RESEARCH WIND TUNNEL OF THE AERONAUTICAL INSTITUTE OF TECHNOLOGY: MANUFACTORING ASPECTS AND DESIGN DETAILS

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Abstract. The present paper objective is to describee ITA's wind tunnel characteristics, giving dimensions and design details of each element This is an open circuit wind tunnel with a closed test section, with 1.0 m height by 1.28 m width. The test section maximum velocity is approximately 80 m/s and the turbulence level was designed to be lower than 0.05%, at the maximum velocity. An eight blades fan, connected to a 200hp electric motor, is used to generate the flow. The wind tunnel entrance nozzle is located inside the Prof. Feng Aeronautical Engineering Laboratory. This feature is interesting because atmospheric wind variations are damped before entering in the wind tunnel. In the settling chamber there are one honeycomb and three screens, used to reduce the turbulent intensity of the test section flow. The test section is designed to be very flexible, in order to reduce the time and cost for implementing new experimental apparatus. Such flexibility was obtained by using interchangeable windows, which can be adapted to special requirements of new experiments. The wind tunnel diffuser is divided in two parts, separated by the fan. The exit section of the diffuser second part is connected to an element, where the flow velocity is diminished and deflected in the upward direction. Such procedure was adopted to minimize the atmospheric wind variations effect on the test section flow. After starting operations, the test section flow will be calibrated and the new wind tunnel will be used in two research programs proposed by EMBRAER.

***Keywords** .Wind Tunnel, Low Speed Flow ,Design Details, Open Circuit*

1. Introduction

ITA's new wind tunnel is part of a greater project whose main objective is to increment the productivity and reliability of aerodynamic testing. The IAE-CTA and USP-São Carlos wind tunnels are still used in the developments performed to reach the goal mentioned above, which must solve some problems observed by the EMBRAER personnel in the area of aerodynamic tests.

This new wind tunnel is the answer to the long term need of an equipment which allows aerodynamic testing with low operating cost, as well as, low cost for the experimental apparatus implementation (complex models manufacturing can be a very expensive activity). The requirements above can be satisfied with a 1.0 x 1.28 m test section, where a flow with, at least, 70 m/s must be established, in order to reach, at least, a Reynolds number of 10^6. This new testing facility, equipped with a 200 hp electric motor, must be compared to the IAE-CTA wind tunnel, where part of the aerodynamic tests are performed to the Brazilian aeronautical industry and, in particular, to the EMBRAER. The IAE-CTA wind tunnel has the following characteristics: test section with 2.1 x 3.0 m, maximum velocity of approximately 100 m/s and 1600 hp of power. From the comparison of the figures given above it is possible to verify that ITA's wind tunnel arises to complement the IAE-CTA facility.

ITA's wind tunnel conceptual design was reported by Girardi et all (2002), where the solutions adopted for this project are discussed in detail. The present paper objective is to describe such wind tunnel characteristics, giving information about each element of the aerodynamic circuit. Design details and difficulties observed during the wind tunnel manufacturing and mounting are reported, in order to become easier future works on this subject.

ITA's wind tunnel starts operating on February 2003 with a series of experiments to calibrate the test section flow. After this phase, two research programs will be implemented to reach the following objectives: (i) Experimental methodology development to minimize the three-dimensional flow observed in two-dimensional airfoil models at high angles of attack. This problem occurs due to the interaction between the airfoil extremity and the tunnel wall boundary-layer flow and cause great uncertainty in the measurements of the airfoil Cl_{max}. (ii) Development of a methodology for estimating a wing Cl_{max} , once the airfoil Cl_{max} is known. In order to accomplish this objective a set of experiments will be conducted to understand the separated flow evolution, at the upper surface of a wing, while the angle of attack is incremented up to the wing stall. It is worth to mention that these two research programs were proposed by the EMBRAER personnel to solve important practical problems.

2. Wind Tunnel General Characteristics

The Aeronautical Institute of Technology (ITA) wind tunnel is an open circuit type, as can be seen in the figure 1. Such configuration was adopted to minimize initial cost and time for manufacturing and for the mounting operation.

The atmospheric air is admitted in the wind tunnel by the entrance nozzle, which was designed to minimize the pressure losses associated to skin friction and to local flow separations. In the settling chamber, the airflow pass trough a honeycomb and three screens in order to minimize flow non-uniformity and turbulence level of the air admitted by the entrance nozzle. In an open circuit wind tunnel such flow straightening elements are very important due to the fluctuations caused by atmospheric wind variations.

After the settling chamber there is a nozzle, with contraction ratio of 10:1, which is responsible for accelerating airflow up to the specified velocity at the test section. Care must be taken in this element design, in order to avoid local flow separation, which could cause an increment in the flow turbulence level at the test section.

The test section is 1.0 m high and 4.0 m length. The width varies from 1.20 m to 1.36 m along the test section length, in order to compensate the boundary layer growth and to minimize the static pressure gradient. The maximum flow velocity is 80 m/s and the Reynolds number is 4.7×10^6 considering a characteristic dimension of 1 m. The test section walls are constituted by some windows to allow: (i) flow visualization, (ii) implementation of optical measurement techniques, such LDV and PIV and (iii) become easy the implementation of new experimental apparatus, constituted normally by the model and auxiliary devices, such as the injection equipment which will be used to minimize the tree-dimensional effects observed when a two-dimensional airfoil model is tested at high angles of attack, as mentioned above.

