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BENEFIT OF WIND TUNNELS WITH LARGE TEST SECTIONS FOR WIND ENGINEERING APPLICATIONS

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Abstract: Atmospheric Boundary layer wind tunnels (ABLWT) dedicated to building safety and comfort have been operated by CSTB in Nantes since 1971. Because ABLWT only deal with reduced scale models of real structures, the necessity of a larger wind tunnel, the Jules Verne Climatic wind tunnel (CWT), able to reproduce extreme wind loads on real scale structures arose in the years 80. Hence, it became a major European facility operating for improvement of the safety, quality and environmental impact of buildings and civil engineering works as well as products from industrial fields (transportation, energy…) with respect to strong winds and other climatic hazards. Both wind tunnel types, the ABLWT and the CWT are complementary and used for studying the effect of wind on the same structures at two different scales, when the effect of wind scaling is important. During the 2018 year, several modifications were made to the CWT facility. The atmospheric test section of the existing facility was elongated preserving the initial advantages, very large test section (approximately 120 m2) with wind velocity performance compatible with many applications (up to 90 km/h). This new test section makes it possible to simulate turbulent wind and driving rain testing. The sand winds capabilities have been maintained in the new design, despite the closed loop configuration, by fitting a filtering. The modifications of the wind tunnel geometry now offer a long test section upstream the turning vanes where a whole set of new tests can be carried out, as windmill field, natural ventilation of urban environments, slender structures (large bridges, pylons, cable transport systems,)

Keywords: wind tunnel, simulation, full scale experiments, metrology, rain, sand storm

1. Introduction

Wind tunnels are tools at the service of their owner. When answering questions from tower builders or insurance companies about the resistance of tall buildings to high wind, the best practice is to use a boundary layer wind tunnel. In such wind tunnels the turbulence of natural wind is reproduced on a reduced scale ranging from 1/200 to 1/2000. The model representing the building must be at the same reduced scale as the turbulent wind. This is a first strong limitation in reproducing the effect of wind on detailed elements used in buildings, such as balcony, antennas, windows, air inlet, etc…

2. Limits of scaling

The downscaling implemented during the wind tunnel tests, which objective is the study of the effects of a fluid on a solid body, induces side effects that influence the representativeness of the modelling. One of the first consequence of this influence concerns mean forces acting on moving bodies in a fluid, such as for example a boat or an airplane, respectively sliding on the water or flying through the air. These forces depend on the density of the fluid and its viscosity, leading to very different loads on a reduced scale model than on a full scale one if no precautions are taken. Similitude laws have been introduced to overcome this problem, looking at the various factors influencing the physics of the phenomenon and aiming at evaluating their sensitivity to scaling and compensating it in the experiment. When a complex situation involves several phenomena, it is required to apply several downscaling laws that are often incompatible with each other.

For instance, respecting the balance of the viscous forces to the inertia forces into the fluid means respecting the Reynolds number, what is verified at a scale 1/N only if the viscosity is divided by a factor N or the speed of the fluid multiplied by this factor N. At the same time, if the balance of the potential energy due to gravity effect to the cinetic energy of the fluid must be respected, represented by the respect of the Froude number, the speed at scale 1/N must be divided by a factor $\sqrt{N}$. Therefore it is not possible to respect both dimensionless quantities at the same time and an approximation must be made on one of them.

In ordinary wind engineering study it is most of the time possible to focus on one phenomenon and try to reproduce it with the highest accuracy, accepting a deterioration in the modelling of other inputs. In any case, the largest the downscaling, the poorer the accuracy, hence the importance of modelling structures with a scale as close as possible to 1. The limits of the wind tunnels are mainly found in their dimensions when it comes to large structures. For instance a vehicle can be modelled at a scale 1/10 or 1/20 for a wind tunnel of reasonnable size. But when it comes to the study of an urban environment, taking into account structures measuring from 100m to 1000m, the reduced scale to use is closer to 1/100 and sometimes to 1/1000. In such case the effect of the downscaling on the physics is high and prudence is necessary for interpreting the measurements, giving way to intense activity by specialists, the wind engineers.

