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INTERNATIONAL WIND TUNNEL TEST COMPARISON INVOLVING THREE LABORATORIES: IPT-BR, IMFIA-UY AND LACLYFA-AR

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Abstract. *This study presents an inter-comparison of results obtained by the members of the MERCOSUL Wind Tunnel Net (RETUNEL), IPT (Brazil), IMFIA (Uruguay) and LACLYFA (Argentina). The object of this study was to compare the results obtained in all 3 facilities of the flow on a type II terrain of a building 40 m high with square base 20 m wide at an angle of incidence of 45°. Results obtained in the 3 wind tunnels were closed but the correct modeling of the integral-length scale of the simulated boundary layer is difficult.*

Keywords: *atmospheric boundary layer, wind tunnel, conical vortices, turbulence, pressure coefficient*

1. INTRODUCTION

Wind tunnel simulations of structures subjected to strong wind require the correct modeling of several parameters. Simple geometric scaling is not enough and dynamic simulation, which requires equal Reynolds (Re) numbers in both the prototype and model, is not usually possible due to scale problems: prototype Reynolds number is just too large. If the model has fixed separation points (surfaces) and the model Re is large enough, the flow is insensitive to Re.

On the other hand, other difficulties arise. It is not enough to simply to setup the model in the wind tunnel and measure pressure coefficients. Jensen (1958) showed, 50 years ago, the importance of correct modeling of the atmospheric boundary layer and this is not a simple problem. Also, Baines (1963) showed the significance of boundary layer simulation. To get an appropriate boundary layer in a wind tunnel it is necessary to have very long test sections. Even in facilities with long wind tunnels (boundary layer wind tunnels), unless very small scales are used other devices besides a rough floor are necessary. The literature presents several possibilities (e.g. Counihan, 1969; Standen, 1972; Cook, 1973).

Therefore, wind tunnel testing of wind load depends not only on model but also on facility characteristics and boundary layer simulation. Actually, simulation scale is a result of important scales on the simulated boundary layer.

In this study a building 40 m high with a square base 20 m wide at 45° angle of incidence on a type II terrain (ABNT/NBR-6123) is simulated on three different atmospheric boundary layer wind tunnels, LACLYFA (Argentina), IMFIA (Uruguay) and IPT (Brazil) which form the MERCOSUL wind tunnel network (RETUNEL) as part of an ongoing effort to determine important aspects of wind loads on structures.

2. EXPERIMENTAL SETUP

Each facility used its own method to simulate the appropriate boundary layer. The models scales and dimensions used in each facility are presented in Tab. 1.

Notice that IMFIA used a cubic building which may affects the results even though comparisons are still possible.

IPT used the Counihan technique, Counihan (1969), with 4 elliptical spires with triangular cross section 1.4 m high, a castellated barrier 150 mm high and a rough floor composed of 60 mm high (H), 80 mm wide (W) and 20 mm thick (T), set-up in diamond configuration resulting in a roughness density λ of 0.05 where the roughness density is defined according to Raupach, *et al.* (1991):

$$\lambda = \frac{A_f}{A_t} \tag{1}$$

Table 1. Model scales

Characteristic Parameters	LACLYFA	IPT	IMFIA
Scale	1:100	1:57	1:67
Height, H (mm)	400	700	300
Width, W (mm)	200	350	300
Blockage, B (%)	5.7	4.1	1.9

where A_f is the total frontal area of every roughness element and A_t is the total surface area of the rough floor.

IMFIA applied a technique similar to Cook (1973) using a grid with 25 mm diameter rods positioned every 130 mm and a saw barrier composed of triangular spires 300 mm high and a rough floor with 28 mm cubes set-up in diamond configuration resulting in a roughness density of 0.01.

LACLYFA used 12 strips 35 mm wide spaced 70 mm from each other. These strips have 10 mm holes located every 50 mm. Downstream from this "grid", a rough floor composed of three sections on the following sequence: 65 mm x 65 mm x 200 mm (H x L x W) blocks; 5 spires; and more 40 mm X 40 mm X 200 mm (H x L x W) blocks in diamond configuration. The resulting roughness density was $\lambda = 0.06$.

Figure 1 shows the boundary layer simulation methods used by all three wind tunnels. Figure 2 shows the position of the pressure taps on the models.

