Evolution of Modern Wind Turbine Rotors

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February 2004

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Personal History

- In wind industry since 1980.
- With Garrad Hassan (GH) since 1991 – founder member of their Scottish office.
- Previously with James Howden of Glasgow who manufactured wind turbines from 1980 – 1988.
- Currently heading “Special Projects” department in GH with involvement in innovative designs of wind turbine and component developments. Also involved in technology review for government, wind industry and commercial organisations.

Overview

1. Evolution of blade design
2. Blades in the context of machine design
3. Future

Evolution

1. Size

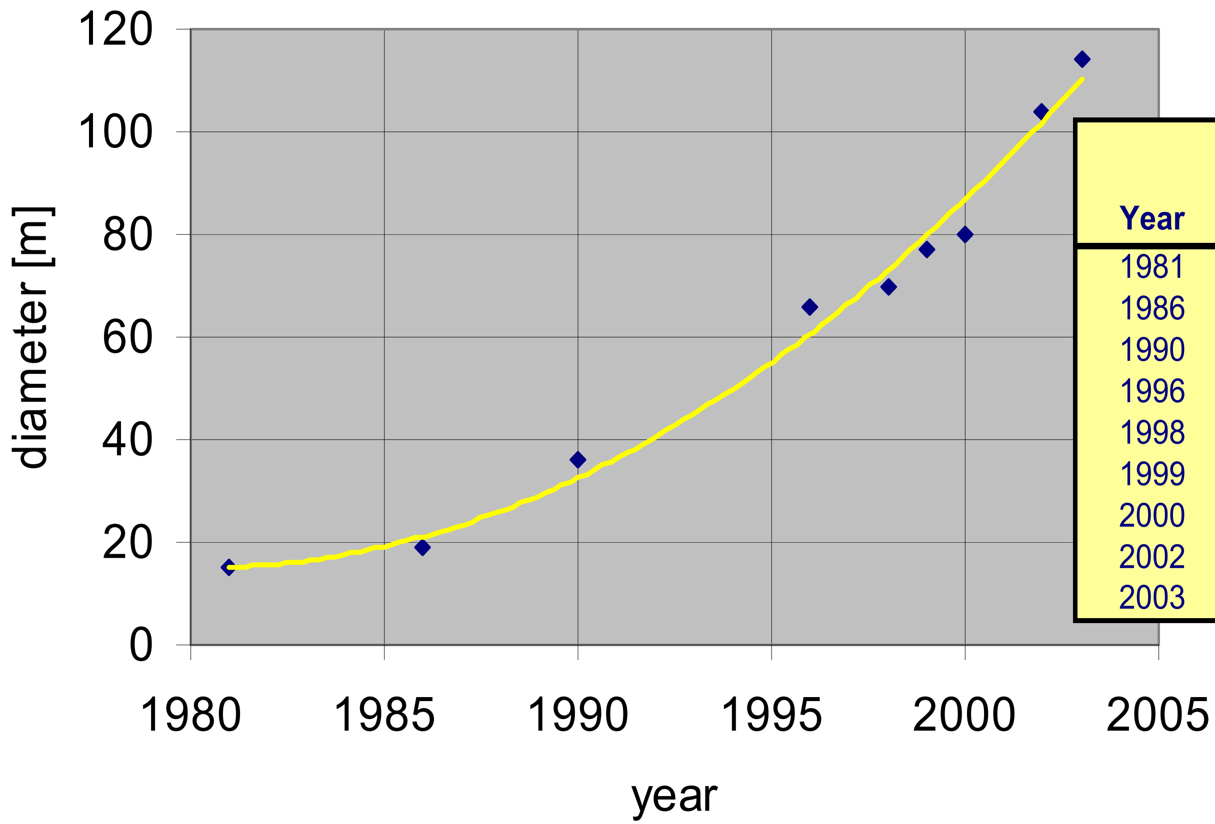
2. Materials and processes

3. Structure and aerodynamics

4. Testing and certification

Blade Length, 3.5 m 1980 → 54 m 2004

Growth of Commercial Wind Turbines



Year	Turbine	Power Rating [kW]	Diameter [m]
1981	Vestas V15	55	15
1986	Vestas V19	90	19
1990	Vestas V36	500	36
1996	Enercon E66	1500	66
1998	Jacobs MD70	1500	70
1999	Tacke 1.5sl	1500	77
2000	Vestas V80	2000	80
2002	GEWind 3.6MW	3600	104
2003	Enercon E112	4500	114

