national swedish board for
energy source development

acting for the

IEA R&D WECS
EXECUTIVE COMMITTEE
BP/cg

1979-02-05

IEA/RDWECS/AR 78

ANNUAL REPORT 1978

INTERNATIONAL ENERGY AGENCY Programme of

RESEARCH AND DEVELOPMENT ON WIND ENERGY CONVERSION SYSTEMS

Obs. tryckfel på p. 3 (rättat i EC exemplar)

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ANNUAL REPORT 1978

IEA Programme of

RESEARCH AND DEVELOPMENT ON WIND ENERGY CONVERSION SYSTEMS

Contents

To IEA

R&D WECS Annual Report 1978

As agreed in the CRD an annual report should be worked out for each of the IEA projects and submitted to IEA before the end of January 1979.

This document contains the report of the Executive Committee of the R&D WECS programme for the period to the end of 1978. By decision in the Executive Committee ✓ on behalf of the Operating Agent for the four Tasks.

Rey

Lars Rey
Chairman

✓ it is submitted by the Executive Committee

IEA Programme of

RESEARCH AND DEVELOPMENT ON WIND ENERGY CONVERSION SYSTEMS

Executive Summary

The Programme consists of four Tasks according to Annex I-IV of the Implementing Agreement:

Annex	Title	Operating Agent
I	Environmental and Meteorological Aspects of Wind Energy Conversion Systems	National Swedish Board for Energy Source Development
II	Evaluation of models for wind energy siting	Department of Energy, USA
III	Integration of wind power into National Electricity Supply Systems	Kernforschungsanlage Jülich GmbH
IV	Investigation of Rotor Stressing and Smoothness of Operation of Large-Scale Wind Energy Conversion Systems	Kernforschungsanlage Jülich GmbH

Participation in the Tasks is shown on the following page.

The Programme was initiated in 1977. The start-up of Tasks I and II has been delayed, and the revised schedules extend to 1981. Tasks III and IV progress as planned which means that Task IV and Phase I of Task III will be completed in 1979.

Tasks I, III and IV are common fund projects. A call-up for contributions to Task I was sent out in December 1978 based on a revised budget adopted by the Executive Committee. Expenditures for Tasks III and IV are as originally projected.

The Executive Committee held its inaugural meeting in Paris on March 7 and a second meeting in Amsterdam on October 6. At the first meeting Mr. Rey (Sweden) was elected Chairman and Mr. Sens (the Netherlands) Vice Chairman. At the second meeting Norway and the U.K. entered as new contracting parties.

The Programme of Work and Budget for the Tasks were unanimously adopted at the second EC meeting.

No expert meetings have been held during 1978. No new projects have been proposed.

The technical progress is summarized in the attached Annual Progress Reports for each Task as prepared by the Operating Agents.

IEA Programme of

RESEARCH AND DEVELOPMENT ON WIND ENERGY CONVERSION SYSTEMS

Participation of contracting parties

Country	Contracting party	Task I	Task II	Task III	Task IV
Austria	the Republic of Austria	X			
Canada	National Research Council of Canada	X	X		
Denmark	Ministry of Trade and Industry	X			X
Germany	Kernforschungsanlage Jülich GmbH	X	X	OA	OA
Ireland	the Government of Ireland	X			
Japan	the Government of Japan	X	X	X	X
Netherlands	Stichting Energieonderzoek Centrum Nederland	X		X	X
New Zealand	New Zealand Meteorological Service	X			
Norway	Institutt for Atomenergi	X	X		
Sweden	National Swedish Board for Energy Source Development	OA	X	X	X
UK	Department of Energy	X	X		
USA	Department of Energy	X	OA	X	X

national swedish board for
energy source development

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OPERATING AGENT ANNEX I
BP/cg

ANNUAL PROGRESS REPORT 1978

IEA Implementing Agreement for a Programme of

RESEARCH AND DEVELOPMENT ON WIND ENERGY CONVERSION SYSTEMS

Annex I

Environmental and Meteorological Aspects of Wind Energy Conversion Systems

Operating Agent: National Swedish Board for Energy Source Development

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Environmental and meteorological aspects of wind energy conversion systems

Summary

The objectives of this Task include studies of the environmental impact and operational safety of large-scale wind energy systems (WECS), investigation of uncertainties in wind forecasting for wind power networks, and recommendation of load cases for the design of WECS.

Participating countries in this Task are Austria, Canada, Denmark, Federal Republic of Germany, Ireland, Japan, the Netherlands, New Zealand, Norway, Sweden, the United Kingdom, and the United States.

The Task is divided in eight Sub-Tasks. Sweden is responsible country for five Sub-Tasks, the Netherlands for two and Ireland for one. Three Sub-Tasks include collaborative efforts between the participating countries. Two of the Sub-Tasks are add-on projects to independent base projects.

The programme was initiated in 1977. The start-up of most of the Sub-Tasks has been severely delayed. The revised schedule extends to 1981.

One of the Sub-Tasks concerns a study of wind wake effects which is carried out at TNO, the Netherlands, in order to determine at which distance windmills have to be placed for optimum energy output from a group of windmills. Experiments on vertical axis Darrieus type turbines have been completed. The results show that a maximum output of about 7 W/m^2 is reached with a spacing of about 6.5 windmill diameters.

Environmental and meteorological aspects of wind energy conversion systems

Introduction

The objectives of this Task are divided in the following three areas:

Area A: Environmental Impact and Operational Safety of Large-Scale Wind Energy Conversion Systems (WECS).

Area B: Investigation of the Uncertainty in Wind Forecasting for Wind Power Networks.

Area C: Load Case Recommendations.

In area A there are six Sub-Tasks. Areas B and C have one Sub-Task each as shown in the following table.

Sub-Task	Title	Responsible Country
A1	Study of WECS farm area and WECS safety limit requirements	Sweden
A2	Study of combined wind-biomass energy systems	Ireland
A3	Study of wind wake effects	Netherlands
A4	Study of thé impacts of large-scale WECS on the performance of electro-magnetic wave systems	Netherlands
A5	Study of aestethic factors and visual effects of large-scale WECS	Sweden
A6	Report of A1-A5	Sweden
B1	Investigation of uncertainty in wind forecasting for wind power networks	
C1	Load case recommendations	Sweden

The Participating Countries in this Task are Austria, Canada, Denmark, Federal Republic of Germany, Ireland, Japan, the Netherlands, New Zealand, Norway, Sweden, United Kingdom and United States of America.

Substantial delays have occurred in the start-up of most Sub-Tasks. Summaries of technical progress during 1978 are given below. Sub-Tasks A1 and A5 are add-on projects to independent base projects. Brief status reports of the base projects are included for information.

Sub-Task A1: Study of WECS farm area and WECS safety limit requirements

This Sub-Task is carried out at the Aeronautical Research Institute in Stockholm as an add-on effort to a base project.

The objective of the base project is to analyze the probability of ultimate failure for a wind turbine system due to loadings and other actions, considering choice of material, structural design, production control, service inspections, inbalance detection, de-icing, and operation routines. Land-based large scale or small scale turbine systems with horizontal axis are treated assuming propeller material to be steel, aluminum, or composite material. The aim is to develop a method for checking the safety against catastrophic failure and to evaluate which safety level may be attained in a realistic design.

The investigation is performed in two stages. No 1 includes, study of available design information, analysis of loadings and other actions, collection of material properties including scatter, ice accumulation, and definition of method for risk analysis including inventory of possible accident chains with fatal consequences. In stage No 2 a number of critical events will be analysed using statistical methods considering the effects of inspection and service control. Numerical examples for typical structures will be treated and safety requirements presented.

The first stage is now being performed implying collection of basic material.

Sub-Task A2: Study of combined wind-biomass energy systems

This Sub-Task is carried out under the coordination of The National Board for Science and Technology, Dublin, Ireland.

The purpose of the project is to determine the potential cost reductions and other advantages/disadvantages resulting from co-locating WECS farms and Short Rotation Forestry (SRF) energy plantations and associated thermal power stations.

The following elements and revised schedule have been defined:

A1-A3	Electrical system design and costing for WECS farm and facilities shared with SRF thermal plant	Feb-July 79
B1-B2	Optimization of electrical system costs, O+M costs, mode of operation, of combined plant	Feb-July 79
C1-C2	Effects of high wind speed on SRF growth rates	Dec 78 - May 79
D1-D2	Optimization of access requirements and costs	Jan-June 79
E	Coordination and report preparation	Nov 78 - Aug 79

Sub-Task A3: Study of wind wake effects

This work is carried out at TNO, Apeldoorn, the Netherlands.

The aim of the experiments is to determine at which mutual distance windmills have to be placed in order to achieve an optimal energy output of a group of windmills.

The experiments on vertical axis turbines have been completed. Only this part of the wake-effects work is contained in this Sub-Task. Extension of the experiments with horizontal axis turbines is foreseen to mid 1980.

