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DESIGN ISSUES OF A NEW WIND TUNNEL LABORATORY FOR ENVIRONMENTAL AND VEHICLE AERODYNAMICS

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ABSTRACT

The paper discusses the options for the upgrade of a boundary-layer wind tunnel located outside of a lab building and thus, exposed today to the adversity of weather. The design of the new Atmospheric Flows Laboratory (*Atmoszférikus Áramlások Laboratórium*) is presented, which will allow the wind tunnel to be used in a wide range of applications. Some of the basic design choices are discussed.

1. INTRODUCTION

The Theodore von Kármán Wind Tunnel Laboratory operates three large wind tunnels with cross sections between 1.25 to 5 m^2, and wind speeds up to 60 m/s. Three other small test section wind tunnels are also available for education and research with 0.12 – 0.25 m^2 test section size and 18-24 m/s top speed.

There exist several other wind tunnels in Hungary. Their specific capabilities correspond to their field of application, which goes from combined thermodynamic and fluid dynamics research to agricultural spraying device testing and soil erosion studies. Table 1. gives an overview of the not less than 16 research wind tunnels in Hungary.

The 2nd largest wind tunnel of our laboratory, built originally as a closed return boundary-layer tunnel, is currently located in the yard of the laboratory under a shed, and thus exposed to weather, and making the use of sensitive instrumentation difficult. Our aim is to find a solution for the preservation of this wind tunnel and extend its field of use to further improve our national research infrastructure.

2. HISTORY OF THE EXISTING TUNNEL

The wind tunnel was designed for the Hungarian Institute for Building Science (*ÉTI – Építéstudományi Intézet*) by Zoltán Szalay of ÉTI and Dr. Miklós Blahó of BME as a closed-return wind tunnel. The original design of 1978 included a larger wind tunnel (Fig. 1) with horizontal return leg, 2.6 × 1.8 m test section, 10 m long flow preparation section, and switchable recirculation for a total cost of 5 M Ft (approx. 200M Ft / 650k € in today's prices), and also heater and cooler units were considered for additional 3M Ft. A new building for 3.5M Ft (440k €) should have facilitated the wind tunnel.

Due to financial constraints, the wind tunnel was built finally 1984 in slightly smaller size, with a 2.2 × 1.4 m test section and 7 m long flow preparation section. The return channel was located on the top of the one-storey building. The tunnel was used in several studies in building aerodynamics ([2,3]). After the shutdown of

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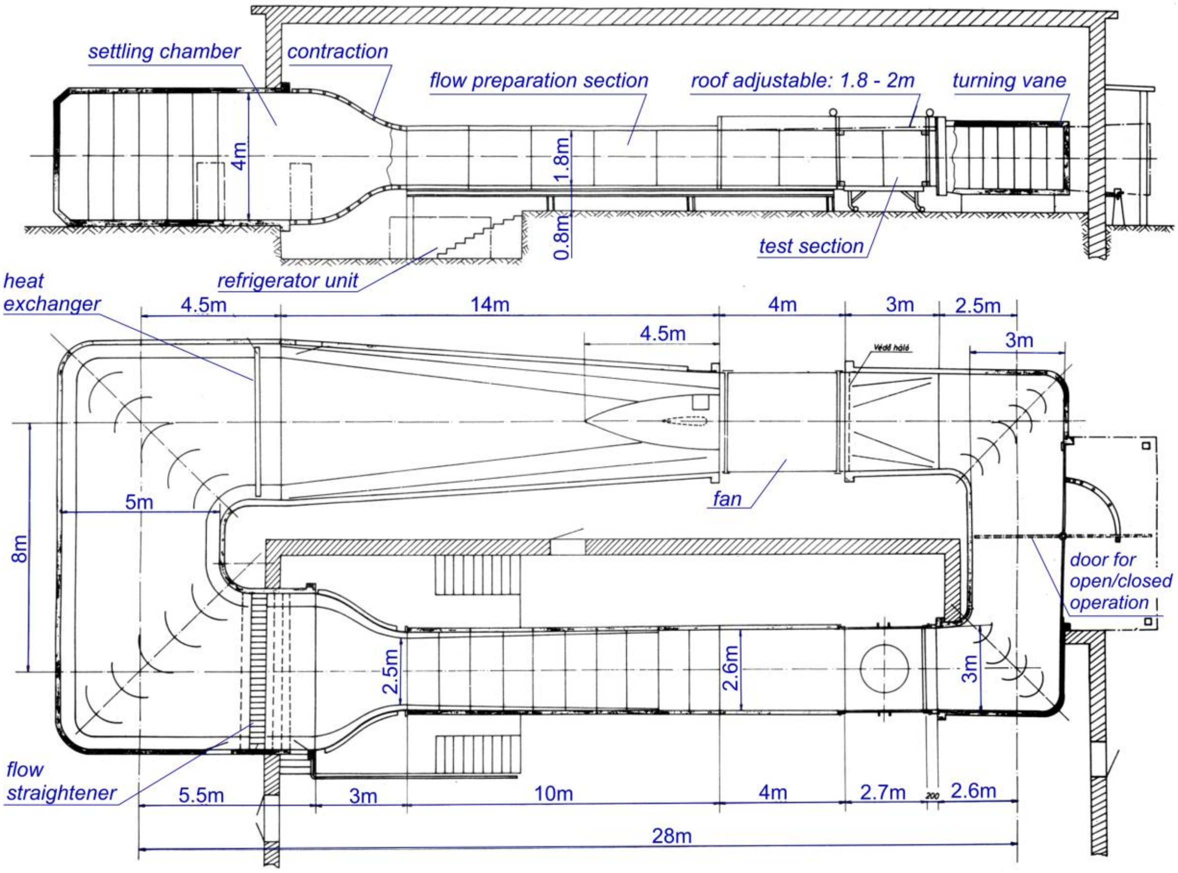

