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CLIMATIC WIND TUNNEL FOR MATERIAL AND STRUCTURES INVESTIGATION

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Summary: *The paper deals with a description of the new climatic wind tunnel laboratory built in historical city Telč. As a separate unit of the Institute of Theoretical and Applied mechanics of the Academy of Science of the Czech Republic, the tunnel will be used for fundamental research in engineering problems within civil engineering, architecture, heritage care and in other fields where wind effects appear along with further factors. The paper presents essential information about the interior layout of the tunnel together with description of advanced facilities serving for simulation of a strong wind, rain, freeze and solar heat radiation. Fundamental part of the paper is devoted to pressure losses determination. Using two different methods, the principal parts of the tunnel are designed taking into account both the optimal flow characteristics and flow resistance.*

Keywords: Climatic Tunnel; Flow Resistance; Aerodynamics; Tunnel Testing.

1. Introduction

New climatic wind tunnel laboratory was founded in spring 2012 within the project "Centrum Excelence Telč" (CET). It has been named after eminent Czech physicist Vincenc Strouhal. CET research center creates a separate unit of the Institute of Theoretical and Applied mechanics of the Academy of Science of the Czech Republic.

The aerodynamic/climatic tunnel simulates a strong wind, rain, freeze and solar heat radiation. This facility will serve basically for investigation of climatic effects on historical buildings and monuments. Because of unique combination of the aerodynamic working section and climatic chamber, the tunnel offers investigation of mutual interaction of several physical phenomenon at the same time ever at constant laboratory conditions. The similar climatic laboratory resides in France only.

Vincenc Strouhal tunnel will be used for fundamental research in aeroelasticity, aerodynamic instability prediction, fluid-structure interaction and also an interaction of the wind with influences of climatic parameters. It can be a significant tool for scientific work in many engineering problems within civil engineering, architecture, heritage care and in other fields where wind effects appear along with further factors, e.g. glaze ice or water-penetration into materials. Application in fashion branch, cosmetics or assessment of comfort level can not be excluded as well.

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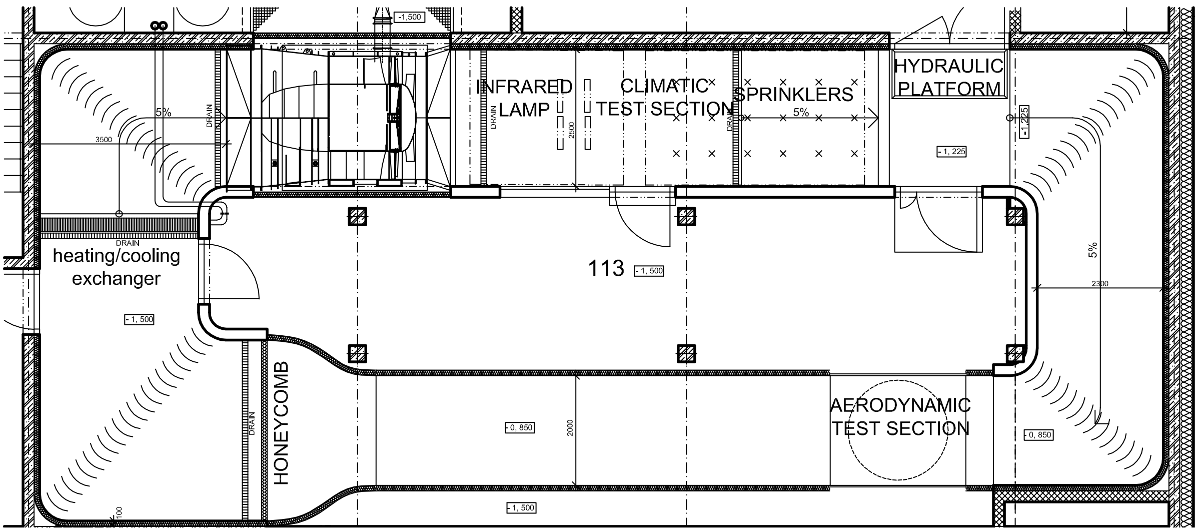

Fig. 1: Ground plan of the wind tunnel laboratory. It is designed in oval closed shape adapted for aerodynamic and climatic testing, respectively.