In an wind tunnel the wake of a turning model of a Darrieus-rotor has been measured in a homogeneous flow field. This wake has been simulated on a smaller scale by a stationary grid to be able to investigate a group of windmills. The stationary grid has been placed in the scaled atmospheric boundary layer of the windtunnel and the wake of it within this layer has been measured. In order to simulate the interaction of the wakes of a whole group or part of up to about 100 windmills the grids have been placed on a circular turn-table in the windtunnel. By measuring the force on the different windmill - simulating grids in a group an estimate can be made of the energy output of such a group of windmills. By doing so for different spacings between windmills an idea can be gained about the size of the spacing that is required to get a maximum energy output of a group of windmills on a given area. The results show that a maximum output is reached of about 7 W/m^2 with a spacing of about 6.5 windmill diameters.

Results from this work were presented at the 2nd International Symposium on Wind Energy Systems in Amsterdam in October 1978.

Sub-Task A4: Study of the impact of large-scale WECS on the performance of electromagnetic wave systems

This work is carried out under the direction of the Netherlands Energy Research Foundation, Petten.

A classification of services which may be disturbed by large scale WECS has been completed at PTT Leidschendam. Problems that may occur at fixed services are investigated. The conditions which have to be met in order to avoid interference are derived. The study of the interference of WECS on broadcasting and mobile services is in progress.

Sub-Task A5: Study of aestethic factors and visual effects of large-scale WECS

This Sub-Task is performed at the Swedish Agriculture University, Institution of Landscape Planning at Alnarp as an add-on effort to a base project.

In the base project two methods of visualizing a moving wind turbine system in a natural environment have been worked out. The best results were obtained with the chroma-key videotape method. The second method using front projection on 35 mm film gave less satisfactory results.

Background films have been taken for three different locations in Sweden. The background films will be scanned in videotape and mixed with studio pictures of moving wind turbine models on a second videotape. Still pictures in colour will be produced by a different method.

Sub-Task B1: Investigation of uncertainty in wind forecasting for wind power networks

This project will be performed at The Swedish Meteorological and Hydrological Institute in Norrköping.

The project has been delayed and is now expected to start in March 1979 and last until December 1980.

An expert meeting is planned to take place during two days in April/ May 1979 in order to define criteria for an objective wind forecast verification scheme.

Sub-Task C1: Load case recommendations

Saab-Scana, Linköping, has been selected as prime contractor with ERNO, Bremen, as a subcontractor for work concerning vertical axis turbines.

Review of existing load case definitions has been initiated. A request for load case data has been sent to the Participants. Detailed data have been received from Denmark. New Zealand has asked for additional information. West Germany will send data in November. No other data have been received. An attempt will be made to get more information.

The present schedule is as follows:

Review and study phase	- Jan 1979
Development phase	Jan 1979 - June 1979
Formulation of load case list	July 1979 - Sept 1979

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IEA Implementing Agreement for a Programme of

RESEARCH AND DEVELOPMENT ON WIND ENERGY CONVERSION SYSTEMS

Annex II

Evaluation of models for wind energy siting

Operating Agent: The Department of Energy,
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ANNUAL REPORT OF ACTIVITIES IN THE IEA PROGRAMME OF RESEARCH AND DEVELOPMENT OF WIND ENERGY CONVERSION SYSTEMS: ANNEX II

Through Annex II of the Implementing Agreement for a Programme of Research and Development on Wind Energy Conversion Systems an international program on windfield model verification has been undertaken. The objectives of Annex II are to evaluate the role of numerical models in wind turbine siting. The verification program has been subdivided into three tasks. Task I provides for the preparation of a detailed verification plan. In Task II, model verification will be carried out by the various participants. Task III covers reporting the final results.

The verification plan, which is the final product of Task I, will identify the models to be tested and will name the data sets to be used. The plan will present a detailed description of the verification procedures and will define the responsibilities of each participant. Figure 1 is a milestone chart for Task I. Milestone 1 represents the IEA meeting of last March where the plan for Annex II was presented for comment and concurrence of other participating countries. In April 1978, a letter was sent to each participant inviting him to submit descriptions of computer models that have application to WECS siting and to describe those data sets in the participant's possession that might be used for verification. The letter also included, as examples, descriptions of a model and data sets proposed by the United States and a draft procedure for model verification.

Since that time, informal discussions between the Operating Agent and some of the participants have been held as plans for specific activities are being considered within each country. In addition, the Federal Republic of Germany and Norway have joined Annex II and have been sent initial planning information for consideration.

On 15 November 1978, a letter was sent to participating countries proposing an initial meeting of technical representatives that would be held at IEA headquarters in Paris. This meeting has been scheduled for 1 and 2 February 1979 and is shown as milestone 3 in Figure 1. The purpose of the meeting will be to give the technical representatives of each participating country an overview of the plans and objectives for Annex II. It will also provide an opportunity for each participant to discuss his country's plans and objectives and to suggest modifications or improvements to the draft verification plan.

After the meeting, activity in Task 1 should proceed approximately as indicated in Figure 1. Inputs and suggestions from all participating countries should be received by mid-March 1979. Based on these suggestions, a revised plan will be prepared and sent to the participating countries by 15 April 1979. Written concurrence is expected by early June, and a second meeting of technical representatives is planned for early September 1979. This meeting will be scheduled for a time and place agreeable to all participants. Subjects to be addressed will include:

- Presentation and review of the proposed models and data sets.
- The status of verification activities in participating countries.
- Critiques of the proposed models.
- A working session in which final adjustments to the plan will be made.

The result of the meeting will be the International Verification Plan.

The operations involved in implementing the verification activity are shown in Figure 2. Implementation will begin around 15 September 1979 with the preparation of users' manuals that will fully document the various models. At this time the adaptation of data sets to the participant's computer facilities will also begin.

By 15 November 1979 all participants should be applying their models to the test cases. In mid-March 1980 a meeting of technical representatives of the participating countries will be held to discuss preliminary verification results. An assessment will be made, from the limited verification data that will be available, of the usefulness of the models in siting. At this time, a decision will be made on additional verification tests. It is anticipated that additional verification data will be required before an accurate assessment of the siting models can be given.

The target date for completing the first stage of verification computations is 15 July 1980. Additional case studies will be initiated at that time. All verification computations, will be completed by January 1981.

Milestones for the reporting task are shown in Figure 3. By 15 August 1980 each participant will have submitted a report to the Operating Agent containing a complete users' manual for the model. This manual will contain the information specified in paragraph 2(d) of Annex II. In addition, the report will contain:

- initial verification results for the model tested,
- recommendations on the applicability of the model to various types of terrain and meteorological conditions,
- identification of those terrain types and meteorological conditions for which the model should yet be evaluated,
- recommendations for any additional modeling work or field tests that appear to be needed.

After the Operating Agent consolidates the reports and users' manuals, they will be distributed to participants for their review and use.

Participants will send a report to the Operating Agent on the results of any additional verification tests agreed to in the March 1980 meeting or in other communications between the Operating Agent and the participants by 1 February 1981. These reports will supplement the conclusions of the report on the initial verification tests and will be circulated to all participants for their information.

In early May 1981 a meeting will be held in which the final results and recommendations will be presented and discussed. The Operating Agent will consolidate all of the participants' final reports, including all comments and conclusions from the meeting, and complete a comprehensive final report on the results and recommendations by 1 September 1981.

In the United States, model verification activities have already started on the Oahu data set that was briefly described in an attachment to the April 1978 letter (Milestone 2, Figure 1). Models that are being tested include a primitive equation model and two objective analysis techniques. One of these techniques is the model that the United States has proposed for testing in Annex II. A brief description of the model is given in Appendix A of this report.

Oahu is an island (~1570 Km^2) situated in the northern portion of the trade wind zone of the Pacific Ocean (21° 30' N, 158° 00' W). The island has fairly rugged topography as indicated in Figure 4.

Two ridges that run north to south lie along the eastern and western edges of the island. The average elevation of the windward (eastern) ridge is about 600 m. The leeward ridge is slightly higher. The maximum elevation on the island is 1225 m.

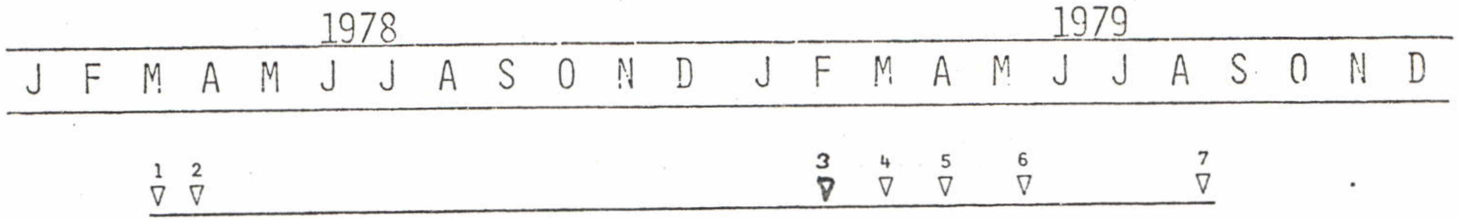
Preliminary results from the verification tests have shown that the objective analysis models reproduce the general features of flow over Oahu quite well. Figure 5 shows a computed wind vector field at 15 m above the surface for an idealized trade wind day.

