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Reliable Optimal Use of Materials for Wind Turbine Rotor Blades (Optimat Blades)

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Semi-annual Progress Report

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1. INDUSTRIAL OBJECTIVES AND STRATEGIC ASPECTS

As the required financial investments increases due to the growth of the installed capacity of wind turbines, the economical pressure on reliable and structurally optimised blades, that are fit for their designed life, will increase. Especially for larger wind turbines, optimisation of the use of material becomes more effective and necessary since the blade mass increases more than proportional to the energy output. Very large blades may even become practically impossible without further knowledge of the material behaviour since the blade mass causes a dominating load on the blade material.

Rotor blades are unique structures, because of a combination of factors:

- Blades are subjected to complex and severe fatigue loads (variable amplitude loads), comprising often more than one billion fatigue cycles.
- Blades are subjected to a variety of external environmental conditions.
- The inner structural parts of the blades where most of the material is located consist of thick laminates that have a complex stress state.

Therefore, a sound and accurate understanding of the structural behaviour of the material under complex loading, complex stress states and a variety of environmental conditions and their possible interactions is necessary, in order to optimise the use of material in the blade and to obtain reliable blades. This also includes the knowledge of thick laminates and the effects of residual stresses.

The project aims to provide accurate design recommendations for the optimised use of materials within wind turbine rotor blades and to achieve improved reliability. This considers the design of new blades, but also the prediction of the residual strength and life. The latter can be used to extend the life of the blade or avoid unexpected failures, which will result in a better use of material. Furthermore, the possibility of repair will prevent waste of material. To achieve this overall objective, the project will investigate the structural behaviour of the composite material under the unique combination of conditions experienced by rotor blades such as variable amplitude loading, complex 3-D stress states, extreme environmental conditions, thick laminates and their possible interactions. For life extension, condition assessment and repair techniques will be developed. The major deliverable of the project will be improved design recommendations for the next generation of rotor blades.

With the accurate and reliable design recommendations resulting from this project, reliable blades with optimised use of materials can be designed. Together with the application of condition assessment and repair, this will result in:

- Reliable blades (fewer unexpected or premature failures)
- Reduced use of material and environmental impact
- Life extension of blades
- Less waste of material (fewer rejected blades and components)
- Larger availability of the wind turbine
- Extension of the possible size of turbine.

All these aspects can contribute to the reduction of costs for wind energy. This concerns investment costs by lighter components and less waste of material as well as running cost due to the larger availability.

The increased reliability and weight reduction of the blades will stimulate further offshore exploitation with large capacity wind turbines. This supports the increase in wind energy and by that helps to reach the White Paper target of 40GW of installed power by 2010.

The possible reduction of the material use will lower the impact on the earth resources and environment. The reduction can result from direct weight saving or from the increased reliability which prevents the need for replacements and waste of material.

2. EXECUTIVE SUMMARY

This report is the progress report over the first half year of the Optimat Blades project.
In this first half year the kick off meeting and a first progress meeting were organised.
In order to deal with contractual matters in an orderly fashion a Project Co-ordination Committee has been installed during the kick off meeting.

The programme of this project explicitly includes a start-up phase, meant to discuss and finalise the test programme, and to carry out preliminary tests, analyses and literature studies.
A major topic during this start-up phase is the definition of the exact test programme including the shape of the test specimens and material to be tested for the first phase of the project as a reference material. In order to get consistent test results across the whole project, it is desirable to arrive at a uniform test specimen for the bulk of the tests. To support the choice for the test specimens a first preliminary test series has been executed by the Task Groups involved in testing. From the results of this first test series the shape of the test specimens was changed and it was concluded that some additional tests were needed to reduce the occurrence of tab failures.
While the preliminary test were carried out the Task Leaders set up preliminary Detailed Plans of Action for their Task Groups. During the first progress meeting of the Technical Committee the draft DPA's were compared and overlapping tests were eliminated. After the results of the second test series will be available the DPA's can be finalised.

During this first half year some Contract Modifications were proposed and approved by the Scientific Officer of the European Commission.

3. ACTIVITIES DIRECTLY RELATED TO THE PREVIOUS REVIEW REPORT

Not Applicable

4. KEY EVENTS DURING THE REPORTING PERIOD

During the first six months of the project the following key events took place:

Kick off meeting
The project kick off meeting was held on 11-12 March 2002 at the Delft University of Technology. This meeting was attended by 17 out of the 18 participants and by the Scientific Officer from the European Commission. This meeting consisted of meetings of the different Task Groups, the Technical Committee, the Steering Committee and the Project Co-ordination Committee.

First Progress Meeting
The first progress meeting was held on 17-20 June 2002 at Risø National Laboratory.
This meeting was organised to discuss the Detailed Plans of Action for Task Group 1-5 within the different Task Groups to present and discuss the resulting Plans in the Technical Committee.