3. Needs for very large boundary layer wind tunnels

Today, wind engineering is requested to help answering new questions in connexion with the new societal concerns.

Concerning the size of modern civil engineering structures, there is an increase with towers going up to 1000m in height and bridges overpassing 1500m in length. For a faithfull reproduction of the wind loads on such structures, it is essential to recreate in the wind tunnel the structure of the natural wind, which is composed of eddies of various dimensions. With wind scaling limits close to 1/100 or 1/200, the size of the wind tunnels section built to host the study of such large constructions must be close to 10m in height and 15m to 40m in width. This is considerably larger than the usual size of common boundary layer wind tunnels.

There are also new fields of investigation, with the development of wind turbines' farms, needing longers test sections. With turbines more than 100m in diameter, a few hundred meters apart, the modelling of interference between rows of turbines aligned with the oncoming wind leads to favor testing chambers more than 10m in length. This is a strong incentive to increase not only the height and the width of BLWT section, but also its length.

The recent questions asked to the wind engineering community are also impacted by the effect of global warming and the necessary reduction in carbone dioxide for every day life. One of the consequences is the development of natural ventilation in residential buildings, which requires at the design stage to reproduce with great care the inner flows and the effect of air buyancy. As the Grashof number, that must be respected for a good simulation of thermal effects in air ventilation, depends on the scale of the model at the power 3, it is difficult to deal with models at very reduced scales. In such case the structure of the wind turbulence is secondary compared to the wake of the surrounding buildings, what allows to work at scale close to 1/10 or 1/20 making it necessary to use a wide wind tunnel section to avoid blocage effect. In this type of modeling, tracing gaz is often used for measuring the ventilation rate inside the rooms, therefore a large testing chamber provides another advantage while reducing the pollution quantity in the wind tunnel.

Comfort in cities is also a domain of wind engineering responding to people's demand, requiring very large models. In order to correctly reproduce the interactions between streets, boulevards, high rise buildings and also ground vegetation, all influencing the feeling of pedestrians or other public space users, city neighboroud models are necessary which stretch for several meters. In this configuration also the need for a wide and long tunnel section is the only issue, but there is no special need regarding its heigth.

All these elements campaign for the creation of BLWT larger than the classical ones, which range from 1 to 4m wide, 1 to 2m high and mostly not exceeding 10m long.

4. Improvements to the existing large wind tunnel

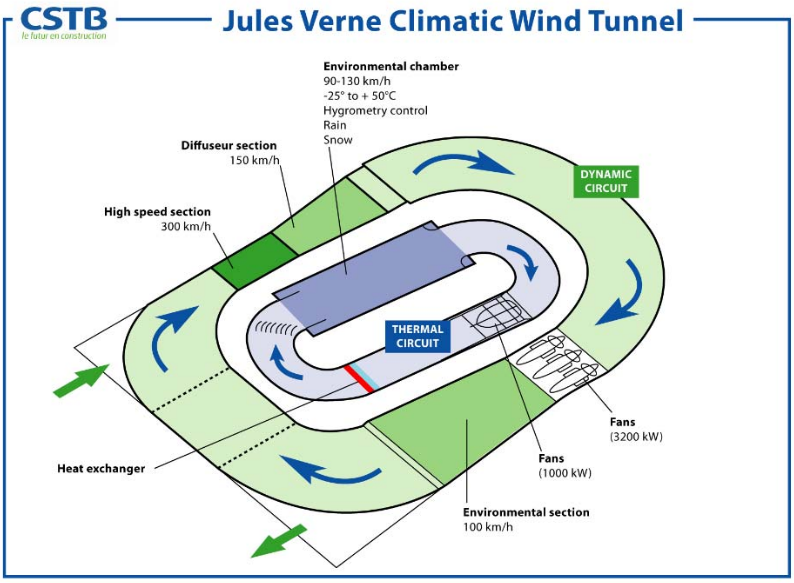
The Jules Verne wind tunnel has been operating since 1991. It is a large facility with a 3.1MW electric power, the wind circuit included in a rectangle 80m x 55m. It was initially designed for reproducing the effect of wind on structures or building elements at full scale, or close to [1]. In that view, the test section downstream the 6 fans was designed with a diverging size, going from 8x6m to 15x8m, with a turbulent flow and the possibility to control each fan individually, with the capacity to recreate flow bursts from 0m/s to 20m/s in less than 3s; After more than 20 years of use, the market for this unique instrument has changed and it was deemed necessary to adapt it to the new trends of the ecological and energetical transition.