Fig. 1.
The original –not realized– wind tunnel design (1978) [1].

ÉTI's wind tunnel laboratory in 2003, the removable parts of the wind tunnel from contraction to the fan were taken over by the Dept. of Fluid Mechanics and placed in the yard of the Department's laboratory (Fig. 2).

The major problems with its use in the current location are: (1) exposure to weather, (2) dust generation during operation, (3) no security of valuable instrumentation, (4) extreme heat under the pentice during summer, (5) lack of curtains or disillumination for flow visualisation, (6) no laser protection of trespassers, (7) use of external air causes fluctuations in flow temperature.

The solution for these problems is clearly the accommodation of the wind tunnel in a closed laboratory space. This gives also opportunity to reconsider the design of the wind tunnel, thus a common solution is needed for a new laboratory and a new or upgraded wind tunnel.

3. INTERNATIONAL EXAMPLES

Wind tunnels in building and environmental aerodynamics are still a very important research tool, which is underlined by the fact that several new tunnels were built in the past years or are in construction. A selection of these is shown in Table 2.

Most new tunnels [4, 5, 7] are recirculating tunnels, [5] with optional use of external air in open circuit mode, which gives additional flexibility at experiments. The recirculation is useful when particle seeding is needed with laser based

Table 1.
Research wind tunnels in Hungary

Wind tunnel (WT)				Test section				Total length	Motor power
Owner	Department	**Name**	Type	Type	W [m]	H [m]	L [m]	[m]	[kW]
Budapest University of Technology and Economics, Faculty of Mechanical Engineering	Dept. of Fluid Mechanics	**Large horizontal WT**	recirculating	open	2.6	2.6	3.8	28.2	650
		Vertical WT	recirculating	open	1.4	2.4	1.4	10.2	220
		Boundary-layer (ÉMI) WT	open return, suction type	closed	2.2	1.4	5.5 + 2.1	13.6	55
		NPL WT	open return, suction type	closed	0.5	0.5	2.2	6	2
		Blackbird 1 WT	open return, blower type	open or closed	0.35	0.35	1	5	3.5
		Blackbird 2 WT	open return, blower type	open or closed	1	0.15	1	5.2	3.5
University of Miskolc, Faculty of Mechanical Engineering and Informatics	Dept. of Fluid and Heat Engineering	**Isolated WT**	recirculating	closed	1.2	0.8	2	13	63
		Closed WT	open return	closed	0.5	0.5	0.8	8.6	0.12/ 18.5
		Open WT	open return	closed	0.4	0.4	1	6.5	3
National Agricultural Research and Innovation Centre	Institute of Agricultural Engineering	**WT**	open return, suction type	closed	2	1.5	2.5	13	22
Szent István University, Faculty of Mechanical Engineering	Institute of Process Engineering, Dept. of Energetics	**Calibration WT**	open return, suction type	closed	0.5	0.5	1	6	1.5
		Calibration WT	open return, suction type	closed	1	1		5.6	n/a
Hungarian Meteorological Service	Dept. of Observation Calibration Laboratory	**Calibration WT**	open return, suction type	closed	0.652	0.652	0.6	6.1	42
University of Debrecen, Faculty of Science and Technology	Institute of Geosciences, Dept. of Physical Geography and Geoinformatics	**WT**	recirculating	closed	0.8	0.5	2	12.3	8.5
University of Szeged, Faculty of Science and Informatics	Institute of Geography and Geology	**Mobile WT**	open return blower	closed	0.8	0.75	5.6	12	7.5
University of Nyíregyháza	Institute of Engineering and Agricultural Sciences	**Closed WT**	open return or recirculating	closed	0.25	0.25	1	9	2.2