5. LIST OF DELIVERABLES MADE DURING THE REPORTING PERIOD

Not yet applicable.

6. SCIENTIFIC AND TECHNICAL PERFORMANCE

The programme explicitly includes a start-up phase, meant to discuss and finalise the test programme, and carry out preliminary tests, analyses and literature studies.

A major topic is the exact test programme including the shape of the test specimens and material to be tested for the first phase as a reference material.

Uniform test specimen
In order to arrive at consistent test results across the whole project, it is desirable to arrive at a uniform test specimen for the bulk of the tests. This approach has a number of advantages:

- The static and fatigue performance can be related to each other
- The residual strength after fatigue tests can directly be compared to the static results.
- The various results of the different task groups can be related to each other without the possible influence of the test shape.
- Fabrication and logistics are greatly simplified.

There are also a number of disadvantages of a uniform specimen:

- A test specimen that is stocky enough to prevent buckling under compressive loads is not ideal for tensile testing (too thick and short).
- Also the gauge length needed for especially NDT methods is rather long.
  In order to prevent buckling, the thickness has to be increased which in turn causes problems such as tab failures and the capacity of the testing machines might be exceeded.
- The partners differed of opinion on the general choice between a dogbone-shaped geometry and straight specimens. Compared to straight specimens, dogbones have lower stresses at the tabs and therefore are less prone to tab failures. On the other hand it was felt that dogbones are less suitable for unidirectional material.
- The conversion from test results and material characterisations according to (ISO-) standard tests is lost.

The last disadvantage can be eliminated by including a small number of static tests on ISO test specimens next to the static tests on the uniform OPTIMAT test specimen.

Reference material
A choice was made for an epoxy-glass fibre composite, due to its widespread use in the industry.
The resin selected is Prime 20 from SP Systems with slow hardener.
The details are provided in document OB_SC_R001.
The fibre reinforcement comes in two versions:

- 1150 g/m2 in 0° and 100 g/m2 in 90°, with a thickness of 0.88 mm
- 400 g/m2 in +45° and 400 g/m2 in –45° with a thickness of 0.61 mm.

In order to cover the use of a material in rotor blades, it was felt necessary to test both unidirectional (UD) as used in the spars and multidirectional (MUD) lay-ups as used in the root section.

Pure UD material is quite attractive, since it provides an easy way to model the individual layers of other lay-ups, for instance using the mixture law or as input for Finite Element analyses. Unfortunately, pure UD material is difficult to test due to its high degree of anisotropy. Furthermore, a number of effects such as fatigue damage initiating from local stress

concentrations due to layers of fibres in different directions cannot be determined from pure UD tests.
Therefore, another option was considered: “MUD” material which is UD material with two added 45° layers at the outside.

First preliminary test series
In order to get a good impression of the various options, both a dogbone and a rectangular shape were selected for the preliminary programme, made out of UD, MUD and MD, for a total of 6 combinations.
All materials contained five layers UD material, the MUD had two additional ±45° layers at the outside and the MD had six ±45° layers, of which two at the outside and four inter-spaced with the UD layers.

Per combination of geometry and material (6), each task leader involved (5) received 7 specimens, so that the total number of test specimens was 210 for this series.
The task leaders were at liberty to test them as they judge fairly or redistribute the specimens over the partners.

The results were compared at the first progress meeting at Risø. While there were differences due to the test set-ups, a number of results were general:

- Buckling occurred frequently, particularly for the dogbones, due to the longer gauge length. Failure for the dogbones occurred typically by a rectangular part tearing out from the dogbone, even when material with a 45° facing (MUD) was tested.
- UD was preferred over MUD, mainly because some tests, such as off-axis tests and hygro thermo tests have to be carried out on pure UD anyway. The MUD results were not significantly better than the UD results. Testing both MUD and UD would put too much strain on the test facilities, which might be put to better use elsewhere.
- The tab length is reduced to 55 mm, so that all institutes will be able to carry out the tests with the non-tapered tabs fully enclosed by the grips.

It was decided to drop the MUD, since the results were not better than the UD material and especially for off-axis tests in the main programme, pure UD has to be tested anyway.
Also, the results with dogbones did not seem favourable: buckling occurred frequently and UD material tore out a straight portion from the dogbone. It was decided to select a straight test specimen, except for tests at Risø, where the dogbone was chosen for TG3.

Second preliminary test series
In order to reduce the occurrence of tab failures and the needed capacity of the test machines to below 100 kN, one layer of UD material was dropped.
In addition, the gauge length was reduced in order to prevent buckling. Each task leader will receive 4 specimens per gauge length.

