EVALUATION OF THE OPERATIONAL PERFORMANCE MAPS FOR THE IEAv's HYPERSONIC TUNNEL T2

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Abstract. *The purpose of this work, which has been done under the Space Brazilian Agency´s (AEB) UNIESPAÇO Program, is to show the results for a series of operational performance maps for the T2 hypersonic shock tunnel which is installed at the Instituto de Estudos Avançados-IEAv. These maps express the dependence between chosen free-stream parameters at the test-section and parameters associated with the tunnel initial conditions and are presently been used by the laboratory operating team as a tool for helping in the choice of the initial pressures and the throat and nozzle diameters to be used in the experiments. For an extensive range of initial driven pressures, the performance maps indicate that free-stream Mach numbers at the exit of the test section nozzles are approximately constant. Using dry air in the driver, Mach numbers of about 10 can be reached in the test section. With the utilization of helium as the driver gas, values in the vicinity of Mach 12 can be obtained and atmospheric conditions for altitudes as high as 50 km can be simulated.*

Keywords: *Hypersonic shock tunnel, Free-stream parameters, Operational performance map*

1. INTRODUCTION

The development of space vehicles is strongly dependent on the realization of a large variety of experiments that will allow the reproduction, as best as possible, of several conditions encountered during the space flight. Tests can be performed not only in ground laboratories but also by means of real flights, which are considerably more expensive and for this reason must be initiated after a thorough analysis of the ground test results. Only after an extensive testing, any decision regarding the vehicle's geometry modification or the definition of its thermal protection system, for instance, may be safe and reliably taken.

For the execution of ground tests, the devices that are more commonly used are the pulsed hypersonic shock tunnels, such as the ones in operation at the Instituto de Estudos Avançados-IEAv, in São José dos Campos, São Paulo. In order to answer the question as to what extent a hypersonic tunnel can be useful for specific experiments, it is necessary to evaluate its operational performance maps, that graphically display a group of selected free-stream parameters (e.g. pressure, enthalpy, Mach number, temperature etc.) evaluated at the exit of the nozzle, as a function of the initial shock tunnel conditions.

The purpose of this work is to show the results for a series of operational performance maps for the T2 hypersonic shock tunnel which is installed at the "Prof. Henry T. Nagamatsu" Aerothermodynamics and Hypersonics Laboratory, in IEAv. These maps are presently been used by the laboratory operating team as a tool for helping in the choice of the initial pressures and the throat and nozzle diameters to be used in the experiments.

2. HYPERSONIC SHOCK TUNNELS – A BRIEF DESCRIPTION OF THE HYPERSONIC TUNNEL T2

Hypersonic shock tunnels are devices capable of producing, at relatively low costs, flow conditions that are very similar to the ones encountered by spaceships, including the most adverse, which occur for example when they re-enter the atmosphere in the direction of the soil. Although these tunnels can reproduce those conditions only for very short time intervals, typically of the order of a few milliseconds, they still are very important tools for supporting space vehicle designs, especially in their first stages.

Very concisely, shock tunnels are constituted of a cylindrical or a rectangular tube, divided by a main diaphragm in two regions, one called *driver* and the other called *driven*, this one coupled to a convergent-divergent nozzle that ends inside a test section, which is followed by an exhaustion tank. The driver is the high pressure region and is usually filled with helium gas, although other gases may be used; the low pressure region, or the driven, contains the test gas, normally air, when simulating the Earth's atmosphere and is separated from the nozzle by a thin secondary diaphragm to avoid the inflow of the test gas into the dump tank before the test starts. To initiate the test, the main diaphragm is burst by any means, and a shock wave propagates into the test gas, compressing it to a higher pressure and temperature. When the shock wave reaches the end of the driven, it is reflected and the secondary diaphragm also bursts. The highly compressed and high temperature test gas then expands through the nozzle, converting its stagnation enthalpy to a high free-stream velocity in the test section, where the model to be studied is located.

