

# Assessment of the transition strip effect in the transonic flow over the sounding rocket Sonda III

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**Abstract.** Measurements of normalized pressure distribution are carried out over a 1:8 scale half-model of the Sonda III sounding rocket. The objective is to analyze the effect of the implementation of transition devices on the flow over the vehicle. Measurements show that the presence of the transition devices affect pressure distributions in different Mach numbers around the inter-stage region of Sonda III depending on its location and independently of the turbulent transition method employed. The study of these effects plays a significant role for future developments, since transition phenomena and the modification of the boundary layer behaviour due to the expansion can alter the load distributions and the turbulent structures of the flow. Furthermore, the experimental verification of such phenomena is crucial for the correct implementation of computational fluid dynamics calculations, as they might be able to capture the correct flow behaviour in these regions.

## 1. Introduction

To perfectly represent steady flight conditions in an experimental facility without significant effect of height variations and heat transfer it is necessary to reproduce the same Mach (Ma) and Reynolds (Re) number conditions. Generally, the flow around small size models have very low Re giving rise to large laminar regions over the model, when compared to real flight conditions. This is even more present in wind tunnels with limited test section dimensions, which is the case of the Pilot Transonic Wind Tunnel (TTP) used in the experiments.

At the full scale Re, it is likely that the boundary layers will be turbulent, so the laminarity of the flow can have a profound impact on the determination of forces and moments over the vehicle. In order to better mimic real flow phenomena in experimental tests, the use of roughness elements adequately located over the model surface is a common practice [1, 2]. These roughness elements, as discussed by Klebanoff *et al.* [3], cause the excitation of traveling wave instabilities or serve as catalysts to stationary crossflow modes and vortex instabilities promoting earlier transition to turbulence in the boundary layer.

Here, we present the results of a transonic test campaign with the Sonda III sounding rocket half-model in 1:8 scale, where two different devices were used to promote transition earlier in the flow after the inter-stage section. Normally, transition to turbulence takes place near the conical nose for

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rocket models, but some previous experimental results raised doubts as to the existence of a possible flow relaminarization after the inter-stage region of the Sonda III model. The laminar region is expected to be shorter in length in real flight. The shock wave boundary-layer interactions are governed by different physical processes depending on the condition of the boundary layer, *i.e.*, laminar or turbulent, thereby it is important to use a transition strip during the wind tunnel tests to fix the location of transition from laminar to turbulent. The location on the model and the characteristics of the strip such as thickness and roughness must be carefully chosen to prevent undesirable effects on the pressure distribution over the model [4].

This is the aim of this study: to investigate the impact of changing strip configurations on the pressure distribution over the model surface. Comparison of experimental results is shown in this paper for the subsonic and transonic regimes.

The Sonda III is an 8 m long two stage rocket with a maximum flight altitude of 600 km and liftoff thrust of 102.00 kN. It is part of a family of sounding rocket vehicles developed by the Institute of Aeronautics and Space (IAE) of the Brazilian Air Force.

The objective of this test campaign was to assess the surface pressure distribution over the vehicle, especially in the vicinity of the inter-stage region where the interaction between the compressible flow and the boundary layer is expected to be complex [5].

The Sonda III test half-model was installed on the side wall of the TTP test section of the IAE. The model has 154 pressure taps distributed over the first, second and inter-stage regions in order to provide finely distributed pressure measurements. The experimental tests were conducted with test section nominal Mach number varying from 0.20 to 1.00, stagnation pressure of 94 kPa and 0° angle of attack.

