TECHNOLOGICAL IMPLEMENTATION PLAN

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1. DESCRIPTION OF THE PROJECT

EC programme:	5th RTD Framework Programme
Project title:	Reliable Optimal Use of Materials for Wind Turbine Rotor Blades
Acronym:	OPTIMAT BLADES
Programme type:	Energy, Environment and Sustainable Development
Contract number:	ENK-CT-2001-00552
Project web site (if any):	www.ecn.nl/optimat
Start date:	01-01-2002
End date:	01-05-2006
Coordinator details	L.G.J. Janssen Energy research Centre of the Netherlands (ECN) P.O. Box 1 1755 ZG Petten The Netherlands Tel.: +31 224 56 46 64 E-mail address: l.janssen@ecn.nl

Partners names:

Short name	*Legal name*	*Department*	*Nat.*
ECN	Netherlands Energy Research Foundation	ECN Wind Energy	NL
TUDT	Delft University of Technology	Aerospace engineering / WMC group	NL
DLR	Deutsches Zentrum für Luft- und Raumfahrt e.V.	Institut für Bauweisen- und Konstructionsforschung	D
DEWI	Deutsches Windenergie-Institut Gm		D
CCLRC	Council for the Central Laboratory o the Research Councils	Rutherford Appleton Laboratory	UK
RISØ	Risø National Laboratory	Materials Research Department	DK
CRES	Centre for Renewable Energy Sour	Wind Energy Department	EL
VUB	Vrije Universiteit Brussel	Dept. Of Mechanics, Materials and Constructions (MEMC)	B
UP	University of Patras	Dept. of Mechanical Engineering and Aeronautics	EL
VTT	Technical Research Centre of Finla	VTT Energy	FIN
GL-Wind	Germanischer Lloyd Windenergie GmbH		D
DNV	Det Norske Veritas, Danmark A/S	Wind Turbine Certification	DK
LM	LM Glasfiber A/S	Research & Development Department	DK
Polymarin	Polymarin B.V.		NL
Nordex	Nordex Energy GmbH		D
Gamesa	Gamesa Eólica S.A.	Engineering Department	E
EW	Enron Wind GmbH	Engineering	D
Vestas	Vestas Wind Systems A/S	Research & Development	DK

2. EXECUTIVE SUMMARY

Original research objectives

Various factors are determining the development of wind energy. Economy plays a dominant role, but also rational use of resources. Economy dictates minimisation of investment and operational costs of wind turbines that have reliable and structurally optimised blades over their designed lifetime. Rational use of materials supports this but also the policy to minimise such use for reasons of minimal use of earth resources and for environmental reasons. The economy of large wind farms calls for reliable and non-stop operation and for dedicated methods for repair, in particular for offshore wind farms owing to poor accessibility. To these ends, design data and tools need to be accurate and trustworthy. However, before this project such data and tools are quite often far from being consistent, reliable, sufficient and satisfactory. The project aims to provide the necessary underlying knowledge for strongly improving this situation. The outcome is a consistent set of accurate and reliable design recommendations.

More in particular, the project OPTIMAT BLADES addresses the problem of strain, stress and fatigue in wind turbine blades for various materials. Such blades are subject to severe fatigue loadings, e.g. variable amplitude loadings, with often more than one billion fatigue cycles and to a variety of external environmental, sometimes of a severe nature. Moreover, the blades consist of thick laminates that are in a state of complex stresses. Therefore, the scientific and technical objectives of the project are

- to obtain improved and profound knowledge of blade material behaviour under variable amplitude loading, under complex stress states and under external (extreme) conditions,
- to obtain improved and profound knowledge of the stress state and behaviour of thick laminates,
- to obtain improved knowledge of the interaction of the conditions mentioned above,
- to develop methodologies for repair,
- to develop methodologies for condition assessment, residual strength and life time prediction,
- the knowledge obtained is implemented into a consistent set of accurate and reliable design recommendations.

The knowledge and acquired knowledge will result in reliable blades, reduced use of material and less waste, reduced environmental impact, extended lifetime for blades, larger availability of wind turbines and extension of the possible size of wind turbines.

The broad participation of European research institutions and wind industries as well as that of certification bodies in the project warrants acceptance and use of the design recommendations by virtually all parties involved in the development of wind energy in Europe, possibly even in more parts of the world. Also, the gathered knowledge will find its way to European industries through the underlying publications and reports.
Particularly, in order to enable all European industries and turbine owners to fully profit from the results of the project the results have been made public by means of

a. Publications; the research institutes will publish the results of the research. This includes technical and scientific publications in international journals and presentations at international conferences. Publication will be in journals and on conferences on wind energy and also on materials and structures.
b. Design recommendations; the project will lead to design recommendations based on consensus between the researchers, manufacturers and certifying bodies participating in the project.

c. Workshops; during the project two workshops will be organised for dissemination of results and for feedback.

