DUTCH WIND ENERGY RESEARCH

PREFACE

WIND ENERGY RESEARCH AND EDUCATION IN THE NETHERLANDS

We are very pleased to present you an overview of the wind energy research and education in the Netherlands. It is both inspiring and fitting that our relatively small nation competes at highest level in wind energy, with a strong international reputation. Fitting because of our country's long history in using the power of the wind as an integral part of sustained prosperity. And it is inspiring for all of us involved in research and education, to be part of a powerful community that can and will make a difference for the knowledge based economy and for a path to a global sustainable energy future.

For wind energy has a bright future ahead. Driven by innovation in policies, business models and technology, the current installed and projected capacity of wind turbines show that wind technology is a highly competitive sector with an incredible rate of growth. To keep up with the pace, Europe as a whole will require the best and most creative minds, supported by an internationally competitive research and test infrastructure. And it will require all knowledge and innovation enterprises joining forces to provide education and to perform R&D at the highest possible levels.

Joining forces has been the major driver for this publication, both from the Wind R&D-sector and from the Netherlands Energy Research Association (NERA). It is our firm belief that Dutch wind energy research and education is already very strong – as evident from internationally acclaimed projects such as the Far and Large Offshore Wind program (FLOW) – but the best has yet to come. Teaming up will unleash its full potential, and this booklet shows we are doing just that.

On behalf of the Dutch wind energy research and education institutes,

Gijs van Kuik (TU Delft) and Theo de Lange (ECN)

DELTARES

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Deltares is a leading, independent, Dutch-based research institute and specialist consultancy for matters relating to water, soil and the subsurface. The advanced expertise is used to help people live safely and sustainably in delta areas, coastal zones and river basins. Deltares conducts research and provides specialist advisory services for government authorities and the corporate sector in The Netherlands and globally. The essence of the work is the development, application and sharing of knowledge. Deltares develops knowledge in partnerships with universities, other knowledge institutions and the business sector, not only in government research programmes but also in contract research. Deltares has more than 800 employees. Main offices are based in Delft and Utrecht, The Netherlands, with affiliations in Singapore and USA.

RESEARCH GROUPS INVOLVED

Deltares' hydraulic, geotechnical and ecological expertise in marine environments supports offshore engineers in the development, safe operation and monitoring of offshore wind farms. The following research groups work closely together, each from their own field of expertise:

Harbour, coastal and offshore engineering Design of scour protection, (operational) prediction of scour development in time, environmental design conditions for foundation design, operational prediction of metocean parameters during installation and maintenance, weather window analysis, evaluation of performance of existing wind parks.

Geo-engineering Geotechnical stability of offshore wind turbine foundations, offshore foundation design, cyclic liquefaction (mainly relevant for gravity base structures), geohazards, site approvals.

Coastal structures and waves Wave runup and wave impact against foundation structures, flow through porous media like scour protections.

Water quality and ecology Ecological impacts and risks of installation of offshore wind parks, effects on local habitat and biotope mapping, marine spatial planning, environmental legislation, environmental monitoring techniques.

Applied Geology and Geophysics Marine surveys for monitoring local bathymetrical changes around the foundations and performance of scour protection, short- and long-term morphological changes, risk assessments for electricity cables.

Morphology and sediment dynamics Dredging technology (e.g. for soil improvement), handling of solids, characteristics of cohesive soils.

The number of full time-equivalent persons working on wind energy is 20-30.

FACILITIES & ADVANCED RESEARCH TOOLS

Atlantic Basin	This combined wide wave-and-current basin (75 x 8.7 x 1.3m) is used for offshore, coastal, river and harbour projects.
Delta Basin	Is a multidirectional wave basin (50 x 50 x 1m), equipped with 2 multidirectional wave generators, placed at a right angle to each other. The Delta Basin is used for offshore and coastal related projects.
Delta Flume	Deltares' largest wave flume (240 x 5 x 7m). The size and available wave conditions make it possible to test almost every structure on a near-to-prototype scale.
GeoCentrifuge	Is a unique facility in which geotechnical phenomena can be investigated by artificially increasing the gravitational force (up to 300g) to enable proper modelling of the soil behaviour.
and many more smaller basins, flumes and geotechnical facilities	

Bioremediation Lab	In-situ bioremediation uses the capacity of bacteria to degrade contaminants at contaminated sites for a better soil and groundwater quality.
Geochemical characterisation laboratory	To research the interactions at the interface between water and sediment and to analyse both the solid matter as well as the water.
Laboratory for microbial diversity	For research into the microbiological composition of a system and how that determines the functions of the soil system.
Delft-3D	A world leading 3D modelling suite to investigate hydrodynamics, sediment transport and morphology and water quality for fluvial, estuarine, coastal and offshore environments.
ComFLOW	Is a computational model that is capable of accurate and efficient simulation of the complex wave field near, and the wave impacts on, offshore and coastal structures. ComFLOW is developed in cooperation with Rijksuniversiteit Groningen and MARIN.
D-OSCAR, D-PROBED, D-ORCA, D-Pile Group. D-Cycle and D-Sheet Piling	Engineering software tools to respectively predict scour development , make a conceptual design for scour protection, perform statistical analyses on metocean data, design a pile foundation, calculate cyclic liquefaction and determine three-dimensional behaviour of single piles and pile.
Measurement instruments	Custom-made measuring instruments for waves, current velocities, profiles, sediment transport.
Calibration facilities	For pre- and post-calibration of instruments, sensors and systems for use in laboratory, industrial systems and hydrographic/hydrometric field work.

R&D STRATEGY

	Term		
R&D STRATEGY	Short	Medium	Long
Improvement of scour prediction in time around various foundation types, suitable in deeper water (focus on backfilling, tidal effect, validation of timescales against field measurements, more complex soil types).	●	●	
Optimization of design formulae for scour protection consisting of loose rock (in terms of volume, rock size and number of layers).	●		
Edge scour around the scour protection of offshore structures (irt safety of electricity cables).	●		
Wave models for impact on and kinematics around offshore structures and through permeable scour protection.	●	●	●
Integrated approach for hydraulic and geotechnical stability of marine structures.	●	●	
Numerical modelling of structure-fluid-soil-interaction.		●	●
Impact of sand waves on wind park design.	●		
Optimization of weather windows for installations in the offshore environment.	●	●	
Innovative solutions for scour protection around offshore structures, including frond mats, collars, gabions, rock bags etc.		●	
Monitoring of existing wind parks and survey evaluation (stability of scour protection, edge scour development, impact of short- and longterm morphological changes).	●	●	●
Cyclic loading and water pressure build-up below Gravity Base Structures (influence of history effect).		●	
Differences in design between driven and drilled offshore foundation piles (is p-y method still suitable?).	●	●	
Cumulative displacement of Gravity Base Structures under the influence of waves (interest in translation and rotation, related to cable connections).		●	
Multi-purpose use of offshore structures.		●	●

EDUCATION & TRAINING ACTIVITIES

Deltares gives software courses and lectures at both universities and companies and assists in training and tutoring MSc and PhD candidates. Furthermore, Deltares staff is involved in expert groups, which establish guidelines and manuals.

