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IDENTIFICATION OF WALL INTERFERENCE PARAMETERS IN TWO-DIMENSIONAL TESTING IN TRANSONIC WIND TUNNEL USING THE PSP TECHNIQUE

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Abstract: *The main factors which influence the accuracy of two-dimensional flow test results in the Pilot Transonic Wind Tunnel (TTP) of IAE are analyzed. The influences of Reynolds number, Mach number, wall interference whereas solid and slot walls, and flow blockage as well as the influence of side-wall boundary layer control are analyzed. Modern instrumentation was used for qualification and quantification of the physical phenomena occuring in the wind tunnel tests using a NACA 0012 airfoil as a test model. In the experiments investigated systematically, different configurations were considered to characterize the influence of the walls with respect to data measured and, mainly, Physical behavior of the phenomena. The analysis showed that it is possible to obtain zero blockage ("choke") interference in a slotted wall test section. It is necessary actively intervene in the boundary layer control to avoid, partially or completely, three-dimensionality effects. The PSP technique proved useful in this application, providing to be a great quality and important tool. This paper presents, in detail, the use of this technique and its benefits for this study.*
Keywords: *Transonic Flow, PSP Technique, wall-interference*

1. INTRODUCTION

Transonic aerodynamics and especially transonic wind tunnel testing constituted for a long time one of the critical chapters of aerodynamic science. The theoretical reason can be easily seen: purely subsonic and purely supersonic flows can be described by approximate solutions derived from linear differential equations; therefore scaling rules and fundamental properties of such flows can be described in physical terms, which can be visualized in a relatively easy manner. If we have to deal with a flow in the transonic regime, the similarity laws and scaling rules are not directly apparent and the measurements become highly dependent on the ratio between dimensions of the wind tunnel and the dimensions of the model. The first observations showed, for example, a rapid increase of the drag of wing profile as the speed approached the sound velocity; however, the value of the speed at which this drag increase occurred, and its magnitude, depended more on the characteristics of the wind tunnel than on the characteristics of the wing profile. Some of the quite experienced experimentalists published test results before they realized the enormous influence of wind tunnel effects. But even today with all the experiences derived from a large number of interesting publications, a comprehensive study of the problems of transonic wind tunnel testing has a great value (Goethert, 1961).

Wind tunnels operating in the transonic speed regime, critical speed range, have slot and/or perforated walls in the test section to avoid choking the flow and reduce as much as possible, the need for speed correction and wall interactions with the flow around the model. It is imperative to understand the mechanics of these interactions, thus can provide knowledge of the aerodynamic behavior of a specific wind tunnel, in this case the transonic tunnel Pilot IAE (TTP), and more reliable aerodynamic tests for this regime speed.

The PSP technique is a relatively new technology and consists of a pressure sensitive paint, which offers affordable means of acquiring static pressure measurements in complex geometries. This article describes a practical application of the PSP technique for obtaining static pressure measured on the surface of an airfoil NACA 0012, for testing high speed flows. The emphasis of this work is to identify the TTP wall interference parameters using the PSP technique. Data are presented to illustrate the features and technical capabilities as well as permit an analysis of the aerodynamic behavior of TTP test section. The first section describes a brief overview of the basic physical phenomenon on the PSP technique. This is followed by descriptions of the test section configuration and components of the PSP measurement system. Then the test procedure is outlined.

Finally, the presentation of the data and the appropriate conclusions based on the analysis of the results acquired by PSP technique (Shuo Fang, 2012).

2. PSP OVERVIEW

The physical phenomenon that describes the PSP technique can be best exploited in work of Morris and Crites (1993b) and Bell and Mclachlan (1993). Therefore, this article will be only a brief discussion on the subject. The technique consists basically in the attenuation of luminescence for oxygen that are emitted by the molecules of the paint excited at visible wavelengths and ultraviolet radiation, then the higher the pressure in the coated type paint, the higher the partial pressure of oxygen, and also, the higher the intensity of light emitted by the paint, which is sensed by CCD sensor (Charge-Coupled Device) and quantified by software (Crites, 1993). Thus, through the light intensity emitted from the painted pattern obtained from images acquired by the equipment can be correlated, in a proportional manner, the variation in light intensity with local pressure, i.e., obtaining the pressure field on the model. The phenomenon visualization as shock waves is easiest with the use of this technique (Liu and Sullivan, 1997a). For pressure sensitive paint, excess energy can be absorbed by oxygen molecules in a process called dynamic quenching. This quenching is usually modeled by some variation of the Stern-Volmer relationship:

$$\frac{I_0}{I} = 1 + K_q P_{O_2} \tag{1}$$

where I is the luminescence intensity of the paint, I_0 is the luminescence in the absence of oxygen, P_{O_2} is the partial pressure of oxygen, and K_q is the Stern-Volmer constant. Thus, the intensity ratio is directly related to the partial pressure of oxygen, and hence, to the local absolute static pressure. Unfortunately, the pressure sensitive probe molecules have other mechanisms by which they can change energy state, the most significant of which is manifested as a sensitivity to temperature. Techniques for dealing with these temperature effects are critical to the successful use of PSP (Morris and Crites, 1993b).

3. TEST SETUP

The tests were performed in Pilot Transonic Tunnel of the IAE (Aeronautical and Space Institute of the Brazilian Air Force), in which the test section has the following measures: $0,30$ m x $0,25$ m x $0,815$ m, with slotted wall totalling an open area ratio of 5%, the model is a NACA 0012 with 83 mm of chord and 250 mm wingspan. Figure 1 shows the model installed on the test section of the TTP.

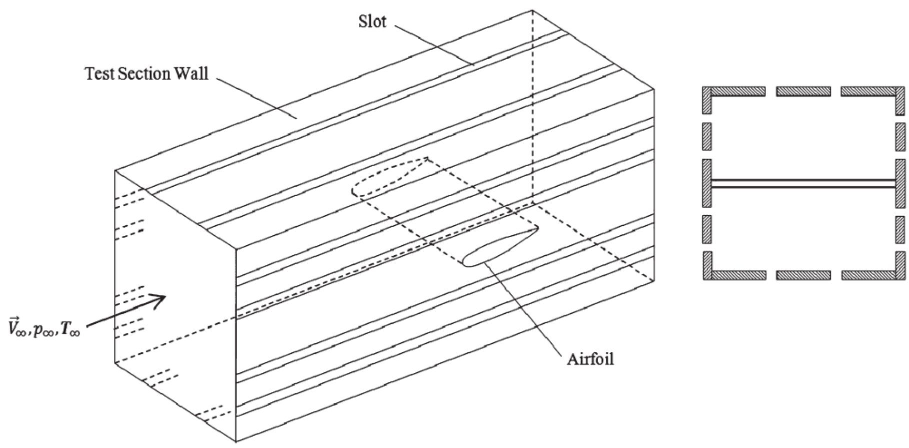

Figure 1: **Test section with the installed model NACA 0012.**

The corresponding experimental apparatus to the PSP system consists basically of a light source in which the wavelength is short (usually ultraviolet radiation), a special camera (photodetector) capable of capturing different wavelengths, optical filters, processing unit and data acquisition and paint with the molecular probes to be excited by the light source and sensitized by oxygen molecules. From the PSP technique, it is necessary to give a brief description of two metering systems: the system by CCD cameras and laser scanning system. The system most commonly used in aerodynamic tests is the CCD system for fluorescent dyes. Figure 2 shows a schematic of the PSP system (configuration used in this work).

3.1 PSP System

At schematic of Fig.2 it is possible to verify the three components of the PSP data acquisition system: 1) paint, 2) illumination source, and 3) a luminescence detector.The paint was formulated to show characteristics of high sensitivity to pressure and minimum sensitivity to temperature. It's summarized in three steps the painting process. First, the model surface was thoroughly cleaned with alcohol and lint-free cloths to remove all traces of dirt and oil. Then, a white primer layer was applied. After drying for 4 h, the primer was hand rubbed with lint-free cloths to achieve a smooth, uniform finish. Finally, the pressure sensitive layer was sprayed on with a modified commercial spray gun.