The wind tunnel diffuser is divided in two parts by the fan, as can be seen in the figure 1. Such configuration was adopted to minimize the diffuser length and, as a consequence, to minimize the initial cost. Care must be taken in such element design, because flow separation can occur due to the adverse pressure gradient of the flow inside a diffuser. The wind tunnel fan has 200 hp of power and a frequency inverter, capable to vary the rotation in steps of 1 rpm, can control its rotation.

After the diffuser second part, there exist a fast expansion diffuser, used to reduce the velocity of the flow entering in a chamber, designed to damp the effects of atmospheric wind variations in the test section flow. In such chamber the wind tunnel flow is deflected to upward direction, which seams to be the most appropriate configuration to minimize the effect of the atmospheric wind variations.

The wind tunnel positioned inside the Prof. K. W. Feng Aeronautical Engineering Laboratory is shown in the figure 2, where it can be seen that air is aspirated from a region inside the laboratory. Such configuration has the advantage that the atmospheric wind variations are partially damped before the flow pass through the entrance nozzle. On the other hand, the air sucked by the wind tunnel fan has to flow through the laboratory doors and high turbulent flow structures are generated. Such structures certainly have influence in the flow quality at the test section.

Around the test section there is a chamber totally sealed from the external region. In this chamber the pressure is equal to the static pressure inside the test section (approximately 350 mm of water bellow atmospheric pressure) and allows the introduction of probes in the tunnel flow, without causing major disturbance on the test section flow.

All wind tunnel elements after the test section are located outside the laboratory, including the electronic equipments used to control the fan rotation (frequency inverter). In order to protect this wind tunnel part, a ceiling was built as can be seen in the figure 2.

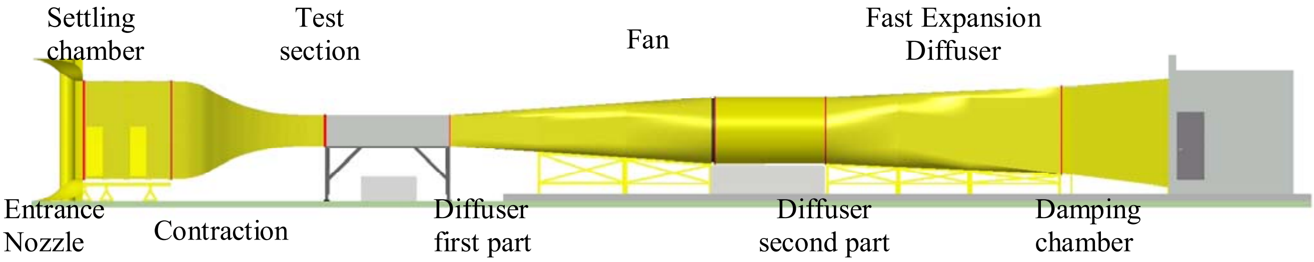


Figure 1: General view of the ITA's teaching and research wind tunnel and its elements.

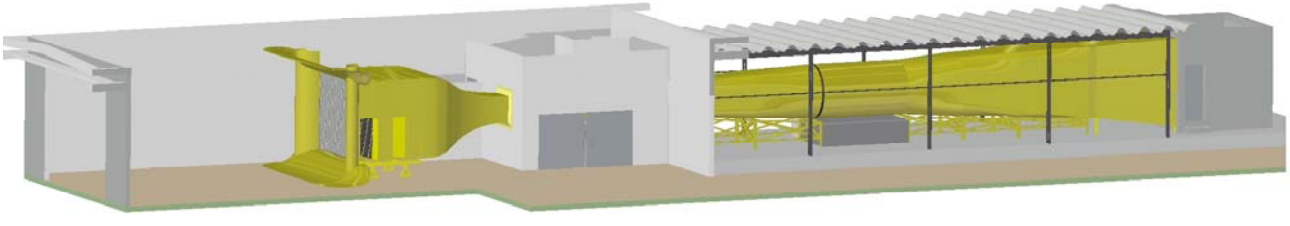


Figure 2: Wind tunnel inside the Prof. K.W. Feng Aeronautical Engineering Laboratory.

3. Specific Characteristics of Each Wind Tunnel Elements

In this paper section, specific characteristics and constructing information will be given about each one of the wind tunnel elements.

3.1. Entrance Nozzle

In general, the entrance nozzle of a wind tunnel is designed as a circle or elliptical arc with a dimension specified by a fraction of the hydraulic diameter of the settling chamber. Such kind of configuration works well when the entrance nozzle extremities are far from other surfaces, like the laboratory ceiling, floor and lateral wall. Unfortunately, this is not the situation of the ITA wind tunnel (mainly because the high contraction ratio adopted in such installation) and a special entrance nozzle has to be designed.