In producing the vector field shown in Figure 5 the model was initialized by assuming a uniform wind direction of 065° at all grid points. A uniform wind speed of 10 m s^{-1} was assumed at 200 m above the surface. The wind speed followed a 1/7 power low below the 200-m level and was constant above it. The features in Figure 5 - enhanced wind speeds over the mountain ridges and around the points as well as the low wind speeds in the central valley and on the east side of the windward mountain range - correspond to observations.

Work is currently underway to obtain more quantitative observations by comparing computed and observed wind speeds at a number of points on the island for several days throughout the period from 1 August 1976 to 31 July 1977.

EVALUATION OF MODELS FOR WIND ENERGY SITING

TASK I: PREPARATION OF VERIFICATION PLAN



1. PRESENT PLAN FOR ANNEX II TO IEA
2. LETTERS TO PARTICIPANTS, APRIL 1978
3. INITIAL MEETING OF TECHNICAL REPRESENTATIVES 1, 2 FEBRUARY 1979
4. INPUTS FROM PARTICIPANTS RECEIVED, 15 MARCH 1979
5. PROPOSED INTERNATIONAL VERIFICATION PLAN SENT TO PARTICIPANTS, 15 APRIL 1979
6. WRITTEN CONCURRENCE OF TECHNICAL REPRESENTATIVES, 1 JUNE 1979
7. MEETING OF TECHNICAL REPRESENTATIVES 1 SEPTEMBER 1979

FIGURE 1

EVALUATION OF MODELS FOR WIND ENERGY SITING

TASK II: IMPLEMENTATION OF VERIFICATION ACTIVITY

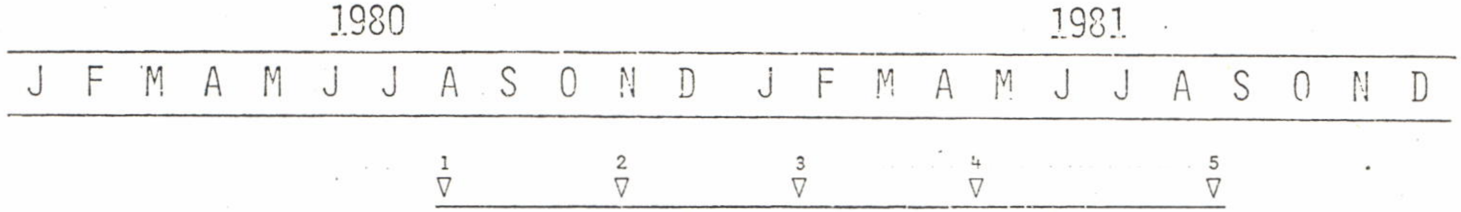
1979												1980											
J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
								1, 2 ▽		3 ▽				4, 5 ▽				6, 7 ▽					8 ▽

1. BEGIN PREPARATION OF USER'S MANUAL, 15 SEPT 1979
2. BEGIN ADAPTATION OF INITIAL DATA SETS, 15 SEPT 1979
3. START MODEL RUNS, 15 NOVEMBER 1979
4. MEETING ON INITIAL RESULTS, 15 MARCH 1980
5. DECISION ON ADDITIONAL CONDITIONS UNDER WHICH MODELS WILL BE TESTED WITH NEW CASE STUDIES
6. INITIAL VERIFICATION COMPUTATIONS COMPLETED, 15 JULY 1980
7. ADDITIONAL CASE STUDIES INITIATED, 15 JULY 1980
8. ADDITIONAL CASE STUDIES COMPLETED, 1 JANUARY 1980

FIGURE 2

EVALUATION OF MODELS FOR WIND ENERGY SITING

TASK III: REPORTING



1. REPORTS ON INITIAL CASE STUDIES AND USER'S MANUALS SUBMITTED TO OPERATING AGENT, 15 AUGUST 1980

2. CONSOLIDATED USER'S MANUALS AND REPORTS ON INITIAL CASE STUDIES COMPLETED AND DISTRIBUTED TO PARTICIPANTS FOR EVALUATION AND APPLICATION, IF DESIRED, 15 NOVEMBER 1980

3. SEND REPORT ON ADDITIONAL CASE STUDIES TO OPERATING AGENT FOR COORDINATED DISTRIBUTION, 1 FEBRUARY 1981

4. MEETING OF PARTICIPANTS TO PRESENT AND DISCUSS RESULTS AND MODEL APPLICATIONS, 1 MAY 1981

5. FINAL REPORT, 1 SEPTEMBER 1981

FIGURE 3

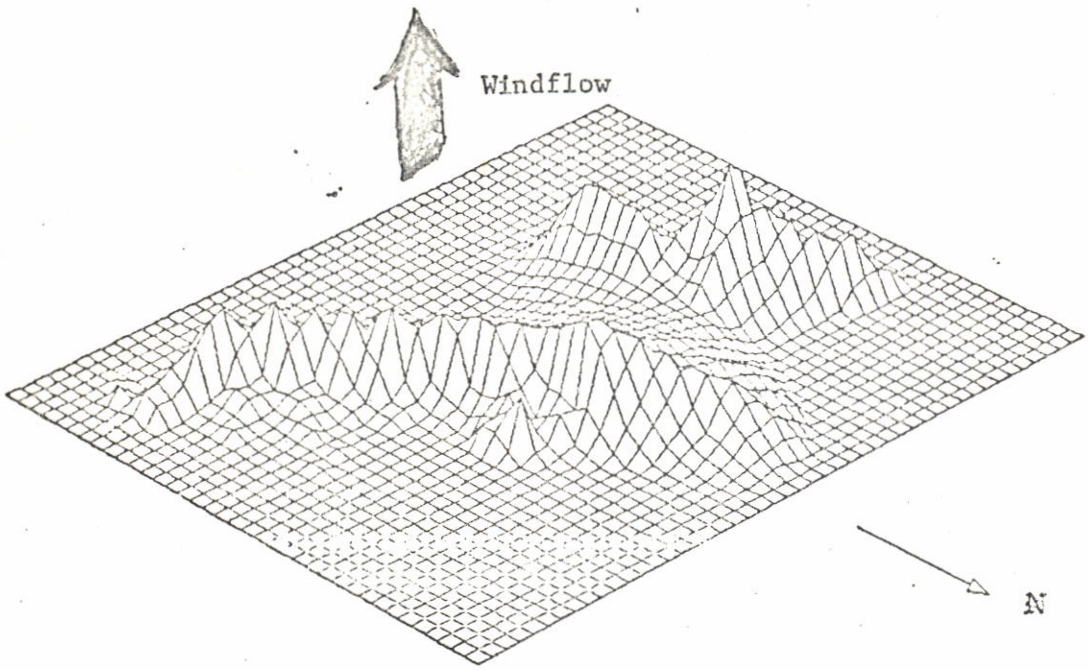


FIGURE 4. Perspective of Oahu Looking Southwestward (downstream).

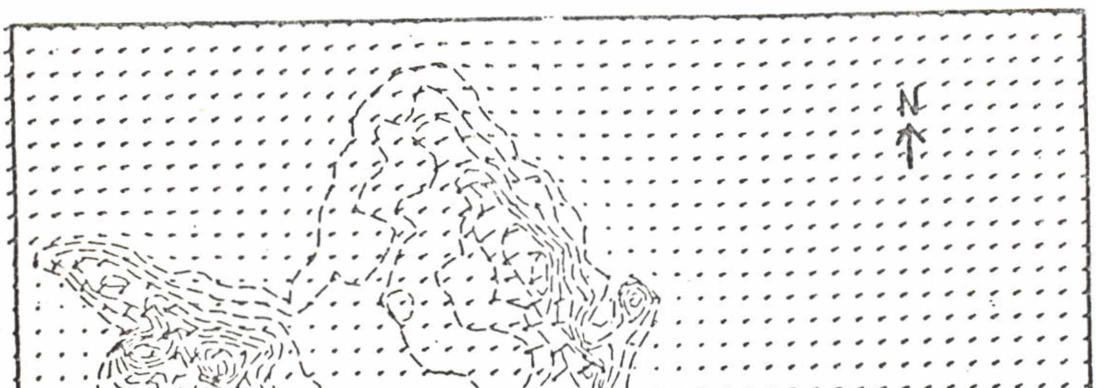


FIGURE 5. Wind Vectors at 15 m Above the Surface for Idealized Trade Wind Flow Over Oahu

APPENDIX A

Two types of models have been considered for site screening on the mesoscale in the United States -- primitive equation models and objective analysis schemes. In principle, the primitive equation models should yield better wind field simulations since they incorporate more accurate physics. However, it is not clear whether this potential advantage would be realized in most practical applications. The reason being the uncertainties in initial and boundary conditions that would exist in actual practice.

The objective analysis schemes that have been proposed for site screening are of the "mass consistent" type similar to the MATHEW model described by Sherman (1978). The advantage of these models is that they require very little computer time to run and are thus relatively inexpensive. The mass consistent models also contain some rudimentary physics, for they produce a three-dimensional, nondivergent flow field which is subject to slip boundary conditions at the surface of the earth. Thus they should be superior to other objective analysis techniques that interpolate wind observations according to some arbitrary weighting scheme.

