and reduce plasma interaction with nozzle walls, $\mathbf{E} \times \mathbf{B}$ forcing to introduce controlled plasma rotation, magnetic or geometric approaches for distributing arc attachment, and alternative electrode or discharge configurations intended to reduce erosion and improve stability. Because the platform is reconfigurable, these concepts can be evaluated through repeated design–build–test cycles before they are considered for implementation in operational facilities.

The platform also supports the development and validation of diagnostics that may be difficult to introduce initially into a large arcjet. Current and planned measurements include spatially resolved optical emission spectroscopy, electrostatic probes, fast imaging, pyrometry, calorimetry, laser-induced fluorescence, and absorption spectroscopy. These diagnostics are intended not merely to document a nominal operating condition, but to constrain the local plasma state and its relationship to component or material response. The modular facility geometry allows diagnostic concepts to be tested, calibrated, and compared under repeatable conditions before deployment in more demanding environments.

ARCTRON is also supported by an integrated software suite. Automated control and data acquisition allow discharge parameters, gas composition, magnetic fields, diagnostic timing, and test configuration to be recorded as part of each experiment (STARDAC - Software for Testing, Analysis, Research Data, and Control). The Backend for Experiment Analysis, Storage, and Traceability (BEAST) [1] is a database that provides the infrastructure needed to

associate heterogeneous measurements with facility configuration, specimen identity, calibration state, geometry, and analysis provenance. This backend is particularly important for exploratory campaigns, in which many related configurations may be tested and the value of an individual experiment depends on its connection to earlier and subsequent iterations. Complementary analysis capabilities, including computer-vision-based transient response measurements (arcjetCV), three-dimensional surface reconstruction (STARSCAN), and model-based Bayesian inference (SHIELD), and tomography data analysis (TOMATO, PuMA) can be incorporated when required by a specific hypothesis without becoming the focus of every campaign.

The central objective of ARCTRON is therefore not to maximize heat flux or reproduce a complete flight environment. Its purpose is to reduce the cost and time required to ask consequential questions about plasma behavior, plasma-facing materials, diagnostics, and arcjet technology. By providing a controlled environment for rapid reconfiguration, mechanism isolation, quantitative measurement, and iterative engineering, ARCTRON can help mature concepts that would otherwise remain too speculative or too risky for evaluation in production facilities. The resulting knowledge can then guide the design of material models, focus test objectives in larger arcjets, reduce facility-development risk, and improve the physical basis of high-enthalpy ground testing.

This work will present the ARCTRON architecture, operating modes, diagnostic suite, and digital experimental workflow. Initial experimental results from the first integrated operation of the facility will be presented, including flow characterization, power limitations, and deployment of the initial diagnostic suite. Ongoing development efforts aimed at catalycity characterization, magnetic plasma control, and advanced optical diagnostics will also be discussed, illustrating how the platform supports rapid iteration from concept to experiment.

Keywords: plasma-material interaction, arcjet, high-enthalpy testing, magnetohydrodynamics, facility development, experimental diagnostics

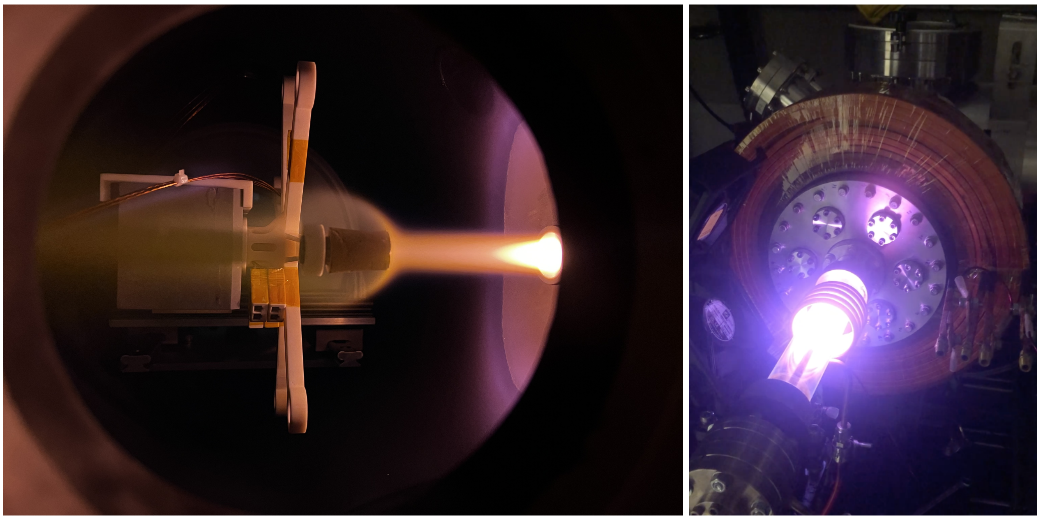

Figure 1: ARCTRON images (left) ARCTRON test of cork sample held in 6-position sting arm (2D axial and rotation motion axes) (right) image showing plasma generation external to the chamber

References

[1] M. A. Haw, M. E. MacDonald, S. V. Colom, Big-data Efficient and Automated Science Transfer (BEAST): an open-source software architecture for arc jet data management, modeling, and automation. arXiv:https://arc.aiaa.org/doi/pdf/10.2514/6.2023-2712, doi:10.2514/6.2023-2712.

*Corresponding author.
Email address: magnus.haw@nasa.gov (Magnus Haw)