INTERNATIONAL ENERGY AGENCY

Programme of Research and Development
on Wind Energy Conversion Systems
(IEA R&D WECS)

ANNUAL REPORT 1982

A report of the IEA R&D WECS Executive Committee

January 1983

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FOREWORD

This is the fifth Annual Report of the IEA Programme for Research and Development on Wind Energy Conversion Systems IEA R&D WECS, summarizing the progress during 1982. It is submitted to IEA in accordance with the recommendations of the IEA Committee on Research and Development. The report is prepared by the Secretary of the IEA R&D WECS Executive Committee, Mr B Pershagen.

E Kinsella
Chairman of the Executive Committee.

EXECUTIVE SUMMARY

The IEA R&D WECS is a project for co-operative research and development in wind energy, in effect since 1977. The activities include the following Tasks:

I Environmental and meteorological aspects of WECS (completed in 1981)

II Evaluation of wind models for WECS siting (completed in 1982)

III Integration of wind power into national electricity supply systems (Phase 1 completed in 1979, Phase 2 in 1982)

IV Investigation of rotor stressing and smoothness of operation of large-scale WECS (completed in 1979)

V Study of wake effects behind single turbines and in wind turbine parks (on-going)

VI Study of local wind flow at potential WECS hill sites (on-going)

During 1982, a draft Annex for a new Task VII on Study of offshore WECS was approved by the Executive Committee and endorsed by the IEA Working Party on Renewable Energy.

Final reports were prepared for Task II and Task III, Phase 2. Activities in Task V and VI proceeded according to plan. The Dutch part of the joint NL/UK work in Task V was completed, resulting in 11 technical reports on wind tunnel measurements and modelling of wind turbine arrays. The first field experiments in Task VI were carried on the hill site on South Uist in the outer Hebrides.

The expert group on Recommended Practices for Wind Turbine Testing and Evaluation published a report on Power Performance Testing. Other documents are in preparation.

Topical workshops were arranged for investigating the need for further cooperative action, for example in the area of Decentralized use of WECS.

Participating Countries: Austria, Canada, Denmark, Germany, Ireland, Japan, Netherlands, New Zealand, Norway, Sweden, United Kingdom, United States.

Operating Agents: National Research Council of Canada (Task VI), Kernforschungsanlage Jülich GmbH (Task III and IV), Stichting Energionderzoek Centrum Nederland (Task V), National Swedish Board for Energy Source Development (Task I), United States Department of Energy (Task II).

1 IEA R&D WECS PROGRAMME

This report reviews the progress during 1982 of IEA R&D WECS, the Programme of Research and Development on Wind Energy Conversion Systems, operated since 1977 under the auspices of the International Energy Agency. IEA R&D WECS is one of two IEA projects in wind energy, the other being concerned with co-operation in the development of large-scale wind energy conversion systems (IEA LS WECS).

The overall objectives of IEA R&D WECS are to perform collaborative research and development and to exchange information in the field of wind energy. The Tasks are described in Appendices to the Implementing Agreement. Originally, the Programme had four Tasks

Task I Environmental and Meteorological Aspects of Wind Energy Conversion Systems.
Operating Agent: National Swedish Board for Energy Source Development

Task II Evaluation of Models for Wind Energy Siting.
Operating Agent: U.S. Department of Energy

Task III Integration of Wind Power into National Electricity Supply Systems.
Operating Agent: Kernforschungsanlage Jülich GmbH, Germany

Task IV Investigation of Rotor Stressing and Smoothness of Operation of Large-Scale Wind Energy Conversion Systems.
Operating Agent: Kernforschungsanlage Jülich GmbH, Germany

Task I was completed in 1981. The first phase of Task III was finished in 1979 and was followed by a second phase, called Task IIIa. Task IV was completed in 1980.

During 1980 a new Task was initiated:

Task V Study of Wake Effects behind Single Turbines and in Wind Turbine Parks
Operating Agent: Stichting Energieonderzoek Centrum Nederland

Another Task was started in 1982:

Task VI Study of Local Wind Flow at Potential WECS Hill Sites.
Operating Agent: National Research Council of Canada.