For the international verification exercise, the United States is proposing a mass consistent objective analysis model. The particular version proposed is one that has been developed for the U.S. Department of Energy by Science Applications, Inc., of La Jolla, California. An early version of this particular model is described by Traci et al. (1977).

The theoretical foundation of the mass consistent wind flow models was established by Sasaki (1958). The approach defines a variation integral whose solution minimizes the variance between an initial guess of the wind field and the final, adjusted field. This solution is subject to the constraint that the adjusted field be everywhere nondivergent (Sherman, 1978). This variation integral is

$$I(u,v,w,\lambda) = \iiint \left\{ \alpha_1^2\left[(u - u_o)^2 + (v - v_o)^2\right] + \alpha_2^2(w - w_o)^2 + \lambda\ \nabla\cdot\vec{V} \right\} dxdydz \quad , \qquad (1)$$

where x,y,z are the usual meteorological coordinates; u,v,w are the adjusted velocity components in the x,y,z directions, respectively; u_o, v_o, w_o are the corresponding initial values; $\lambda(x,y,z)$ is the Lagrange multiplier; α_1, α_2 are Gauss precision moduli. The Gauss moduli govern the size of the wind field adjustments and vary with position in the model. In the vicinity of actual wind observations, α_i should be large and the relative adjustment of the wind field small. Well away from locations of wind observations, α_1 should be smaller, the ratio α_1/α_2 also governs the relative size of adjustments in the horizontal and vertical wind field. With increasingly stable atmospheric stratification, for example, α_1/α_2 should decrease. Thus, empirical adjustments for the gross effects of stratification on the wind field are possible.

The Euler-Lagrange equations associated with (1), and whose solution minimizes that expression, are

$$2\alpha_1^2(u-u_o) - \frac{\partial\lambda}{\partial x} = 0 \qquad (2)$$

$$2\alpha_1^2\left(v-v_o\right) - \frac{\partial\lambda}{\partial y} = 0 \quad , \tag{3}$$

$$2\alpha_2^2\left(w-w_o\right) - \frac{\partial\lambda}{\partial z} = 0 \quad , \tag{4}$$

and

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \quad . \tag{5}$$

These equations are subject to the boundary conditions

$$\lambda\delta(\vec{V}\cdot\hat{n}) = 0 \quad , \tag{6}$$

where $\delta()$ denotes the first variation of the quantity bracketed and $\hat{n}$ is an outward positive unit normal vector. Specifying $\lambda=0$ is appropriate for "open" or "flow-through" boundaries while setting $\nabla\lambda\cdot\hat{n}=0$, which results in no adjustment to velocity normal to the boundary (see (2)-(4)), is used in producing impermeable boundaries.

The major difference between the proposed model (called NOABL) and MATHEW is the introduction of a nonorthogonal, terrain-conformal coordinate system. The principal advantages of this approach are:

- a more accurate representation of the surface boundary condition;
- the capability to use a grid which is "stretched" in the vertical; and
- the elimination of unused storage locations (grid cells which fall inside terrain in a rectangular coordinate system).

The latter two advantages primarily affect computational efficiency. The stretched grid enables one to obtain the desired vertical resolution near the surface while keeping the total number of grid cells reasonably small.

In the new nonorthogonal coordinate system, the horizontal coordinates x and y remain the same. The vertical coordinate, however, becomes

$$\sigma = \frac{z_T - z}{z_T - z_s} = \frac{z_T - z}{\pi} \qquad (7)$$

where z_s and z_T are the elevations of the surface and the top of the model, respectively. Transforming (2)-(4) into the new coordinate system results in a new set of Euler-Lagrange equations. These are

$$2\alpha_1^2 \left(u-u_o\right) - \left[\frac{\partial\lambda}{\partial x} + \frac{\sigma}{\pi} z_{sx} \frac{\partial\lambda}{\partial\sigma}\right] = 0 \quad , \qquad (8)$$

$$2\alpha_1^2 \left(v-v_o\right) - \left[\frac{\partial\lambda}{\partial y} + \frac{\sigma}{\pi} z_{sy} \frac{\partial\lambda}{\partial\sigma}\right] = 0 \quad , \qquad (9)$$

and

$$2\alpha_2^2 \left(w-w_o\right) + \frac{1}{\pi} \frac{\partial\lambda}{\partial\sigma} = 0 \quad , \qquad (10)$$

where

$$z_{sx} = \frac{\partial z_s}{\partial x} \qquad (11)$$

and

$$z_{sy} = \frac{\partial z_s}{\partial y} \quad . \qquad (12)$$

The equation for the Lagrange multiplier, λ, is found by substituting (8)-(10) into the transformed version of (5). The result is

$$\frac{\partial}{\partial x}\left[\pi \frac{\partial \lambda}{\partial x} + \sigma\, z_{sx} \frac{\partial \lambda}{\partial \sigma}\right] + \frac{\partial}{\partial y}\left[\pi \frac{\partial \lambda}{\partial y} + \sigma\, z_{sy} \frac{\partial \lambda}{\partial \sigma}\right]$$

$$+ \frac{\partial}{\partial \sigma}\left\{\left[\left(\frac{\alpha_1}{\alpha_2}\right)^2 + \sigma^2\left(z_{sx}^2 + z_{sy}^2\right)\right] \frac{1}{\pi} \frac{\partial \lambda}{\partial \sigma}\right.$$

$$\left. + \sigma\left[z_{sx} \frac{\partial \lambda}{\partial x} + z_{sy} \frac{\partial \lambda}{\partial y}\right]\right\}$$

$$= -2\alpha_1^2\left[\frac{\partial \pi u_o}{\partial x} + \frac{\partial \pi v_o}{\partial y} + \frac{\partial \pi \tilde{w}_o}{\partial \sigma}\right] , \qquad (13)$$

where

$$\pi \tilde{w}_o = \sigma\left[z_{sx} u_o + z_{sy} v_o - w_o\right] . \qquad (14)$$

The lateral boundary conditions are

$$\left.\begin{array}{r} \lambda = 0 \\ \text{or} \qquad \nabla\lambda \cdot \hat{n} = 0 \end{array}\right\} \qquad (15)$$

depending on whether these boundaries are desired to be impermeable or "leaky". At the upper boundary it is assumed that $(z_T - z_s)$ is sufficiently large that $w \equiv 0$. Thus, the upper boundary condition is

$$\frac{\partial \lambda}{\partial \sigma} = 0 . \qquad (16)$$

At the surface $\tilde{w} \equiv 0$. This implies

$$\frac{\partial \lambda}{\partial \sigma} = \frac{-\pi\left[2\alpha_1^2 \tilde{w}_o + z_{sx}\frac{\partial \lambda}{\partial x} + z_{sy}\frac{\partial \lambda}{\partial y}\right]}{\left[\left(\frac{\alpha_1}{\alpha_2}\right)^2 + z_{sx}^2 + z_{sy}^2\right]} \quad . \qquad (17)$$

The solution strategy is to solve (13) subject to the boundary conditions (15)-(17). The adjusted wind field is then calculated using (8)-(10).

The initial wind field u_o, v_o, w_o is obtained by interpolating the available wind observations. If a vertical wind profile is available in addition to surface wind observations, a linear interpolation is used in the vertical and a $1/R^2$ interpolation is used in the σ plane. The initial vertical velocity field is set equal to zero everywhere.

Since the number of wind soundings is usually smaller than the number of surface observations, the wind field above some convenient boundary layer height is assumed to be specified by the available profile or profiles. Thus, the surface observations are only used below this height. When there are no wind profiles, surface observations are extrapolated vertically by a prespecified power law and a linearly-varying turning angle.

REFERENCES

Sasaki, Y., 1958: An Objective Analysis Based on the Variational Method. J. Meteor. Soc. Jap., 36, p. 77.

Sherman, C. A., 1978: A Mass-Consistent Model for Windfields Over Complex Terrain. To appear in J. Appl. Meteor., 17, March.

Traci, R. M., G. T. Phillips, P. C. Patnaik, and B. E. Freeman, 1977: Development of a Wind Energy Site Selection Methodology, DOE Report RLO/2440-77/11.

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ANNUAL PROGRESS REPORT 1978

IEA Implementing Agreement for a Programme of

RESEARCH AND DEVELOPMENT ON WIND ENERGY CONVERSION SYSTEMS

Annex III

Integration of Wind Power into National Electricity Supply Systems

Operating Agent: Kernforschungsanlage Jülich GmbH,
Federal Republic of Germany

Mailing address: Box 1103 S-163 12 SPÅNGA Sweden
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IEA PROGRAMME OF RESEARCH AND DEVELOPMENT ON WIND ENERGY CONVERSION SYSTEMS, Task III (Annex III)

TITLE: Integration of Wind Power into National Electricity Supply Systems

Prepared by: Lorenz Jaraß
Universität Regensburg
Forschungsprojekt Windenergie
Postfach
8400 Regensburg

Operating Agent approval
By
Kernforschungsanlage Jülich GmbH

Date
27. FEB. 1979

1) PROGRAMME OF WORK

Task III (Annex III), Phase I

Objective

Based on original hourly data of wind velocity, wind direction, energy production and energy demand, we have analysed the engineering and economic possibilities of large - scale wind energy systems converting wind power into electrical power with special attention to complementary power regulation capacity, particularly with respect to coastal areas of Northern Germany. At the same time, the integration of wind energy into national energy supply systems has been examined.

