INTERNATIONAL ENERGY AGENCY

Implementing Agreement for Co-operation in the Research and Development of Wind Turbine Systems
ANNEX XI

27th Meeting of Experts

Current R&D Needs in Wind Energy Technology

Utrecht, September 11-12, 1995

Organized by : NOVEM

Scientific Coordination :

B. Maribo Pedersen
Dept. of Fluid Mechanics
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ISSN 0590-8809

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27th IEA Experts Meeting, sept. 11.-12. 1995, Utrecht

Current R&D Needs in Wind Energy Technology

INTRODUCTORY NOTE
by

Ian Page, ETSU

R&D NEEDS IN WIND ENERGY TECHNOLOGY

The use of wind turbines to contribute to national energy supplies will be greatly enhanced if firstly, the technology can be demonstrated to be cost competitive with other forms of generation and secondly, there is increased public acceptance of their siting. This note is concerned with identifying technological areas where further R&D will help achieve these goals.

The cost of energy (CoE) generated by wind turbines is arguably competitive with that from conventional sources, especially when environmental costs are taken into account. However the main criteria used by power utilities are economic rather than environmental and so there is a need for the wind industry to reduce the CoE further to illustrate clearly the industry's competitiveness. Cost reductions can be achieved in most components of wind turbines and in the operation of wind farms.

The main technological issues associated with public acceptability are those of noise and visual intrusion.

The following table summarises some of the ways improvements in cost or public acceptability could be achieved together with the author's perception of where further R&D is an important consideration (* least interest, *** most interest).

Aim	Method	Options	Comment	R&D?
Reduce WTG Costs	Improve manufacturing methods	Automation	Currently man-power intensive Not R&D topic?	
	Cheaper components	Series production	Function of Market size Not R&D topic?	
	Reduce weights	Value engineering	Most suitable for "traditional" design machines but how far can we go?	
		Lighter machines	Introduces flexibility and theory not well understood Design tools/Modelling requirement	***
		Alternative conventional materials	Already explored?	*
		Unconventional materials	e.g. Use of deformable plastics for passive pitch control Other applications?	**
	Reduce loads	Teetering hubs	Well understood	*
		Load-shedding rotors	Necessary part of light machine? e.g. Carter WTG	***
		SMART systems for local management of loads	e.g. deformation of blades into/out of stall	
		Free yaw		
	Reduce number of components	Integrated drive trains	Engineering design	*
		Direct drive generators	Already commercial but still in infancy. New types?	**
		Braking philosophy	Dependent on Standards & Certification?	**
Reduce Balance-of-Plant Costs	Cheaper equipment	Bulk buying	Depends on size of market	
		Reduce rating of electrical plant due to fluctuating output	Depends on Standards?	*

Reduce Operational Costs	Higher reliability			
	Less frequent servicing	Health monitoring	Too expensive?	*
		Better components through improved standards	Need to balance savings against increased costs	
	Lightning protection			
Increase Energy Capture	Aerodynamic performance	Blade design	Linked with lighter blades?	**
		High lift aerofoils		**
		Better stall regulated blades		**
		Better understanding of turbulence and stall		
	Increase operational window	High/low wind speed operation	Linked to decreased loads	
		Variable speed operation		
		Site specific machines		
	Better control systems	Non-linear control	Much theory, not tried in the field	**
		Active stall control	Increasing interest	**
Increase public acceptability	Reduce noise	Noise reduction in drive trains	Well understood? Engineering solution?	*
		Reduce aerodynamic noise	Linked to blade design	***
	Improve visual appearance	Improved surface finishes		
		Optimum colouring		

IEA expert meeting on
Current R&D needs in Wind Energy Technology

11 & 12 sept. 1995
NOVEM, Utrecht

Status and Expectations of R&D in Wind Energy Technology

Gijs van Kuik

Stork Product Engineering

Based on survey of R&D status for NOVEM in january 95,
report SPE95002 (in Dutch, same title)

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Methodology used for NOVEM survey:

- interviews with 'all' Dutch wind energy experts
- EWEC Thessaloniki conference oct.'95, several survey papers

Results in report SPE-95002:

- status and expectations for short, mid and long term, for unlimited resources
- merely a survey: no priorities, no judging.
- consensus about content of 'everyone' in the Netherlands !!

This presentation:

- based on this report, but with personal opinions.

Progress in designing Wind Turbines

- progress is shown by the design requirements:

  1985: simple engineering rule for thrust

  1996: international IEC standard, with prescribed, detailed load cases and safety factors.

- yet the present standard is not satisfying:
  - some topics not covered
  - level of conservatism unclear

Justification of R&D continuation: why anyway?

- see introductory note of Ian Page:
  - reduction of costs
    - wind turbine
    - balance of plant
    - operation
  - increased energy capture
  - increased public acceptance
- but also:
  - increased accuracy and reliability of design / development tools in order to:
    - minimize probability of failure
    - enable further conceptual developments
    - reduce development costs

Some topics (not a comprehensive list), presented in following slides

- stochastic wind field description
- aerofoil design
- unsteady aerodynamics
- rotor aerodynamics
- aeroacoustics
- materials
- reliability analyses
- rotor development

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Stochastic wind field modelling

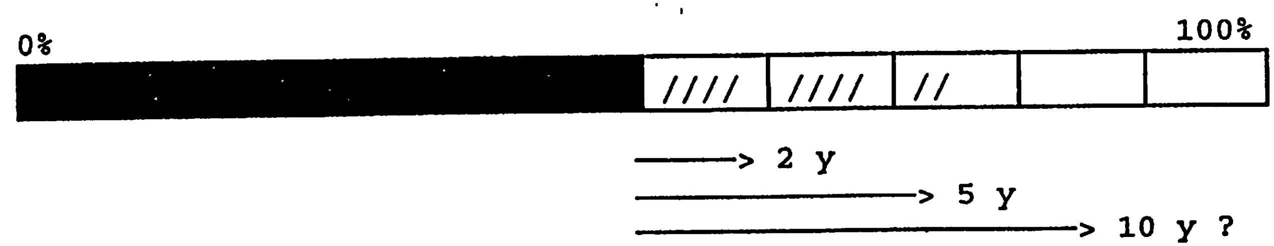
- Status - Stochastic modelling is standard, also in industry

    - Short term (0-2 year)
        - extension with non-longitudinal components
        - choice of turbulence spectrum and coherency function

    - Mid term (0-5 year)
        - higher accuracy at low frequencies
        - modelling of rare events (thunderstorms, etc.).

    - Long term (>5 year) - possible use of chaos theory

- Expectations
    - less failing turbines.
    - increased reliability of design proces



Aerofoil design

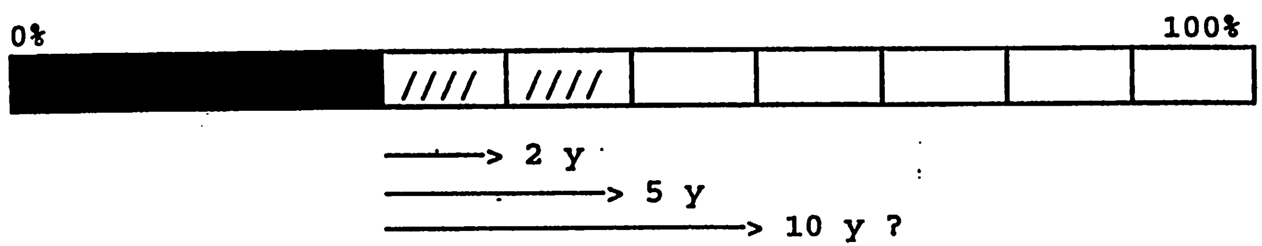
- **Status**
  - preference for thick aerofoils with good 2-D behaviour
  - modelling of 3-D stall is still 'educated guess'

  - **Short term (0-2 year)**
    - development of thick aerofoils, possible wil low Cl
    - validation of engineering rules 3-D stall

    - **Mid term (0-5 year)**
      - application of validated engineering rules in design and optimization of aerofoils

      - **Long term (>5 year)**
        - applicaton of 3-D boundary layer models: development of specific wind turbine aerofoils (invers design)

- **Expectations**
  - increased energy capture
  - increased reliability of design proces
  - controlled stall loads



Unsteady aerodynamics

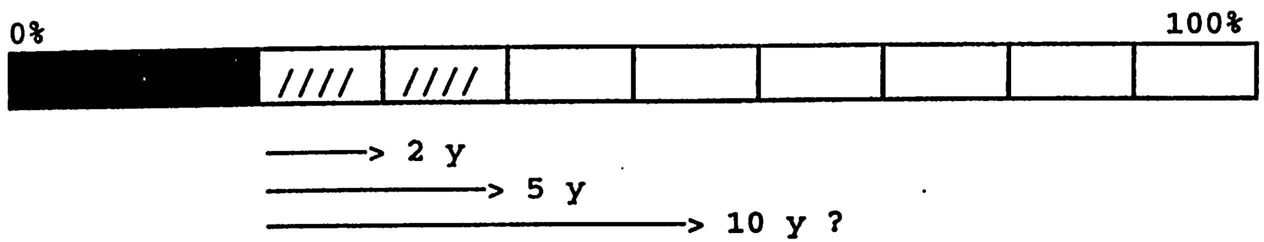
- Status
  - insufficent knowledge of unsteady, 3-D, stall, thick aerofoils
  - too little concern about aeroelastic stability in blade design

- Short term (0-2 year)
  - development & validation of engineering rules for dynamic stall
  - transfer of aeroelastic helicopter knowledge to wind

- Mid term (0-5 year) - unsteady, aeroelastic analyses in blade design

- Long term (>5 year) - application of 3-D boundary layer models for unsteady stall behaviour

- Expectations
  - increased accuracy of load predictions
  - increased reliability of design



Rotor aerodynamics

- Status
  - knowledge sufficient for design conditions
  - insufficient for:
    - heavily loaded rotors
    - rotors in yaw
    - tip loads & tip noise

- Short term (0-2 year) - validation engin. rules dynamic inflow, specially in yaw

- Mid term (0-5 year) - knowledge of near-wake vortex structure by experiments / calculations

- Long term (>5 year) - coupling of rotor-aerodynamics with aerofoil design

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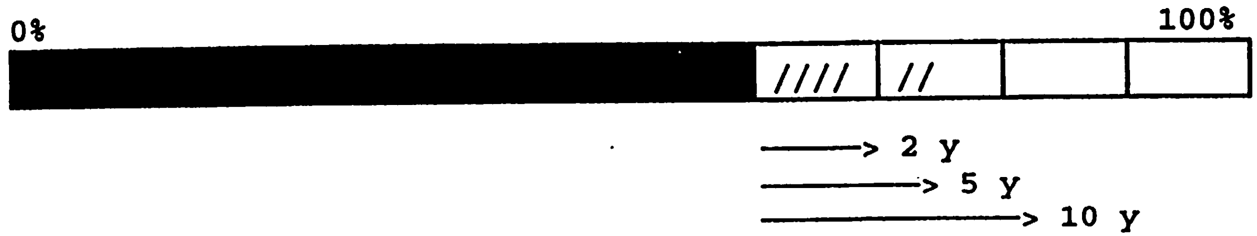
- Expectations
  - better modelling off-design conditions
  - increased possibility for tailoring rotor/aerofoil design



Aeroacoustics

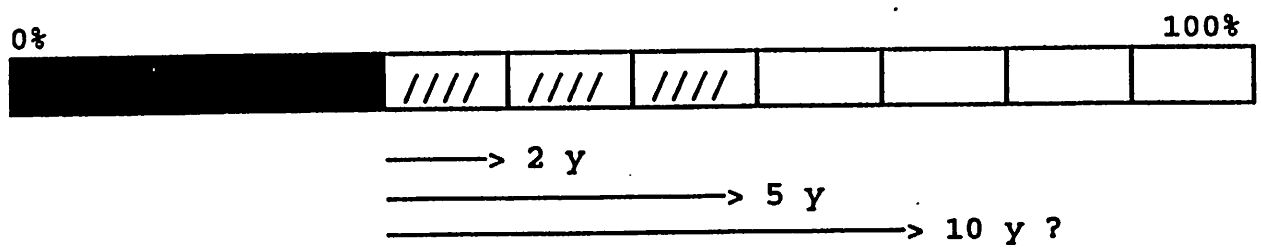
- Status
  - aerodynamic noise is dominant
  - urgent need for design rules
  - increasing knowledge of leading & trailing edge noise, not of tip noise

  - Short term (0-2 year)
    - analysis of measurements and drawing up of design rules for load - noise relation

    - Mid term (0-5 year)
      - first models based on physics of aerodynamic noise

      - Long term (>5 year)
        - incorporation of acoustic requirements in aerofoil design

- Expectations
  - decrease of source level by some dB's
  - more accurate prediction of source level



Materials

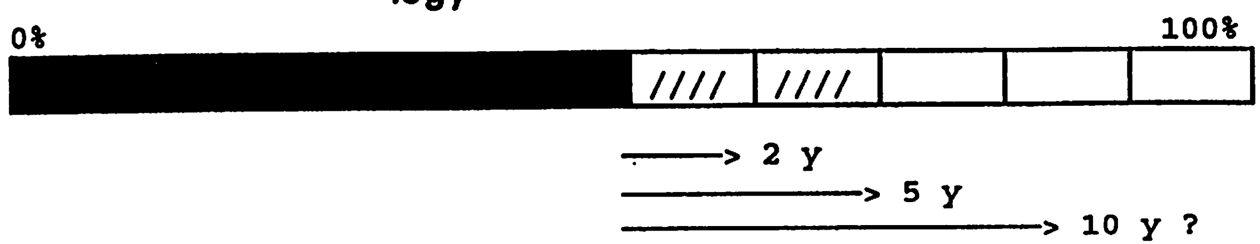
- **Status**
  - sufficent knowledge of glasfibre and wood-epoxy in design conditions
  - insufficient for off-design (humidity, UV-radiation)
  - carbon fibre: status unclear
  - no consensus of manufacturers about continued research

- Short term (0-2 year) - consensus about material properties & safety factors under normal conditions

- Mid term (0-5 year) - R&D of combined material / manufacturing technology, specific for each blade manufacturer

- Long term (>5 year) - who knows

- Expectations - cheaper blades by optimized use of new material & manufacturing technology



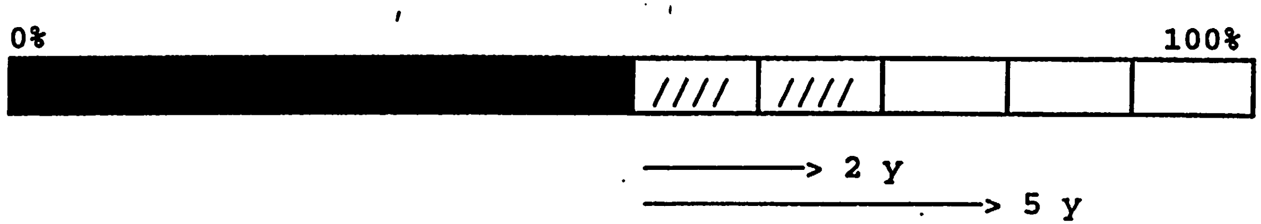
Reliability Analysis

- Status
  - System Reliability well developed; Structural Reliability at its beginning
  - too little failure and operational data available
  - the same for data of typical wind turbine components

  - Short term (0-2 year)
    - transfer of System Reliability to manufacturers
    - start of data bases to support reliability analysis
    - development of Structural Reliability

    - Mid term (0-5 year)
      - firm basis for design method using data bases
      - application of Structural Reliability to calibrate safety factors

- Expectations
  - improved operation, less maintenance
  - more balanced design
  - more sophisticated safety systems



Rotor development

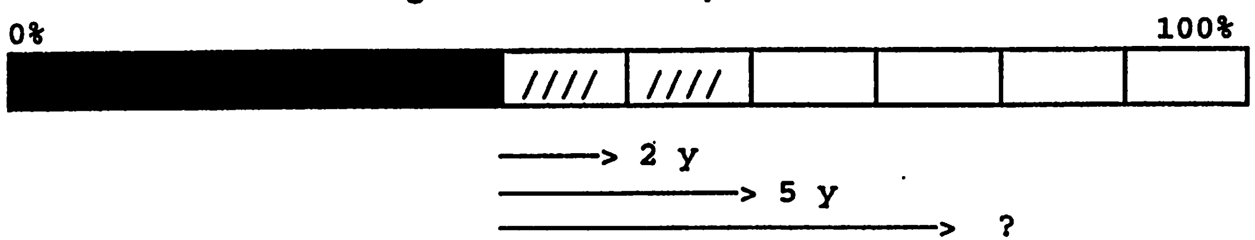
- **Status**
  - extreme loads and buckling become dimensioning, not fatigue
  - high accuracy in aerodynamic geometry
  - no problems any more with blade roots, bonding etc, but with dynamics

- **Short term (0-2 year)**
  - automation of production
  - manufacturers go their own way, no generic R&D support as was done with blade roots
  - increased interest in teetering rotors

- **Mid term (0-5 year)**
  - development of smart blades: load reduction by prescribed deformation under loading

- **Long term (>5 year)**
  - continuation

- **Expectations**
  - cheaper rotors by improved manufacturing process
  - lighter turbines by load alleviation in blades



Summary: Status of current knowledge

- gaps
  - modelling of extreme conditions
  - unsteady, 3-D aerofoil behaviour, particularly in stall
  - complex terrain
- general
  - sufficicient to construct reliable, efficient turbines
  - much use of educated guess and engineering rules
  - insufficient for optimization towards
    - minimal loads
    - minimal maintenance
    - minimal noise
- status of current design proces:
  - more or less reliable, as long as conceptual changes are minor
  - each major design change requires a long development period, trial and error

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Summary: possible results after 2 years (short term)

- extension / validation of stochastic wind models
- validation of engineering rules for
  - dynamic inflow
  - 3-D stall, unsteady stall
  - loads in wind farms
- development of thick aerofoils
- improved understanding of noise emission by exploring relation: loads - noise
- introduction System Reliability in design proces
- support for manufacturers in concept / component development:
  - easy to use, quick software tools
  - quick look testing facilities
  - variable speed operation
  - direct drive generators
- condition monitoring of drive train
- failure registration and analyses, black boxes, databases

Summary: possible results after 5 years (mid term)

- improved accuracy of low frequencies in wind field simulation
- design rules for extreme wind conditions, based on databases
- design methods for complex terrain, wind farms
- first 3-D boundary layer calculations in stall
- measurements / calculations on vortex structure of the wake
- development of first aeroacoustic theories
- component- and concept development
    - new production technologies
    - in relation to this: material knowledge
design methodology
    - 2d generation direct drive generator.
- condition monitoring of rotor.

Summary: possible results after more than 5 years (long term)

- calibration of safety factors by structural reliability
- design methods for low-noise aerofoils - blades
- modelling of unsteady aerodyamics of blades
- continuous development of components / concept

Comparison with current R&D activities: main topics

Small problems:

- high industrial priority of noise research, but slow progress in current R&D
- only limited research for most urgent gap in knowledge: extreme wind conditions
- (very recently) start foreseen in setting up databases for reliability analysis

Big problems

- big need for support of component development through testing facilities, software tools
- the same for new material / manufacturing technology
- validation of aerodynamic engineering rules is very urgent, very expensive, and not foreseen.
- not enough basic, generic research to convert (engineering) rules into knowledge

Hindrances for generic knowledge development

Conflict of interest

- maximum increase of knowledge versus maximum protection of 'own' product:
    - no free access to winddata, failure data, noise data
    - more and more manufacturer related research on technology, materials, components

Lack of fundings

- national and Joule fundings shift from research to support of manufacturers.
- opinion of (some) policy makers: wind turbines work, so why research anyway?

Shifting of R&D funding

Past:

- renewables are good
- renewables are in pioneering phase

so Research funding (nat. programs, Joule I & II)

Now:

- wind turbines are out of pionering fase
- industry has limited money for R&D

so funding of industr. Developm. (nat. pr, Joule III)

How could future look like ?

- Assumptions:
  - wind turbine industry is big and mature
  - situation similar to aircraft, shipbuilding, nuclear industry
- Then:
  - industry related R&D partly supported by funding
  - industrial cooperation in common interest activities (databases etc.)
  - basic R&D funded by governments to support wind industry / wind energy

Conclusions R & D topics

- **permanent R&D** on topics, typical for wind turbines:
    - aerofoil design
    - rotor aerodynamics / acoustics
    - turbine dynamics
    - materials / manufacturing technology
    - electric conversion

- **development to design tools**, then continuation as engineering practice
    - reliability analyses
    - wind field description
    - load and fatigue calculation
    - test and monitoring

Conclusions policy

- funding for generic research is diminishing, while minimum level is required.
- initiative required to remove hindrances, and to discuss possibly new funding structure.
- Task for IEA ?

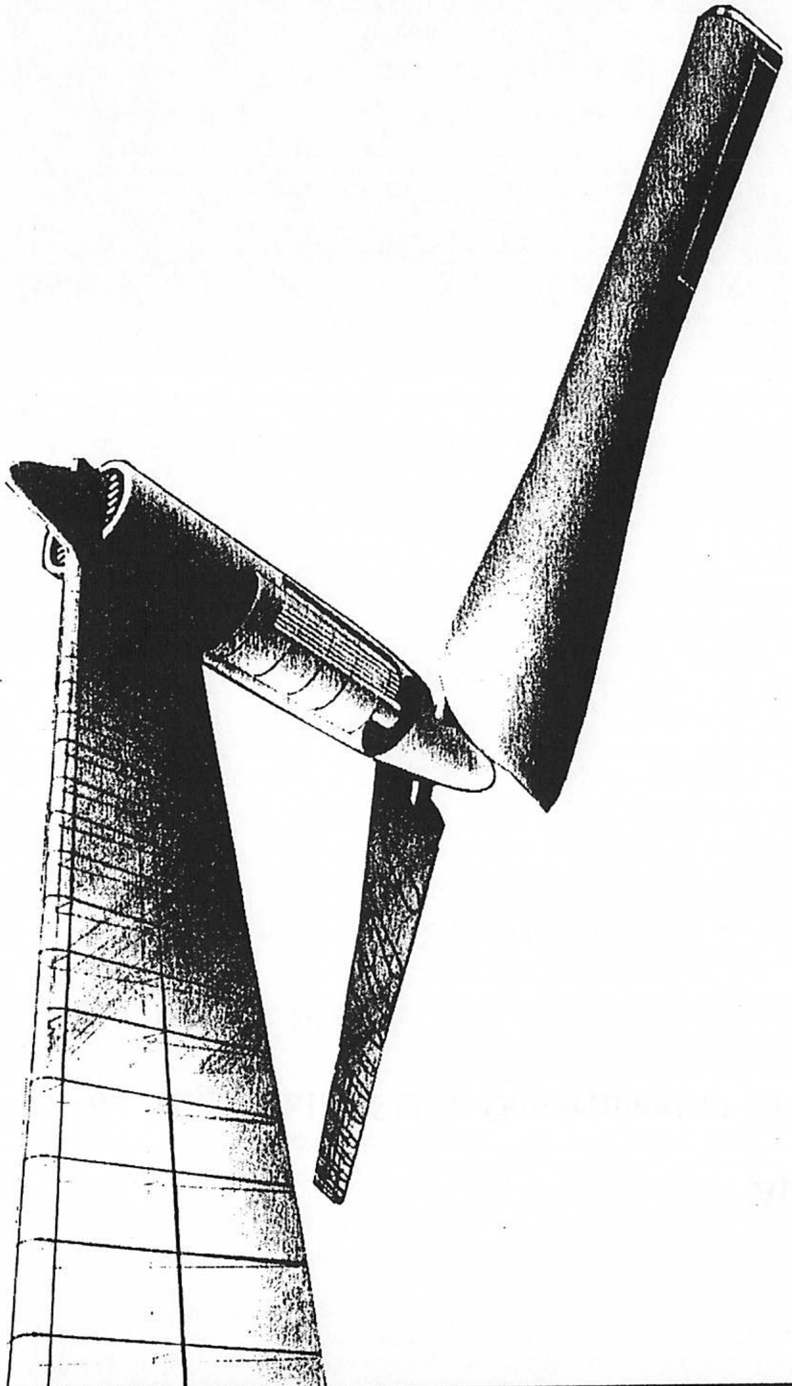
Perspective: we are only in Dakota phase

Present status of technology is comparable with Dakota technology :

- no pionering any more
- start of series production
- reliable product with reasonable performance
- only in basic concept similar to present day aircraft

Transferred to wind turbines this yields the perspective that in 50 years time:

- some present day turbines still will work
- wind turbine development is continuously supported on all levels of R&D
- turbines will have blades, but further ?



Wind Energy Systems

Wind Energy in the U. S.
A Status Report

Jack Cadogan

IEA Annex XI
R&D Workshop

September 1995

Agenda of Talk

- Highlights of U.S. Department of Energy Program
- Budget Status
- Changes in U.S. Marketplace (set stage for R&D discussion)

DOE Program Highlights

- Climate Change Action Plan Announced in October 1993
  - 5 year, $100 million/year support for renewables deployment
  - National Wind Technology Center at NREL dedicated by Secretary O'Leary in October 1994
- Continued Strong Technology Development Focus
  - Near-term turbines (including Valued Engineered Turbines) nearing completion
  - NREL evaluating proposals for Next Generation Turbine Development
  - Several Innovative subsystems under development
- Applied Research Continues as Foundation (SNL and NREL)

Wind Commercialization Collaborative

User Sector
- Utilities
- IPPs
- Trade Organizations
- UWIG

Supplier Sector
- Turbine Manufacturers
- Project Developers
- Consultant Support
- AWEA

National Wind Coordinating Committee
- A forum for key stakeholder viewpoints
- Concensus on collaborative activities
- Coordinate implementation

Facilitator Sector
- DOE/Labs
- EPRI
- Environmental Groups
- State Energy Offices
- Regulators
- Financial Community

Program Actions in Support of the Climate Change Action Plan

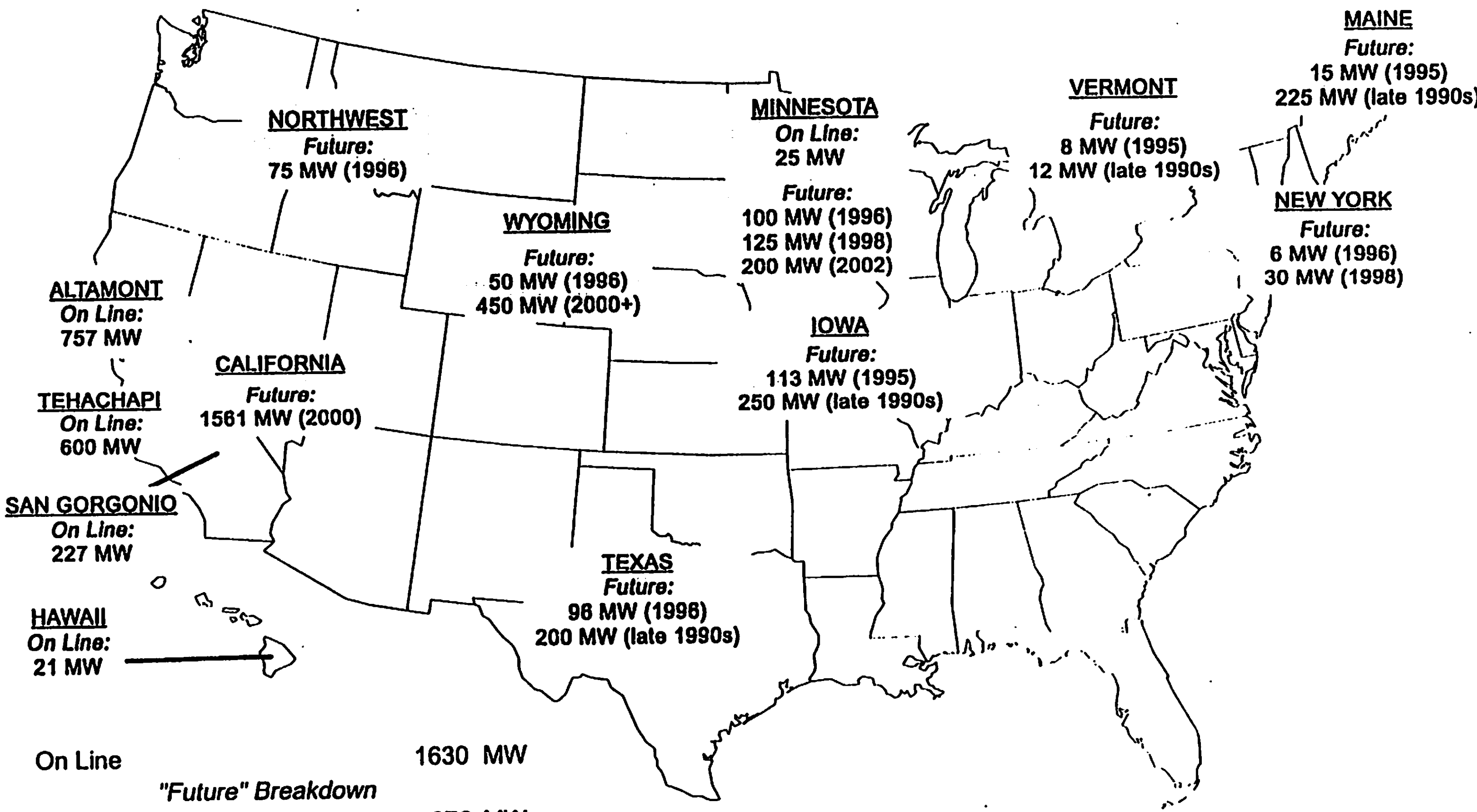
Collaborative Role

- The Wind Collaborative will identify needed activities at the Federal, State and local level to expedite deployment of wind energy

FY 1995 Actions

- Initiate windfarm deployment projects
- Expand the Turbine Verification Program
- Initiate avian research
- Initiate a Utility Wind Resource Assessment Program

Selected Wind Power in the U.S.