A series of heavy work was undertaken, with a budget of 7 M€ (8 MUS$) beginning in july 2018 and a forecast end at the end of the same year. The strong demand from the industry for the wind tunnel availability pushed to reduce downtime as much as possible. This is the reason why prefabricated walls and ceiling elements were mainly used, the activity break being finally 6 months. The design of the improved and enlarged wind tunnel, the area of which passing from 5000m² to 6000m², was anticipated by two years of preliminary calculations and experiments [2] leading up to some changes in the air circuit and the creation of a new test section, the Atmospheric Test Section substituted to the former Environmental Section.

The geometry of this part of the wind tunnel was greatly changed, the former diverging section being replaced by a straight one, 25m longer. This evolution opens the possibility to create in this area a boundary layer by classical mean of roughness elements placed on the ground upstream the location of the model. This is now a 14m wide and 20m long testing area, that is preceded by a 26m long fetch area dedicated to the creation of a turbulent boundary layer.

Upstream this new test area the remaining turbulence at the outlet of the propellers was modelled and corrective screens made of inclined perforated plates were designed for making the flow more uniform. The homogeneity of wind speed after the 6 propellers was strongly improved with this device. Of course these perforated screens reduce the maximum wind speed that can be reproduced inside the wind tunnel, but for BL testing this is not a major inconvenience.

In case the mean wind speed should be increased, an inflatable convergent can be deployed from the roof, reducing the height of the test section by a half, accordingly doubling the mean wind speed in the test section. But in much configurations this convergent will not be necessary, letting the possibility to the boundary layer to developp up to some meters above ground, what is really necessary when it comes to study high rise buildings. The height of the test section is 8.3m.



