The 2016 World Congress on
Advances in Civil, Environmental, and Materials Research (ACEM16)
Jeju Island, Korea, August 28-September 1, 2016

Wind tunnel testing and CFD analysis of an airport terminal building

*Roberto Gómez[1)], R. Sánchez[1)], A. Pozos-Estrada[1)], L. Arenas[1)], O. Rosales[1)] and M. Mendoza[1)]

[1)] *Institute of Engineering, National University of Mexico, 04510 Mexico D.F., Mexico*
[1)] *rgom@pumas.ii.unam.mx*

ABSTRACT

A new terminal building is planned for an airport in Mexico. The architectural design of the new building prompts the analysis under two schemes: structural and comfort. These, because the concrete external circular façade has vents which allow the flow of wind into the terminal. Inside the concrete façade an internal hermetic arch glass structure is placed with a corridor between both structures. Building design manuals do not include this type of geometries, so it is necessary to compare the magnitudes of the pressures that recommended design standards with those obtained from a wind tunnel test. On the other hand, the corridor between the concrete façade and the arch of glass give place to an irregular and turbulent flow of the wind inside the building which may cause inconvenience to passengers and visitors.

This paper summarizes the results of test program in a boundary layer wind tunnel laboratory of a scale model of the ventilated airport terminal. The model used and the different considerations for the study of the model are presented. A Computational Fluid Dynamic (CFD) analysis was also carried out in order to provide magnitudes of wind forces and comfort parameters.

1. INTRODUCTION

A new airport terminal building was projected based on a circular concrete roof (cover or dome) with vents and an interior circular glass dome. The concrete dome comprises 16 arches separated each 12 m, and has a total length of 180 m with a width of 62 m and a height of 30 m (Figs. 1). Concrete arches are joined by means of horizontal concrete tablets that allow the flow of air into the interior arch, and between the two arches a corridor of approximately 20 m wide by 156 m long is conformed. The ends of the external concrete arch in the longitudinal direction, allow wind flow between the two arches (concrete and glass) in the longitudinal direction of the building. The interior of the internal glass structure is completely closed or isolated from air flow.

The architecture of the new terminal cannot be cataloged as a typical structure, is an example without precedent in Mexico's airports architecture: a functional terminal, light and transparent. Given the atypical architecture, design by wind of the new building prompts the testing in a laboratory or wind tunnel, as specified in the Mexican Manual of Civil Works of the Bureau of Federal Electricity (MOC, 2008).

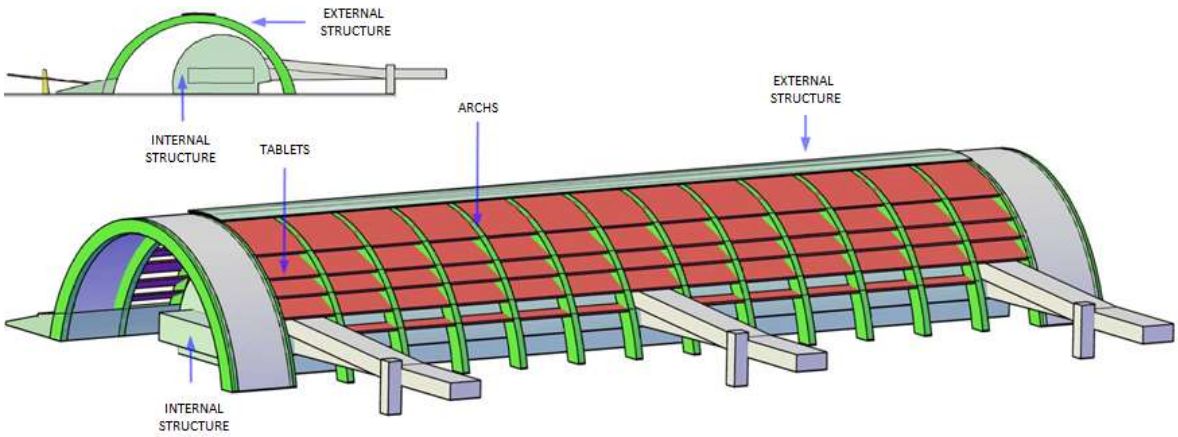


Fig. 1 Computer renders of the new airport terminal

Currently, the preliminary project is finished and some architectural and structural details including the review of pressures produced by wind for the design of the two arches and the evaluation of the comfort of the passengers inside the terminal are being evaluated. Access to waiting areas will be an experience for visitors, since they extend all along the two arches mentioned. The architectural design of the new terminal will allow the flow of wind through the two longitudinal sides and the gaps between the concrete arches, which can give rise to an irregular and turbulent wind flow inside the terminal producing discomfort of the visitors.

On the other hand, the new air terminal is located in a zone that has practically no neighboring buildings so it can be categorized as open exposure in accordance with the classification for wind design (MOC, 2008). In addition, the building could present an issue of comfort for passengers, since from the point of view of comfort, in structures as the proposal (an external arch and another inmate), and the corridor (interspace) between arches lends itself to the formation of an artificial "venturi" so the wind flow is one of the most important issues to be considered in its architectural design parameters.