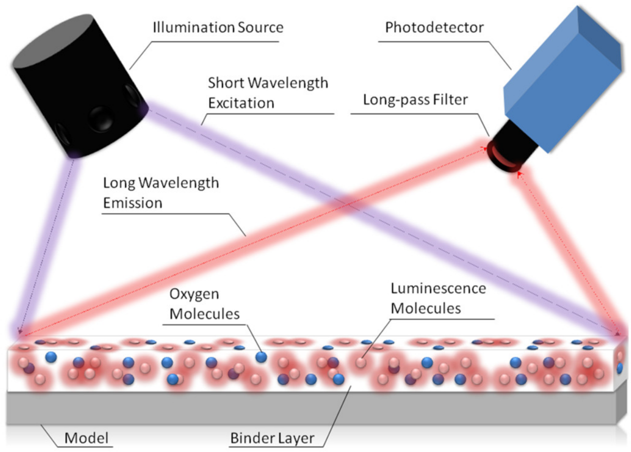

Figure 2: **PSP Setup. Sorce: Morris and Crites (1993b)**

4. TEST PROCEDURE

The experiments were performed according to Tab.1, where the cases investigated are listed. After painting the model, it was installed in the test section of TTP. The main objective was to identify the action of slotted wall comparing information obtained for the same speed regime and angle of attack, but with different wall configurations, namely: solid wall, partially open wall without forced mass extraction, partially open wall with forced mass extraction and slotted walls (normal operating conditions).

Table 1: **Investigated Conditions**

Mach Number	Alpha	Wall Condition	Observations
0.76	0°	Solid Wall	
0.80	0°	Solid Wall	
0.802	0°	Solid Wall	Choke Condition
0.70	0°	2 Open Slots	Without Forced Extraction
0.76	0°	2 Open Slots	Without Forced Extraction
0.80	0°	2 Open Slots	Without Forced Extraction
0.70	0°	2 Open Slots	With Forced Extraction
0.76	0°	2 Open Slots	With Forced Extraction
0.80	0°	2 Open Slots	With Forced Extraction
0.60	0°	Slotted Wall	
0.76	0°	Slotted Wall	
0.80	0°	Slotted Wall	

The information obtained from the result were displayed on graphs and some conditions were selected for further analysis, namely: Mach number 0.6, 0.76 and 0.80; for wall conditions: solid wall, 2 open slots with and without extraction and slotted wall. The results are presented and discussed in the following section.

5. RESULTS AND DISCUSSIONS

Analyzing the data of the tested cases, the qualitative level, you can see clear changes in the pressure field on the model for the selected wall conditions. In Fig.3 it is possible to observe these changes directly associated with the boundary condition (wall configuration) for each image taken.

The result of the experiment for the solid wall condition is represented by Fig.3a, note which there is a large area of low pressure and displacement of the shock wave towards the trailing edge of the airfoil, this shock wave has behavior softer compared to the other conditions for the same speed regime. It's possible to see also that the paint stripped the leading edge of the airfoil, this is due to extensive testing by varying the speed range in the high subsonic regime, the compressible region.