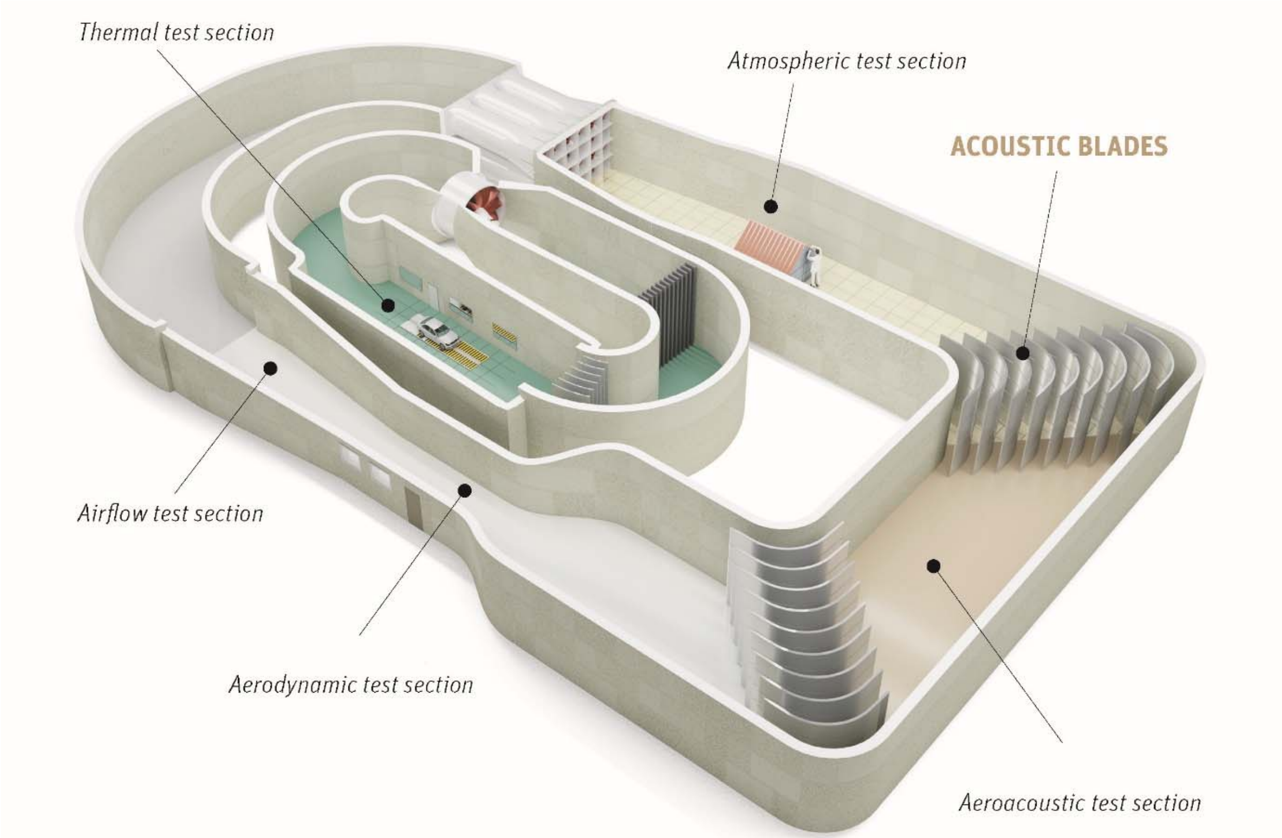


Fig. 1 - map of the climatic wind tunnel before its improvement and after it.

In the atmospheric test section it is also possible to add fine sand to the air flow for the reproduction of sand storms. In the previous shape of the wind tunnel operated in open configuration, this sand, or dust, was ejected outside the wind tunnel and fell down at some distance. Because the wind tunnel was made longer, its output was going too close from the public road passing along CSTB's lot. To avoid the sand could be sprayed away on the trafic, a new dust catcher was added to the wind tunnel. It is composed of two large fans suking the air from the lateral wall of the wind tunnel and letting it go through a battery of filters catching most of the dust. The exhausting dust ratio of $50 mg/m^3$ is more environment friendly than the former way of doing and also preferable for wind tunnel's operators.

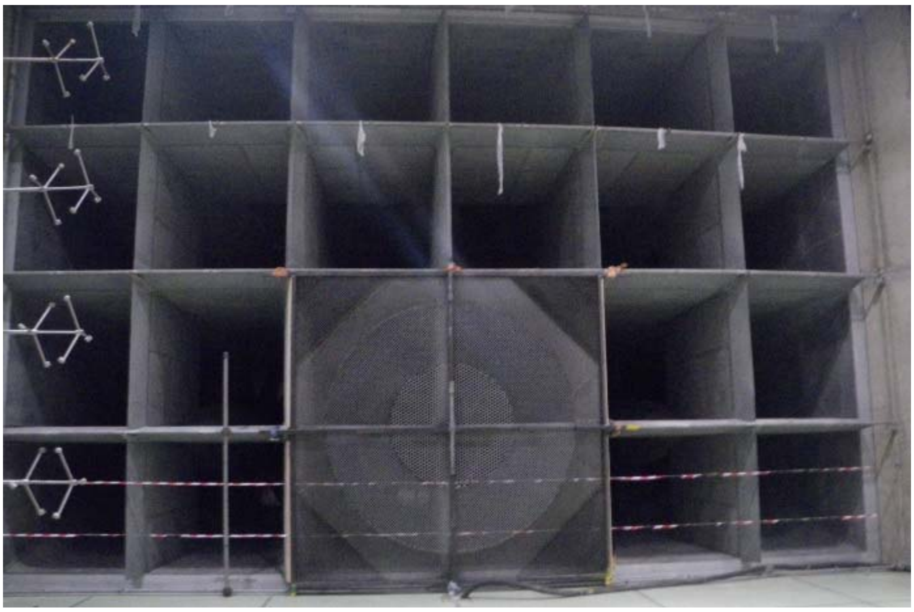


Fig. 2 - use of perforated screens at the output of the propellers, for the reduction of flow turbulence