In the following, results from a wind climate study in the area of the airport will be presented. Some aspects of the construction and implementation of the scaled 3D model of the terminal building for representation and study at the wind tunnel will be described; the results of the analysis of the information recorded in the wind tunnel when the model is exposed to different angles of incidence of the wind will be presented as well. This information is presented in terms of pressure coefficients which can be used to check the structural design of the building.

On the other hand, part of the paper will be used to describe the 3D computer model which was used to simulate the flow of wind around and inside the terminal building. Through the analysis of this model, using techniques of Computational Fluid (CFD), conditions of comfort for the passengers inside the terminal were evaluated using the wind and the flow distribution of wind velocities. It should be noted that this study does not review the structural design of the building of the new air terminal. Finally, the conclusions of the study are presented.

2. WIND CLIMATE

The wind climate study was developed based on information corresponding to 29 months of records of wind velocity in three different years. The data obtained shows that the maximum speed recorded is 36 m/s corresponding to the month of May of 2014. Another important factor in the characterization of the wind is the direction of incidence.

The following figure shows the distribution of angles of incidence of the maximum wind velocities with respect to the North. The red numbers indicate the number of times that the angle of incidence of the wind falls within a particular sector of the wind. It is shown that the incidence of the dominant wind is in the 240 to 270 ° sector. Superimposed in this figure is a view of the airport.

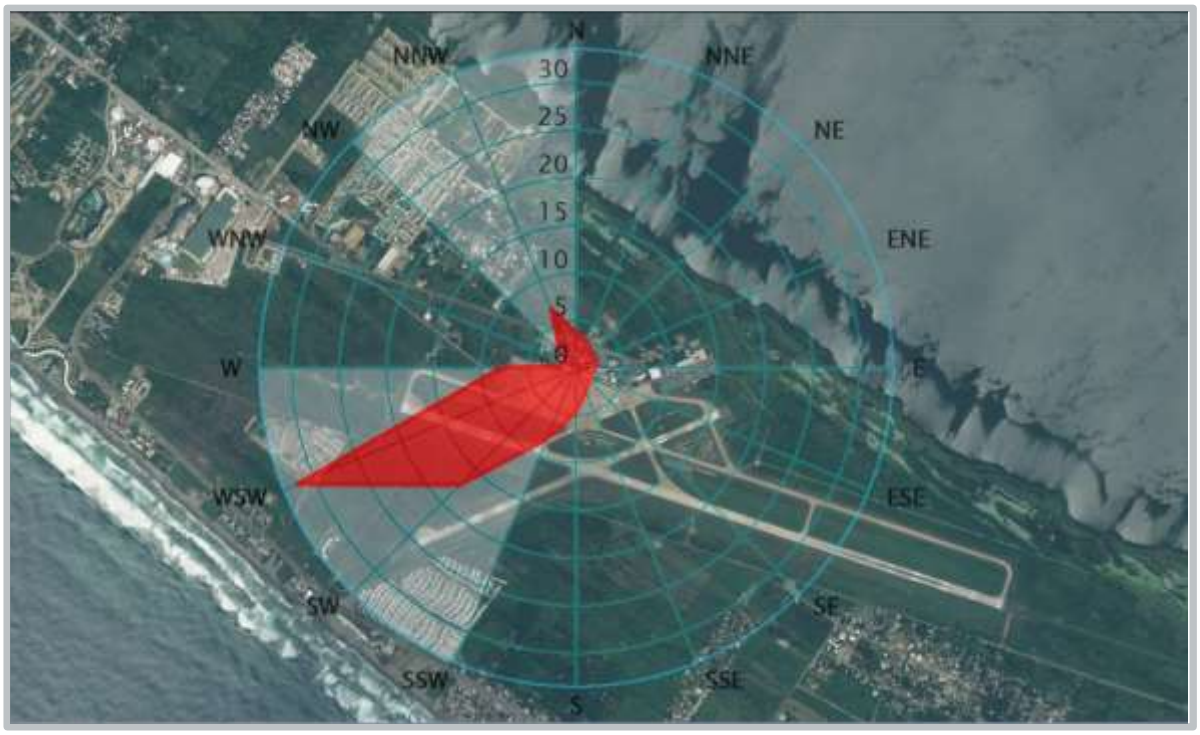


Fig. 2 Distribution of angles of incidence of maximum wind speeds

In order to count with more elements for the development of the statistical model, graphs presenting the seasonal variation of the maximum speed of the wind and its direction of incidence were also derived. These graphs are not presented in this work.

2.1 Statistical wind climate model

The development of the statistical wind climate model was based on the information described above. The mean hourly wind speeds in open terrain predicted by the statistical model developed by the authors are shown in the following table. The same table shows mean wind speeds provided by the Manual of Civil Works (MOC, 2008), which were transformed into mean hourly wind speeds for comparison.

Table 1 Comparison of mean wind hourly speeds for open terrain

Return period (years)	Author´s model V (km/h)	MOC (2008) V (km/h)	MOC (1993) V (km/h)
10	96.44	87.8	-
50	115.10	105.57	-
200	130.84	127.8	122

Table 1 shows that wind speeds obtained with the model developed by the authors are approximately 3% greater than those proposed by the MOC (2008) for a return period of 200 years. This may be due to the difference in corrections, quality of data and methodologies adopted in the prediction of wind speeds. Fig. 3 shows the wind speeds predicted with the author´s model for different return periods for a height of 10 m.

