STUDY OF THE UNIFORMITY OF THE MACH-NUMBER OVER A HORIZONTAL PLANE INSIDE THE TEST SECTION OF THE PILOT TRANSONIC WINDTUNNEL

André Fernando de Castro da Silva, andre.fernando.t10@gmail.com
Comando-Geral de Tecnologia Aeroespacial (CTA)
Instituto Tecnológico de Aeronáutica (ITA)
Praça. Marechal Eduardo Gomes, 50
CEP: 12228-900 , São José dos Campos, São Paulo

Rodrigo de Oliveira Braz, ro-braz@uol.com.br
Universidade de Taubaté (UNITAU)
Rua Daniel Danelli, s/n, Jardim Morumbi
CEP: 12060-440, Taubaté, São Paulo

Ana Cristina Avelar, anacristina@iae.cta.br
João Batista Pessoa Falcão Filho, jb.falcao@ig.com.br
Comando-Geral de Tecnologia Aeroespacial (CTA)
Instituto de Aeronáutica e Espaço (IAE), Divisão de Aerodinâmica (ALA)
Praça. Marechal Eduardo Gomes, 50
CEP: 12228-904 , São José dos Campos, São Paulo

Abstract: *The Pilot Transonic Tunnel (PTT) is located at the Aeronautics and Space Institute (IAE), one of the institutes that embody the Aerospace Technology General-Command in São José dos Campos - Brazil, is a reduced-scale version of an industrial transonic wind tunnel project. It is a closed loop tunnel with a 0.25 x 0.30 x 0.81 m slotted test section, powered by an axial compressor and an injection system that enable the tunnel to reach Mach-number from 0.2 to 1.3 in a continuous operation. An important task in the calibration routine of a transonic wind tunnel is to ensure that the Mach number is relatively constant in the test section for as much as the test endures. This kind of assurance gives a greater reliability to the results obtained in subsequent tests in the same tunnel. In this sense, measurements of the Mach-number distributions over a horizontal plane inside the test section were made to estimate the variation of this quantity over the test section during an experiment. The chosen form to make this estimation is to plot the surface of the Mach-number versus the position of the measurement, following with the calculation of the standard deviation. In the performed experiments the tunnel circuit was operated only by induction with the injection system. The stagnation pressure in the injection nozzles were adjusted to 4 and 6 bar. This configuration only reached Mach-number of 0.3 and 0.4, respectively. So the operation occurred in an intermittent way with average time of 80 seconds during the test. Mach number was calculated by the measurement of the total and static pressure in different points of the horizontal plane with a Pitot probe. Since the test section is involved by a plenum chamber, a remote-positioning system had to be developed to make several measurements in a single trial possible. This system is basically constituted of two platforms that move in perpendicular directions powered by two step motors. Over this assembly was set the Pitot probe holder. The positioning system was controlled by a routine created in the software LabView©, that allows the user to set the length travelled and the velocity of the Pitot probe during the experiment. The data acquisition system was formed by a 16-channel PSI module controlled by a LabView© software. Among the others measurements made there are the static pressure at the wall of the test section and the pressure of the plenum chamber. With the data acquired it was possible to determine the Mach-number standard deviation as a parameter of the global uniformity of this quantity over the plane. The surface distribution of the Mach number, however, gives a local approach of the uniformity criteria since it shows the points where there are the bigger variations. This kind of information is very relevant because allows studies about the optimization of the geometry of the test section longitudinal slots, for example.*

Keywords: *Transonic Wind Tunnel; Flow Uniformity; Experimental Results; Calibration.*

1. INTRODUCTION

An important task in the calibration routine of a transonic wind tunnel is to ensure that the Mach number is relatively constant in the test section for as much as the test endures. This kind of assurance gives a greater reliability to the results obtained in subsequent tests in the same tunnel. The main objective is to know how uniform the airflow inside the test section is for the various operation schemes previously defined and, then, it becomes possible the estimation of the influence of the parameters fluctuation on the results acquired in any other tests that would be made in the same tunnel. This kind of information is very important since it allows a reliability analysis of the conclusions made on the results to be obtained. The region of the tunnel in which there is an interest to proceed such a process is the called nominal test section, which corresponds to the region in which it is possible to place the model to be tested.

Results of experiments with this objective for many transonic tunnels spread around the world are accessible in the literature. Centre-line Mach number distribution testing with utilization of a centre line static pressure probe was addressed in the works of Brooks *et al*. (1994), Haines and Jones (1958), and Muylaert (1988). The evaluation of Mach number at the test section walls was dealt by Van Ditshuizen (1995) and by Quest (1994). It can be noticed from these works that different approaches may be used to make this kind of calibration study.

As the major part of the models used in the experiments carried out in a wind tunnel involves, at least, bidimensional flow, it is interesting to make a study to verify the flow parameters uniformity over a bidimensional surface inside the nominal test section. Beside this, since it had already been carried out experiments to get the centre-line Mach number distribution in the test section and in the throat section (Zanin *et al.*, 2008, Escosteguy, 1998), it was chosen to perform the mapping of a horizontal plane inside the test section, verifying the maximum variation of the Mach number through the plotting of the surface distribution of the Mach number (giving the local approach of the uniformity criteria) as well as the standard deviation as a parameter of the global uniformity of this quantity over the plane. Identifying the position of the major non-uniformities, one can conduct an optimization study on the tunnel geometry or the operation control (control system, valves control, etc) that leads to a more reliable wind tunnel. In the present paper, the experiments that were carried out will be described, and the results obtained for Mach-number values of 0.3 and 0.4 will be presented. A calibration study for the whole operation range, 0.2 to 1.3, will be addressed in future works.

