CHARACTERIZATION OF THE EXPERIMENTAL OPERATION, IN THE ATMOSPHERE AND VACUUM, OF A SMALL PLASMA TORCH, DEVELOPED FOR THERMAL PROTECTION MATERIALS TEST.

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Abstract. *The Physics Department of the Aeronautics Institute of Technology, together with the Aeronautics & Space Institute and Brazilian Space Agency, is coordinating a project with the primary purpose of making feasible the construction of a Plasma Tunnel in order to study the aerothermodynamic conditions on atmospheric reentry. This paper present firsts results characterization of a small plasma torch with has been developed to generate a plasma jet for realizing thermal heat shield tests. The plasma jet was generate by torch in two cases: atmospheric pressure (100kN/m^2) and vacuum with pressure between 80 and 400 N/m^2 which simulate altitude (50-35)km. The torch input power was in the rang of (1.5-7)kW, the gas transferred power between (0.5-2.6kW). Best efficience of torch was obtained for the gas max flow used (20L/min) and max efficiency (60%) is obtained with current 80A and voltage 43V between electrodes. In the nozzle, exit position were plasma jet has area 1cm^2 power density 2.5MW/m^2 required for SARA (satellite of atmospheric re-entry) heat shield materials test.*

***Keywords**: arc-heated, re-entry, plasma torch, plasma jet, thermal protection system.*

1. Introduction

The aerothermodynamics flow generated during the ballistic reentry of an orbital vehicle is too much intense, thus, an efficient thermal protection system becomes essential to keep the pay load integrity. Since no similarity law is valid in the flow in total and flow-wall interaction in terms of thermal and chemical kinetics and response of the material contacting the flow, particularly for the application to estimating the aerodynamic heating, and to the thermal protection materials and systems of the vehicles which fly with hypersonic speed in the atmosphere, flight conditions in terms of the flow enthalpy, temperature of wall surface, impact pressure, and so on, are to be simulated by ground-based test facilities as close as possible to those of real flight.

Plasma Wind Tunnels (fig. 1) can partially reproduce certain atmospheric re-entry conditions. They are used for many applications, particularly for to estimating the aerodynamic heating, and to the thermal protection materials test. Among many existing high enthalpy flow test techniques, arc-heater is the unique solution for the evaluation of the material's durability for the thermal protection purposes, simply because of its continuous flow generation capability and higher enthalpy.

An arc-heater system is being constructed at ITA (fig. 2), with the purpose to produce an intense thermal flow, like those that are necessary in thermal protection materials test. In a first stage, it will only serve as the heat source, having the capacity to generate plasma jet with great enthalpy. And later, it will be improved to simulate the aerodynamic ballistic re-entry conditions.

2. Experimental apparatus

The experimental apparatus (fig. 2) is composed by: a stainless steel vacuum chamber (3m^3); vacuum system with two stage rotary pumps (160m^3/h) connected to a booster roots (500m^3/h); pressure sensors and gas lines (oxygen, nitrogen, argon, methane, hydrogen) with mass flow. Through a programmable controller connected to a butterfly valve it is possible to automatically adjust the pumping speed, keeping the constant pressure inside of the vacuum chamber, for small variations in the injected gas flow.

The arc-heater is constituted by two hollow copper electrodes (cathode and anode), inserted inside the stainless steel supports, cooled internally through the forced water circulation and electrically separated by an electric insulator (fig. 3). The gas injected in the plasma torch is ionized and heated by the arc between the electrodes, producing a plasma jet in the exit nozzle. The flow enthalpy depends on factors as the temperature, pressure and transferred electric power.