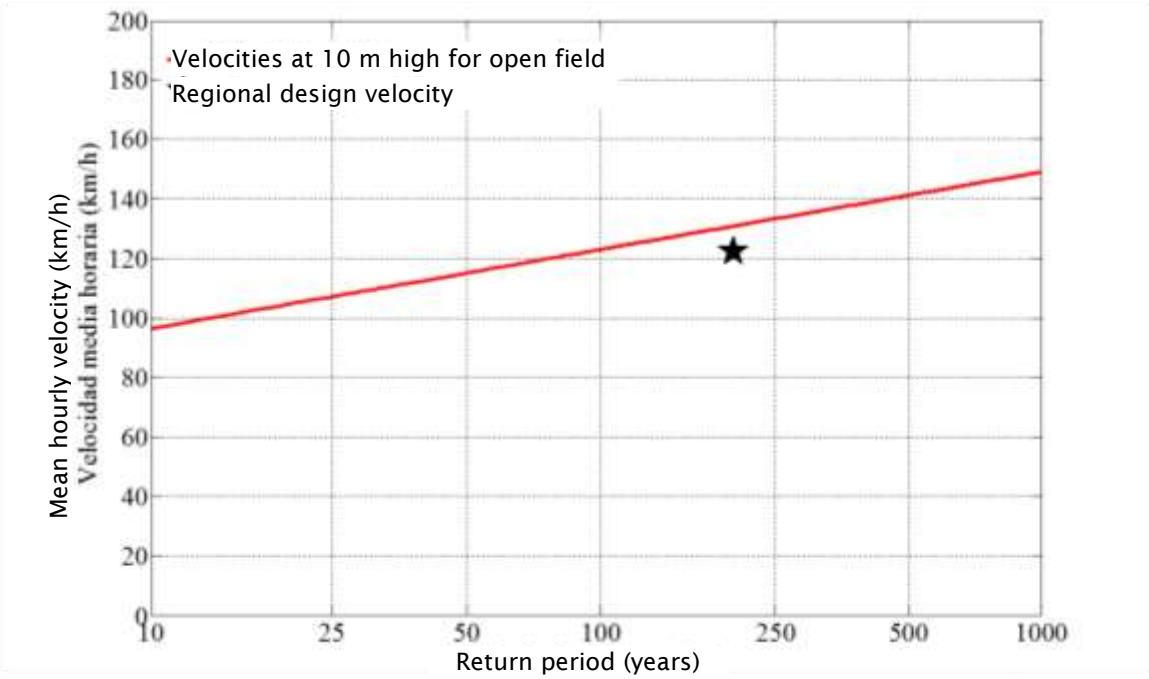


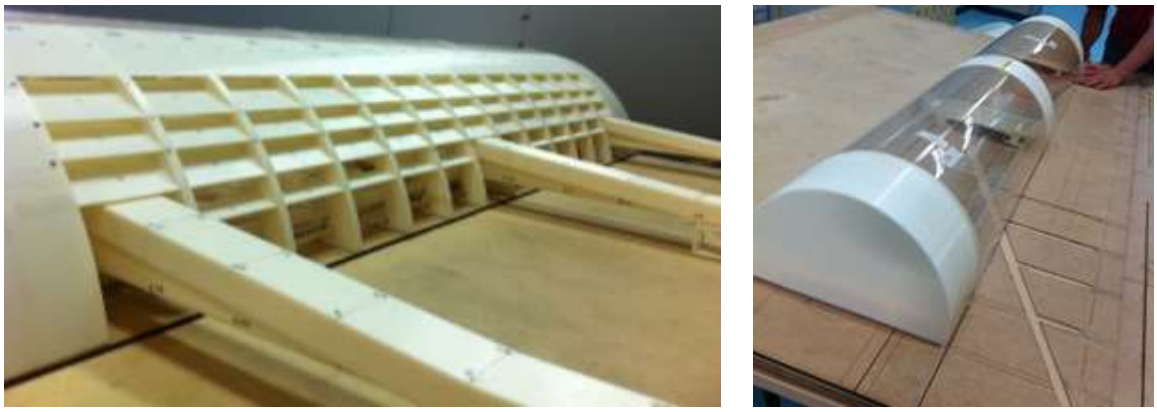
Fig. 3 Mean hourly wind speeds at 10 m height predicted with the author´s statistical model for different return periods

3. WIND TUNNEL TESTING

Because of the geometry of the prototype and dimensions of the cross section of the wind tunnel, to study the terminal building of the airport a model with a scale 1 to100 was fabricated with final dimensions of 1.5 x 1.9 x 0.3 m. The model was developed with the combination of different techniques of additive manufacturing. The national laboratory of additive manufacturing, 3D scanning and computed tomography (MADiT) of the Center of Applied Sciences and Technological Development (CCADET), of the National University of Mexico allowed the use of two additive manufacturing technologies: Fused Deposition Modeling or FDM (for its acronym in English), and Stereolithography (SLA, also for its acronym in English). The FDM technology was chosen (Ruiz - Huerta et al, 2014; Ruiz - Huerta et al, 2015), due to its advantages, for

the preparation of most of the scale model of the external arch of the terminal building of the airport (Fig. 4a)

The internal glass dome of the terminal building model was manufactured with acrylic of thickness of 6 mm (Fig. 4b).



