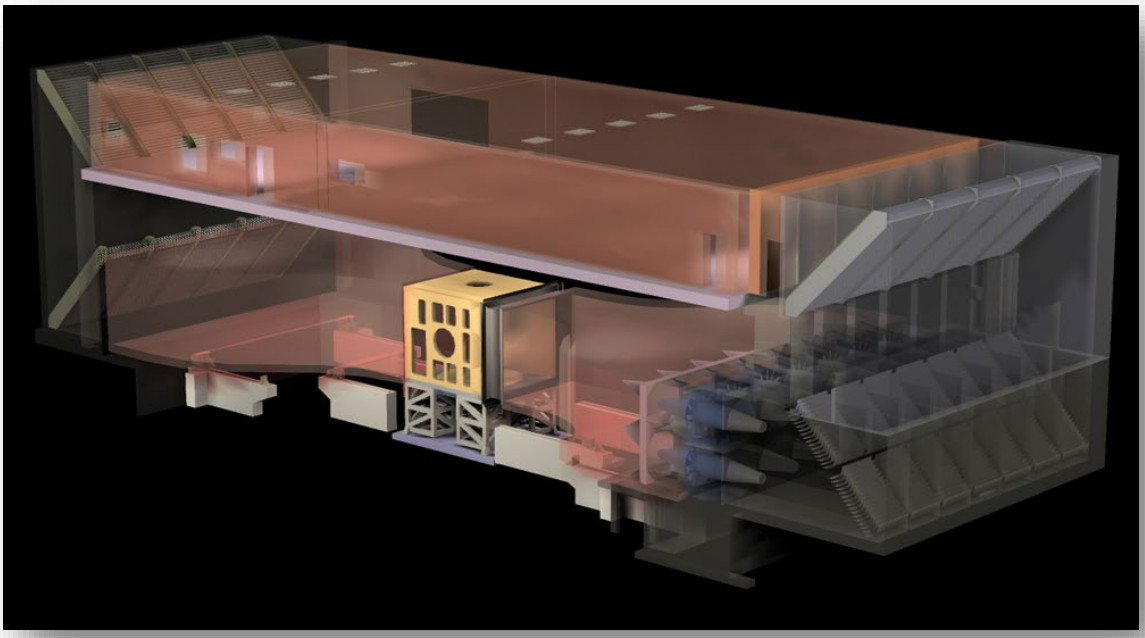


GVPM (www.windtunnel.polimi.it) is a special closed-circuit wind tunnel, arranged in a vertical layout with two test rooms located on the opposites sides of the loop. The first one is located in the lower part of the loop and is suitable for Low Turbulence tests. The second one, bigger, is located in the upper part of the loop and is intended for civil engineering testing (the Boundary Layer Test Section). Due to this unique feature, GVPM offers the widest possible range of test arrangements and alternatives. The facility is powered by a flow generator array of 14 1.8m diameter, 100kW, fans, for a total power of 1.4 MW. The fans are organized in two rows of seven 2x2m independent cells. Independent inverters drive the fans allowing for continuous control of the rotation speed of each fan to obtain the desired wind speed in the test section.

After the fans two corners fitted with vanes conducts the flow to the upper level of the facility in the opposite direction. The flow is than cooled by a heat exchanger that is placed just downstream of bend number 2 and, after a grid, enters the boundary layer test section.

A second set of two corners fitted with vanes conducts the flow back to the lower level where, after a 2 meters long settling chamber, it passes a honeycomb screen and a set of three different porosity wire nets to reduce axial and lateral turbulence and to promote a more uniform axial flow. A two-dimensional contraction cone with area ratio 3.46:1 reduces the duct section to fit

the low turbulence test section size. Finally a short diffuser expands the duct section back to the fans array size.

The optimization and check of the facility layout and components design has been achieved with the help of a 1:9 scale powered tunnel model that was modified several times up to the final design. This model is currently available and used as a check for modifications to the full scale tunnel and to design testing devices in a reduced scale before realizing them for the large tunnel.

Low turbulence test section

The Low Turbulence test section is 4m wide, 3.84m high and 6m long. It is possible to perform tests in a closed test section and in an open jet.

The maximum wind velocity is 55m/s and the turbulence level is less than 0.1%. It is possible to remove the whole section from the airflow circuit allowing for an off-line setting-up of the test. There are two inter-changeable test sections to prepare a new experiment while the wind tunnel is running.