In order to perform the special entrance nozzle design, a 1/10 model of the wind tunnel entrance region and the building around it was built, as can be seen in the figure 3 (a). The laboratory walls and ceiling were made of transparent material to allow flow visualization in the region near the wind tunnel model, in particular, on the surface of the entrance nozzle configurations tested during the research. This flow visualization, made with wool tufts, gave information about local flow separations, vortices induced by the entrance nozzle configuration and its interaction with the near surfaces and, finally, about the flow fluctuations. The major concern during the entrance nozzle design was the flow fluctuations at the entrance of the settling chamber, because the flow turbulence level at this position should be lesser than 8% to guarantee a good flow quality in the test section. A hot wire anemometer, connected to a traversing system used to map the settling chamber entrance section, measured this turbulence level. This flow mapping was performed to each configuration proposed for the entrance nozzle and the results are reported in Assato et al (2003).

The best configuration analyzed is shown in the figure 3 (b). It was made by iron plates with 3 mm thick and the overall dimensions are 4.6 m high and 5.15 m width.

3.2. Settling Chamber

This wind tunnel element is responsible for rectifying the airflow admitted through the entrance nozzle, in order to obtain uniform velocity profiles and a low turbulence level flow at the entrance section of the contraction element. As mentioned in the previous section of this paper, the flow sucked by the fan can arrive, at the settling chamber entrance, contaminated by vortex structures, generated by several reasons (atmospheric wind variations, obstacles like the laboratory doors and by the entrance nozzle and its interaction with near surfaces), which cause fluctuations in all directions.

These flow fluctuations can be reduced by using a honeycomb and screens (Rae & Pope, 1984). The main disadvantage of these elements is the pressure losses introduced in the flow, which have to be minimized. Such minimization is performed by placing these elements in a low velocity regions and this is one of the reasons to use a high contraction ratio (10:1), resulting a settling chamber with large dimensions (3.16 m high and 3.80 m width) and low velocity.


(a) (b)

Figure 3: (a) Wind tunnel entrance and laboratory building scale model and (b) entrance nozzle of ITA's wind tunnel.

Honeycombs are constituted by a set of cells, which are characterized by a cross section dimension (M) and by a length (Lc) in the flow direction. The honeycomb used in the ITA wind tunnel was designed by following the directions reported in the work of Loehrke & Nagib (1976) and more details can be found in Girardi at all (2002). Such honeycomb is made of aluminum and its cross section has hexagonal shape, with M = 4.76 mm (3/16"). Its length, in the flow direction (Lc), is equal to 50.8 mm (2"). It is interesting to report that the honeycomb was the unique imported item of the ITA wind tunnel.

Screens are characterized by the mesh size (Mt) and by the diameter (d) of the wire used in the mesh manufacture. An important parameter is the screen porosity (β), defined as the ratio between the open and the total areas. In the work published by McKinney & Scheiman (1981) it is possible to obtain all the information required to specify a screen appropriated to reduce turbulence level and to improve the flow uniformity. In Girardi at all (2002), such information was described and applied to the ITA wind tunnel, resulting in a screen with the following characteristics: (i) wire diameter, d = 0.2 mm, (ii) porosity, β = 0,67 and (iii) the pressure loss coefficient, k = 1.0. The screen is made of inox steel and it is found in the market in rolls with 1.6 m width. Once the settling chamber cross section is 3.16 m high by 3.80 m width it was necessary to sew some pieces to make a panel with the required dimensions. The screen sewing was performed manually and a steel wire of 0.1 mm was used to join the screen panels.

Screens are elements that accumulate dirt and the settling chamber design was made in order to allow a simple manner to clean the screen panels. In the ITA wind tunnel, the screen panels are too large (3.16 m x 3.80 m) and it is convenient to perform their neatness without removing them from the settling chamber. Therefore, to accomplish the requisite discussed above, the screen panels are separated by a distance of 700 mm, which allows the motion of a person between two panels. Two doors, located at the settling chamber lateral wall (see Fig 4b), give the access to the chamber interior.

The analysis of the flow turbulence level reduction indicates that one honeycomb and three screen panels are sufficient to obtain a 0.05% turbulence level flow in the wind tunnel test section, considering, as mentioned above, a 8% turbulence level flow at the entrance section of the settling chamber. The honeycomb and the first screen panel are assembled together, with the screen positioned at the downstream honeycomb surface. The second and third screen panels are separated by a distance of 700 mm and positioned downstream from the first one, as shown in the figure 4 (a). In order to allow the screen panels assembling (and withdrawn, in case of maintenance), the settling chamber was designed as a set of four modules (see fig. 4(b)), joined together by three beams located bellow the inferior surface and other three located at the upper surface. The inferior beams are positioned above three supports, as can be seen in the figure 4 (b). Each module has 700 mm length and the screen panels are positioned at the interface among them. Although only three screens are initially planned to be used, a fourth screen panel can be placed at the interface between the third and fourth modules, in order to improve the turbulence level of the flow in the test section.