It is envisaged that the obtained knowledge is also applicable to the use of (thick) laminates in other fields, such as civil engineering, aeroplanes structures and ship structures.

<< Further information on results to be inserted at the end of the project >>

3. OVERVIEW OF ALL MAIN PROJECT RESULTS

3.1. Task group 1

Task: investigation of blade material behaviour under variable amplitude loading
Work packages 3, 4,5
Deliverables (d) and expected results (r):

- Test report describing the material, laminates and fatigue tests (d)
- Report on fatigue results including damage accumulation factor (d)
- Fatigue test programme variable amplitude (r)
- Description of NEW WISPER standard load spectrum (d)
- Validation report of NEW WISPER (d)
- Evaluated influence variable amplitude effect (r)
- Report on interaction tests and NEW WISPER testing on alternative materials (d)
- Finalisation of activities on interaction effects (r)

Status:

1. As to lifetime benchmarking, first calculations have shown that the basics, e.g. statistical evaluation of fatigue data and rainflow counting, have to be adapted before the different existing models can be compared.
2. Evaluation of the static tests has shown that the results of the participating test institutes are within the tolerance bounds. Significant differences in engineering constants were dissolved by relating them to sensitivities in the thickness measurements of the specimens.
3. Five data bases have been identified so far with normalised and processed data.
4. The procedure of recovery and adaptation of the WISPER synthesis is based on literature and has been studied.

Publications: first results on item 1. have been presented at the EWEC in Madrid.

3.2. Task group 2

Task: investigation of blade material behaviour under complex stress states
Work packages 6, 7
Deliverables (d) and expected results (r):

- Report on validated composite mechanics and FEM formulation guidelines and recommendations for rotor blade design (d)
- Validated multi-axial static and fatigue failure criteria (d)
- Mechanical property data base for reference materials (including fatigue data, d)
- Assessment of failure probability under uni-axial and multi-axial static and fatigue load (d)
- Quantification of complex stress state effect on blade design (d)
- Test plan for complex loading (r)
- Evaluated complex stress state effect (r)
- Report giving the variations in multi-axial predictions due to material choice (d)
- Proposal for eventual modifications of partial safety factors (d)
- Test plan for complex loaded alternative materials (r)
- Finalisation of activities on complex loading (r)

Status:

1. Preliminary tests have been conducted to determine the optimal coupon geometry for all kind of tests.

2. Preliminary bi-axial tests have been performed supported by FE analysis.
3. Preliminary tests have been performed to study the overall stress distribution.
4. Several composite specimens of different geometry have been tested to study failure modes.
5. Benchmark test results of experiments on standard OB UD coupons under static tensile and compressive loads have been presented in a technical report.
6. Fatigue tests to determine the s-n curve under reversed loading have been performed.

Publications:

3.3. Task group 3

Task: investigation of blade material behaviour under external (extreme) conditions
Work packages 8, 9
Deliverables (d) and expected results (r):

- Micro-structural model and identification of degradation parameters (d)
- Definition of extreme conditions and procedures for testing under extreme conditions (d)
- Phenomenological micro-mechanics models for sensitivity analyses (d)
- Effects of extreme conditions on properties of the reference material (d)
- Report on the effect of environmental ageing on reference material (d)
- Identification of extreme conditions and action plan (r)
- Evaluated extreme conditions effect (r)
- Report on variations in extreme conditions predictions due to material choice (d)
- Database containing degradation behaviour of tested material combinations (d)
- Test plan for alternative materials under extreme conditions (r)
- Finalised database of properties under extreme conditions (r)

Status:

1. Extreme conditions have been determined, in particular temperature variations and saline environment.
2. Stiffness degradation as function of applied strain and number of loading has been identified as damage parameter.
3. A variety of fatigue characterisation methods for composite materials has been identified from literature.