Materials and Processes

- glass polyester, wet, hand lay-up
- wood epoxy
- glass epoxy resin infusion
- glass epoxy prepregs
- carbon reinforcement
- carbon spar
- carbon blades
- thermoplastics

Ecological performance

Material	Description	Density kg/m^3	Energy kWh/kg	Flexural Strength MPa	Energy per unit load kWh/N
Aluminium	Extrusions	2700	60	290	**559**
Concrete	Walls (compressive loads only)	2200	0.33	30	**24**
Reinforced Concrete Beams		2400	0.7	30	**56**
Timber	Glulam, temperate softwood	500	1.33	14	**48**
Steel	Grade 43 sections	7850	11.5	275	**328**
GRP	Glass/Polyester 1:1	1950	26.4	150	**343**
CFRP		1900	60	600	**190**

Source: Chris Hornzee-Jones

Blade Manufacture at NEG Micon

Blade Manufacture at Bonus

Structure and Aerodynamics

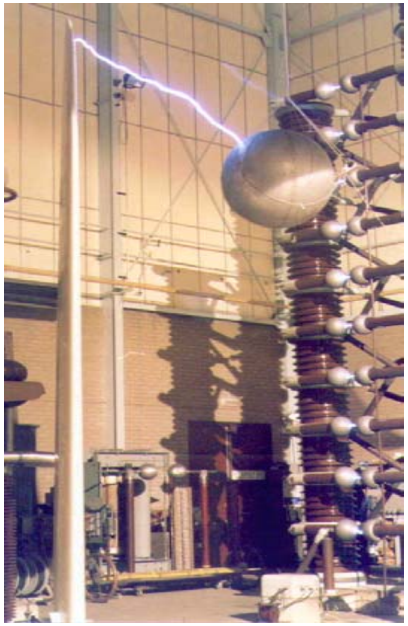
- Which comes first? Design democracy overdue.
- High lift and low lift aerofoils
- Cylinder versus aerofoil
- Aeroelastic design

Rotor Blade “Add-ons”

- Stall strips
- Vortex generators
- Gurney flaps
- Edgewise vibration dampers
- Dinotails

Testing and Certification

- Testing – absolutely vital, an obvious but slowly learned truth
- Certification – development of industry standards reflects maturing of the industry