- The gauge lengths to be tested are 30, 35 and 40 mm for UD material, and 35, 40 and 45 mm for MD material.
- In addition, ISO/ASTM static tests will be carried out and combined loading compression tests, so we can see the difference between the OPTIMAT specimens and the ISO/ASTM test results.
- Furthermore, 10 cruciform test specimens are to be produced to check the usability of the cruciform shape with various corner radii. These specimens are to be manufactured with 3, rather than 4 UD layers to ensure failure.

DPA’s of the task groups
While the preliminary tests were carried out, the task leaders set up preliminary DPAs for their task groups. In the DPA the number and type of tests are specified, as well as the distribution over the partners. Furthermore, the DPA should contain the general aims of the task group,

numerical studies and literature reviews. Diversions from the project proposal of Annex I will be specifically mentioned.

During the meeting of the Technical Committee at Risø, the draft DPA's were compared to each other and overlapping tests eliminated. The task leaders will then finish their DPA's and distribute the tests over the task partners. The Technical Co-ordinator can then construct an overview of the tests per partner, which should be balanced against the person months of each partner in order to arrive at a reasonable distribution of tasks.

7. EXPLOITATION AND DISSEMINATION OF RESULTS

Document web site

At this stage, no external dissemination has occurred. Internally however, a special website has been set up which contains all reports, notes, agenda's minutes etc. in an orderly fashion and accessible for all partners. The structure of the web site has been kept quite simple as all partners are allowed access to all the project documents. Access to the web site requires a user name and a password. The scientific officer of the Commission also has access to the web site.
A general web site will be set up containing general information about the project and it's partners, and possibly the public documents in a similar fashion as the internal web site.

Test results database

A database format has been set up for a uniform presentation of the test results.