Publications:

3.4. Task group 4

Task: investigation of the stress state and behaviour of thick laminates and development of methodologies for repair
Work packages 10, 11, 12
Deliverables (d) and expected results (r):

- Definition report of typical thick laminate (d)
- Evaluation report comparing the analytical methods with experimental data (d)
- Test plan and laminate definition thick laminates (r)
- Evaluation of thickness influence (r)
- Selected repair techniques for small specimens (d)
- Report evaluating repair techniques as used for small specimens (d)
- DPA on repair locations and techniques (r)
- Go/no-go decision repair of curved components (r)

- Report on design and test of thick, curved components (d)
- Large components with and without repaired flaws (d)
- Test plan and curved component definition (r)
- Finalisation of activities on thickness influence (r)
- Finalisation of activities on repair (r)

Status:

1. Thin laminate plate theory has been applied and FEM analyses carried out with linear material behaviour
2. An overview of repair techniques that could be used for wind turbine blades has been written.
3. It has been established that industries are interested in repair of defects, scarf repairs as well as plug/patch repairs.
4. Repair of specimens have turned out to be of very good quality since the ultra-sonic testing could not distinguish flaws.

Publications:

3.5. Task group 5

Task: development of methodologies for residual strength and life prediction and condition assessment
Work packages 13, 14
Deliverables (d) and expected results (r):

- Review of existing residual strength predictive models (d)
- Experimental data base from residual strength tests (d)
- Validated engineering model for residual strength prediction (d)
- Validated engineering model for residual life evaluation and strategy for condition assessment (d)
- DPA for condition monitoring and residual life and strength (r)
- Validated engineering model for residual life and strength (r)
- Experimental data base from residual strength tests on alternative materials (d)
- Validated engineering models for residual strength and life prediction using condition assessment (d)
- DPA for residual strength programme, phase 2 (r)
- Fully evaluated residual strength model (r)

Status:

1. A literature review on residual strength characterisation has been carried out.
2. Static and fatigue benchmark tests were carried out on the selected basic UD and MD materials.

Publication:

3.6. Task group 6

Task: implementation of the obtained knowledge of the above tasks into a consistent set of design recommendations
Work package: 15
Deliverables (d) and expected results (r):

- Summary report of results TG1 to 5 (phase 1, d)
- Draft Design recommendations for the reference material (d)

- Summary report of results TG 1 to 5 (d)
- Design recommendations for next generation of wind turbine rotor blades (d)
- Summary reports (r)
- (Draft) Design recommendations (r)

Status: as yet no activities because of the dependency on the results of the other task groups.

The following items from the TIP layout as presented at the EU website can not be detailed as yet. No specific actions on technological implementation have been put forward.

4. QUANTIFIED DATA ON THE DISSEMINATION AND USE OF THE PROJECT RESULTS

5. COMMENT ON EUROPEAN INTEREST

Community added value and contribution to EU policies

European dimension of the problem

Many countries in Europe, collectively in the EU but also individually, have set out policies for a substantial development of wind energy. Significant progress has been made and many industries, institutions and other bodies are strongly involved.
At present, many parties feel that in order to keep up the pace of the growth and development of wind energy the design recommendations for wind turbines and wind parks need reflection. As economy and rational use of earth's resources increasingly become determining factors for future developments, the present recommendations and knowledge base in that area are considered non-optimal. In particular, data and research outcomes with respect to blade material show a lack of accuracy and are occasionally even contradictory.
The project aims at strongly improving this situation. The objectives mentioned in paragraph 2 are meant to do precisely that. Knowledge and methodologies will be developed and eventually come together in new, consistent, accurate and reliable design recommendations.
Such new knowledge and design recommendations for wind turbines and wind parks will enable industries to design and build more efficient wind turbines, economically as well as energetically, and also energy suppliers to plan and manage wind parks more effectively to the benefit of the energy consumer. The implementation of wind energy as an energy source in Europe will certainly gain momentum.
The ambitions are realised not only by the contents of the project but also by the large number and the kind of participants. They come from virtually all parties involved in wind energy and constitute from their individual and collective excellence a considerable and recognised power to bring forward a strong future for wind energy.

Contribution to developing S&T co-operation at international level. European added value

The project brings together many outstanding S&T institutions, industries and certification bodies. Their co-operation is basic to the success of the project that greatly enhances global competitiveness of Europe.
It is anticipated that the co-operation will not end with the project, as the development of design recommendations is an ever-ongoing activity. The project has laid the foundations for new alliances and strengthened existing ones. << More concrete later on in the project >>
Moreover, industries will not only benefit as regard to wind energy, but also in other areas such civil engineering, ship building, construction etc. The project has contributed to an improved access of industries to the area of S&T from which both sides will benefit.

The added value for Europe is summarised as follows:

- through the gathered knowledge and the developed design recommendations Europe has established a prominent position in the area of wind energy world-wide for a considerable time;
- industries, including energy providers, have strengthened their competitive position inside but also outside Europe with many export opportunities,
- S&T institutions have again demonstrated their ability to build up and maintain networks to the benefit of science;
- Europe is now better equipped to proceed with the speedy development of wind energy;
- Wind energy S&T and also materials S&T greatly benefit from the results of the project;

- The economics and rational use of resources in the area of wind energy have improved considerably.

