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Arc Heater Capability Upgrade at AEDC

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Arnold Engineering Development Center's (AEDC) arc heater facility upgrade allows for materials testing in nonoxidizing flows. The H2 Huels arc heater facility has undergone recent upgrades to allow bottled gases to be used as a test medium. This upgrade allows testing heat shield materials in test gases other than air.

Key words: AEDC; Huels arc jet heater; H2 facility; simulation; thermal protection systems.

The U.S. Air Force's Arnold Engineering Development Center (AEDC) High Temperature Laboratory (HTL) has recently altered the gas supply system of the H2 arc heater facility *(Figure 1)*. The H2 facility can provide up to a 24 inch diameter hypersonic flow with simulated pressure altitude ranging from 20 to 50 km (70 to 160 kft). This facility is used for ground simulation testing of thermal protection systems, antenna transmission windows, hypersonic leading edges, and missile forebodies and nose tips. Usually, the H2 facility is configured to use air as the test gas for the simulation of atmospheric ascent, maneuvering, and reentry. Recent modifications to the H2 facility allow the use of test gases other than air for simulation of oxygen-deficient environments, where combustion effects and atomic oxygen effects are minimized.

Arc heaters are ground-test facilities that are capable of reproducing the thermal environments of hypersonic flight for times long enough to validate thermostructural performance of shielding materials and components. Because of the complexity and cost associated with hypersonic vehicle components, structures, and propulsion systems, arc heater facilities are critical in the design, development, and qualification of those elements before flight testing.

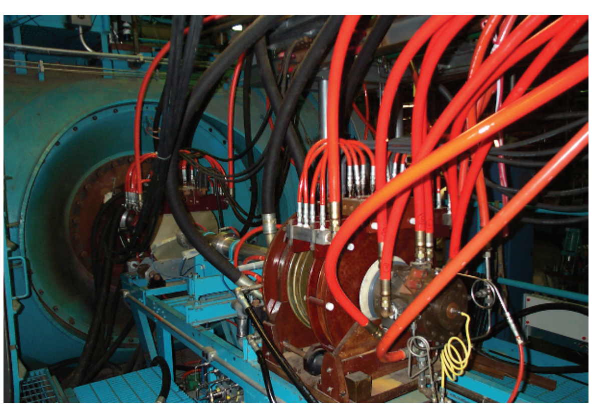

Figure 1. H2 arc heater facility.

The H2 arc-heated wind tunnel uses an N-4 Huels-type arc heater to generate high-temperature high-pressure flow for expansion through a hypersonic nozzle into a subatmospheric test cell to provide flows at Mach numbers ranging from 3.4 to 7.0. The facility uses a high-voltage, direct current power supply to generate an electric arc discharge, heating the test gas to a total temperature of up to 5,300K (9,600°R). *Table 1* lists the H2 arc-heated wind tunnel specifications.

The Huels-type arc heater is a relatively simple arc heater configuration consisting of two coaxial electrodes separated by a swirl chamber *(Figure 2)*. The arc is vortex stabilized, meaning that the test gas is injected tangentially into the swirl chamber at the electrode interface. This generates a helical vortex as the fluid is heated by the arc discharge before being expanded through the nozzle. The arc is further stabilized by the use of two coaxial electromagnetic spin coils located at each electrode.

Table 1. H2 arc-heated wind tunnel specifications.

Facility type	Subatmospheric free-jet exhaust
Max. run time	Up to 30 min
Nozzle Mach number	3.4–7.0
Nozzle exit diameter	5–24 in
Stagnation pressure	Up to 50 psia
Stagnation enthalpy	1,200–4,200 Btu/lbm
Mass flow rate	2–10 lbm/s
Facility power	Up to 42 MW

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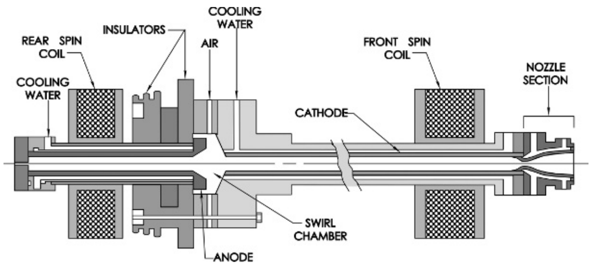

Figure 2. Huels arc heater configuration.