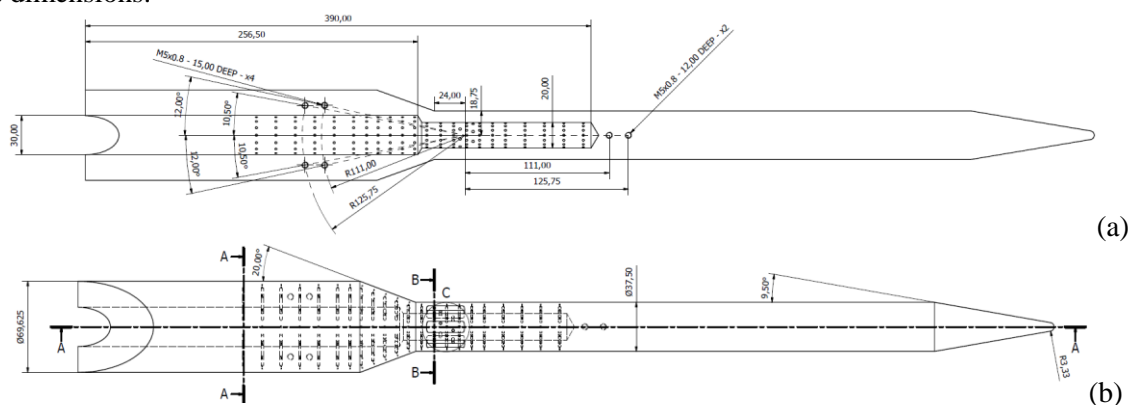
The detailed analysis of the flow behaviour around Sonda III, especially in the inter-stage region, is of great importance for the development of future launchers by IAE, as it experimentally describes the gas dynamics around a critical part of the vehicle. Also, it is expected that the better understanding of the flow behaviour around the vehicle will help improve the IAE computational modeling capability for the development of the next generation of launching vehicles.

## 2. Sonda III experimental campaign

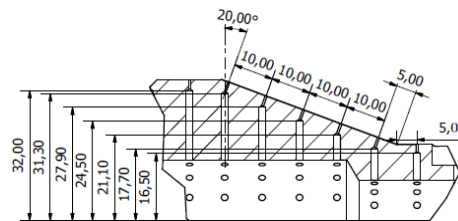
A 1:8 scale half-model of the Sonda III vehicle was built using aluminum for the experimental campaign. As described by Falcão Filho *et al.* [6], the test model is 0.778 m long and has a first stage diameter of 0.070 m.

The half-model has a total blockage of 2.5 % that combined with the slotted walls of the TTP causes no significant wall effects on the pressure distribution over the model. Furthermore, the model is mounted on the side wall of the test section in a way to leave a 0.004 m of spacing between the model and the wall to impede the boundary layer flow from reaching the model surface.

Figures 1 and 2, adapted from Falcão Filho *et al.* [6], show the drawing views of the test model and its dimensions.



**Figure 1.** Drawings of the inner (a) and outer part (b) of the Sonda III half-model.



**Figure 2.** Detailed view of the inter-stage region with 5 stations on the frustum cone. The 0.5 mm pressure taps had to be connected to the 2.0 mm holes with an angle of  $20^\circ$ .

In the inner part of the model, figure 1a, there are 154 holes with 2 mm diameter circumferentially distributed at 22 stations. Figure 1b is a drawing of the outer surface of the model with 0.5 mm of diameter holes connected perpendicularly to the surface, so that the 0.5 mm and 2 mm holes are connected. Figure 2 presents the pressure taps distribution around the inter-stage region of the model.

The stations are distributed in such a way that there are 7 stations in the first stage, 5 in the frustum cone and 10 in the second stage, with a distance of 10 mm between the stations close to the frustum cone and 15 mm between those outside the inter-stage region.

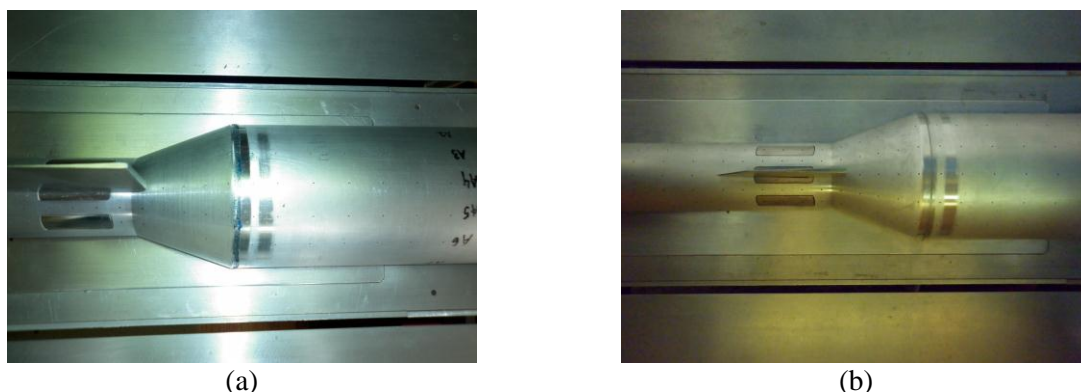
Pressure measurements were performed at  $0^\circ$  angle of attack with and without transition strips placed in two distinct regions upstream of the expansion corner. Different techniques for transition strip placement were employed, *i.e.*, grit (carborundum) strip and nylon wire.