OTHER INFORMATION

Deltares incorporates a unique combination of hydraulic and geotechnical expertise and a combination of experimental facilities and software development.

Deltares
Enabling Delta Life

DUWIND

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Research on wind energy at the Delft University began 35 years ago, starting with an aerodynamic project at Aerospace Engineering. Nowadays the research programme covers almost all aspects of modern wind turbine technology, and is undertaken across 5 faculties. Each of the research groups at these faculties has its own specific expertise, but an increasing number of research problems require a multi-disciplinary approach. The focus of Duwind is on long term, pioneering research, which implies that PhD research is the core of Duwind. Duwind comprises approximately 50 (full time equivalent) researchers, of which about 30 PhD candidates. The focus of Duwind's program is on the development of turbine and wind power station technology, ranging from fundamental aerodynamic research to development of design methodologies, and anything in between. Duwind offers a MSc curriculum in wind energy, and provides courses for professionals in the wind energy industry.

RESEARCH GROUPS INVOLVED

Duwind encompasses 13 research sections. The Wind Energy Section at Aerospace Engineering is the only one fully dedicated to wind energy, all others use wind energy as a challenging application of their expertise. Key-words of the research are:

Faculty of Aerospace Engineering Aerofoil and blade design, rotor aerodynamics (experimental, analysis, CFD), fluid-structure-interaction, rotor dynamics, aeroelastic stability, design of turbines and of offshore wind power stations, design methodology, wind field description, structural reliability, composite materials, component testing, production techniques, smart structures, urban wind turbines.

Faculty of Civil Engineering and Geosciences Offshore design tools, support structure, access systems, offshore availability and reliability.

Faculty of Electrical Engineering, Mathematics and Computer Science Electric conversion systems, direct drive generators, configuration of offshore wind parks.
Wind as part of renewable energy systems, integration of renewable energy in the grid, stand-alone systems.

Faculty of Mechanical, Maritime and Materials Engineering Fault-tolerant control. Nonlinear analysis, control and identification. System identification, design and testing of turbine control systems, analysis of turbine dynamics, reliability based design methods.

Faculty of Technology, Policy and Management Introduction of new infrastructures in society, scenario development for large scale Dutch offshore windpower.

FACILITIES & ADVANCED RESEARCH TOOLS

Low speed, low turbulence tunnel	High quality closed loop wind tunnel, up to 120 m/s wind, turbulence ranges from 0.015% at 20 m/s to 0.07% at 75 m/s. The 10 interchangeable octagonal test sections are 1.80 m wide, 1.25 m high and 2.60 meters long.
Open Jet Facility	The OJF is an open jet tunnel specifically for wind energy. The test section is 3m Ø, max windspeed is 30 m/s.
Several small wind tunnels	Ideal for small scale test, as preparation for experiments in the large tunnels.
Structures and Material Laboratory	Laboratory for composite material development and coupon testing, testing of structures, development of manufacturing processes.
Wave basin, towing tank	The towing tank has a length of 145 m, width of 4.22m, equipped with a wave generator. The wave basin is 25*25m, with wave generators in three directions
Many other university laboratories	

EDUCATION & TRAINING ACTIVITIES

Duwind offers a specialization on wind energy in many Delft MSc degrees, supported by dedicated MSc-courses on *wind turbine design, rotor aerodynamics, wind and site conditions, support structure design, offshore wind farm design, electrical machines and drives, design and manufacturing of wind turbine blades*. Students can choose an MSc track of the faculty that best fits their BSc education, and develop themselves in their chosen expertise, applied to wind energy. Highly specialized research on topics like aerodynamics of wind turbines, materials, control, dynamics, aeroelastic stability, electromagnetic conversion, is possible, as is more applied research into wind and wave loading, reliability of components, concepts for deep water support structures and the economic costs of wind energy. Duwind is developing an official Master in Wind Energy degree, and cooperates with universities abroad. Duwind welcomes international students to do a MSc at Delft, or a traineeship. The same holds for the PhD research: Duwind also takes care of the wind energy education at the other Dutch Technical Universities in the framework of the joint MSc in Sustainable Energy Technology, and contributes to the EUREC MSc. Duwind offers post-academic courses for industry (Introduction to Wind Energy and Offshore Technology), and courses on advanced topics.

R&D STRATEGY

R&D STRATEGY	Term: Short	Medium	Long
Duwind cooperates closely with ECN, the Energy research Centre of the Netherlands. The research program and expertises are adapted to each other, keeping the character of each institution in mind: Duwind focuses on long-term, fundamental R&D while ECN focuses on applied R&D, with enough overlap to cooperate and compete. Duwind and ECN share a common international Advisory Board. The research programme of Duwind is driven by the following three objectives: • To maximise the reliability of wind turbine and wind farm operation. • To minimise the loads on the structures (on both the rotors and support structure). • To optimise the entire energy supply chain (wind, wind turbines, grid layout and onshore connection, integration into the main grid). The Duwind research program is divided into 5 program lines. These five major areas are: • unsteady aerodynamic loads • smart dynamic control (smart structures) • offshore design aspects • design methodology • electric conversion and large scale electricity supply The majority of the research is done by PhD researchers (in the Netherlands a PhD takes 4 years full-time research). The first objective is knowledge and understanding, with design tools and guidelines at the second place. This implies that almost all work is considered to be long-term research. However, when possible knowledge is transferred to the market either by direct contact and training of industry, or by design projects together with ECN.			●

OTHER INFORMATION

Duwind is an active part of the international wind energy community, and cooperates with other R&D groups and industry in European projects, and projects of the International Energy Association. Duwind is active in the European Wind Energy Association and the wind energy Technology Platform of the European Commission. Duwind is founding member of the European Academy for Wind Energy, and has launched its scientific conference series 'The Science of making Torque from Wind' and its Summer School.
The cooperation with industry is increasing. Almost all MSc students find jobs in wind energy industry. This industry supports the Duwind R&D programme by an increasing number of PhD researchers funded by them.
Within the TU-Delft, Duwind is part of the Delft Energy Initiative, in which all energy research at TU-Delft joins forces.