Means

A simulation model of wind energy integrated into the national energy supply system has been developed in which, among others, the following parameters have been taken up wind data, energy demand data, technical data of wind energy conversion, technical data of conventional energy production and storage as well as considerations for the location of wind power plants.

Preliminary,the models are limited regionally to the North-German coastal area and utilities located there. Later on these models have served as basis for the integration of wind energy in the existing energy supply system of the BRD. The models are build in such a way that not only the integration of wind energy in the national energy supply system of the BRD can be examined by making use of these models, but also of other countries.

Sub Task	Title
	Determination of Energy Flow
1 a)	Collection of German wind and demand data
1 b)	Collection of newest turbine - data
1 c)	Computer processing of data
2 a)	Preliminary studies of model simulation for integration of wind power into national electricity supply systems
2 b)	Building of simulation model
3)	Test and expansion of model using original hourly wind and demand data
	Evaluation of Energy Flow
4)	Collection of cost data Cost and value assessment of wind energy
5)	Final Report Preparation of final report

There are no changes in objectives and technical approach as described in Implementing Agreement, Annex III.

Costs for the project WECS, Task III (Annex III)

Points of work as defined in the Implementing Agreement, Annex III 2. Means	Points in the Programme of Work	Salary	Computer[1]	Working funds	Operating Cost	Taxes	Total
(a) (2) (i)	Collection of German data	17.000		5.000			22.000
(a) (2) (ii)	Computer processing of data	27.000		3.000			30.000
(a) (1)	Preliminary study of model	44.000		4.000			48.000
(a) (2) (iii)	Building of model	19.000		1.100			20.100
(a) (2) (iv)	Test and exp. of model	56.000		2.000			58.000
	Simulation using original hourly data	65.000		3.000			68.000
(a) (2) (v)	Collection of cost data	31.000		4.000			35.000
(a) (2) (vi) (a) (2) (vii)	Value assessment of wind energy	64.000		2.000			66.000
(a) (1) (a) (2)	Preparation of final report	40.160		3.000			43.160
(5)	Means Phase I	78.416			3.640	5.427	87.483
column sums		441.576,-	(400.000,-)	27.100,-	3.640,-	5.427,-	477.743,-

Travelling cost to (1) - (5) were estimatet to be DM 29.100,-, thus the total sum is DM 506.843,-.

1) DM 400.000,- paid separately in total by the German Covernment

3. STATUS OF WORK

TIME FRAME

PHASE I

Determination of Energy Flow

1a,b) Collection of German Data
(wind speed, demand, conversion, technology)

1c) Computer processing of data

2a) Preliminary study of model

2b) Building of model

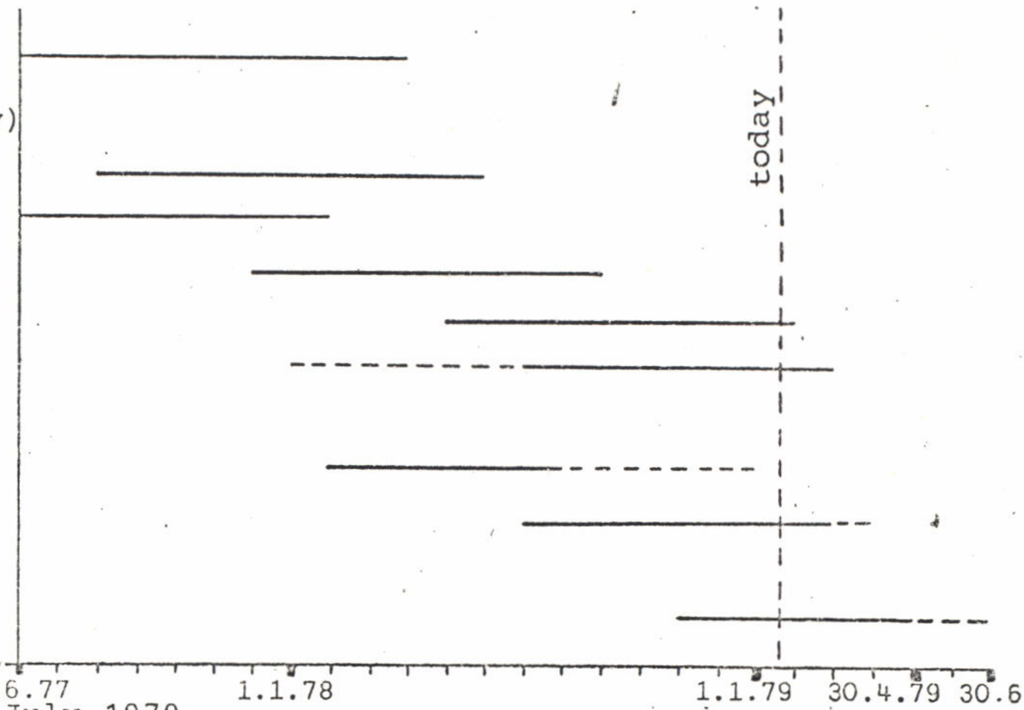
3) Test and expansion of model
Simulation using original hourly data

Evaluation of Energy Flow

4) Collection of cost data
Value - assessment of wind energy

Final Report

5) Preparation of final report



PHASE II* (Participating Countries), starting in July 1979

Determination of energy Flow (Collection of data of other countries with respect to wind speed, demand, cost --- Computer processing of data by means of the model)

Evaluation of Energy Flow (Value - assessment of wind energy)

Preparation of Final Report

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* The proposal for Phase II will be submitted before the next meeting of the Executive Committee on April, 2 nd. 1979 in Copenhagen

Status of Work:

Programme of work is in time (see time frame).

The models of wind energy production and the models of conventional energy production for the North-German coastal area have been finished. Original, hourly wind data of the German Weather Service of 5 coastal weather stations for the period of 1969 - 1976 as well as demand data of utility companies of North-Germany for 1975 have been provided and processed for the computer. Also detailed availability data of conventional power plants have been collected as a basis of the determination of the "value" of wind energy. Based on these facts, the maximum admissible investment costs of wind power plants (break - even - point) have been calculated by making use of investment and fuel costs of conventional power plants.

Based on the improved experience a second phase of the project is proposed, to do a thorough investigations on the prospects of wind energy for more coutries - partly outside Europe.

Publications

1. Firma/Institut : Universität Regensburg
2. Name : Lorenz Jaraß
3. Thema : Stromerzeugung aus Windkraft: Ein alter Traum kann Wirklichkeit werden
4. Ort/Datum : Gräfelfing, Juni 1978
5. Art : Veröffentlichung in: Energiewirtschaftliche Tagesfragen, Zeitschrift für die Elektrizitätswirtschaft, 28. Jg. (Heft 6), S. 357 - 365

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1. Firma/Institut : Universität Regensburg
2. Name : Lorenz Jaraß
3. Thema : Integration of Wind Energy in National Energy Supply Systems - Comparison of Conventional and Wind Power Plants
4. Ort/Datum : Washington, D.C., 19.-21. Sept. 1977
5. Art : Veröffentlichung in: Proceedings of the Third Biennal Conference and Workshop on Wind Energy Conversion Systems, Washington, D.C., Sept. 19 to 21, 1977, Vol. I, S. 444-455, Sponsored by The United States Department of Energy Division of Solar Technology, Coordinated by JBF Scientific Corporation

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1. Firma/Institut : Universität Regensburg
2. Name : Lorenz Jaraß
3. Thema : Garantierte Leistung (Kapazitätseffekt) und Gesamtleistung als Bestimmungsgrößen der Energieproduktion eines Windkraftwerkes
4. Ort/Datum : Hamburg, Juli 1978
5. Art : Veröffentlichung in: 2.nd Internationales Sonnenforum, 12.-14. Juli 1978, Band III, Vol. III, S. 389-402

1. Firma/Institut	:	Universität Regensburg
2. Name	:	Lorenz Jaraß
3. Thema	:	Statusbericht ET 4085 A Abschätzung der technischen und wirtschaftlichen Möglichkeiten einer großtechnischen Umwandlung von Windenergie in elektrische Energie unter besonderer Berücksichtigung des benötigten Reserve- und Speichersystems - Bestimmung und Bewertung der Windenergieflüsse
4. Ort/Datum	:	Veröffentlichung in: Seminar und Statusreport Windenergie, 23./24. Oktober 1978, veranstaltet von der KFA-Jülich GmbH, Projektleitung Energieforschung, im Auftrag des BMFT, Jül-Conf-27, Oktober 1978, ISSN 0344-5798, S. 193-205