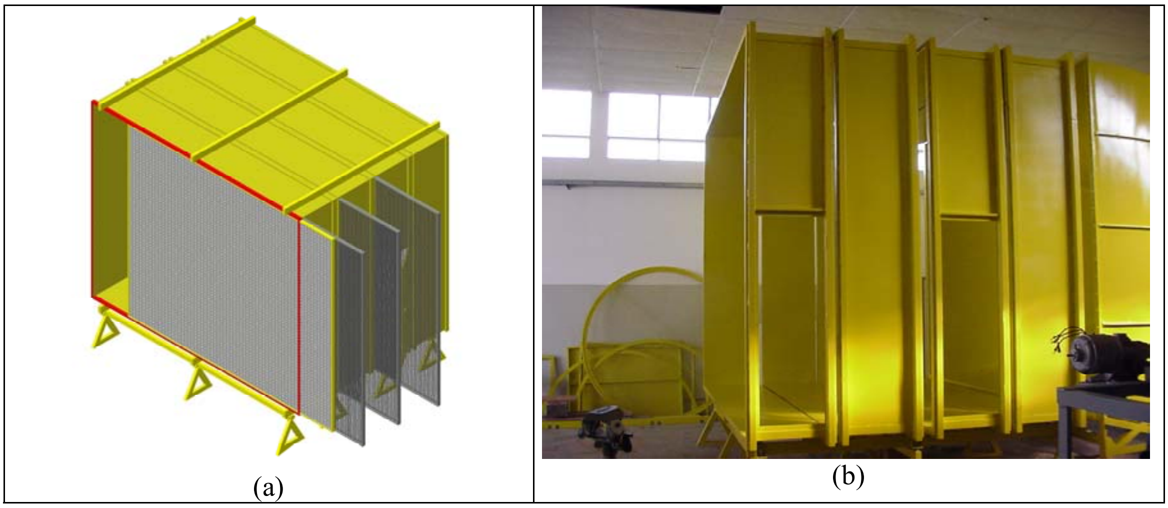

(a) (b)

Figure 4: Settling chamber: (a) Screens and honeycomb configuration and (b) lateral view of the four modules during mounting procedure.

3.3. Contraction Nozzle

The contraction nozzle design was performed following the directions given by Morel (1975). Its shape is modeled by two cubic equations, joined together in a soft way in a point defined by the non-dimensional coordinates (x_c, y_c). These equations are given by the following relations:

$$y = 1 + \frac{y_c - 1}{x_c^3} x^3 \tag{1}$$

$$y = \frac{y_c}{(1 - x_c)^3} (1 - x)^3 \tag{2}$$

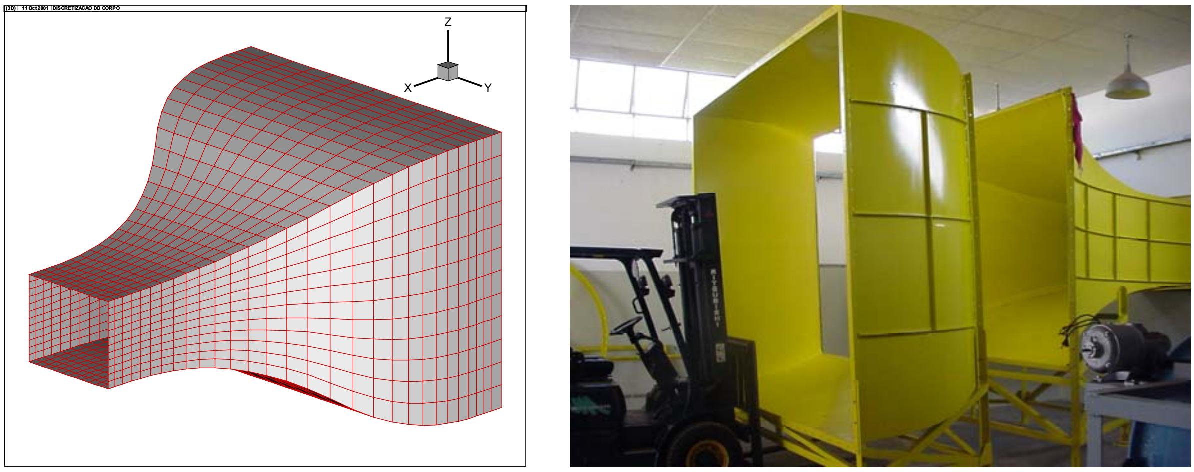
where $y = \frac{H - H_e}{H_t - H_e}$, $x = \frac{x'}{L}$, H_e, H_t and H are, respectively, the test section height, the settling chamber height and the contraction nozzle height at the non-dimensional coordinate x. The x′ variable is the dimensional coordinate in the flow direction and L is the contraction nozzle length. Equations (1) and (2) are valid, respectively, for x varying in [0, x_c] and [x_c , 1].

In order to guarantee that the above define curves have a soft union at (x_c, y_c) the inclinations of such curves must have the same value. This statement leads to the following relation

$$y_c = 1 - x_c \tag{3}$$

Considering equation (3), it is easy to verify that equations (1) and (2) become curve families depending just on a unique parameter (x_c). In the ITA wind tunnel design, the contraction nozzle is defined by the above equations with x_c = 0,28 and L = 4,95 m. These values were obtained after a detailed calculation, by using computational fluid dynamics, of some different contraction nozzles generated with the curve families described above. Specific information about this work can be obtained in Mattos, Nide and Girardi (2003).

