Infrastructure Access Report

*Infrastructure*: UNIFI-CRIACIV Boundary Layer Wind Tunnel

*User-Project*: CRIACIV-BLWT visit (Proj. Num. 56)

Power curve measurements of Vertical Axis Wind Turbines
ABOUT MARINET

MARINET (Marine Renewables Infrastructure Network for emerging Energy Technologies) is an EC-funded network of research centres and organisations that are working together to accelerate the development of marine renewable energy - wave, tidal & offshore-wind. The initiative is funded through the EC's Seventh Framework Programme (FP7) and runs for four years until 2015. The network of 29 partners with 42 specialist marine research facilities is spread across 11 EU countries and 1 International Cooperation Partner Country (Brazil).

MARINET offers periods of free-of-charge access to test facilities at a range of world-class research centres. Companies and research groups can avail of this Transnational Access (TA) to test devices at any scale in areas such as wave energy, tidal energy, offshore-wind energy and environmental data or to conduct tests on cross-cutting areas such as power take-off systems, grid integration, materials or moorings. In total, over 700 weeks of access is available to an estimated 300 projects and 800 external users, with at least four calls for access applications over the 4-year initiative.

MARINET partners are also working to implement common standards for testing in order to streamline the development process, conducting research to improve testing capabilities across the network, providing training at various facilities in the network in order to enhance personnel expertise and organising industry networking events in order to facilitate partnerships and knowledge exchange.

The aim of the initiative is to streamline the capabilities of test infrastructures in order to enhance their impact and accelerate the commercialisation of marine renewable energy. See [www.fp7-marinet.eu](http://www.fp7-marinet.eu) for more details.

Partners

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<th>Sustainable Energy Authority of Ireland (SEAI_OEDU)</th>
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ABOUT THIS REPORT

One of the requirements of the EC in enabling a user group to benefit from free-of-charge access to an infrastructure is that the user group must be entitled to disseminate the foreground (information and results) that they have generated under the project in order to progress the state-of-the-art of the sector. Notwithstanding this, the EC also state that dissemination activities shall be compatible with the protection of intellectual property rights, confidentiality obligations and the legitimate interests of the owner(s) of the foreground.

The aim of this report is therefore to meet the first requirement of publicly disseminating the knowledge generated through this MARINET infrastructure access project in an accessible format in order to:

- progress the state-of-the-art
- publicise resulting progress made for the technology/industry
- provide evidence of progress made along the Structured Development Plan
- provide due diligence material for potential future investment and financing
- share lessons learned
- avoid potential future replication by others
- provide opportunities for future collaboration
- etc.

In some cases, the user group may wish to protect some of this information which they deem commercially sensitive, and so may choose to present results in a normalised (non-dimensional) format or withhold certain design data – this is acceptable and allowed for in the second requirement outlined above.

ACKNOWLEDGEMENT

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EXECUTIVE SUMMARY

This document contains the results of experimental studies conducted at the wind tunnel of the Inter-University Research Center for Building Aerodynamics and Wind Engineering (CRIACIV), at the University of Florence regarding the experimental evaluation of the aerodynamic behavior of wind turbines (Proposal CRIACIV-BLWT Visit, Project Number 56) within the MARINET Project. The project involves tests on various prototypes of Darrieus wind turbines in order to evaluate the power curve characteristics. The report describes the prototypes used, the experimental set-up, and instrumentation adopted. Finally, the main results are discussed.
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1. INTRODUCTION

This document contains the results of experimental studies conducted at the wind tunnel of the Inter-University Research Center for Building Aerodynamics and Wind Engineering (CRIACIV), at the University of Florence (Figures 1 and 2) regarding the experimental evaluation of the aerodynamic behavior of wind turbines (Proposal CRIACIV-BLWT Visit, Project Number 56) within the MARINET Project.

![Fig. 1 The CRIACIV BLWT.](image)

![Fig. 2 Plant of the wind tunnel.](image)

(A): initial contraction; (B) boundary layer; development zone; (C) test section (2:40 x 1.60 m); (D) connecting section; (E) motor; (F) divergent.

The project involves tests on various prototypes of Darrieus wind turbines in order to evaluate the power curve characteristics. In this report results of the tests will be provided with reference to conditions corresponding to average wind speeds.
The first part of this report covers a brief description of the prototypes used, the experimental set-up, and instrumentation adopted. Later, the results will follow.

2. DESCRIPTION OF PROTOTYPES

The testing activity involved several prototypes of small VAWT turbines of type H-Darrieus (DAR). In particular, 6 rotors with 3 blades (asymmetric NACA profiles made of carbon fiber) with two chord values (4.7 and 9.4 cm), two diameters (50 and 100 cm) and two different lengths of the blades (75 and 150 cm). Table 1 shows the characteristic parameters of the turbines tested, the various test configurations and the conditions of the test flow. Figure 3 shows the pictures of the six rotor tested.

<table>
<thead>
<tr>
<th>Model</th>
<th>Diameter [cm]</th>
<th>Chord [mm]</th>
<th>Blade length [mm]</th>
<th>Flow type</th>
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<td>100</td>
<td>94</td>
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<tr>
<td>94x1500 R25 EP*</td>
<td>50</td>
<td>94</td>
<td>1500</td>
<td>Laminar</td>
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</table>

EP* Turbine equipped with End Plates.

Fig. 3 Details of the rotors tested.

a) 94x1500 R50

b) 94x750 R50
3. EXPERIMENTAL SET-UP AND INSTRUMENTATION

For the extraction of the power curves, the different rotors were mounted on a splined shaft connected to a motor capable of being adjusted both in torque and in speed. The shaft on which the turbine is located is supported at two points outside the test chamber of the wind tunnel through 4 ball supports SLB UKFC 206 and connected to the brushless motor by means of a torque bidirectional (DR20) of Lorenz Messtechnik (Fig. 4).