There are 13 Contracting Parties to the Implementing Agreement from 12 countries. The countrywise participation in the current Tasks is shown in Table 1.

Table 1 Participation in current Tasks
OA indicates Operating Agent

Country	Task II	Task IIIa	Task V	Task VI
Austria				
Canada	x		x	OA
Denmark	x		x	x
Germany	x	OA		x
Ireland			x	
Japan	x	x	x	
Netherlands		x	OA	
New Zealand				x
Norway	x			
Sweden	x	x	x	
United Kingdom	x		x	x
United States	OA	x	x	

Task II is a task-sharing and IIIa a cost-sharing undertaking. Task V and VI are mixed task- and cost-sharing projects.

During 1982 a new Annex VII on the Study of Offshore WECS was approved by the Executive Committee. This Annex has not yet been legally finalized.

A special Study of Recommended Practices for Wind Turbine Testing and Evaluation is being conducted for the Executive Committee by an expert group under the direction of Denmark.

2 TASK II. EVALUATION OF WIND MODELS FOR WECS SITING

The objectives of this Task are to verify selected atmospheric boundary layer numerical models by comparison with each other and with observed data, and to evaluate the usefulness of such models for wind turbine siting.

Three data sets were chosen from the island of Oahu (Hawaii), the state of Nevada and the island of Gotland in the Baltic. Five numerical models were used:

- a simple mass-consistent wind interpolation code, NOABL, developed by Science Applications, Inc., USA
- a one-level, primitive equation model, SAM, developed by the Atmospheric Environment Service of Canada
- a multi-level, time-dependent, hydrostatic model (the University of Virginia mesoscale model)
- a multi-level, time-dependent, hydrostatic model, SIGMET, developed by Science Applications Inc., and having a different turbulence model and numerical procedure than the UoV model
- a multi-level, time-dependent, non-hydrostatic model (the UK Meteorological Office).

The models thus ranged in complexity from a simple kinematic wind interpolation routine to sophisticated models that solve the complete hydrodynamic equations of motion. The models were tested by comparing their predictions of surface wind flow with the sets of wind observations. The data sets covered a range of meteorological and topographical conditions. The input data used to run the various models were fairly meager. This sparcity of data is thought to be typical of the conditions under which these models would actually be run when used for WECS siting purposes.

The results showed no correlation between model complexity and ability to simulate the surface wind flow. The simplest model did as well as the most sophisticated model. The conclusion to be drawn is that including more physics in a model does not guarantee improved performance, if many of the crucial data needed to run the more sophisticated models are not available.

From the viewpoint of wind turbine siting, the study showed that numerical wind field modeling can be useful in the initial stages of siting, where a relatively large area is screened for those portions having the greatest wind energy potential. However, the study showed that the accuracy of modeling results is low. To be most effective, numerical modeling techniques should be applied only by persons experienced in problems of flow over topography.

3 TASK IIIa. INTEGRATION OF WIND POWER INTO NATIONAL ELECTRICITY SUPPLY SYSTEMS

Task IIIa is a continuation of Task III, in which a computer model for determining the value of wind energy to large utilities was developed and applied to the case of Germany. In Task IIIa the cases of Japans, the Netherlands, Sweden and the USA are studied. The analysis includes the following main steps:

- Acquisition of meteorological, cost and utility system data
- Analysis of wind data
- Estimation of WECS power output
- Integration of wind power into the electric grid
- Cost-benefit aspects of wind power.

The Task was carried out by a research team at the University of Regensburg with Kernforschungsanlage Jülich as the Operating Agent. The work was finished during 1982. The results were published in case reports for the participating countries and in a final summary report.

In March 1982 a two-day expert meeting was held in Jülich for discussion of the main results. The discussion focussed on the central issues for wind power integration, e.g. the dynamic production function of WECS and the effects of WECS on utility operation, the forecasting of wind speeds and WECS power output, and the capacity credit of WECS. The papers presented were published by the Operating Agent.