Test samples, coupons, and probes are inserted by means of a five-strut water-cooled model positioning system (MPS) featuring rotary model injection and axial drive. This allows the testing of multiple samples, collecting parametric data during a single test run.

The purpose of the upgrade was to allow the comparative testing of thermal protection systems with and without the presence of oxygen. This modification now allows the use of any stored gas as a potential test medium.

A validation run was completed for comparison of facility performance using both air and nitrogen. For each type of run, facility startup began with initialization of the arc heater current and stabilization of the arc, allowing the facility to reach predefined conditions. Once the heater reached a steady-state condition, flow-field instrumentation was swept through the flow to gather benchmark data for the comparison. All instrumentation was swept at 0.225 inch axially from the nozzle exit plane. *Table 2* presents a summary of the collected results.

The results of testing show that the H2 facility is indeed capable of operating using nitrogen as the test gas; however, the facility is slightly less stable because of voltage fluctuations caused by the use of nitrogen instead of air.

As seen in *Table 2*, the average heater efficiency (at these conditions) is 65% when using air as the test medium. Using nitrogen as the test gas shows an average efficiency of 55%, giving an average loss of 10% efficiency by switching the test gas from air to nitrogen.

This efficiency reduction is primarily due to the fluctuation of voltage in the Huels heater with the change in test gas. With air, the voltage trace is fairly stable; however, with nitrogen, the voltage trace has significantly more fluctuation relative to a nominal value as seen in *Figure 3*. These voltage fluctuations may be due to the lack of oxygen reacting with the copper cathode to create a higher resistance copper-oxide band within the electrode. In air, this copper-oxide band would mitigate shortening of the arc beyond the lower-resistance nonoxidized region of the electrode.

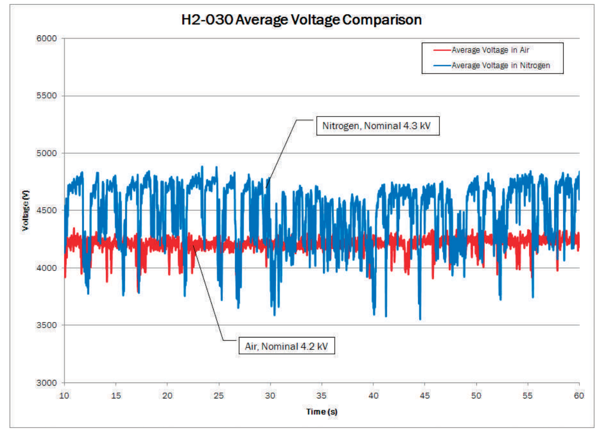

Figure 3. Average voltage comparison.

Because voltage is directly related to the physical arc length, the fluctuations seen in *Figure 3* correspond to a chaotically expanding and contracting arc.

Another key facility parameter is bulk enthalpy. Bulk enthalpy is the enthalpy of the working fluid as defined by an energy balance between the input energy and the temperature rise of the facility cooling water. This is also the same energy balance used in the calculation of heater efficiency, thus a 10% reduction in efficiency corresponds to a 10% reduction in the nominal level of the bulk enthalpy.

Though the facility has a reduced bulk enthalpy when using nitrogen as the test gas, the average flow-field stagnation heat flux profile does not significantly differ from operation with air. This could be due to catalycity effects, which would become significant—regardless of test gas—for highly dissociated flows. *Figure 4* shows a comparison of the radial stagnation heat flux between the two test gases.

Table 2. H2-030 run summary.