On Line	1630 MW
"Future" Breakdown	
Under Contract	376 MW
Mandated	455 MW
Proposed	2684 MW
Total "Future"	3515 MW

November 1994

Budget Status is Uncertain

- o Congress has changed significantly
- o President announced a 10 year plan to balance budget
- o Budget Appropriations for FY 1996 still to be determined

Brief Wind Budget history:

FY 1994 Appr.:	$26.1 million	
FY 1995 Appr.:	$47.1	
FY 1995 Appr.:	$45.0	(after rescission in August 1)
FY 1996 Request:	$49.8	
House Auth:	$10.3	
House Appr.	$20.0	
Senate Appr:	$32.0	
Senate Floor:	$42.0	

A Sea Change Has Occurred in the Market in the United States

- Wind technology has improved significantly

But,

- Gas Turbine Technology Has Improved Also
- Natural Gas prices and price prospects are lower than even two years ago
- The prospect of restructuring in the electric power business has virtually stopped new orders for wind energy projects

How has the market changed?

- o EPAct provided for transmission access and Exempt Wholesale Generators (EWG)

- o Utilities have proposed repeal of Section 210 of PURPA (perhaps important symbolic value to retain; largely irrelevant in marketplace).

- o Utility Restructuring (unbundling or deregulation of generation) is occurring

  - California proposals
  - New England

- o Risk minimization already suggested to CEOs of IOUs to put new resource acquisition out for bid (been happening for 5 (?) years or more).

- o POOLCo structure favors low avoided cost, low capital cost options, essentially a spot market.

- o Emphasis on short term is major problem for wind with high capital cost

- o Existing wind capacity, except for SMUD is QF or power purchase deals. New capacity is likely to be non-utility owned.

We are Re-thinking our Cost/performance Projections

What's the purpose of a cost goal?

- o Cost/performance target that says if wind achieves this target it'll be competitive (for given application) and achieve some share of market.

Can express it as $/kW, $/Sq. meter, cents/kWh, etc.

Simplicity (and simple minds) favors cents per kWh, but I'd rather physical units, i.e. Annual KWh/ sq. m. and $/sq. m.

What did we do historically?

- o 1984 plan set a cost/performance target in ranges of $/annual kWh and $/sq meter.

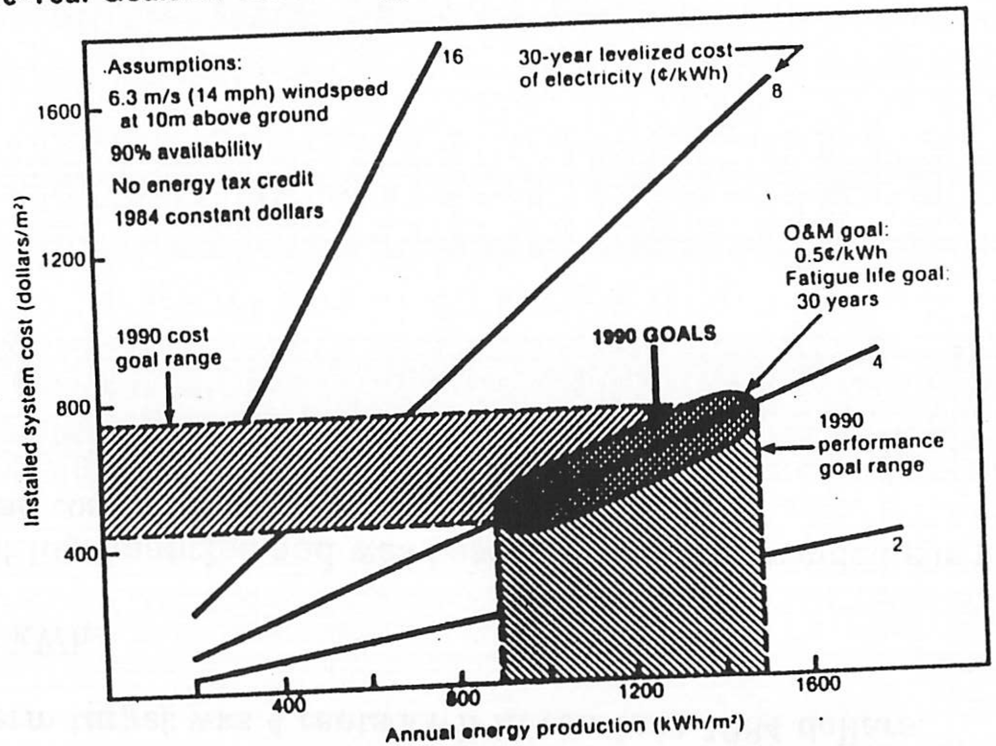
Allowed for big versus small turbines, VAWT versus HAWT, and other design tradeoffs.

In 1984 Plan, 1990 Near term target was 4 cents/kWh in constant 1984 dollars.

Long term was 3 cents per kWh.

Assumed investor owned utility financing and was based on levelized avoided gas prices (near term) and a blend of gas and coal prices in long term..

Figure A-1. Five-Year Goals for Wind Energy Technology R&D



Historical (cont'd)

- o In National Energy Strategy (1989-1991), the accelerated R&D case cost goal was 5 cents per kWh in 1990 $ for 1995 sales and 4 cents for 2000 based on levelized gas prices, assuming utility ownership and the canonical class 4 wind regime.

We're still carrying these goals even though the market has changed.

Are these still acceptable? Are they relevant?

- JBC: Not really.

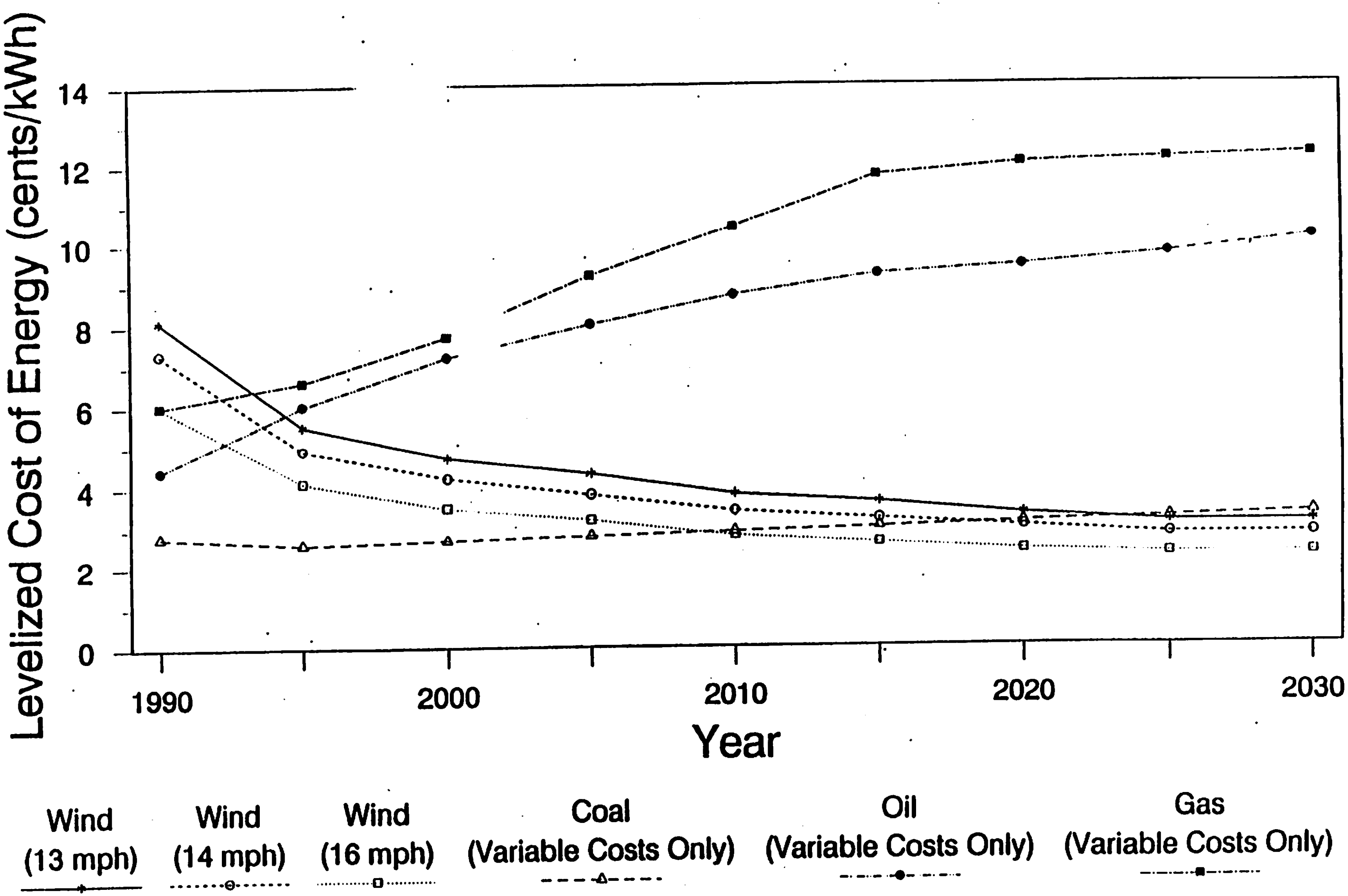


Figure 12. Intermittent Renewable Technologies - Accelerated Funding Case

What's the most favorable financing scheme for Wind?

- MUNI financing is 100 percent debt at tax-advantaged rate and retires debt over plant lifetime, typically 30 years. (Best, i.e. most advantageous to wind).

- IOU is perhaps 50/50 debt equity but pays back investment over 30 years. (okay for wind)

- IP/QF uses project financing and retires debt over a shorter period, typically the length of the first contract. Often more highly leveraged than IOU, but equity rate is much higher. (toughest for wind). IP/QF often must bid against market price.

What's POOLCo look like?

- o Data from Northbridge Group at National Wind Coordinating Committee (NWCC) Restructuring Workshop showed that avoided costs in many power pools may be below 2 cents per kWh most hours of the year.

- o Claim is that new capacity may not be needed for 10 to 20 years in most pools and/or regions, and even then it may be gas-fired.

POOLCo is not the only model

- o Bi-lateral transactions between buyers and sellers, say MUNIs, coops and buying groups who might prefer renewables at least as a portion of portfolio. Advocated by southern California Edison.

- o Renewable aggregators (al la Jan Hamrin).

Message:

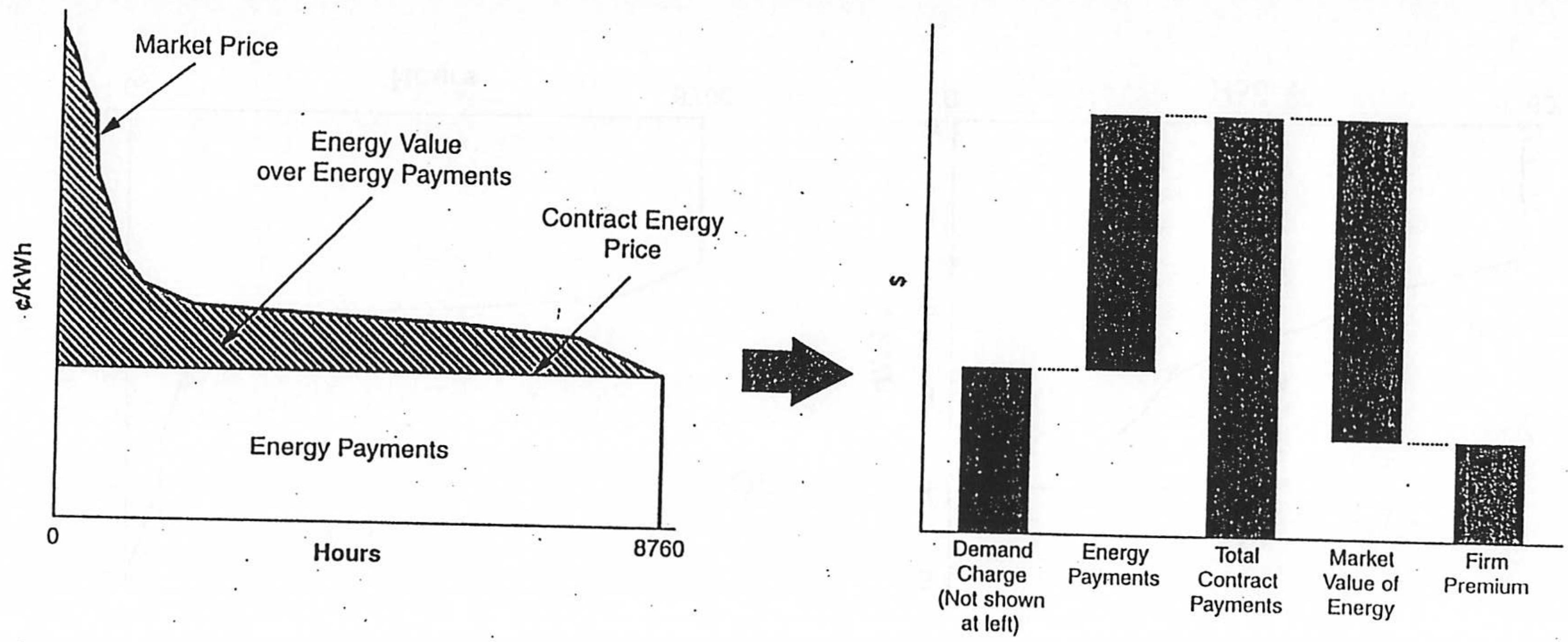
- o "Old" IRP model that emphasizes societal costs and life-cycle payback is falling out of favor

- o Will anything take IRP's place?

COMPETITION AND WIND

Price Insurance

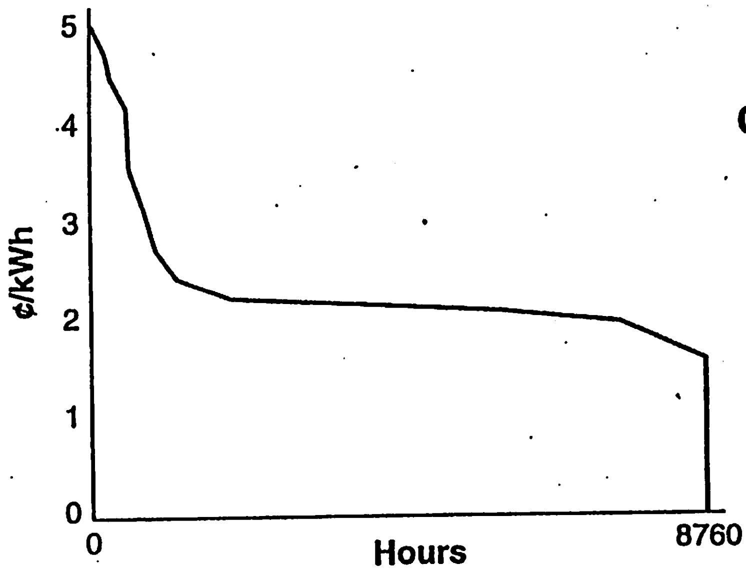
Spot price information will provide a ready mechanism for evaluating the economics of classical demand/energy deals:



Price stability has historically been overpriced.

Source: Northbridge Group

Spot prices will provide clear information as to when energy is valuable and when it is not:



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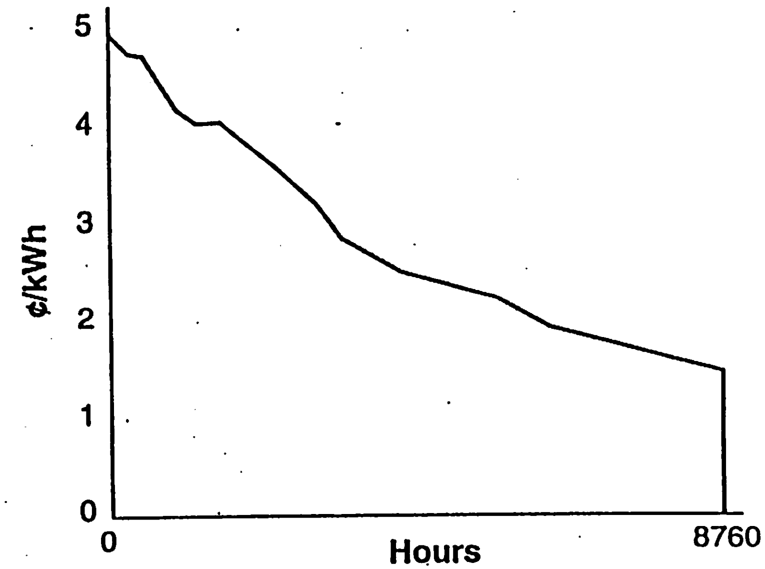


Unfortunately, most of the country looks more like the left side of the page than the right. Profitable generation opportunities will be scarce for a number of years.

Northbridge Group

For the internal targets and to improve our marketing, examine the market:

- o Market oriented approach in which avoided energy is based on POOLCo type arrangements.

- o FERC access requires that each utility charge itself and users of its transmission system the same rates for different services, including point-to-point transmission, network services (dispatch and regulations, etc.)

  These costs should be added to avoided energy to compute a minimum cost of energy bogey.

  Wind transmission costs should be considered too, say 100 miles of transmission. (We'll have to think hard about this; perhaps use NREL and ORNL reports as sources.)

- o Assume financing typical of market entities such as IP, Munis and coops.

- o For near term, assume favorable winds (say class 5 to class 6)

- o Because of remote location, wind would be relatively disadvantaged using the bus-bar plus transmission framework.

Conclusions

- o IP/QF financing (15 year debt) requires significantly improved cost/performance beyond nominal 4 cent per kWh IOU-owned 30 year Class 4 resource technology

- o We don't know how far the technology can be pushed

    - All options are important

- o Also need to address how to add value to wind beyond short term fuel savings

    - Several projects underway at NREL, EPRI, etc.

WIND ENERGY R&D NEEDS

J R C Armstrong, Wind Energy Group, September 1995

Introduction

First, a personal introduction, as I have not participated in sessions of this type before, and am not known to many of you.

I am a mechanical engineer by training, and have been with WEG since 1978. Before that I was with the Intermediate Technology Development Group from 1976 designing a water-pumping windmill for production in developing countries, and later with a helicopter company (Cierva Rotorcraft) working on the use of compliant rotors for power generation. My wind energy experience therefore spans about twenty years.

While with WEG, I led the technical teams that developed the medium-size (MS) turbines, while my colleague Peter Simpson co-ordinated the large machine developments, notably the LS-1 and LS-2. My first major project was the 250 kW MS-1, which has operated on Orkney from 1983 until recently, developed as a joint project between Taylor Woodrow (WEG's owner), British Aerospace and GEC. After that came the three-bladed MS-2 and two-bladed MS-3, designed 100% in-house at WEG and put into windfarms in California, England and Wales. Most recently, we have stretched the MS3 design to 400 kW, and are well advanced with the design of a completely new concept of compliant turbine at 600 - 700 kW. My present responsibility as Technical Director is for an engineering group of 25 or so, and for a variety of technical projects.

Over the years, WEG has carried out dozens of R&D projects. The company's emphasis has been on developing technology rather than production, largely because of an absence of home market until quite recently. One of WEG's strengths has been the development of an in-house blade-making capability, encompassing wood, glass and foam composites bonded with polyester, epoxy and vinyl resins. The blade group has been so successful at selling to WEG's traditional competitors that we recently set it up under a separate company to provide customers with an assurance of independence.

The Purpose of R&D

Before looking at what R&D is to be encouraged, I would like to ask what our overall objectives are. We can talk about a domestic (ie European) policy of achieving such-and-such capacity by 2005, phasing out subsidies and satisfying all kinds of environmental constraints, but what of the rest of the world? Our prediction is that about 10,000 MW of wind capacity will be installed globally between now and the year 2000: of this we think one third will be in Europe, one sixth in the USA and one half in the rest of the world. Much of this latter half will be in low production cost areas which can ultimately re-import into Europe and under-cut our producers - should our policy be to encourage or oppose this?

My guess is that the **strategic** goals of an overall European policy are two-fold:

1. Encourage the maximum development of non-polluting energy sources in Europe and in the rest of the world
2. Maximise the wealth-creating opportunities for our (ie European) industries.

I am not sure whether bringing wealth-producing opportunities to the rest of the world should be included as a third goal.

From these goals (including the third one), we could then write a list of tactical objectives for achieving them. This list might include:

Domestic Objectives

- achieve 3500 MW of new installation by the year 2000
- achieve energy cost parity with conventional sources by 199x
- be "good neighbours" in terms of installation policy and environmental constraints
- encourage stable and steady market development
- encourage a strong domestic turbine industry
- encourage a strong domestic component supply industry.

European Objectives Relative to Rest of World

- encourage achievement of say 5000 MW by the year 2000
- export capital, ie grant aid and project finance
- export services, such as prospecting and planning
- export projects (to sell electricity)
- export European wind turbine products
- export European component products
- export European technology, ie help locals to set up prospecting, project know-how, windfarms, turbine assembly and component manufacture
- **import** turbines
- import components
- import services (a software engineer in Madras costs 10% of one in London).

I am sure that in practice there will be individual examples of all these activities over the next 5 years, and as a sign of a flexible free market this will surely be a good thing. However, it is when we come to distort the market with a central R&D subsidy (which is what we are now discussing) that some care is needed in defining our purpose.

A further point to be made is that the "industry" is not one homogeneous whole, but consists of several levels: utilities, developers, contractors, turbine suppliers, component manufacturers, prospectors, consultants, test & certification authorities, academics and so on. Most of these will have conflicting objectives to some extent; for instance consultants will gain from the export of technical know-how while component manufacturers may lose out. Again, it is important to be aware of these conflicts when advising on a policy for dispensing central funds.

R&D Options

If we put aside for a moment the more political considerations mentioned above, we might ask if there is an obvious overall R&D objective from a purely technical point of view. It could be something like: "reduce the lifetime cost of energy generated from the wind as far as possible, commensurate with local environmental and land use requirements". This would lead in turn to more detailed objectives, for instance:

1. Develop new turbine configurations which promise lower cost or more energy
2. Develop cheaper or more effective components for existing or new configurations
3. Define more closely the available wind resource
4. Evolve clearer and more consistent guidelines (design, environmental, land use etc).

I have used the word "develop" here to cover the whole process from concept design to production engineering and testing. Also a distinction is made between new or improved configurations of turbine, and component development. The former is the province of a specific turbine supplier; for example a relevant question here might be about the merits of applying variable speed operation to a design such as the very lightweight Carter 300. Component development on the other hand, undertaken by a company such as Flender to say reduce gearbox noise levels, could benefit many different turbine products.

Configuration Development

Advances in turbine configuration can contribute to the overall goal put forward above either in a non-specific way, by improving general cost-effectiveness, or by meeting some specific market requirement.

I recently presented one way of looking at turbine configurations (Ref 1). Diagrams from this paper showing the most popular three and two bladed configurations are shown in Figures 1 & 2. Without repeating the analysis from the paper, it is clear that there is considerable variety, some clear favourites, and some relatively unexplored channels. As far as improvements in general cost-effectiveness are concerned, my own view, and one which we are pursuing at WEG, is that configurations which introduce compliance into the up-tower structure are those with the best potential for weight-saving and therefore cost reduction. This "palm-tree vs oak-tree" approach is of course not new, and was pursued throughout the last decade in the US. However, it has not been adopted in Europe with its more demanding certification and environmental requirements, and I believe the time has now come to put this right.

Another factor in the "general improvements" category is size. During the spate of MW turbine building as the main thrust of national programmes in the late 1970's, the optimum **commercial** size of turbine was 50 - 100 kW. Since then it has steadily increased, and with the encouragement of the Joule programme, commercial turbines of 1 MW are now available. The incentive to increase size is highly dependent on project financing: larger turbines tend to be more attractive where balance-of-project costs are high, for instance in Europe. In the US or India, balance-of-project costs form a smaller proportion of overall costs, and the optimum turbine size is lower. I am not sure that larger size in itself should be a valid qualifier for Community R&D funding, since there are plenty of commercial incentives for manufacturers to develop larger components and larger turbines. (The implication of this statement is of course that Community funding should only go to those projects that would **not** otherwise be supported).

In the "specific" category are particular market requirements, such as:

- island or isolated sites; needing matched wind-diesel system
- poor access sites (or no cranes); needing self-erect towers & nacelles
- weak or sensitive grids; needing close power factor/inrush control
- noise-sensitive sites; needing very low aerodynamic/mechanical noise isolation
- extremes of temperature or atmospheric conditions needing special measures,

and so on. I believe there is a case for funding R&D in these cases if a minimum ratio of market size to investment can be demonstrated.

Component Development

With the exception of blades, the development of components for wind turbines has received little direct public funding. This is at first sight surprising, since it is in the hardware that the real savings are made, and turbine suppliers actually manufacture little or nothing themselves. However, it is the turbine designer who must define the need for a particular component development, and he naturally wants to keep the benefits of the innovation to himself. Thus the variable slip generator developed by one generator supplier in conjunction with a Danish turbine manufacturer is not generally available to other turbine designers. It is hard for the component manufacturer to specify closely enough the technical development that is needed, and carry it through with central funding, without involving a turbine supplier who will in turn want some measure of exclusivity.

This is generally not the case with blades, since the blade manufacturer has to employ designers who know as much as (or more than) the turbine designer about aerodynamics, aero-elastics and structures. The blade supplier can therefore control his own R&D programme, using central funds, to develop products which turbine manufacturers want to buy. The exceptions to this are:

1) in the cases of the 4 or 5 turbine manufacturers who choose to fabricate their own blades, presumably because of perceived advantages in exclusivity or margins
2) in the case of highly integrated designs (such as the light-weight compliant turbines), where the blade may have to be precisely tailored to the dynamic requirements of the turbine.

As the whole market becomes more sophisticated, I believe that component suppliers will become more capable of specifying developments themselves, and that this is an area for central funding which should increase. The obvious candidates are the blades, gearbox and generator, but other areas of technology such as noise isolation, installation systems, electrical drives and damping will also be relevant. Ideally, the turbine designer wants to be able to buy the most effective components at a similar price from at least two suppliers, thus gaining the advantages of multiple sourcing and stability of supply.

The foregoing paragraphs concern the **design** of the components. A mention should be made here of **quantities** and **manufacturing methods**. Clearly 1000 turbines can be built more cheaply than 100, and those produced by robots more cheaply than those built by expensive

European labour. Also there is a trade-off, because the cost of the robots has to be amortised, and it may be cheaper to set up manufacture in some low-cost area of the world - but we are now back with the more political factors I started with and this is supposed to be a technical review! I will just make two points regarding manufacturing methods:

1) this is principally a matter for the component suppliers, since it is they who produce the hardware, not the turbine designers and assemblers
2) the distribution of central funds for improving manufacturing methods should be focussed on those components that are specific to wind turbines: this will principally mean the blades.

Resources Definition

This is always a valid topic for central R&D funding, and the potential for refining and making ever more comprehensive the data base is almost unlimited. Perhaps the budget for this kind of work - which should include utility studies, topographical modelling etc, as well as wind mapping - should be set at some fixed proportion of the overall wind R&D budget.

Evolution of Guidelines

The development of Standards and Guidelines is desirable for many reasons, not least the potential to export a responsible attitude to the technology and provide opportunities for the many European certification bodies which already have offices throughout the world.

Comment

Arriving at this point, having categorised from a technical point of view the things which ought to be funded, I am left with a gap between this statement and my earlier plea for a definition of what our strategic and tactical objectives should be. In other words, how would a component development programme for example be affected by our policy towards third world imports vs exports? If we wanted to encourage exports to China, say, we might fund the development of an integrated gearbox of great complexity using exotic materials which would be hard to indigenise. On the other hand, if we wanted to encourage local overseas industry we would lean towards a basic and rugged gearbox design using low grade but available materials.

In practice, I think market pressures will sweep away any attempts at protectionism, and it is better to acknowledge this and take a global view. I would therefore favour the wider strategic objectives being adopted, and R & D funding applied to developments that will help achieve these wherever they are.

One more comment I would like to make, and that is to do with the **process** of doing R&D. Maribo states in his briefing that universities and research institutes carry out most of the R&D and he wants feedback from the "users", ie manufacturers, designers and planners. As a user, I must say I do not find that much of **technical** value comes from the universities or research institutes, at least in Britain, although we have a few consultants and departments whom we use regularly for specific services or consultancy. The real value of the academic institutions, and of the projects they do, is in training the students whom we can then take on and put to work. Perhaps that is as it should be. But I contend that R&D money spent in universities will improve the people whereas R&D money spent in industry will improve the technology.

Conclusion

In summary, our industry's objective should be to encourage the maximum development of wind energy generation throughout the world, aiming at an additional 3500 MW in Europe, 1500 MW in the US and 5000 MW in the rest of the world by the year 2000. This should be done in a way which encourages as far as possible local manufacture.