(a) (b)

Fig. 4 Scale model of the airport terminal. a). External facade (airside) and jet bridges; b). Internal glass dome

3.1 Instrumentation of the model

To define the instrumentation of the scale model, a preliminary gross computer analysis was carried out based on an approximate model of the air terminal building. Information related to the structural design of the air terminal was also reviewed. This activities allowed the identification of higher pressure and suction areas which were used to locate 768 registration points on the concrete dome and 176 recording points in the glass dome of the scale model; 64 registration points (2 of 3 runways with 32 sensors at each of these) were used for catwalks and 16 more for the records in the roof cantilever. A total of 1024 registration points were defined and grouped into 8 blocks with the objective of organizing the testing sequence.

3.2 Results

The following paragraphs summarize the results of pressure magnitudes recorded in the air terminal model. Based on the wind climate study described above, the model was analyzed at intervals of 10˚ of incident simulated wind flow in a range of 360°. Typical time records of pressures were recorded for each recording point: maximum, minimum and mean values were determined for each time history and incident angle.

Because of the architectural design of the external concrete dome, both outside and inside surfaces were instrumented in order to record time histories of pressures, assuming the same locations for recording. For the internal crystal dome, only recording points on its external surface were assigned.

Figs. 5 and 6 show the maximum values (considering the whole range of incident wind directions) acting on the outside of the concrete dome. Only half of this dome is displayed since the structure is symmetrical. The maximum recorded value was 2.7kPa. Figs. 7 and 8 present similar results but associated to negative pressures (suction).

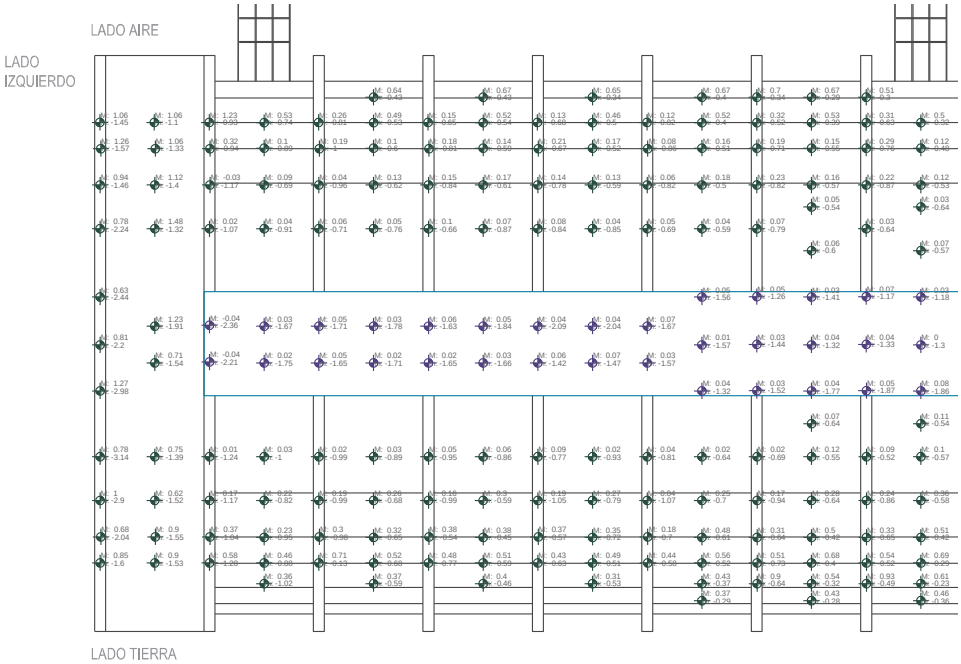


Fig. 5 Maximum values of pressures on the external surface of the concrete dome. View from the top.

Fig. 6 Maximum values of pressures on the external surface of the concrete dome. Lateral view