The ITA contraction nozzle shape can be observed in the figure 5 (a). Such contraction nozzle was manufactured in two parts, each one made with a set of 3 mm iron plates, fixed to a primary structure responsible to assure the correct nozzle shape (see figure 5 (b)). These parts were joined together by a set of screws along each part interface.



(a) (b)

Figure 5: (a) ITA contraction nozzle shape (x_c = 0,28 and L = 4,95 m). (b) The two parts of the contraction nozzle during their assembling procedure at the correct position inside the laboratory

3.4. Test Section

In the wind tunnel described in the present paper, the test section has the following dimensions: (i) length equal to 4.0 m, (ii) height equal to 1.0 m and (iii) width varying from 1.20 m to 1.36 m, in order to compensate the boundary layer growth and, as a consequence, keep static pressure approximately constant along the test section length.

The test section cross section area variation was determined by using numerical codes capable to calculate the displacement thickness along the test section length. Considering this result, it is easy to calculate the divergence angle that each test section wall must have in order to prevent static pressure variations. The result obtained of 0.5^{o} is coincident to the one suggested by Rae & Pope (1984). In order to make easier tasks like models and probes initial alignments (Jacek, 1992) the superior and inferior test section surface were designed parallel and the required area variation was given by the lateral walls divergence, resulting in the dimensions furnished above

An important detail is to brake the corner sharpness through a small inclined surface (45^{o}), as can be seen in the figure 6. Such design detail avoids secondary flow in the region near the corners, which could increment the pressure losses and cause problems to the test section flow quality. In the region of the central window (see figure 6), the corners are used to shelter lamps (normal or ultraviolet), very useful to perform model illumination and flow visualization. Finally, the corners can be used for the fine adjustment of the pressure gradient along the test section length. In order to make easy such procedure, the corners are made of wood.

One of the most important characteristics of a research wind tunnel is the flexibility to exchange the experimental apparatus installed in the test section. That is, new experiments must be implemented with low cost and as fast as possible. In ITA's wind tunnel, the above characteristic was obtained by designing the test section with removable windows, which can be transparent or opaque, as can be observed in the figures 7 (a) and 7 (b). In the central region of the test section there are four windows, one at each wall. The windows located at the upper and lateral walls are made of reinforced glass and the other two windows are made of metal plates (see figure 7b). Additionally, two more windows at the upper and lateral walls are used to complement the test section configuration (see figures 6 and 7a). All these windows are transparent (see figure 7b) and can be used to perform flow visualization and to introduce probes inside the test section.

Models will be installed in middle region of the test section and, depending on the model under analysis, the windows can be exchange in order to fit specific requirements needed to perform an experiment. For example, in the case mentioned above, where a methodology to avoid three-dimensional flow in a two-dimensional airfoil has to be developed, one of the alternative solutions uses compressed air blowing in the region near the model extremities. For this case, the upper and lower windows will be exchanged because the airfoil extremities have to be fixed at round tables, which will be made of wood, and air injectors have to be placed in different positions relative to the airfoil leading edge. The lateral window will be kept transparent, because it is important to perform flow visualization of the airfoil upper surface.

Finally, its worth to mention that the transparent windows are a very important feature once modern optical measurement methods, like LDV and PIV, are intended to be applied in the aerodynamic research conducted in this wind tunnel.

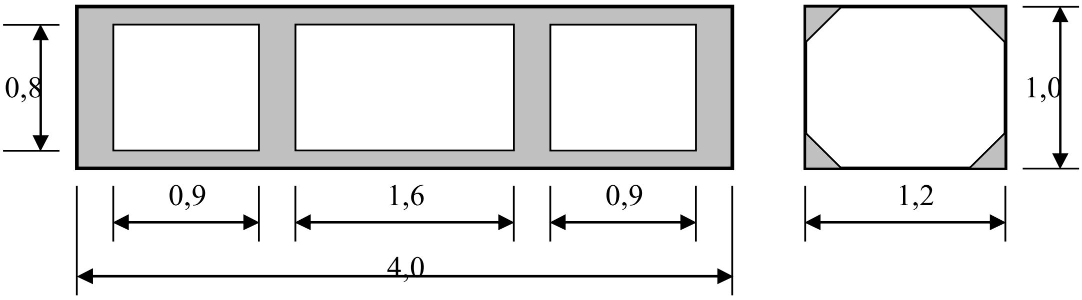


Figure 6: Test section lateral view and its cross section at the upstream extremity. Dimensions in meters.

(a) (b)

Figure 7: (a) Test section basic structure inside the sealed chamber. (b) Test section final adjustments. Assembling procedure of the transparent and opaque windows.

3.5. Diffuser

As mentioned before, ITA’s Wind tunnel diffuser is constituted by two parts, connected by the fan (see Fig. 1). Such configuration was adopted in order to minimize the diffuser length and the power required to overcome the losses of such wind tunnel element, once an area ratio is fixed. This area ratio is defined as the ratio between the exit area and the entrance one and such parameter is connected to the amount of the kinetics energy lost to the ambient.