1. Firma/Institut: Universität Regensburg
2. Name : Lorenz Jaraß
3. Thema : Statusbericht ET 4085 A
Abschätzung der technischen und wirtschaftlichen Möglichkeiten einer großtechnischen Umwandlung von Windenergie in elektrische Energie unter besonderer Berücksichtigung des benötigten Reserve- und Speichersystems - Bestimmung und Bewertung der Windenergieflüsse
4. Ort/Datum : Veröffentlichung in:
Seminar und Statusreport Windenergie, 23./24. Oktober 1978, veranstaltet von der KFA-Jülich GmbH, Projektleitung Energieforschung, im Auftrag des BMFT, Jül-Conf-27, Oktober 1978, ISSN 0344-5798, S. 193-205

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1. Firma/Institut: Universität Regensburg
2. Name : Lorenz Jaraß
3. Thema : Stürmische Entwicklung der Windenergie
4. Ort/Datum : Gräfelfing, Nov., Dez. 1978
5. Art : Veröffentlichung in:
Mitteilungsblatt der Deutschen Gesellschaft für Sonnenenergie e.V. (DGS), Heft 6, 1978, S. 14-17

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1. Firma/Institut: Universität Regensburg
2. Name : Lorenz Jaraß
3. Thema : Wind Power: A Good Chioce for OPEC Countries
4. Ort/Datum : Gräfelfing, ...
5. Art : wird veröffentlicht in:
MAK Power News

Reports

1. Firma/Institut : Universität Regensburg
2. Name : Lorenz Jaraß
3. Thema : Integration of Wind Power in National Supply Systems
4. Ort/Datum : Paris, Febr. 1977
5. Art : Vortrag beim Expertentreffen der IEA

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1. Firma/Institut : Universität Regensburg
2. Name : Lorenz Jaraß
3. Thema : Integration of Wind Energy in National Energy Supply Systems-Comparison of Conventional and Wind Power Plants
4. Ort/Datum : Vortrag beim United States Department of Energy anläßlich des Third Wind Energy Workshop

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1. Firma/Institut : Universität Regensburg
2. Name : Lorenz Jaraß
3. Thema : Report on "Integration of Wind Power into National Electricity Supply Systems"
4. Ort/Datum : Paris, März 1978
5. Art : Vortrag bei IEA, anläßlich Annex III of the "Implementing Agreement for a Programme of R + D on Wind Energy Conversion Systems"

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1. Firma/Institut : Universität Regensburg

2a Name : Lorenz Jaraß

3a Thema : (1) Statusreport of the Project "Integration of Wind Power into National Electricity Supply Systems"

(2) Optimal Quantities of

a) Installed Capacity/m^2

b) Nominal Frequency

c) Variation of Nominal Frequency

d) Storage Size

(3) Analysis of Wind Speed and Wind Frequencies at Coasts and Northern Germany with Respect to Diurnal and Seasonal Variations and to Directions

2b Name : Rudolf Meyer

3b Thema : Integration of Wind Power into National Electricity Supply System: A Simulation Model

4. Ort/Datum : Stuttgart, Juni 1978

5. Art : Vorträge beim Expertentreffen der IEA anläßlich Annex III, IV

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1. Firma/Institut : Universität Regensburg

2. Name : Lorenz Jaraß

3. Thema : Garantierte Leistung (Kapazitätseffekt) und Gesamtleistung als Bestimmungsgrößen der Energieproduktion eines Windkraftwerks

4. Ort/Datum : Hamburg, Juli 1978

5. Art : Vortrag beim 2. Int. Sonnenforum

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1. Firma/Institut : Universität Regensburg
2. Name : Lorenz Jaraß
3. Thema : Die "gesicherte Kapazität" zur vergleichenden Betrachtung alternativer Energiequellen mit konventionellen Kraftwerken und die Wirtschaftlichkeit großer Windkonverter bei der Stromerzeugung
4. Ort/Datum : Jülich, Sept. 1978
5. Art : Vortrag beim Energieseminar der Vorstandsmitglieder der KFA-Jülich

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1. Firma/Institut : Universität Regensburg
2. Name : Lorenz Jaraß
3. Thema : Report on "Integration of Wind Power into National Electricity Supply Systems"
4. Ort/Datum : Amsterdam, Okt. 1978
5. Art : Vortrag bei der IEA, anläßlich Annex III

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1. Firma/Institut : Universität Regensburg
2. Name : Lorenz Jaraß
3. Thema : Statusbericht ET 4085 A
Abschätzung der technischen und wirtschaftlichen Möglichkeiten einer großtechnischen Umwandlung von Windenergie in elektrische Energie unter besonderer Berücksichtigung des benötigten Reserve- und Speichersystems -
Bestimmung und Bewertung der Windenergieflüsse
4. Ort/Datum : Jülich, Okt. 1978
5. Art : Statusseminar "Windenergie"

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1. Firma/Institut: Universität Regensburg
2. Name : Lorenz Jaraß
3. Thema : Was kann die Windenergienutzung leisten?
4. Ort/Datum : Regensburg, Okt. 1978
5. Art : Vortrag bei der Deutschen Naturschutzakademie e.V. und dem kath. Bildungswerk Regensburg-Stadt, Seminar "Alternative Energien"

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1. Firma/Institut: Universität Regensburg
2. Name : Lorenz Jaraß
3. Thema : Technische und wirtschaftliche Möglichkeiten der Windenergienutzung
4. Ort/Datum : München, Januar 1979
5. Art : Vortrag beim Meteorologischen Institut der Universität München

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1979-02-05

IEA/RDWECS/IV/APR 78

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IEA R&D WECS
EXECUTIVE COMMITTEE
The Secretariat
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ANNUAL PROGRESS REPORT 1978

IEA Implementing Agreement for a Programme of

RESEARCH AND DEVELOPMENT ON WIND ENERGY CONVERSION SYSTEMS

Annex IV

Investigation of Rotor Stressing and Smoothness of Operation of Large-Scale Wind Energy Conversion Systems

Operating Agent: Kernforschungsanlage Jülich GmbH, Federal Republic of Germany

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IEA PROGRAMME OF RESEARCH AND DEVELOPMENT
ON WIND ENERGY CONVERSION SYSTEMS
TASK IV

SEMIANNUAL PROGRESS REPORT NO. 1

TITLE: Investigation of rotor stressing and smoothness of operation of large-scale wind energy conversion systems

Prepared by:

Prof.Dr.J.H. Argyris
Institut für Statik und Dynamik
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7000 Stuttgart 80
Germany

Prof.Dr.F.X. Wortmann
Institut für Aero- u. Gasdynamik
Universität Stuttgart
Pfaffenwaldring 21
7000 Stuttgart 80
Germany

Signatures:

Operating agent approval

By

Date

0. OBJECTIVE AND MEANS

The objective of this task is to investigate possibilities for low rotor stressing, high operational smoothness and system vibration control of a 3 MW wind power system. The technical objective involves controlling the rotor blades in order to reduce additional loads resulting from wind profiles, gusts and gravity, to the extent that the rotor has to carry a minimum of loads not required to produce the input power of the plant.

By means of improved design, accurate calculations and experiments using a wind tunnel model, an extremely light but durable design of a 3 MW plant is prepared. For the rotor, a hub concept is developed which minimizes stressing of the structure and disturbances to the operational smoothness by external influences. A dynamic analysis of the whole system is being carried out in order to avoid damage due to unacceptable vibrations. By means of wind tunnel experiments, the computational methods are being verified, measures are taken to increase the smoothness of operation, and decreases of stressing are being verified. The task is carried out on the basis of the following outline programme of work.

1. PROGRAMME OF WORK

Task IV includes 12 Sub-Tasks.

Responsible Participant: Germany

Sub Task and title

a) Rotor Development

1) Aerodynamically optimal rotors;

2) Smoothness of rotor operation;

3) Rotor blade computations using Finite Element Methods; and

4) Investigations into materials behaviour;

b) Vibration of the Complete Wind Power System

1) Examination of the interference between tower and rotor which provides an important load case for the blade; and

2) Computations for different types of towers and selection of best tower design;

c) Wind-Tunnel Investigations

1) Investigation methods and determination of data for models and wind tunnels;

2) Computation, design and construction of several wind-tunnel models in connection with the investigations to be carried out according to item (4) below;

3) Development and completion of the systems for acquisition, transfer and evaluation of data for experiments provided under item (4) below, planning a system for the supervision of operational data for a prototype;

4) Wind-tunnel experiments;

5) Two-dimensional investigations (profiles);

6) Three-dimensional investigations.

2. BUDGET

A revised budget was adopted at the 2nd Executive Committee meeting as shown in table I.

Since there is only one responsible participant (Germany) it was not felt necessary to split the budgets and expenditures resp. for the years 1978 and 1978 further than in Table II.

Cost item	Budget 1978 (Decided)	Budget 1979 (Decided)
Salaries	623.172	193.747
Computer costs	72.400	7.600
Working funds	17.600	40.800
Travel costs	13.960	5.840
Other costs and taxes	124.464	5.436
Sums total (DM)	851.596	253.423

Table II Budgets of the years 1978 and 1979 split into different cost groups.

The financial contributions for the contracting parties for 1979 are given in the minutes of the 2nd Executive Committee meeting and will be called up after approvement.