Contribution to policy design or implementation

Since the project contributes significantly to the economics and rational use of materials in the area of wind energy, new plans can be drawn for the development and implementation of wind energy. Policy makers, publicly as well as industrially, have more accurate, reliable and consistent data at hand to develop such new plans in the area of energy. Implementation will gain momentum as the design recommendations are widely accepted.

Rational use of earth’s resources is another policy issue that is served by the results of the project.

b. *Contribution to Community social objectives*

It is evident that the project supports sustainable development. The improved opportunities for wind energy as well as the use of resources preserve and enhance the environment. In that way it contributes to the quality of life in the EU.

The gathered knowledge and new design recommendations strengthen European industries and S&T institutions in wind energy. Their competitive positions have certainly gained from the project. Jobs will well increase in number and have higher quality content.

6. EXPECTED PROJECT IMPACT

a EU policy goals

The results of the project enable the EU to continue its policy on the advancement of wind energy. The improved quality of both wind turbines and parks through the recommendations renders possible a more dedicated approach for that. The progress and growth in wind energy will continue.

b Economic development and growth, competitiveness and employment

Since the competitive position of European industries is strengthened by the project, a growth in production is anticipated. << More concrete later on in the project >> A favourable contribution to the economic development is thereby warranted.

Indirectly, through the improved opportunities for wind energy, the overall economy in the EU will benefit.

c Employment

No doubt, the better economic prospects will create jobs. << More concrete later on in the project >>

d Quality of life and health and safety

Improvement of quality of life and health is indirectly supported by the outcome of the project. Sustainable development and preservation of the environment through rational use of resources are key elements in that respect.

The new design recommendations will greatly improve the safety situation. Here, from the project's results less accidents and longer lifetimes are expected. << More concrete later on in the project >>

e Improved education

f Preservation and enhancement of the environment

The optimal use of material in manufacturing blades has a large potential to reduce the use of material in the blade. If the blade as a major component of the wind turbine becomes lighter, the loading on other components might reduce as well leading to even more reduction of material use for the turbine as a whole. The fact that the blades are reliable will reduce the use of material by itself by preventing the need of replacement. This need of replacement will also be reduced by the application of repair and residual life prediction.

This reduction of material use will lower the pressure on the earth resources in term of raw material use and the required energy to produce the actual materials. It also reduces the impact on the environment that is a consequence of the production processes. Secondly the impact on the environment is reduced by the fact that less material has to be scrapped.

The project results of the project can lead directly to less pressure on the earth resources and less impact on the environment. Indirectly the environmental impact is reduced by the increase of wind energy, providing a healthier environment by the reduced dependency on fossil energy and improving our quality of life *g S&T quality*

The project has produced widely accepted ways and means to do research on the pertinent materials for turbine blades and on other issues such as repair techniques and condition assessment. Researchers and technicians are now enabled to do more or less standardised measurements and experiments in these areas. << More concrete later on in the project >>

h Regulatory and legislative environment

The wide acceptance of the design recommendations will make them to a standard. Regulatory and legislative bodies may well use the recommendations to set out rules for wind turbines and parks.

On top of that, in case of disputes, courts may apply such rules but also the recommendations themselves for resolution.

i Other

<< More concrete later on in the project >>

7. Description of results

Result TG1

- a. Contact person for result TG1
- b. Summary
- c. Subject description codes
- d. Documentation and information on the result
- e. Intellectual property rights
- f. Market application sectors
- g. Current stage of development
- h. Quantified data about the result
- i. Further collaboration, dissemination and use of the result
  - a. Collaborations sought
  - b. Potential offered for further dissemination and use
  - c. Profile of additional partner(s) for further dissemination

Result TG2 ….

8. Exploitation plan (confidential)

Description of the use and the dissemination of result TG1

- Contact person
- Title and brief description of main result(s)
- Timetable of the use and dissemination activities within the next 3 years after project end
  - Activity
  - Timescale (month)
  - Brief description
  - Activity …
- Foreseen collaborations with other entities
- Quantified data
  - Economic impact (€)
  - Number of licenses within EU
  - Number of licenses ouside EU

- Total value of licenses (€)
- Number of entrepreneurial actions (start-up company, joint ventures a.o.)
- Number of direct jobs created
- Number of direct jobs safeguarded
- Number of direct jobs lost

Same for other TG's