The fan is fundamental part of the tunnel. Powered by 200kW motor, it delivers a possibility to reach the wind velocity of more than 30 m/s. The tunnel is equipped with simulators of climatic effects. Using the cooling/heating exchanger cycle temperature changing of the airflow is available within the range of -5 to 30 °C in raletively short time. Furthermore, the laboratory provides rain simulators and infrared lamps that allow loading the structures by rain and heat radiation, respectively. Integral part of the tunnel equipment consists of instruments for airflow diagnostic, data acquisition system, direct pressure surface measurement, precise thermometry and of many other types of handy accessories for instant use. Workshops for manufacturing of testing models are available in the same building.

2. Facility description

From the operating point of view, the climatic wind tunnel can be divided into two fundamental parts - (i) aerodynamic part and (ii) climatic part, see Fig. 1. While the aerodynamic part provides well-fitted conditions to study wind effects on scaled model of prototypes, an equipment of the climatic part is suited for investigation of influences of weather including the wind, temperature, rain and radiant heat. Both tunnel parts are designed to respect aerodynamic laws to minimize energy cost and airflow turbulence. The shape of the air conduit forms a flow field with different characteristics. High quality airflow with low turbulence of about 1% is achieved in the aerodynamic section. The converting nozzle placed upwind compresses the incoming flow at ratio of 2.85. This brings increase in the wind speed approximately at the same rate and forms the airflow uniformity over the rectangular cross-section with the maximal wind speed exceeding 30 m/s. Using the diffusion passage and a pair of elbows, the cross-section expands twice towards the climatic chamber. To make this chamber versatile for various types of experiments as much as possible, the ceilings with sprinkler system and infra red lamps are continuously adjustable in height within the wide range independently, see Fig. 2. Transition zone between the fixed tunnel roof and sliding ceiling with the sprinklers is ensured with a rotationally positionable nozzle.

Further downwind the fan, an exchanger unit for air cooling/heating is integrated into the entire cross-section. It consists of very thin aluminium ribs put on a distribution pipe next to each other with a small gap. Due to a low porosity this element represents an obstacle with large flow resistance that can further increase if an ice accretion occurs. Therefore, a position with relative low wind velocity has been chosen. The exchanger also fulfills the role of turbulent screen reducing considerably non-uniform flow generated by the fan. This arrangement shortens the disturbed zone behind the propeller by equalizing the wind speed distribution over the cross-section and prepares favourable airflow conditions for the aerodynamic section.

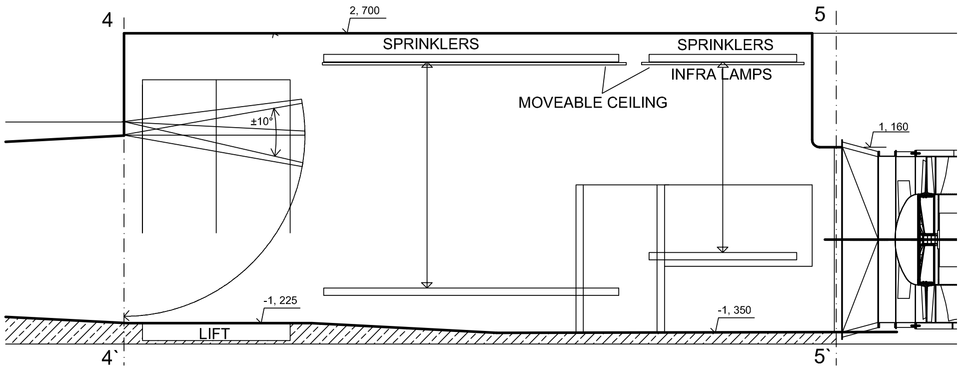

Fig. 2: Side view of the climatic chamber. The wind approaching from left can be adjusted by the nozzle and the moveable ceilings provide the flat plane towards the fan.