### 2.1. Transition strip and nylon wire placement

As stated above, two different types of transition strips were used, namely, grit strips and nylon wire. The grit is made of carborundum particles spread over the surface and glued with glaze. The carborundum particles used were of the same size for all the strips (120 grit [1]).

Additionally, the size and placement of the strips were varied in order to assess the effect of the different techniques on the flow characteristics around the inter-stage region of the test model.

Two different strip sizes of 2 mm and 4 mm width were used and placed between stations F and G or stations G and H. Figure 3 shows the photographs of the half-model with the different methods used in the experiments. The height of the transition strip is approximately 0.2 mm and the diameter of the nylon wire is 0.5 mm.



**Figure 3.** Photographs of the Sonda III half-model with the implementation of the transition devices, 2 mm transition strip (a) and nylon wire strip (b). The transition strips and the nylon wire in the figures are placed between the stations G and H, but the space between stations F and G are also visible as a bright region after the transition devices.

## 2.2. Pressure coefficient distribution over Sonda III

The experimental campaign results are shown in figures 4 and 5. Pressure normalized distributions for different configurations but same Mach numbers are shown together for clarity. Pressure scanners were connected to the model pressure taps to measure local static pressures. The scanners are calibrated prior to the tests. The measurements were performed with Mach numbers varying from 0.20 to 1.10, with an error below 1 % in the test section, as shown in Reis *et al.* [7]. The static pressures,  $p$ , at the stations over the test model are normalized by the freestream pressure,  $p_\infty$ , measured at the inlet of the test section. The axial nondimensional distance shown in the graphs corresponds to the position from the beginning of the frustum cone divided by the diameter of the first stage of the test model. The dashed vertical lines highlight the limits of the frustum cone, around where the most complex flow dynamics is akin to occur.

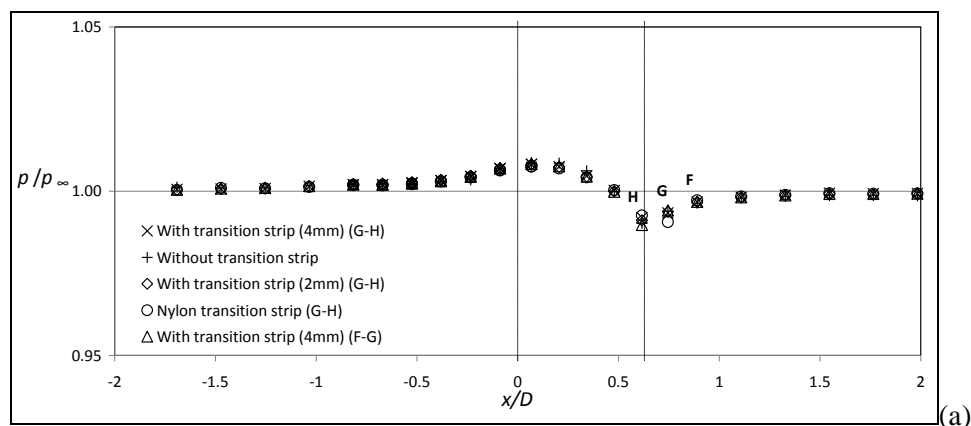
Figure 5 presents subsonic flow results, while in Figure 6 transonic results are presented. For the subsonic cases, the Reynolds numbers are at the limit of transition, while for transonic cases, the boundary layer is expected to be turbulent. The Reynolds numbers are 212786, 531967, 744754, 957541, 1010737, 1063934 for Mach numbers 0.20, 0.50, 0.70, 0.90, 0.95 and 1.00, respectively, based on the linear length of the frustum cone.