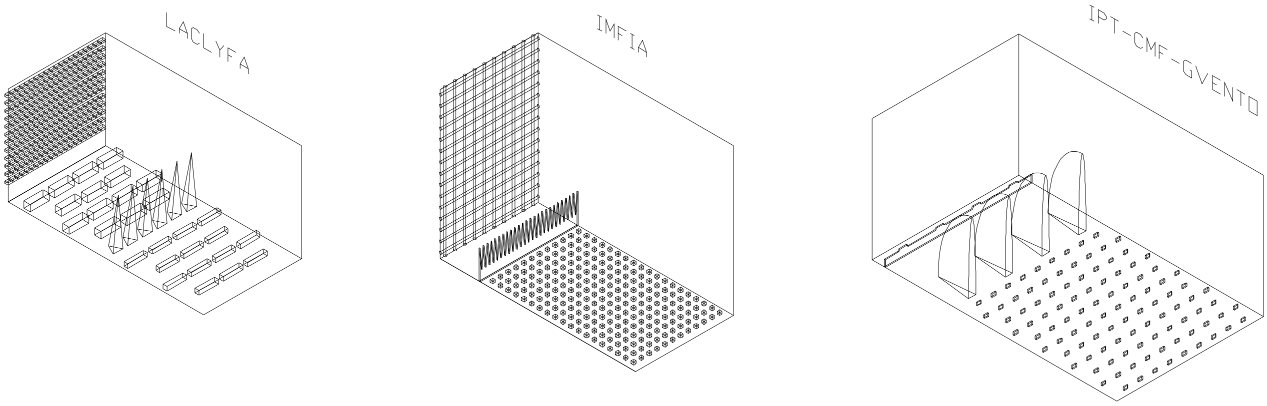

Figure 1. Boundary layer generation devices for all facilities

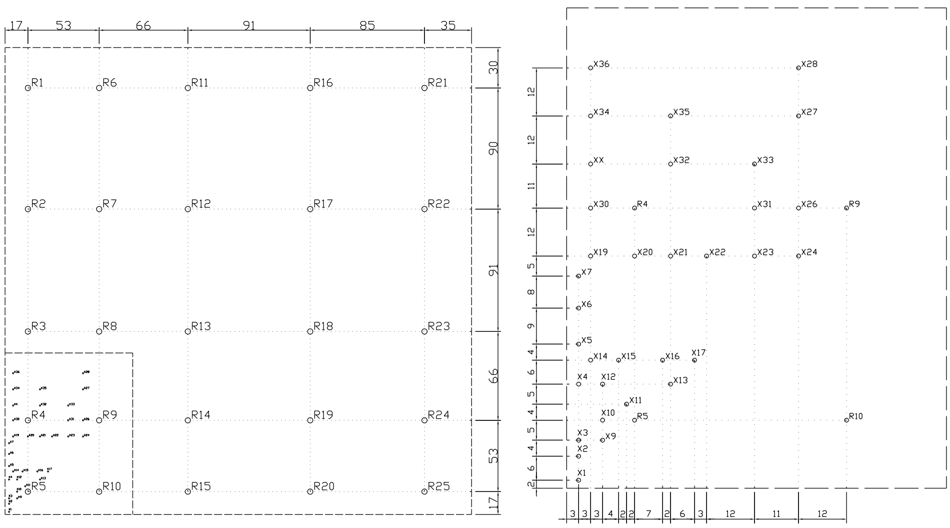

Figure 2. Position of pressure taps

3. ATMOSPHERIC BOUNDARY LAYER MODELLING

The prototype is a prismatic building 40 m high with a square base 20 m wide located in a flat terrain with sparse low buildings corresponding to rural areas. This type of terrain presents two advantages: (1) simple and homogeneous; (2) typically observed in Brazil, Argentina and Uruguay. This corresponds to type II terrain defined in ABNT/NBR-6123 (1988) and ESDU-85020 (2001). This terrain presents a roughness length $z_0 = 0.1\ m$.

Figure 3 shows the velocity and turbulence intensity profiles. The height is non-dimensionalized with respect to the building height and the velocity with respect to the boundary layer velocity at the top of the building (note that IMFIA's top corresponds to 0.5 since the building is lower).