The engine may act as a brake in case the turbine delivers a positive torque (production); or by an actual engine dragging the turbine rotor to a fixed torque and speed of rotation (absorption). In the modes of operation "Engine" and "Brake" there is a reversal of the sign of the torque due to the entry into production of the turbine. The engine allows to select the operating mode: speed control (max. 1500 r / min) or torque (max 19.6 Nm), and real time monitoring of the performance offered by the engine.

Fig. 4 Detail of the measurement set-up.

3.1. ACQUISITION SYSTEM

The instrumentation used during testing consisted of:

- Bi-directional Torque DR20 Lorenz Messtechnik with FS ± 0.1% FS accuracy and 20Nm (0.02 Nm, which corresponds to the limit of measurement of torque);
• Optical encoder for measuring the speed of angular rotation, consists of a laser beam optical readers, optoNCDT model 1605 Micro-epsilon.

Wind speeds were controlled with a Pitot tube connected to a high precision pressure transducer SETRA, positioned 3 meters upstream from the turbine in undisturbed flow. The signal acquisition is performed with a A/D card NiCDAC National Instruments model 9239 24-bit with a sampling frequency of 2000 Hz. Data were recorded with a dedicated Lab View Signal Express based software and stored in ASCII format. The Lab View program allows monitoring the signals mean values and the relative standard deviations in real time for all the recorded variables.

4. EXPERIMENTAL RESULTS

The tests were conducted with fixed wind speeds, between 4 and 15 m/s. The speed of rotation of the turbine (u) is varied by the motor, which starts the rotor in "Engine" mode. An increase of the speed of rotation makes the turbine start producing with a consequent inversion of the torque of the engine that operates in the "Brake" mode. By further increasing the speed of rotation it is noted a progressive increase of driving torque and power until a maximum characteristic value is reached. Increasing further the speed of rotation causes a drop in power until it goes back to a negative value of the torque corresponding again to the "Engine" condition.

Before reporting the experimental data for the curves of power it is necessary to define the main dimensionless quantities that are commonly employed to characterize the operation of a wind turbine.

- Tip Speed Ratio (TSR) expresses the ratio between the tangential velocity of the blade (rotation speed of the turbine) and the velocity of the undisturbed flow (wind speed test):

  \[ \text{TSR} = \frac{uR}{v} \]

- Reynolds Number (Re), a dimensionless group, is proportional to the ratio between the forces of inertia and viscous ones:

  \[ \text{Re} = \frac{\rho vc}{\mu} \]

- The power coefficient (Cp) represents the fraction of wind energy converted into useful energy by the turbine:

  \[ C_p = \frac{2uT}{\rho v^3 DL} \]

where: \( u \) [rad/s] is the speed of rotation of the turbine; \( R \) [m] is the radius of the rotor; \( v \) [m/s] is the wind speed reference; \( \rho \) [kg/m³] is the density of the air; \( c \) [m] is the chord of the NACA profile of the blade; \( \mu \) [Pa s] is the dynamic viscosity of the air; \( T \) [Nm] is the torque; \( D \) [m] is the diameter of the rotor and \( L \) [m] is the length of the turbine.
4.1. POWER CURVES

Model: 94x1500 R50
Flow: Laminar ($I_t < 1\%$)
Data: $t=60$ s, $f=2000$ Hz

Model: 94x750 R25
Flow: Laminar ($I_t < 1\%$)
Data: $t=60$ s, $f=2000$ Hz

Model: 94x750 R25
Flow: Laminar ($I_t < 1\%$)
Data: $t=60$ s, $f=2000$ Hz
Model: 47x750 R25
Flow: Laminar ($I_t < 1\%$)
Data: $t=60\ s$, $f=2000\ Hz$

Model: 94x1500 R25
Flow: Laminar ($I_t < 1\%$)
Data: $t=60\ s$, $f=2000\ Hz$

Model: 94x1500 R25
Flow: Turbulent ($I_t = 23\%$)
Data: $t=60\ s$, $f=2000\ Hz$
The above figures show the values of the coefficients of power (Cp) measured at various wind speeds for the seven configurations examined. The data of torque and rotation speed obtained from the experimental campaign have not been corrected. Solid lines in the above figures have been added to show more clearly the trend of the data. It is interesting to note that the best performance measured (Cp = 0.17 and about 0.13) are reached by the rotors 94x1500 94x1500 R50 and R25 at TSR of 3 and 1.75, respectively. Regarding the configuration 94x1500 R25 tested in laminar flow, turbulent and with the installation of end plates, no substantial differences between the various cases appear. In the case of prototypes with rotor blade length of 750 mm, it was not possible to identify a maximum positive value of Cp, excepting for the case 94x750 R25 at wind speed very high (> 17 m / s).

5. CONCLUSIONS

The best configuration in terms of energy is definitely the 94x1500 R50 because it is able to provide high values of the coefficient of power even at low values of wind speed. The turbine also starts at a relatively low wind speed (4.5 m / s) and also presents a good transient response. Clearly, given the size of the rotor, the effects due to the locking on the results should not be neglected. The 94x1500 R25 turns out to be a good compromise between performance and locking with a maximum power coefficient of 0.13. The turbines with rotor blade length of 750 mm provide positive values of Cp at very high wind speeds but much less compared to the turbines with a length of 1500 mm. Therefore, they seem to be the worst by the aerodynamic and energy points of view mainly due to the influence of the aerodynamic effects of three-dimensional edge. Regarding the end plates, they cannot reduce the edge effects due to their small size.

BIBLIOGRAPHY