Table 1.
Research wind tunnels in Hungary (continued)

Built [year]	Top speed [m/s]	Turbulence intensity [%]	Application area	Comment / Specialities	Contact / WT location
1936-38	60	0.3	aerodynamics of airplanes, vehicles, buildings, pollutant dispersion	3D probe traversing system, modular floor, 2m-turntable	Dr. Balczó Márton 1111 Budapest, Bertalan l. u. 4-6. AE épület
1936-38	20	0.5	drag force measurement on smaller objects	originally built for aircraft spin testing	
1984	19	0.5	building and environmental aerodynamics, pollutant dispersion	long flow preparation section for boundary layer modelling, adjustable roof	
1941	18	0.3	calibration of anemometers	3D traversing system installed	
2013	24	0.8	vehicle aerodynamics measurements	at low speeds: recirculating / high speeds: open return	
2013	24	0.8	flow around 2D bluff bodies and 2D airfoils	equipped with 3-component force balance	
1982	30	0.8	general fluid dynamics, boundary layer modelling	isolated wind tunnel, heater & cooler unit, temperature adjustable between -10 to +50 °C	Dr. Bencs Péter 3515 Miskolc-Egyetemváros C/2 épület, Északi oldal, 2. hajó
2009	30	0.8	fundamental fluid dynamics research		
2014	6	0.8	turbulence, turbulence generator research	3D traversing system available	
2004	10	n/a	testing of agricultural spray application techniques	adjustable roof, turntable	Kovács László 2100 Gödöllő, Tessedik Sámuel u. 4.
2004	19	n/a	calibration of anemometers		Dr. Schrempf Norbert
2014	25	n/a	calibration of anemometers		
2002	50	0.3	calibration of anemometers	Theodor Friedrichs Co. Type 8420. Min. speed 0.15 m/s	Nagy Zoltán 1181 Budapest, Gilice tér 39.
1970	14	n/a	soil erosion experiments	eqipped with a particle filter	Dr. Négyesi Gábor 4010 Debrecen, Egyetem tér 1., Kémia Épület
1980	17	n/a	in-situ soil erosion experiments	WT without a bottom to be placed on the investigated soil surface, mobile unit transportable on a trailer	Dr. Farsang Andrea 6725 Szeged SZTE Tompai Kapu úti Központi Raktár
2012	n/a	n/a	drying research	not operational at the moment due to change of location	Lajtos István 4400 Nyíregyháza Kótaju út 9-11

measurement techniques, saves fan power, and ensures steady flow conditions. The wind tunnel of [6] in open return design, recirculating the air of the facilitating room, which results in a cost- and space saving construction built mainly of wood.

New possibilities arise with so called fan wall technology, the use of multiple smaller fans built side-by side and controlled together or individually. The use of a fan wall saves wind tunnel length, because long nacelles and cross-section changing elements are not needed, and low wind speeds are better adjustable [*Bernd Leitl*, personal communication, 2015].