The test section is equipped with a 2.5m diameter turntable and a traversing system behind the model's location, suitable for wake measurements. There are several model supports equipped with a positioning system in order to vary the incidence angle. take performance testing.

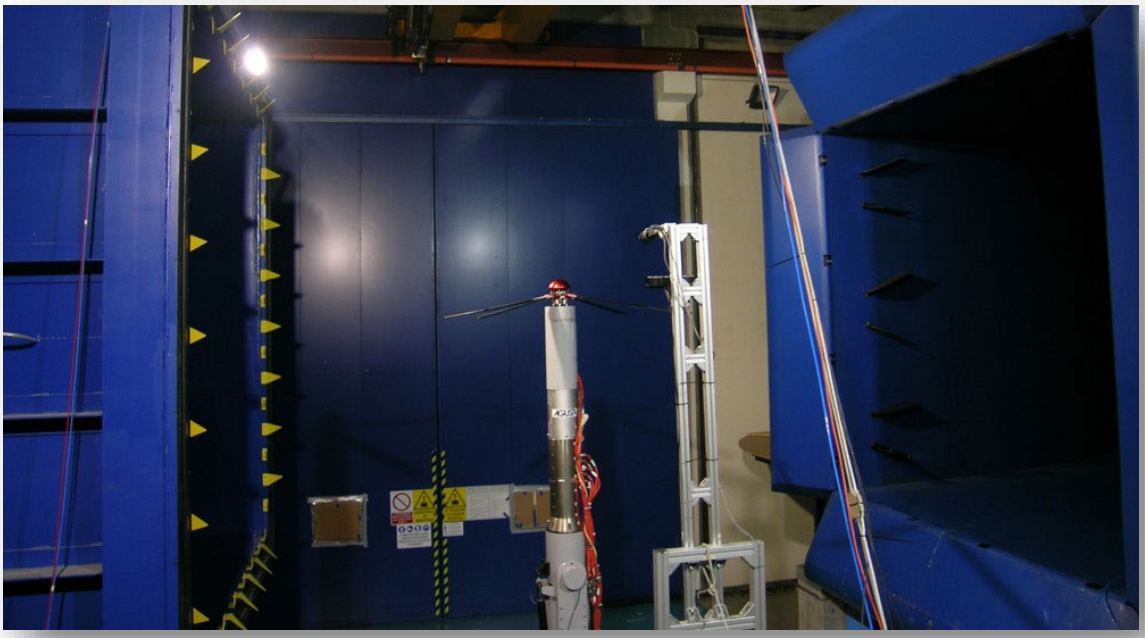
Characteristics:

- **Overall dimensions:** 4m wide x 3,84m high x 6m long
- **Maximum wind speed:** 55 m/s
- **Mean velocity variations in the test section:** 0,25%
- **Turbulence intensity:** 0,1%
- **Turntable:** 2,5m diameter

Typical activities:

- Aircrafts Helicopters
- High-speed trains
- Vertical and horizontal axis small and micro wind turbines
- Sport aerodynamics
- Bridge sectional models high Reynolds number tests.

Open jet test section



The Low Turbulence test section can operate also in Open-Jet mode. Open-jet testing is well suited for tests on helicopters rotor.

Characteristics:

- **Jet dimensions:** 4m wide x 3,84m high x 5m long
- **Maximum wind speed:** 55m/s.

Typical activities:

- Helicopters
- Vertical axis small and micro wind turbines.

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Boundary layer test section

The large Boundary Layer Test Section is 13.84m wide x 3.84m high, and is specifically designed for wind engineering tests on civil structures scaled models. The maximum wind speed is 16m/s and the turbulence index in smooth flow condition is about 2%. The 35m long, constant section test room enables the setting up of upstream active or passive turbulence generators to simulate the atmospheric boundary layer, with turbulence intensity that can be higher than 35%. Several layouts of spires and floor roughness elements makes possible to reproduce different terrain roughness length categories in a wide range of geometric length model scales.

The model to be tested, together with the related environment, is set-up on a 13m diameter turntable, included in the wind tunnel floor, allowing an easy wind incidence angle change. A floating floor allows for a clean model set-up, living all the instrumentation cable connections out of the flow.

Characteristics:

- **Overall dimensions:** 13,84m wide x 3,84m high x 35m long
- **Maximum wind speed:** 16 m/s
- **Mean velocity variations in the test section:** 5%
- **Turbulence intensity:** 2% (smooth flow conditions) / Up to 35% (atmospheric boundary layer simulation)
- **Turntable:** 13m diameter.