Our overall R&D objective should be to reduce the lifetime cost of energy generated from the wind as far as possible, commensurate with local environmental and land use requirements. Effort should be aimed at :

1. New turbine configurations which promise lower energy cost: the most fruitful area is likely to be in reducing weight with more compliant designs (but without introducing over-specialised components).
2. New turbine configurations which satisfy some special market need, provided a minimum ratio of market size to investment can be demonstrated.
3. Developing cheaper or more cost effective components, and in the case of components specific to wind turbines, improving manufacturing methods.
4. Defining more closely the available wind resource.
5. Developing clearer and more consistent guidelines (design, environmental etc).

Funding to universities and research institutes should be done with the awareness that its main function is to improve the people not the technology.

FIGURE 1 Map of 3 Bladed Turbine Configurations

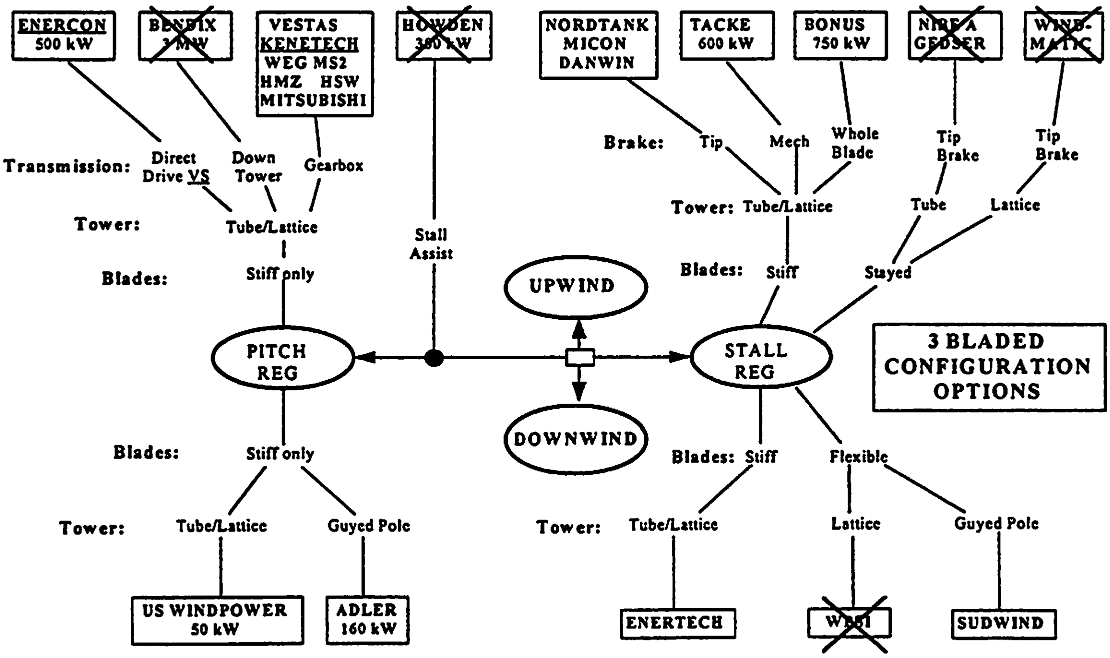
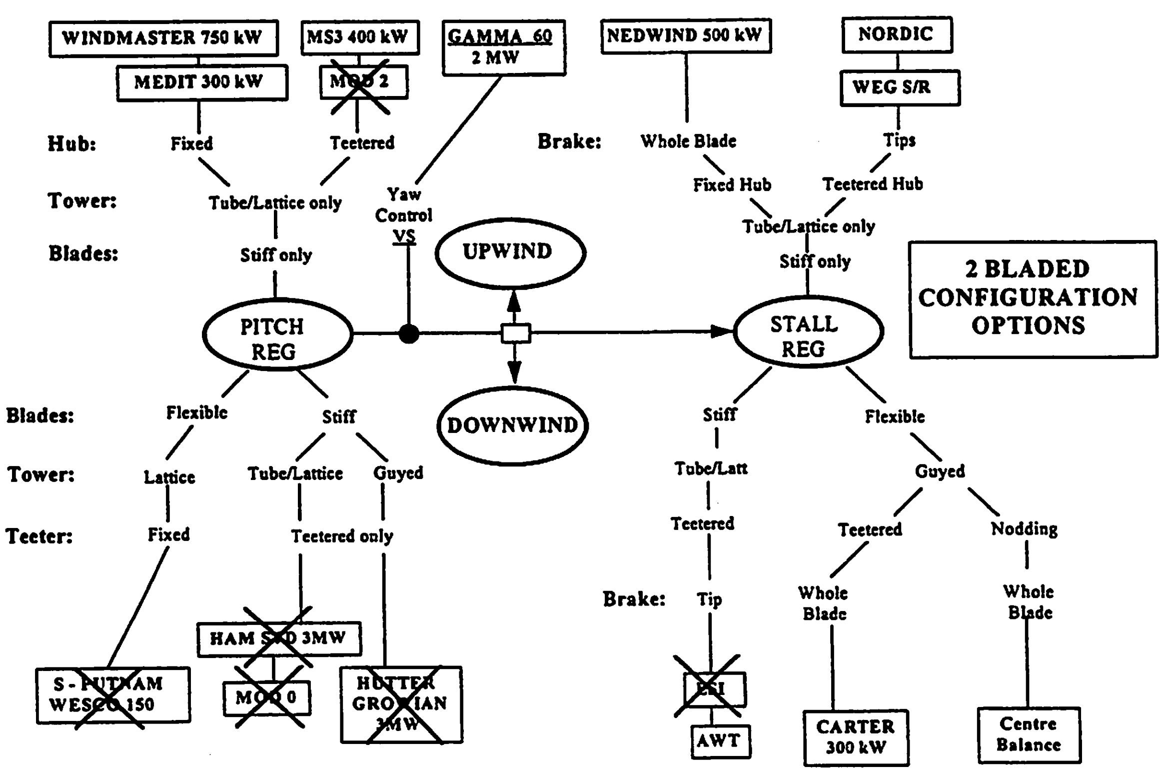


FIGURE 2 Map of 2 Bladed Turbine Configurations



IEA-27th Topical Experts Meeting

Current R&D Needs in
Wind Energy Technology

Utrecht, 11-12 September 1995

ECN-contribution

by

L.G.J. Janssen

ECN

STARTING POINTS

* Cost reduction
* Improvement of reliability
* Improvement of acceptance

WIND MODELLING

* Stochastic wind description
* Wind turbulence in complex terrains
* Park effects
* Interpretation of wind data

ECN

cost reduction

INCREASE OF E-OUTPUT

* Optimization of blade design
* Optimization of control systems
* Optimization of wind park layout

LOAD REDUCTION

* Improvement of aerodynamics and -elastics
  (in order to improve the reliability of
  of the load analyses and to avoid the
  applications of partial load safety factors)
  - stall effects
  - tip effects
  - yaw effects
  - misalignment
  - elasticity effects
  - wind modelling

* Flexible systems
  - hinged rotors
  - variable speed

* Avoiding special load cases

ECN

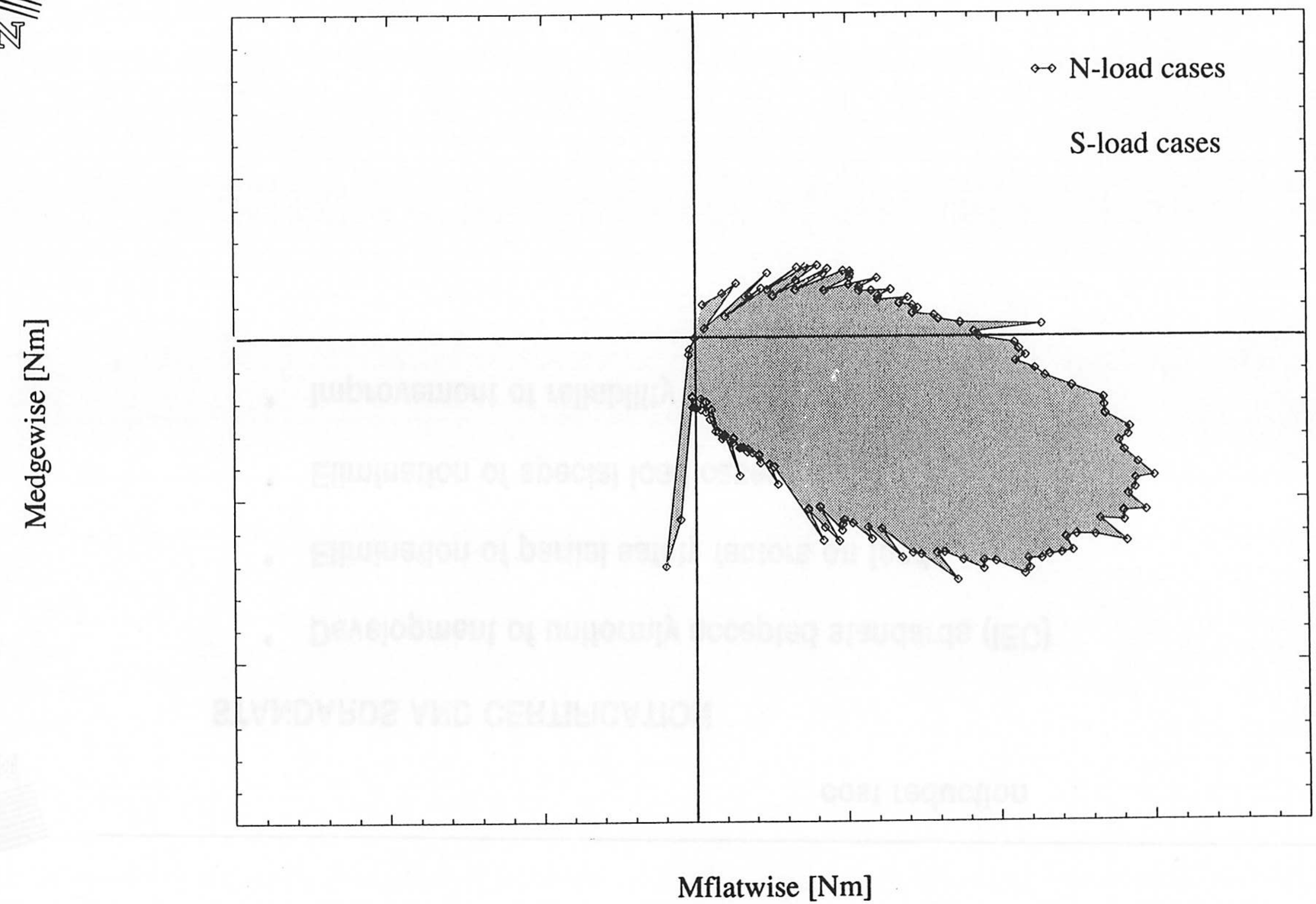
cost reduction

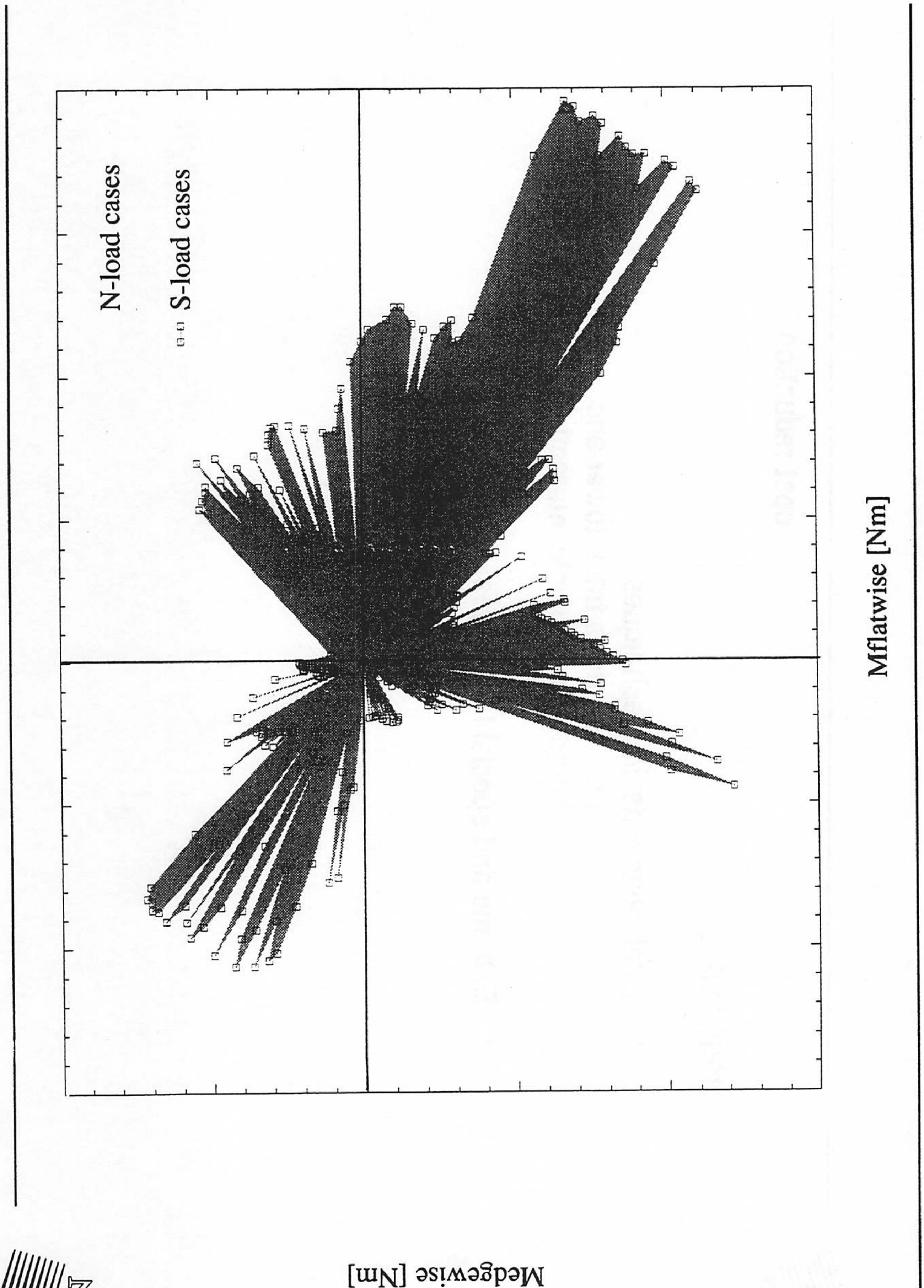
IMPROVEMENT MATERIAL DATA BASES

* Extension existing data bases
* Engineering methods for data transformation
* Intelligent interpretation software

STANDARDS AND CERTIFICATION

* Development of uniformly accepted standards (IEC)
* Elimination of partial safety factors on loads
* Elimination of special load cases
* Improvement of reliability of material data


N-load cases
S-load cases
Medgewise [Nm]
Mflatwise [Nm]



N-load cases
S-load cases
Mflatwise [Nm]
Medgewise [Nm]

cost reduction

UPSCALING

* Total system design techniques
  (blades, drive train, tower and
  foundation dynamic interactions)

* Extreme and special load cases

ECN

cost reduction

NEW CONCEPTS

* Smart flexible rotor systems
* Reduced component concepts
* Free yaw concepts
* Direct drive concepts
* Unconventional materials
  - LCA approach

improvement reliability

RELIABILITY ANALYSES

* Systems reliability
  - Fault and event tree analyses
  - Failure data bases
  - Effects on and of maintenance

* Structural reliability
  (long term research)

ECN

improvement reliability

DESIGN VERIFICATION TECHNIQUES

* Prototype testing
* Component testing
* Load monitoring
* Smart strands
* Condition monitoring

improvement acceptance

UTILITY ACCEPTANCE

* Power electronics
  - grid connections
* Prediction power availability

ECN

improvement acceptance

PUBLIC ACCEPTANCE

* Visual impact

* Noise reduction
  - specific measurements techniques
  - aerodynamic noise research

National Wind Technology Center (NWTC) Research Facilities and Objectives

Michael Robinson, Ph.D.
National Renewable Energy Laboratory
Jack Cadogan, Ph.D.
Department of Energy

NREL National Renewable Energy Laboratory

NWTC Test Site

Objective:

- "The Wind Technology Division performs and supports the research, development, demonstration and technology transfer necessary to make wind energy systems cost-effective for utility use and stand-alone power applications."

Facility Description:

- Located 5 miles south of Boulder, Colorado
- Occupies 280 acres
- Comprised of 9 separate research facilities

NWTC Test Site

Research and Test Capabilities:

- 16 individual turbine test sites
- 4 MW utility feed capability
- 60 m/s peak wind speed; 4 m/s average

Status:

- Operational - Dedicated by Secretary O'Leary on October 25, 1994.

NWTC Research Center

Facility Description:

- Research, administration and technical support
  - ⇨ 60 + full time staff
  - ⇨ 20 + visiting professionals and students
- Current space configuration
  - ⇨ 4,900 sq. ft. research and laboratories
  - ⇨ 17,100 sq. ft. office

Research Facilities:

- High bay blade test facility
- Power electronics laboratory
- Computer resource center

Research and Test Facilities

- NWTC Research Center
- Industrial User Facility
- Hybrid Power Test Facility
- Blade Structural Test Facilities
- Advanced Research Turbine
- Modal Test Facility
- Dynamometer Test Facility
- Meteorological Calibration and Test Site
- Computer Resource Center

National Renewable Energy Laboratory

Industrial User Facility

Objectives:

- To build and operate a laboratory facility at the National Wind Technology Center designed to facilitate cooperative wind energy research between NREL and the U.S. Wind Industry.

Facility Description:

- New 12,000 sq. ft. (1115 sq. m.) Laboratory Facility
- 130 ft (39.6-m) by 30 ft (9.14-m) Highbay Area with 35 ton (31,818 kg) Bridge Crane
- 2 high Capacity 4,000,000 ft-lb Test Bases (5,400,000 N-m)
- 2 Private Industrial User Bays
- Wood Working and Machine Shops
- Turbine Teardown and Assembly Area
- Hydraulic Power and Control Rooms
- Instrumentation Laboratory
- Private Office Space for Industrial Users

Industrial User Facility, con't

Research and Test Capabilities:

- Static and Fatigue Testing of Wind Turbine Blades up to 30 M
- Instrumentation Calibration
- Test Turbine Staging
- Turbine Setup and Spin Bay
- Turbine Component Fatigue Testing
- Certification Activities

Status:

- Detailed Architectural Design Complete
- Construction Bidding Process is Underway
- Anticipated Completion in April 1996.

Structural Test Facility

Objectives:

- To maintain and operate a high quality structural test facility to evaluate and verify commercial wind turbine blades for the U.S. Wind Industry.
- To perform selected research activities on composite wind turbine blades and blade components to advance the development of wind rotor technology.

Facility Description:

- Two Separate Operating Facilities
- Two Blade Test Stands
- Closed-loop servo-hydraulic systems
- State-of-the-art Data Acquisition System using LabView Software
- Large Highbay clearance for large deflections
- Trained staff with over five years of experience testing blades.

Structural Test Facility, con't

Research and Test Capabilities:

- Static Strength Testing
  - ⇨ Blades up to 20-m
  - ⇨ 1,000,000 ft-lb (1,350,000 N-m) moment capacity
  - ⇨ 30,000 lb (13,636 kg) hoist
- Blade Fatigue Testing
  - ⇨ Blades up to 25-m
  - ⇨ Hydraulic Actuator Force to 28 kip (12,727 kg)
  - ⇨ Actuator Displacements from 0 to 40 inches (0 to 1.02 m)
  - ⇨ 75 gallons per minute (288 liters per minute) flow capacity.
- Photoelastic Stress Analysis
- Non-Destructive Evaluations (Acoustic Emissions, Ultrasound)

Status:

- Two facilities are currently operating at NREL.
- The development of a new test facility at the Industrial User Facility Eight blade tests were performed during 1995 fiscal year.
- Thirteen blades tests are scheduled for fiscal year 1996.

Hybrid Power Test Bed

Objectives:

- In collaboration with industry, develop & test new power system approaches that will improve performance & cost-effectiveness
  - ⇨ component dispatch/control
  - ⇨ innovative components
  - ⇨ advanced system configurations
- Provide a system development user facility for US industry and provide a hands-on training facility for foreign nationals

Facility Description:

- Real & simulated village loads (both resistive and reactive)
- Real & simulated wind (DC & AC) and PV, for repeatable testing
- Capability up to 100 kW loads
- Central PC-based data acquisition & control system with graphical interface
- Allow for rapid reconfiguration of the facility

NREL National Renewable Energy Laboratory

Hybrid Power Test Bed

Research and Test Capabilities:

- Characterize performance - energy delivery & fuel consumption
- Demonstrate full operating range and overload conditions
- Exercise alarm & system protection functions
- Determine power quality, harmonics, dynamic response to transients / surges
- Examine low power factor (down to 0.5) and phase imbalance
- Test control schemes, hardware and software

Status:

- New World Village Power 50 kW system delivered, installed and commissioned in March, 1995
- Test Bed construction underway August, 1995

National Wind Technology Center

National Renewable Energy Laboratory

Advanced Research Turbine

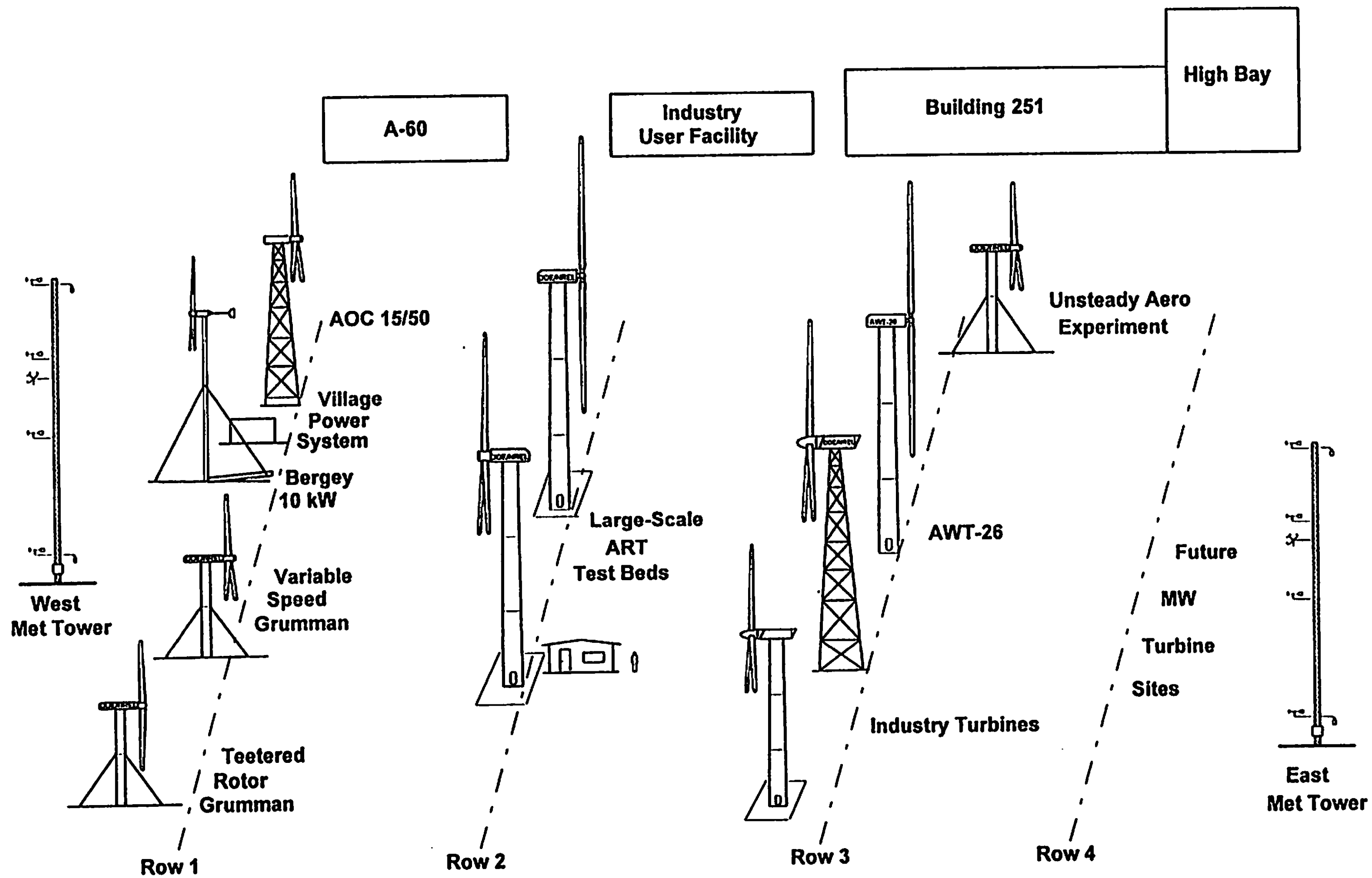
Objectives:

- Full-scale wind turbines which can be used for:
  - ⇨ Advanced component development testing on promising technology
  - ⇨ Research testing to improve fundamental understanding of wind turbine technology
- Rugged, heavy-duty experimental turbines
  - ⇨ Test rotors and power trains
  - ⇨ Diverse operational conditions

Facility Description and Test Capabilities:

- Multiple full-scale turbines
- Various configurations and sizes
- Test bed turbines
- Modified and instrumented as needed for testing
- Return to normal operation after tests

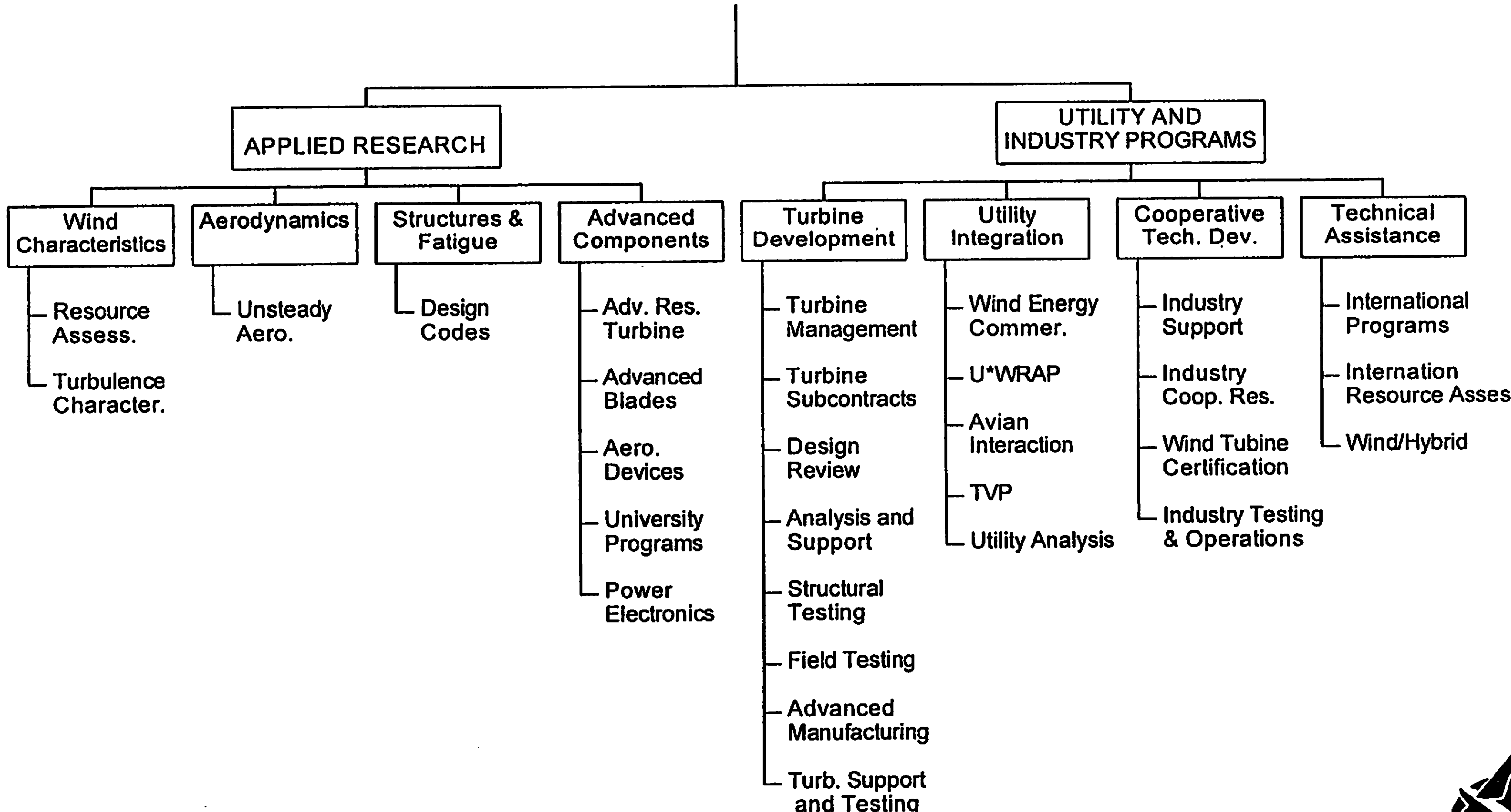
National Renewable Energy Laboratory



National Wind Technology Center

National Renewable Energy Laboratory

Wind Energy Division



Applied Research

Objectives: Identify, develop, validate and transfer the technology necessary to support US wind industry's development of utility class turbines with COE's < 4¢ / Kwh.

