Advanced High-Power Arc Heaters for Simulating Entries into the Atmospheres of the Outer Planets

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Theme

HIGH-ENTHALPY electric-arc plasma jets that operate above 15 Mw are being developed at Ames Research Center to simulate the heating environment of Jupiter entry.

Content

Entry into the Jovian atmosphere at 50 km/sec produces stagnation enthalpies of about 9×10^8 joule/kg at maximum heating. At a relatively shallow entry angle of $-6.3°$, stagnation-point pressure is approximately three Earth atmospheres and the stagnation-point cold-wall heat-transfer rate is about 50 kw/cm^2. To simulate these entry conditions for adequate periods, a constricted-arc supersonic jet appears to be a logical laboratory device.

The 20-Mw Constricted-Arc Jet, Fig. 1, is a supersonic nozzle with electrodes at either end. The nozzle throat is a constant 6-cm internal diameter tube, 1.2 m long, that constricts the high current, d.c. arc to produce high enthalpy. This constrictor tube consists of a number of copper rings that are electrically insulated one from another to accommodate the arc voltage. The arc heats a test gas (in this case, a mixture of hydrogen and helium) that is injected along the constrictor tube. The location of one electrode downstream of the nozzle throat is critical to the generation of high-enthalpy test streams. It extends the heating into the supersonic nozzle so that the gas is prevented from cooling and high enthalpy is maintained at the test section. The arcjet was designed to operate at power levels four times greater than its predecessor. Heat capacity cooling limits the operating time of this device to about 1 sec. These test times, it should be noted, are orders of magnitude greater than those of hypervelocity free flight facilities.

The low-expansion ratio (2.78) provided by the 10-cm-diam nozzle exit makes relatively high-impact pressures possible at low-supersonic Mach numbers and modest constrictor tube pressures. Experience has shown that high enthalpies cannot be attained at high-constrictor pressures without excessive losses to the constrictor wall.

The cold-wall heat-transfer-rate characteristics of the 20-Mw calorimeter. This method is based on the time required to cause Constricted-Arc Jet have been studied by means of a copper melting on a 2.54-cm- (1-in.) diam, flat-faced copper rod. The minimum time-to-melt of 0.0575 sec. indicates a maximum heat-transfer rate of 15.2 kw/cm^2, which is about one third of the maximum expected during a $-6.3°$ Jovian entry.

The diameter of the test stream core of constant heat-transfer rate was estimated to be about 3 cm at an impact pressure of 0.4 atm. As the impact pressure was increased to 1 atm, the core diameter decreased to about 1 cm.

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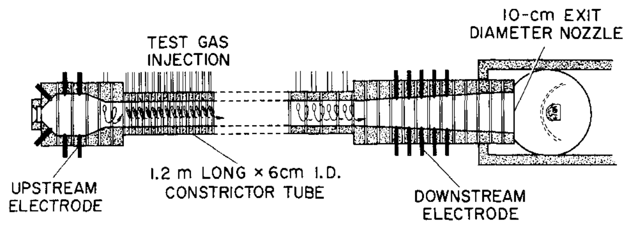

Fig. 1 20-Mw Constricted-Arc Jet.

The centerline impact pressure and total enthalpy of the stream core are the important stagnation-point heat-transfer rate parameters for test bodies mounted on the jet centerline. Impact pressure was measured by means of a 2.54-cm- (1-in.) diam flat-faced pressure probe connected to a pressure transducer. Centerline enthalpies have been measured by the hydrogen-beta line broadening method. This method utilizes a 2.54-cm- (1-in.) diam flat-faced copper impact probe mounted on the jet centerline. Because the impact pressure and test body size are sufficient to insure thermodynamic equilibrium,[1] the centerline enthalpy can be calculated from the measured impact pressure and the electron number density. The later is a function of the hydrogen-beta line width.