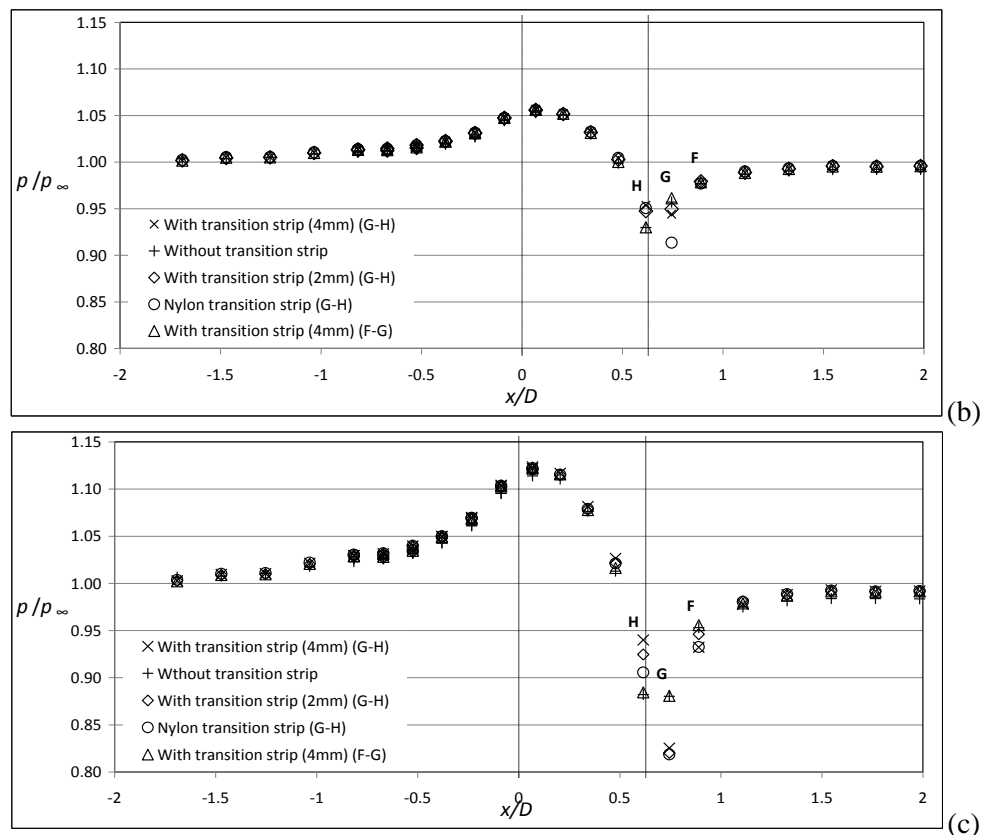
For Mach number 0.20, figure 4a, the normalized pressure distributions are the same for all cases, within data error, with no significant difference obtained when using the transition devices. For Mach numbers 0.50 and 0.70, although, the experiments show quite a different behaviour, as can be observed in figures 4b and 4c. The pressure variations are more pronounced in figure 4c.

The results presented in figure 4b show that the pressure distribution is not altered when the transition strip is placed between stations F and G, where the boundary layer is expected to be turbulent, as the pressure values are almost equal to those obtained without the transition device.

Upstream of the end of the frustum cone (station H), in the streamwise direction, the pressure values obtained with the usage of the transition strip and nylon between stations G and H, are slightly above the pressure values observed without the transition strip or with the strips placed between stations F and G. Downstream of the inter-stage corner, at station G, the pressure value obtained for the nylon wire is noticeably below those obtained for the remaining four cases.

In figure 4c, Mach number 0.70, just before the end of the frustum cone (station H), the pressure values measured without the use of transition devices or with the transition strip placed between station F and G are equal, and smaller than the pressure values obtained when the other transition devices are employed, with the pressure values being slightly higher for more intrusive devices (transition strip 4 mm). At station G, just after the end of the frustum cone, the opposite behaviour occurs: the pressure values when transition devices are placed between stations G and H are smaller when compared to the pressure values measured without the use of transition devices or with the transition strip placed between station F and G. Thus, figure 4c shows that the use of transition devices between stations G and H noticeably impacts the pressure values at these sites, as they compress the flow before the end of the frustum cone and expands the flow after the end of the frustum cone.