Approach:

- Identify critical technologies with substantial COE impact potential.
  - ⇨ Internal technology assessment
  - ⇨ AWEA technical advisory committee
  - ⇨ Strong industrial interactions through the turbine development program
- Coordinate current and future NREL and SNL research activities and align projects in support of these critical technologies.
  - ⇨ Fundamental research of basic science issues
  - ⇨ Design tools for advanced turbine development
  - ⇨ Proof of concept development and test activities
  - ⇨ Test and validation of new designs and concepts

Cost of Energy

$$COE = \frac{TSC \bullet \sigma_{TSC} + BSC \bullet \sigma_{BSC} + O\&M \bullet \sigma_{O\&M} + LRC \bullet \sigma_{LRC}}{AEP \bullet \eta}$$

$$COE \approx \quad 3.2 \quad 0.65 \quad 1.0 \quad 0.1 \quad \Rightarrow \quad 5.0\ ¢ / Kwh$$

AEP - Annual Energy Production

TSC - Turbine System Cost

BSC - Balance of Station Cost

O& M - Operation and Maintenance

LRC - Levelized Replacement Cost

σ - Cost Reduction Factor

η - Conversion and Energy Capture Efficiency

AEP Efficiency Factors (η)

		Current Designs	Variable Speed	Direct Drive	Insensitive Blades	Low Wt. Blades	Low Wt. Towers
Blade	B	75	75	75	85	75	75
Optimal Cp Operation	Cp	80	99	99	80	80	80
Generator	G	95	95	95	95	95	95
Power Electronics	PE	95	95	95	95	95	95
Transformer	Tf	98	98	98	98	98	98
Mechanical	M	98	98	98	98	98	98
Control System Losses	CS	95	95	95	95	95	95
Array Losses	Ary	95	95	95	95	95	95
Collection System Losses	CS	98	98	98	98	98	98
Availability Losses	Av	98	98	98	98	98	98
	Tot	45	56	56	51	45	45
	(% Inc)	0.0	23.8	23.8	13.3	0.0	0.0

TSC Reduction Factors (σ)

		Current Designs	Variable Speed	Direct Drive	Insensitive Blades	Low Wt. Blades	Low Wt. Towers
		% Turbine Cost	Multiplication / Reduction Factors				
Rotor	R	20	1	1	1	0.6	1
Low Speed Shaft	LSS	3	1	1	1	1	1
Drive Train	DT	24	1	0	1	1	1
Nacelle	N	3	1	1	1	1	1
Electrical	Elec	11	1.5	1.5	1	1.5	1
Instrumentation	Inst	17	1	1	1	1	1
Tower	Twr	22	1	1	1	1	0.5
	% Cost	100.0	105.5	81.5	100.0	95.5	89.0

COE Reductions: ¢/Kwh

		Current Designs	Variable Speed	Direct Drive	Insensitive Blades	Low Wt. Blades	Low Wt. Towers
Turbine System Cost	TSC	3.25	2.77	2.14	2.87	3.10	2.89
Balance of Station Cost	BSC	0.65	0.53	0.53	0.57	0.65	0.65
Operation & Maintenance	O&M	1.00	0.81	0.81	0.88	1.00	1.00
Levelized Replacement Cost	LRC	0.10	0.08	0.08	0.09	0.10	0.10
	Tot	5.00	4.18	3.55	4.41	4.85	4.64
	(% Decrease)	0.0	16.3	28.9	11.8	2.9	7.2

Preliminary Technology Assessment

- No single technology development program will achieve COE's < 4¢/Kwh.
- Greatest COE impacts obtained from increased energy capture & conversion efficiency.
  - ⇨ Low speed direct drive
  - ⇨ Variable speed control for Cp optimization
  - ⇨ Increased rotor blade efficiency
- Lighter-weight machines are still necessary to reduce manufactured costs and COE.
  - ⇨ Dynamically active
  - ⇨ Require real time monitor and control

Preliminary Technology Assessment, con't

- Peak power transients & 30 year fatigue life predictions - the great unknown !
  - ⇨ Extended turbine operation and performance data do not exist
  - ⇨ Component cycle load data do not exist
  - ⇨ Composite material performance prediction just beginning
  - ⇨ Stochastic inflow environment and fatigue response being quantified
  - ⇨ Unsteady aerodynamic effects under investigation

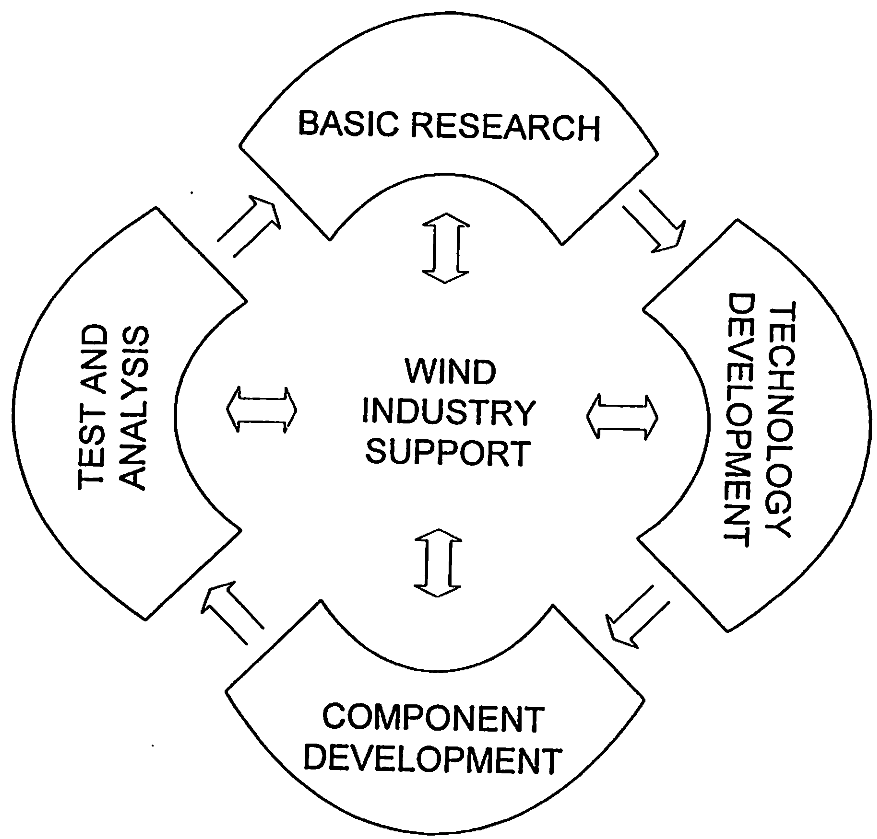
NREL National Renewable Energy Laboratory

Research Opportunities

- Increased energy capture at low wind velocities: larger rotor diameters.
  - ⇨ Shed peak power at high velocities
  - ⇨ Passive and active load control through vorticity dissipation
  - ⇨ Adaptive structures
- Rated power operation in high stochastic winds.
  - ⇨ Stalled rotor designs subject to large load transients
- Integrated controls & systems analysis.
  - ⇨ Floquet analysis
  - ⇨ Rotational mode analysis
- Self-diagnostic "Smart" turbine designs.
  - ⇨ Acoustic and vibration signature determination
  - ⇨ Active monitoring and control for maximum COE in stochastic inflows

NREL National Renewable Energy Laboratory

Technology Transfer



National Wind Technology Center

Applied Research Activities

BASIC RESEARCH

- ✓ Aerodynamics
- ✓ Inflow Characterization
- Materials
- Power Electronics
- Structures and Fatigue
- (University Programs)

TECHNOLOGY DEVELOPMENT

- ✓ Design Codes
- Controls
- Flexible Structure Designs
- Integrated Systems Analysis
- Reliability
- Adaptive Structures ("Smart")
- ✓ Variable Speed

COMPONENT DEVELOPMENT

- ✓ Advanced Blades
- Aerodynamic Devices

Subcontractor Supported Research

- Variable Speed
- Blade Dynamics
- Stall Flutter
- System Dynamic Response
- Aerodynamic Devices
- Acoustics

Turbulence Characterization

Objectives: Establish The Casual Relationships Between 3-D Turbulent Inflow Structures And Wind Turbine Response In Order To Develop Engineering Design Guides For Increased Energy Capture And Reduced Fatigue Loads.

Approach:

- Develop a generic experimental capability to acquire long-term load spectra and turbulent inflow scaling parameters from turbines operating in diverse environments.
- Conduct preliminary cycle load and inflow scaling investigations to validate experimental methods.
- Retrofit several identical turbines at different site locations with standardized data acquisition hardware.
- Establish relationships between the shape parameter of the statistical distributions for high load cycle stresses and turbulent scaling inflow parameters.

Turbulence Characterization, con't

Status:

- Loads/inflow proof of concept based on Somat ® measurement system complete.
- Measurement system under evaluation on the Bergey Excel-S turbine at NWTC.
- Analysis of European and San Gorgonio loading spectra using Wisper protocol presented at ASME WETC '95 conference.
- Predicted fatigue damage using Wisper on San Gorgonio load data presented at Wind Power '95.

Future:

- Standardized Somat ® measurement system for remote site data acquisition.
- Correlate analytic models with experimental field data.

Unsteady Aerodynamics

Objective: Mitigate the 3-D unsteady aerodynamic response of rotor blades to stochastic inflows in order to expand turbine operation envelopes and reduce fatigue loading.

Approach:

- Quantify the steady and unsteady aerodynamic response of rotor blades operating in a stochastic inflow environment.
- Derive semi-empirical analytic models to predict transient rotor loads from the unsteady aerodynamic inflow response.
- Devise methods to mitigate the transient load response through active and passive vorticity (aerodynamic control).
- Characterize 3-D rotational effects.
- Provide data and instrumentation support for industry and university research.

Unsteady Aerodynamics, con't

Status:

- Rectangular blade tests complete & data reduced.
- Dynamic stall "phenomenology" identified as the principal source of peak transient loads.
- Twisted rotor characterization tests 75% complete.

Future:

- Wind tunnel tests in 80'x120' facility at NASA Ames - FY96.
- Twisted blade teetered rotor tests - FY97.
- Preliminary wind tunnel tests of passive vorticity control methods - FY96.

Design Codes

Objectives: Develop, validate and support the structural dynamic tools and design guidelines needed by US turbine developers for the design and evaluation of flexible turbine systems driven with interactive control systems.

Approach:

- Develop new modal and stress analysis tools based on finite element methods that are capable of rotating frame analysis.
- Enhance existing dynamics modeling codes with integrated aerodynamic loads and control systems analysis capabilities.
- Use existing analysis methods to evaluate advanced structural blade designs.

Design Codes, con't

Status:

- Updates and enhancements currently under contract for:
  - ⇨ Adams/WT
  - ⇨ AeroDyn
  - ⇨ FAST
- Code validation continuing for enhancement activities.
- Preliminary report of mass distribution effects on dynamic rotor response presented at ASME conference.

Future:

- New FEA code for rotating mode analysis derived from existing helicopter rotor dynamics model.
- Initiate design guide development programs for advanced turbine systems.
- Conduct flexible rotor dynamic response experiments for targeted code validation efforts.

Advanced Blades

Objective: Support the development of low cost, aerodynamically optimized, structurally superior, blades for HAWTs.

Approach:

- Develop new analytic methods to predict rotor and blade performance in various operating environments.
- Design new airfoils with optimized blade geometries for enhanced energy capture using stall regulated, variable pitch and variable speed technologies.
- Support advanced blade test and evaluation activities for new and existing wind turbine designs.

Advanced Blades, con't

Status:

- RFP for 12-21 meter blade (250-600 kW) development program released May 12, 1995.
- Wind tunnel tests of S824 and SNL2150 scheduled at Penn State and Ohio State University.
- Tip loss modeling, blade icing, and airfoil characteristics definition for stall regulated and variable speed operation under development at University of Illinois.

Future:

- Develop improved post-stall prediction method.
- Refine Eppler code for improved laminar bubble drag and clean climax rough airfoil surface performance prediction.

Variable Speed

Objectives: Develop the power generation, power electronics, electronic control systems and control algorithms necessary to test and analyze variable speed and direct drive technology.

Approach:

- Develop a permanent magnet motor capable of low speed direct drive operation.
- Develop state of the art rectifier and inverter for variable speed operation.
- Develop, model and test control algorithms for maximum energy capture.
- Test integrated system in a controlled environment to establish base-line performance.
- Test integrated system in field operations to evaluate energy capture potential.

Variable Speed, con't

Status:

- Permanent magnet generator under dynamometer test at NWTC.
- Power rectifier 90% complete - awaiting large capacity transistors.
- Power inverter complete and tested to 30 kW.
- Integrated system control algorithm modeling near completion.

Future:

- Integrated systems dynamometer test in May, '95.
- Integrated systems field test in September, '95.

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Current R&D Needs in Wind Energy Technology

P Jamieson, Garrad Hassan & Partners Ltd

1 Introduction

Some examination of present research, with a view to identifying future areas of interest, is presented broadly under the following main headings.

- Highlights of Current Research Projects;
- Future Research Areas.

2 Current Research Projects

In recent years, Garrad Hassan have been involved in work in the following areas:

- High lift aerofoil development;
- Advanced wind turbine design;
- Yaw bearing development;
- Air brake development;
- Mechanical variable-speed systems;
- Electrical variable-speed systems;
- Direct-drive generators;
- Switched reluctance generators;
- Electrodynamic braking;
- Network integration.

This list is by no means comprehensive, but it gives a fair indication of the range of work and also some key areas of technology development.

High Lift Aerofoil Design

Garrad Hassan have been engaged in two projects funded by the Department of Trade and Industry in the UK on the development of high lift aerofoil designs. At present, two new high lift aerofoils, designed mainly using the code XFOIL, are being wind tunnel tested at Imperial College, London. Of these two aerofoils, one is essentially a turbulent flow aerofoil, a development of the NASA LS types that have been used in wind turbine operation, and the other, a more radical design of laminar flow aerofoil with extremely high lift to drag ratio. In each case, the focus has been on producing satisfactory performance in various degrees of roughened conditions, as well as in essentially smooth conditions. Figure 1 presents results from a high lift design showing how the lift to drag ratio varies with design lift coefficient. As optimum rotor designs have a predetermined resultant lift distribution, a higher lift coefficient is associated with lower solidity, i.e. a smaller value of the local blade chord width. What Figure 1 shows is that, in the trade-off between design lift coefficient and, hence, chord width and Reynolds number, with appropriate aerofoil design there can be great latitude for the structural design engineer. Designs A and B correspond to very substantial difference in blade chord width or in rotor solidity, but will have an essentially identical performance in terms of the energy capture.

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Advanced Wind Turbine Design

Figure 2 shows the compact integrated drive-train arrangement of the Carter 300 wind turbine. This is a particularly lightweight and flexible wind turbine and designs such as this have had influence in suggesting that a greater exploration of lightweight, structurally flexible design would be advantageous in cost reduction of wind turbines. This led to a project funded by the UK Department of Trade and Industry (DTI) to examine advanced wind turbine design. In the course of this project, Garrad Hassan looked at a number of possible developments and, as the project evolved, found basic themes for cost reduction of wind turbines as follows;

- flexible structures aimed at reducing loads/weights/costs;
- more adaptive design - increase the ratio of energy output to design driving loads;
- increase in the ratio of energy collection area to system volume - multi-rotor systems.

At an early stage of examining the issue of flexible structures, inspired by the Carter machine, the structural flexibility in the blade was approximated by a blade root hinge with variable stiffness. As this analysis proceeded, a completely different idea was suggested. Instead of allowing the usual limited flexure of the rotor, what if the rotor blades were allowed to fold up, coning to angles of the order of 80° to substantially shed the loading that results in extreme winds. As this loading may often dominate the design and costs of machines, it was in that context that this was considered a more adaptive design. For a given rated output, one could initially start with a rotor of larger diameter using the capability of the blades to hinge to subsequently protect the rotor and the tower system from load increase in high winds. Thus, the ratio of energy output to design driving loads had been increased with this concept. Garrad Hassan have no interest in manufacturing in their own right, and this whole project in which a new design - the CONE-450 wind turbine - has been developed is a research project with results open to exploitation by interested industrial parties.

Figure 3 shows a system layout under consideration for the CONE-450 wind turbine design and Figure 4 a more advanced version relying on a direct-drive generator. In Figure 5, the essential concepts of how extreme loading reduction can allow both longer blades and a higher tower, with obviously large advantages in energy capture, are illustrated.

After completion of an initial project showing the outline concepts and the essential promise of the CONE-450, a further project is in progress at present in which very detailed dynamic modelling and evaluation of engineering safety and cost benefit is in progress.

A different theme for cost reduction which has been mentioned was the increase in ratio of energy collection area to system volume. This is realised in principle in a multi-rotor system. Figure 6 shows an example of such a system that was engineered by Lagerwey. In the course of the first Garrad Hassan study on advanced wind turbine design, these concepts were investigated. In Figure 7, for the same given energy output, comparisons are made between a conventional single rotor wind turbine of 1.4 MW and the same output realised by a multi-rotor system of up to 20 rotors. Because of the relationships between torques, volume and costs, it is apparent that gearboxes for 20 rotors amounting to 1.4 MW of capability at generator output are much cheaper than for a single large system.

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P Jamieson, November 1995

Generator costs are more or less constant per kilowatt and independent of the number of rotors, but the wind turbine rotor and blade costs, again, are substantially reduced with a multiplicity of small blades capable of the same energy capture as a single large rotor. The multi-rotor system as compared to a wind farm of medium sized machines has advantages in concentrating construction access and maintenance in one location. Its modular approach allows greater mass production of standard components and a system that could possibly allow self-erection techniques.

Cost analysis from the project conducted suggests that such systems may have a cost benefit compared to conventional single rotor installations. The aspect of land utilisation must be quite favourable and possibly a critical issue is whether such a system will be acceptable from the standpoint of visual impact.

Figure 8 gives some outline comparison of loading of the two systems and one interesting feature of the multi-rotor system is that with averaging over the structure fatigue loads are going to be much less significant. Each single rotor is in much more coherent wind. The system does not have the same capability to develop high cyclic yaw moments and overturning moments, although the net steady values will be similar to the equivalent large wind turbine.

A further area of interest in development of wind turbines is in direct-drive generators which eliminate the need for a gearbox. Figure 9 shows a system currently under development in the UK at the University of Durham. The permanent magnet generator illustrated has a simple modular construction and utilises inexpensive iron magnets. The predicted efficiency is very high and preliminary indications are that such a system will be cost-competitive with conventional gearbox and generator but may not be lighter.

Variable-Speed Systems

The industry has seen a great deal of work all over Europe on the development of electrical variable-speed systems. Garrad Hassan have been very active in many areas of such work. However, a purely mechanical variable-speed system based on a continuously variable transmission, controlled by hydraulic actuators, is illustrated in Figure 10. This system has been developed by Torotrak Ltd for the automobile market, but there is interest in examining its applicability to wind turbines.

Yaw Systems

Yaw systems are among the most problematic mechanical systems on a wind turbine as is illustrated in Figure 11. Garrad Hassan have had considerable experience of the load prediction issues for yaw systems and it is evident that the past loading, especially stochastic loading, has been seriously underestimated. It is possible that the incidence of failures in yaw systems that is evident, although high, would be much higher if many wind turbines nominally designed for Class I sites were actually exposed to those sorts of conditions - the wind climate in Denmark for example is a relatively benign one. Allen Gears, a member of the Rolls Royce Group in the UK, are working on the development of a hydrostatic bearing which may be suitable for the yaw system of the wind turbine. An overview of the essential advantages of such a bearing is given in Figure 12.

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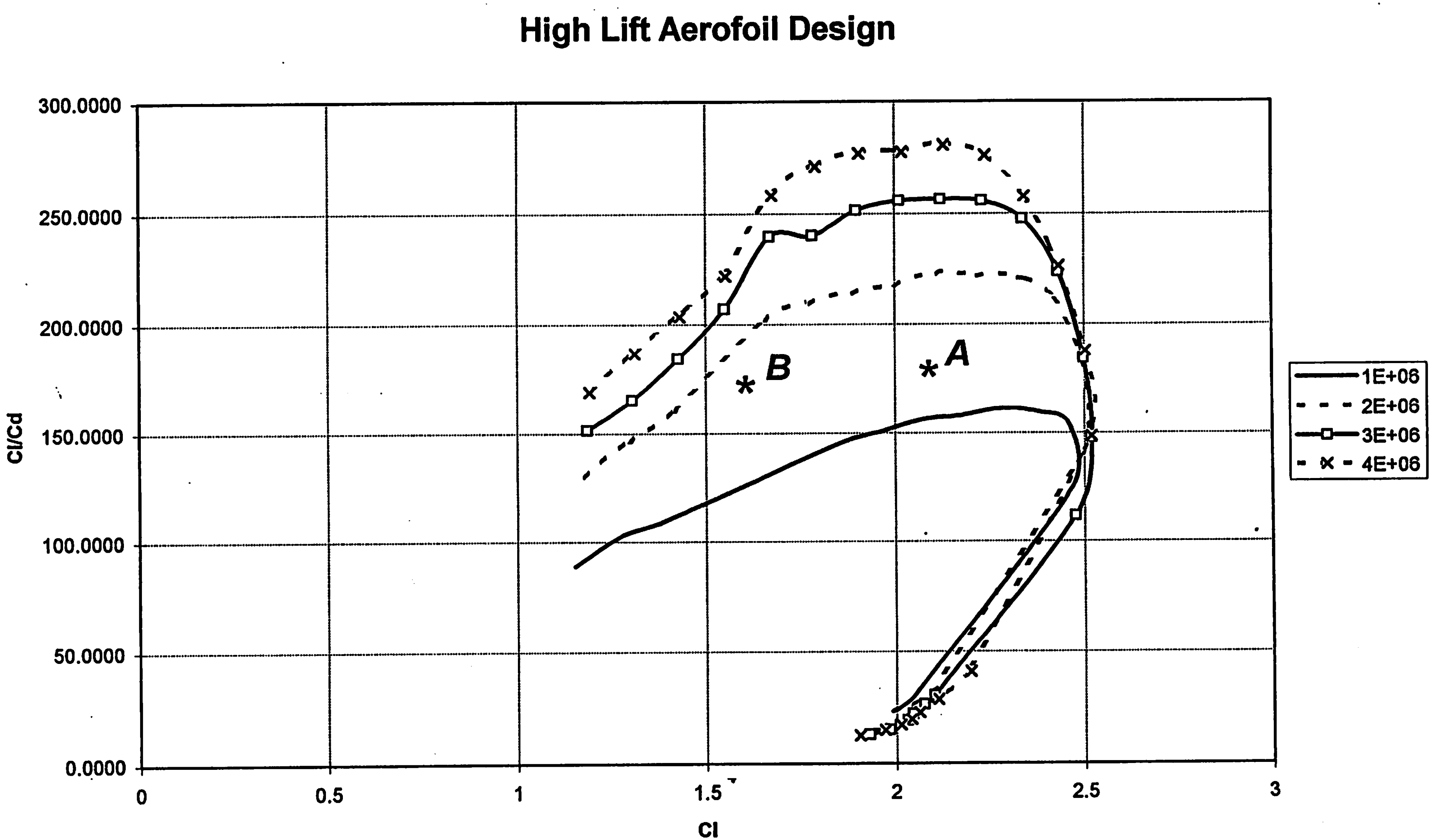
Current R&D Needs in Wind Energy Technology
P Jamieson, Garrad Hassan & Partners Ltd

3 Future Research

Summarising themes that have emerged from current work, the following areas are identified as of particular interest for future research.

- Problem areas, particularly control systems and yaw systems;
- Aiming at weight reduction through greater structural flexibility;
- Various advanced wind turbine concepts - load shedding rotors - multi-rotor systems;
- More integrated drive-trains - especially direct-drive generators.


High Lift Aerofoil Design
300.0000
250.0000
200.0000
150.0000
100.0000
50.0000
0.0000
Cl/Cd
0
0.5
1
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2
2.5
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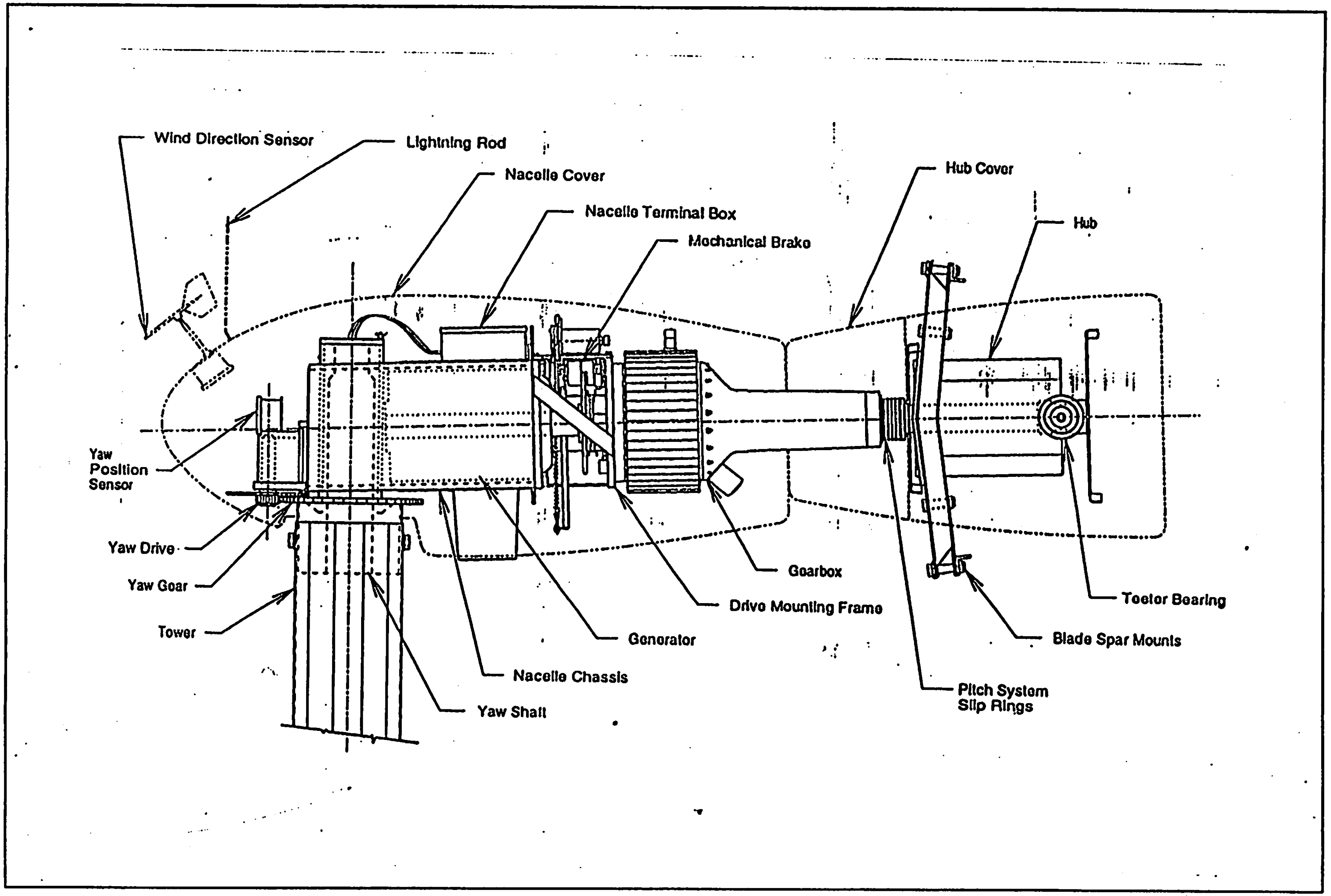
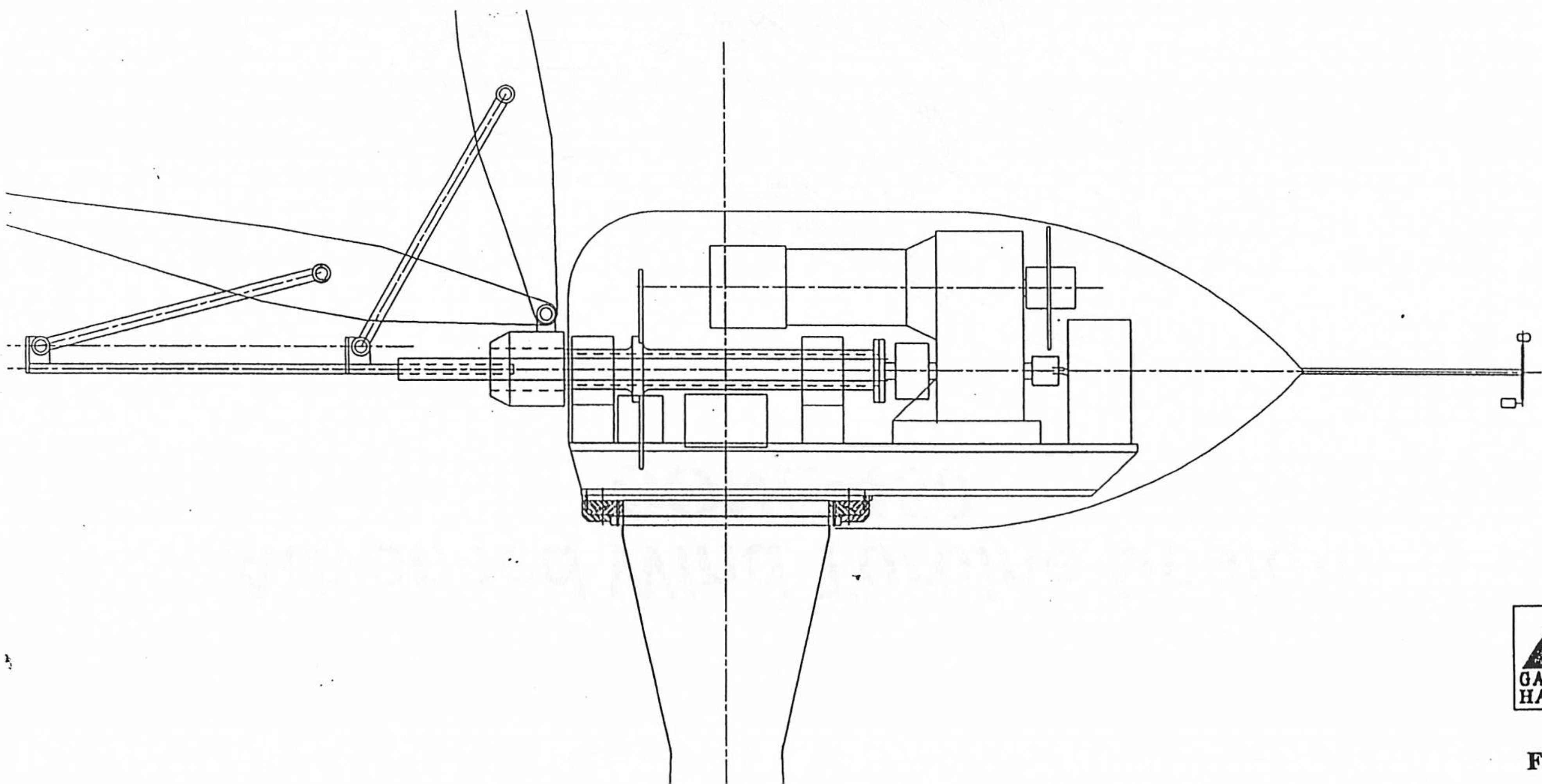
Cl
A
B
1E+06
2E+06
3E+06
4E+06