The hypersonic tunnel T2 (Fig. 1) is one of the three tunnels in operation at the "Prof. Henry T. Nagamatsu" Aerothermodynamics and Hypersonics Laboratory, in IEAv. It consists of a high pressure 180 cm long driver cylindrical tube connected to a 640 cm low pressure driven, separated by a Double-Diaphragm Section (DDS), which is in general filled with argon and is used to have a more precise control of the main copper diaphragms rupture. At the end of the driven section, there is a secondary aluminum diaphragm that prevents the test gas to flow into the test section before the experiment actually begins. The test section has a cylindrical shape with 60 cm length and 40 cm internal diameter and is connected to a 2 m^3 exhaustion tank. The total length of the T2 hypersonic tunnel is about 12 meters. Although the tunnel has been designed to operate up to a maximum pressure of 23.0 MPa, for safety reasons the pressure in the driver has been set to 3000 psi (about 20 MPa) for all runs.

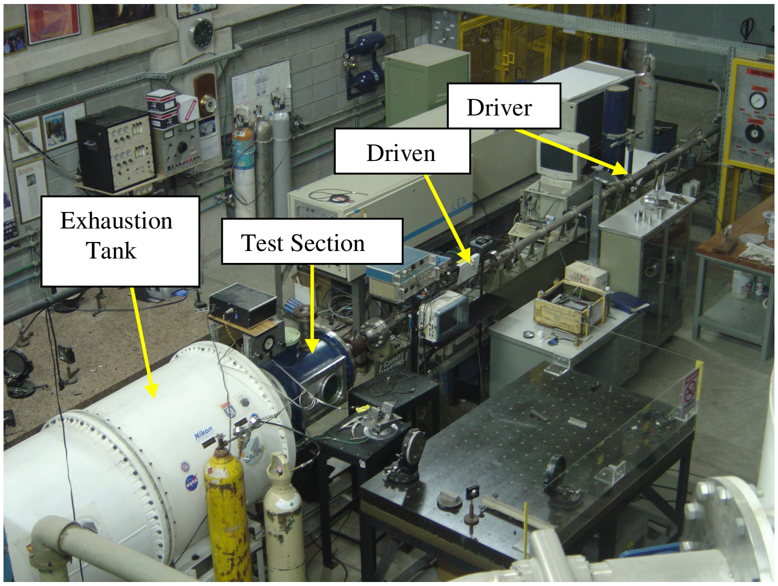

Figure 1. Panoramic view of the T2 hypersonic tunnel

3. METHODOLOGY FOR GENERATION OF T2 OPERATIONAL PERFORMANCE MAPS

As mentioned in previous work (Menezes et alli., 2009), a large number of runs has been executed, for different combinations of driver gases, driven pressures, nozzle throat diameters and nozzle exit diameters, in order to cover, as best as possible, the many situations in which the tunnel has been routinely operated. For every run, the gas pressure in the driver was maintained at about 20 MPa (3000 psi), for safety reasons. The utilization of two already existing conical nozzles, a 10 degree half-angle (200 mm exit diameter) and a 15 degree half-angle (300 mm exit diameter), each one with its corresponding interchangeable throats, would in principle enable us to cover a range from about Mach 7 to about Mach 14.

By measuring the pressure values at conveniently chosen locations in the shock tunnel T2 and using them along with known correlations (Srinivasan et al., 1987) implemented in the computer program STCALC (Rosa et al., 2009), for the determination of the free-stream parameters that at present cannot be directly measured in T2, the relationships between important free-stream parameters at those locations and parameters associated with the initial tunnel conditions. The operational performance maps are just the graphic displays of free-stream temperature, enthalpy, Mach number etc., as a function of any chosen initial parameter; in the present work, all results are expressed in terms of the initial T2 driven pressure.