DUWIND
DELFT UNIVERSITY WIND ENERGY RESEARCH INSTITUTE

ECN WIND ENERGY

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ECN is working on research and development of energy technology for already more than 55 years. ECN's mission is to develop high-quality knowledge and technology for the transition to a sustainable energy system and to introduce this knowledge and technology to the market. At present approximately 600 people work at ECN in the field of biomass, solar energy, energy efficiency, policy studies and wind energy. ECN Wind Energy focuses its activities on the need of industry and government through target-oriented development and transfer of knowledge and technology. Its focus is offshore wind energy, being one of the main contributors to a sustainable energy supply.

ECN Wind Energy employs over 60 experts and holds a strategic position between universities and industry. This has been a successful basis for many developments and innovations since the start of ECN's wind energy activities in 1975. ECN Wind Energy consists of three research groups covering the research on Aerodynamics, Integrated Wind Turbine Design and Operation & Maintenance, and two groups offering services and industrial support: the Experiments & Measurements group and the ECN Wind energy Industrial Support group (EWIS).

RESEARCH GROUPS INVOLVED

Rotor and Farm Aerodynamics The aerodynamic research aims at optimising the aerodynamic performance of the wind turbine rotor and of the wind farm as a whole. By developing new knowledge, methods and design software, the results of the research can directly be transferred to industry.

Integrated Wind Turbine Design The research on integrated wind turbine design focuses on wind turbine control, aero-elastics and structural dynamics. Apart from conducting long-term research and selling the different design tools to industry, this group is often consulted for solving complex problems related to wind turbine loading and aero-elastic behaviour.

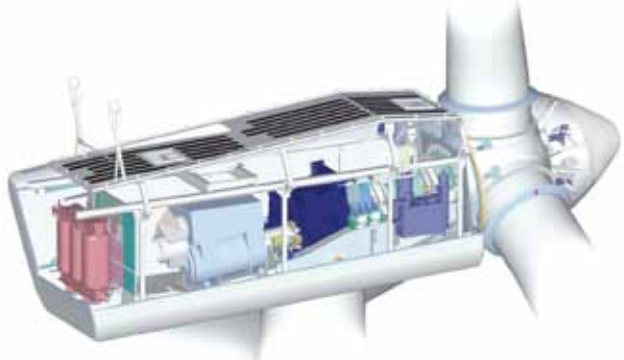
Wind Farm Operation & Maintenance The aim of the research on Operation & Maintenance (O&M) is to develop tools and knowledge to lower downtime and O&M costs of offshore wind farms. Examples are different O&M tools for analysing the O&M aspects in the planning phase and in the operational phase of a wind farm. The group also works on low-cost methods to determine the mechanical loads on individual turbines.

ECN Wind energy Industrial Support (EWIS) This youngest group within ECN Wind Energy has the dedicated task to meet the growing industrial demand for the ECN knowledge, design tools and O&M tools. The group sells the commercially available ECN software and offers services and training programmes to industry.

Services include:

- Making and reviewing aerodynamic blade designs.
- Optimisation of offshore wind farm designs, including the electrical wind farm layout.
- Conducting design load calculations for wind turbines.
- Developing control algorithms for wind turbines.
- Selling different software packages in the field of blade design, wind turbine design, control design and O&M.

Experiments and Measurements The Experiments & Measurements group at ECN Wind Energy is ISO 17025 accredited for measuring mechanical loads, power performance and acoustic noise emission. The group administers the unit's MEASNET membership and it uses self-developed equipment for measurements and data communication. The group maintains a high-standard quality system, including strict safety measures for climbing in wind turbines and working offshore. Many industrial clients benefit from the measurement services of this group.

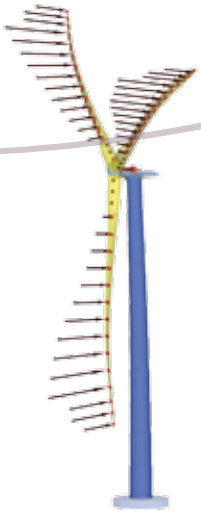


FACILITIES & ADVANCED RESEARCH TOOLS

FACILITIES	
Experimental Wind Farm	ECN operates an own wind farm, consisting of 5 turbines of 2,5 MW each. These turbines can be used for different research purposes.
Scaled Wind Farm	A scaled wind farm, consisting of 10 turbines of 10 kW each is used for experimental research in the field of wind farm aerodynamics and testing of wind farm specific control strategies.
Prototype turbine test site	ECN owns five prototype test positions for testing (offshore) wind turbines up to 6 MW. The number of prototype test positions will most probably be increased to 10 in 2012. These new positions are suited for turbines up to 10 MW.
Meteo infrastructure	On ECN's test site several large met masts (up to 105 metres high) are being operated. From 2011-2015 ECN will operate a met mast far offshore, some 75 km west of IJmuiden.
ADVANCED RESEARCH TOOLS	
FOCUS wind turbine design software	Joint development with WMC, including software packages PHATAS and Bladmode.
Aerodynamic blade design tools	Blade Optimisation Tool BOT and Aerodynamic Table Generator ATG.
Control Design Tool	Software for developing control algorithms for wind turbines.
SILANT	Software for noise calculation.
ECN O&M Tool and O&M Cost Estimation Tool OMCE	Software for analysing O&M aspects of offshore wind farms. The O&M Tool is used in the planning phase of wind farms, whereas the OMCE is used in the operational phase.
Ee-Farm	Software for electrical wind farm design optimisation.
Farm Flow	Software for aerodynamic design optimisation.

EDUCATION & TRAINING ACTIVITIES

ECN offers a wide variety of training programmes and courses in the field of Aerodynamics and Aerodynamic Design Tools, Rotor Aerodynamics, Control of Wind Turbines and Operation & Maintenance of offshore wind farms. On occasion ECN offers contributions to educational programmes at universities.



R&D STRATEGY

	Term		
R&D STRATEGY	Short	Medium	Long
ECN cooperates closely with Duwind, the wind energy research institute of the Technical University Delft and WMC, the knowledge centre for wind turbine blade and materials. The research program and expertises are adapted to each other, keeping the character of each institution in mind: ECN and WMC focus on implementing medium and short-term R&D, while Duwind focuses on fundamental medium and long-term research, with enough overlap to cooperate and compete. Duwind and ECN share a common international Advisory Board. The aim of the research activities are to decrease the cost of offshore wind energy by improved design and a higher reliability in the operational phase. Most of the long-term research at ECN is financed by public agencies, but ECN also carries out dedicated long-term research programmes for (and together with) industrial partners. ECN increasingly is shifting from public financed research to joint industrial projects with partners from all over the world.		●	●
Through the ECN Wind energy Industrial Support group (EWIS) and the Experiments & Measurements group ECN offers a wide range of products and services for industrial partners.	●		

OTHER INFORMATION

ECN Wind Energy is member of the European Wind Energy Association (EWEA), the European Wind Energy Academy (EAWE), the Technology Platform Wind Energy (TP Wind), the European Energy Research Alliance (EERA) and the Netherlands Wind Energy Association (NWEA).