**Figure 4.** Normalized pressure distribution over the Sonda III for Ma 0.20 (a), 0.50 (b) and 0.70 (c).

Figure 5 shows the normalized pressure distribution over the half-model for transonic Mach numbers, namely, 0.90 (figure 5a), 0.95 (figure 5b) and 1.00 (figure 5c).

For figures 5a and 5b the pressure values measured at station H show the same behaviour observed in figure 4c, with the pressure values measured with use of transition devices between stations G and H slightly higher, when compared to the two other cases.

At station G, the pressure values measured when 4 mm and nylon wire transition devices are placed between stations G and H, are higher when compared to the cases where no transition devices were employed or with the transition strip placed between stations F and G. Otherwise, when the 2 mm transition strip is placed between stations G and H for Mach number 0.95 (figure 5b), a different behaviour is observed at station G, with the normalized pressure presenting the lowest value.

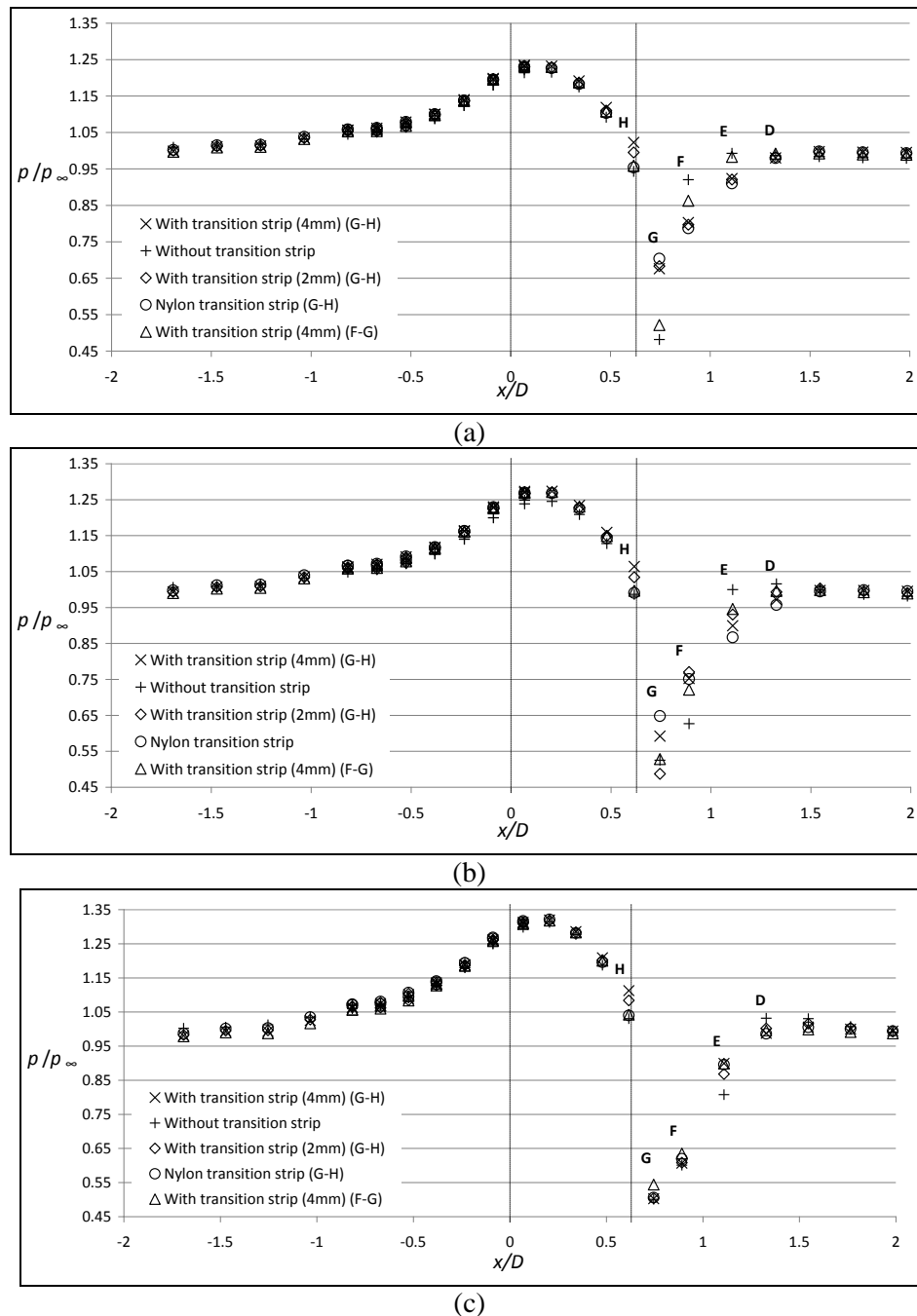
Thus, at the transonic regime depicted in figures 5a and 5b, the presence of 4 mm and nylon wire between the stations G and H compress the flow just after the end of the frustum cone, inversely to what is observed when the 2 mm transition strip is employed, showing that, for Mach number 0.95, this device is less intrusive in the flow. Also, the transition devices alter the values measured at the stations D, E and F which were insensible to the presence of these devices in the subsonic regime.