Costs for the project WECS, Task IV

Table I

Points of work as defined in the Implementing Agreement Annex IV	Points in the programme of work	Salary	Computer	Workg.funds	Equipment	Operating cost	Taxes	Total
a) (1)	1.1.1	14.879	2.400					17.279
	1.1.2	29.757	4.000					33.757
a) (2)	1.2	59.515	2.400	2.000	51.400[1]			115.315
a) (3)	1.3.1	66.954	24.000					90.954
	1.3.2	89.272	24.000					113.272
a) (4)	1.4.1	7.439		3.600				11.039
	1.4.2	14.879						14.879
b) (1)	2.1	14.879						14.879
b) (2)	2.2	44.636	8.000					52.636
c) (1)	3.1	44.636	4.000					48.636
c) (2)	3.2	178.545	9.600	7.000				195.145
c) (3)	3.3	14.879	1.600	5.000				21.479
c) (4); c) (5)	3.4.1	14.879			64.900[2]			79.779
c) (4); c) (6)	3.4.2.1	59.515		42.000[3]				101.515
	3.4.2.2	44.636						44.636
(5)	4.	117.619				5.460,--	8.140	131.219
column sums		816.919	80.000	59.600	116.300	5.460	8.140	1.086.419

Travelling costs to (1) - (4) were estimated to be DM 18.600, thus the total sum is

DM 1.105.019
=============

1) These costs are associated with a) (1) - a) (4) and 1.1 - 1.4, respectively

2) These costs are associated with c) (1) - c) (6) and 3.1 - 3.4.2.2, respectively

3) These costs are associated with c) (4); c) (5) - c) (4); c) (6) [illegible]

3. STATUS OF WORK

The task is carried out at two institutes of the University Stuttgart

Institut für Aerodynamik und Gasdynamik

Institut für Statik und Dynamik der Luft- und Raumfahrtkonstruktionen

The numbering of the sub-tasks follows the updated programme of work from April 1978.

The relevant publications (P) and lecturers (L) are given below and referenced in the following by labels as e.g. (P2) or (L2)

PUBLICATIONS

(P1) Institut für Aero- und Gasdynamik, F.X. Wortmann Beschreibung des Konzepts "Schwingende Windturbine"
Inst. Bericht 77-18 Dez. 1977

(P2) Institut für Aero- und Gasdynamik, F.X. Wortmann "Die schwingende Windturbine"
Stuttgarter Zeitung 13.02.78

(P3) Institut für Aero- und Gasdynamik, F.X. Wortmann
Institut für Statik und Dynamik, J.H. Argyris
K.A. Braun, "Summary of the Status Report given to the Executive Committee of the International Energy Agency "on March 8, 1978 in Paris, Universität Stuttgart, März 1978

(P4) Institut für Aero- und Gasdynamik, F.X. Wortmann
Institut für Statik und Dynamik, J.H. Argyris
K.A. Braun "Summary of the Status Report for the Executive Committee of the International Energy Agency", October 6, 1978, Amsterdam.

(P5) Institut für Aero- und Gasdynamik, F.X. Wortmann
Institut für Statik und Dynamik, J.H. Argyris
Statusbericht zum Forschungsvorhaben ET 4086A "Untersuchungen zum Bau großer Rotorblätter für GROWIAN und zum Schwingungsverhalten des Gesamtsystems. Universität Stuttgart, Oktober 1978, Bericht der KFA Jülich und Vortrag.

(P6) Institut für Aero- und Gasdynamik, F.X. Wortmann
"Tragflügelprofile für große Windturbinen" Universität Stuttgart, Okt. 1978. Bericht der KFA Jülich und Vortrag.

(P7) Institut für Aero- und Gasdynamik, S. Mickeler
"Rotorblätter mit individueller Schlagfreiheit und Blattwinkelrücksteuerung unter dem Einfluß verschiedener Böen" Universität Stuttgart, Okt. 1978, Bericht der KFA Jülich und Vortrag.

(P8) Institut für Statik und Dynamik, J.H. Argyris, K.A. Braun, B. Kirchgäßner
"Einfluß der Zentrifugalkräfte auf die geometrische Steifigkeit des Rotorblattes", Universität Stuttgart, Okt. 1978, Bericht der KFA Jülich und Vortrag.

(P9) Institut für Statik und Dynamik, J.H. Argyris, K.A. Braun, B. Kirchgäßner
"Einfluß der Massenverteilung auf die Beanspruchung von Rotorblättern" Universität Stuttgart, Okt. 1978, Bericht der KFA Jülich und Vortrag.

(P10) Institut für Statik und Dynamik, J.H. Argyris, W. Aicher, F. Karl, W. Kümmerle M. Müller "Rechnergestützte Meßtechniken für die Datenerfassung an Windenergiekonvertern", Universität Stuttgart, Okt. 1978, Bericht der KFA Jülich un Vortrag.

LECTURES

(L1) Institut für Aero- und Gasdynamik, F.X. Wortmann
Institut für Statik und Dynamik, J.H. Argyris
Vortragender: K.A. Braun
Status Bericht vor dem Executive Committee der Internationalen Energie Agentur, Paris, 7.3.1978

(L2) Institut für Aero- und Gasdynamik, F.X. Wortmann
Institut für Statik und Dynamik, J.H. Argyris
Vortragender: K.A. Braun
Status report of the project: "Investigation of Rotor Stressing and Smoothness of Operation of Large-Scale WECS", IEA-Expert meeting, Stuttgart, 8.6.1978.

(L3) Institut für Aero- und Gasdynamik, F.X. Wortmann
How far will the blade of a windturbine fly?
IEA-Expert meeting Stuttgart, 8.6.1978.

(L4) Institut für Aero- und Gasdynamik, F.X. Wortmann
Das Konzept der schwingenden Windturbine
Vortrag KFA Jülich, 19.9.1978.

(L5) Institut für Aero- und Gasdynamik, F.X. Wortmann
Institut für Statik und Dynamik, J.H. Argyris
Vortragender: K.A. Braun
Status Bericht vor dem Executive Committee der Internationalen Energie Agentur, Amsterdam 6.10. 1978

(1) Rotor Development

(1.1) Aerodynamically optimal rotors

(1.1.1) Investigations into system optimisation for blade and rotor (rotor design, load distribution and geometry of the blades).

Technical status

A computer program was developed to find the optimum of the distribution of circulation and corresponding to it the wing chord and twist distributions by iteration.
Input data are rated speed, tip speed ratio, diameter of the rotor, root diameter, the desired distribution of the angle of attack and the digitized airfoil characteristics.
Preconditions therefore are constant rated speed, rigid blades and coning angle zero.
Another program was developed to calculate the load distribution and power coefficient for any speed ratio and given geometry i.e. for off-design conditions.

Financial status (Budget DM 17.279)

Expenditures as projected

External activities

P1, P2, P3, L1, L2,

(1.1.2) Design and experimental studies concerning the development of airfoil profiles with zero pitching moment, featuring high glide ratios and good stall characteristics; clarification of the nonstationary behaviour paralell to all other investigations.

Technical status

The blades of windturbines feature usually extrem high aspect ratios. In order to reduce the flutter stability problem and the control loads it is necessary to reduce the pitching moments of the airfoils as much as possible. At the same time the glide ratio of these airfoils should be high and the stall behaviour should be smooth. For the inner part of the blades the airfoils should be extremely thick to support the strength and stiffness of the blade root. Such airfoils are not available and require a special development. Therefore a first set of airfoils with a thickness ratio of 15 % to 50 % was designed, build and investigated with a free and forced transition in the range of Reynoldsnumbers between $3 - 5 \cdot 10^6$.

These tests demonstrates the capabilities of these airfoils for a smooth surface and the large losses which occur especially for the thicker airfoils, when the surface roughness provokes a premature transition. In the immediate future there will be a further development to improve the stall behaviour of these airfoils.

Financial status (Budget DM 33.757)

Expenditures as projected

External activities

P6, L1, L2, L5

(1.2) Smoothness of rotor operation

Theoretical and experimental investigations using functional models for different rotor hubs in order to reduce the stressing of the blade and increase the smoothness of operation.

Technical status

Theoretical and experimental investigations were performed for rotor hubs with different degrees of freedom for the blades and the rotor axis. One part of this work concentrated on the flapping motion of the blades with extremely large δ_3 -angles. Flapping angle and pitch angle are coupled and when the rotor axis is not perpendicular on the plane of rotation there will be a cyclic pitch which restores the orientation of the blades. On the other side the damping of the flapping motion is reduced by large δ_3 -angles and the control moments, which bend the rotor axis increase with δ_3 . In practice it seems reasonable to restrict the ratio of the pitch to flap angle to 3 - 5.

Another extremely useful device to improve the smoothness of the power output is connected to a certain lead-lag motion. The degree of freedom is partly a necessity of the flapping motion, because it reduces the dangerous coriolis forces. However the rotor of the horizontal axis machine with lead-lag freedom experiences a strong instability, called ground resonance. Whe the rotor axis has some yaw and pitch freedom it can be shown that this difficulty can be overcome when the lead-lag freedom is released only near the designed rotational speed of the rotor and, when the ratio of rotorfrequency and lead-lag frequence is of the order of .3. The most important discovery came with the windtunnel model which proved that lead-lag freedom is capable to absorb completely any gustiness of the wind or the tower wake.