ECN co-operates with many universities, research institutes and industrial companies in Europe, Asia and North America.

IMARES

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IMARES is a leading, independent and international scientific institute for strategic and applied marine ecology. The institute focuses on fisheries management, aquaculture, environmental protection and spatial use of the seas and coastal zones.
The core competencies are (marine) ecological research in support of maritime policies and innovation, conservation, water quality, contaminant risks, biological production and marine governance.
The research incorporates fieldwork, laboratory experimentation and testing, data management, modelling, simulations and stakeholder participation.
IMARES employs over 200 people representing a broad variety of scientific disciplines. IMARES is an independent specialized contract research organization within Wageningen University and Research Centre.

RESEARCH GROUPS INVOLVED

Several departments within IMARES are involved in research concerning the development of offshore wind capacity through contract research projects. These projects focus on the socio-economic and ecological effects of construction, operation and decommissioning of offshore turbines. IMARES develops solutions for integrated marine spatial planning, governance and stakeholder participation. The institute develops and executes assessments of ecological impacts of offshore wind farms on marine life, like fish, seabirds, marine mammals and invertebrates. IMARES does this by using a wide variety of observational monitoring techniques in the field and experimental studies in the lab focused on determining dose-response relationships. The main departments performing research related to the development of Offshore Wind Energy are the Department of Fish and the Department of Ecosystems. The focus at the Department of Fish is on research related to fish, fishlarvae, underwater noise and fisheries. Within the Department of Ecosystems the focus is on research related to seabirds, marine mammals and zoobenthos. The number of full time-equivalent persons working on wind energy is 7.

FACILITIES & ADVANCED RESEARCH TOOLS

Acoustics - Field measurements of underwater sound

Acoustics - Marine mammal detection

Acoustics - Fish survey and behaviour

Monitoring - Fish (field sampling & acoustics)

Monitoring - Benthos (field sampling)

Monitoring - Assessment of dynamic mooring system loads and tanker motions.

Monitoring - Birds (shipborne and airborne observations & radar)

Monitoring - Marine mammals (acoustic, ship- & airborne)

Micro- and mesocosm facilities (marine fish & invertebrates)

Tools for marine spatial planning

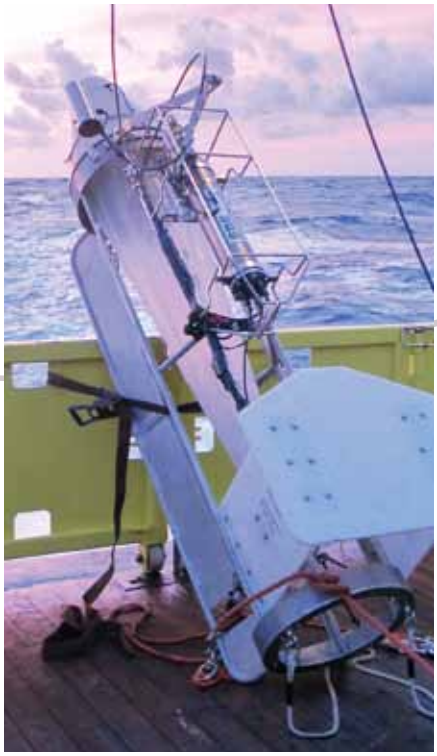
Tools for stakeholder participation

EDUCATION & TRAINING ACTIVITIES

IMARES has structural links with Wageningen University and Research Centre and the Van Hall-Larenstein applied university. Imares has 9 professors, 2 lectors, 30 PhD-students and takes part in organizing MSc and professional bachelor courses, as well as in joined research with the university and the other research institutes of Wageningen UR. IMARES furthermore cooperates with other universities on a project basis in lecturing and training on both the MSc, PhD level.

R&D STRATEGY

	Term		
R&D STRATEGY	Short	Medium	Long
Measuring and modelling the mortality and behaviour of migrating and foraging birds and marine mammals around offshore turbines.		●	
Development of marine spatial planning tools for the integrated use of the oceans and its resources.			●
Measuring and modelling the effects of underwater sound from construction, operation and decommissioning of offshore wind farms on marine life.		●	
Development of novel concepts and technology for measuring the ecological effects of offshore wind farms.			●
Understanding the effect of introduction of artificial structures and habitat on marine life.		●	
Develop concepts to use offshore wind farms as seed areas to create new or restore lost nature.			●
Integration of sustainable infrastructure with the natural environment by solutions in adequate design and execution processes.			●



OTHER INFORMATION

IMARES has ample experience with research related to the impact of offshore wind farms on the marine environment, but also executes innovative research to seek out chances for combinations with other human use of the sea, i.e. multifunctional use, and solutions for mitigating impacts. Furthermore IMARES collaborates with several research institutes, both in the Netherlands as well is in Europe, and is therefore experienced and equipped to lead and execute multidisciplinary research programmes making use of the specialized expertise of other research organizations.

IMARES WAGENINGEN UR

MARIN

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The Maritime Research Institute Netherlands was founded in 1929 as the Netherlands Ship Model Basin (NSMB) by the Dutch government and industry. Work was started in 1932, following completion of the deep water towing tank. To cope with the ever-increasing demands of the industry for research in the fields of powering performance, seakeeping and manoeuvring, including shallow water effects, cavitation, vibration, noise etc., a whole series of special test laboratories was successively built (Deep Water Towing Tank 1951, Shallow Water Basin 1958, High Speed Basin 1965, Depressurised Towing Tank 1972, Cavitation tunnel 1979). A new Seakeeping and Manoeuvring Basin became operational in the course of 1999. The upgrading of the Depressurised Towing Tank was completed in 2001. As Offshore technology experienced extensive growth, MARIN became involved in offshore projects since 1960. A Wave and Current Basin was built in 1973, it has been replaced by a complete new Offshore Basin in 2000. As early as 1970, MARIN extended its activities to include nautical research and training. For this purpose a modern Vessel Traffic Simulator and two full-mission simulators are available today.

At present, approximately 300 people work at MARIN; together they are responsible for a turnover of € 33 million. 85% is earned on the commercial worldwide maritime market.

So for more than 75 years, the Maritime Research Institute Netherlands (MARIN) has been contributing to the development of safe and economic ships and offshore structures as independent advisor, therefore MARIN sees it as its responsibility to contribute to the development of renewable energy offshore from waves, tides and wind. For this reason, MARIN has recently started a special Renewable ENergy Team (RENT).