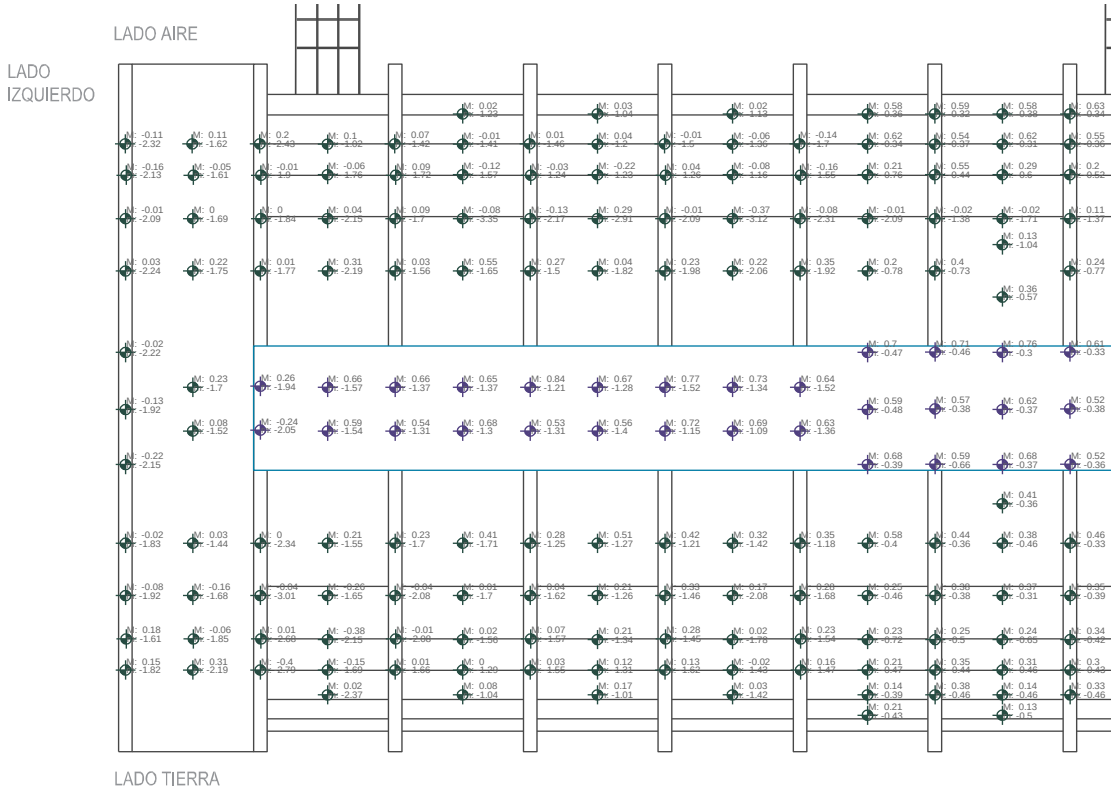


Fig. 7 Maximum values of pressures on the internal surface of the concrete dome. View from the top.

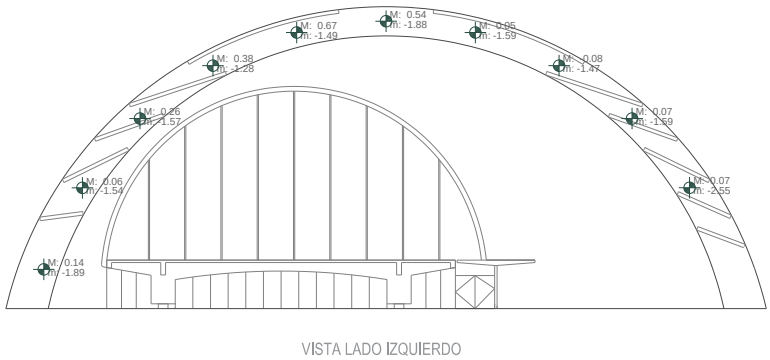


Fig. 8 Maximum values of pressures on the internal surface of the concrete dome. Lateral view

As mentioned, at the recording points of the concrete dome both outside and inside pressures were recorded. These values were subtracted (internal - external pressure) and their maximums magnitudes for all angles of incidence of wind flow were calculated as well as their mean values.

With respect to the internal glass dome, since its interior is isolated from the wind flow, only pressures acting on its outer surface were registered. The corresponding maximum and mean values were – 3.03kPa and - 2.9kPa. The same procedure was applied for catwalks and the roof at the entrance of the terminal building.

The described results are all associated to a wind velocity of 27 km/h and correspond to values of pressures expected at the real structure.

4. CFD ANALYSIS

This part of the paper is dedicated to the evaluation of pedestrian comfort to windy conditions that may develop in and around the building of the air terminal, considering aerodynamic and architectural issues, and magnitude and direction of the wind at the construction site. The objectives of this part of the study are: determine the pedestrian-level wind distribution, detect critical comfort areas (Stathopoulos y Baskaran, 1996) and identify the source of any undesirable wind conditions. The analysis and distribution of velocities and pressures is performed using Computational Fluid Dynamics.

4.1 Human comfort

Human comfort outdoors can be affected by a wide range of parameters including the speed of the wind, temperature of the air, relative humidity, solar radiation, the quality of the air, human activity, type of clothing, age of persons, etc.; so, the acceptability of wind conditions in any atmosphere will always be, to some extent, subjective.

From research studies (Lawson, 1990; Mohamed, 2013) some parameters have been derived to evaluate the comfort of pedestrians walking in areas of strong winds. However, wind tunnel studies have shown that these levels of comfort must be modified to include the effects of wind gusts or peaks of high velocities of short duration, that is, 3 seconds (3s).

4.2 Mathematical model

A 3D finite volume numerical model was developed to perform various simulations. A general view of the mesh used for the study of the air terminal building is shown in Fig. 9.