The centerline enthalpy and impact pressure performance is shown in Fig. 2. Also shown on Fig. 2 are the enthalpies and impact pressures expected for $-6.3°$ and $-15°$ Jovian entry angles. The regions of maximum convective, radiative, and total cold-wall stagnation-point heating rates are also shown. The attainment of an enthalpy above 9.1×10^8 joule/kg (3.5×10^5 Btu/lb) indicates that the enthalpy corresponding to maximum total cold-wall heat transfer is already available, and, with a modest improvement, the enthalpy required for maximum cold-wall convective heat-transfer rate can be obtained. As shown in Fig. 2, the impact pressures are low by a factor about 5 for the

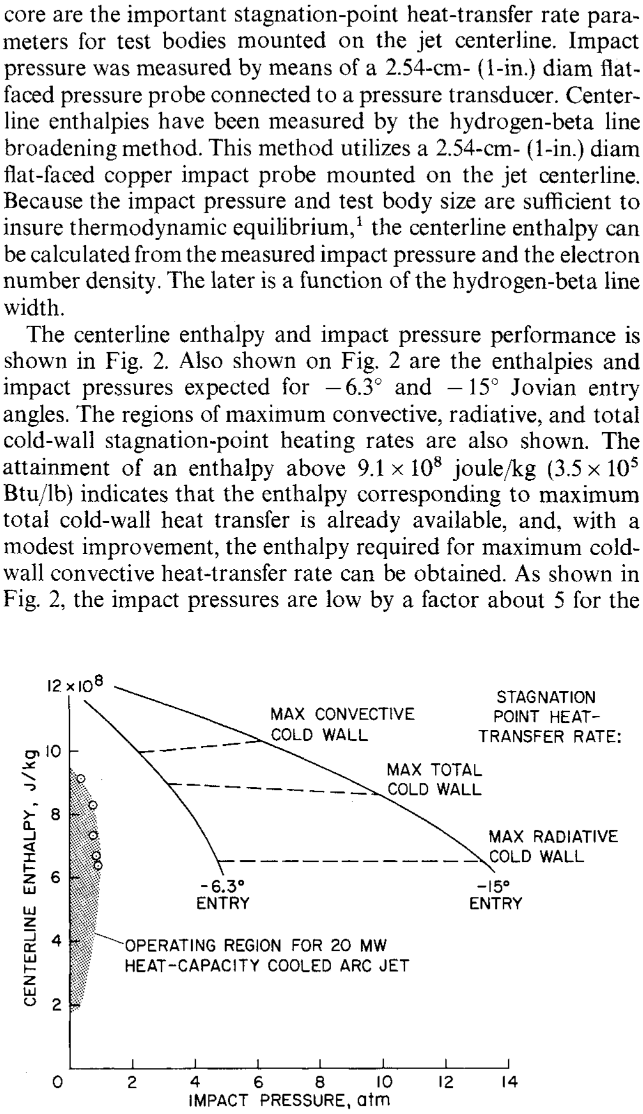

Fig. 2 Jovian entry simulation capabilities of the 20-Mw Constricted-Arc Jet.

$-6.3°$ entry, and by a factor of about 15 for the $-15°$ entry. The prospects for increasing the pressure are good; however, there will be an attendant decrease in the run times, because of increased constrictor-wall heat-transfer rates with higher power supply voltages.

Tests with the 20-Mw Constricted-Arc Jet to provide a ground based facility capable of simulating the heating of a probe entering the atmosphere of Jupiter demonstrated that the enthalpy and heat-transfer rates for the facility were sufficiently high for it to be a valuable tool for preliminary studies of planetary atmosphere entry heating. However, to simulate the entry conditions, increases in impact pressure and test duration are needed.

Reference

[1] Okuno, A. F. and Park, C., "Stagnation Point Heat-Transfer Rate in Nitrogen Plasma Flows: Theory and Experiment," *Transactions of the ASME, Ser. C: Journal of Heat Transfer*, Vol. 92, No. 3, Aug. 1970.