2. TUNNEL DESCRIPTION

The Pilot Transonic Tunnel (PTT) is a reduced-scale version (1:8) of an industrial transonic wind tunnel project, conceived as a way to validate the engineering solutions designed to the later as an answer to the efforts made to provide the country with a high-quality transonic wind tunnel able to accomplish the research demands and small-scale industrial projects. Even with a reduced-size test section, the PTT has been used to perform high-speed experiments in simplified geometries as a basic research tool.

The main characteristics of the PTT are transcribed in Table 1 and more details may be found in Falcão Filho and Mello (2002).

Table 1. Main Characteristics of the PTT.

Test Section Dimensions	0.25 x 0.30 x 0.81 m
Mach Number Range	0.2 to 1.3
Circuit Pressurization	0.5 to 1.2 bar

- Closed loop circuit;
- Continuous operation powered by a two-stage axial compressor of 830 kW;
- Intermittent operation powered by an injection system for 30 seconds (at least);
- Slotted test section up to 11% of open area and plenum chamber evacuation system;
- Automatic controls of speed, pressure, temperature and humidity related to test section;
- Possibility to perform static forces and moments tests, pressure distributions and visualization by schlieren;
- Control e data acquisition by LabView© platform.

Figure 1 shows the installation scheme of PTT operating with the injection system. The closed circuit is characterized by its four corners and the tunnel´s main components are nominated, as it is normally found in wind tunnel literature (Pope and Goin, 1978). In normal continuous operation, the main compressor establishes the flow in the circuit as showed by the arrows at the figure. In this operation mode, the circuit is practically isolated from the outer atmosphere in order to guarantee the pressure control, which is performed by the pressure control auxiliary compressor.

The injection system was conceived to operate in a combined action with the main compressor, extending the operational envelope of the tunnel for the same installed power. While the main compressor is running in a stable condition, the injection control valve (V_{inj}) automatically acts in order to obtain the desirable stagnation pressure at the injection nozzles. The pressure in the circuit is controlled by means of the blow-off valve (V_{bo}) in an automatic way and the air mass flow is spontaneously expelled to atmosphere. The injection nozzles have supersonic geometry and operate with stagnation pressure varying from 4 bar to 12 bar. The system uses the compressed air available in two reservoirs (see Fig. 1), whose maximum pressure is 40 bar. Since the mass stored in the reservoirs is limited, the operation occurred in an intermittent way and the average runtime was about 80 seconds. More details about the injection system operation can be found in Goffert *et al.* (2008).

At the time of the mapping tests, the axial compressor had been damaged so that only the injection system was used to power the tunnel. Remember that the use of injection as a mean to provide energy to the flow is well known. The principle of operation of this kind of system is the introduction of mass in a high enthalpy of stagnation after the end of the test section, thus inducing the flow on the test section. In this particular mode of operation only with the injection system, the blow-off valve was kept completely open, without pressure control. The mass flow introduced to the circuit through the injection control valve causes a small increase in internal pressure and it escapes spontaneously to the atmosphere through the blow-off valve.

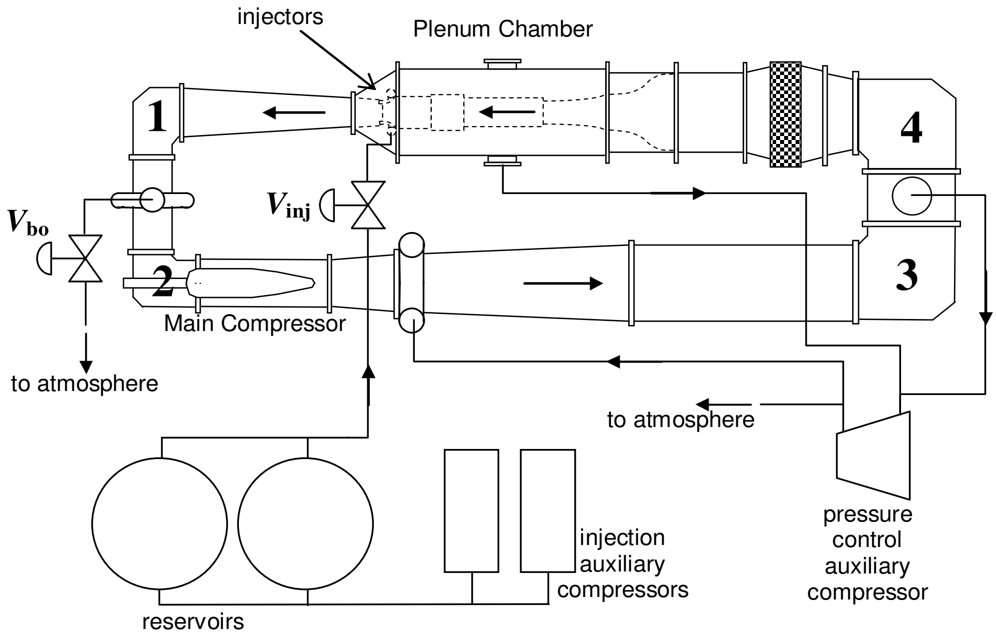

Figure 1. Scheme of PTT operating with the injection system.