4. THE EXPERIMENTAL SETUP

The experimental setup has also been previously described (Menezes et alli., 2009) and was constituted by: a) two pressure transducers (Kistler, model 701 A) located in the driven section and positioned 50 cm from one another, for the determination of the velocity of the incident shock wave; b) one transducer (Kistler. Model 701 A), located at the very end of the driven section, for the measurement of the stagnation pressure and; c) thirteen transducers (PCB Piezotronics, model 112A22) adequately fixed in a cruciform support ("rake") positioned at the nozzle exit, with the objective of producing information on the radial pressure profiles at that location. After amplification, the signals from the transducers were collected by a Yokogawa Model DL 750 acquisition system.

5. RESULTS FOR THE TUNNEL T2 PERFORMANCE MAPS

As mentioned before, a large number of T2 runs has been made, for both the 200 mm and the 300 mm nozzles and either helium or dry air as the driver gas. All results presented in this work were generated using dry air in the driven region under four different pressures: 288.0, 96.0, 26.7 and 6.7 kPa, which correspond respectively to 3.0, 1.0, 0.3 and about 0.07 atm, as measured in the "Prof. Henry T. Nagamatsu" Aerothermodynamics and Hypersonics Laboratory. Three different throat diameters were used for each one of the nozzles: for the 200 mm diameter nozzle, throat diameters equal to 10.0, 15.0 and 19.0 mm were considered; with the 300 mm diameter nozzle, all the runs have been made with the 20.2, 12.6 and 6.4 mm diameter nozzle throats. Based on simple calculations and assuming perfect gas conditions, these combinations would produce Mach numbers ranging from about Mach 7 to around Mach 14.

Figures 2, 3 and 4 display the free-stream pressure, temperature and Mach number, respectively, evaluated at the nozzle's exit, as a function of the initial driven pressure, considering dry air in the driver region. For the 300 mm diameter nozzle, the 6.4 mm diameter throat was not used because the expected value for the free-stream pressures were of the same order of magnitude of the initial pressure in the test section, which could eventually mask the pressure detector readings.

Figure 2 shows that with dry air in the driver and the 200 mm diameter nozzle, the smallest free-stream pressure values (around 200 Pa) are reached for initial driven pressures which are very low and for small throat diameters. Increasing the nozzle diameter from 200 to 300 mm, free-stream pressure as low as 60 Pa can be obtained, which corresponds to an altitude in the vicinity of 50 km (NASA, 1976).

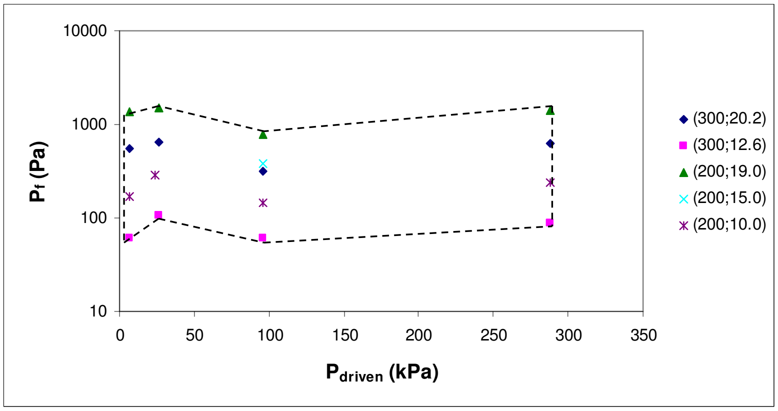

Figure 2. Free-stream pressures as a function of the shock tunnel T2 driven pressures (dry air in driver)

Free-stream temperatures as low as 50 K can be achieved in the test section of the IEAv's T2 hypersonic tunnel if one uses helium in the driver, a small diameter throat and the 300 mm diameter nozzle, as it can be seen in Fig. 3.