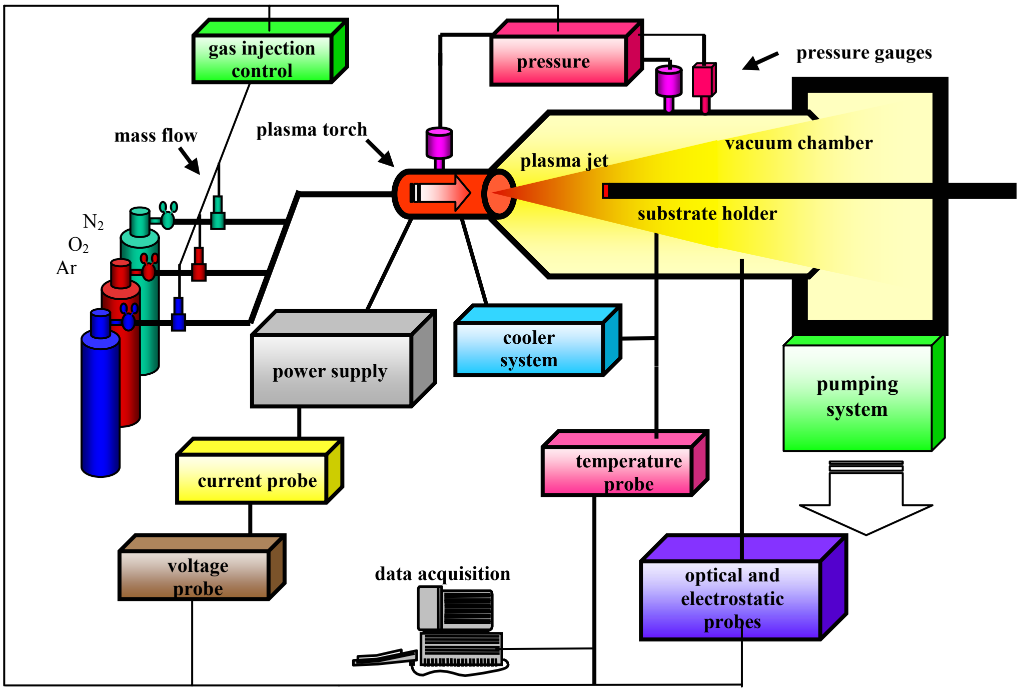

Figure 1 – Plasma wind tunnel diagram

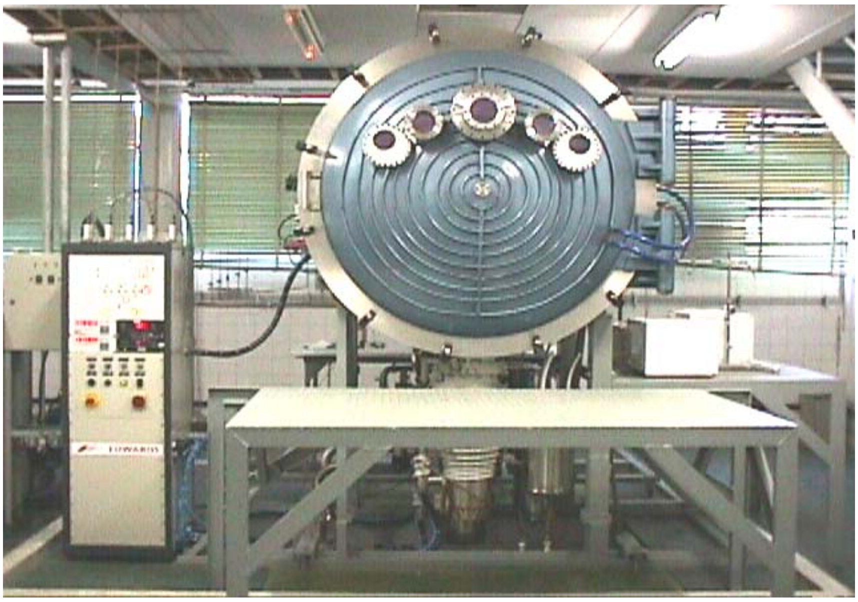

Figure 2 – ITA experimental apparatus

Figure 3 – Plasma torch

Figure 3 shows the new plasma torch build with a geometric configuration for the electrodes to improve the vortex generation, to try to minimize the premature consuming of the electrodes and copper vapor problems in first version.

The electric power source used in early experiments was capable to supply a tension of 120V, without load, and around 70V, with load, keeping voltaic arcs with current until 400A. Due to the low value of maximum tension that this source is capable to supply, it is only possible to carry through tests with argon. That is an easy gas of being ionized, with low electric breaking strength. To solve this problem its is being constructed a new power source, capable to supply tension higher (600V), that it will allow to the accomplishment of experiments injecting itself other gases in the plasma torch. The case of special interest is dry air or nitrogen and oxygen mixture similar to the atmosphere.