The test section is slotted all over its extension to enable the mass extraction (this phenomenon is of fundamental importance to ensure the operation continuity along the transonic zone). The mass extracted may be readmitted to the tunnel circuit by the reentry flaps, which kind is known as finger flaps. Figure 2 shows the plenum chamber open with the test section with longitudinal slots, the reentry flaps and the end of it. In some intervals of the tunnel operation the pressure control auxiliary compressor (see Fig. 1) may be used to increase the mass extraction from the test section by the mass extraction of the plenum chamber.

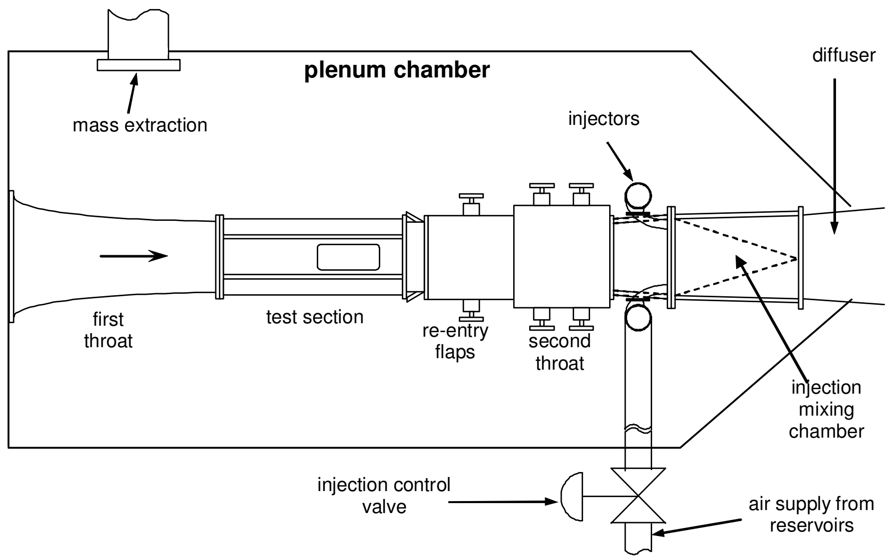

Figure 2. Plenum chamber of PTT showing its inner parts.

In the performed experiments, no mass extraction was made off the plenum chamber by the auxiliary compressor and the reentry flap was set at zero angle of incidence, what, because of its geometry, still guarantee some efficiency in the readmission of mass extracted by the wall slots.

3. EXPERIMENTAL APARATUS AND METHODOLOGY

To ensure that the results of this study will be valid in a range of operational envelope as larger as possible, the Mach number mapping was made for different values of stagnation pressure at the injection nozzles. Since the operation had to be made in an intermittent way and the test duration was fixed in about 80 seconds, as the stagnation pressure at the nozzle used in the trial increases, a higher pressure in the reservoirs have to be used to maintain the pressure required during all the test extension.

The measurement of the air speed and, consequently, of the Mach number, was made using a Pitot probe with an ellipsoidal head introduced into the test section through the lateral wall slots. So, for each stagnation pressure in the injection nozzle, it was used a measurement mesh consisting of five stations along the longitudinal direction of test section. In the other direction (transversal), it was assumed the symmetry hypothesis with respect to central-vertical plane since the length of the Pitot probe was not long enough to reach the opposite wall of the test section.

3.1 Remote-positioning system

The handling of the Pitot probe during the mapping of the test section is, at first, a critical problem because the tunnel operation is made with the test section confined inside the plenum chamber, so it is necessary the user to be able to remote-position the Pitot probe to make several measurements in a single trial possible.

With this purpose it was idealized a XY table (constituted of two platforms that move in perpendicular directions) coupled to the plenum chamber structure. The assembly was powered up by two step motors and over it was set the probe holder. Figure 3 shows the remote-positioning system installed inside the plenum chamber.

The positioning system was controlled by a routine created in the software LabView©, that allows the user to set the length travelled and the velocity of the Pitot probe during the experiments. In the performed experiments, the advance speed was set in 0.005 m/s. The travel length was controlled by the number of steps performed by the motors. A simple calibration process indicated that 4195 steps were equivalent to 0.01 m.

In this way, the surface mapped has a length of 170 mm (in the transversal direction of the tunnel) by 214.5 mm of width.