Blade Testing at LM

Blades in the Wind Turbine Design Context

1. Cost of Energy

2. Up-scaling

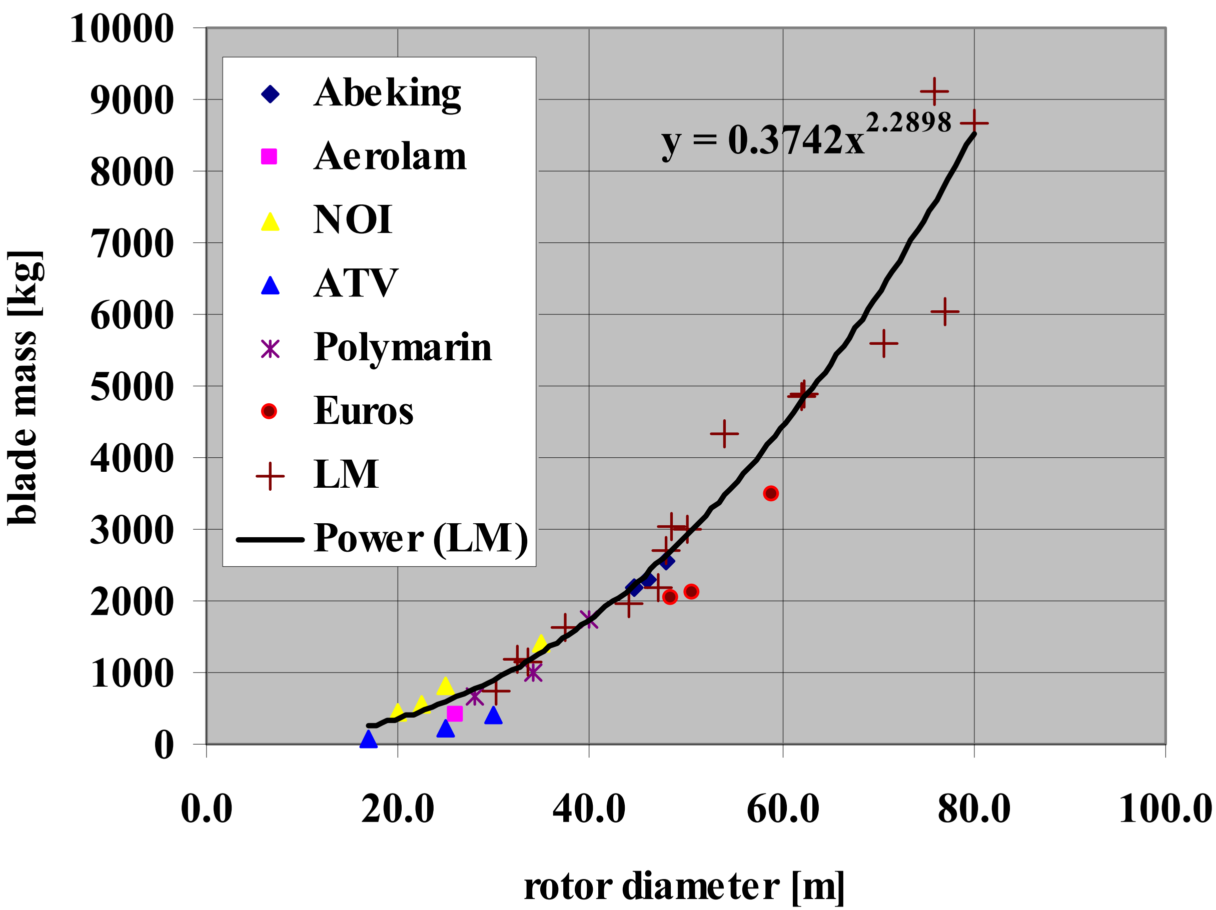
3. Structural flexibility

4. Control of loads

Cost of Energy Context

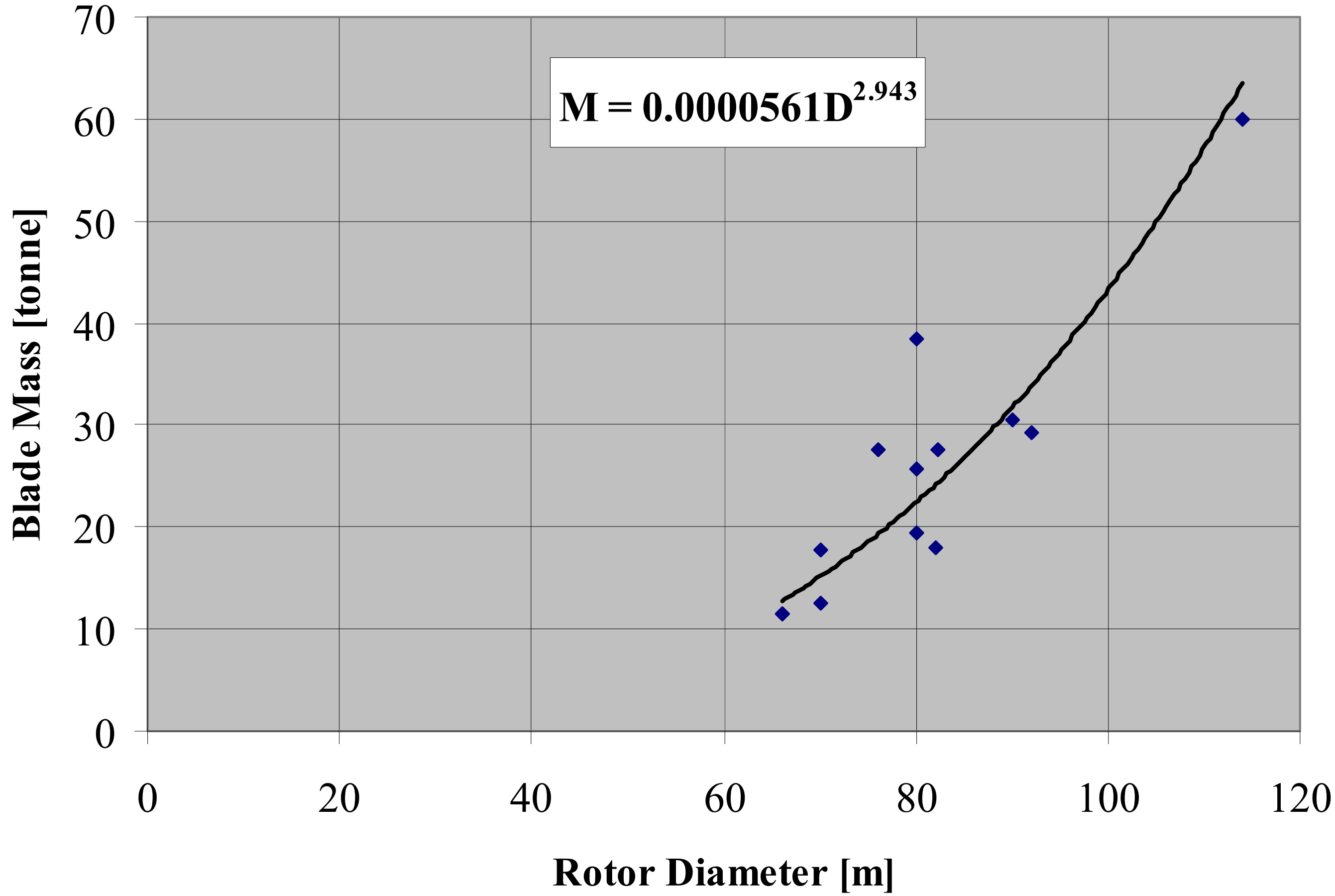
- Blades are about 18% of wind turbine ex works cost
- The turbine is about 55% of lifetime capital cost
- Hence blades amount to about 10% of total lifetime cost
- Thus 1% energy gain trades with 10% blade cost reduction
- It may pay to introduce more intelligence and actuator capability into blades rather than simply to pursue manufacturing cost reduction
- This means – larger rotors with better system load management, possibly through added rotor cost and complexity