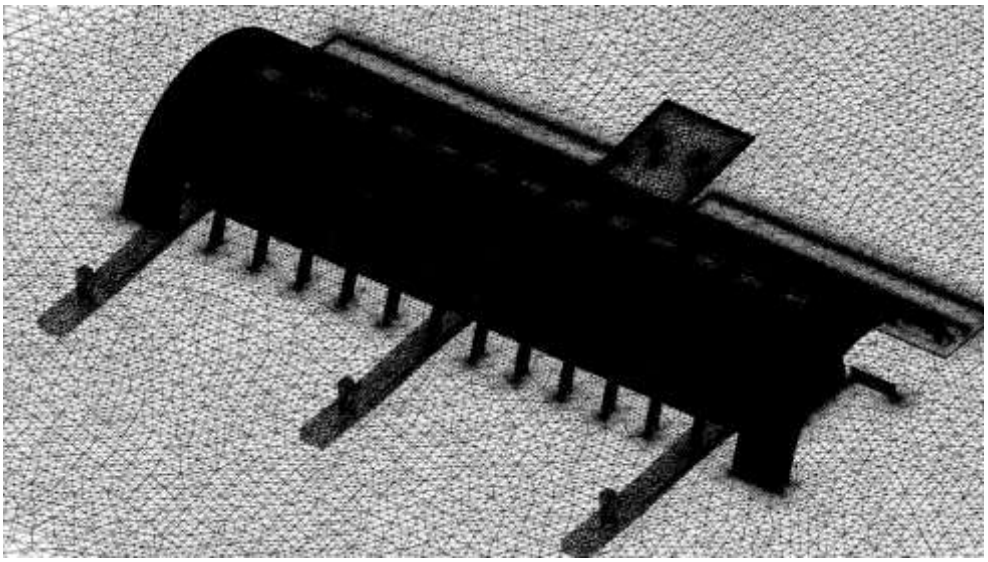


Fig. 9 Discretization of the numerical domain for the air terminal building.

4.3 Numerical results

For each direction of analysis three plots were prepared. The first shows the wind speeds that could be reached at 1.5 m above the floor level; the second shows wind speed contours or streamlines, also at 1.5 m above the floor level; and the last plot presents a perspective of the 3D model in order to illustrate how the wind "bathe" the structure. Also, for the description of the effects of wind on pedestrians, the areas or zones shown in Fig. 10 were used; these are areas within the terminal building between the two domes, both the land side and air side; in the inner part of the internal or glass dome (last waiting area) identification zones were not defined because the wind does not penetrate into this area.

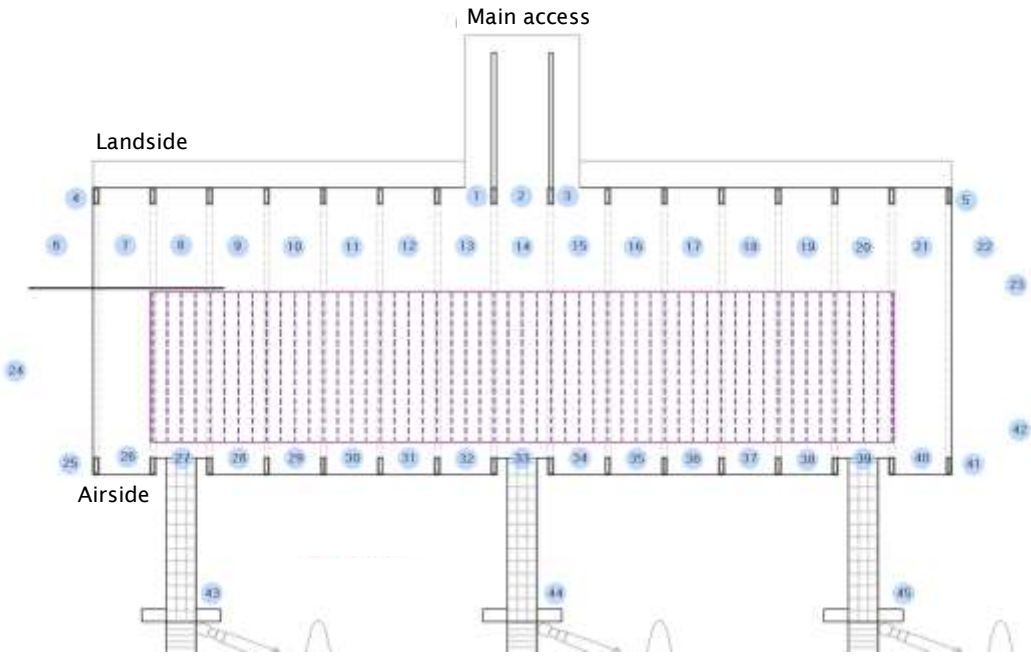


Fig. 10 Zones for description of comfort analysis

An example of the aforementioned plots is presented in Figs. 11 to 13. These correspond to an incident wind flow at 90º with respect to the longitudinal axis of the terminal building.