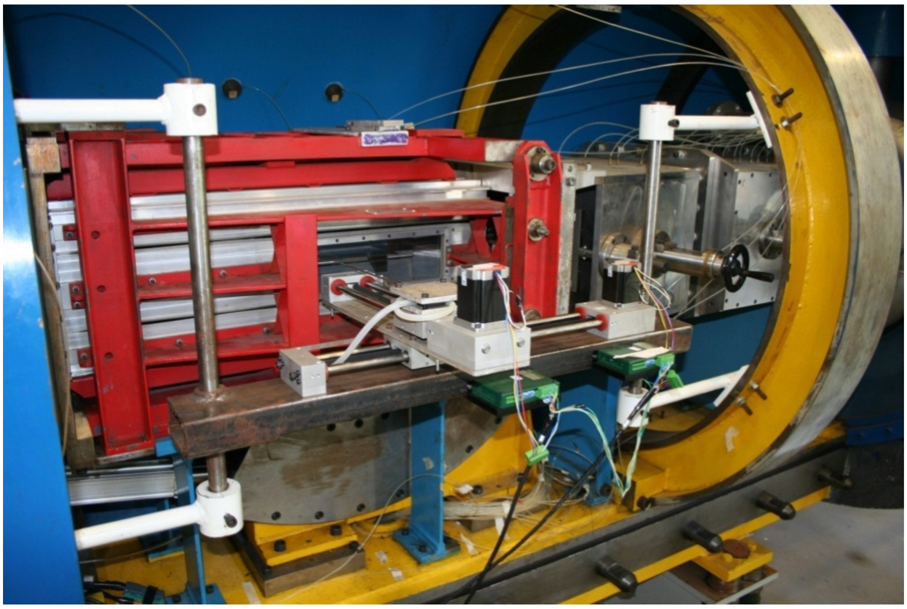

Figure 3. Remote-positioning system installed inside the plenum chamber.

3.2 Data Acquisition System and Pressure Measurements

The data acquisition system was formed by a 16-channel PSI pressure module controlled by a LabView© software, continuously scanning the channels and performing the data collection. Since the pressure values acquired correspond to manometric pressures, the value of the atmospheric absolute pressure (measured with a special equipment of reference pressure, able to make absolute measurements with great precision) had to be added to them. In addition to the total pressure and the static pressure measurements of the airflow made with the Pitot probe, among the others measurements made, there are static pressure measurements at the test section walls and the pressure of the plenum chamber. In order to facilitate the posterior data reduction, the machine time of the computer at each measurement was also taken.

In order to verify the accuracy of measurements made with the PSI module, initial tests were performed using known pressures. These tests revealed good results (good accuracy with low oscillations).

Since the only total pressure measurement point was at the Pitot probe and this value is critical to the Mach number calculation, it was used a second, and redundant, channel to obtain this data in order to take an average value later.

3.3 Control System

The appropriated operation of PTT, including its extensive network of valves, requires the implementation of various control loops aimed at monitoring the conditions of interest in various parts constituting the circuit of the tunnel and establish the desired conditions in the test section. This will control all the valves used in the tunnel to establish the desired pressure in the injection nozzles and set the desired flow.

Quantities as the stagnation pressure, stagnation temperature and humidity are obtained by sensors in the stagnation chamber. Other values such as reservoirs pressure, temperature of oil in compressors, among others are also obtained to ensure the safety of tunnel operation. The control system stores these data, which can be analyzed a posteriori.

3.4 Influence of Advance Speed in the Accuracy of the Pitot Probe

The use of a Pitot probe aims to acquire the total and static pressure of the airflow in which it is inserted in order to obtain the airspeed. It is also known that its correct use must be aligned with the upstream main flow direction.

However, according to Ower and Pankhurst (1977), for a Pitot probe of ellipsoidal head, the errors made in the pressure does not exceed 0.5% for misalignment angles of up to 20°. Thus, since the speeds measured in the test section is greater than Mach 0.3, corresponding to speeds exceeding 100 m/s, the advance speed can be viewed as a misalignment of the resulting relative velocity of flow in relation to the Pitot probe. For the operation conditions observed, this variation angle has a maximum of 0.002°. So, it is clearly justified the fact that the influence of speed on accuracy of the Pitot probe is considered negligible.

3.5 Trials Methodology

It was realized five trials for each value of stagnation pressure on the injection nozzles corresponding to five stations on the longitudinal direction into the known nominal test section, totaling about 214.5 cm. In each experiment, the Pitot probe travelled from 15 cm inside to 2 cm outside the test section and then returned to the original position. The stagnation pressures at the nozzles were set in 4 bar and 6 bar.

4. DATA REDUCTION

Since the experiments were made taking the measurements while the Pitot probe traveled in and out the test section, there were two sets of data acquired for each trial. Figure 4 is one example of the Mach number evolution during a single trial for a stagnation pressure at the injection nozzle of 4 bar.

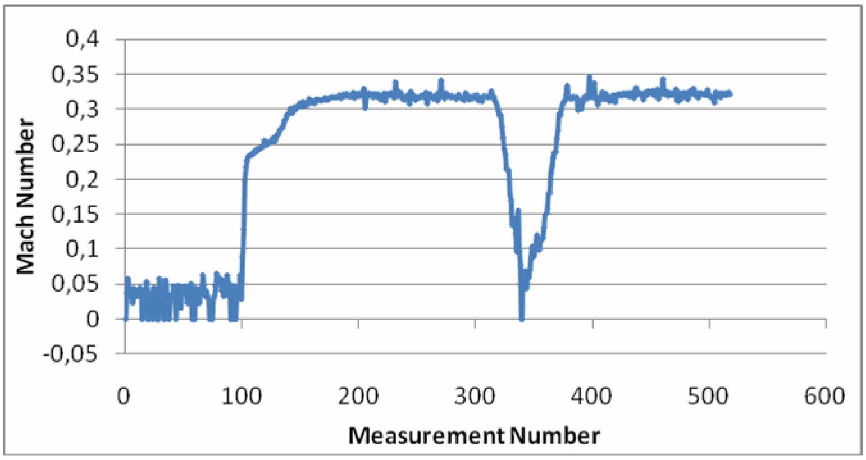

Figure 4. Results obtained for a single trial before the data reduction (injectors pressure: 4 bar).