Blade Mass Scaling – All Sources

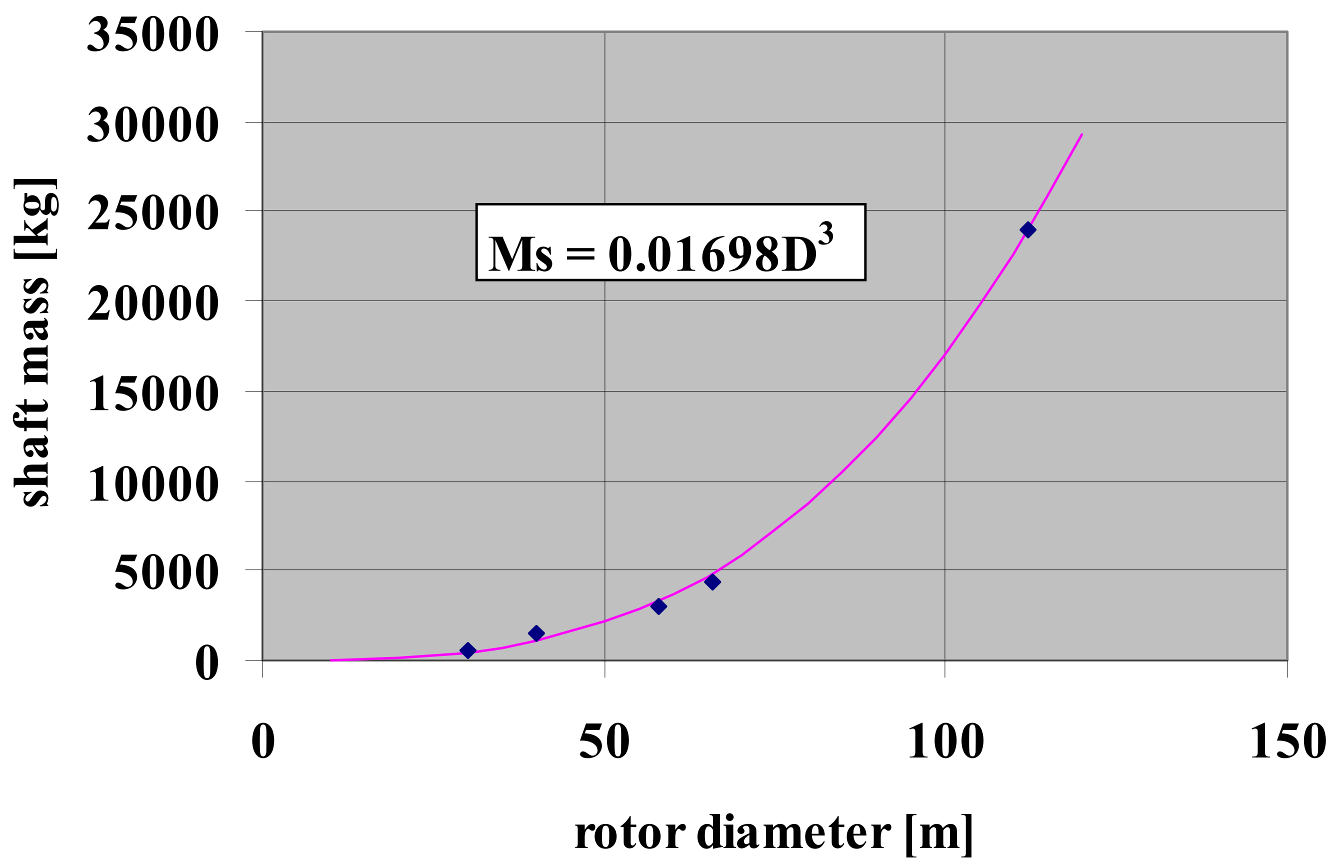


NOI	2.05
ATV	3.07
Polymarin	2.76
Euros	2.92
LM	2.30

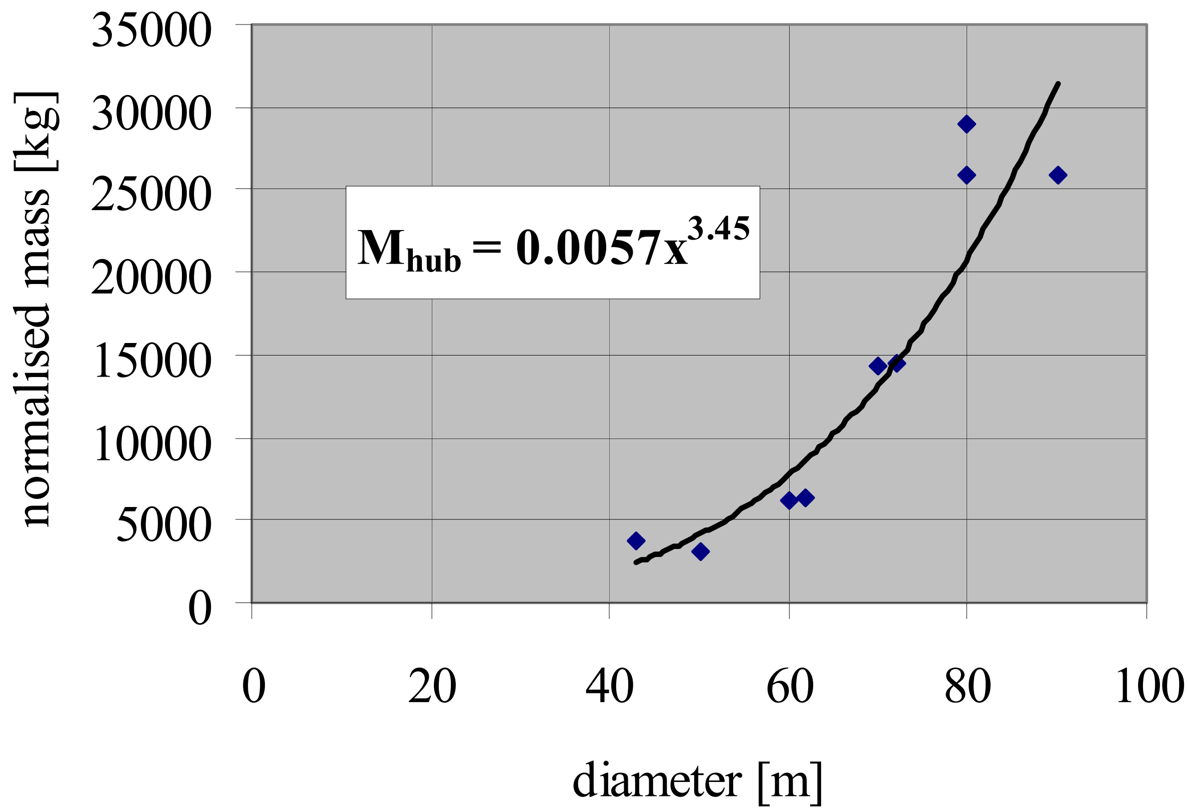
Blade Mass Scaling – Big Blades Only