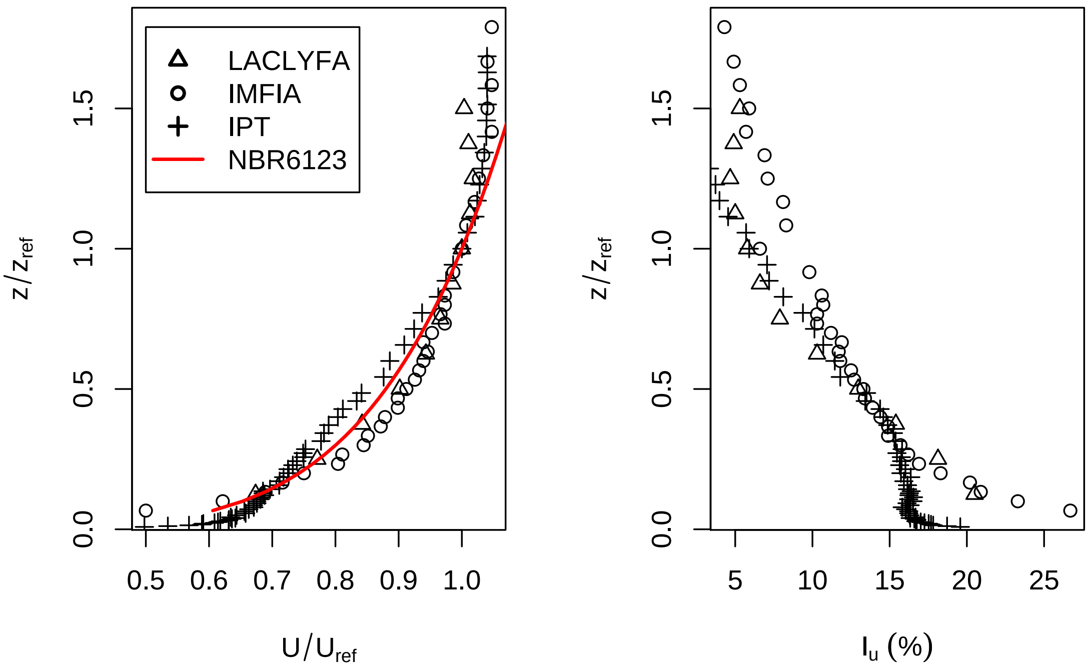

Figure 3. Velocity and turbulence intensity profiles

On the lower boundary layer, near the ground, the logarithmic law of the wall is valid:

$$\frac{U}{u_*} = \frac{1}{\kappa} \ln \frac{z-d}{z_0} \tag{2}$$

where $u_* = \sqrt{\tau/\rho}$ is the friction velocity, $\kappa = 0.40$ is the von Karman constant, d is the zero-plane displacement. This equation is usually valid for $h_0 << z << \delta$ where h_0 is the mean size of the roughness elements and δ is the boundary layer height. Fitting the logarithmic law to the velocity profiles (Fig. 3) using equation 2 the roughness length z_0 can be calculated for each facility (Tab. 2).

Table 2. Roughness length for each facility

Wind tunnel	Roughness length (mm)	Scale (z_{0M}/z_{0P})
LACLYFA	1	1/100
IMFIA	1.8	1/55
IPT	2.2	1/45

Table 2 also shows the scale factor calculated from z_0:

$$e_L = \frac{z_{0M}}{z_{0P}} \tag{3}$$

Notice that the scale factors are approximately the same as the scale deduced from the geometry. (Tab. 1).

Another important characteristic parameter of turbulent flows is the integral length scale. For $z_0 = 0.1\ m$, Simiu and Scanlan (1996) provide the following equation:

$$L_u^x = 65z^{0.25} = 163\ m \tag{4}$$

ESDU (2001) provides a value:

$$L_u^x \approx 290\ m$$

These two values show that the integral length scale is not an accurate parameter and different sources present different values. The basic definition for the integral length scale is:

$$L_u^x = \overline{U} \int_0^\infty \rho(\tau)\, d\tau \tag{5}$$

where $\rho(\tau)$ is the auto-correlation function of the velocity. Simiu and Scanlan (1996) propose another method of estimating the integral length scale from the non-dimensional velocity spectrum:

$$L_u^x = \frac{1}{2\pi} \frac{\overline{U}}{f_{peak}} \tag{6}$$

where f_{peak} is the frequency with maximum non-dimensional spectral density defined as:

$$\frac{fS(f)}{\sigma_u^2}$$

Figure 4 shows the non-dimensional spectrum of the velocity fluctuations obtained for all wind tunnels at the height of the top of the model. This figure also shows the Kolmogorov spectrum slope at the inertial range. Table 3 shows several parameters characterizing the simulated boundary layer and velocity spectrum at the top of the model.