8. MANAGEMENT AND CO-ORDINATION

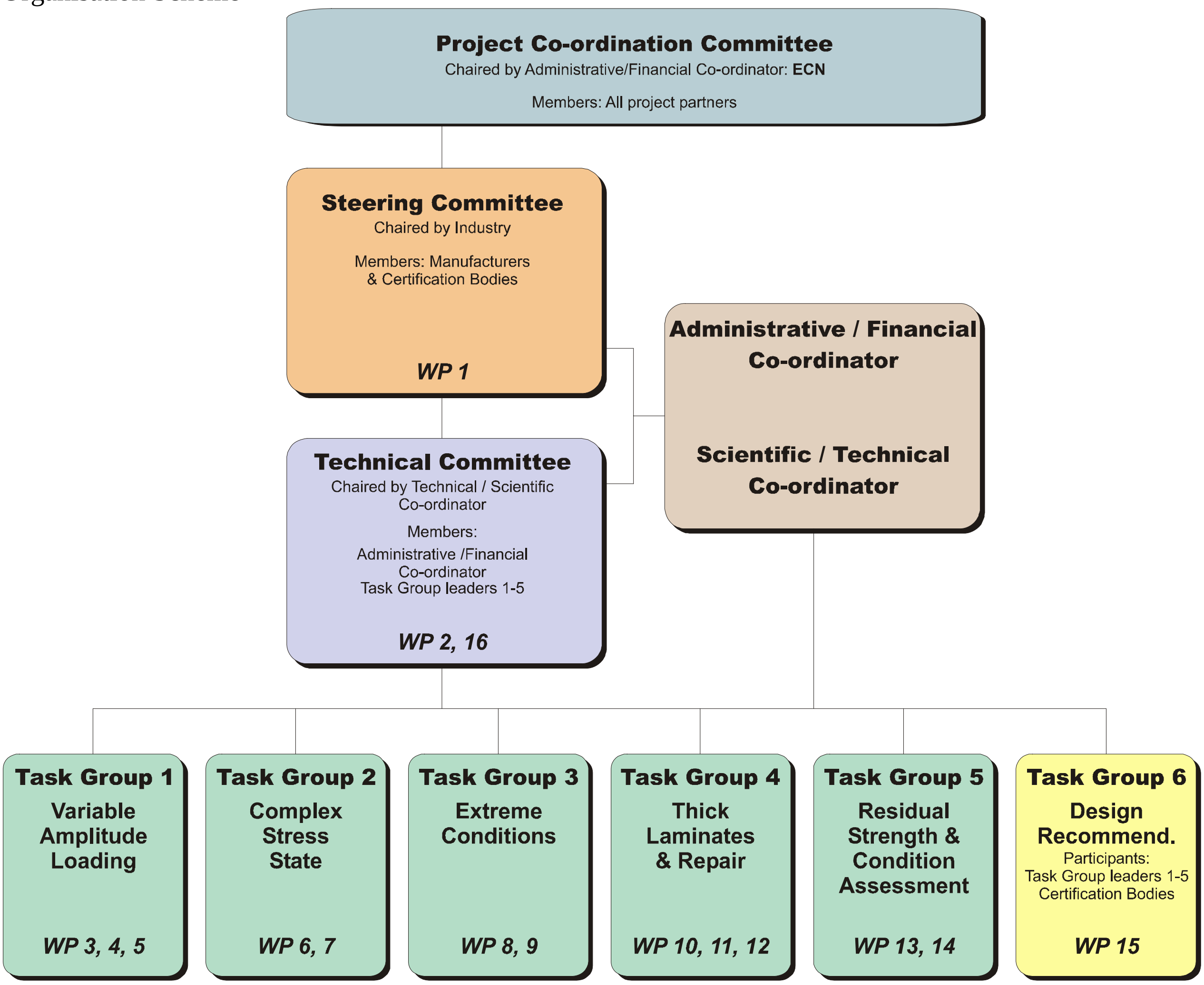
1. Kick off meeting

At the Project Co-ordination Committee meeting held in Delft, 12 March 2002, 17 out of 18 partners were present. (This meeting was part of the kick off meeting)
During this meeting the following important decisions were taken unanimously by the partners present:

Project Co-ordinating Committee
In order to deal with contractual matters in an orderly fashion, the organisation of the project has been extended with the Project Co-ordination Committee (PCC), on top of the Steering Committee (SC) and the Technical Committee (TC). The extension was considered necessary since neither the SC nor the TC contains all project partners. Also, according to Annex I, Description of Work, both committees have other tasks. The role of the PCC is clarified in the draft Consortium Agreement in Section 4.

The new organisation scheme of the project is now as follows:

Organisation Scheme



Consortium Agreement
In order to define certain of their rights and obligations to each other with respect to the carrying out of the contract the parties present agreed to set up a Consortium Agreement based on the Unified Consortium Agreement as provided on the Cordis web site

Contract modifications (Annex I)

a. Databases of load spectra

In the description of WP4 Task 4.1 (Annex I) it is stated that 10 databases will be processed and prepared for the NEW WISPER evaluation. This number is not correct anymore, since during the contract negotiations the amount of man months available for this task had to be reduced considerably. As a consequence it was agreed upon to reduce the number of databases from 10 to 6. Unfortunately this number was not changed in the text of the task description.

Furthermore the assembly of the databases will be performed by DEWI instead of TUDT.

The task description should be changed accordingly and should read as follows:

Set-up of criteria for acceptance and normalisation of available load measurement data and specification of a common data format for further processing and preparation of 6 databases. The load spectrum assembly method will be defined and applied for a flap wise load spectrum for each database for a selected turbulence level and a selected wind distribution. The assembly for all the databases will be performed by DEWI, supported by TUDT. This task will be co-ordinated by DEWI. ECN and CRES will support this task through contribution and preparation of data.

b. Manufacturing of coupons

In the description of WP16 Task 16.1 it is indicated that Polymarin is tentatively selected to produce the small specimens for phase 1. In consultation with Polymarin and LM Glasfiber it is proposed and agreed upon to shift this task from Polymarin to LM Glasfiber.

This means that about four person months have to be shifted from Polymarin to LM in WP 16.

The Scientific Officer, present at the meeting, agreed on both modifications.

Web site organisation
The partners agreed on the proposal to set up a web site to facilitate the distribution of the documents to all the partners in the project.

2. Developments since the Kick off Meeting

Consortium Agreement
During the last week of June the Consortium Agreement has been finalised. This agreement is now ready for signing by all the partners.

Document Web Site
The document web site is operational since the Progress Meeting of June.

Contract Modification (Annex 1)
On May 29 the University of Patras has been authorised by the Scientific Officer to:

1. transfer 30.000 Euros from "personnel costs" to "Other specific costs" With this amount of money necessary changes in the control unit of one of our tests rigs (DENISON-MAYES DH100S), not foreseen initially to be used for OPTIMAT BLADES, will be performed in order to meet the requirements for fatigue testing such as strain-controlled fatigue and operative clip-gauge control unit.

2. to sub-contract NTUA part of the test programme if finally it is confirmed that the UP's test rig (MTS 810) cannot be used. If this is the case the Scientific Officer must be informed in advance on the details of the subcontract.

On May 6 we were informed that General Electric Company had acquired Enron Wind Turbine Business. In connection therewith General Electric has taken over the contractual relationship in our contract. Our new partner is: GE Wind Energy GmbH.

9. TERMS AND DEFINITIONS

UD unidirectional: material with (most of) the fibbers in 0° direction.
MD multidirectional: material with about 50% in ±45° direction and 50% in 0° direction.
MUD multi/unidirectional: UD material with two outer layers in ±45° direction.