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Predicting Catalycity of Si-Based Coating and Stagnation Point Heat Transfer in High-enthalpy CO_2 Subsonic Flows for the Mars Entry Conditions

A.F. Kolesnikov , *S.A. Vasil'evskii, I.S. Pershin*

CONDITIONS Institute for Problems in Mechanics RAS, Prospect Vernadskogo 101/1,119526, Moscow, Russia.

email: koles@ipmnet.ru

Aerodynamic heating of a vehicle surface during entry into the Martian atmosphere is quite sensitive to surface catalycity with respect to recombination reactions O+O <=> O_2 and CO+O <=> CO_2. This paper deals with methodology for predicting TPM catalycity in dissociated CO2 mixture (the dominant chemical component in the Martian atmosphere) combined with direct duplication of the stagnation point heat transfer for the Martian atmosphere entry conditions. The main aspects of this methodology will be presented as follows: (1) the concept of the local heat transfer simulation (LHTS), (2) thermochemical capabilities of the IPG-4 plasmatron, (3) test instrumentation and measurement techniques for heat transfer tests, (4) CFD tools and (5) results of predicting catalycity of Si-based coating and stagnation point heat transfer for the Mars entry conditions.

LHTS concept is based on the requirements to duplicate in aerothermal test the same total enthalpy, stagnation pressure and velocity gradient at the outer edge of the boundary layer at stagnation point as in hypersonic flow. According to this theory the hypersonic flight conditions and free stream parameters of the high-enthalpy subsonic flow have to be in correlation as follows:

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where subscripts and S correspond to free stream conditions in hypersonic flight and high-enthalpy test, R_N is an entry vehicle nose radius, $R^*{}_m$ is an effective radius of the test model.

The operating envelope of the 100-kW plasmatron IPG-4 covers the peak-heating parts of the Mars Probe and Mars Pathfinder trajectories. This feature combined with a high purity of the inductively coupled plasma provides the capability to rebuild the TPM catalycity and duplicate stagnation point entry heating at the same test conditions.

The characterization of plasma flow and heat transfer includes the measurements as follows: 1) stagnation point heat fluxes to different metallic and quartz cooled surfaces; 2) dynamic pressure; 3) TPM surface temperature.

CFD modeling of the subsonic plasma and high-enthalpy reacting flows and heat transfer for the plasmatron test conditions is an essential part of the rebuilding free stream conditions and predicting surface catalycity. Modeling plasma and high-enthalpy carbon dioxide reacting flows includes the three problems and appropriate CFD tools as follows: 1) equilibrium inductively coupled swirling plasma flow within the cylindrical discharge channel; 2) equilibrium subsonic axisymmetric high-enthalpy laminar jet flow past a cylindrical model; and 3) nonequilibrium multicomponent boundary layer with surface catalysis at the stagnation point.

Three heat transfer regimes were realized by the IPG-4 in subsonic carbon dioxide flows at the enthalpy 17

MJ/kg in the pressure range 60-140 hPa using 50-mm diameter cylindrical model with a flat face. The appropriate entry conditions in the Martian atmosphere correspond to entry velocity 5830 m/s, the altitude range 46-39 km and nose radius range 0.65-1.48 m. For these test conditions catalycity of the Si-based coating in respect to surface recombination reactions O+O <=> O_2 and CO+O <=> CO_2 was determined through comparison of the calculated and measured stagnation point heat transfer rates. At the three appropriate Mars entry conditions the predicted surface temperature of Si-based material in stagnation point is found to be about 1600 K. The opposite trend in the behavior of w with respect to pressure is found in the range $w = 9 * 10^{-3} - 3.2 * 10^{-3}$.

The results of direct duplication of the convective stagnation point heating "Mars Probe" and "Mars Pathfinder" vehicles at the trajectory peak-heating points using high-enthalpy subsonic carbon dioxide flows in the IPG-4 facility will be presented as well.