In the area of Offshore wind energy, much is related to normal floating and fixed offshore structures. Installation, removal, maintenance, survivability and vessel traffic safety are topics that link offshore wind energy to MARIN's broad maritime expertise. Finally, MARIN also contributes to the development of wind turbine installation vessels.

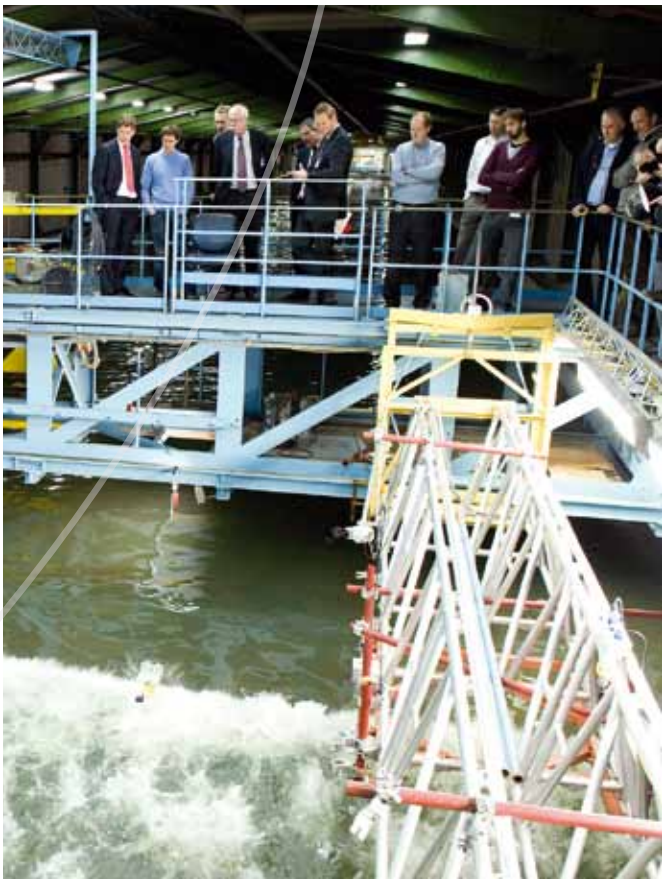
RESEARCH GROUPS INVOLVED

RENT is a MARIN-wide team of specialists covering all aspects of offshore renewable energy systems. MARIN offers dedicated people, dedicated research, dedicated model test facilities, dedicated simulation tools and dedicated offshore measurements to help make a renewable energy concept a success.

MARIN RENT has key competence in:

- Analysis of motions and loads of marine structures.
- Analysis of weather sensitive operations.
- Wave hydrodynamics.
- Model testing of marine structures.
- Hydrodynamic testing and simulations.
- Mooring and positioning systems.
- Development of numerical simulation tools.

The number of full time-equivalent persons working on wind energy is 2-3.



FACILITIES & ADVANCED RESEARCH TOOLS

FACILITIES	
Offshore basin	The Offshore Basin (40x40x10 m) is a realistic environment for testing offshore models. Its current generation system allows different vertical current profiles. Combined wind, waves and swell are generated using wave generators on both sides of the basin and a movable windbed. A movable floor allows testing from shallow to deep water, while a 30 m deep pit is available for ultra deep water testing.
Seakeeping and manoeuvring basin	The Seakeeping and Manoeuvring Basin (170 x 40 m) is designed for making arbitrary (high-speed) manoeuvres in realistic waves from arbitrary directions. The free-sailing or captive tests provide insight into the seakeeping and manoeuvring characteristics.
Ship model towing tank	The Deepwater Towing Tank (252 x 10.5 x 5.5 m) is used to optimize resistance and propulsion characteristics of ship designs.
Depressurised Towing Tank	The pressure of the Depressurised Towing Tank (240 x 18 x 8 m) can be reduced to an ambient pressure of 25 millibar. The tank is used to optimise the erosion and vibration characteristics. To avoid erosive cavitation and vibration hindrance on the propellers, rudders or struts, cavitation is observed using regular and high-speed cameras coupled to pressure pulse measurements.
ADVANCED RESEARCH TOOLS	
aNySIM-PHATAS coupling	Time domain analysis of Multi Body Dynamics for Offshore operations. Together with ECN MARIN is developing a coupled hydro-area dynamic simulation program for floating wind turbine.
Dynfloat	Assessment of dynamic mooring system loads and tanker motions.
Comflow	Comflow is a CFD code to compute non-linear wave loads on offshore structures (for instance green seas, wave impact loads and sloshing). Furthermore ComFLOW is used to calculate the (breaking) wave loads on a offshore wind turbine.

EDUCATION & TRAINING ACTIVITIES

In addition to Joint Industry Project and Cooperative Networks, MARIN transfers expertise and knowledge through training. Courses for designers and architects are held periodically throughout the year. Furthermore MARIN has about 10-20 students which perform their master thesis project at MARIN, and about 5-10 PhD students at the moment.

R&D STRATEGY

	Term		
R&D STRATEGY	Short	Medium	Long
MARIN cooperates closely with ECN, the Dutch Energy Research Centre in the area of floating and fixed wind turbines.			●
To assist in the testing of fixed and floating wind turbines, MARIN is presently working on a high quality local wind field modelling set-up for model tests in the Offshore basin.			●
Start up Joint Industry Project (JIP), see other information.		●	

OTHER INFORMATION

MARIN, ECN, DNV, GL, Statkraft and Ramboll are in the process of starting up a Joint Industry Project (JIP) with the acronym 'WiFi': Wave impacts on Fixed turbines. The objective of this WiFi JIP is to improve the way effects of steep (and breaking) waves are taken into account in the design methodology of fixed offshore wind turbines, so that optimized offshore wind turbines can be developed. In preparation of the JIP, MARIN performed pilot model tests in November 2010 with a special model of an offshore wind turbine with realistic flexibility tested in (extreme) waves. These tests confirmed that significant oscillations can occur in the turbine as a result of steep and breaking waves.