FIGURE 1



Carter 300 nacelle configuration

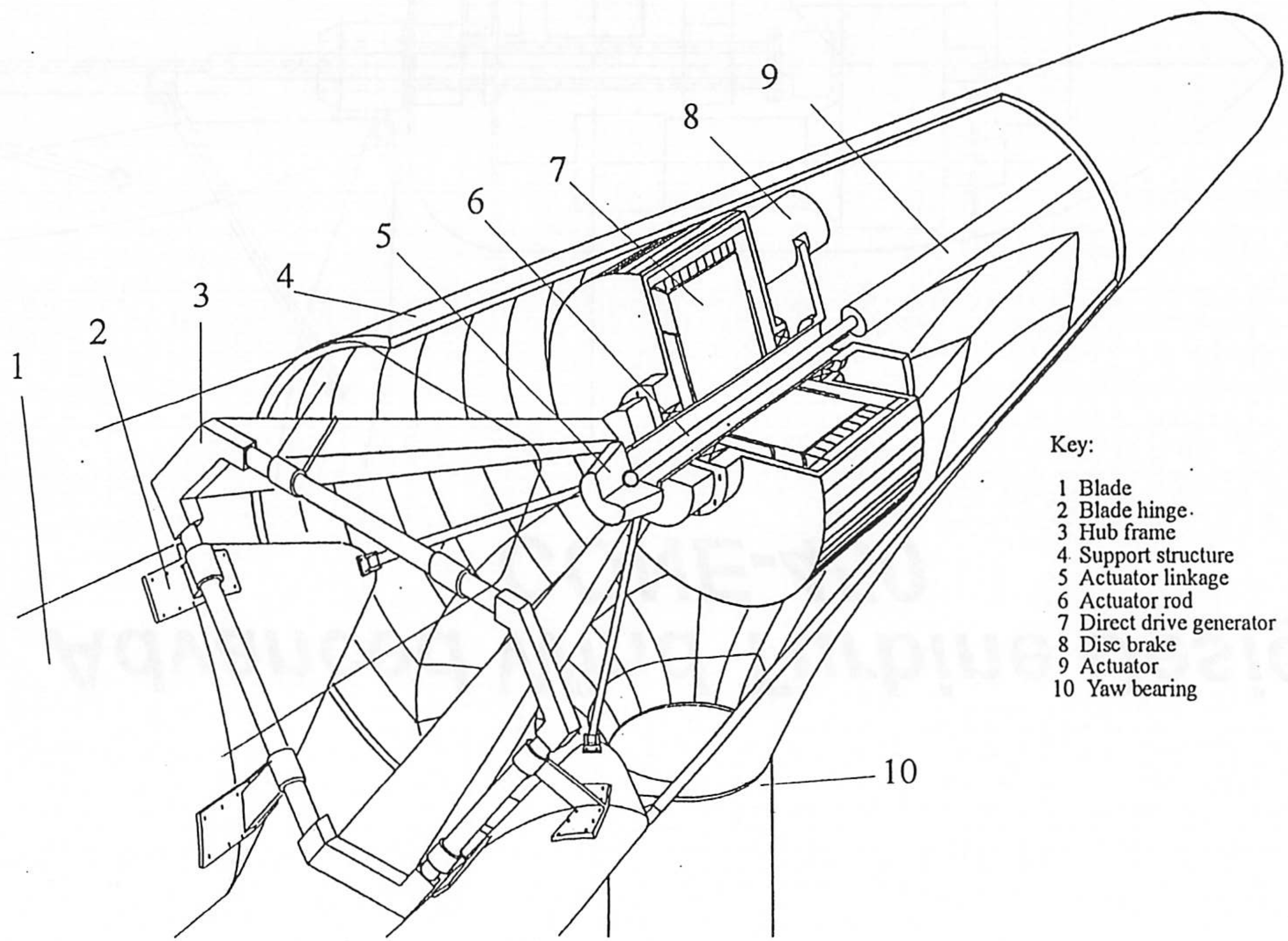
Advanced Wind Turbine Design
CONE-450



GARRAD HASSAN

FIGURE 3

Advanced Wind Turbine Design
CONE-450



Key:

1 Blade
2 Blade hinge
3 Hub frame
4 Support structure
5 Actuator linkage
6 Actuator rod
7 Direct drive generator
8 Disc brake
9 Actuator
10 Yaw bearing

GARRAD HASSAN

CONE-450 Wind Turbine

70 m/s, 5 s gust, GL Class I Site

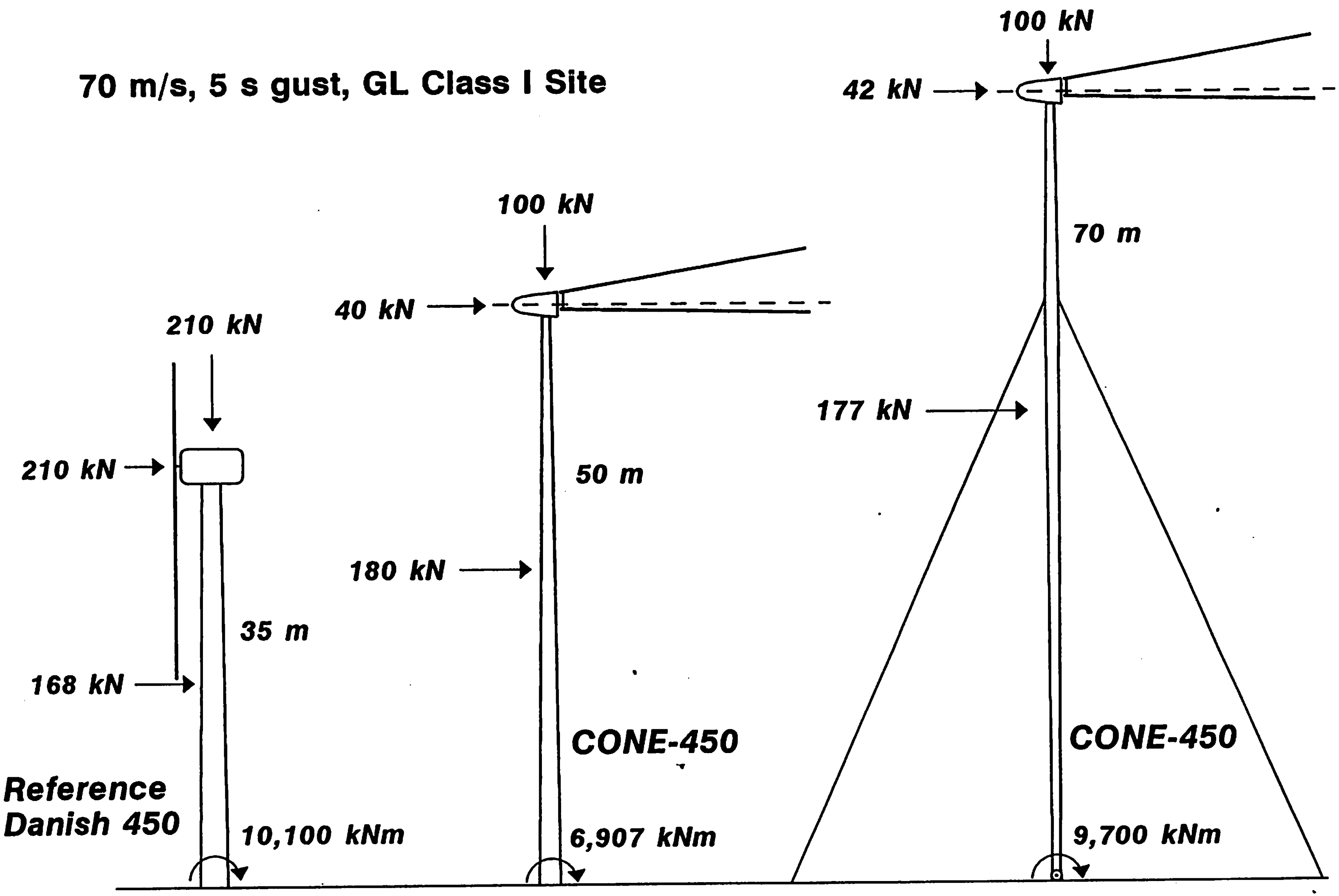
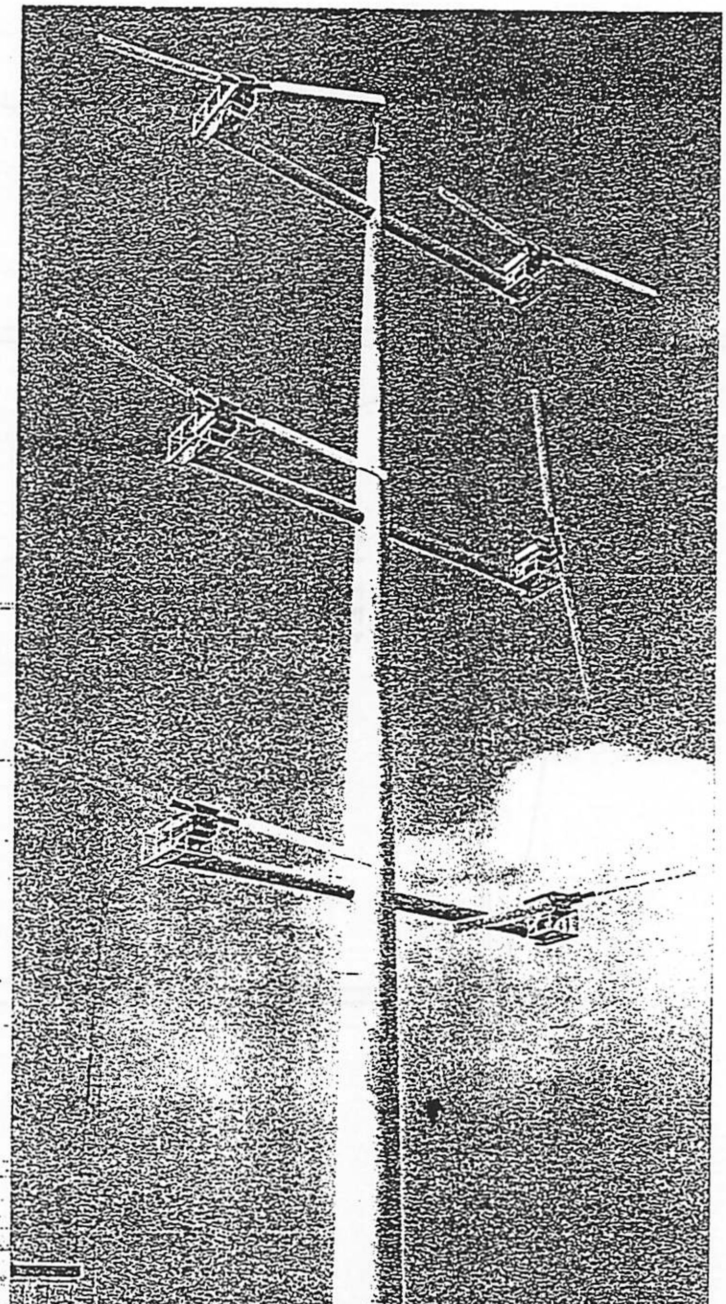
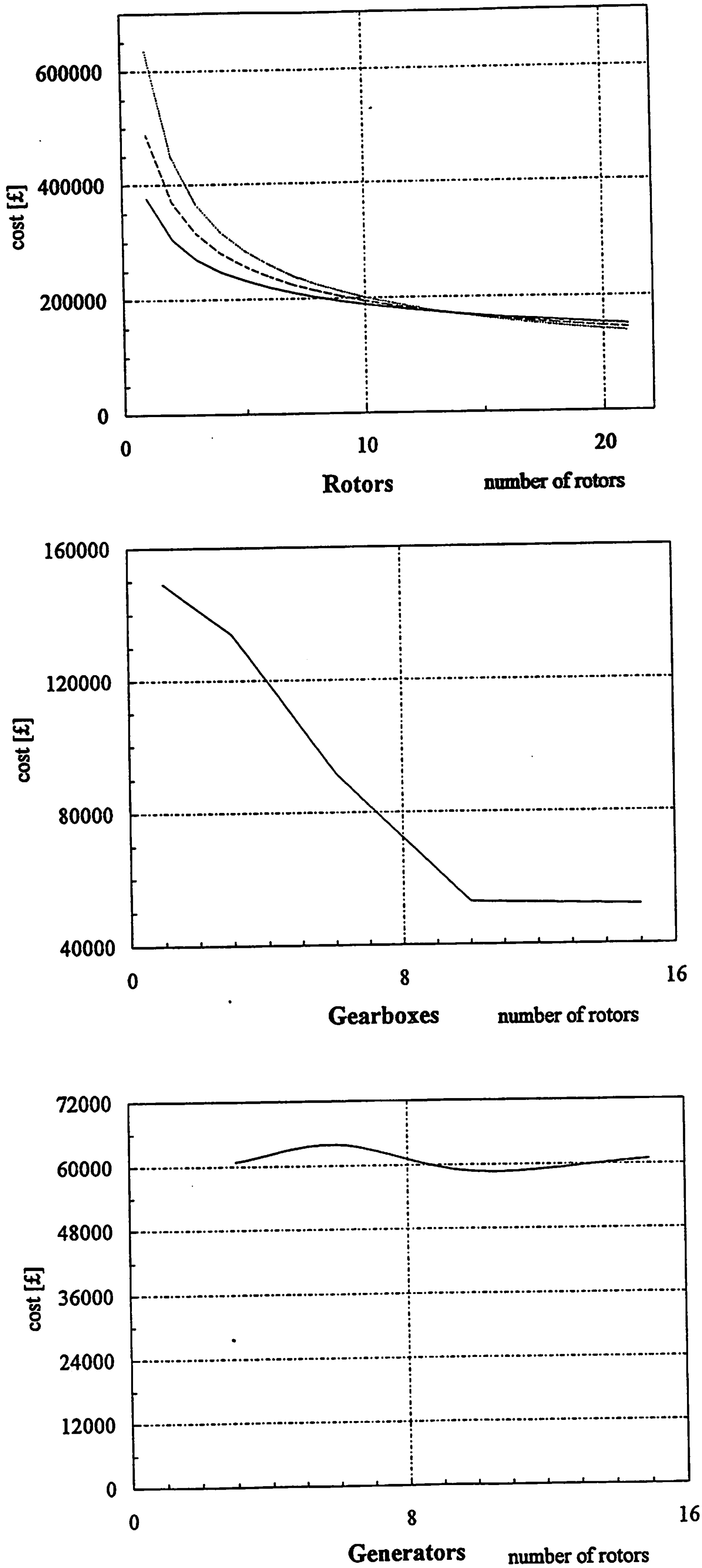


FIGURE 5



Lagerwey multi-rotor system

FIGURE 6


600000
400000
200000
0
cost [£]
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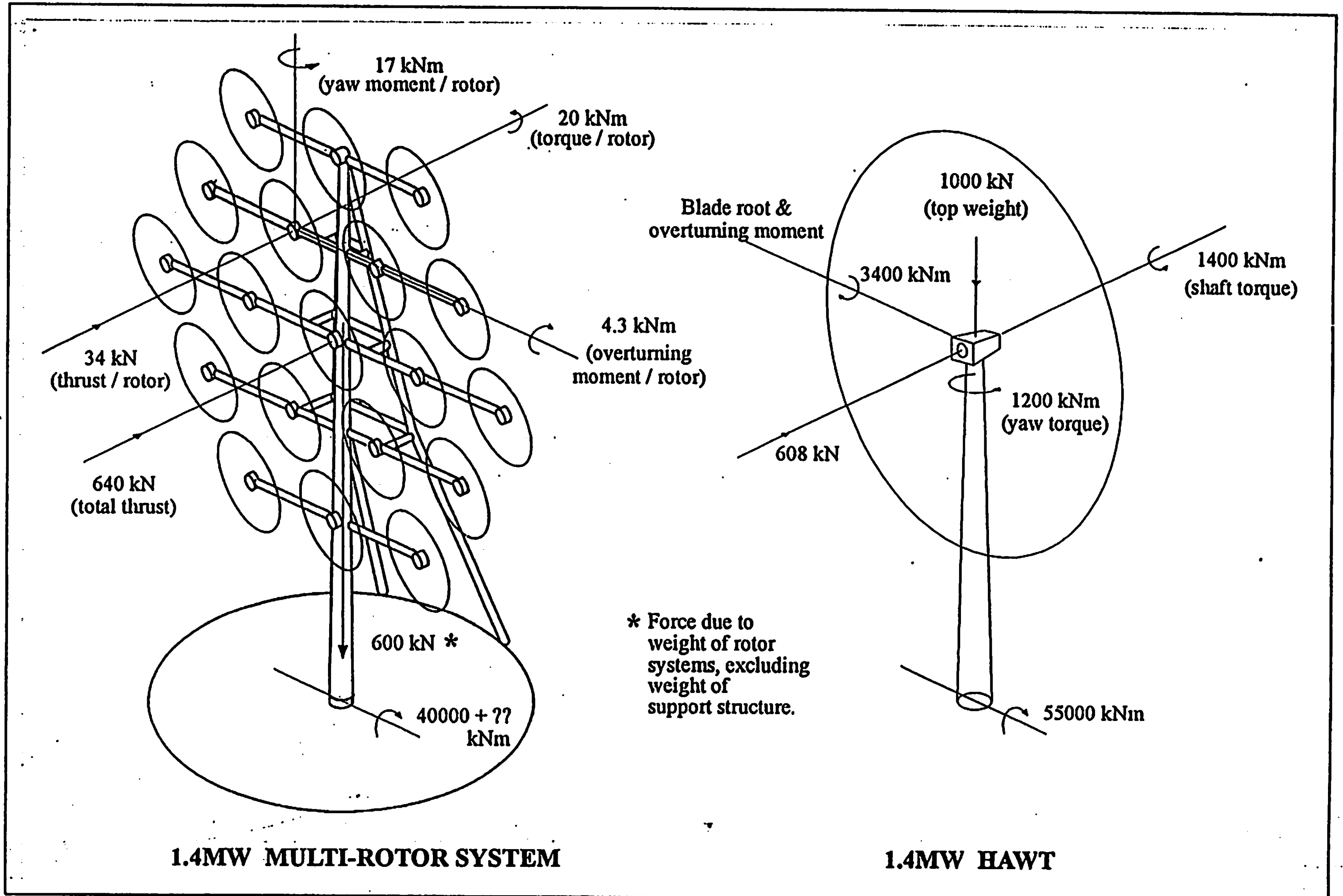
10
20
Rotors
number of rotors
160000
120000
80000
40000
cost [£]
0
8
16
Gearboxes
number of rotors
72000
60000
48000
36000
24000
12000
0
cost [£]
0
8
16
Generators
number of rotors

FIGURE 7



Comparison of loads in an extreme gust

Direct Drive Permanent Magnet Generator

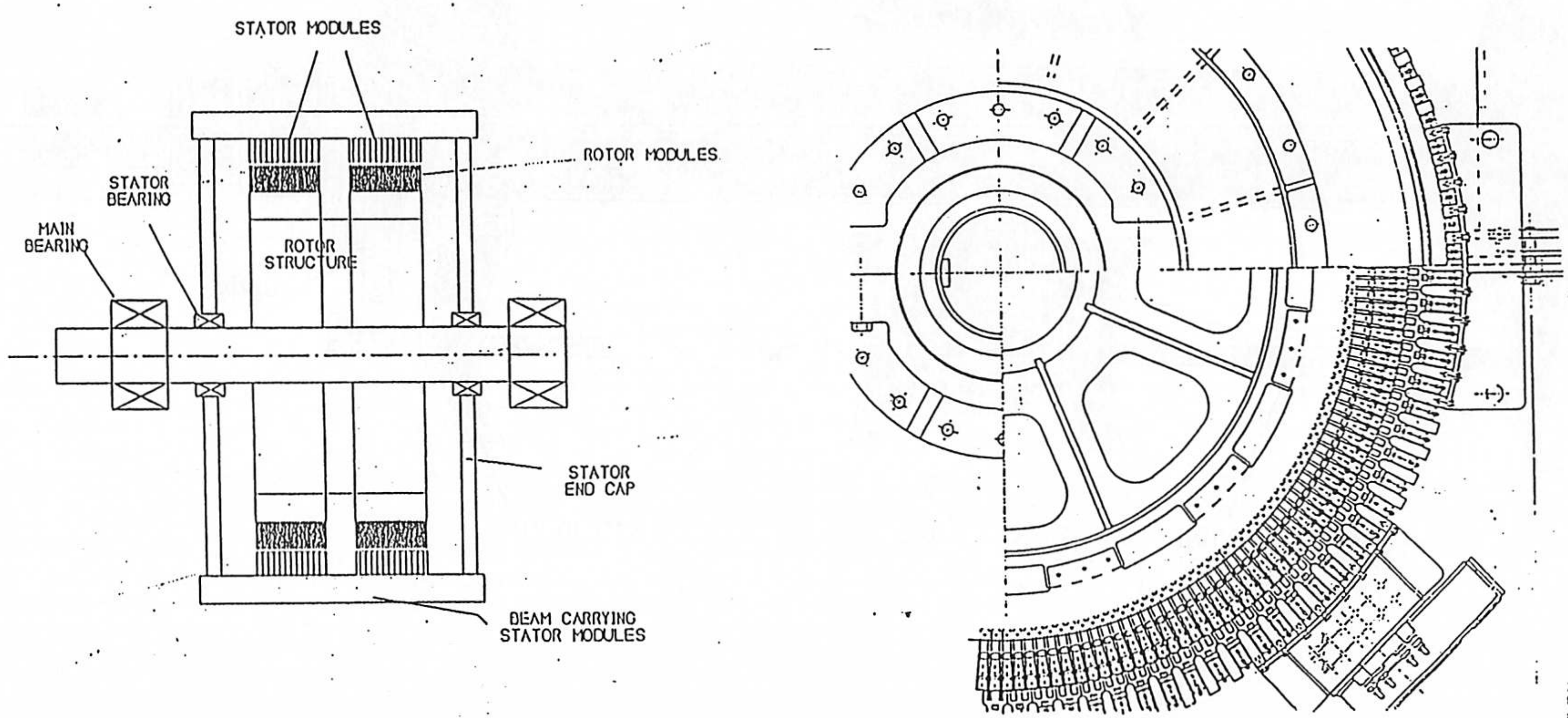
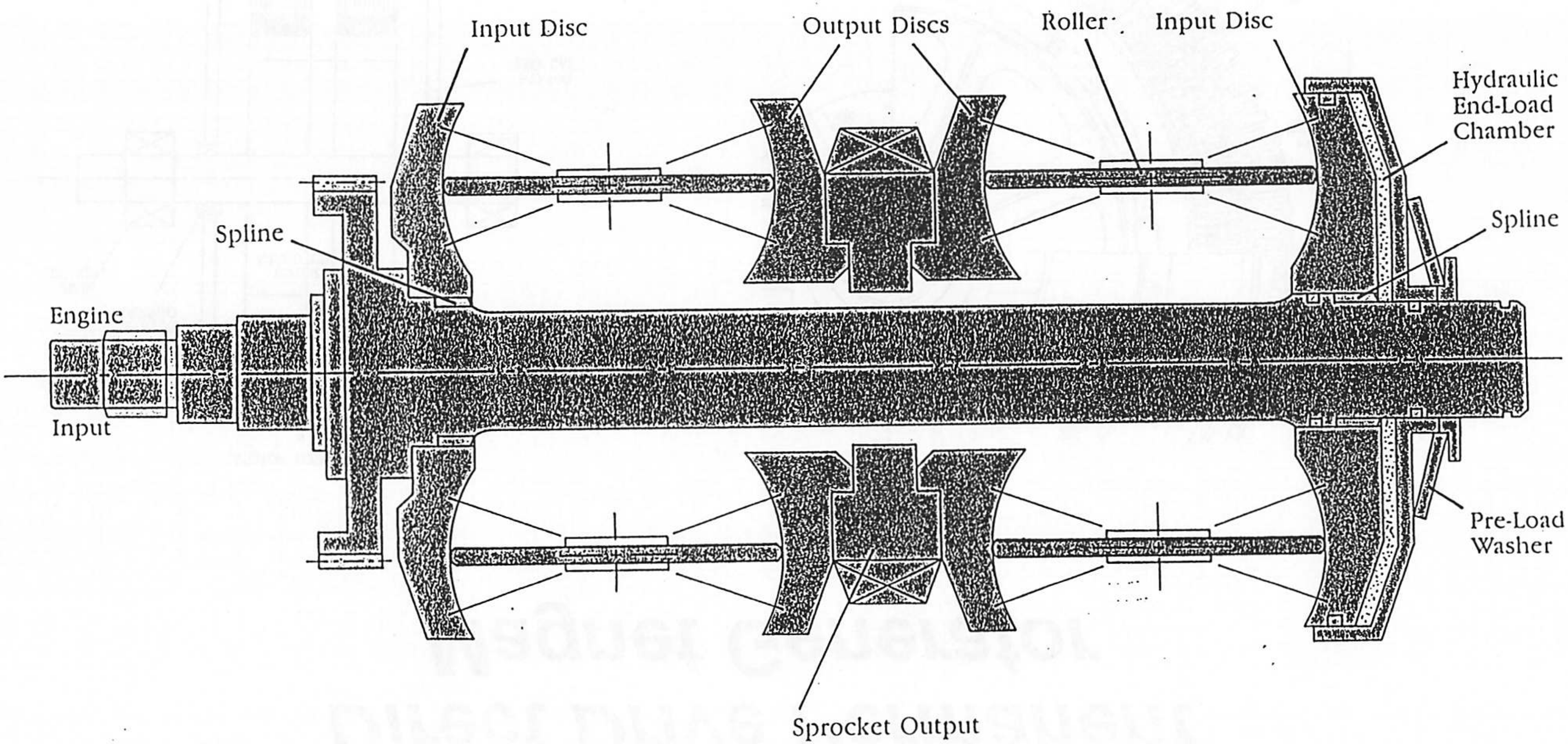


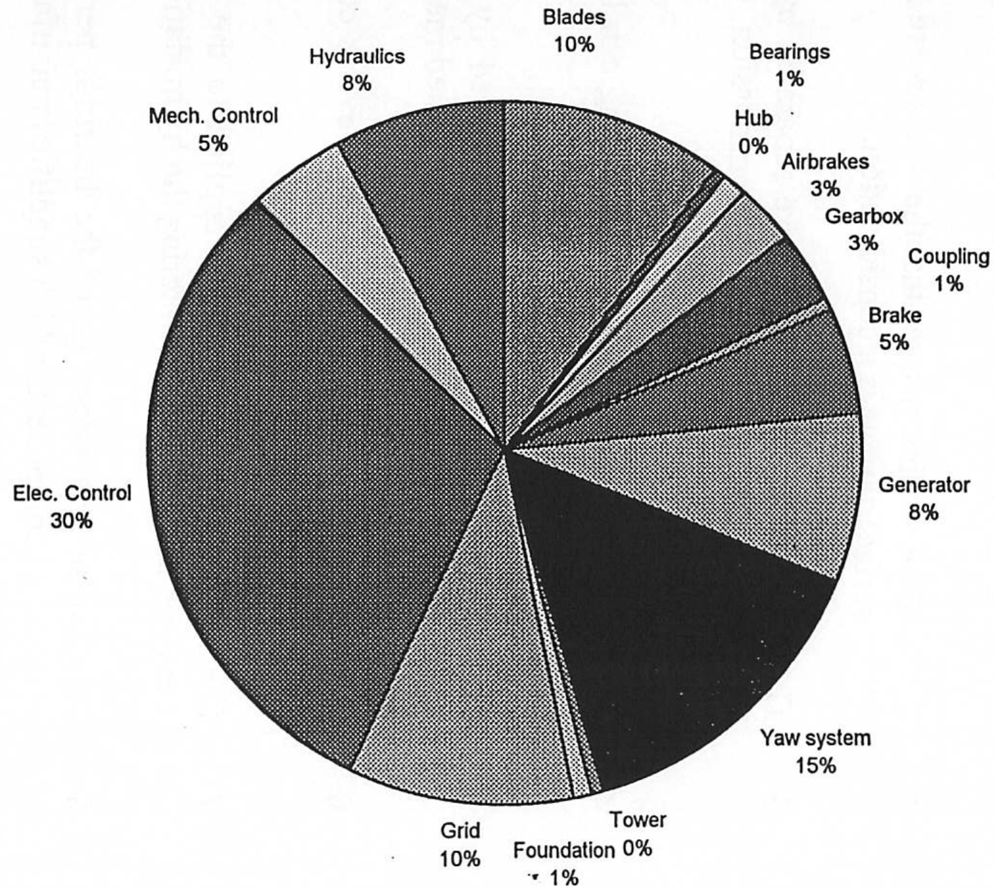
FIGURE 9



THE TOROTRAK VARIATOR

FIGURE 10

Wind turbine component failures



Results for Denmark in the first quarter of 1994

FIGURE 11

The Development of a Hydrostatic Bearing for the Yaw Control of Wind Turbine.