4 TASK V. STUDY OF WAKE EFFECTS BEHIND SINGLE TURBINES AND IN WIND TURBINE PARKS

This Task was initiated in 1980 with the Stichting Energionderzoek Centrum Nederland as the Operating Agent. The objective is to produce estimates of the performance of arrays of wind turbine generators, including:

- power output efficiency as a function of spacing, dispositions and number of machines and machine types
- generated turbulence levels and associated dynamic effects

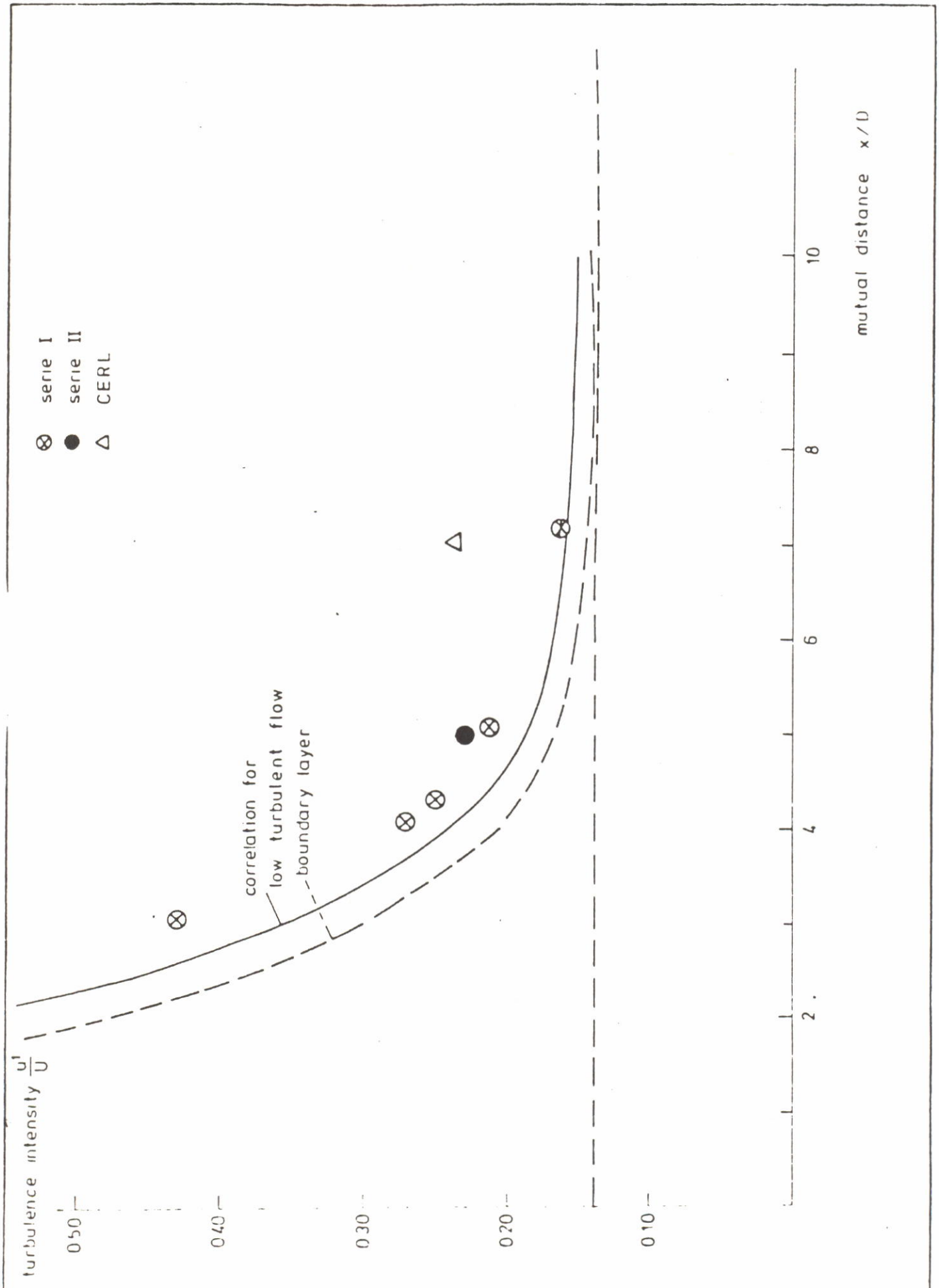
Work is performed jointly in the Netherlands and the United Kingdom in three major areas:

- o Measurements of individual wake structure and decay
- o Measurements of machine performance in velocity fields of the type that may be encountered in a wake
- o Theoretical and experimental modeling of machine cluster performance by combining information on individual wakes with knowledge of machine performance in wake-type flows.