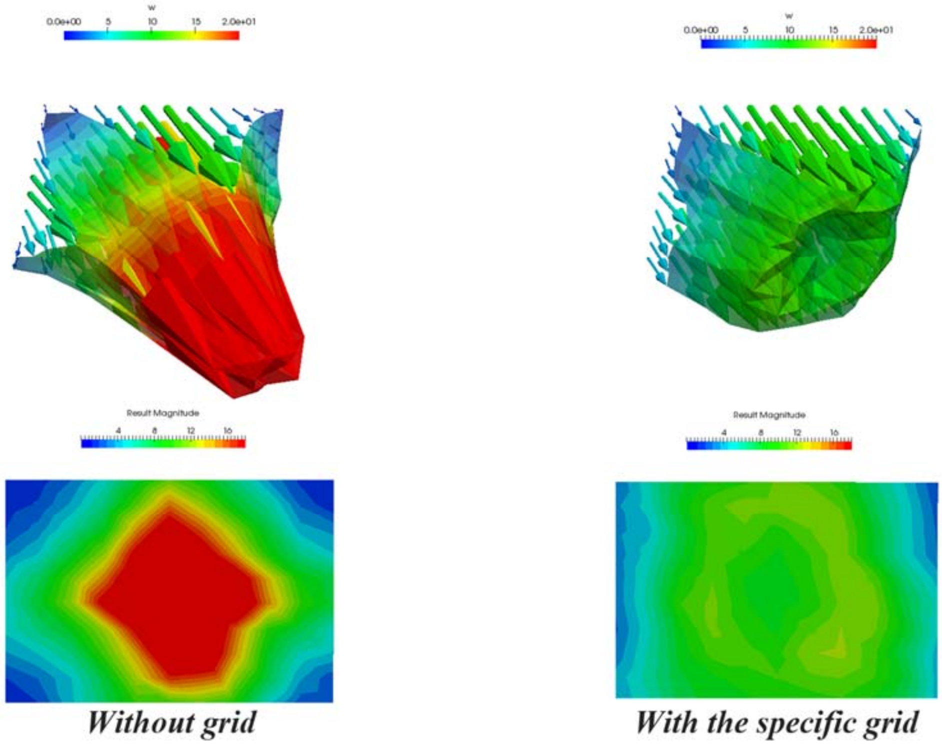


Fig. 3 - performance of the perforated screens for improving the air flow at the output of the propellers

Another improvement that will have a positive impact on the quality of pressure measurements in the wind tunnel is the introduction of acoustic absorbers in the turning vanes. The initial purpose of these vanes was purely an aerodynamic one, with the improvement of the homogeneity of the flow in the various test sections, but an acoustic modelling of the wind tunnel [3] evidenced that making these turning vanes with perforated metal sheet with fiberglass filling would reduce the noise by 15dB over all the frequency range 0-10kHz. More than a better confort for people working in the wind tunnel, this reduces the acoustic noise when making pressure measurements. Of course this does not transform the test section in an anechoic chamber, but for study of facades in urban environment, where the mean noise level is close to 63dB, a whistle or a beat above this level will be detected. There is a crucial demand for such tests of emerging sounds on full scale piece of façade, usually with a size close to 4mx4m. These acoustic blades could be complemented by absorbing panels on the wall and upstream the propellers, which may be installed in the future.

Fig. 4 - acoustic turning vanes for the mitigation of noise inside the wind tunnel

Fig. 5 - model of an urban area in the large boundary layer test section

4. Conclusion

In order to meet the needs of new markets in the wind engineering service field, it was decided to carry out a series of works improving the existing large climatic wind tunnel „Jules Verne". One main improvement has been the creation of a long and wide turbulent boundary layer test section. The new design of the wind tunnel was prepared by extensive CFD and acoustic modeling. Measurements performed in the wind tunnel after its re-opening confirm the expected performances.

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