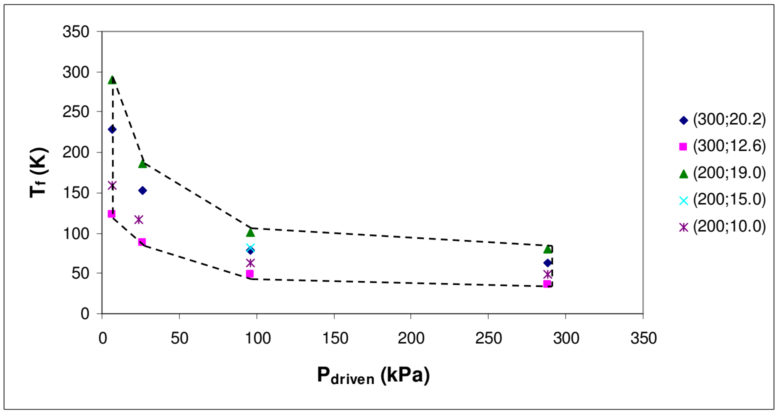

Figure 3. Free-stream temperatures as a function of the shock tunnel T2 driven pressures (dry air in driver)

Figure 4 indicates that for an extensive range of P_{driven} values, the free-stream Mach numbers are approximately constant and depends essentially on the ratio between the nozzle and throat diameters. It can be observed that with dry air in driver, Mach numbers around 10 can be reached, with the 300 mm diameter nozzle and the 12.6 mm throat.

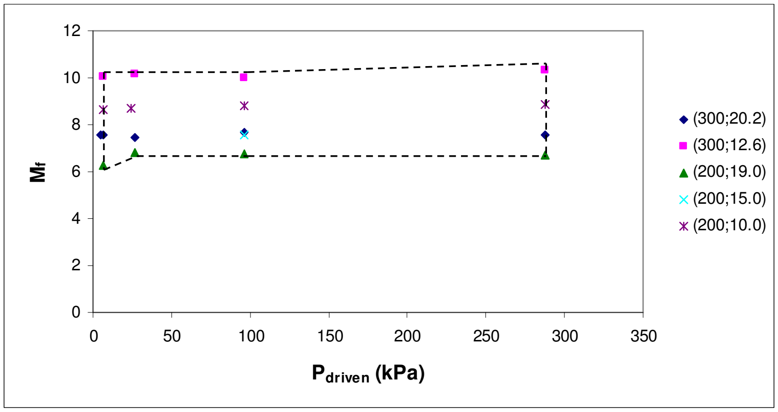

Figure 4. Free-stream Mach numbers as a function of the shock tunnel T2 driven pressures (dry air in driver)

If we now consider helium as the driver gas, it can be seen from Fig. 5 that free-stream pressures as low as about 45 Pa are reached in the test section, with the 300 mm diameter nozzle and the 6.4 mm diameter throat. This pressure corresponds to altitudes of about 55 km (NASA, 1976).

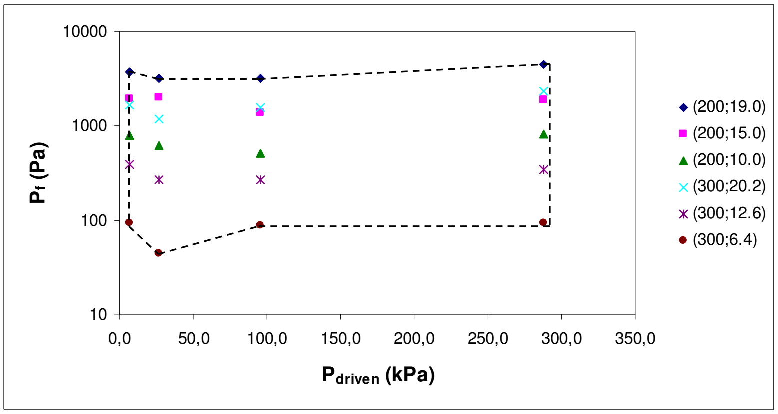

Figure 5. Free-stream pressures as a function of the shock tunnel T2 driven pressures (helium in driver)

With helium in the driver region, temperatures lower than 100 K can be obtained in the test section only with the 300 mm diameter nozzle, the smaller throat (6.4 mm) and for higher values for the initial driven pressure, as it can be seen in Fig. 6.