MARIN

NLR

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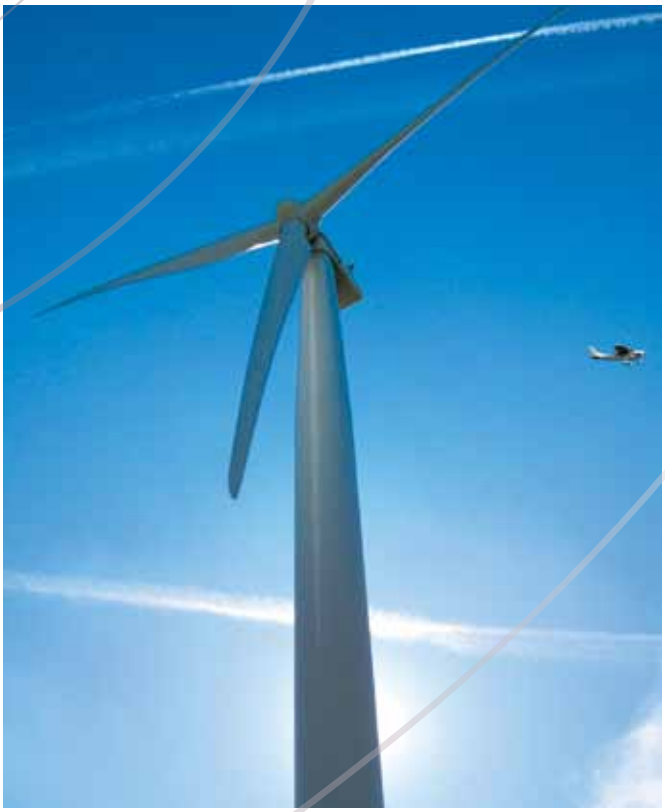
The Dutch National Aerospace Laboratory (NLR) carries out applied research on behalf of the aviation and space sectors. NLR is an independent technological institute and performs research to develop new technologies for aviation and space travel, not only from a scientific perspective, but also for the application of this research in industrial and governmental sectors. NLR's aerospace capabilities have a logical spin-off to wind energy such as applying safety methods, aerodynamic design, applying high tech materials and wind tunnel testing. NLR's clients include governmental authorities, large and small industries, and aerospace organizations - both in the Netherlands and abroad. NLR has a number of specialized research facilities such as wind tunnels, which it operates together with its German sister organization DLR. It is one of the Netherlands' major technological institutions. Three-quarters of the research it performs is commissioned by clients.



RESEARCH GROUPS INVOLVED

Environment & Policy Support NLR has the capability to apply external safety methodologies for wind turbines, to determine the external risk associated to installations of wind turbines.

Safety issues of wind turbines around airports NLR Air Transport Safety Institute has experience in analysing collision risks and the effect of wake turbulence behind wind turbines to aircraft. NLR has the tools to identify conflicts of objects with flight procedures and to advice on possible solutions. Regarding wake turbulence behind a wind turbine, NLR is able to analyse the strength of the wake turbulence that an aircraft could be exposed to and to assess the impact on the encountering aircraft. NLR has carried out several aeronautical studies and obstacle assessments for project developers and other stakeholders in The Netherlands and abroad.

NLR has also experience in the assessment of the influence of wind turbines on the electromagnetic waves being used by aircraft for communication and navigation. Electromagnetic waves may be reflected or scattered by the wind turbines, depending on the shape and materials used, thereby causing electromagnetic interference for aircraft.

Theoretical Aerodynamics/design/aero elasticity In the area of Flight Physics and Loads, NLR has capabilities in the application of aerodynamic design methods, aero-elastics and loads (spectra) for wind turbines.

Wind turbine noise reduction NLR has many years of experience with predicting, detecting and reducing aerodynamic sound from rotor blades. NLR uses semi-empirical in-house developed noise prediction methods for trailing edges.

Composite materials and structures NLR explores new automated manufacturing technologies like fibre placement in combination without autoclave curing technologies are being developed. NLR is heavily involved in these developments for aerospace applications.

FACILITIES & ADVANCED RESEARCH TOOLS

FACILITIES	
Safety database	NLR maintains a large database of aircraft accidents and incidents worldwide, which help assessing collision risks.
Composites manufacturing facility with an industrial fibre placement machine	A well-equipped facility with an industrial fibre placement machine for development of new manufacturing concepts, structural details and even full scale prototypes.
Wide range of different static and dynamic testing machines	A well-equipped testing facility with a range of different static and dynamic testing machines in which composite materials and structural elements / prototypes are tested.
Wind tunnels (DNW)	Acoustic and aerodynamic wind tunnel testing (2D airfoils and model scale rotors).
ADVANCED RESEARCH TOOLS	
FPDAM	Commercial tool-set to support in the identification of conflicts with obstacles and the design of flight procedure adaptations.
Wake Vortex Induced Risk (WAVIR)	Tool-set to analyse impact of wake turbulence on aircraft.
Semi-empirical noise prediction methods for trailing edges	NLR has developed a semi-empirical (fast and accurate) prediction method for trailing edge noise, validated by various large acoustic microphone array for source localisation, wind tunnel and field measurements. This tool allows supporting the design of quiet wind turbines and land use planning purposes of wind farms.

EDUCATION & TRAINING ACTIVITIES

NLR co-operates with among others the Technical University Delft in education and training of students and graduates.

ATM Safety Assessment Courses providing an overview on safety regulation and safety assessment techniques, which are also relevant for the assessment of effects of wind turbines on aviation safety.

R&D STRATEGY

	Term		
R&D STRATEGY	Short	Medium	Long
NLR's primary focus is to carry out applied research for aviation and space, containing elements of High Tech Systems and Materials (HTSM) and Energy. In the field of HTSM programmes are carried out such as High Tech Materials and Lightweight composite structures, Knowledge Based Engineering, Future technologies for High Tech Systems, High Tech Aircraft and Cabin Systems (including aircraft on-board electrical power generation), Engine components and Maintenance, Repair en Overhaul (MRO). Both areas are also applicable to wind energy which is a spin-off of NLR's aerospace research, technology development, test and evaluation. NLR's integrated approach in aerospace combining technology, environment and safety is also well suited for application in the domain of wind energy.	●	●	

OTHER INFORMATION

The Foundation German-Dutch Wind Tunnels (DNW) is a non-profit organisation jointly established by the Dutch National Aerospace Laboratory (NLR) and the German Aerospace Centre (DLR).
DNW provides a wide spectrum of wind tunnels and simulation techniques to customers from industry, government and research. See also DNW for more details.