The main parameter gotten in the characterization of this plasma torch is the enthalpy of the plasma jet generated in the torch through the voltaic arc in the gas (fig. 4 and fig. 5). The measure of the enthalpy was gotten by stipulated in ASTM E 341-81 (standard practice for measuring plasma arc gas enthalpy by energy balance). The temperatures of water refrigeration in the input and output of the plasma torch had been monitored with thermocouples, and the temperature gain is multiplied by water flow to obtain the lost power. The arc electric current was measured through a hall-effect sensor, and multiplied by a voltage measured with a digital voltmeter, to obtain the input electric power. The difference between input electric power and refrigeration lost power give the transferred power. The characterization of the plasma torch is divided in two distinct situations: (1) with plasma jet being produced in atmospheric pressure (without vacuum). (2) With plasma jet being produced in the interior of the vacuum chamber, where the pressure is reduced to simulate definite altitude in relation to the level of the sea (fig. 6).

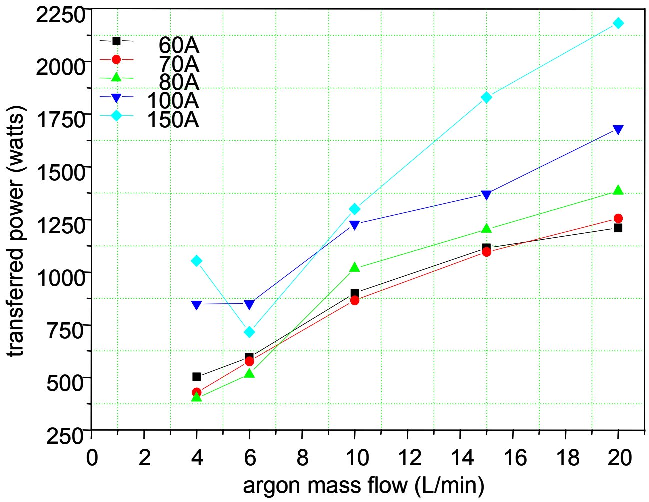

Figure 4 – Transferred power for plasma jet in function of the argon flow in atmospheric pressure

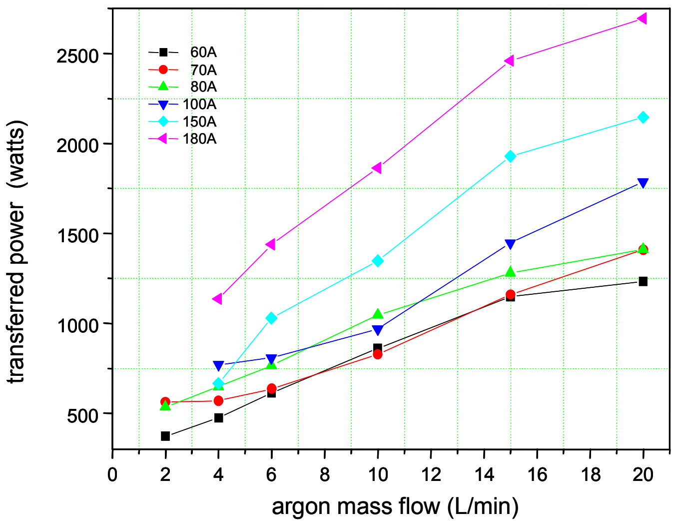

Figure 5 - Transferred power for plasma jet in function of the argon flow in vacuum