A hydrostatic system for supporting the dead weight and wind reaction forces of a wind turbine has a number of advantages including the following:-

1 The construction and unit loading of the bearings give very large margins of safety for static and dynamic loading.

2 The surface loading ensures that the stresses are not in the range where surface fatigue is a consideration.

3 The components of the bearing are separated by a thin film of lubricant which dampens the transmission of noise and vibration.

4 The stiffness and dampness of the bearing can be varied by its construction and the choice of lubricant.

5 Braking of the slewing system is achieved by control of the lubricant and if necessary, can be argumented mechanically.

6 The positive flow of filtered lubricant prevents contamination of the bearings and seals.

7 The service load and moments applied to the system can be measured accurately by monitoring the hydrostatic pressures.

8 The low surface stressings of the bearings permit the use of unhardened components which simplifies manufacture.

9 The resistance to movement is very small and permits the use of smaller motors and the possibility of microrotational adjustments.

INDUSTRIAL POWER GROUP
Allen Gears

FIGURE 12

Current R&D Needs in Wind Energy Technology

IEA Topical Experts Meeting

Utrecht

11-12 September 1995

Jack Noakes

Renewable Energy Systems Ltd

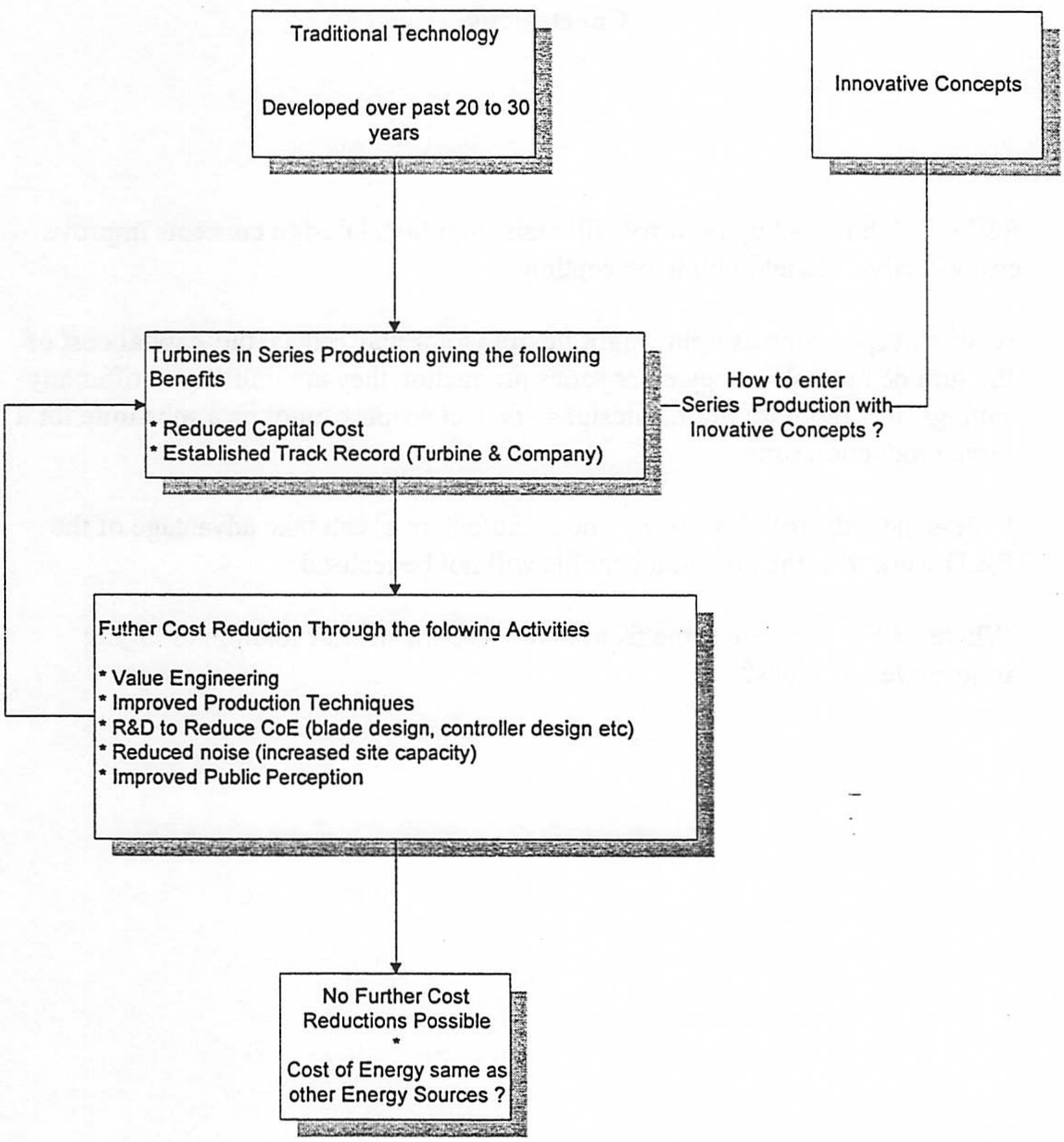
Renewable Energy Systems Ltd

- **Objectives**

  The objective of this meeting is to identify R&D tasks which will reduce the generated cost of wind energy to a level which is comparable with other sources of power generation.

  The aim of this presentation is to promote discussion on the issues relating to the more innovative design concepts and their acceptance by the wind industry (manufacturers and developers).

Renewable Energy Systems Ltd



Renewable Energy Systems Ltd

Conclusions

- R&D which is lead by industry will assist traditional design concepts improve cost effectiveness and public perception.
- New concepts, such as lightweight flexible rotor may reduce the capital cost of the turbine but unless they enter series production they are unlikely to offer any savings over more traditional designs - new concepts cannot be a substitute for a large production runs.
- Unless the industry (developers and manufacturers) can take advantage of the R&D work then the potential benefits will not be realised.
- Where will the finance come from to develop the next generation of highly innovative machines?

R&D NEEDS FOR FUTURE WIND TURBINE DEVELOPMENT (From the Swedish Horizon)

Bengt Göransson, Kvaerner Turbin AB
Sven-Erik Thor, FFA

(Presented at IEA Annex XI Expert Meeting, Utrecht 1995-09-11 - 12)

1 SUMMARY

The development of wind turbines during the last decade has produced WECS with increased economic strength. Costs for electricity generation have been decreased. However the cost per kWh is yet not down to a competitive level in many countries. In order to reduce these costs further a number of development steps have to be introduced. This paper discusses the R&D needs for such a development.

2 STATE OF THE ART

The commercial market today is dominated by stall regulated 3-bladed turbines. This generally means heavier machines with stiff dynamic properties. The concept is fairly well known and the development is characterised by a continuous increase in size. The upper size limit is yet not found even if it has been foreseen by a number of "experts" for many years.

For the 3-bladed stiff concept the main problem areas are:

- Stall behaviour with overproduction of energy and uncertainties in prediction of aerodynamics, loads etc.
- Weight increase is a growing problem as the size of the machines grows.
- No reliable way to decrease the loads.

In Sweden the development of wind energy technique started in the mid-70ies. The national wind energy programme, which has been dominating the scene, was from the initiation focused on large turbines. The activities started with design and manufacturing of the Näsudden (2 MW) and Maglarp (3MW) turbines. In the end of the 80ies the design line continued with development of Näsudden II (3 MW) and NWP 400 (400 kW) and recently the NWP 1000 (1 MW). Work is now carried out to develop both the 3 MW and the 400 kW turbines further on the way to commercial machines. Parallel to this activity focused on large wind turbines there is also a branch with a smaller concept with a self pitching rotor.

The Swedish activities have consisted of 2-bladed turbines only. The dynamic configuration alternatives were investigated early with a stiff concept for the Näsudden I and a soft design for Maglarp. The recent developed concept all covers more or less soft dynamic behaviours like variable speed, teetered rotor, flexibleyaw systems and towers as it is believed that flexibility will reduce costs in the long term.

The three manufacturers' different concepts are described in table 1.

Manufacturer	Turbine	Size	Status	Features
Zephyr		250 kW	3 machines in operation	aerodynamic pitch
Nordic Wind Power	NWP 400	400 kW	In operation	teetered rotor, variable speed, stall control, soft concept
Nordic Wind Power	NWP 1000	1000 kW	Commissioning	improved, enlarged NWP 400
Kvaerner Turbin AB	WTS 80-3	3000 kW	2 machines in operation	CRP-blades, variable/two-speed
Kvaerner Turbin AB	U III	3000 kW	Development	soft concept, direct generator

Table 1: The Swedish wind turbine development programme.

None of these manufacturers has yet reached a commercial state for their wind turbines. Sweden has both low energy prices and a surplus of energy production capacity. The integration of renewables is already about 50% as hydro power is well exploited. These factors reduce the demand for energy production capacity and gives little room for revenue when investigating in wind turbines. A national support programme has been in operation for some years and has resulted in about 60 MW wind energy. The market is to a 100% developed by imported machines. A growing problem here as well as elsewhere is the complicated procedures to find new sites. There is often a very strong local opposition when developing plans are presented. The main issues seem to be noise and visual impact.

Apart from the dominating problem of the lack of commercial activities, the most important technical problem areas are :

- Aerodynamics, particularily 3D-effects
- Aeroacoustic noise
- Meteorology

3 FUTURE CONCEPTS

It is obvious that lower energy production costs will increase the market for wind turbines. The key to lower production costs in the future will probably be the introduction of flexible and lighter concepts.-A number of innovative technical solutions will probably be seen.

Innovative technique has been realised in some prototypes currently in operation in different countries. Experience from such machines show that a number of research areas need more attention. On the other hand it can be seen that a flexible concept has the capacity of a 50% weight reduction compared with traditional designs. This will also lead to a reduction of the machine cost when the effects of weight reduction is fully utilised.

The problem and research areas coupled to the development of the new concepts are:

- Wind data and behaviour
- Design codes
- Engineering models for dynamic stall and 3D-effects
- Structural dynamic codes that can handle flexible concepts
- Flexible electric systems
- Innovative generators
- Converter system dynamics

4 NEED FOR R&D

The Swedish development line means 2-bladed rotors with a soft concept which will reduce the weight, and in the future, also the cost of the turbines. The introduction of softer and more flexible turbines however increases the need for better understanding of the dynamics. The technical problem areas have been mentioned above but will also be summarised here, but there are also more general issues where future R&D should be attended.

4.1 General needs

- Realistic norms and standards
  - Wind description
  - Windfarm operation
  - Load description
  - Extreme situations

- Development
  - Legal aspects
  - Noise

Public acceptance
Visual impact

- Lightning

4.2 R&D needs in different technical areas

- Meteorology
  - Wind description
  - Extreme wind situations
  - Complex terrain
- Aerodynamics
  - General stall behaviour
  - Dynamic stall and 3D-effects
  - Aerodynamic damping
  - Windfarm operation
- Structural dynamics
  - Incorporating new aerodynamic models
  - Flexible structures
  - Damping
- Loads
  - Ultimate and fatigue loads for flexible structures
  - Loads in norms
- Electrical systems
  - System integrated in the total flexibility
  - Direct driven generator technique
- Noise issues
  - Aerodynamic noise

4.3 Priorities

Concluded from what is said in part 2 the areas with highest priority are aerodynamics (3-D, stall), noise (aeroacoustics) and meteorology (better knowledge of wind loads, especially extremes).

IEA R&D Wind, annex XI, expert meeting on Current R&D needs in Wind Energy Technology

by

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Introduction

On the basis of the material passed forward in the invitation to this meeting some headlines are given to form a basis for a discussion. These are summarized below and originate from the overheads presented at the meeting. A few comments have been added.

It is important for the reader to know that LM Glasfiber produces a large varerity of blades for stall and pitch regulated turbines in the size from 6 meter to 29.2 meters blade length. Our view points are naturally centered around this production.

The first "slide" shows some abstract keywords, the second "slide" shows some specific suggestion for future R&D areas.

1. What do we wanna do ?

Increase Cost efficiency
Cost efficiency is probably controlled well by competition and market conditions. But, it is important to consider that the industry is growing rapidly and that many new principles may appear in the future as they become attractive to mass production for one or the other reason. Lower price and increased energy production are goals which are reached through lower material cost, low maintenance and precision handling of delicate aerodynamics. This may be achieved by a large number of actions. For the blade part, it is important to notice that lower price may entail lower weight, but that weight in itself is not an objective because lower weight for example may entail increased dynamic response, thereby complicated control requirements to the turbine. Also lowered weight do at the moment entail advanced materials which needs special attention.
A cost efficient turbine is a balanced act in the development phase, where technical trade-off are made to economical possibilities and availability of suitable sub-product/raw materials.

Increase Stability of energy production
Simplified turbine and blade design, leads to less probability of damage, less service, lower operational costs.
Detailed control or understanding of aerodynamics in stall, leads to smaller fluctuations in load and power, leads to more optimized structure.

Increase Safety
Safety can always improve.
For example, there are several different braking philosophies, and for each the limiting cases are controlled by complicated mechanisms. Lightning protection is possible an other safety aspect.

Increase Recyclability
Recyclability is a real important and very difficult topic. It must link to materials selection of future blade.

Decrease Environmental impact
NOISE, NOISE and NOISE
All other issues are not technical R&D topics, but a link in the industrial development, i.e., planning, architectural development, work environment ect. The topic of environment is also introduced with market competition and environmental regulations.

Increase Precision of approval procedures
Design load cases are often not in direct consideration of the site, the operational conditions, the performance of materials and much more.

2. Summary important areas

Suggestions of objectives for future research seen from a manufacturer of stall regulated blades point of view. There is in most of these areas a wide activity already, hence mentioning these is just a confirmation of their importance.

Better definition of approval procedures (development of tools)
* Definition of load cases (i.e. peculiar wind statistic of sites, operation conditions)
* Definition of aerodynamics for approval (i.e. out of the ordinary operation)
* Definition of operating conditions and safety aspects (i.e. parking and aero-braking)
* Definition of materials operation (i.e., safety on materials testdata)

All the above do have definitions, but there are wide room for research, which may lead to better safety, better use of resources and better economy, etc.

Better understanding of aerodynamics
* Deep stall behavior (i.e., dynamic stall)
* Triggering of stall (i.e., stabilized behavior under all conditions)
* Innovative aerodynamics (for example high lift)

Better working conditions for aero-elastic codes
* Improvement of input aerodynamics
* Bench mark test cases (data bases) for comparison of codes

Better understanding of Noise
* Understanding of mechanisms to details
* Prediction codes, both for detailed research and user levels
* How to measure for R&D purposes, tool development ?
* How to measure for reference and approval purposes, tool development ?
* Innovative aerodynamic actions to lower noise emission
* Profile design in combination with tip shapes for lower noise emission
* How to predict potential tonality sources in given and new designs, user level.

Research and Development Themes for Wind Energy Use
- Control and Electrical Grid Connection -

Dr.-Ing. Siegfried Heier, University of Kassel
Dipl.-Ing. Martin Hoppe-Kilpper, ISET
Prof. Dr.-Ing. Werner Kleinkauf, University of Kassel & ISET

IEA Expert Meeting, September 1995
Utrecht, Netherlands

CONTENTS

1 Preliminary Remarks

In the past years, a dramatic increase in the use of wind energy in Germany is evident. This development has been supported by federal and state programmes promoting wind power and particularly by a new electricity feed-in law (EFL). A constantly rising share of the annually newly installed WECs operate without support of the federal "250 MW Wind" Programme. This is a most satisfying development and also invalidates the frequently considered fear of a possible breakdown in the WEC market due to decreasing public support. It commends the high quality standard of wind energy technology already achieved.

In Germany, great efforts were taken to introduce innovative technologies. New concepts are currently in introductory stages and could assert themselves in the market with remarkable success. The further promotion of research should specifically focus on the continuation of promising development approaches. Developments in the past years prove, that an increase of the rated power of WECs results in an obvious reduction in costs. Because of limited site potentials and a rising demand for integration of WECs into the public electrical grid, this development should be continued into the MW range. Particularly, in the case of large wind energy converters, more favourable cost and efficiency levels can be expected with the application of innovative WEC concepts.

German support of research projects must ensure that the existing advantage of innovative German WEC technology can be retained and continued. This is especially relevant considering the rising importance of EU programmes.

2 Focal Points of Research and Development

In considering the large-scale application of wind power, R&D programmes must aim at further cost reductions for wind energy technology, by improving efficiency and reliability. The necessity of intensifying the use of renewable energy sources, for an environmentally beneficial energy supply and the creation of promising employment, will gain importance as a political frame condition.

Research programmes in wind energy can be divided into two main subject areas:

- the research and development accompanying direct application of wind energy technology,
- progressive research tasks.

2.1 Accompanying Research and Development

Wind energy technology has reached a stage of development where research promotion activities that neglect industrial trends can be disqualified. Further development of technically innovative concepts should be particularly focused. Furthermore, technical problems occurring during WEC operation should be described - e.g. by the respective manufacturer - and handled in cooperation with institutions within R&D projects. Possible topics could be

- lightning and overvoltage protection (directly, indirectly),
- noise reduction,
- reduction of grid interferences,
- further development of multi-pole generators,
- self-commutated inverters,
- new materials for weight reduction,
- production engineering for rising efficiency and quality.

2.2 Progressive Research Tasks

Research and development tasks concerning the possible future role of wind power, in a centralized or decentralized energy supply structure, can be divided into projects for:

large-scale technical application of wind power, including the development of

- large wind energy converters,
- energy supply structures with high shares of wind energy,
- large hybrid systems in the MW range,
- offshore wind energy technology,

and projects for the integration of WECs into **small hybrid systems** (especially for export into developing countries). These include

- stand-alone systems (e.g. wind pumps),
- small energy supply systems for villages,
- plants for basic electrification.

3 Contents of Possible Research and Development Projects

In the following, possible contents of the described R&D topics are briefly outlined. Accompanying and progressive R&D projects are also considered here. The project "Extension of contents for the WMEP basic evaluation" described under 3.1 can be related to both categories.

3.1 Extension of contents for the WMEP basic evaluation

The conception of the "250 MW Wind" Programme always intended the implementation of subject-specific evaluations by various institutions. This should contribute to the further development of wind power technology. The range of the WMEP basic evaluation is to be enlarged in preparation for these subject-specific evaluations. The better direct utilization of the large amount of data through third parties (e.g. WEC manufacturers) will also be achieved. In the framework of this expansion, no isolated R&D themes are to be undertaken. Themes are to be restricted to the evaluation of the essential measurement information. The following topics are of particular relevance:

- capacity effects of WECs,
- operational behaviour of WECs,
- typical WEC malfunctions,
- cost of electrical power from wind energy,
- completion of the WMEP data supply.

3.2 Development of gearless conversion systems with multi-pole generators

Gearless WECs with directly driven generators display a number of technical and economical advantages over conventional systems:

- no gearbox noise,
- no environmental danger with oil spill accidents,
- no standstill periods for oil change (lower maintenance requirements),
- gearbox costs do not apply (15 to 20 percent of the total plant costs),
- increased energy yields,
- decreased mechanical drive train loads by variable-speed operation.

The generators employed in this area require particular development regarding

- increased electrical and magnetic utilization of active generator components (compact, light construction),
- improvement of efficiency in the low and partial load range (permanent excitation),
- control and energy processing by adapted inverter systems.

3.3 Self-commutated inverter systems in the kW to MW range

WECs with variable-speed operation and synchronous machines, require inverter systems for energy processing and electrical grid connection. By applying modern power semiconductors in self-commutated inverters, inverters for WECs can be realized that provide a high flexibility regarding control measures, allowing for the optimal adaptation to the electrical grid condition (voltage, reactive power demand, load condition, grid interference, etc.).

Furthermore, structures of modular parts and modular power dimensions should be the goal of future developments.

3.4 Remote control and supervision systems for the interaction of distributed plants

Systems for remote supervision and active remote control can considerably increase the reliability and cost efficiency of WECs. These can be achieved, for example, by the adaptation of power control to the load condition of the electrical grid or by sophisticated planning and coordination of maintenance and repair activities. For these purposes, energy prognosis systems and fault-detection systems are especially helpful.

Systems for early fault-detection enable the exact control of characteristic WEC parameters. Occurring damage can be detected at an early stage, i.e. before the first optical or acoustic signs. Plants can be repaired before damage has reached a serious stage that could result in high repair costs and prolonged and inconvenient standstill periods.

3.5 Reduction of dynamic loads through control engineering methods

Short-term fluctuations of the wind supply result in significant power fluctuations and increased mechanical loads. This is particularly apparent where WECs have constant speed and direct grid connection. Wind speed fluctuations and the resulting changes of the torque can be balanced considerably by variable speed operation. This results in the stabilisation of power with significant reduction of mechanical drive train loads and prolonged life expectancy of highly loaded mechanical components.

3.6 Reduction of grid interferences and increase of the grid capacity

In regions with high wind energy potential, e.g. coastal areas, islands and mountain ranges, electrical grids usually have a low capacity. Technical restrictions for grid connection often limit or even prevent the installation of very productive WECs.

For a better utilization of the existing electrical grid when feeding-in wind power, various measures may be applied. Quality losses occurring in the form of increased grid interferences can also be avoided. Within research and development projects, aiming towards the reduction of grid interferences and an increase in grid capacity, possible areas of exploration include the development of

- suitable filter concepts,
- low-interference inverter concepts (e.g. WECs with multi-pole generator and variable-speed grid connection through pulse inverter) and
- compensation measures (cluster formation, Power-Quality-Improver).

3.7 WECs in small and large hybrid systems

Hybrid energy supply systems combine different energy sources, such as WECs or photovoltaic plants, but also conventional Diesel generators. These plants are distinguished by a number of system inherent advantages, e.g. especially high supply security. With the rising complexity of these systems, their control and supervision gains special importance, as does the adjustment and proportion of the respective components. For this reason, the development of suitable modules and the standardisation of sub-systems and interfaces is a particularly important development task.

Concept development

by

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Presented at the 27th Topical Expert Meeting
on Current R&D needs in Wind Energy Technology
Utrecht, Holland 11-12 Sept 1995

Introduction

The wind energy development started up with a variety of wind turbine concepts, and at the same time with the establishment (at least in Denmark) of a very efficient network of acquainted people for exchange of information and experience.

As a result of an unconscious common "decision" within this network, the three-bladed standard type was selected quite expedite. Some manufacturers had good results with this type. Blades became available, and new manufacturers had a "receipt" to start up. Furthermore, it was generally accepted that only limited time was available for the wind energy technology to show promising perspectives in competition to other sources of energy production.

Other countries worked at the same time on more advanced concepts with a longer time frame before commercialization (large two-bladed teetering rotors). Unfortunately many of these developments were not sufficiently successful in time, and it came to a point where the three-bladed standard concept was widely selected worldwide for commercialization - but this might not be as a result of a competition between concepts on equal conditions. Rather, it could be seen as a way of getting respite in the competition to conventional energy sources, where wind turbines in the meantime have shown "arguably" competitive. This achievement gives the freedom to the wind turbine community to develop new concepts from the present day foundation of experience and knowledge and relate to the standard concept.

Development lines

The wind turbine development is now free to run along two lines:

1. Pure development leading into evolution of the three-bladed standard concept.

2. New concepts (revolution), where cost efficiency can be related to the three-bladed standard concept.

The development of the standard turbine has until recently been experience based rather than research based. However the aeroelastic codes have been developed and verified to an extent that their application change from establishment of the design basis to be used in relation to optimization. We are at a point, where optimum structural characteristics are being built into the turbines. Furthermore, the codes are very efficient tools in a systematic development effort on new concepts as a basis for calculation of the competitiveness relative to present concepts. An example on such a comparison is presented in the following section.

Prediction of potentials for new concepts
A relative measure for the economic competitiveness of a new concept can be obtained by making a kind of transformation or scaling of an existing concept into the new one and performing aeroelastic predictions (Ref. 1 and 2) on both concepts under the same conditions. Such a transformation of the standard three-bladed turbine into a free-yawing, downwind two-bladed teetering rotor turbine is illustrated in Fig. 1.

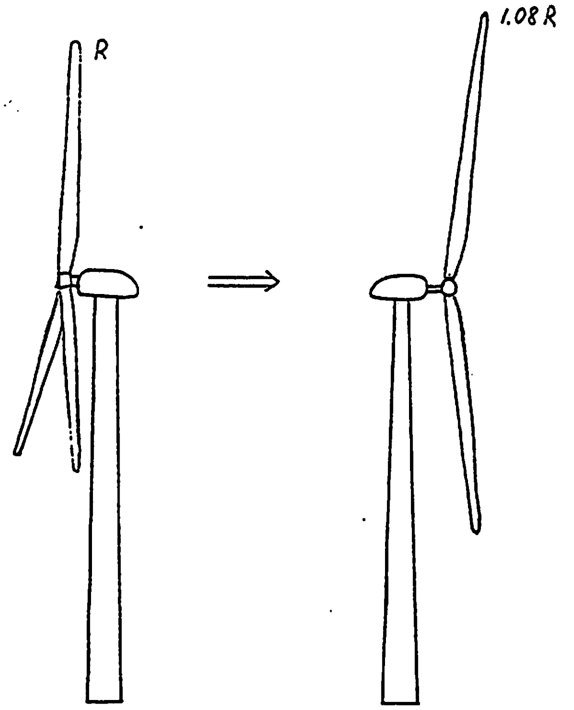

Fig.1. "Transformation" between two concepts

The comparison is quite difficult unless some parameters are kept constant. The three-bladed wind turbine is characterized by a stall-regulated Danish standard upwind turbine of 300 kW and a rotor diameter of 31 m with active yaw control. A two-bladed stall-regulated free-yawing, downwind, teetering rotor turbine is assumed to be designed using the same blade aerodynamic design but with larger blades so that the same maximum power is obtained with two blades at the same rotational speed (which means that the drive train is similar with respect to mean torque).

Larger blades could be obtained in two ways. The blades could either be scaled with similarity in all dimensions (R-scaling) or only the chord could be increased by 3/2 (C-scaling) which will give the same power except for increased tip losses. The latter scaling maintains solidity and is theoretically the most appropriate. However, scaling with similarity increases tip speed and decreases solidity which is typical for existing designs.

R-scaling. Assuming similarities between the different blades the following relation 1) between maximum (stall) power for different turbines holds:

1) $$\frac{Power_x}{Power_y} = \left(\frac{\omega_x}{\omega_y}\right)^3 \left(\frac{R_x}{R_y}\right)^5$$

2) $$\left(\frac{R_{2b}}{R_{3b}}\right)^5 = \frac{3}{2} \quad -> \quad \frac{R_{2b}}{R_{3b}} = 1.08$$

$Power_i$ = power of turbine$_i$
R_i = rotor radius of turbine$_i$
ω_i = rotational speed of turbine$_i$

R_{2b} = radius of two bladed turbine
R_{3b} = radius of three bladed turbine

As the rotational speeds are equal and the stall power almost proportional to the number of blades, the ratio between rotor radius is calculated from the formula 2), which means that the two-bladed should have 8% larger radius. The two-bladed rotor is thus designed by increasing all blade dimensions, except the material thickness which is chosen to be constant, by this factor. This means that blade weight is increased by 1.08^2 and stiffness by 1.08^3.

C-scaling. In order to maintain maximum power the chord is increased by 1.5. The blade is chosen to be designed by decreasing the material thickness to 2/3, which will maintain blade weight. Stiffness is thus increased by 1.5^2.

Calculations are performed on all three concepts and related to that of the three-bladed. From the power curves it is calculated that the energy production in a Danish class 1 wind site is 4% lower (due to increased tip losses) for C-scaling and 2% higher for R-scaling, as compared to the three-bladed rotor.

In order to get some expression for the relative fatigue loading, aeroelastic calculations have been performed on all three concepts. Time series for the principal loads have been generated for the same turbulence wind field input, assuming a wind speed of 10 m/s and 20% turbulence intensity to be representative values for the comparisons. Rainflow counting and fatigue damage calculation gives an equivalent fatigue load which is related to that of the three-bladed turbine (Predicted by Flex 4, Ref. 3.). It is further assumed that the material fatigue exponent for blades (GRP) is 8 and for tower and machine foundation (Welded steel) is 4.

The comparison for power output is based on standard deviation, and extreme loads during stand still are assumed to be proportional to projected blade area. However, the comparison is only based on fatigue loads.

Summing up with these assumptions the ratio between different relations for the two-bladed teetering rotor and the three-bladed is given in Table 1.