The Dutch part of the work was finished in February 1982. The UK part is continuing and is planned to be completed in 1983. The progress during 1982 may be summarized as follows.

Wind tunnel studies

The turbulence measurements in simulated wind turbine clusters (carried out in 1981) have been analysed and empirical correlations have been derived. Fig 1 shows an example from ref 1. From the measurements a data base has been constructed which contains velocity-time



Equilibrium turbulence intensity in an array

FIGUR 1

MT-TNO
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Fig 13

histories of turbulence in wind turbine clusters. This data base is available for design purposes (TNO, Apeldoorn).

Wake measurements on a 3 m diameter horizontal axis rotor have indicated the validity of simulators for wind tunnel tests of clusters and also shown the effects of changes in machine performance on wake characteristics. Analysis of the data from a 17 m diameter horizontal axis wind turbine has also confirmed the similarity between rotor and wire gauze simulators. The effects of turbulence will be studied in more detail.

Outdoor studies

A program of measurements is being carried out at Alresford, Hants, on a mini array of three vertical axis rotors. The machines are three-bladed, Musgrove type with inclined self-furling interconnected blades. Rotor diameter is 6 m, rotor height 7 m and blade length 3 m. The planned machine array is triangular with spacings of 3, 5 and 7 machine diameters. In addition to the three turbines, three 6 m x 3 m perforated screens suitably mounted at hub height are also available to act as wake simulators.

Theoretical studies

A comparison has been made of the CERL model EMWAC, the Lissaman program and the TNO wake interaction model MILLY. All these programs use a similar technique to calculate the cluster efficiency for clusters of a specified geometry. The effective differences between the models lie in the equations used to describe the decay of a single wake. Comparison of the models with available experimental data from wind tunnel cluster studies shows reasonable agreement (cf Fig 1), but large differences can occur and none of the models gives consistently good agreement.

The major uncertainties in the wake decay equations occur in the treatment of the near wake, where the equations are known to be unrealistically simple, and in the far wake, where experimental data is sparse and of limited accuracy. The comparison of the three computer models indicated that the far wake behaviour does have a significant influence on the performance of a cluster.

The behaviour of an axisymmetric wake in a low turbulence uniform flow is well known. The mean velocity, shear and substantial ambient turbulence in the atmospheric boundary layer, as well as the ground plane and tower wake, removes the wind turbine wake problem away from this ideal state. Theoretical work is in hand to examine the influence of these effects, and this necessarily involves a consideration of the turbulence structure of the wake.

Reference

1 Vermeulen, P E J, Builtjes, P J H
Turbulence measurements in simulated wind turbine clusters
MT-TNO Report 82-03003, February 1982

5 TASK VI STUDY OF LOCAL WIND FLOW AT POTENTIAL WECS HILL SITES

Although formal notices of participation in this Annex were not all filed until June 1982 the participants had already held a preliminary planning meeting in March and were able to get a "running start" on the project this summer. The central component of the Task is a two-stage experiment which is being carried out on Askervein, a relatively isolated 125 m hill located on South Uist in the Outer Hebrides (Scotland), Fig 2. The aim of the experiment is to collect field data on the local variations in wind speed and turbulence produced by the hill and to compare these against both wind tunnel and numerical model predictions. The preliminary field experiment was held during September and October 1982. Two 50 m towers were erected, one on the hilltop and one at an upwind reference site, and profile and turbulence measurements were made using cup and sonic anemometers respectively. A further eight 10 m climbable towers were used for additional turbulence measurements and sensor intercomparisons while spatial variations in the mean wind field were obtained from simple cup anemometers mounted on thirty-five "portable" 10 m towers. These were deployed in two radial lines through the hilltop with 50 m or 100 m separation between the towers. Weather and wind cooperated for this year's experiment and good data were obtained for several wind directions. Detailed analyses are still under way but some preliminary sample results for mean wind speed variations are given in Fig 3. The hill is approximately elliptical in plan view with smooth cross sections and the wind speeds shown are for a wind direction normal to the major axis of the hill (see sketch). The wind speeds are normalized by the wind speed measured at the reference station and show hilltop "speed-ups" of approximately 80 %.