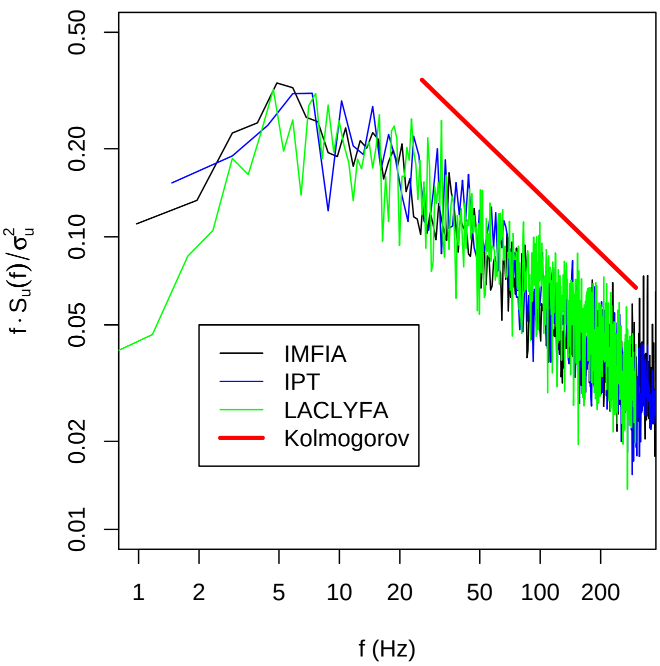

Figure 4. Non-dimensional spectrum

From the mean flow point of view the three simulations are similar and agree with a rural terrain wind exposure. The roughness length (z_0) obtained belongs to the prototype scale between 0.10 up to $0.13\ m$, similar to described by ESDU (2001).

At the building height LACLYFA and IPT flow simulations show a similar intensity of turbulence, around 7%, while the IMFIA one shows a 13% intensity of turbulence. It must be quoted that the IMFIA building height is the half of the other ones in dimensionless form.

A similar observation for the small scale parameter is valid. The main difference between simulated flows and prototype situation is the integral longitudinal turbulence scale.

Table 3. Characteristic parameters of the boundary layer at the top of the model

Parameter	Prototype	LACLYFA	IMFIA	IPT
Scale factor	1	1/100	1/67	1/57
Roughness length - z_0 (mm)	100	1	1.8	2.2
Integral length scale - L_u^x (m)	163-290	0.1	0.54	1.63
Small scales (mm)		20	30	35
Turbulence intensity - I_u (%)		7.8	13.3	7.2
Frequency of small scales (Hz)		480	450	531
Non-dimensional spectrum peak		0.0245	0.0215	0.0252
Parameter of small scales	1100	149	363	131

4. RESULTS

The building models were tested for a wind incidence 45° from the normal to a face, let say collinear to the roof diagonal. On the roof were located pressure taps as Fig. 2 shows. Since the flow has an incidence angle of 45^o, two conical vortices form on the leading corner with very low mean pressure and high fluctuations, Banks *et al.* (2000). These two vortices, when forming, have much small length scales than the boundary layer and should be excited by the corresponding length scales present on the turbulent boundary layer. The small scale turbulence parameter (Ahmad and Kumar, 2002), S, is defined as

$$S = \frac{fS_u(f)}{\sigma_u^2} \cdot \frac{\sigma_u^2}{\overline{U}^2} \qquad f = 10\frac{U}{W} \tag{7}$$

The small scale turbulence parameter characterizes the content of turbulence energy at the small scale turbulence (10% of the width of the model in this case). As shown in Tab. 3, IPT and LACLYFA present very similar S but IMFIA has a higher result because the model is lower and the flow has a higher turbulence intensity, as it was quoted. Also, all these values are much lower than the results of Tieleman (1996) which corresponds to a much smaller, almost cubic prototype building.

Figure 5 presents the mean pressure coefficient defined as

$$C_p = \frac{P - P_0}{\frac{1}{2}\rho U^2} \tag{8}$$

The lower pressure present in the edges of roof clearly indicates the presence of conical vortices from the leading corner. Figure 6 shows the minimum pressure coefficient and Figure 7 shows the standard deviation of the pressure coefficient. Again, the conical vortices can be easily identified from the standard deviation of the pressure coefficient. The mean pressure coefficient is very important in determining structural loads on the building. The minimum pressure, on the other hand, since it is related to smaller scales is important when estimating local loads on windows and other smaller constructs. Table 4 shows the mean and minimum pressure coefficients on two pressure taps.