Typical activities:

- Aeroelastic models of long span bridges
- Bridges static and dynamic sectional models
- High and low-rise buildings
- Large roof structures
- Wind turbines scaled models and wind farms Sailing yachts.

Available instrumentation and devices

- 6 components internal and external force balances (RUAG, various)
- 6 components toroidal load cells for propellers and helicopter rotors thrust measurements
- Up to 512 ports on multi-channel simultaneous pressure scanning system (PSI, several pressure ranges)
- High sensitivity miniature pressure transducers (Kulite, various)
- Displacement transducers and accelerometers for tests on dynamic and aeroelastic models
- 3 component anemometry (hot wire, multi-hole pressure probes)
- Particle image velocimetry (PIV)
- 2 component Laser Doppler Velocimetry
- Automated flow traverse rigs
- Flow visualization (smoke, tufts, oil)
- Video and image recording devices
- High-speed cameras
- Electric and hydraulic motors for powered models
- Suction system for aeronautical engines air intake performance testing
- Active harmonic turbulence generators for admittance function evaluation
- Twisted flow generator
- Compressed air supply

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Sergio De Ponte Wind Tunnel at Politecnico di Milano

Description of facility

The experimental aerodynamics laboratory of the Department of Aerospace Science and Technology is provided with different wind tunnels of various dimensions and test regimes. The complete experimental equipment allows carrying out a wide range of tests:

- Low-turbulence closed-loop subsonic wind tunnel with 1x1.5m test section. 55 m/s max. speed.
- Closed-loop wind tunnel 0.45x0.3m test section, 25 m/s max speed.
- Open-loop subsonic wind tunnels, 0.5x0.7m, 0.3x0.3m and 0.2x0.15m test section; speed up to 90 m/s.
- Experimental rig for the simulation of dynamic stall phenomenon on blade section.

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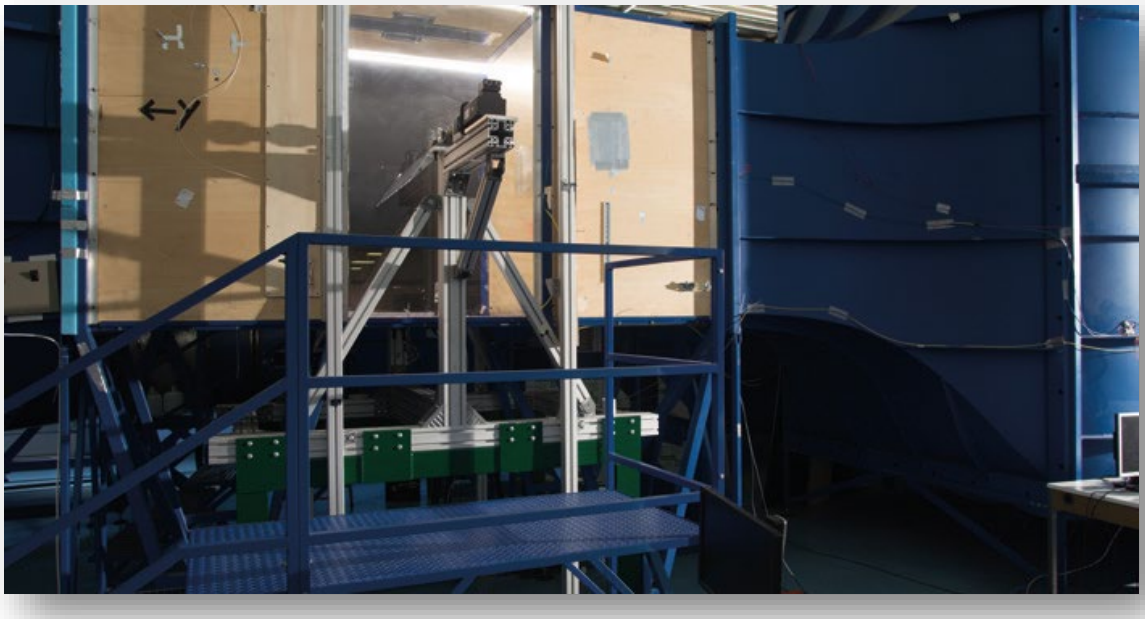

General description:

- Type: closed loop type wind tunnel
- Size of test section: 1.0m x 1.5m x 3m (width x height x length)
- Velocity range: up to 55m/s
- Re number per m chord: 4.5 million
- Background TI below 0.1%