Table 1. Relation between two- and three-bladed turbines

Parameter	Ratio: Two-bladed/Three-bladed R-scaling	C-scaling
Stall power	1	1
Rotational speed	1	1
Number of blades	0.67	0.67
Rotor diameter	1.08	1
Energy production (Class 1)	1.02	0.96
Thrust fatigue loading	0.91	1.10
Thrust extreme loading	0.78	1
Blade flapwise fatigue loading	1.14	1.18
Blade flapwise extreme loading	1.27	1.50
Edgewise fatigue loading	1.18	0.97
Yaw moment fatigue	0.01	0.01
Tilt moment fatigue	0.33	0.31
Main shaft torque	1.05	1.15

The figures for loads in Table 1 represent the result of the first iteration in the optimization of the two-bladed turbines. However, only this first iteration is performed. In order to get an expression for the implication of the factors in Table 1 on the use of material for the load dependent components, it is assumed that the material thickness is adjusted to give equal stress for the different concepts.

Blades. Stress in the blades is expressed by the ratio between bending moment and moment of resistance. The latter is proportional to material thickness and for a direct scaling it is proportional to the third power of the scaling factor. The blade material factor for the two ways of scaling is thus equal to the ratio on bending moment divided by the ratio on moment of resistance and multiplied by the ratio on number of blades. For C-scaling and flapwise the material factor is thus (Mf= $1.18/1.5 \cdot 2/3$) equal to 0.53. Edgewise it is (Mf= $0.97/1.5 \cdot 2/3$) equal to 0.43. Assuming that the influence on blade weight from flapwise and edgewise loads are 2/3 and 1/3 respectively, the material factor reduces to Mf = 0.50. For R-scaling and flapwise, the material factor is (Mf= $1.14/1.08^2 \cdot 2/3$) equal to 0.65. Edgewise it is (Mf= $1.18/1.08^2 \cdot 2/3$) equal to 0.67. This reduces to Mf = 0.65.

Tower. For the bottom 3/4 of the tower, the design criteria is assumed to be the thrust force and for the upper 1/4, a combination of rotor torque, yaw and tilt moments.

The material factor for C-scaling is (Mf= $3/4 \cdot 1.10 + 1/4(0.5 \cdot 1.15 + 0.5 \cdot 0.31)$) equal to 1.01.
The material factor for R-scaling is (Mf= $3/4 \cdot 0.91 + 1/4(0.5 \cdot 1.05 + 0.5 \cdot 0.33)$) equal to 0.86.

Main shaft. The main shaft dimensions are given mainly by bending moment from a combination of yaw and tilt moments and from gravity.

For C-scaling the final rotor mass is reduced to 0.50 and yaw and tilt moment to 0 and 0.31, respectively. This gives a reduction in stress to approximately 0.5, which gives a material factor of 0.64, as the shaft is massive.

For R-scaling the rotor mass is reduced to 0.67 and the yaw and tilt moments to 0 and 0.33, respectively. This gives a material factor of 0.74.

Hub. The weight of the hub is decreased but the complexity increased, which is assumed to balance in total.

Machine economy

In order to get an estimate for the total machine economy the relations have to be associated with costs for the different components and afterwards expressions for component costs as function of the use of material. A cost break down of a standard three bladed turbine is assumed as given in Table 2.

Table 2. Relative machine costs

Component system	3-bladed		2-bladed, c-scaling		2-bladed, r-scaling	
	Relative cost	Cost function	Material factor Mf	Relative costs	Material factor Mf	Relative cost
Blades	24.5	0.2+0.8 Mf	0.50	14.70	0.65	17.64
Hub	3.2	Mf	1	3.2	1	3.2
Main shaft	3.3	0.3+0.7 Mf	0.64	2.47	0.74	2.70
Main gear	14.3	Mf	1.15	16.45	1.05	15.02
Generator	6.4	Mf	1.15	7.36	1.05	6.72
Machine found.	4.5	0.4+0.6 Mf	0.31	2.64	0.33	2.69
Yaw system	4.0	Mf	0.25	1.00	0.25	1.0
Controller	9.5	Mf	0.90	8.55	0.90	8.55
Tower	17.6	0.4+0.6 Mf	1.01	17.71	0.86	16.12
Brake system	4.7	Mf	1	4.7	1	4.7
Cover, finish	5.0	Mf	1	5.0	1	5.0
Assembly	3.0	Mf	1	3.0	1	3.0
Total	100%			86.78%		86.34%
Energy prod.	100%			96%		102%

The component cost function is assumed to be a simple sum of a constant cost and a marginal cost, proportional to the component mass. This relation is different for the various components and dependent upon the actual material cost. Estimates for these functions are also presented in Table 2.

Cost estimates are obtained by multiplication of the different factors and estimates for e.g. savings in yaw system and controller for the two bladed. The resulting distributed relative costs are also given in Table 2.

By relating total costs to the energy production, a relative competition factor (Cf) for the two-bladed wind turbine can be defined. This is thus:

C-scaling: Cf= 1.11, R-scaling: Cf= 1.18,

which indicates that the two-bladed concept has roughly 15% better machine economy than the three-bladed.

This figure is on one hand a "universal" one, independent of the actual development stage of wind turbine technology, but just based on the assumption that the two concepts are developed to the same level and based on the same design philosophy. On the other hand, the competition factor depends upon the design assumptions e.g. site (turbulence intensity, wind gradient), materials and especially size.

By changing the design philosophy for the two-bladed and taking advantage of the reduced loads by applying e.g. a guyed tower and further introduce a hinge in nacelle tilting, the competition factor would be somewhat increased. An example of this further development is illustrated in Fig. 2, but a similar prediction for this concept is not performed here.

Fig. 2. Further developed two-bladed concept.

However, also the reference turbine, the three bladed turbine, could undergo further concept development, which would affect the competition.

The important conclusion from this exercise is that the aeroelastic prediction codes are now so reliable, that they can be used to support such a scientific based concept development. Further work on this subject using numerical optimization algorithms is presented in Ref. 4.

General R&D areas

The previous sections have dealt with the technical wind turbine development. After 20 years of development this subject is in general quite well handled and we are at a point in time, where it is rather "untechnical" things that sets up restrictions to the development. In this context the maintenance and further extension of the international network in the wind turbine community is of major importance.

The EUREC Agency have in their preliminary position paper (Ref. 5) set up the following RD&D areas in order to pursue future goals:

- A Meteorology
- B Aerodynamics and aeroacustics
- C Aeroelasticity and loads
- D Concept and component studies including new materials
- E Operation and maintenance (logistics) studies
- F Power control
- G Power quality, grid interface, transmission and storage issues
- H Other applications
- I Certification
- J Testing and measurement procedures
- K Technology transfer

The content of these areas is rather straight forward when related to the goals and not elaborated further upon in this paper, except that a "soft" subject like Public acceptance might be important and determining for the development and thus the actual content of the research areas.

Proposals

The last point, Technology transfer, is closely related to Market development. A proposal for an activity on this point could be the elaboration of a World Wide Wind Turbine Implementation Map including not only wind conditions and technical aspects, but also infrastructure, social and economical aspects and any preconditions giving advantages or restrictions to the installation of wind turbines. A valuable strategy could be made on the basis of this. An example, where a big market has shown up, is India and an example with an enormous potential is Egypt

A lot of research funds have been put into development and demonstration of large turbines of rather advanced concepts at an early stage where the necessary prediction codes were not sufficiently developed. Probably these turbines contained a lot of ideas and perspectives and the reason that quite many seemed unsuccessful might not be due to the basic philosophy. After 20 years the first generation of researchers and designers are just about retirement. Furthermore time has gone and the people involved would probably be willing to give a first hand explanation about the history. The proposal is at this moment to make a review of all the projects on development of large "advanced" turbines, including deep discussion and evaluation of the design philosophy. This would represent valuable information for future developments and may be turn some of the projects into a "success", seen in the light of the present know-how.

Further proposals are aiming at reducing the visual intrusion and promote acceptability of wind turbine installations. Installations with less impact on the landscape can be obtained by e.g.:

-Better design (relative to the landscape and other turbines)

-Installations without roads (This means that service should be more seldom and cranes only available in certain periods of the year. Turbines should be designed accordingly, and stand still of some turbines for certain periods should be acceptable.)

-Installations in a row along the coast or along natural lines in the landscape. (This seems controversial, but examples in Denmark show very good results).

-One large turbine owned by a few persons (farmers) and installed at the intersection of their properties, like trees. (This would promote large turbines, solve the neighbour problem concerning noise and visual impact, and minimize inconvenience with respect to agriculture)

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DELFT
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OF
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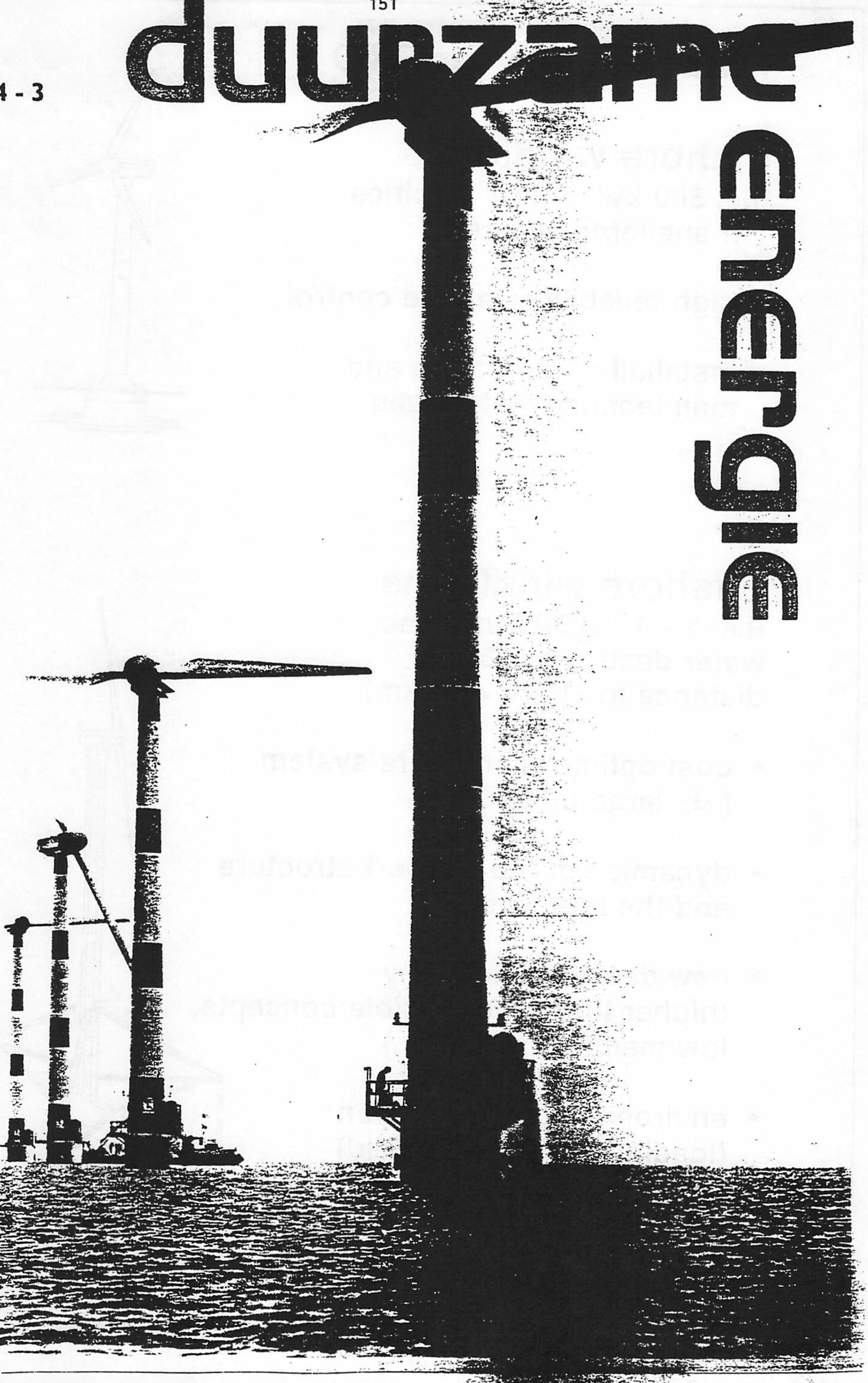
CURRENT R & D

FOR

FUTURE NEEDS

juni '94 - 3

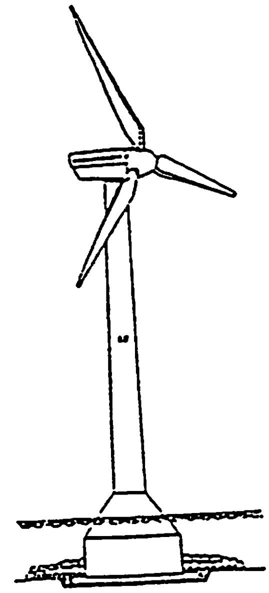
duurzame energie



Future Needs for R&D

inshore windfarms

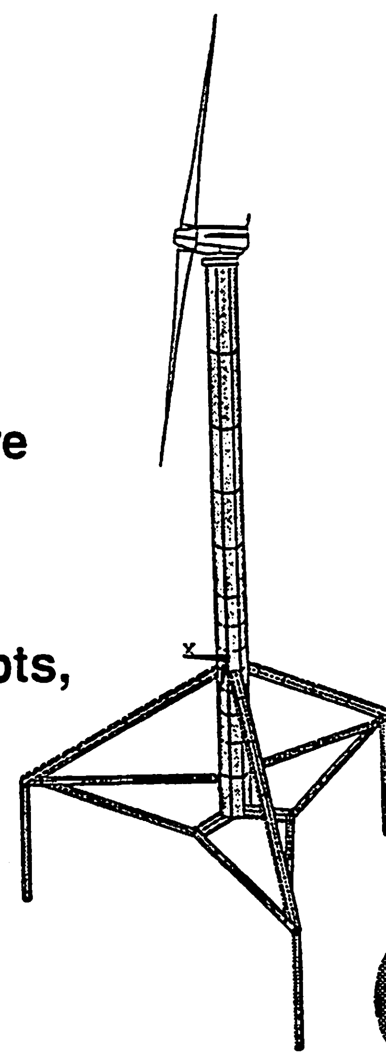
(i.e. 500 kW - 1 MW turbines
in sheltered waters)



- high reliability, remote control
- installation, operation and maintenance techniques

offshore windfarms

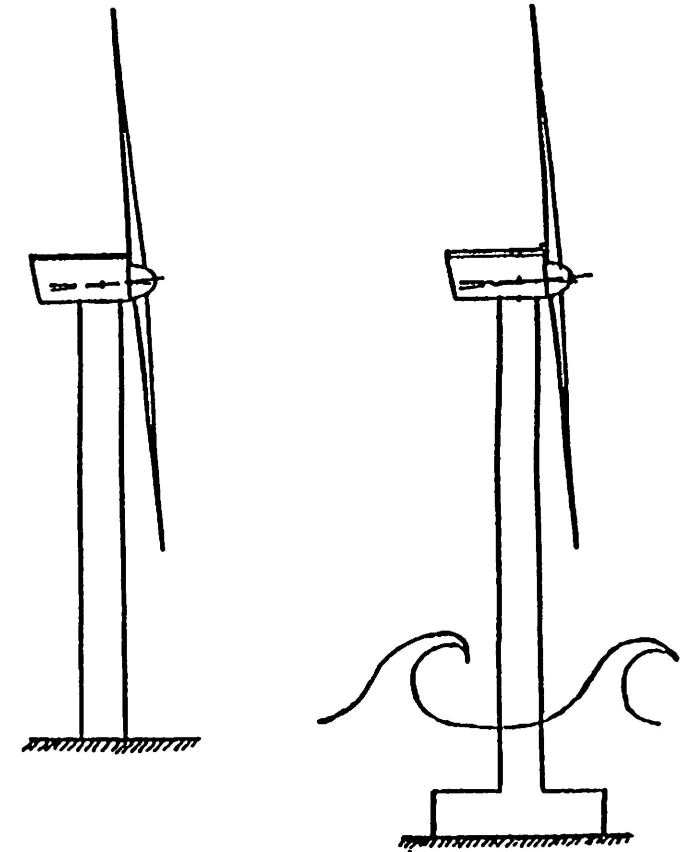
(i.e. 1 - 3 .. 5 MW turbines,
water depth 10 - 25 m,
distance to shore < 20 km)



- cost optimization entire system (=> large units)
- dynamics of the support structure and the total system
- new design philosophy (higher tip speed, flexible concepts, low maintenance, etc.)
- environmental description (loading and energy yield)

Cost break-down onshore - offshore

	onshore [Post WEGA 1991]	offshore [RES study 1993]
rotor, nacelle	57 %	23 %
tower,foundation	22 %	30 %
grid connection	11 %	27 %
other	10 %	20 %



Main cost drivers offshore

- support structure
- submarine cable
- offshore environment
- work is 3 - 10 times more expensive

=> higher investment cost

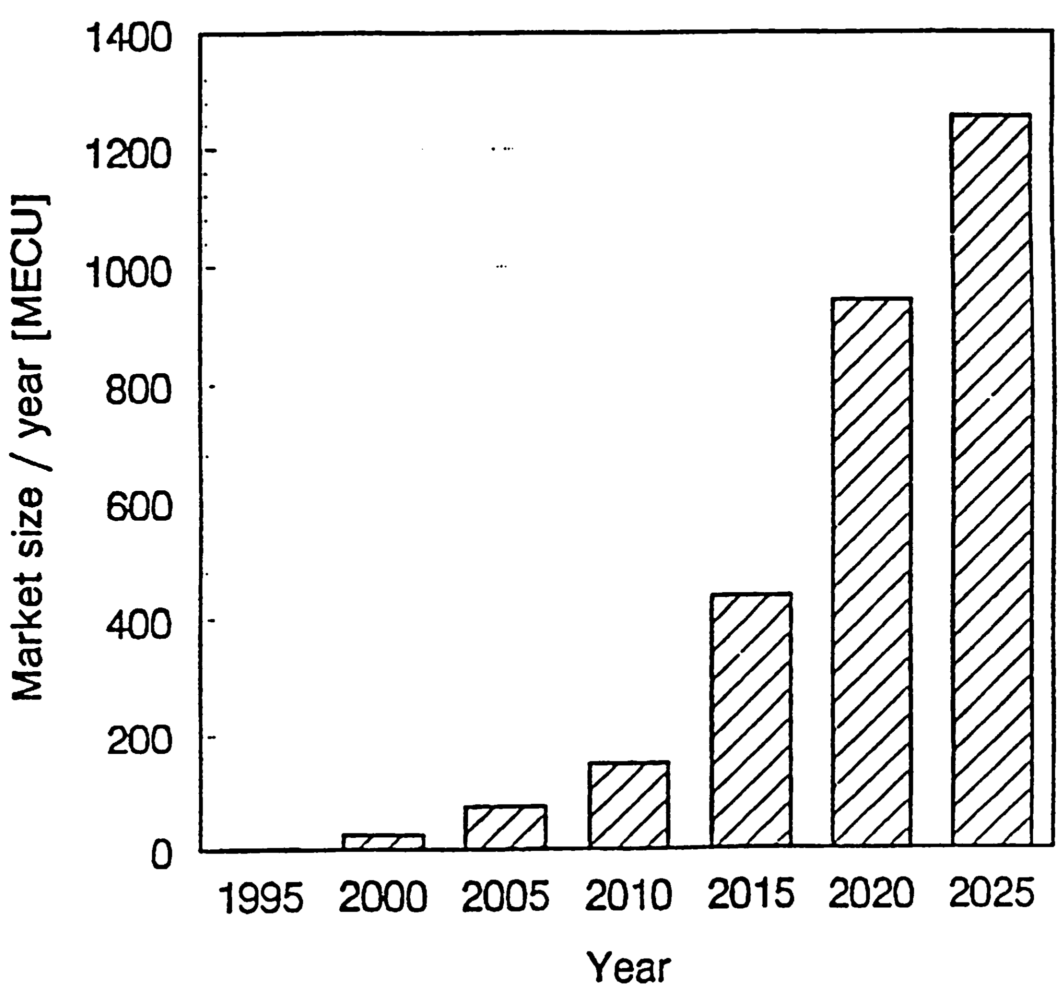
=> different cost structure

=> **different optimal design**

Why R&D on offshore wind power?

- enormous potential
- additional to land-based wind energy
- less environmental constraints
- positive feed-back on land-based turbines
- prospective international market

Annual European Market for Offshore Wind Turbines [MECU]



Institute for Wind Energy

JOULE III proposal 'Opti-OWECS'

(Structural and Economic Optimization of Bottom-Mounded Offshore Wind Energy Converters)

Strategy

- first representative European design study
- continue work done in JOULE I
- use state-of-the-art in wind engineering, offshore technology and offshore wind energy
- most feasible concepts (i.e. HAWT 1 - 3 MW)
- true offshore wind farms (not only inshore)

Objectives

i.) cost estimation and comparison of OWECS

ii.) estimate p/kwh in Europe

iii.) methods for the structural and economic optimization

iv.) typical design solutions

The Assessment of the Ecological Quality of WECs as an Impetus for R&D Activities

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September 11, 1995

Paper presented at

27th Topical Experts Meeting
Current R&D Needs in Wind Energy Technology

11./12. September 1995
Utrecht
The Netherlands

Abstract

Mankind with most of its contemporary behaviour causes mindless consumption and waste of resources thus creating environmental damages. To reduce - or even better: to avoid - this situation, it is necessary to examine the complete life cycle of a product with respect to its ecological quality. Lately, changing customer behaviour as well as new legislation like the European Community regulation on eco-audits are gradually changing the market conditions in favour of a higher significance of the product's ecological quality. At the same time in the discussion about public acceptance of wind energy a new argument was brought up by wind energy critics: the lack of a proven environmentally safe disposal concept for the WEC after operation. In the past, exclusive emphasis in the development of a WEC has been placed on technical aspects, neglecting the environmental aspects. The ecological quality of the product „WEC" is not considered at the moment, leading to the use of ecologically critical materials like PVC, hydraulic fluids, reinforced plastics, etc..

Therefore it is necessary to assess and employ the existing and available know how in order to examine all phases of a WEC's life cycle with respect to their effects on environment. Weak points will thus be recognized and suggestions for advanced production procedures and substitutes materials, in terms of environmental amicability, can be given. Without doubt further R&D activities in the field of materials, fatigue evaluation and measuring methods will be initiated and supported. The technical development of new wind turbines will thus be broadened by incorporating the quoted aspects making the product "wind turbine" inherently ecologically safe.

Furthermore, R&D activities should identify the possible ways of disposal for wind energy converters. These ways of disposal shall be examined with respect to their environmental amicability and the cost involved.

By means of future R&D activities in these fields a sustainable development of wind energy industries and its products will be promoted assuring improved public acceptance and rational use of energy and resources. Thus, the integration of renewable energies in todays and tomorrows energy supply systems will be strongly supported.

1. Introduction

More and more the significance of a sustainable development in general and of products in special increases. When talking about "sustainable development" and the way to realize it, the life cycle of a product has to be assessed. It is out of doubt that for wind energy converters (WEC) the phase of operation contributes to a better environment, but how is the state of the art when regarding the phases of research, development, production, marketing and disposal ?

In the beginning of DEWI's research in the field of ecological quality was the question of disposal of WECs and from that the resulting lack in public acceptance. Mainly, public acceptance is connected to noise emission (noise from gear, generator and aerodynamic noise from rotor blades) , visual impact (shadow casting, reflections etc.) and nature conservancy (influence on the animal kingdom, especially birds); but nowadays, caused by a changed customer conduct, a growing number of wind energy critics ask the question of disposal. So DEWI examined the phase of disposal and recognized quite fast that a single reflection of this phase is not more than an end-of-pipe solution. So it is clear that to avoid problems in the phase of disposal, the ecological quality has to be improved in all phases of a product's life cycle, especially even in respect to a later disposal.

Another important resaon to deal with the subject of WEC disposal is the probability that a new, more restrictive legislation will force the wind energy industry to take care of their products even after use in future. Clearly this will cause higher costs for the industry, especially if the industry can only react to legislation instead of being able to present solutions from itselves.

This article will describe the way from disposal to ecological quality and the resulting R&D activities which could result from this.

2. The Phase of Disposal

First of all, the disposal of products and materials is always also a logistical problem. The WEC has to be dismounted after its life time and has to be separated into single parts. Afterwards, the parts have to be sorted according to material groups (metals, wood, plastics, concrete, etc.) and have to be stored intermediately, before transported to the disposal site. Yet two problems occur: Dismounting and sorting after nearly 20 years. So it is recommended to take care of this questions already in the phase of research and development to guarantee an easy dismounting and sorting. An easy sorting could probably be realized by means of a good marking of materials during the phase of production.

After solving the logistical problems the real disposal can be performed. The way of disposal depends on the kind of material. Generally, four ways are possible:

1.) Re-use of materials,
e.g. the foundation of a WEC can be used more than one time.
2.) Reutilization (recycling),
e.g. steel components like the tower can easily be recycled and then steel products for the same range of application can be made of it again.
3.) Incineration (preferably with generation of energy),
if no re-use or reutilization is possible or available, uncritical materials can be incinerated.
4.) Waste dump,
which represents the last solution for disposal, if no other way is possible.

Referring back to WECs, it is important to know the amount and kind of materials to handle after the phase of operation. Table 1 gives an overview of materials and their approximate amount in Germany at the moment and in future.

	30.06.95	increase first half 1995	estimation for the year 2000
number of WEC	3027	441	ca. 8000
installed MW	837	204	ca. 3200
average power	275 kW	465 kW	ca. 400 - 500 kW
total mass per WEC	29.000 kg	54.500 kg	54.500 kg
foundation (steel, concrete)	60.000 kg	80.000 kg	80.000 kg
tower (steel, concrete)	17.500 kg	30.000 kg	30.000 kg
nacelle (steel, NF-metals)	9.000 kg	20.000 kg	20.000 kg
rotor blades (GRP, CRP)	2.500 kg	4.500 kg	4.500 kg
sum	270.000 t	60.000 t	1.000.000 t

Table 1: Main materials of WECs and their amount in Germany. The values were determined by the author with the help of [1] ,[2] and [3].

The amount of material for the foundation is reduced because of the fact that only a part of the foundation has to be disposed. Besides this main materials a survey among the manufacturers of WECs [2] reveals that the following materials are also used for a WEC:

- PVC-foam
- wood
- aluminium
- copper
- plastics (Polystyrol, Polycarbonat, PVC, ...)
- rubber
- gear oil
- hydraulic fluids
- brake fluids
- lubricating grease
- electronic parts
- coatings of zinc, lacquer, ...

As shown in [2], for most of these materials technical solutions of disposal were achieved in the recent years, which are already translated in many industrial areas. More difficulties occur with the re-use of reinforced plastics; for GRP, a pyrolysis with a following reduction into gas could be a possible way, but this method will not preserve the original value of the glas fibres. Other materials are still recycable, but remain critical materials, e.g. PVC. An overview for the disposal of the main materials of a WEC is given in the annex, number 5.

When looking at the phase of disposal, it becomes clear that for some existing problems a solution can only be found in another phase of the WEC's life cycle. Even if recycling procedures exist, it is necessary to examine this procedures with respect to their environmental effects and their demand on energy, water and other media as well as their emissions into air, ground and water. As a result of this investigation, a catalogue of critical materials can be achieved, so that the impetus for the research of substitute materials, preferably on the basis of secondary growthing materials, is given. Also the impetus for research in the field of a new design (e.g. with less material or even less components) is supported by the assessment of the ecological quality of WECs.

3. The Ecological Quality of Products and Resulting R&D Activities

As described in detail above, it is necessary to examine the whole life cycle of the product WEC to improve the product under environmental aspects. The life cycle of a product can be devided into the following phases:

- phase of research and development,
- phase of design,
- phase of production,
- phase of transportation,
- phase of operation,
- phase of transportation,
- phase of disposal.

For each phase, the ecological quality has to be assessed. The following aspects can be used for this task:

- use of materials,
- use of energy,
- emissions into air, ground, water,
- heat,
- radiation,
- noise.

The phase of disposal is a good example that there exists a strong relationship between the single phases and that the improvement of the ecological quality is an iterative task. Analogous to the proceeding when introducing an environmental management system according to the eco-audit degree of the EC [4], the first step is the assessment of the state of the art. On this basis an improvement of the ecological quality can be achieved step by step. This will result in a need for future R&D activities in the following fields:

* *Material Science:*
  Ecologically safe materials must be developed which has nearly the same material properties as conventional materials. The materials should be recycable and comprise as less contaminants as possible. The ecological quality can also be improved through a prolonged life of components. Therefore it is necessary to examine the influence of special environmental conditions (e.g. ice, moisture, etc.) on material properties. Furthermore, the development of monitoring systems which operate during the life time can help to assess the remaining life of the components after 20 years.

* *Improved design:*
  Especially to lighten the logistical problems of dismounting and sorting during the phase of disposal, it is necessary to integrate new design aspects into the phase of research and development, leading to easily dismountable structures and marking of materials to ensure a sorting after 20 years. A new design can also lead to less materials through less components (e.g. gearless WEC) or through reduced weight (e.g. rotorblades as light weight constructions). Design aspects should also take

into account the avoiding of critical materials, which are ecologically unsafe in the phases of production and/or disposal.

* *Production procedures:*
R&D activities should lead to clean production procedures and a guideline to introduce environmental management systems according to the eco-audit degree of the EC [4] in the firms of the wind energy industry should be supported.