Comparing figures 5a and 5b, there is a tendency of departure in pressure values obtained in stations D and E when using no transition devices from those obtained in the other four cases, *i.e.*, the pressure is higher without the transition devices. The same tendency of departure is observed in station F, with pressure values being lower for the case without transition device.

For Mach number 1.00, figure 5c, the pressure values do not show significant differences for the five cases studied, the largest difference in pressures values being noted at station E. One possible explanation could be the effect of a thick, full turbulent boundary-layer profile over the model, for which the presence of transition devices is not felt anymore. Another possibility could be the effect of

the flow dilatation that thickens the boundary layer. The same explanations can be applied for the case where the 2 mm transition strip is placed between station G and H, for Mach number 0.95 (figure 5b).

According to Dussauge and Gaviglio [8] and Smith and Smits [9], flow dilatation due to supersonic expansion in high speed flows reduces turbulence in the boundary layer leading to relaminarization of the flow, creating a thick, almost laminar, boundary-layer after the expansion region. Although, Mach number 1.00 is small for the occurrence of full relaminarization, bulk dilatation of the flow could thicken the boundary layer, which would be less sensible to the presence of the transition devices.



**Figure 5.** Normalized pressure distribution over the Sonda III for Mach number 0.90 (a), 0.95 (b) and 1.00 (c).

### 3. Conclusions

Pressure distribution for subsonic and transonic flow regimes along the SONDA III vehicle half-model were carried at the Pilot Transonic Wind Tunnel Institute of Aeronautics and Space. Particularly, the effects of the usage of transition devices over pressure profiles along the model surface were analyzed.

The transition devices used to promote transition to turbulence of the boundary-layer flow over the model were seen to affect the pressure distribution around the model inter-stage region.

In the experiments performed we are not able to assert if transition to turbulence occurs, or where it takes place without the transition devices, because only pressure measurements were carried out.

We can conclude that the use of transition devices employed after the end of the frustum cone affects the pressure distribution over the model, notably at high subsonic and transonic regimes, altering the flow characteristics when compared to the cases where no transition devices are employed.

This leads to the need to carefully analyze the impact of the usage of transition devices for vehicles such as the Sonda III, for high subsonic and transonic flow experiments to judge if the gain obtained in correctly representing the boundary-layer dynamics is overshadowed by the effect of the devices on the pressure distribution over the model.

As other measurements such as surface shear stress, particle velocimetry or *schlieren* optics were not performed it is difficult to weave accurate conclusions about the flow behaviour downstream of the expansion corner. Surely, such additional information would greatly assist correct interpretation of the pressure behaviour observed in the experiments. Tests for the above mentioned measurements are being planned and are essential for the more accurate aerodynamic analysis to be employed in the future launching vehicle developed by the Institute of Aeronautics and Space.

### Acknowledgment

The authors would like to express their gratitude to FAPESP, the São Paulo Research Foundation, through grant FAPESP/CEPID 2013/07375-0 and to CNPq, the Brazilian Counsel of Research and Development, through grant 560200/2010-2 and 384491/2013-8, for their support during the development of this study.

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