Table 4. Mean and minimum pressure coefficients on positions X1 and X4 (Fig. 2)

	LACLYFA	IMFIA	IPT
C_p X1	-0.9	-3.7	-4.45
C_p X4	-4.0	-2.4	-3.7
$C_{p,min}$ X1	-1.5	-9.3	-7.9
$C_{p,min}$ X4	-5.9	-5.0	-5.4

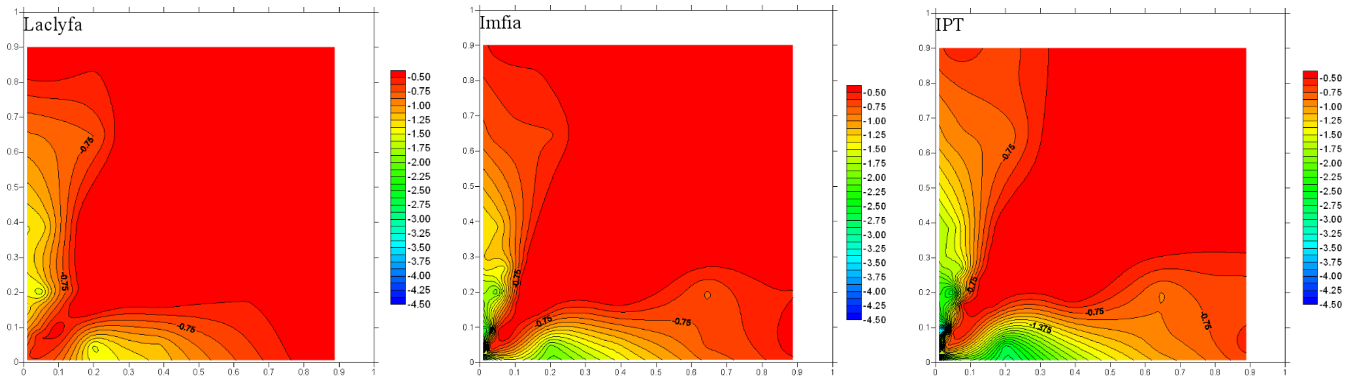

Figure 5. Mean pressure coefficient

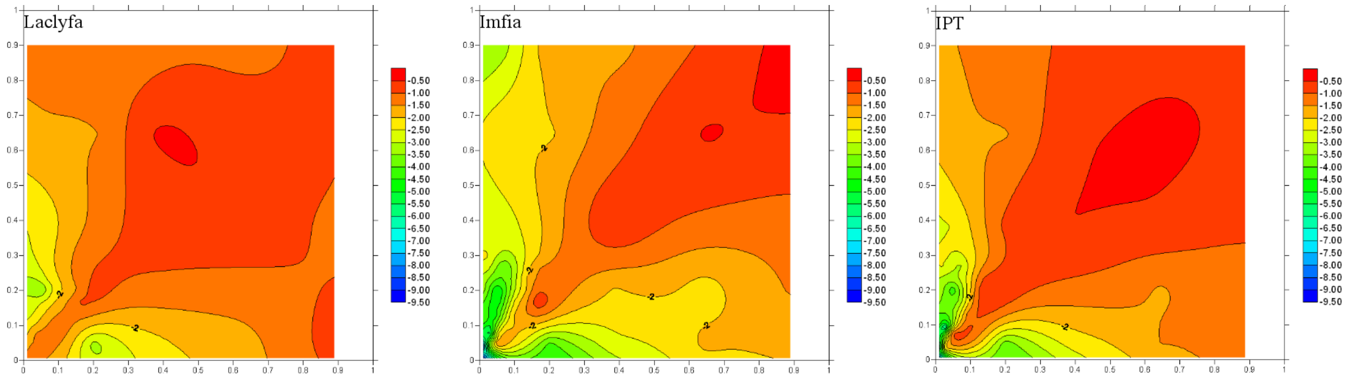

Figure 6. Minimum pressure coefficient

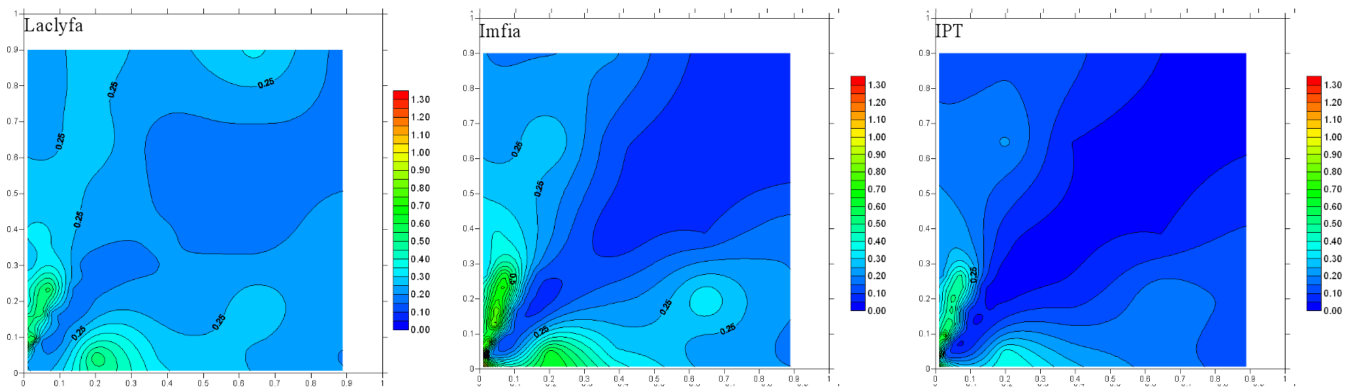

Figure 7. Standard deviation of pressure coefficient

Qualitatively, the pressure distributions are similar in the three cases and the pressure level is similar in all cases. It is interesting analyze the results on the roof corner. In the taps X1 and X4 all tests show similar mean pressure values. The minimum values obtained at the tap X4 are near one of other, but there are some differences on the tap X1. A source of differences should be expected since both pressure taps are very close to the leading edge and any errors in positioning either the pressure taps or the model can result in large differences in mean and minimum pressure.

As shown in Cheng-Hsing and Meroney (2003) there is a large correlation between winds with high lateral components and lower pressure on the roof right under the conical vortices. The energy of this lateral wind component, which is associated with the small scale turbulence content as shown in Tieleman and Akins(1996). Figure 8 shows the relation between the small scale turbulence content and minimum pressure coefficient $C_{p,min}$.

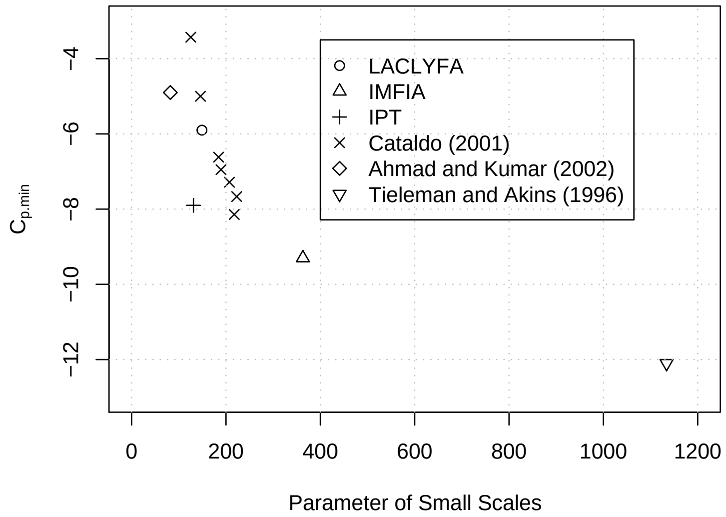

Figure 8. Correlation of pressure peak and small scale turbulence content