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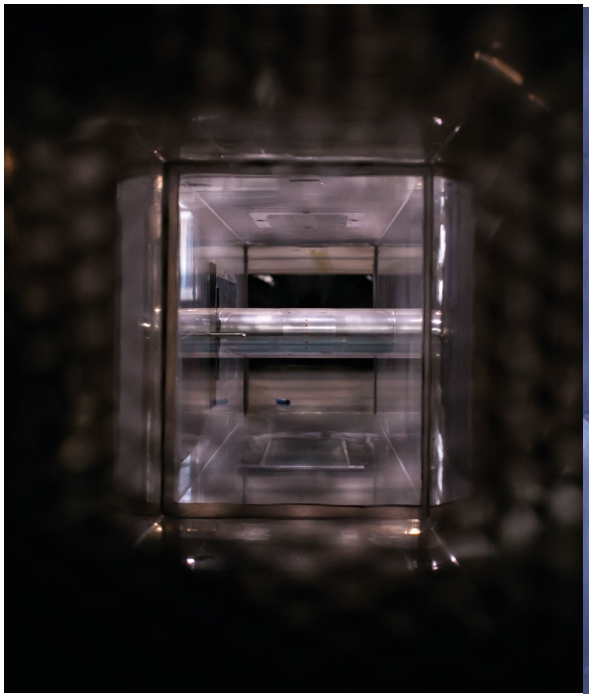
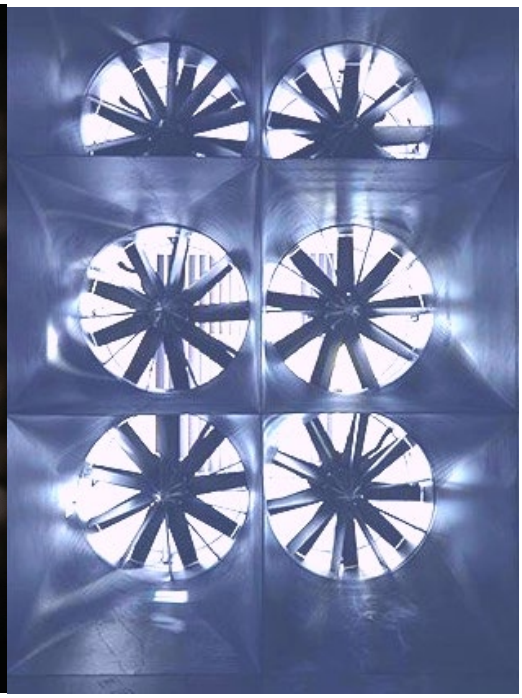
Measurement equipment:

- Two 2C/3C Particle Image Velocimetry measurement systems.
- Hot wire measurement equipment: 6 measurement channels, hot wire and film probes for 1C, 2C and 3C measurements.
- 2C Laser Doppler anemometer.
- Differential pressure transducers, uni-directional and bi-directional, ranges from 100 Pa up to 1 PSI, accuracy up to 0.01% FS.
- Dynamic pressure transducers.
- Esterline DTC Initium pressure measurement system.
- Six components balances, load cells for aerodynamic loads measurements.
- High accuracy absolute pressure transducers.
- Temperature and relative humidity probes.
- Smoke and fog generators for flow visualization.
- Long-wave IR camera.
- motion capture and 3D positioning tracking system with 8 cameras.





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The Hardware-In-the-Loop system

Hardware-In-the-Loop testing techniques were recently proposed to overcome the scaling issues evidenced by ocean-basin model tests on floating wind turbines (i.e. the Froude-Reynolds conflict). In these methodologies, aerodynamic loads or hydrodynamic loads are reproduced exploiting a dedicated facility (a wind tunnel or an ocean-basin), while complementary forces are computed in real-time and provided to the scale model by means of a proper actuation system.