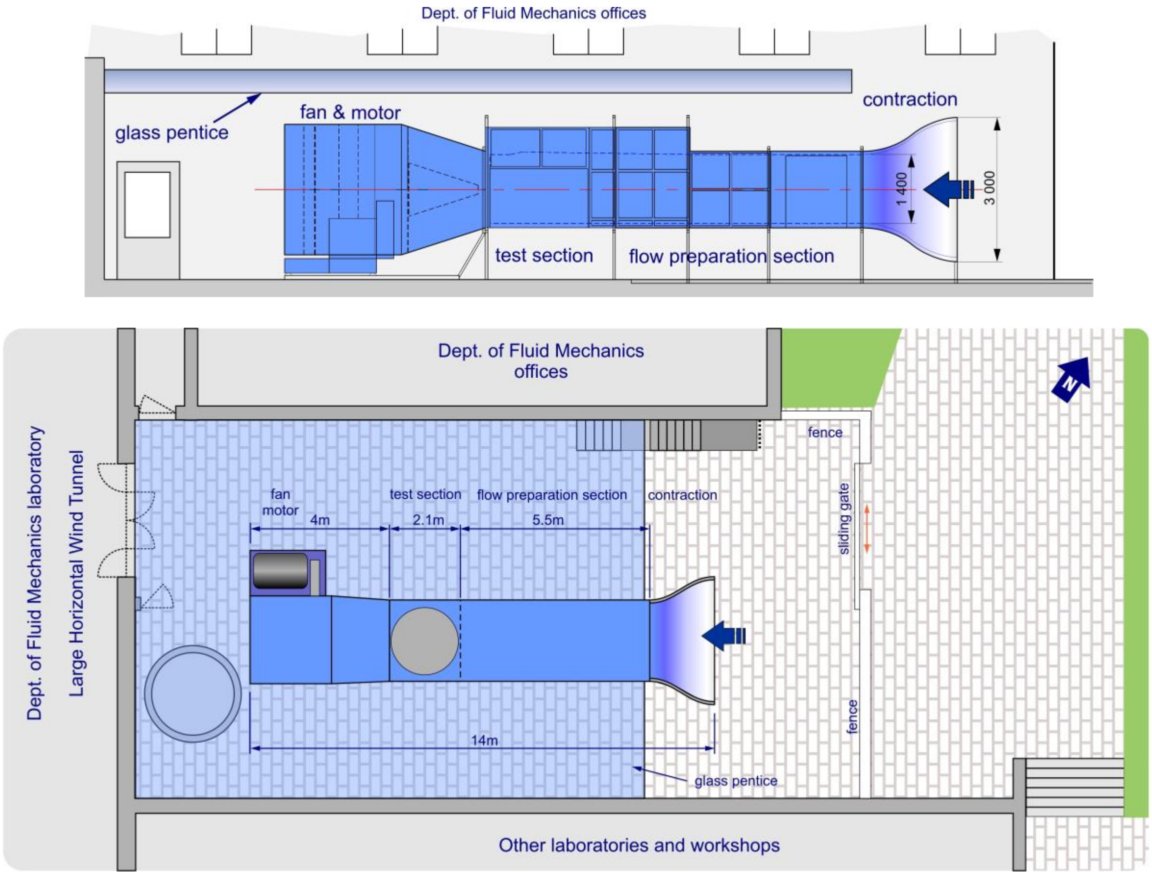

Fig. 2.
Side view and location of the existing wind tunnel in the yard under a pentice.

4. DESIGN OF THE NEW LAB BUILDING

The vicinity and accessibility requirements of the laboratories around the yard limit the size of the new laboratory, which is not allowed to reach further than the eastern border of the existing southern side wing. On both the southern and northern side of the yard existing office and lab windows need ventilation, thus corridors were necessary on both sides.

The building itself is located in the buffer zone of the Budapest world heritage conservation area, which made the ‘hideaway’ of the wind tunnel inlet behind a vertical grid necessary. The final architectural design by *M Architects Ltd.* (leading architect *Viktor Szentkuti*), which gained building permission from the authorities, is shown in Fig. 3 and Fig. 4. Estimated costs for the building are in the range of 280k €.

Table 2.
A selection of newly designed boundary-layer wind tunnels

Wind tunnel				Test section				Motor power	Top speed	Comment / Specialities	Approx. costs
Owner	Built	Layout	Size [m^2]	Type	W x H x L* [m]			[kW]	[m/s]		[€]
University of Adelaide	2011	recirculating	30.6×18.7	closed/ open	3	3	14.8	6 × 135	33	2.75 × 2m high speed test section for aeronautical testing up to 50 m/s is located in the other leg.	3.65M
ETH Zürich / EMPA	2011	recirculating	25.1×6.5	closed	1.9	1.3-1.6	10.4	110	28	Use of external air possible instead of recirculation. Test section blocks easily removable.	n/a
Leibniz Institute for Agricultural Engineering Potsdam	2012	open return	25×6.5	closed	3	2.0-2.5	20	260	20	used for agricultural research, indoor naturally ventilated barn flow structures, tracer dispersion near agricultural buildings	1.18M
TU Eindhoven	-	recirculating	44×11	closed	3	2	26	n/a	n/a	WT is in design phase, all values are estimations based on [7] and [8]	1.4M