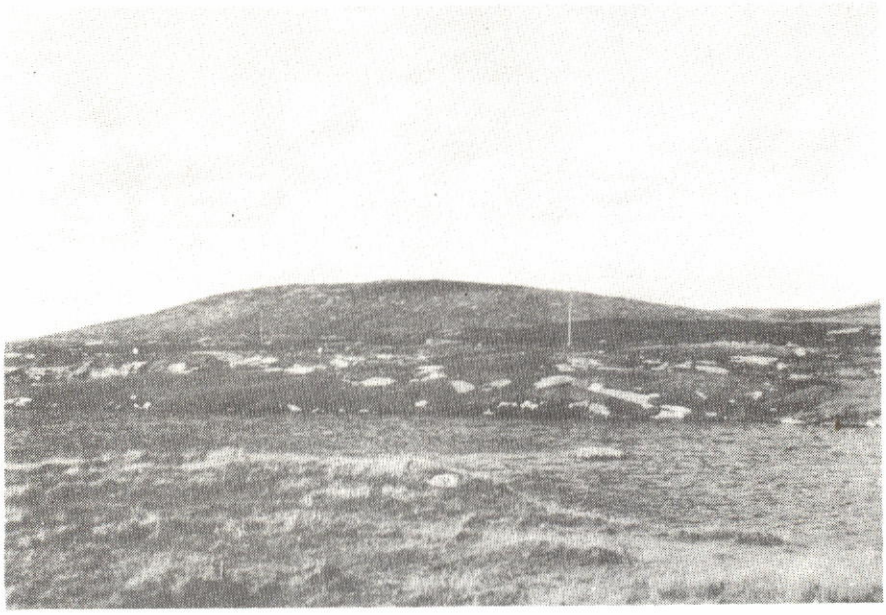

Fig. 2 View of Askervein from the S.

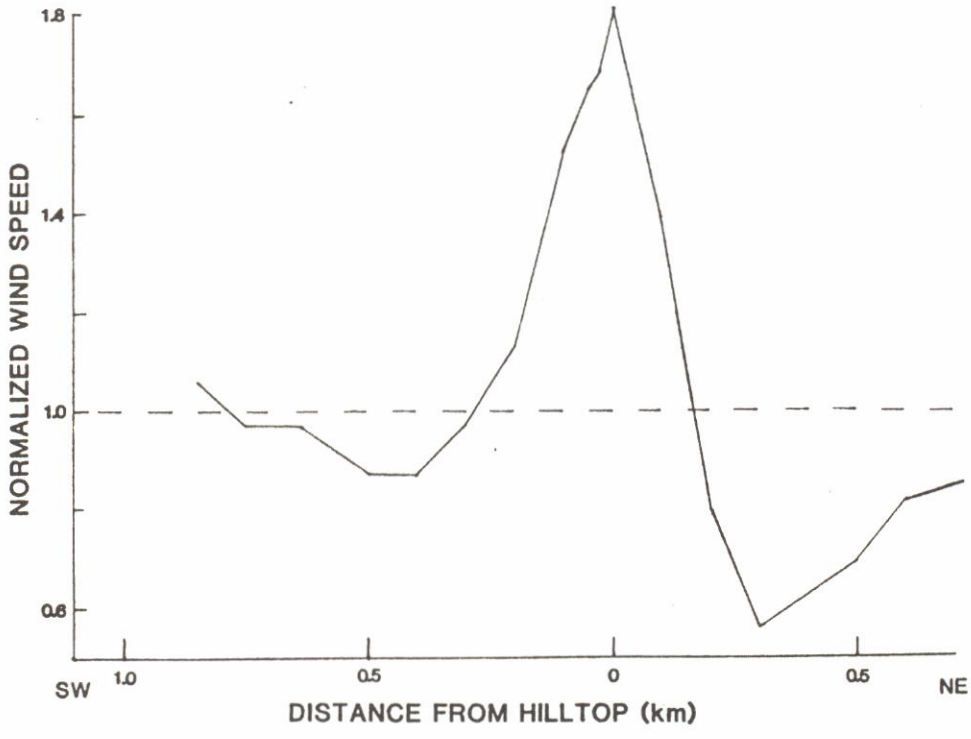

Fig. 3 Mean wind speed variation 10m above the surface along a NE-SW line through the hilltop. Preliminary analysis of data for SSW winds.