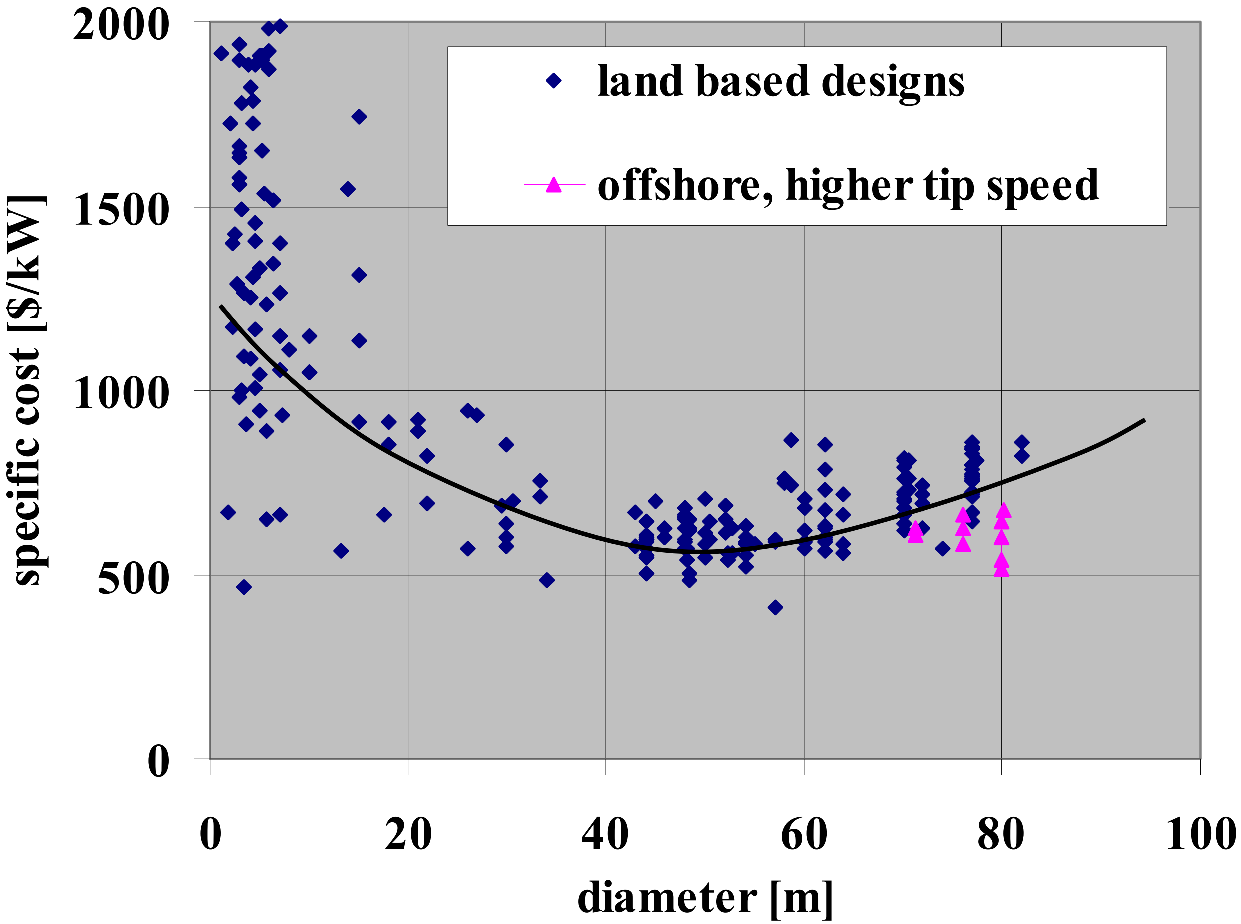
Shaft Mass Scaling



Hub Mass Scaling



Scaling of Turbine Price/kW



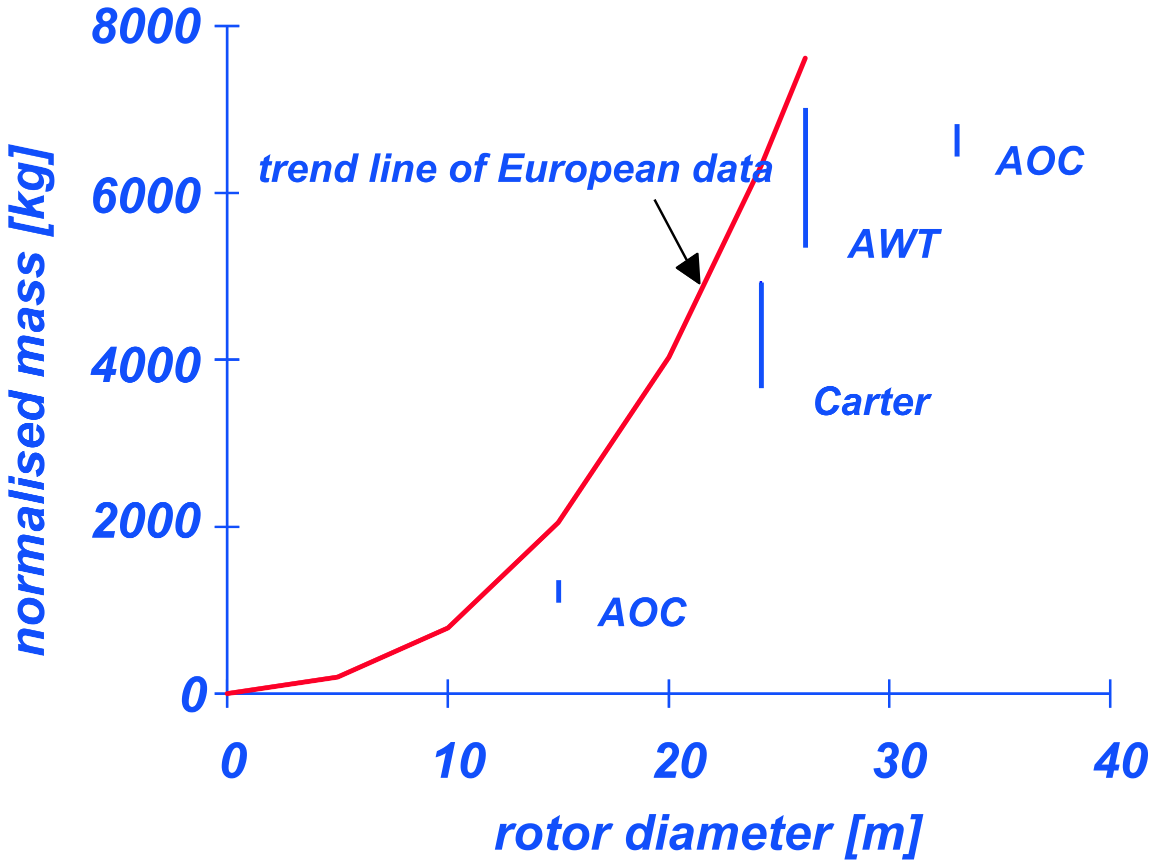
Significance of Scaling Trends