A 7.4 m diameter functional rotor model, driven by an electric motor, was built and is used for measurements in order to verify computational methods. The present rotor hub is a simplified version of the final one, which is under consrruction. This model is equipped with the data acquisition system (see 3.3) and used as test bed for the further development of the mentioned system plus software.

Financial status (Budget DM 115.315)

Expenditures larger than projected; budget partly transferred from (3.2)

External activities

P1, P2, P3, P4, P5, P7, L1, L2, L4, L5

(1.3) Rotor blade computations using Finite Element Methods

(1.3.1) Static computations allowing dimensioning of the blade. Comparison between linear and non-linear computations.

Technical status

Using the FEM several rotor blades were calculated for the loading case deadweight what led to a material choice (CFRP or Steel), a reasonable dimensioning of the wall thicknesses and modification in the aerofoil thicknesses.
For the chosen layout the consideration of non-linearities does not occur to be necessary. Estimates for the number of loading cycles were gained from publications on wind measurements in northern Germany. Quasistationary loading (without influence of gravity) was found to cause smaller stresses in the structure than the deadweight if a special mass distribution was chosen over the length of the blade.

Financial status (Budget DM 90.954)

Expenditures as projected

External activities

P3, P4, P5, P8, P9, L1, L2, L5

(1.3.2) Dynamic computations to obtain resonances and the response to time-dependent excitation (non-linear, if necessary). Consideration of stochastic wind loads and aeroelastic stability. The results will allow adequate dimensioning for dynamic load cases and/or improvement of the structure with respect to its dynamic behaviour.

Technical status

The eigenfrequences of the braked and rotating full scale blades were calculated. The geometric stiffness caused by centrifugal forces and by the lead-lag motion are taken into account with the FEM computation. The influence of aerodynamic forces on the vibration is not yet implemented. For comparison of the eigenfrequencies nonlinear computations were performed for a small mathematical model which led to good correspondence.
For a mathematical full scale rotor model with non elastic blades and support but with flap hinges and mechanical flap-pitch coupling the response to global gusts and local gusts (e.g. tower wake) was calculated. For different gear ratios (flap-pitch) the response of coning angle, rotor thrust and driving moment was found using the actual polars and taking into account all non linearities due to aerodynamics.
Eigenfrequencies for the 7.4 m model were calculated using the FEM.

Financial status (Budget DM 113.272)

Expenditures as projected

External activities

P3, P4, P5, P7, P8, P9, L1, L2, L5

(1.4) Investigations into materials behaviour

(1.4.1) Accompanying investigations into the strength of materials and joints (static and/or dynamic) as far as necessary (parallel to all other investigations).

Technical status

Literature studies and a few experiments with CFRP-specimens lead to the material data for the FEM computations.

Financial status (Budget DM 11.039)

Expenditures smaller than projected, budget partly transferred to (3.3)

External activities

none

(1.4.2) Planning of major fatigue tests to prove the service life of highly stressed rotor components.

Technical status

No activities have started yet.

Financial status (Budget DM 14.879)

Expenditures will be smaller than projected; budget partly transferred to (1.2)

External activities

none

(2) Vibration of the complete wind power system

(2.1) Examination of the interference between tower and rotor which provides an important load case for the blade.

Technical status

The nonlinear equation of motion for an isolated rotor blade with pitch-flap coupling is derived to study the dynamic response under gravitational loading and various gust conditions.

To provide a first information of the behaviour of the windturbine and of the forces and moment at the rotor hub the complicated coupling and interaction of other degrees of freedom forced to restrict the derivation of the first step to a one degree of freedom system.

Numerical instability problems resulting from the stepwise integration of the highly nonlinear integrodifferential equation had to be solved in order to allow nonlinear computations with linear and nonlinear aerodynamic coefficients. The discussion includes the response to

- nonhomogenious wind distributions, e.g. surface boundary layer, shear flows,
- global gusts, e.g. step gusts, single and multiple pulse gusts,
- local gusts, e.g. tower influence.

Flutter instability due to certain gust loadings depending on the pitch-flap coupling is determined by computations with nonlinear aerodynamic coefficients, whereas the solution of the nonlinear differntial equation with linear aerodynamic coefficients still shows a stable behaviour.

As the computation time is dependent on the degree of nonlinearity a comparison between the solutions of the linearized and the different nonlinear differntialequations has been made considering the accuracy of the results under an economic viewpoint.

Financial status (Budget DM 14.879)

Expenditures as projected

External activities

P7,

(2.2) Computations for different types of towers and selection of best tower design.

Technical status

Two steel towers - the rotor idealised as lumped mass - are investigated with the Finite Element Method. A free standing and a guyed construction are investigated for stresses, displacements and eigenfrequencies. As loading dead weight, prestressing of cables, different gusts and v. Karman excitation are considered. The dynamic loading is obtained from a rotor model with flapping degree of freedom and pitch-flap coupling with rigid blades and a rigid support.

Financial status (Budget DM 52.636)

Expenditures as projected

External activities

none

(3) Wind Tunnel Investigations

(3.1) Investigation methods

Determination of data for models and wind tunnels, either by computation or experimentally on a minor wind tunnel, dependent on problems to be investigated;

Technical status

An investigation has been started to clarify the influence of different typical parameters in windtunnel tests. This is necessary to plan and evaluate windtunnel tests, which make sense. The following parameters were considered:

1. Reynoldsnumber: it is not possible to duplicate the high Reynoldsnumbers of large windturbines in the windtunnel, however with airfoils below 10 % thickness the windtunnel model will yield meaningful results as long as the Reynoldsnumbers stay above 150 - 200 000.

2. Froude number: This parameter cannot be simulated with windtunnel models. However the influence of the gravity may be studied separately by special rotating models which neglect all other parameters and concentrate only on the Froude number. This may be allowed because the interference between aerodynamic and gravity effects is usually small.

3. Locknumber: This ratio of aerodynamic forces to mass forces can easily be reproduced by windtunnel models.

4. Flutter: The similarity with respect to aeroelastic phenomena can also be realized by windtunnel models, when the frequency ratios and the geometry of the model and the full size rotor are the same.

5. Simulation of gusts: In this field the properly instrumented windtunnel and turbine model are extremely useful. Devices to introduce gusts into the windtunnel flow are necessary and their frequency must increase inversely with the model scale. With expecially designed gust lattices and carbonfibre materials it seems possible to build such gust devices.

6. The test section of the windtunnel has to deal with the high drag of a windturbine. In order to reduce the interference of the model with the tunnel boundaries it seems appropriate to apply similar techniques as they are common in transsonic windtunnels, with other words the boundaries of the test section should consist of slotted walls.

Financial status (Budget DM 48.636)

Expenditures as projected

External activities

none

(3.2) Computation, design and construction of several wind tunnel models in connection with the investigations to be carried out according to 3.4:

Technical status

Differont windtunnel models were designed and build and tested. The aim of these models was not to simulate a complete windturbine, but was directed to single problems as mentioned in foregoing notes.

Financial status (Budget DM 195.145)

Expenditures smaller than projected, budget partly transferred to (1.2)

External activities

none

(3.3) Development and completion of the systems for acquisition, transfer and evaluation of data for experiments provided under 3.4, planning a system for the supervision of operational data for a prototype:

Technical status

The data acquisition system is implemented in the 7.4 m rotor model. The measured data are digitalised in the rotating system and are transmitted via an optical slip ring (12 bits parallel) into the stator. Up to now one channel is operational and measurements of the gravity induced lead-lag angle oscillations and the bending moment at the root of the blade were successfully performed. The extension to a 16-channel system is performed at present.

Up to now the measured data can be shown on a screen, plotted against the angular position of the blade. The rotational speed of the rotor can be controlled interactively via light pen and screen.

Financial status (Budget DM 21.479)

Expenditures larger than expected, budget partly transferred from (1.4.1)

External activites

P4, P5, P10, L5 .

(3.4) Wind tunnel experiments

(3.4.1) Two-dimensional investigations (profiles)

Technical status

Compare (1.1.2)

Financial status (Budget DM 79.779)

Expenditures as projected

External activities

P3, P4, P5, P6, L1, L2

(3.4.2) Three-dimensional investigations.

(3.4.2.1) Investigations on rigid models:
general characteristics of the stream around the wind wheel in parallel flow, with simulation, in a small-size wind tunnel

Technical status

No activites have started yet.

Financial status (Budget DM 101.515)

Expenditures as projected

External activities

none

(3.4.2.2) Investigations on an aeroelastic model of tower and rotor, with reduced design of the planned hub construction in a major wind tunnel

Technical status

No activities have started yet.

Financial status (Budget DM 44.636)

Expenditures as projected

External activities

none

(4) Specific Responsibilities of the Operating Agent according to the Implementing Agreement and especially Annex IV. 5.

Technical status

Financial status (Budget DM 131.219)

External activities