In order to isolate the appropriate data it is necessary to look to the fact that the probe takes 34 seconds to complete his route from the test section center-line to outside of the test section and then 34 seconds to return to its original position. The machine time previously stored, then, was used to truncate the acquisition sequence in two sets of 34 seconds whose decreasing part, corresponding to the track outside the test section, overlapped one over the other (Fig. 5). The point of minimum showed in Fig. 4 and 5, corresponds to the farthest point of the Pitot probe trajectory from the test section.

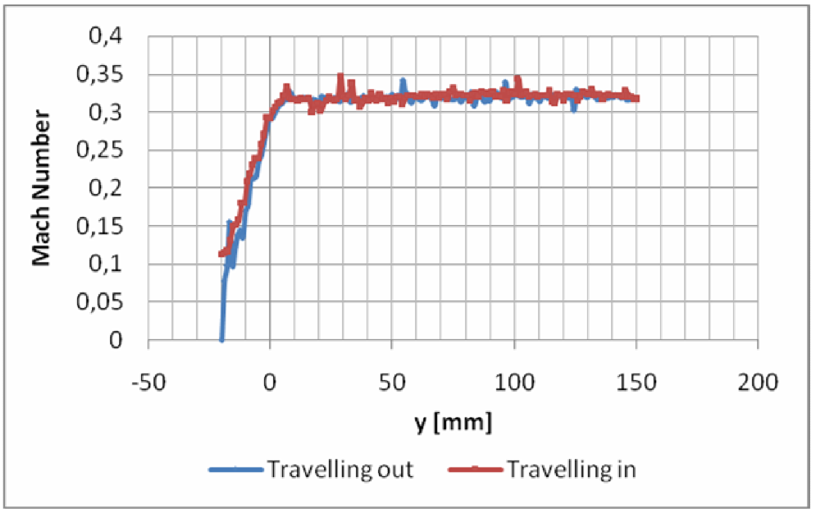

Figure 5. Data reduction in order to adjust the data acquired to the corresponding position.

The local Mach number was calculated using the isentropic relation (Anderson, 2001),

$$M = \sqrt{\frac{2}{\gamma-1}\left[\left(\frac{p_0}{p}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]}, \qquad (1)$$

where γ is the specific heats ratio for the air (assumed to be 1.4), p_0 is total pressure of the airflow measured by the Pitot probe and p is static pressure of the airflow measured by the Pitot probe.

The value of total pressure was taken as been the average of the two measurements taken from the redundant channels. To each data set was assigned coordinates equally spaced along the transversal axis corresponding to a total length of 170 mm. Since the distances between the longitudinal stations are known, it is possible to define $M = M(x, y)$ and list ordinate triplets $(x, y, M(x, y))$.

With this data, both the surface distribution as the dispersion parameters can be obtained with the appropriate software (in this case, it was used the graphic toolbox of Wolfram Mathematica© and the statistical function of Microsoft Excel©). Since the data obtained represent a discrete distribution, to perform the surface distribution it was necessary to execute a surface interpolation. For that, it was chosen to use a third degree interpolation.

5. RESULTS

After the data reduction, it was plotted the surface distribution of the Mach number inside the test section. As previously said, this kind of representation permits a visual perception of the phenomenon, emphasizing both qualitative and quantitative aspects of the problem.

So, for the stagnation pressure at the nozzles of 4 bar, the surface distribution of the Mach number inside the test section is showed in Fig. 6 (the x axis correspond to the longitudinal direction and the y direction, to the transversal direction).

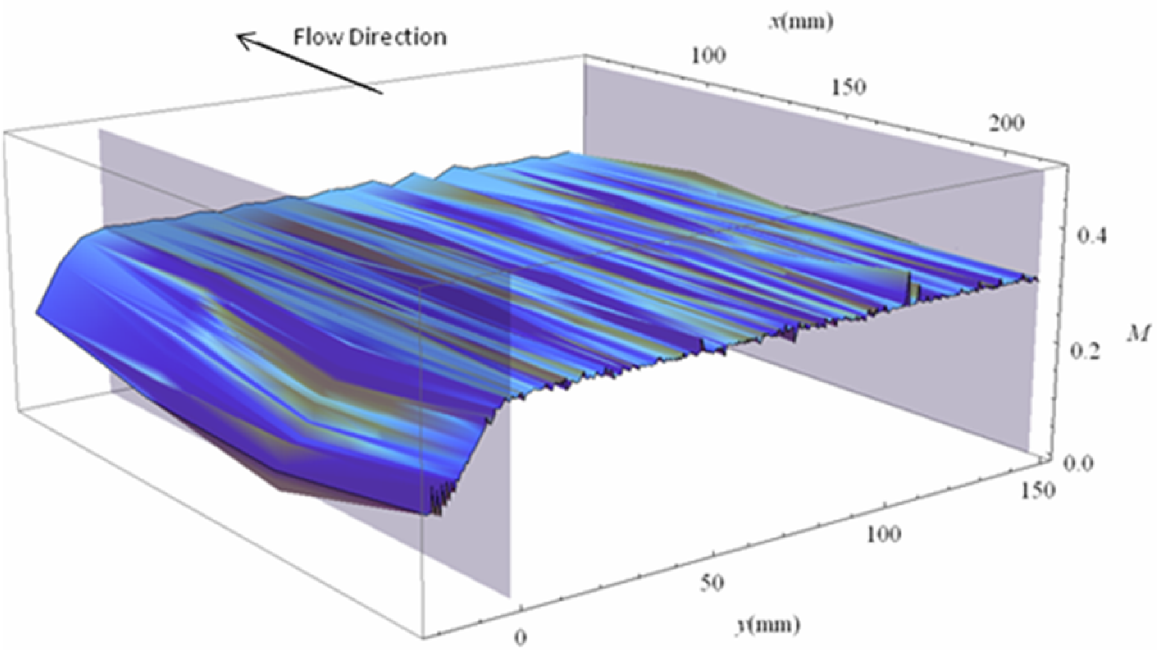

Figure 6. Surface distribution of Mach number for a stagnation pressure of 4 bar.