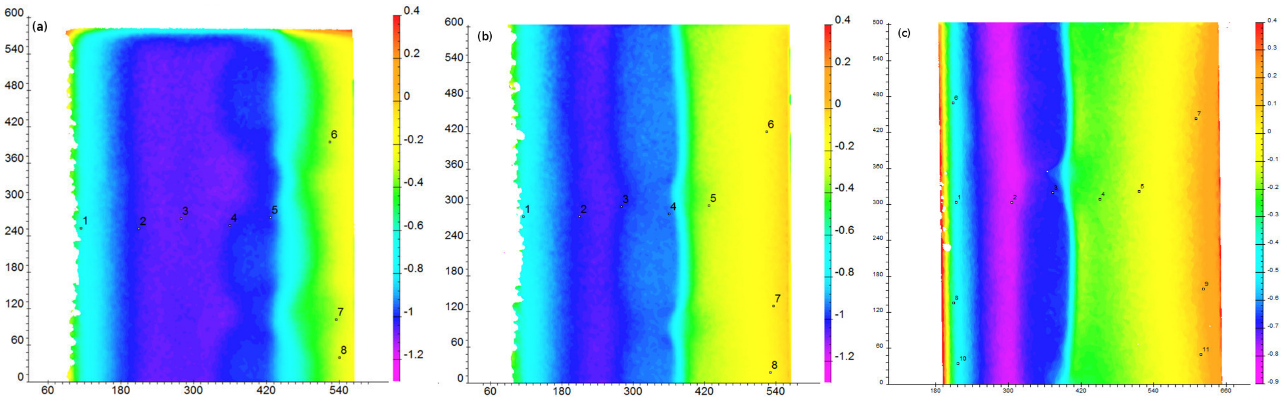

Figure 3: **Mach number 0.8 - a)solid wall, b)2 open slots and c)slotted wall.**

The case of the wall provided with only two open slots, presents a displacement of the shock wave towards the leading edge of the airfoil, the representative shock wave region is sharper, which means a greater pressure gradient for this condition wall and two regions where the shock wave clearly interacts with the boundary layer.

The normal condition of TTP operation, ie. slotted wall of the test section, presented a more incisive action of slots. It is noted a higher pressure gradient in the shock area and a shock wave interaction event boundary layer (SBLI - Shock Boundary Layer Interaction. The occurrence of SBLI is a consequence of the Reynolds number effects, because when the flow is laminar, the velocity profile of the confined turbulent flow is different from the turbulent flow, it has greater layer thickness limit, see Fig.4 where it is shown the two profile speeds, for laminar and turbulent flows.

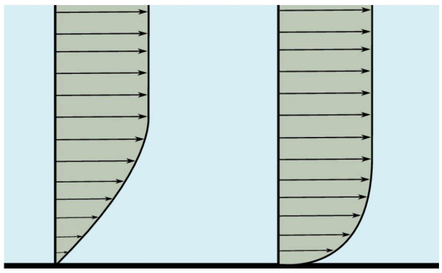

Figure 4: **Internal flow speed characteristics for laminar and turbulent flow. Source: Delery and Marvin (1986)**

For a better understanding of SBLI, it can be seen in Fig.5 a representative diagram of what occurs in this region. It is possible to observe the occurrence of compressional waves before the shock wave, this prevents the shock wave touching the wall, interacting with the boundary layer, as the flow decelerates. Notes a change in the thickness of the boundary layer after the shock wave, this is due to pressure rise that occurs in the pre-shock region where there is occurrence of compression waves and regions with different speed regimes. It also presents an image obtained by the Schlieren technique, enabling the visualization of the flow occurring in the region of the SBLI.

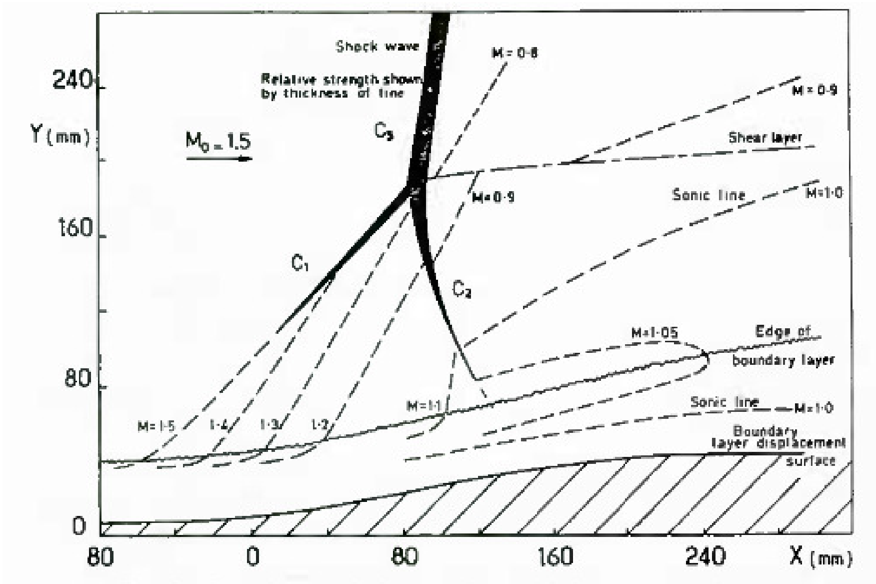

Figure 5: **Scheme representative of SBLI and Schlieren image. Source: Delery and Marvin (1986)**