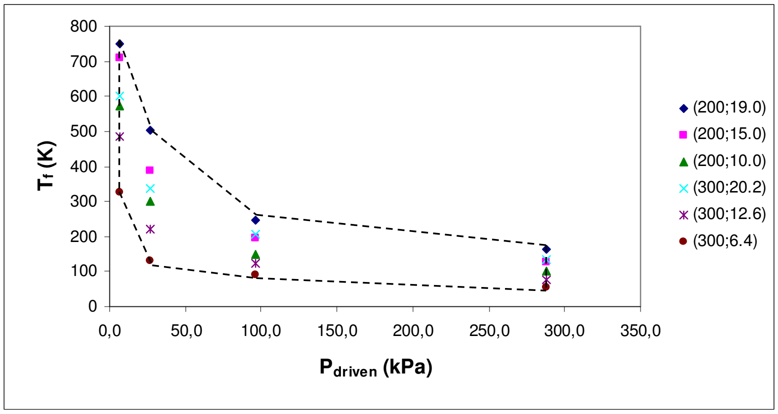

Figure 6. Free-stream temperatures as a function of the shock tunnel T2 driven pressures (helium in driver)

With respect to the free-stream Mach numbers as function of P_{driven} (Fig 7) it can be observed that there is no significant differences, for the 200 mm nozzle, as we go from dry air to helium in the driver. However, with the 300 mm diameter nozzle, Mach number slightly above 12 can be reached.

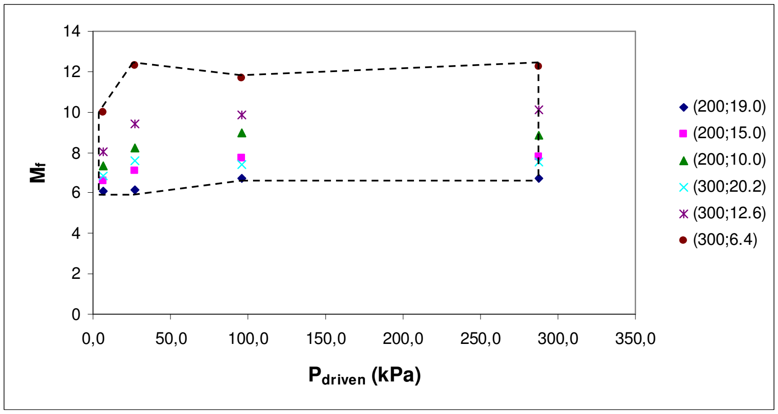

Figure 7. Free-stream Mach numbers as a function of the shock tunnel T2 driven pressures (helium in driver)

6. FINAL REMARKS

As a general rule, it is not possible to simultaneously simulate all the free-stream parameters for a given point of a space vehicle trajectory in only one run of the hypersonic tunnel. Besides the structural restrictions of the driven, which impose a limitation in temperature raise, for example, it must be considered that a given initial tunnel setup (driven initial pressure, throat diameter etc.) that is adequate for the simulation of a given set of parameter values may be inadequate for others. For this reason, different combinations of initial driven pressures and throat and nozzle diameters must be selected for a reliable reproduction of relevant free-stream parameters such as Mach number, temperatures, enthalpies, Reynolds numbers, among others.

In this work, only the operational performance maps (or “envelops”) for free-stream pressures, temperatures and Mach numbers are shown, as a function of the initial driven pressures, for the T2 hypersonic tunnel installed at the Instituto de Estudos Avançados. The whole set of maps developed in the project supported by the UNIESPAÇO Program, which also includes free-stream densities and velocities, are presently being used by the laboratory operating team as a tool for helping in the choice of the initial driven pressures and the throat and nozzle diameters to be used in the experiments with the tunnel.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

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