Due to the adverse pressure gradient established along the diffuser length (Ld), the area ratio (AR) is linked to the non-dimensional diffuser length (Ld/R_1), where R_1 is the equivalent circular radius of the element entrance section. The above two non-dimensional parameters are related to the diffuser divergence angle (2θ) and a good relation between them was formulated by Eckert et al (1976), based on data colleted from a set of wind tunnels built around the world. This relation was used to design both parts of the diffuser, which are dependent from the fan diameter (Dv), specified with a value equal to 2.14 m, after a research of the national fan manufactures. Once Dv was fixed, all other dimensions of both diffuser parts can be calculated (Girardi et al, 2002) and they are shown in the table 1.

Table 1: Dimensions of both parts of the ITA wind tunnel diffuser

Diffuser part	AR	Ld/R_1	Ld (m)	2θ (degrees)
First	3,0	13.52	8.36	7.2
Second	2.3	7.0	7.50	8.2

Both diffuser parts are made of iron plates with 3 mm thick and are supported by structures made of angle iron (see figure 8), which have adjustable feet, used to make the alignment of the wind tunnel axis. The diffuser first part is constituted by three modules, joined together by a set of screw. The rectangular entrance section (1.0 m high by 1.36 m width) is connected to the test section exit and is located inside the sealed chamber, as described above. The circular exit section has a diameter equal to 2.14 m and is located just ahead of a concrete block, used to support the tunnel fan, as can be seen in the figure 8 (a). The cross section shape transition is made along the whole length of the diffuser first part, in order to guarantee a soft shape variation and a small pressure loss. For the diffuser second part (see figure 8b) the circular entrance section has a diameter equal to 2.14 m and the square exit section has 2.83 m of side length. Again, the cross section shape transition is performed along the element whole length.


(a)
(b)

Figure 8: (a) Diffuser first part during mounting procedure and (b) Diffuser second part being positioned after the first one.

3.6. Fan

ITA's wind tunnel fan has 2.14 m of cross section diameter, 3.5m of length and weights about 3500 kgf. Eight blades and a spinner (see figure 9a), both made with composite material, constitute the fan rotor. This rotor is connected to an electric motor, with 200 hp of power, which is fed by three-phase circuit of 440 volts. The electric energy required by the fan motor is supplied by a dedicated electric transformer, connected to the high power electric tension and this is an important detail when electric noise has to be minimized, as is the case of a wind tunnel, where very sensitive instrumentation has to be used.

Just after the rotor, there is a set of 9 straightener vanes (see figure 9b), designed to minimize the flow rotation induced by the rotor. This aspect is very important to minimize the diffuser second part losses, because the cross section is changed from circular to square shape and a flow rotation would cause problems in the corner regions.

The electric motor has a fairing, designed as a slender body of revolution (see figure 9b), in order to avoid flow separation and the formation of a wake that could introduce flow fluctuations in the test section region. The space inside such fairing used as a duct for the electric motor refrigeration system. This system is constituted by two auxiliary fans (see figure 9c) that blow air through two ducts, shaped as airfoils. The refrigeration air flows inside the fairing and by the motor and exit through two outlets, as can be seen in the figure 9(d).

In order to minimize the fan vibration transmission to the test section, two actions were taken during ITA's wind tunnel design phase: (i) the fan is supported by four dampers, which are placed over a concrete block built to resist the fan weight as well as the charges generated by the rotor and (ii) a flexible union (made of rubble) is used in the interface between the fan and the diffuser first part, as can be seen in the figure 9 (d).

The test section flow velocity is controlled through the motor rotation variation, which is performed by a frequency inverter located inside the cabinet shown in the figure 9 (c). This electronic equipment is able to vary the motor rotation in steps of 1 rpm and to control this rotation to avoid variations lesser than 1% of the maximum value, designed to be 890 rpm. The frequency inverter can be manually controlled or by using a computer, allowing experiments automation.

In order to protect the rotor blades, a screen was fixed at the fan entrance section, as can be observed in the figure 9 (a). The function of such screen is to avoid damage of the fan blades in case of a structure failure of the model fixed in the test section.