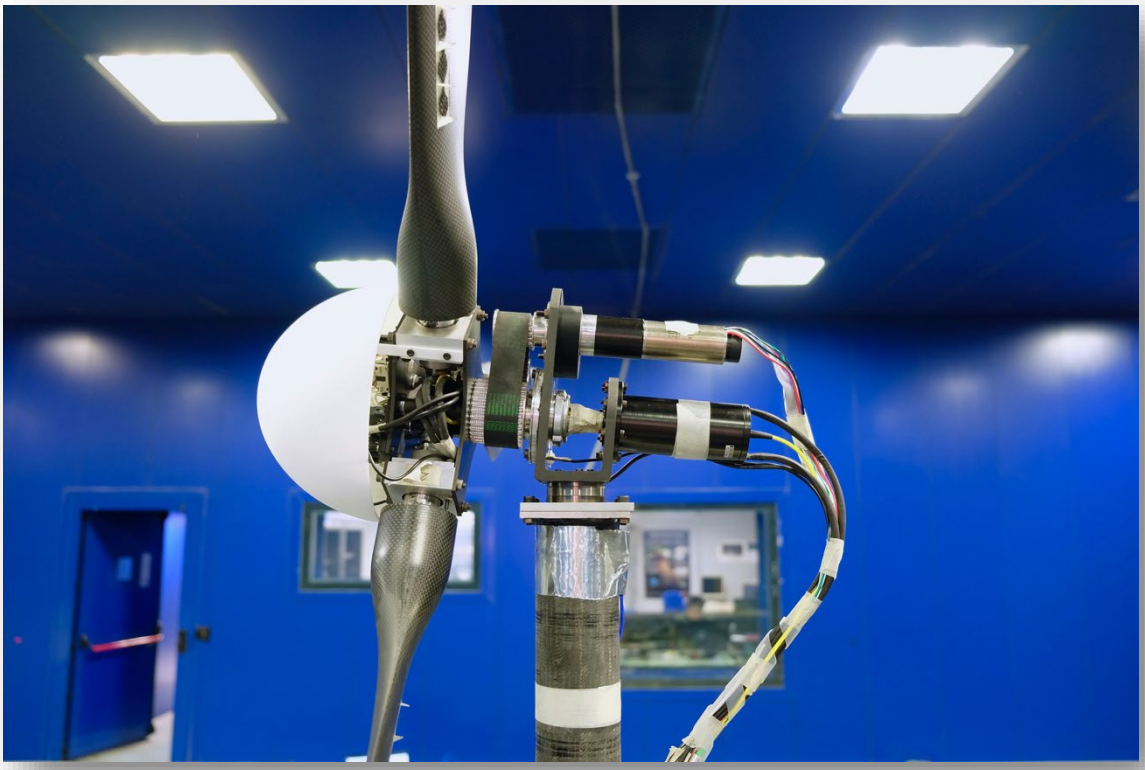
The PoliMi hardware-in-the-loop system is used to carry out experiments about floating wind turbines in the atmospheric boundary layer test section of the wind tunnel.

The setup used for the wind-tunnel hybrid experiments consists of a wind turbine scale model, a 6-degrees-of-freedom robot, and a hardware-in-the-loop control system.

The floating wind turbine is split into two complementary subsystems. The physical subsystem is the wind turbine scale-model which is designed to reproduce the rotor loads and to have the same actuation capabilities of a full-scale wind turbine. The numerical subsystem is instead a

simulation code of the rigid-body dynamics of the FOWT, of the hydrodynamic loads and of the mooring system. The coupling between the physical and numerical subsystems is the force measurement provided by a 6-components force transducer mounted at the tower-to-platform interface. The platform motion resulting from real-time integration of the numerical model is applied to the wind turbine scale-model by means of a parallel kinematic 6-degrees-of-freedom robot.

The wind turbine scale-model



On top of the HIL system is mounted the PoliMi WTM, a scale-model of the DTU 10MW RWT, which was designed and built at PoliMi within the H2020 LIFES50+ project. The scale factors adopted for model design as well as for wind tunnel experiments were derived by choosing the length scale factor λ_L and the velocity scale factor λ_V. The first one was fixed to 1/75 to limit the blockage effect avoiding, at the same time, an excessive miniaturization of the model components. The second one was set to 1/3 to limit the Reynolds number discrepancy with

respect to full-scale, while setting reasonable design requirements for the model actuators and for the natural frequencies of aeroelastic components.

The scale-model rotor was specifically designed to operate at low-Reynolds through an ad-hoc optimization procedure. The aerodynamic design was focused at minimizing the difference between the scale model and full-scale thrust coefficient. The SD7032 airfoil was used in place of the FFA-W3 series airfoils of the RWT since its lower thickness makes it less sensible to flow separation.

The PoliMi WTM is featured by a complex mechatronic system.

The generator is emulated by an electronically commuted (EC) motor and a dedicated servo-controller. Servomotors mounted on-board the hub are used to set the individual pitch angle of the blades. An embedded control system based on *NI LabVIEW* provides the interface with actuators and measurement instruments on-board the scale-model and control strategies developed in *Simulink* for FAST co-simulations can be directly deployed on the real-time controller for experimental validation.