Note that the shadowed planes corresponding to $y = 0$ and $y = 150$ mm refer, respectively, to the test section wall and the vertical central plane of symmetry. In a similar way, for the stagnation pressure at the nozzles of 6 bar, the surface distribution of the Mach number inside the test section is showed in Fig. 7.

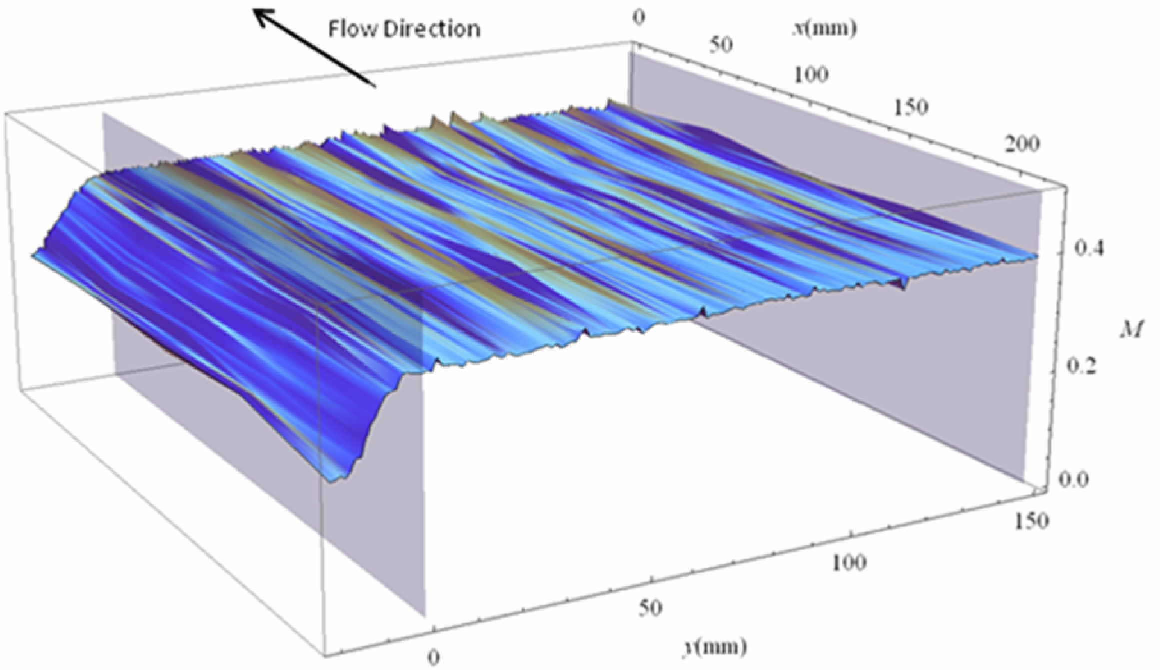

Figure 7. Surface distribution of Mach number for a stagnation pressure of 6 bar.

Quantitative aspects of the global uniformity criteria may be obtained from the statistical analysis of the data gathered. Thus, considering the dispersion parameters presented in the Table 2 (here it was only taken the points inside the test section).

Table 2. Global uniformity criteria over a horizontal plane for different values of stagnation pressure.

Stagnation Pressure at injectors [bar]	Mach-number Average	Mach-number Average Deviation	Mach-number Standard Deviation	Mach-number Standard Deviation 95%
4	0,3182	0,0042	0,0062	0,012
6	0,3856	0,0053	0,0067	0,013

These parameters are very important since they provide a way to compare the airflow quality and the trial performance of different tunnels.

As a manner to look for factors that lead to these performance parameters of the tunnel, it was analyzed the variation of the stagnation pressure at injection nozzles along the trial time. This data is acquired and stored by the control system is showed in Fig. 8 for one of the experiments with commanded stagnation pressure of 6 bar.