3. Fundamental elements design

Design of a such complex facility always requests a thorough preparation before the beginning of the work, see (Barlow, Rae and Pope , 1999). Basic requirements on the climatic wind tunnel laboratory were set beforehand and carefully considered with regard to intended experiments. Unlike conventional wind tunnels for which the only requirement regarding the flow characteristics is crucial, the climatic wind tunnel expanded the basic requirements with other variables like air temperature, air humidity, intensity of sunlight or rain.

The airflow temperature ranks among the main parameters of the climatic tunnel. This parameter is measured and controlled within the range that is critical from the material degradation point of view. Design of cooling capacity of the heat exchanger being of water-air type takes into account three basic forms of heat gains: (i) dissipative heat generated by air flow friction, (ii) accumulated heat in the tunnel structure and internal air, and (iii) heat transfer due to temperature gradient between the tunnel and surroundings. In order to minimize energy performance of cooling unit, aluminium-wool insulation material was used on outer walls, where appropriate the polystyrene covered with cement glue was applied.

Due to an extreme technical difficulty and economical coast of performing, the air humidity parameter remained uncontrolled and its value is just monitored. In certain unfavourable cases at temperatures below zero, the humidity can be artificially decreased by repeated condensing of the air moisture on the cooling exchanger. This procedure serves for reduction of ice accretion causing the potential decrease in the cooling efficiency and rise of pressure losses on the heat exchanger. Obviously, this way does not allow precise regulation of the air humidity level.

The significant source of the humidity comes from the sprinkler system. The rain intensity together with the size of drops is regulated to simulate the effects corresponding to drizzle or heavy rain. Up to eighteen spray heads mounted on the moveable frame generate water drops with aerosol drifted with the air current towards the specimen. Afterwards, water is collected to several floor drains located at felicitous places.

Infra red radiation belongs to the last simulated climatic phenomenon in the tunnel. Four halogen lights placed over the specimen radiates infrared parts of solar radiation at comparable intensity. The power is regulated in full extent and, if needed, just one lamp can be in operation.

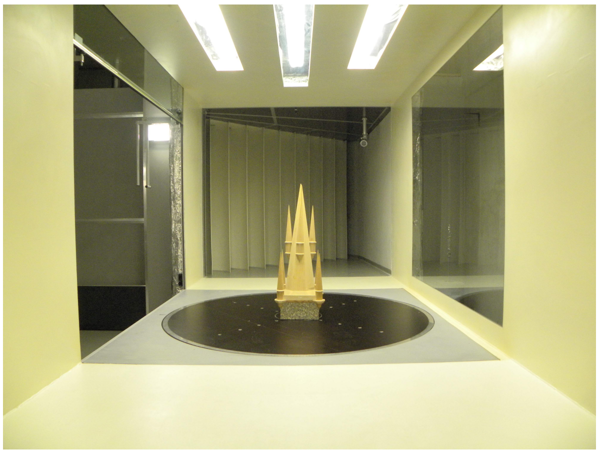


Fig. 3: Downwind view on aerodynamic section with historic tower model (left); View on the climatic chamber with 200 kW fan (right). Adjustable ceiling with water sprinklers provides a simulation of driven rain with various intensity. If needed, infra red lamps may be used for radiant heat simulation.

The high moisture generated with sprinkler system brings increased demands on materials used both for the tunnel core itself and for the principal equipment. The material surface protection or noncorrosive materials have been used. It is worthy to note that the vast majority of the tunnel devices is fully controlled by a central computer. It makes possible to schedule a test plan in advance using a common spreadsheet document and after importing execute the given tasks in chronological order automatically. Because of remote access via internet and two cameras installed in both test sections, the tunnel can be controlled from a remote computer, tablet or smartphone with a live video streaming.

4. Pressure losses determination

Based on the maximal wind speed requirement, pressure losses at individual principal parts of the tunnel were evaluated. Two ways of the determination were used. The first one follows from the experimental work by (Fried and Idelchik , 1989) that provides a solution of fundamental cases appearing in internal fluid engineering problems. While the straight parts with constant cross-section profile did not exhibit significant issue, an increase attention was paid to tunnel components in complicated shape such as contraction duct, elbows and screens. As an alternative methods, we have used the numerical analysis of the whole tunnel based on Computational Fluid Dynamics model (CFD). Starting from basic arrangement as introduced in (Fried and Idelchik , 1989), step-by-step modelling consisting in a slightly change of geometry was applied in order to achieved an optimal geometry from both the flow characteristic and flow resistance point of view.