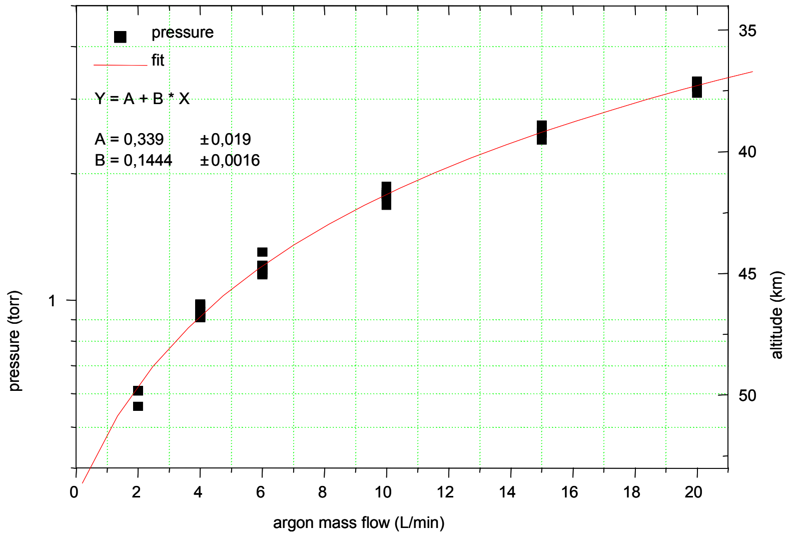

Figure 5 – Pressure in the vacuum chamber and equivalent altitude simulated in function of the argon flow

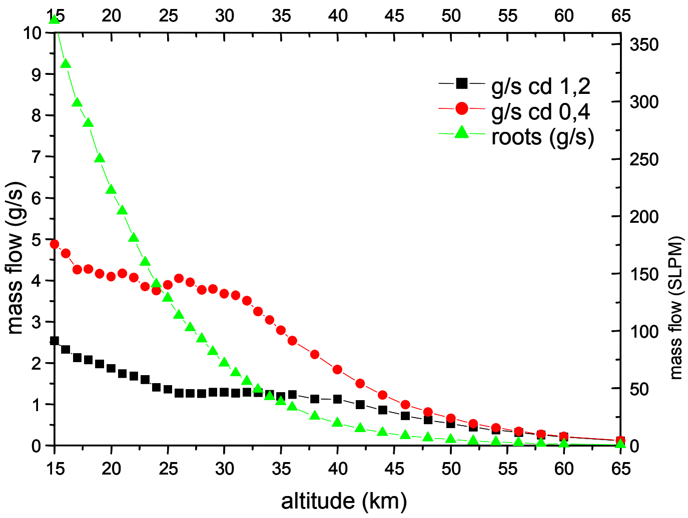

Figure 7 – Mass flow in vacuum system and for two ballistic reentry conditions

2.2 Results and Commentaries

Upon reentering the Earth's atmosphere, an orbital vehicle encounters gases at velocities of more than ten km/s, thereby being subjected to great heat loads. For the development of thermal protection systems for reentry bodies are needed to simulate in steady state conditions the required surface temperature on the material, pressure, specific enthalpy and mass flow rate. With plasma wind tunnels a continuous stream of plasma of high specific enthalpy and velocity is produced with the help of thermal plasma-dynamic generator. The accuracy of the simulation of reentry conditions strongly depends on the ability to determine the flow conditions.

The average specific enthalpy of the flow in exit plane of the plasma generator nozzle can be derived for all kinds of plasma wind tunnels by an energy balance. Therefore, the electric power consumed by the plasma source, the mass flow rate and the heat losses within the plasma generator are measured. The average specific enthalpy at the end of the plasma generator is then derived as the difference of the electrical power and the total heat loss related to the mass flow rate. This result is very important for an initial estimation of flow situation and even more so for assessment of the plasma source condition and reproducibility of a test series.

This study confirmed that in the function of the capacity of the vacuum system shown in figure 7 was possible to simulate the band of pressures of 0.6 torr up to 4 torr that corresponds to the pressures found in altitudes between 50km and 35km. The applied electric power in the torch was between 1.5kW and 7kW, the power transferred to the gas between 0.5kW and 2.6kW. It was observed that the income of the torch was bigger for the biggest used gas outflow (20L/min) and that the maximum income (60%) is gotten with a current of 80A and tension of 43V between the electrodes. In the position where the plasma jet area is 1 cm^2 is possible to get it density of power of $2.5MW/m^2$ required for some assays of materials of thermal protection of the SARA.

3. Acknowledgements

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