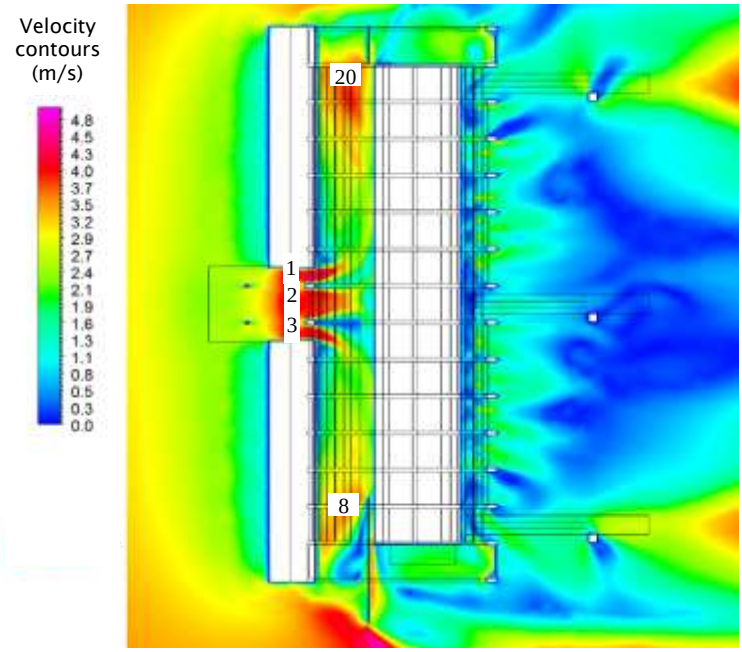


Fig. 11 Plan view of velocity contours, incident wind at 90˚

Figs. 11 shows that for zones 1, 2, 3, 8, and 20 within the terminal building, wind speeds around 4.5 m/s are developed. However, this value meets the criteria of comfort for people who remain standing and walking. This value is on the edge of the criterion comfort for people seated or having a sedentary activity. It should be remembered that the model does not consider any kind of door at zones 1, 2 and 3.

Figs. 12 and 13 show the effect at the corners: increased pressures and dispersion of the streamlines, as reported in the literature (Dyrbye, 1997; Simiu, 1978).

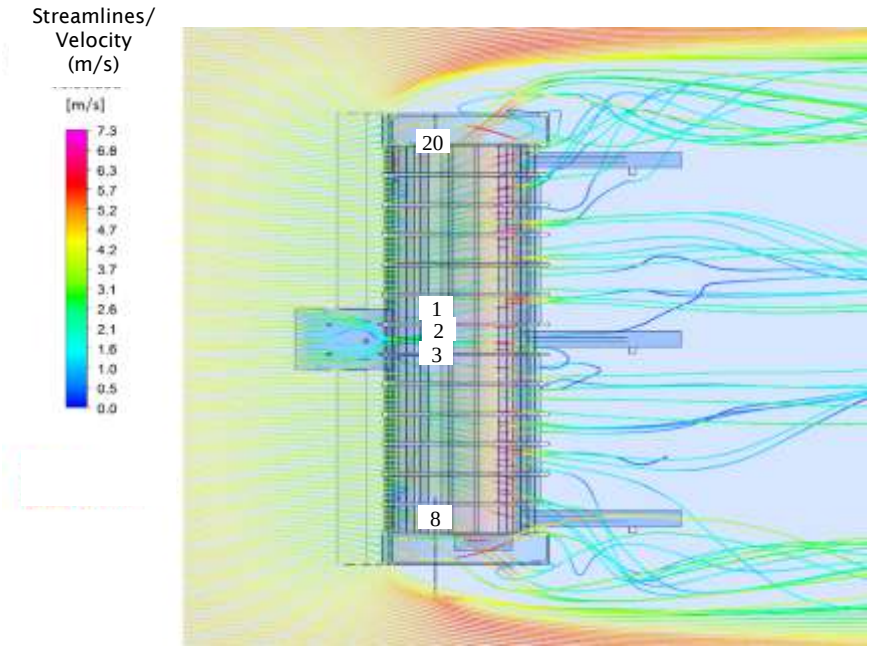


Fig. 12 Plan view of streamlines, incident wind at 90˚

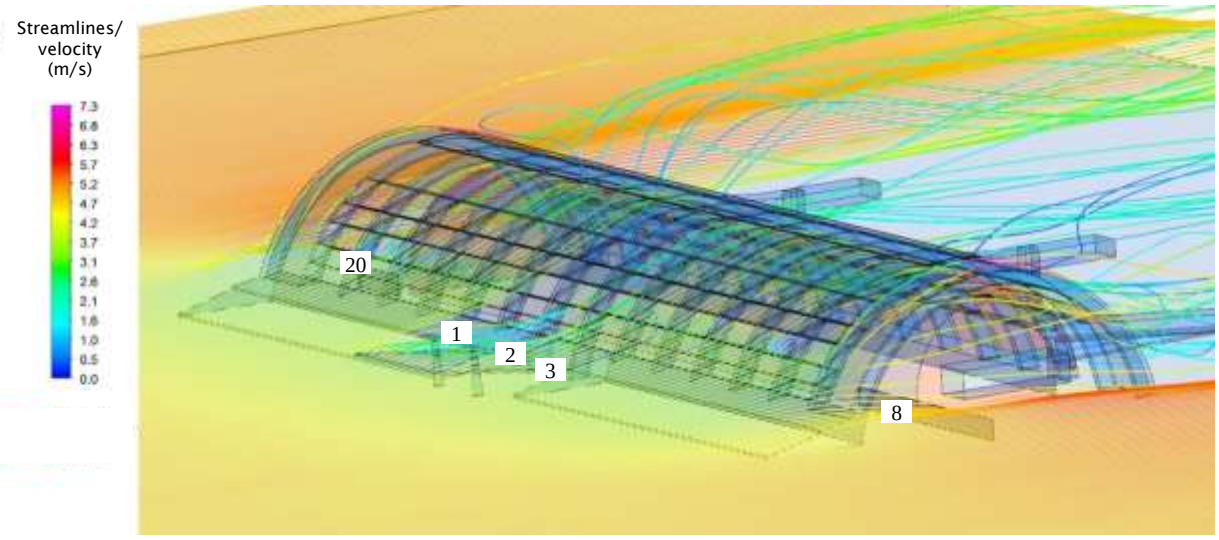


Fig. 13 Isometric view of streamlines, incident wind at 90˚

5. CONCLUSIONS

For different return periods, mean speeds of wind were determined at the construction site of a new air terminal. The hourly average regional speed for the site under study, in accordance with the Manual of Civil Works (MOC, 2008), is 127.8 km/h for a return period of 200 years; in this study the estimated value based on the provided data and statistical analysis, was 130.8 km/h.