Run number H2-030	Test gas	Chamber pressure (atm)	Arc current (amp)	Arc voltage (kV)	Power (MW)	Efficiency (%)	Mass-flow rate (lbm/s)	Bulk enthalpy (Btu/lbm)
−001	Nitrogen	19.1	3,130	4.2	13.1	52	2.7	2,750
−002	Nitrogen	20.4	3,100	4.4	13.3	57	2.8	2,750
−003	Air	20.4	3,140	4.2	13.4	65	2.8	3,020
−005	Air	20.0	3,120	4.2	13.2	64	2.8	2,980

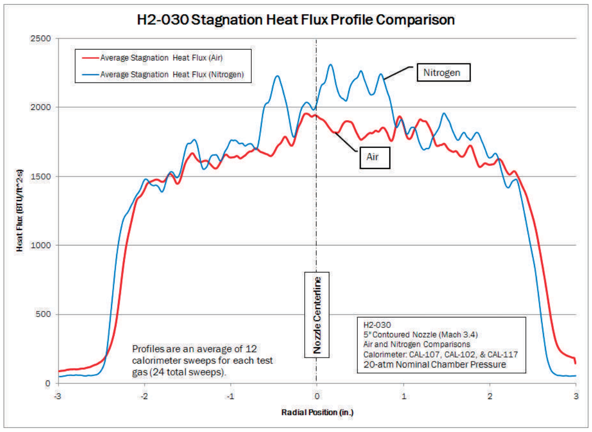

Figure 4. Average stagnation heat flux profiles.

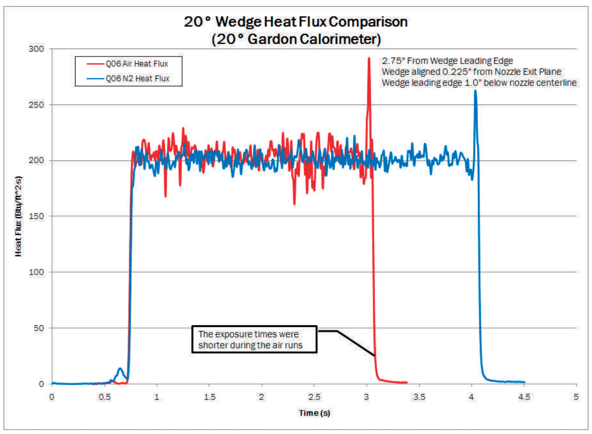

Figure 5. 20° Gardon wedge incident heat flux comparison.

Because the stagnation heat flux profiles do not significantly differ between the two test gases, wedge heat flux profiles would be expected to display similarity for both test gases at these facility operating conditions. For this test series, a 20° wedge plate with Gardon calorimeters was used to measure the incident heat flux. *Figure 5* shows that for both test gases the incident heat flux on a 20° wedge is nominally the same magnitude.

In conclusion, AEDC's arc-heated wind tunnel facility is traditionally configured to use high-enthalpy air to simulate reentry environments for thermal ground testing; however, it is sometimes preferable to simulate a nonoxidizing reentry environment to reduce combustion and reactivity effects of user hardware. To offer this additional simulation capability, the H2 facility was reconfigured to use nitrogen as a test gas. The facility operating parameters are slightly less stable using nitrogen as a working fluid, as seen by fluctuations in the voltage trace, but the facility is able to produce comparable flow-field parameters using nitrogen as opposed to air. Conversion of the facility supply system is a relatively quick operation that allows increased simulation capability at no detriment to facility operation. ❑

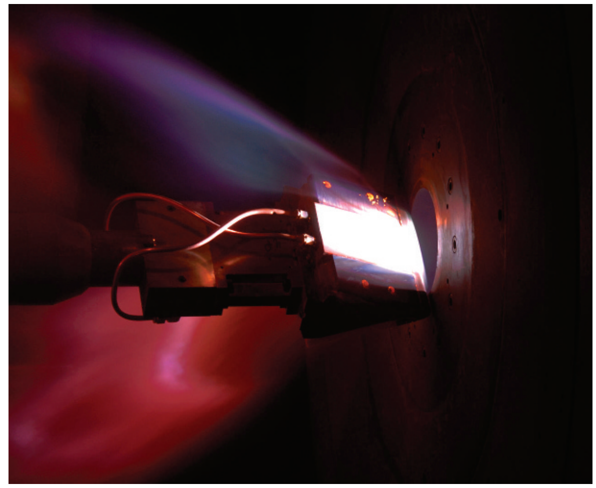

Figure 6. 20° Gardon wedge in nitrogen flow.

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