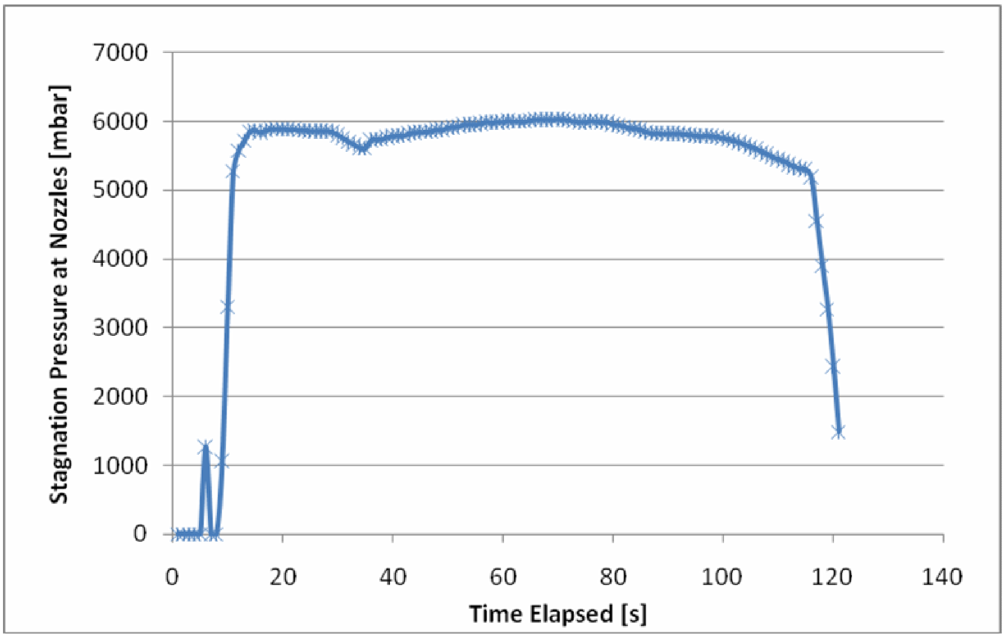

Figure 8. Evolution of the stagnation pressure at injection nozzles.

Considering the stagnation pressure values after a short period of stabilization and discarding the end when the injection valve had already been closed, the average stagnation pressure is 5.84 bar with a standard deviation of 0.298 bar, a value that can explain the deviation found in Table 2.

The mass flow at the injection nozzles may be expressed by (Shapiro, 1953)

$$\dot{m} = \frac{p_0 A M}{\left(1 + \frac{\gamma - 1}{2} M^2\right)^{\frac{\gamma+1}{2(\gamma-1)}}} \sqrt{\frac{\gamma}{R\,T_0}}, \qquad (2)$$

where all the parameters refers to the injection nozzles airflow conditions, been M the respective Mach number, A, the cross section area, R, the gas constant with respect to the air and T_0, the stagnation temperature of the reservoirs.

The test section Mach number strongly depends on the injectors' mass flow, which is responsible by the airflow induction. It can be pointed that the mass flow varies in a linear way with the stagnation pressure in the injection nozzles, as showed by Eq. 2.

From Silva and Falcão Filho (2007), it can be noted that the relation between the mass flow in the injection nozzles and the test section Mach number for the stagnation pressure range studied can be considered linear with reasonable precision, as it can be noted in Fig. 9.

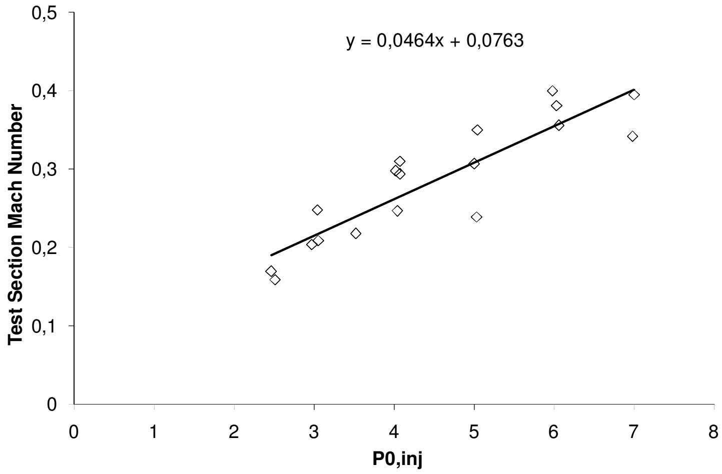

Figure 9. Variation of the test section Mach number with the stagnation pressure at the injection nozzles.

Thus, the Mach number variation due to the stagnation pressure oscillation can be estimated from the experimental data acquired using the hypothesis of the linear relation by

$$\Delta M = \left(\frac{\Delta M}{\Delta p_0}\right)_{\exp} \Delta p_0 . \tag{3}$$

So, the estimated test section Mach number variation due to stagnation pressure oscillation is 0.01. This fact corroborates to the idea that the stagnation pressure oscillation is one of the major sources of Mach number variation inside de test section during the experiments.

6. ANALISYS

The surface comparison promptly reveals that the Mach-number distribution is more uniform for the stagnation pressure of 4 bar. It seems to suggest that the higher the stagnation pressure the least the Mach-number uniformity. Note that the local Mach-number seems to randomly oscillate around the average and does not indicate the existence of possible geometric imperfections of the test section.

Comparing the dispersion parameters with the performance results achieved in others transonic tunnels described in the literature (Quest, 1994, Brooks *et al.*, 1994, Haines and Jones, 1958, Muylaert, 1988), which provide a ΔM in the order of 0.002 for subsonic trials, it seems that the results reached in PTT are unsatisfactory. But, the major of the flow uniformity studies to what they refer considers only the flow uniformity along the test section centerline, what, certainly, is a weaker criteria. An analysis on the uniformity of the Mach number over a 2-dimensional surface is much more susceptible to random oscillations and wall effects. It should also be pointed out that the results obtained are conservative, since they are still subjected to the measurements errors.