The simulations were carried out in Comsol software environment with adopted stabilisation technique for Direct Numerical Simulation method (DNS) with high Reynolds number (Tezduyar

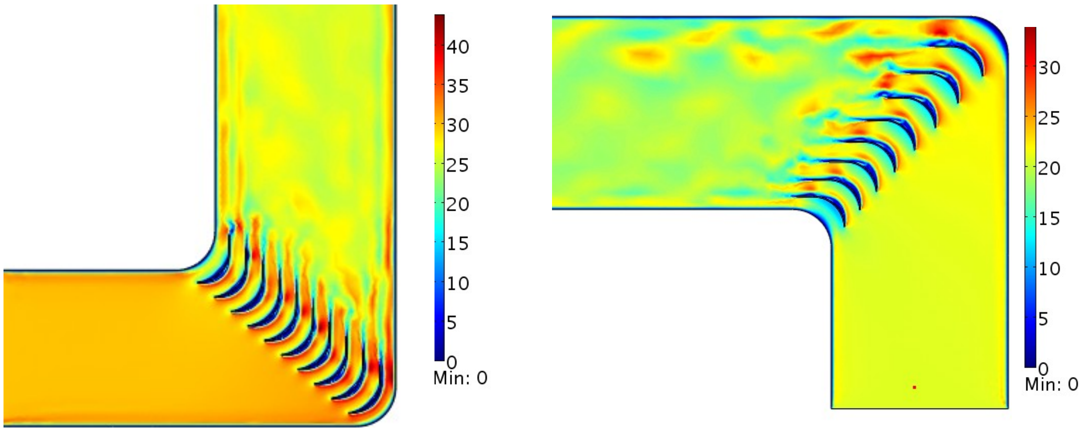

Fig. 4: Velocity field formed through the tunnel elbows. Fine distribution of vanes is used for the elbow placed downwind the aerodynamic section (left), for the remaining elbows coarser spacing is employed (right).

T.E. , 1992). In Fig. 4, velocity field distributed over the elbow area is presented. Picture on the left hand side shows the elbow behind the aerodynamic test section. The right hand side displays the elbow located upwind the climatic section. The wind speed at inlet corresponds to the designed velocity. Once the air stream passes the set of vanes, the airflow velocity reduces adequately to the area ratio of the inlet and outlet. Pressure at inlet increases correspondingly to maintain the inlet velocity as demonstrated in respective graphs in Fig. 5. Here after transition behaviour subsiding, the steady pressure level emerged with low fluctuation character.

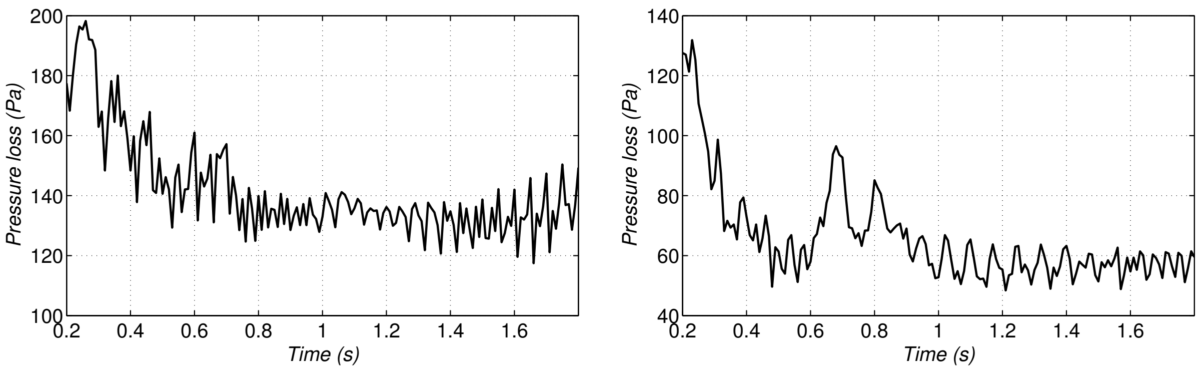

Fig. 5: Numerically identified time-history records of pressure losses of the first and second elbow downwind the aerodynamic section. After transition behaviour the steady pressure level appears with low fluctuation character.