On Fig. 8 a curve can be seen that relates pressure peak and small scale turbulence content using several published results and all ordered over it. This shows the importance of modeling correctly the smaller scales of turbulence is more important than the integral scales when conical vortices are present.

5. CONCLUSION

In the three wind tunnels similar flows were established in different scales, as can be seen on Section 3. These flows presented to the prototype scale a roughness length (z_0) between 0.10 up to $0.13\,m$; longitudinal turbulence intensity near of 7 % at height of the roof of the models, which correspond to 40 m in the prototype. In all cases the terrain was a rural type. From the results it can be seen that the simulation of the integral scales strongly depends on the each particular media, in the case, the size, length, and devices used in each wind tunnel.

It must be emphasized that the wind tunnels characteristics, the devices used to simulate the atmospheric boundary layers, the instrumentation used to the velocity measurements, the reference velocity during the tests and the flow simulation scale factors are all specific of each laboratory. Hence, these results make valid in the specific circumstances they were carried out.

It was also observed in Section 4 that the pressure distribution on the roofs are similar. Additionally, it was possible to evidence that the minimum pressure coefficients obtained on the roofs of the models by the three involved laboratories fits well on one curve when the small scales parameter is used as the variable. This results also is in accordance with other authors as can be seen in Fig. 8.

6. ACKNOWLEDGEMENTS

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8. Responsibility notice

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