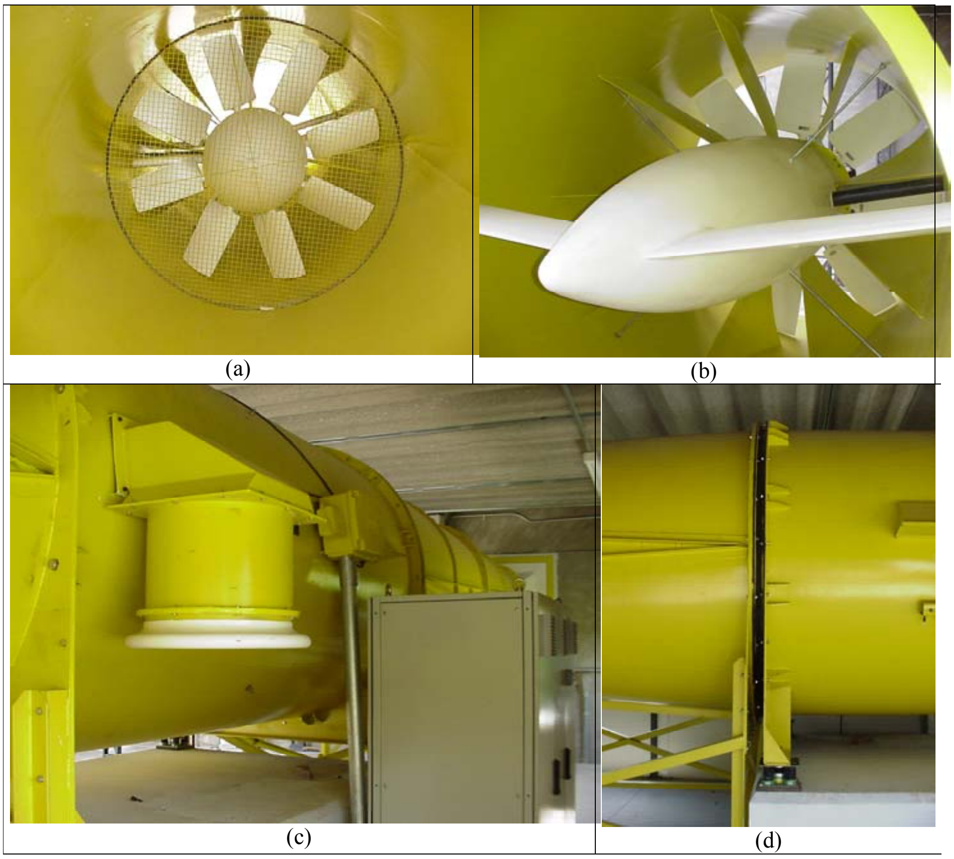

(a) (b) (c) (d)

Figure 9: (a) Fan frontal view, (b) fan back view, (c) Fan external view, showing one auxiliary fan and the frequency inverter and (d) interface between diffuser first part and the fan over the concrete block.

3.7. Fast Expansion Diffuser and Wind Effect Damping Chamber

As mentioned before, due to the open circuit type, ITA’s wind tunnel flow is affected by atmospheric wind variations, which must be minimized in order to improve the test results reliability. According to information acquired in the international literature (Eckert et al, 1976), the minimization of the atmospheric wind effects can be made by deflecting the wind tunnel exit flow to upward direction. In this wind tunnel this task is performed by an element constituted by two parts: (i) the first one is a fast expansion diffuser, made of 3 mm tick iron plates and (ii) a wind effect damping chamber, made of masonry, responsible for deflecting the wind tunnel flow upward, by using a set of guiding vanes.

The dimensions of both parts mentioned above are shown in the figure 10. The fast expansion diffuser is connected to the exit section of the diffuser second part (see figure 11a) and its function is to promote an additional reduction of the flow velocity, in order to minimize the pressure losses occurring due to the flow deflection. Its design was based on the works performed by Cochran & Kline (1958) and Moore Jr. & Kline (1958), that reports the possibility of using splitting plates to correct problems associated to flow separation. This kind of problems can still be treated by placing a screen in the entrance section of the fast expansion diffuser as reported by Schubauer & Spangenberg (1949). Both kinds of solutions can be implemented in ITA’s wind tunnel if problems were detected during the calibration work.

The wind effect damping chamber is designed like a closed wind tunnel 90 degrees bend (see Rae & Pope, 1984), where the entrance and exit cross section areas are the same. The set of guiding vanes mentioned before was designed, according to Rae & Pope (1984), and it is used to minimize the pressure loss coefficient associated to a 90 degrees flow bend. The guiding vanes are designed as arc of circle and they are made of 3mm thick iron plates with approximately 2m of span and 1m of chord. Once the wind effect damping chamber has a width of 4 m, a vertical wall, located at the middle of such chamber (see figure 11 b), had to be built to fix the guiding vanes extremity. After the determination of the best distance among the guiding vanes it was verified the need for 12 ones in each side of the wind effect damping chamber. The last two detail of this element are: (i) the presence of a screen located at the exit section, whose objective is to avoid the entrance of small animals inside the wind tunnel and (ii) the presence of a door at the side wall of the wind effect damping chamber (see figure 11 b), used to allow access to the interior region of the wind tunnel, which is very useful in case of fan maintenance and to clean the region near the door, where dirt can fall through the exit section.

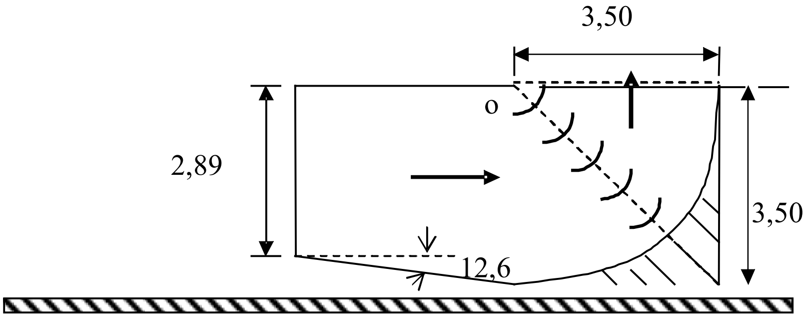


Figure 10: Side view of the fast expansion diffuser and the wind effect damping chamber. Dimensions in meters.


(a) (b)

Figure 11: (a) Fast expansion diffuser (in red) (b) Internal view of the wind effect damping chamber, with vanes being installed.

