Rarefaction effects in NASA arc jet testing at SCIROCCO facility

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I. Introduction

This work describes the numerical analyses carried out at CIRA in order to rebuild the tests performed for NASA in SCIROCCO Plasma Wind Tunnel (PWT) under increasing enthalpy level and constant pressure. The SCIROCCO PWT is an arc jet facility capable of producing a high enthalpy, low pressure, hypersonic flow of large dimension (further details can be found in[1]). The flow parameters in the test section are characterized measuring heat flux and pressure at the stagnation point of a probe.

During the activities of numerical rebuilding, that usually follows the tests in order to duplicate the values measured by the probe,[2] the discrepancies with the experimental data have lead to examine the numerical models tailored for chemical reacting, non-equilibrium flows showing the lack of consistence of the continuum hypothesis that holds for the Navier-Stokes (NS) model. After preliminary evaluations of the global and local rarefaction levels reached in the test section and around the probe, considering the continuum Breakdown Parameter, further numerical analyses were conducted employing a DSMC model, giving better results in terms of the heat flux reached at the stagnation point of the probe.

II. Experimental Results

The NASA tests in SCIROCCO Plasma Wind Tunnel were performed with the Conical Nozzle 'D' (length of 3.1 m from the throat section, exit diameter 1.1 m) and with an increasing arc heater electrical power from 27 to 31 MW. The flow conditions were characterized at a distance of 37.5 cm from the nozzle exit section inserting at the jet center-line a CIRA probe, hemispherical with radius 50 mm, water cooled, fully catalytic and instrumented at the stagnation point with a Gardon gage and a pressure tap for the measurement of heat flux and pressure. A huge amount of experimental data was acquired, the set analyzed here is resumed in the following Table 1.

Table 1. Experimental Test conditions

Test ID	H_0 $[MJ/kg]$	P_0 $[bar]$	P_{exit} $[mbar]$	q_{Probe} $[kW/m^2]$	p_{Probe} $[mbar]$
396	23.8	2.5	0.24 $\pm$0.01	1543 $\pm$33	17.9 $\pm$1.1
399	24.0	2.4	0.23 $\pm$0.01	1609 $\pm$32	17.9 $\pm$1.1
400	26.2	2.5	0.23 $\pm$0.01	1710 $\pm$34	18.4 $\pm$1.1

The table contains the results of three tests characterized by increasing enthalpy level and constant reservoir pressure. Here are reported, for each test, the following measured values: total enthalpy (H_0) and pressure (P_0), static pressure at the nozzle exit plane (P_{exit}), Probe stagnation heat flux (q_{Probe}) and pressure (p_{Probe}). The numerical rebuilding aims to capture the physical values measured by the probe, modeling the flow in the nozzle and in the test section around the hemispherical nose of the probe, as described in the next section.

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