Completion of data analysis from this year's experiment is scheduled for February 1983 while the main experiment in October 1983 will concentrate on a more detailed resolution of spatial variations in turbulence on and around the hill. Preparations for wind tunnel and numerical model tests are well in hand.

6 STUDY OF OFFSHORE WECS

In 1980, the Executive Committee initiated a comparison by an expert group of offshore WECS (OWECS) feasibility studies carried out in the Netherlands, Sweden, United Kingdom and United States. The expert group came to the conclusion that the installation of offshore WECS was technically feasible and could be economically attractive if large power stations were considered. The group identified certain areas requiring further studies and outlined a plan for further action in international cooperation within the framework of IEA.

Representatives from Denmark, Germany, the Netherlands, Sweden and the United Kingdom met in Stockholm on May 28, 1982 to define activities for a joint program and forms of cooperation. As a result, a draft Annex VII for a Study of Offshore Wind Energy Conversion Systems was prepared. The participants in the draft Annex (Denmark, the Netherlands, Sweden and the United Kingdom) agreed to undertake a two-year task-sharing program of preparatory studies aiming at a decision to jointly design, construct and operate a large-scale offshore WECS prototype in about three years' time.

The Task, as specified in the draft Annex, aims at (1) assessing the economic viability of offshore wind power, (2) defining design criteria for an offshore WECS prototype, and (3) outlining a plan for the design, construction and operation of a joint prototype. The Task is subdivided into four Sub-Tasks:

- Provision of wind data for the assessment of OWECS
- Conceptual design of an OWECS power station
- Technical specification of an OWECS prototype
- Generic studies

The draft Annex was approved by the Executive Committee at its 1982 fall meeting and submitted to the IEA Working Party for Renewable Energy for consideration. The Working Party endorsed the draft Annex in December.

7 RECOMMENDED PRACTICES FOR WIND TURBINE TESTING AND EVALUATION

The Executive Committee organized in 1980 an expert group for recommending test procedures for the evaluation of WECS performance. The group identified the following areas of interest:

- Power performance testing
- Costing of WECS
- Determination of power quality
- Acoustic noise measurements
- Fatigue life evaluation
- Electromagnetic interference
- Safety and reliability

A report on Power Performance Testing was published in 1981. A report on Costing of WECS is in print. Documents in the other areas are in various stages of preparation. It is planned that the first series of reports will be completed during the first half of 1983.

During 1982, the expert group had three meetings:

March 18-19	Leatherhead
June 21-22	Copenhagen
December 13-14	Hamburg.

Due to the considerable interest in the activities of the group, it has been suggested to continue its work in a standing committee.

8 ACTIVITIES OF THE EXECUTIVE COMMITTEE

The Executive Committee held its ninth meeting on March 22, 1982 in London. At this meeting Dr E Kinsella (Ireland) and Mr P F Sens (the Netherlands) were elected Chairman and Vice-chairman for 1982. The tenth meeting was held on September 20 in Stockholm, immediately prior to the 4th International Symposium on Wind Energy Systems.

The technical and financial status of the Tasks were reviewed at the meetings and appropriate decisions taken. Proposals for new Tasks were discussed, including

- Offshore siting of WECS
- Decentralized use of wind energy
- Stability of wind turbine and arrays
- Comparison of test facilities for small WECS

For the purpose of investigating the needs for cooperative action the following topical workshops took place:

Subject	Date	Place
Decentralized use of wind energy	March 15-16	Shannon
Offshore siting of WECS	May 28	Stockholm
Site evaluation techniques	June	Dublin
Integration studies in the fast regime	Sep 30-Oct 1	Jülich

A list of Executive Committee members is attached.

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IEA R&D WECS
EXECUTIVE COMMITTEE
The Secretary

1982-10-27

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