DNW

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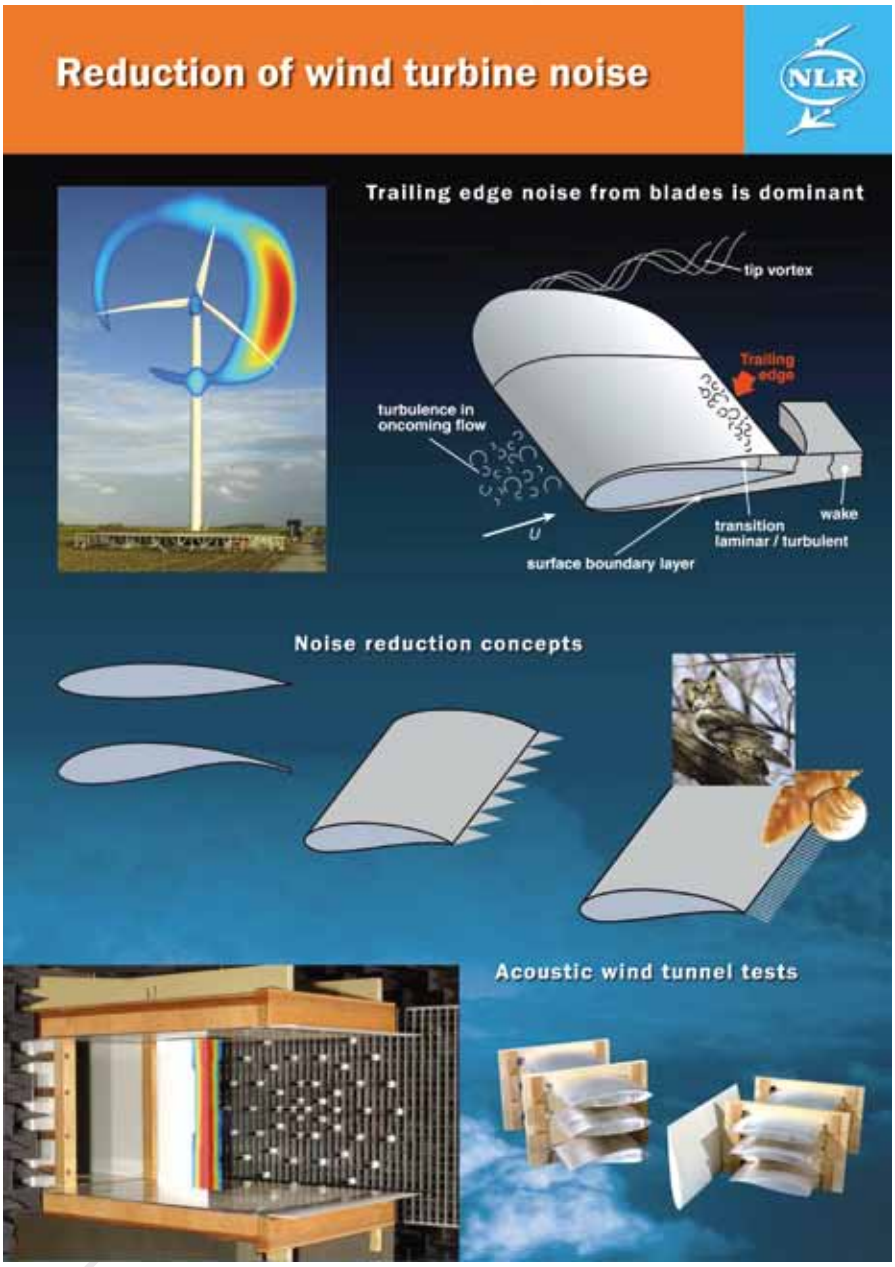
The Foundation German-Dutch Wind Tunnels (DNW) was jointly established in 1976 by the Dutch National Aerospace Laboratory (NLR) and the German Aerospace Centre (DLR), as a non-profit organisation under Dutch law. The main objective of the organisation is to provide a wide spectrum of wind tunnel tests and simulation techniques to customers from industry, government and research. DNW owns the largest low-speed wind tunnel with open and closed test section options in Europe. Also the major aeronautical wind tunnels of the DLR and NLR are fully integrated and managed by the DNW organisation. DNW provides solutions for the experimental simulation requirements of aerodynamic research and development projects. These projects can originate in the research community (universities, research establishments or research consortia) or in the course of industrial development of new products.



FACILITIES & ADVANCED RESEARCH TOOLS

FACILITIES	
The following four out of eleven wind tunnels are also used for testing non-aeronautical objects:	
KKK	Cryogenic wind tunnel at Cologne, Germany. A closed circuit, continuous, low-speed wind tunnel with a closed wall test section.
LLF	Large low-speed facility at Marknesse, the Netherlands. A closed circuit, atmospheric, continuous low-speed wind tunnel with three closed-wall exchangeable test sections and an open jet.
LST	Low-speed wind tunnel at Marknesse, the Netherlands. A continuous, atmospheric, low-speed wind tunnel with exchangeable test sections.
NWB	Low-speed wind tunnel at Braunschweig, Germany. A continuous, atmospheric, low-speed wind tunnel with optionally a closed or a slotted test section with an open jet.
ADVANCED RESEARCH TOOLS	
6-component external balance (EXB)	The EXB is a platform type balance, with three horizontal load cells with a resolution of 0.15 N and three vertical load cells with a resolution of 0.30 N.
Two acoustic wall arrays of about 140 sparsely distributed microphones each	The array processing technique delivers as its main result so-called noise maps. These maps show the distribution of noise sources in the scanned area and deliver the location, frequency characteristics and relative strength of the noise source. Additionally the array processing delivers power spectra and overall power levels by integration of the scan area.
3-Component Particle Image Velocimetry (PIV)	The flow field of the turbine blades can be measured well with PIV, upstream the rotor plane, within the rotor plane as well as in the wake. PIV measurements provide vector maps of the flow field area and distribution of the vorticity.

OTHER INFORMATION

The figure on the left page shows a three-bladed wind turbine model with a rotor diameter of 4.5m mounted on the external balance in the open-jet test section configuration. The dimensions are illustrated by the presence of the people at the bottom, right. The wind tunnel flow is from the right to the left. Tests comprised the measurement of blade pressures as well as the details of the air flow around the blades and rotor through PIV measurements. The blades were instrumented with 148 high response pressure sensors to measure the fluctuating pressure distributions around the blade airfoils. The wind speed varied between 5 and 30 m/s and the wind direction was set at yaw angles between plus minus 30 degrees.

German-Dutch Wind Tunnels

EDUCATION & TRAINING ACTIVITIES

DNW co-operates with among others the Technical University Delft in education and training of students and graduates.

R&D STRATEGY

	Term		
R&D STRATEGY	Short	Medium	Long
DNW continuously strives for developing and applying the best possible measuring tools and instruments.		●	●

TNO

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Netherlands Organization for Applied Scientific Research (TNO) is a fully independent research organization, established by law in 1932, with a staff of about 4400. TNO expertise and research make an important contribution to the competitiveness of companies and organizations, to the economy and to the quality of society as a whole. TNO's unique position is attributable to its versatility and capacity to integrate this knowledge. TNO works for a variety of customers: governments, the small and medium enterprises sector, large companies, service providers and non-governmental organisations.