The predominant wind direction in the area of the airport, was identified in the sector 240˚ to 270˚.

Using a 3D printer, a rigid 1:100 scale model was built. This model was used in the wind tunnel to determine magnitudes of pressures in the concrete and glass arches of the terminal building. The wind speed on the scale model was simulated with a magnitude of 7.5 m/s (27 km/h) (according to the speeds of the generated boundary layer profile) and for different directions of incidence in intervals of 10˚, including the dominant direction.

The maximum values of pressures recorded at the 1024 instrumented points of the model during the testing in the wind tunnel were:

- 2.7 kPa, maximum pressure, concrete arch
- -3.35 kPa , maximum suction, concrete arch
- 3.69 kPa (net pressure: external pressure minus internal pressure, concrete arch)
- -2.48 kPa (net suction: external pressure minus internal pressure, concrete arch)
- -3.03 kPa maximum pressure, internal glass structure
- -2.92 kPa, mean pressure media, internal glass structure

- -1.57 kPa maximum pressure , cantilever slab, entrance
- -1.15 kPa maximum mean pressure, cantilever slab, entrance
- -2.52 kPa, maximum pressure, jet bridge
- -2.0 kPa maximum mean pressure, jet bridge

In accordance with the Manual of Civil Works (MOC, 2008), the value of pressure for structural design would be 224.61 kg/m2 (2. 20kPa). Based on this value and the analysis of the results of the tests in the wind tunnel, possible design problems are not identified, however, this statement must be verified by the designer, particularly with regard to the effects of suctions. Additionally, the designer should check the possible impact of “projectiles" (debris) towards the inside of the air terminal.

Regarding the CFD analysis, the "venturi effect" occurring between the two structures (concrete and glass) of the terminal building was clearly visualized. In the numerical simulations, a wind speed of 5 m/s was used, which is equivalent to a wind that can be categorized as "gentle breeze" on the Beaufort scale. Nonetheless, areas completely opposite to the areas of incidence of the wind, showed, in some analyses, magnitudes of velocities that exceeded comfort levels according to international standards.

However, the results of the analyses reveal situations that for higher speeds (highly likely in the area of the new air terminal), comfort issues may be generated, so it is recommended to provide mitigation measures for the effects of the wind circulating inside the terminal.

ACKNOWLEDGEMENTS

The enthusiastic support of the technical staff of the Center of Applied Sciences and Technological Development of UNAM is greatly appreciated. Laura J. Olivares collaborated in the implementation of the scale model.

REFERENCES

Dyrbye, C. Hansen, S.O. (1997). “Wind Loads on Structures”. Ed. Wiley & Sons, Ltd.

Lawson, T. V. (1990). “The determination of the wind environment of a building complex before construction”. Report Number TVL 9025, Department of Aerospace Engineering, University of Bristol, Bristol, United Kingdom.

MOC, (2008), “Manual de Diseño de Obras Civiles”, Diseño por viento. Recomendaciones y Comentarios, Instituto de Investigaciones Eléctricas, Comisión Federal de Electricidad.

Mohamed, F. and Karadelis, J. (2013). “CFD simulation for wind comfort and safety in urban area: A case study of coventry University Central Campus”. International Journal of Architecture, Engineering and Construction. Vol 2, No 2, June 2013

Ruiz-Huerta, L., Ortega-Rodriguez, A. and Caballero-Ruiz, A, “Relation between tip size, deposition speed and roughness in FDM technology”, 2014, ASPE 2014 Spring Topical Meeting: Dimensional Accuracy and Surface Finish in Additive Manufacturing; Berkeley, CA; United States; 13 April 2014 through 16 April 2014; Code 107516, Pages 214-218

Ruiz-Huerta, L., Caballero-Ruiz, A., Vega-Alvarado, L., Yañez - San Vicente, R. and Castro-Espinosa, H., “Model – Support material interaction inspection by X-ray

Computed Tomography in FDM Additive Manufacturing Process", ASPE 2015 Spring Topical Meeting: Achieving Precision Tolerances in Additive Manufacturing; North Carolina State University, Raleigh, North Carolina, USA; April 26-29; pages 160-163.

Sakr, M., y Karadelis J., (2013), "CFD Simulation for Wind Comfort and Safety in Urban Area: A Case Study of Coventry University Central Campus", International Journal of Architecture, Engineering and Construction, Vol. 2, No. 2, June.

Simiu, E. y Scanlan, R.H., (1978), "Wind Effects on Structures - An Introduction to Wind Engineering", John Wiley & Sons, New York.

Stathopoulos, T. and Baskaran, B. A. (1996). "Computer simulation of wind environmental conditions around buildings." Engineering Structures, 18(11), 876–885.