4. Final Remarks

One of the most important characteristics of ITA's wind tunnel is the flexibility to exchange the experimental apparatus installed in the test section, in order to reduce the cost and time to implement new experiments. This characteristic was obtained by designing the test section with removable windows, which can be exchanged to fit specific requirements, as explained before.

As mentioned before, there is a sealed chamber around the test section where the pressure can reach about 400 mm of water below ambient pressure when the test section velocity is set to its maximum value. Inside such sealead chamber there is a control cabinet used to operate the wind tunnel and to run the experiments. All information useful to the research works conducted in the wind tunnel is concentrated at a control panel, such as: (i) the air dynamic pressure, velocity and temperature, (ii) the model attitude (angles of attack and yaw), (iii) the status of the laboratory doors, which must be opened during wind tunnel operation and etc. The data acquisition and experiment control are performed by a computer, located near the control panel. A false floor, located above the real one, is used to become easier the tasks performed in the test section, like model installation and adjustments, and it allows the passage of shielded cables, used to signal transmission from the test section region to the control cabinet interior. Finally, it is interesting to inform that: (i) electric, telephone and network cables enter the sealead chamber through passage boxes, which must be sealed too, (ii) water coming from a refrigeration tower is available to be used in the refrigeration system of laser equipments and (iii) a high pressure point (28 atm) is available inside the sealed chamber to be used when compressed air is required, as will be the case in one of the research programs proposed by EMBRAER.

The wind tunnel described in the present paper was designed in 5 months, starting in September of 2001 and was the result of a joint effort of a team constituted by personnel of ITA, IAE-CTA and EMBRAER. Almost all the wind tunnel was manufactured and mounted by TECSIS and financed by the Fundação de Amparo a Pesquisa do Estado de São Paulo (FAPESP), with a cost of R$ 250,000.00 (US$ 86200,00). This activity takes about one year to be executed and starts on February of 2002. The new wind tunnel is located at Prof. Feng Aeronautical Engineering Laboratory and its installation required some building infra-structure adaptation, which was executed by a company contracted by EMBRAER at a cost of R$ 150,000.00 (US$ 51800,00). This activity has taken about 7 months and was started on April 2002.

Since February 2003 a series of experiments has been implemented to calibrate the test section flow. These experiments have been very useful to develop experimental procedures appropriated to an open circuit wind tunnel, where the atmospheric wind variations have an important hole, when reliable experimental results have to be obtained.

After this first phase, the wind tunnel will be initially used to develop the two research programs described above, which were proposed by the EMBRAER personnel.

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6. References

Assato, M, Fico Jr., N.G.C.R. and Girardi, R.M. 2003, Experimental Study of the Turbulence Level at the Intake an Open Circuit Wind Tunnel, AIAA-PAPER 2003-38481

Cochran, D.L. & Kline, S.J., 1958, "Use of Short Flat Vanes for Producing Efficient Wide-Angle Two-Dimensional Subsonic Diffusers", NACA TN-4309.

Eckert, W.T.; Mort, K.W. & Jope, J., 1976, "Aerodynamic Design Guidelines and Computer Program for Estimation of Subsonic Wind Tunnel Performance", NASA TN D-8243.

Eckert, W.T.; Mort, K.W. & Piazza, J.E., 1976, "An Experimental Investigation of End Treatments for Nonreturn Wind Tunnels", NASA TMX-3402.

Girardi,R.M.; Fico Jr., N.G.C.R.; Mello, O.A.F. & Komatsu, P. "Design of the Research Subsonic Wind Tunnel of the aeronautical Institute of Technology", Proceedings of the Mechanical Engineering National Congress (CONEM 2002), João Pessoa, Oct. 2002.

Loehrke, R.I. & Nagib, H.M., 1976, "Control of Free-Stream Turbulence by Means of Honeycombs: A Balance Between Suppression and Generation", J. of Fluids Engineering, Vol. 98, Serie I, N. 3, pp. 342-353.

Lumley, J.L., 1964, "Passage of a Turbulent Stream Through Honeycomb of Large Length-to Diameter Ratio". Journal of Basic Engineering, pp. 218-220.

Mattos, B., Fico Jr., N.G.C.R. and Girardi, R.M, 2003, Design of the Contraction of ITA's Research Wind Tunnel Using CFD Tolls, AIAA PAPER 2003 3949

McKinney, M.O. & Scheiman, J., 1981, "Evaluation of Turbulence Reduction Devices for the Langley 8-Foot Transonic Pressure Tunnel", NASA TM-81792.

Moore Jr., C.A. & Kline, S.J., 1958, "Some Effects of Vanes and of Turbulence in Two-Dimensional Wide-Angle Subsonic Diffusers", NACA TN-4080.

Morel, T., 1975, "Comprehensive Design of Axisymmetric Wind Tunnel Contractions", J. of Fluids Engineering, pp. 225-233.

Rae Jr., W.H. & Pope, A., 1984, "Low-Speed Wind Tunnel Testing", John Wiley & Sons, Second Edition, USA.

Schubauer, G.B. & Spangenberg, W.G., 1949, "Effect of Screens in Wide-Angle Diffusers", NACA Report 949.