TNO Offshore Wind started in 2003 with the Dutch We@Sea research program with development of the 'ROBIN' bird radar for the Egmond aan Zee (OWEZ) wind farm. Other offshore wind projects are corrosion and bio-fouling risk assessment for the wind farm Princes Amalia. Assessment of the impact and on-site measuring of produced sub sea noise during installation of wind turbine foundations. Optimisation of offshore wind farm monitoring, operation and maintenance (O&M). Since 2009 TNO participates in international offshore wind research programs in the European ÆRTO's program (Associated European Research and Technology Organizations). TNO Offshore Wind cooperates with European Research and Technology Organizations (RTO's) like Fraunhofer IWES (D), SINTEF (N) and VTT (Fin).

RESEARCH GROUPS INVOLVED

TNO uses the technology it has developed in various markets (high-tech manufacturing, naval industry, sustainable chemistry, energy and utility companies and building) also in the maritime and offshore market.
The research groups involved with offshore wind are:
Maritime Materials Performance Centre, MMPC, Den Helder Focussing on prevention of material degradation and life time prediction of offshore wind foundations and wind turbine components. Including remote monitoring.
Materials Performance, Eindhoven Focusing on specific materia, wear and erosion aspects for offshore wind constructions.
Center for Mechanical and Maritime Constructions, CMC, Delft Focusing on offshore constructions, mechanical load modeling, fatigue, shock and wave impact loading.
Radar and Sonar, The Hague Focusing on radar and sub sea noise effects of offshore windparks.
Sensors and Monitoring, Delft Focusing on developing specific sensors for remote condition monitoring of offshore wind turbines and constructions. The number of full time-equivalent persons working on wind energy is 10.



FACILITIES & ADVANCED RESEARCH TOOLS

FACILITIES	
Maritime Materials Performance Centre, MMPC	Natural seawater laboratory, maritime exposure site and test raft. Expertise's are corrosion, bio fouling, micro-biology and bio-corrosion, electrochemistry, coatings and metallurgy.
Center for Mechanical and Maritime Constructions, CMC	Testing facilities for shock and vibration loading on offshore and shipment constructions and components. On-site testing. Expertise's shock loading, fatigue, composite materials, special metal construction materials.
Radar test facilities	Radar signature test site. Expertise's are radar visibility and protection of offshore structures.
Monitoring and sensoring	On site sub sea noise measurement, ultrasonic testing, fiber bragg sensor technology. Development and manufacturing facility for sensors.
Materials performance	Tribology and wear laboratory. Expertise's are smart coatings and material development.
ADVANCED RESEARCH TOOLS	
Bio-corrosion (MIC) management and monitoring	Combination of electrochemistry, corrosion and bacterial laboratories facilities and in situ bio-corrosion monitoring.
Combination of microscopic techniques	Characterization of bio-corrosion and degradation of materials and coatings on nano scale by Atomic Force Microscope (AFM).
Shock and vibration testing and modeling	Shock and vibration test equipment for large scale components in combination with wireless sensor systems.
Sub sea noise measurement and modeling	On-site offshore sub-sea noise measurement.

EDUCATION & TRAINING ACTIVITIES

Tailor made courses and standard modules of university programs. Topics are materials science, corrosion management, tribology and wear.

R&D STRATEGY

	Term		
R&D STRATEGY	Short	Medium	Long
Durable and predictive design Life time prediction of offshore structures with focus on corrosion management and structural monitoring. The ÆRTO's research program, an ERA-net cooperation, is focused on cost effective corrosion protection for offshore wind.	●		
Operation and Maintenance optimization TNO focuses on sensor systems and maintenance strategies. The ÆRTO's research program operation and maintenance for offshore windfarms is focused on remote sensing, monitoring and condition based maintenance.	●		
Safety and Environment offshore wind Protection monitoring of offshore sites, unknown hazards (foreign objects, vandalism, illegal fishery), influence of radar detection and signature, sub sea noise and sonar, incident, risk and safety management.	●		

OTHER INFORMATION

TNO participated in several offshore wind research programs like the ÆRTO's program (ERA net program), 'Operation and Maintenance in Offshore Wind' and 'Cost Efficient Corrosion Protection for wind turbines and structures'. TNO was one of the authors of the Knowledge Investment Agenda Offshore Wind 'Wind op Zee', in cooperation with Technical University Delft, different RTO's and industrial partners.

TNO innovation for life

WMC

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Knowledge Centre WMC is a research institute for materials, components and structures. The major activities are fundamental and applied research on Fibre Reinforced Plastics (FRP) and wind turbine structures. WMC is working for both the European and Dutch governments, as well as for the international industry. Full scale tests on rotor blades have been carried out since 1984. WMC develops in close cooperation with ECN the modular integrated design tool FOCUS6 that is being used worldwide by many of the largest wind turbine manufacturers. WMC is actively involved in international standardization committees.
WMC renders services for setting up testing facilities around the world. WMC is situated at a unique location along the border of the IJsselmeer, which enables the transport of large structures to the facility. WMC also offers consultancy for setting up test facilities around the world.

RESEARCH GROUPS INVOLVED

Testing of large components

This includes testing of rotor blades, large subcomponents, hub/bearing assemblies, yawing mechanism, nacelles and other structural components for large wind turbines.

Material and component research

This includes fundamental long term research as well as test programmes for the material characterisation for the industry.

Development of software and electronics

For testing purposes as well as the development of the integral modular design tool FOCUS. FOCUS6 is developed in cooperation with ECN and used worldwide by the larger wind turbine and blade manufactures.
The number of full time-equivalent persons working on wind energy is 25-30.

FACILITIES & ADVANCED RESEARCH TOOLS

Large test facility	Large test area with a dedicated strong floor enabling testing of structures such as rotor blades, large subcomponents, hub/bearing assemblies, yawing mechanism, nacelles and other structural components for large wind turbines.
Material and Component Test Laboratory	16 Testing machines from 1 kN up to 3MN (30MN in 2012) are available for material and component testing, both static and fatigue. This includes climate chambers for temperatures from –180°C to +600°C.

EDUCATION & TRAINING ACTIVITIES

WMC offers internships, graduation projects and PhD positions for (international) students. WMC organizes training courses for the use of software in the design of wind turbines. WMC gives lectures at the Technical University Delft related to the design of wind turbines.

R&D STRATEGY

	Term		
R&D STRATEGY	Short	Medium	Long
WMC combines fundamental and applied research in order to offer the industry the state of the art support for structural research. This includes experimental as well as numerical research. WMC participates in national and European research programmes in many cases in cooperation with Duwind and ECN.	●	●	●

OTHER INFORMATION

WMC is member/participant of:
IEC-TC88 committees
EAWE
EERA
NEC88
IEA
TPWIND

Knowledge Centre WMC
Wind turbine Materials and Constructions

FOR MORE INFORMATION

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