On the way to a sustainable development of the product WEC costs will be reduced and public acceptance will be enlarged. The cost reduction can be achieved through a careful use of resources especially during the phase of production, leading to less materials, less consumption of energy, water, etc. and therefore a potential for cost reduction exists.

Looking on legislation, the presenting of an own solution for the wind energy industry will be cheaper than the simple re-action to restrictive handicaps which propably will occur in future. So R&D activities should also have the aim to implemente an agreement between manufacturer and customer about the taking back of the WEC after use. This will enlarge the public acceptance and therfore will contribute to a wider application of wind energy.

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Current R& D needs as seen by a consulting company

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Summary

It is common knowledge among all our engineers that turbulence and the resulting fatigue loads are an important consideration, and the dimensions of the main components of all large machines are determined with allowance for fatigue.
To cut down the high erection costs of large WECs, special jigs and on-site manufacturing methods are desirable.
The detailed design of structural components can be further optimised by materials research and fatigue testing of typical components
The reduction of fatigue loads by individual fast pitch control (flaps or spoilers) might be effective in the case of large machines and could protect teetered rotors from hard impacts.
The design of glass fibre blades still offers opportunities for further research, and offshore wind power development is seen as a generally promising development.

Introduction

aerodyn GmbH is a consulting company for machine design, structural calculations and the development of wind energy converters and components. Established in 1983, aerodyn currently employs 16 trained engineers, some of whom have over 15 years of experience in the wind power sector. We use finite element methods for structural analysis, dynamic modelling of wind energy converters in turbulent wind fields to evaluate fatigue load collectives, and also a variety of software developed in-house. So far, we have designed 4 complete wind power plants, 16 hubs, 11 machine frames, 28 towers, 16 rotor blades, several operation control computers and further components. At present we are actively involved in 4 development projects of wind power plants of more than 1 megawatt rated power. Our recommendations for research and development come from the practical viewpoint of wind power plant manufacturers and our engineers.

1. Large wind energy converters

It is a common experience that there are many wind park projects in which a larger number of medium-sized plants are more efficient than a small number of large plants. The introduction to the market and further development of megawatt-scale machines will slow down if they are not economic enough.

The crucial question is therefore:

How can we improve the economy of the existing large machines?

1.1 Fatigue loads and turbulence

The first point to be noted is the percentage cost increases for the hub, bearing, mainframe and tower. One of the reasons for this is that fatigue loads determine the dimensions of these components. The load collectives, evaluated by simulation of the plant in a turbulent wind field, exceed the effect of extreme loads, while in the case of medium-sized plants (about 600 kW) there is an approximate equilibrium.

A wind energy converter designed for 20 % turbulence intensity over the whole wind speed range and an annual average of 10 m/s according to IEC class I is overdimensioned for nearly all real sites and is thus uneconomic.On a site with less turbulence and the same wind speeds it can be equipped with a rotor of larger diameter in order to experience the same loads as those assumed in the design (or vice versa). We thus inevitably end up with site-specific machines and have to know the exact turbulence for each site.
This leads to the following research requirements:

Classification of sites according to their turbulence
Testing of the various turbulence models with actual measured loads
Three-dimensional and non-steady aerodynamics for exact calculation of the load with turbulent afflux
Wake flows in wind parks, air flow over mountainous country
Measurement of all relevant data on potential sites well before construction work starts.

1.2 Castings

When designing large castings, it is easy to get into vicious circles of various kinds. As wall thicknesses increase, the strength properties of the material decrease, and the possibility of reject parts increases with their size. Another problem facing the wind power plant manufacturer is that very few foundries are able to manufacure the heavy castings (up to 18 tonnes) and delivery times are long. Despite this, it is difficult to replace castings with welded structures, as each weld seam constitutes a weak spot with regard to fatigue strength.

Research requirement

Fatigue tests on a typical casting (hub) of a megawatt-scale machine using realistic load collectives, determination of stress collectives. Extrapolation software to allow conversion to different hub sizes and shapes. In this connection the manufacturers should agree on the configuration of the test hub. It necessary, the component can be scaled down in order to economise on testing costs.. The test should be carried out in close collaboration with and with financial backing from the manufacturers' associations.

Verification of fatigue calculation procedures on structures with a three-dimensional stress distribution, and incorporation in the official guidelines.

General research equipment:

Welding processes and aftertreatment for particularly fatigue-resistent weld seams (e.g. shot peening)
Strength properties of castings with the usual wall thicknesses and dimensions
Determination of material characteristics for typical wind power components.

This subject is of course not directly linked with wind energy. With a relatively small investment, it should nevertheless be possible to derive the relevant data for wind power components from general mechanical engineering research or to join in current research projects.

1.3 Transport and assembly

A further percentage cost increase is due to the costs of transport and assembly. The weights and dimensions permissible for transport by land mean that the plants can be delivered to the site in an only partially assembled state and the final assembly must be carried out there. An 800 t crane is needed for erection, and this must itself be conveyed to the site on four trucks and set up with the help of an auxiliary crane (approx.. 80 tonnes). The size and weight of the crane call for well paved and sufficiently wide access roads. This leads to an escalation of costs which is not widely appreciated at the present time, partly because the large plants completed so far have not been erected in poblem areas. The cost of transporting a 1.2 MW machine from the assembly hall to the site within northern Germany comes to about 20 TDM, on-site assembly to 90TDM.

Research requirement:

How can we make assembly cheaper by using special equipment?

This item is to a large extent the task of the engineers of the wind power plant manufacturers. Some manufacturers already have such equipment in operation, although not for large plants. An associated research project could support these efforts and give useful hints, for example evaluating the safety demands for such crane equipment and preparing their incorporation in the official rules.

1.4 Tower

Depending on the machine type and height, the tower weighs about 95 % to 140 % of the mass of the tower head and becomes itself a significant cost factor. One important reason is the restricted diameter of about 4 m for land transportation and the separation joints between individual tower sections.

Research requirement:

> **How can we convey the tower in easily transportable sections to the building site and perform final assembly there (welding, testing, quality assurance)?**

The research should aim at establishing the data which the responsible building authorities should demand (e.g. weld seam qualities, amount of testing of welding carried out on site). The procedures themselves can be worked out by the wind power plant manufacturers or specialised companies.

In Germany we find a cost reduction potential simply because the towers have to be designed according to German building law. The building authorities do not accept a structural calculation based on simulated load collectives, finite elment methods or calculations according to general mechanical engineering standards. A verification procedure of this kind could however save several per cent of the cost and weight of the tower.

1.5 Low load concepts

The above-mentioned problems and proposed solutions are of course "treating the symptom and not the disease", as low fatigue strength concepts will not lead to the weight and cost developments mentioned.. It seems that the wind power plant manufactuers have been reluctant to take the risk of developing a large plant at the same time as developing special low load concepts. In any case, the cost advantage of such systems is frequently not enough to justify such a system, at least in the size category of 500 to 600 kW.

Research requirement:

> **Can teeter hubs, flexible blades, coupled flap hinges or other load-minimizing concepts also be realized with the dimensions of MW-scale plants? How large is the saving potential?**
>
> **What are the possibilities of fast single-pitch control (for example spoilers or flaps) for minimizing loads?**

It seems that besides the research, an additional help for market introduction will be necessary in order to establish the concepts showing the best cost/benefit effect in comparison with the lower-risk conventional concepts, as the German market at present does not accept any items of risk or unnecessary wearing parts.

2. Rotor blades

2.1 Manufacture

Hand lamination is a crucial factor driving up the cost of large rotor blades. There have of course been several attempts to rationalise manufacture further, but so far no procedure has been established which lowers the manufacturing cost significantly. Prepregs and tape layers, vacuum injection and filament winding for load-bearing structures are under discussion.

Research requirement:

> **Which manufacturing processes can be used to make rotor blades more cheaply?**

Research activities should prepare a basis for encouraging in-house developments by the glass fibre manufacturing companies. As this item too is not a purely wind power-specific one, we could contemplate cooperation among several branches of industry;.

2.2 Material data base

Although the different rotor blade manufacturers use similar laminates, each manufacturer usually carries out his own test programmes. A systematic test programme plus interpolation software could help, and the official guidelines would refer to the results.

Research requirement:

> **Material tests and the establishment of a data base for all laminates which are regularly used for rotor blades.**

The design of rotor blades can thus be speeded up if reliable material strength data are available in advance.

2.3 Aerodynamic data base

There are no basic aerodynamic data available for very thick airfoils, mainly because they are not used in aircraft design. It would accordingly be desirable to have:

> **A data base of airfoil characteristics of thick (up to 40 %) airfoils for the Reynolds numbers which are relevant for wind power plants with angles of incidence from all sides.**

Benefit: Quicker and more accurate design of rotor blades.

2.4 Noise

Noise limits the tip speed of present-day wind power plants. If detailed measures taken on the airfoil allow the tip speed to rise and the torque to be reduced with the same level of noise, this results in weight and cost savings in the drive train of the plant. Structure-borne noise can be kept extremely low by detail design and scarcely contributes to the general noise level.

Research requirement:

> **Aero-acoustics, calculation models for noise generation and propagation, design of low-noise airfoils and blade contours.**

2.5 Disposal

The disposal of old rotorblades with the minimum of pollution is regarded as important for future acceptance.

2.6 Lightning protection

The already well-proven lightning protection measures should be incorporated in the official guidelines, which could appropriately include neutral testing by a high-voltage laboratory. There is still a need for basic research in the following areas:

> **Correlation between damage and lightning parameters**
> **Statistics and the evaluation of damage incidents**
> **Sensory analysis and the notification of lightning strikes to a central data base for keeping statistics, setting up a data network of this kind.**

2.7 Stall

Full-span pitch control of power output causes problems for fixed-speed plants as their size increases. The reason is the over-proportionally growing share of three-dimensional turbulence in the power fluctuations, which cannot be controlled by conventional pitch control. The stall concept for power control in combination with pitchback for parking after cutout is a possible solution.

Research requirement:

> **Aerodynamic modelling and research into stall, especially 3-D effects, dynamic stall, stall hysteresis and the possibility of influencing these factors.**

3. Offshore

The development to date of wind energy in Germany has resulted in a contribution of less than 0.2 % of total electricity generation. Yet already protests are being heard from people living nearby who feel affected by the wind farm projects. It is not certain that the exploitation of wind energy onshore can be continued as planned by the federal countries. The long-term future of wind energy in Europe lies, in our opinion, in offshore projects, to which the following research and development activities can contribute.

Wind and turbulence over the open sea

Dynamics and loads on the tower and foundations under the influence of waves

Cost optimisation of foundations

Lightning strike probabilities and intensities at sea

Cost reduction potential without transport restrictions

Cost reduction by less strict demands with regard to grid compatibility

Safety requirements in uninhabited areas, possibly influence on load cases

Which systems are especially suited for offshore applications?

Integration of the (high) power output into the existing grids, for example consumer control or storage systems

4. Miscellaneous

In some areas which are basically worthy of research, some manufacturers have already been active. Funding research and developement has to be harmonised particularly carefully in these areas, so as to avoid distortions of competition. This applies in particular to:

Status monitoring by spectral analysis, early detection of damage

Recording of a load pattern and on-line calculation of the accumulated fatigue damage (basis for subsequent further use after the calculated 20 years lifetime)

Non-linear and adaptive controls, fuzzy control (already in operation)

Elastomeric bearings for the reduction of structure-borne noise (in common use)

Lightning protection

We would recommend that such research and development activities be undertaken in close cooperation with the manufacturers' associations.

Novem

This is a contribution to the IEA R&D expert meeting on Current R&D Needs.
Mr. J. Olthoff from Rotorline, The Blade Company. 21 August 1995

Mr. Olthoff is not able to attend because he is in India during the meeting. The contribution of was forwarded to Novem by the chairman of the Dutch association of windturbine and blade manufacturers the FME Branche Group Wind.

To contribute to the discussion I would like to defend the following propositions :

1. Applied R&D does not make wind turbines cheaper, but more reliable and efficient.
2. Only larger series lead to cost reduction. Here I see a significant role for R&D to use the series effect through the adoption of different components and different manufacturing methods.
3. R&D which is aimed at conceptual changes and also from the beginning at manufacturing in large series can lead to a breakthrough in cost reduction.

Ad. 1
In the past 3 to 4 years, the understanding of how to calculate rotor loads has increased considerably. Because of this, the load cases have become more sophisticated, increased in number and more realistic. On balance, the loads have not been reduced, e.g. through less conservatism, but the calculational efforts have become considerably more laborious. Blades have not become cheaper because of this.

Ad. 2
Cost reduction of blades has been reached through reduction on man-hours and through reduction in material costs by buying in larger volumes.
Besides this, the choice of components, e.g. in the blade root, has been of great influence on the costs of blades. The latter especially through materials R&D.

Ad. 3
New concepts are amongst others aimed at lower loads and thus at lighter components or at less components (like a direct drive turbine). As such this does not lead to cost reduction: light components are often more expensive per kg and for example a special electrical generator will not be cheaper a priori. Cost reduction can only be reached if component development is combined with series production and materials technology; taking into account the possibilities of series production.

My conclusion is: that all good R&D elements in it self can not lead to the desired result. From the beginning the seperate elements have to be integrated in the framework of the new concept up to the final product. For wind turbines and especially rotor blades I have come to this conclusion only recently. During the first two phases (pioneer and development phase) R&D was simply needed to build the design tools.

Note that these propositions concern the direct influence of R&D on cost-reduction. Secondary effects like better deployment through more silent windturbines are not addressed.

Free translation by Jaap 't Hooft, Novem with some help from Gijs van Kuik, Stork Product Engineering.

Round Table Discussion

Notes prepared by

Søren Krohn
Danish Wind Turbine Manufacturers Association

12 september 1995.

Ian Fletcher:
• In this group, we have a considerable cosensus on necessary R&D fields, e.g. modelling flexible machines, aerodynamics, aeroelastics.
We have two options:
1) The evolutionary change route (working with industry) on value engineering, increasing effectiveness.
2) The revolutionary change route: E.g. machines with »coning« rotors etc.: This line will need a high level of public funding. Demonstration projects are needed in order to get a breakthrough and carry the technology into industry.
• UK: The major difference between the UK and the Netherlands, Germany, and Denmark is that we have no funding for offshore windpower. Not the same industry in the onshore and the offshore business. We need a drastic change in the basic situation for offshore windpower to become interesting. If the price of wind doubles, many more sites become interesting onshore. A »watching brief« is OK, but no major funding should be invested.
• Prospects for the future: The Dakota aircraft analogy was very appropriate, but costs of wind turbines can certainly come down much further. The 2 cent US cost is simply not realistic, and the estimate is certainly not true in terms of conventional generating costs.
• Subject suitable for intenational funding: Basic research in aerodynamics.

G. van Kuik:
• The trend in interest towards flexible, lightweight machines in the engineering community does not necessarily have any folowing among manufacturers. As an example, the Dutch Flexhat project has had no following whatsoever (until lately).
• We have to fill the gap between manufacturers' short term expectations and the revolutionary technological possibilities.

T. Siebers:
Manuafcturers are risk averse.

Peggy Friis:
ELSAM has shown one useful way of handling that problem: We asked companies if they were interested in building megwatt-sized machines, while we offered to buy prototypes, paying the cost per kilowatt of 500 kW machines. That was a truly useful exercise, because manufacturers got actual experience.

Armstrong:

• But it seems that manufacturers in this case have built rather traditional designs.

Peggy Friis:
• The BONUS active stall machine concept contradicts this. And the other manufacturers have shown major design changes as well, if you compare with their previous models.

Armstrong/Siebers:
• But these are not revolutionary changes, in our view.

Flemming Rasmussen:
• Industry cannot cope with revolutions, but with evolutions. Our investigations should run in parallel with industrial development, and our ideas wil gradually be taken up by industry – piece by piece.

Siebers:
• But some inventions are inseparable: Teetering hub and downwind operation are examples of concepts that cannot be separated.

Peggy Friis:
• Why not?!

[After lunch]

Gijs van Kuik had the following suggestions for modifications of his Dutch survey presented at the beginning of the seminar:

• Mr. Vestergaard claimed that there was no need for basic research in methods, materials, and components, something which was in stark contradiction with the Dutch survey.
• It appears that the dutch survey had an insufficient stress on ecological aspects, if one compares with the views of Dutch manufacturers.

[Reference to OH: Possible results after 2 years]

[Reference to OH: Possible results after 5 years]

[Reference to OH: Possible results after more than 5 years (long term)]

[Reference to OH: Hindrances for generic knowledge development]

• In the latest years generic research has been the victim of budget cutting, and research is moving more in the direction of development and certification.

[Reference to OH: Conclusions policy]

Jack Noakes:
The problem of getting the research adopted by manufacturers needs to beaddressed. There is an urgent need to reduce the cost of wind energy, that much we agree about.

Gijs van Kuik:
Vaue engineering, mass production, better manufacturing facilities and technologies tend to be among the priorities of manufacturers. But there is a need for aerodynamic research etc., financed by the public.

John Armstrong:
We need a division of labour and financing along the value chain:
- Costumers for wind turbines (mapping resources, siting etc.)
- Manufacturers (concept development)
- Technology developers, consultants (also concept development)
- Universities/research institutes (design tools, certification rules)
- Component suppliers (particularly specific components such as blades)

Maribo:
New concepts are what is required to take a large step in cost cutting. One important revolution has bee the launching of the Enercon concept (vaiable speed, direct drive). How did that materialise on the market?

G. Böhmeke:
The buyer has the choice of a classical system with no technical risk, and an advanced system with some technical risk. Costumers are risk averse. Enercon indeed had problems launching the Enercon E40 on the North German market. The costumers wanted to see at least two years of operating experience before they considered buying a machine.

T. Siebers:
Some consumers are willing to take risks, but the actual origin of Enercon is important: They started in power systems engineering. From the start they worked with variable speed. Likewise, Tacke had a background in gearboxes.

G. Böhmeke:
In the beginning one problem of the sector was, that the market was not large enough to warrant the development of special wind turbine components. That is no longer the case. Development risks are not as large as they used to be, as long as we discuss kW-machines. It is, however, quite another story with MW-machines.

Jaap 't Hooft:

Manufacturers in different countries have different conditions. But all share the situation that governments will no longer finance as large a share of R&D as they used to. The origins of each machine architecture are still visibly connected with the origins of each manufacturer. As manufacturers grow richer, they can afford to take larger development risks than they used to. But in reality, many manufacturers need to take exactly the same first steps in the direction of new and more revolutionary technologies. It ought to be possible to pool part of the research needed for that purpose.

Sigfried Heier:
The development of electricity rates and the cost of grid connection are extremely important for the course of development, and indeed, for the use of land sites. The cost of using the public grid amounts to about DM 1,200 per kW for the power companies, they claim, since they have to send the electricity from the Northern to the Southern part of Germany. O&M costs are still very important. Lightning protection is an important field. So are power grid compliance issues.

Jack Cadogan:
The problem of gaining acceptance of new technology among manufacturers is basically an engineering issues. It has to be solved by the manufacturers themselves. But generic research issues remain important and have to be addressed by the public authorities. The United States is considering turning is use of research and development money more in the direction of the Danish model, i.e. supporting development of new series of smaller turbines, the 6 MW verification programme etc.

Gijs van Kuik:
Many of the priorities listed in my short term and medium term OH have both generic and specific elements. A few of them are purely generic. One of the problems we are facing is that we lose the possibility of gaining generic knowledge in the areas where specific manufacturers' equipment is being analysed.

Maribo:
We have to make priorities. Individually or collectively. It is a necessity to have a basic level of generic research funding. The objective of educating users to apply the knowledge achieved though research (as mentioned by Mr. Armstrong) is essential.

Bengt Göransson:
There is a minimum size for research institutions to function properly. The critical volume is larger than one may think at a first glance.

John Armstrong:

The wind industry ought to have the size by now to foot a larger share of the research bill.

Mike Robinson:
We are indeed trying to make priorities on a rational basis, but that is only a analytic tool. Variable speed and direct drive are among the priorities on which we agree.

Jack Cadogan:
Next generation prototypes are important. An increasing number of researchers have had to turn themselsves into engineers and project coordinators as part of this trend in our research setup.

G. Böhmeke:
Fatigue, turbulence and its influence on blade design are important issues. In particular, this work is important in order to update standards.

Ian Fletcher:
Perhaps we need a workshop to define our modelling requirements more clearly field by field: Aeroelastics, structural dynamics, etc.

Maribo:
We already have institutions in the IEA which deal with this. Extreme wind condition data bases are important in this work. Part of this work is already underway and is partly financed through the EU Joule programme.

T. Siebers:
Will your work lead to new design standards?

Maribo:
That database has been used by the standards committees instead of the previously used wild guesses. (It may, of course, also be used to classify different terrains in different regions of the world, so as to avoid uniform overly tight requirements).

Jaap 't Hooft:
Do we all agree with the quest for lighter machines? (More people – yes: That should be the result of our efforts).

Bengt Göransson:
• Lighter machines and more flexible machines will reduce costs.
• Less noise will increase public acceptability.
• Better understanding of turbulence, in particular, with give an important base for further development.

Flemming Rasmussen:

Flexibility may not be the optimum design criterion for all machines. Cost reduction and optimisation are our essential aims. At Risø for the past few years we have made a sort of senitivity study to quantify the advantages of varying a number of parameters on the classical three-bladed design, e.g. blade chord length. In that analysis we see how these marginal changes affect costs and output. That will be used as a basis for making priorities in our work.

Mike Robinson:
We need a verification of our aeroelastic models. They need to be tested much more thoroughly before people invest in using them for actual development work.

G. van Bussel:
The interaction between aeroelastic models and our formulation of strucural dynamics is quite important.

Mike Robinson:
A workshop some years ago on different stall models (codes) used the same data as a basis and we subsequently compared their results with actual test measurements to verify which models were credible and which were not. A similar execise of this kind may be useful in several areas.

27th IEA Experts Meeting, sept. 11.-12. 1995, Utrecht

Current R&D Needs in Wind Energy Technology

SUMMARY

prepared by

B.Maribo Pedersen, DTU

The meeting which was kindly hosted by NOVEM, the Netherlands Agency for Energy and the Environment, was attended by 22 people. The purpose of the meeting was to get an impression of how far the efforts spent up to now on R&D world-wide has brought the general understanding of and possibly solution to the various problems within wind energy technology, thereby providing some guidance as to where to go from now.

In 1994 it is estimated that more than 100 MUSD was spent on R, D & D by those OECD countries which have a wind energy program, and since 1974 at least 1000 MUSD must have been spent.

Hence it appeared proper to step back and take a look at where future spending of R&D money may best contribute to the overall goal of decreasing the cost of energy produced from wind to the point where it is truly competitive with that from conventional sources. In particular it would seem valuable to obtain the views of the manufacturing industry on this issue.

Of the 22 persons attending the meeting, 7 came from industries in the Netherlands, Germany, Denmark, UK,and Sweden , and 5 written contributions are included in the proceedings. Another 5 persons came from various engineering consultancy companies, delivering 3 written contributions. 2 persons came from universities, 4 from research institutes, 3 from National Energy Agencies, and there was 1 IEA representative.

The first paper presented by G.v. Kuik, was based on a recent survey made in the Netherlands, where a great number of dutch wind energy experts - manufacturers, researchers and scientists - were interviewed. This survey gave a well-structured overview of all problem areas and also gave suggestions for further work in the short-, mid- and long term. This paper was frequently referred back to during the discussions. Similarly the tables provided in the introductory note gave a good scope for the discussions.

The meeting seemed to agree, that we have now reached a stage where the industry should be able to foot a larger share of the R&D bill. Also the fact that the industry has moved from the precompetitive phase into the compatitive stage indicates, that most of the product and component development should take place within the companies.

However there was consensus on the view, that there is still a need for basic, generic research to be carried out outside the companies and wholly or partly funded by public money, and that this need will continue to exist as long as there is wind energy development.

It was the impression that development of new "revolutionary" concepts was favoured more among consultants and research institutes than among manufacturers. The idea that the lightweight, flexible, gearless etc. turbine was the ultimate goal was tempered by manufacturers who warned, that such a machine not necessarily would give the lowest COE figures.

The issue of transfer of R&D results from institutions to industry was touched upon. Some manufacturers were of the opinion, that up to now the impact of the R&D work carried out in research institutes and in universities has been limited, and that they felt that the real value of the institutions is in training people who then can be taken on and be put to work by the industry. The contemporary priorities within industry seems to lie more in disciplines like value engineering, improvements in manufacturing technology, access to testing facilities, development of components etc.

Still - as mentioned above - the necessity for continued basic research within certain areas was recognized, and it was emphasized that one should be anxious to keep the size of the research teams above "the critical mass".

There seemed to be consensus among all participants that the areas for continued research were the following:

- Aerodynamics
    - development of aerofoils whose properties are taylored to wind turbine use; experimental verification essential.
    - aerodynamics of rotors operating in deep stall
    - 3D and unsteady aerodynamics
    - dynamic stall characteristics - wind tunnel and field experiments.
- Aeroelasticity and load calculations
    - further development and verification of aeroelastic codes
    - more detailed modeling of atmospheric turbulence and extreme winds as input to these codes, including turbulence in complex terrain and in wind farms.
- Aeroacoustics
    - develop calculational models based on better understanding of the physics of aerodynamic noise
    - incorporation of acoustic requirements in aerofoil design
- Materials
    - verification of fatigue calculation procedures for 3D stress distribution
    - establishing data base of material properties
- Lightning protection measures

- Off - shore installations

  - combined wind - wave loading
  - dynamics of support structures
  - wind and turbulence over the open sea

- Power conversion. Wind turbine - grid interaction

  - direct drive, multipole generators, variable speed
  - power electronics
  - power quality

Apart from these areas which all are directed towards improving the machine design, other areas were mentioned, such as

- recyclability of materials used

- efficient park lay-out

- certification procedures

- public acceptability, legal aspects

If research projects within these areas are carefully planned and prioritized the results will form the necessary background for industrial implementation, at least in the mid-to long term, and pave the way towards more cost-efficient designs.

During the round table discussion, the idea was put forward of trying to pool some of the efforts, particularly concerning costly experimental projects, f.i. wind tunnel testing. This could be one way of partly overcoming the difficulties created by diminishing funding for basic R&D, which has been experienced in several countries lately. The bodies through which such cooperative action could be taken could be the IEA Agreement and perhaps the European Commission.

The idea was favoured by the participants, and as a first step, Jaap 't Hooft proposed to the ExCo of the IEA Agreement at its meeting in october 1995 the idea of a project as a possible new Annex , titled "Aerofoils in Dynamic Stall in Wind Tunnels".

The ExCo beeing in favour of the idea asked the Netherlands, J. Beurskens and J. 't Hooft, to collect existing material on the subject in preparation of a detailed proposal.

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11 - 12 September 1995, Utrecht

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IEA R&D WIND - ANNEX XI
TOPICAL EXPERT MEETINGS

1. Seminar on Structural Dynamics, Munich, October 12, 1978

2. Control of LS-WECS and Adaptation of Wind Electricity to the Network, Copenhagen, April 4, 1979

3. Data acquisition and Analysis for LS-WECS, Blowing Rock, North Carolina, September 26 - 27, 1979

4. Rotor Blade Technology with Special Respect to Fatigue Design Problems, Stockholm, April 21 -22, 1980

5. Environmental and Safety Aspects of the Present LS WECS, Munich, September 25 - 26, 1980

6. Reliability and Maintenance Problems of LS WECS, Aalborg, April 29 - 30, 1981

7. Costings for Wind Turbines, Copenhagen, November 18 - 19, 1981

8. Safety Assurance and Quality Control of LS WECS during Assembly, Erection and Acceptance Testing , Stockholm, May 26 - 27, 1982

9. Structural Design Criteria for LS WECS, Greenford, March 7 - 8, 1983

10. Utility and Operational Experiences and Issues from Major Wind Installations, Palo Alto, October 12 - 14, 1983

11. General Environmental Aspects, Munich, May 7 - 9, 1984

12. Aerodynamic Calculational Methods for WECS, Copenhagen, October 29 - 30, 1984

13. Economic Aspects of Wind Turbines, Petten, May 30 - 31, 1985

14. Modelling of Atmospheric Turbulence for Use in WECS Rotor Loading Calculations, Stockholm, December 4 - 5, 1985

15. General Planning and Environmental Issues of LS WECS Installations, Hamburg, December 2, 1987

16. Requirements for Safety Systems for LS WECS, Rome, October 17 - 18, 1988

17. Integrating Wind Turbines into Utility Power Systems, Virginia, April 11 - 12, 1989

18. Noise Generating Mechanisms for Wind Turbines, Petten, November 27 - 28, 1989

19. Wind Turbine Control Systems, Strategy and Problems, London, May 3 - 4, 1990

20. Wind Characteristics of Relevance for Wind Turbine Design, Stockholm, March 7 - 8, 1991

21. Electrical Systems for Wind Turbines with Constant or Variable Speed, Göteborg, October 7 - 8, 1991

22. Effects of Environment on Wind Turbine Safety and Performance, Wilhelmshaven, June 16, 1992

23. Fatigue of Wind Turbines, Golden Co., October 15 - 16, 1992

24. Wind Conditions for Wind Turbine Design, Risø, April 29 - 30, 1993

25. Increased Loads in Wind Power Stations, "Wind Farms", Göteborg, May 3 - 4, 1993

26. Lightning Protection of Wind Turbine Generator Systems and EMC Problems in the Associated Control Systems, Milan, March 8 - 9, 1994

27. Current R&D Needs in Wind Energy Technology, Utrecht, Sept. 11 - 12, 1995