In quantitative terms, one can evaluate the pressure distribution about the airfoil NACA 0012 in terms of the pressure coefficient in Fig. 6, where the curves are plotted with respect to their respective boundary conditions. It is possible to realize the shock wave displacement from the solid wall condition. Also, in partially open wall condition there is still a shock wave displacement, but less strong compared to the solid wall. However, in normal operation, slotted wall, the flow behavior of the model tends to approximate the results obtained by Harris (1981). However, the conditions used by Harris (1981) differ from the Reynolds number (very high in Harris case), the geometric characteristics of the test section used for it (larger than TTP) and flow type (turbulent flow). Still it is possible to make comparisons with these data, it reflects very well the free flight aerodynamic characteristics for this model.

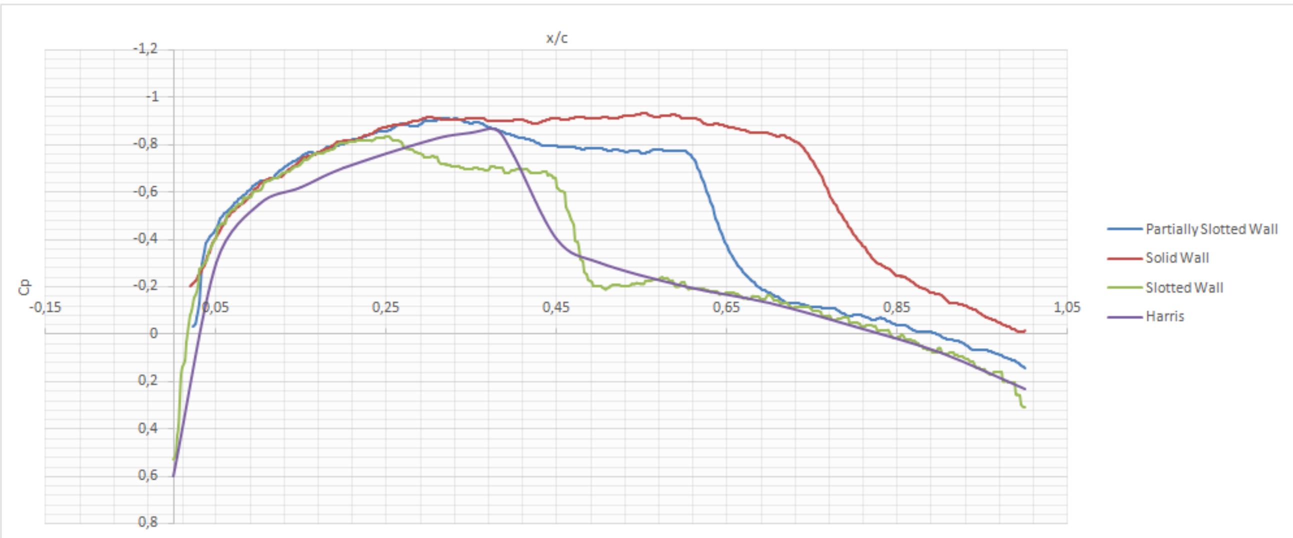

Figure 6: **Pressure coeficient distribution on surface of the NACA 0012 - Mach number 0.8 and $\alpha = 0°$.**

The pre-shock region where it is noted a pressure increase with the data obtained from the literature for the same region is due to the type of flow obtained in the test section, laminar and low Reynolds number. This variation in pressure distribution on model surface, indicates the emergence of shock wave lambda, with shock wave interaction with the boundary layer in this region.

6. CONCLUSION

The PSP technique showed a very useful tool for the identification of the wall interference parameters of Pilot Transonic Wind Tunnel of the IAE. He allowed a qualitative and quantitative analysis of the results, assisting in the observation and understanding of the phenomena occurring in the test section, by providing accurate information about the flow around the model.

It was clear the action of the walls in the flow and effectiveness of the slots in the tentative to minimize as much as possible the action of wall interference. This tool will be used in future studies to survey more flow field information in the test section of the TTP in order to map the aerodynamic behavior of wind tunnel.

7. REFERENCES

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