As showed in Fig. 8, the stagnation pressure at the injection nozzles is not strictly constant but it has a reasonably variation along the experiment duration, what leads to a small variation of the injection Mach number that may be translated as more expressive variation of the mass flow by the injectors and, consequently, of the induced mass flow in the test section. This is due to the fact of the Mach number measurements is not made at same time in every point, but sequentially. Thus, the temporal variation in the stagnation pressure at the injection nozzles leads to a space variation due to the methodology applied in the experiments.

Another critical point is the fact of the tunnel had been operating intermittently only with the injection system, in such a way that the data was acquired in ten different experiments. Thus, the dispersion parameters obtained reveals not only the airflow uniformity over the same trial, but also the test section conditions repetitiveness.

7. CONCLUSIONS

A calibration study to map the Mach variation in a horizontal plane inside the test section was conducted at the PTT and the preliminary results obtained for Mach-number values of 0.3 and 0.4 was presented, and the following observations can be pointed out:

The Mach number surface distribution is more uniform for the stagnation pressure of 4 bar. It seems to suggest that the higher the stagnation pressure the least the Mach-number uniformity. The shape of the surface distribution for both stagnation pressures at the injectors tested seems to indicate that there are no test section geometric imperfections. However, the global uniformity parameters such as the Mach number standard deviation provided values in the order of 0.012, which is above those that has been published for others transonic tunnels around the world (about 0.002).

Among the reasons that can be raised to this results are the analysis of a 2-dimensional surface instead of a line inside the test section, what provides a stronger uniformity criteria but is much more susceptible to random oscillations and wall effects; the fact of the tunnel had been operating intermittently so that the data acquirement was realized in several different experiments and, maybe mainly, the influence of the injectors stagnation pressure oscillation during the experiments that can be responsible for a big part of the deviation found.

So, it has to be highlighted the influence of the injection system action uniformity over the flow quality inside the test section when the tunnel operates only powered by the injectors. The project of a mixing chamber, which is already running, can help to reach more uniform conditions in the injection nozzles along the experiments.

8. ACKNOWLEDGEMENTS

The authors would like to express their gratitude to the National Council for Scientific and Technological Development (CNPq) for the partial funding of this research, supporting under graduation student, under Grant n. 113853/2007-6.

9. REFERENCES

Anderson, J. D., 2001, *Fundamentals of Aerodynamics*, Third Edition, McGraw-Hill Higher Education. ISBN 0-07-237335-0.

Brooks C. W., Harris, C. D., Reagon, P. G., 1994, “The NASA Langley 8-Foot Transonic Pressure Tunnel Calibration”, Technical Facilities Catalog – Vol I, pp. 3-88.

Escosteguy, J. P. C., 1998, “Ensaios Iniciais no Túnel Transônico Piloto do CTA”, Proceedings of the VII ENCIT, Rio de Janeiro, RJ Brazil.

Falcão Filho, J. B. P., Mello, O. A. F., 2002, “Descrição Técnica do Túnel Transônico Piloto do Centro Técnico Aeroespacial”, Proceedings of the 9th Brazilian Congress of Thermal Engineering and Sciences, Caxambu – MG, Brazil, CIT02-0251.

Goffert, B., Truyts, C. F., Lima, D. S. A., Falcão Filho, J. B. P., 2008, “Control of Injection System for the Pilot Transonic Wind Tunnel of IAE in Closed Circuit”, Proceedings of the XII Brazilian Congress of Thermal Engineering and Sciences, ENCIT-2008, Belo Horizonte-MG, article 1-5054.

Haines, A. B., Jones, J. C. M., 1958, “The Centre-Line Mach-Number Distributions and Auxiliary-suction Requirements for the A.R.A. 9-ft x 8-ft Transonic Wind Tunnel”, A.R.A. Report No. 2.

Muylaert, J., 1988, “Pilot European Transonic Windtunnel (PETW) - Preliminary Test Results”, Proceedings of the 70th Semiannual Meeting of the Supersonic Tunnel Association Britisch Aerospace, Preston Lancashire, UK, STA-040.

Pope, A., Goin, K. L., 1978, *High-speed wind tunnel testing*. New York: John Wiley & Sons.

Quest, J., 1994, “ETW Shakedown Tests and Preliminary Calibration Results”, Proceedings of the 18th AIAA Aerospace Ground Testing Conference, Colorado Springs, CO, AIAA 94-2513.

Shapiro, A. H., 1953, *Compressible Fluid Flow.* The Ronald Press Company –New York

Silva, G. S., Falcão Filho, J. B. P., 2007, “Ensaios de Uniformidade Longitudinal na Seção de Testes com TTP em Circuito Aberto (Uso do Sistema de Injeção). Internal Report from IAE-ALA-TTS.

Van Ditshuizen, J. C. A., 1995, “The European Transonic Windtunnel – ETW: Design Aspects and Review of Calibration Results”. Proceedings of Second pacific International Conference on Aerospace Science & Technology, Sixth Australian Aeronautical Conference, Melbourne, paper 160.

Zanin, R. B., Reis, M. L. C. C., Falcão Filho, J. B. P., 2008, “Análise da Uniformidade Longitudinal do Número de Mach na Seção de Testes do Túnel Transônico Piloto do IAE em Circuito Aberto”, Proceedings of the 7th Brazilian Congress of Thermal Engineering and Sciences, CONEM-2008, Salvador-Bahia, artigo 1031.

10. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.