* flow preparation section + test section length added

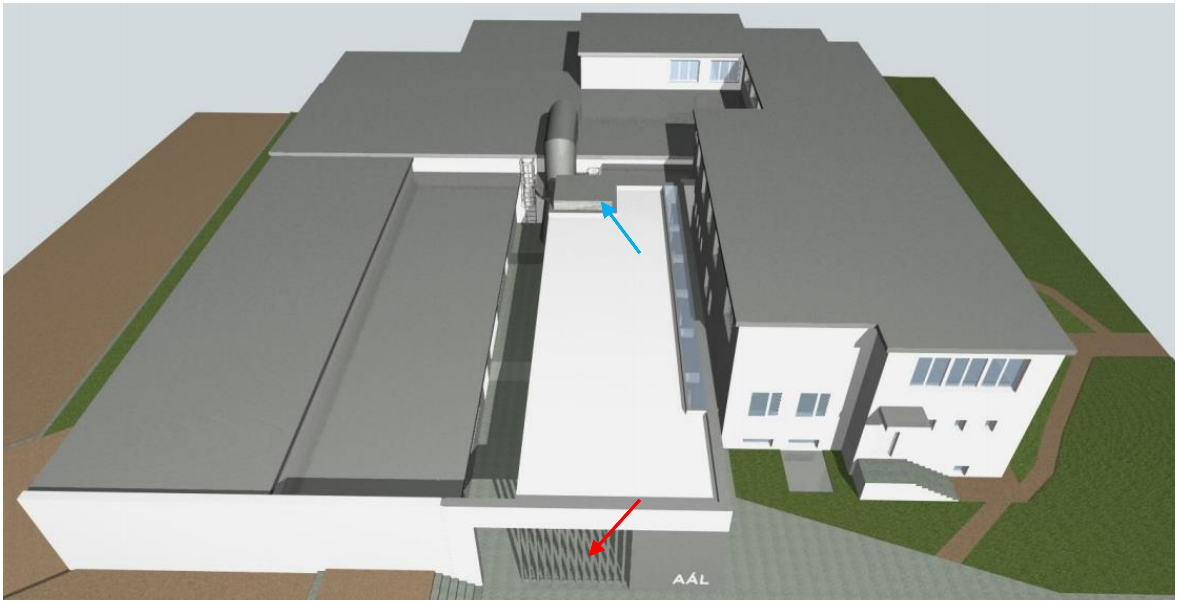

Fig. 3.
The new lab building. The lower arrow indicates the air inlet for the wind tunnel bellmouth. The upper arrow shows the roof opening for the air outlet.

5. IMPLICATIONS FOR THE WIND TUNNEL

The limited space on the yard and world heritage requirements made any recirculating solution impossible, thus the tunnel must remain in open return layout. The use of external air has some disadvantages, the inlet of moisture and dust can be expected, and in winter condensation on wind tunnel surfaces can be a problem.

However, the use of external air has its advantages as well, which makes the application field of the wind tunnel wider, e.g., cold weather testing is possible in winter time. The exhaust of the air into the environment allows ‘dirty’ experiments like sand erosion without any remaining pollution of the lab or the wind tunnel.

To combine the advantages of the two solutions, a moveable wind tunnel is considered, which is shown in Fig. 4. This solution is only possible when using a new multifan unit which saves considerable length and consists of 6 fans in a 3 × 2 layout.

In the first configuration, external air is sucked into and exhausted through wall and roof openings. The contraction and bellmouth are located outside. This gives an 11.5 m long flow preparation section for building/environmental aerodynamic measurements, the possibility to run comparably high flow velocity, and additionally to place a second test section in the forward part of the wind tunnel for vehicle aerodynamic tests. Furthermore, an optional high speed test section is also thinkable.