Tab. 1 gives values of pressure drop at certain parts in the wind tunnel. Results according Idelchik's guide are tabulated in the second column, while the last one expresses the contribution to overall pressure losses. Finally, values in the middle follow from the numerical simulation. Obviously, very good results agreement was achieved although only two dimensional numerical model of CFD was employed. In Fig. 6, the results are processed in graphical form. The blue line represents ideal static pressure determined regardless of the pressure losses. Provided that the losses are respected, a strong discontinuity appears being demonstrated by the magenta line. This jump clearly shows the required pressure gain of the fan to overcome windage losses emerging when the maximal wind speed requirement is met. 20 % pressure reserve was used for the final design, assuming an unpredictable losses can occur.

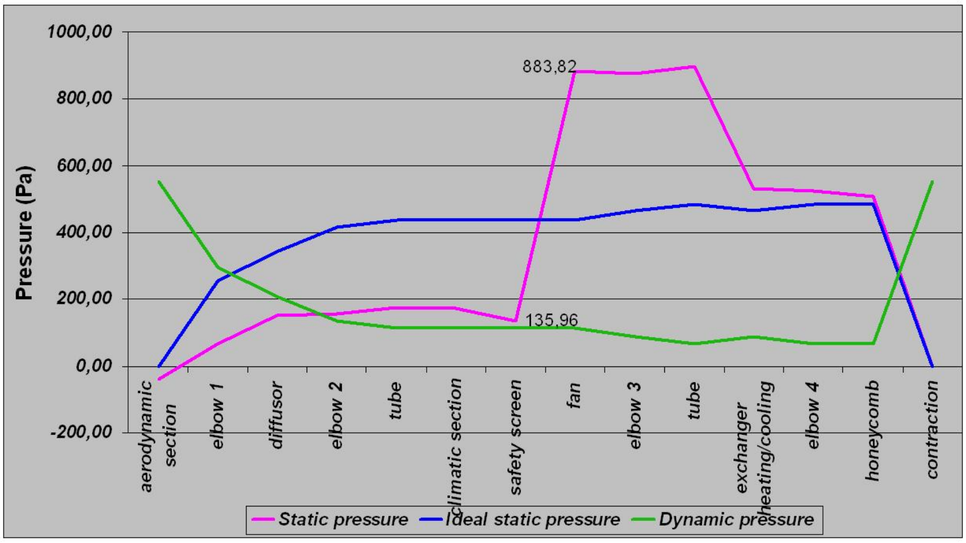

Fig. 6: Pressure development along the longitudinal centerline. The magenta line represents an estimation of static pressure including flow resistance of tunnel elements.

Tab. 1: Pressure losses of tunnel components – empirically and numerically determined values for maximal designed wind velocity.

Flow passage	Pressure loss* [Pa]	Pressure loss† [Pa]	Pressure loss [%]
aerodynamic section	38	-	5
elbow 1	150	135	20
diffusor	3	-	0.4
elbow 2	70	57	9.3
tube	1.8	-	0.25
climatic section	3.4	-	0.45
safety screen	37	-	4.9
fan	-	-	-
elbow 3	33	25	4.3
tube	0.6	-	0.1
heating/cooling exchanger	345	-	46
elbow 4	15	10	3.5
honeycomb	15	-	2
contraction duct	26	25	3.4

* – results based on book by (Fried and Idelchik , 1989) ; † – numerical simulation results

5. Conclusions

The paper presented a basic description of the new-built laboratory facility developed for a fundamental research in engineering problems related to study of climatic effects on structures. This unique wind climatic tunnel uses a combination of two working sections. This arrangement takes an advantage in wide universality and adaptability to experimental demands. Besides interior layout tunnel description, the article was focused on flow resistance of essential tunnel parts. According to the design guide and computational fluid dynamic model, pressure development along the longitudinal centerline was identified that provided a reference material with required pressure gain of the fan.

Acknowledgment

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