In the second configuration, the flow preparation section, the test section and the fan unit is moved to the centre of the laboratory room and equipped with a smaller bellmouth. The vertical turning vane behind the fan is removed. This way, the wind tunnel can be used with internal air, and thus the tunnel can be used also during

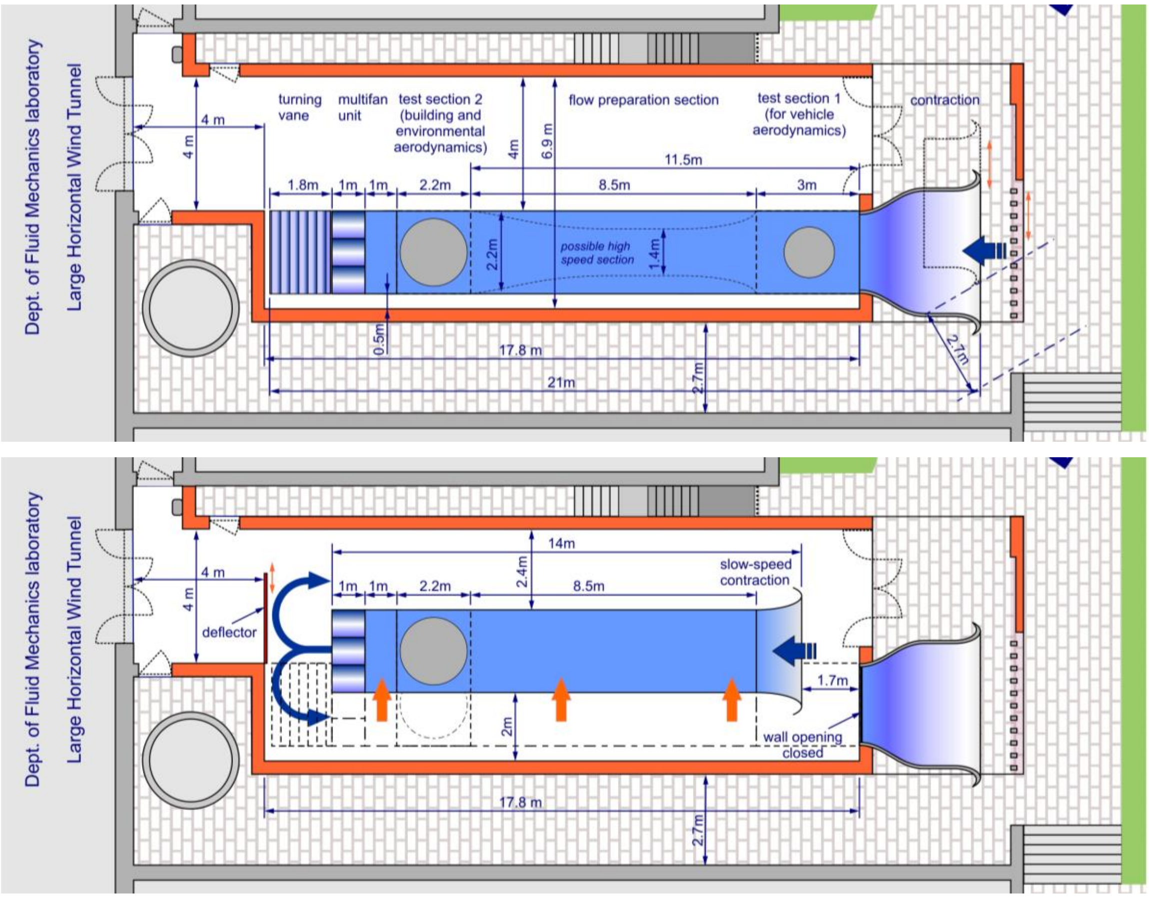

Fig. 4.
Final lab dimensions and designated wind tunnel layout. Top: High speed operation with external air. Bottom: low speed operation with internal air.

winter with very steady flow conditions, although only with lower speeds (around or below 10 m/s) to avoid 'stormy'conditions in the lab. The flow preparation section is in this case 8.5 m long. The inflow conditions at the bellmouth of the wind tunnel are in both configurations of specific importance. The design of the bellmouth in the first configuration was optimized by CFD simulations to improve the homogeneity of the flow. Results will be presented at the conference.

6. CONCLUSION AND OUTLOOK

In spite of the significant constraints of the site, the preliminary design of the wind tunnel upgrade and the new lab building will ensure a comparably wide application area of the facility. The next step is the detailed design phase of the wind tunnel and its new components.

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