- Increasing cost/kW both for blades and complete turbine system points to economic limits for up-scaling
- Blades up-scale with geometric similarity and hence cubically because of a match between the designing aerodynamic loading and structural section modulus
- Self weight loading must not be allowed to become a driver or up-scaling economics will be yet worse

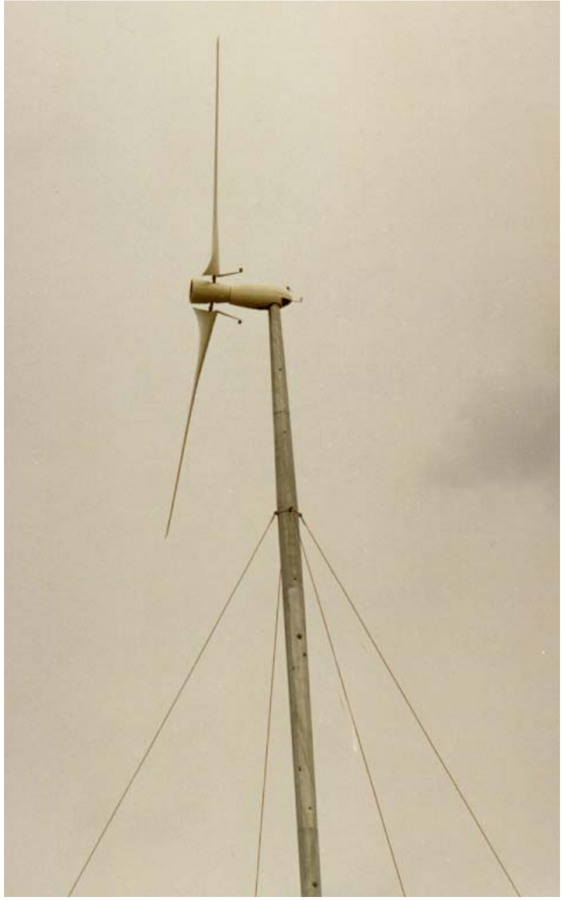
Structural Flexibility

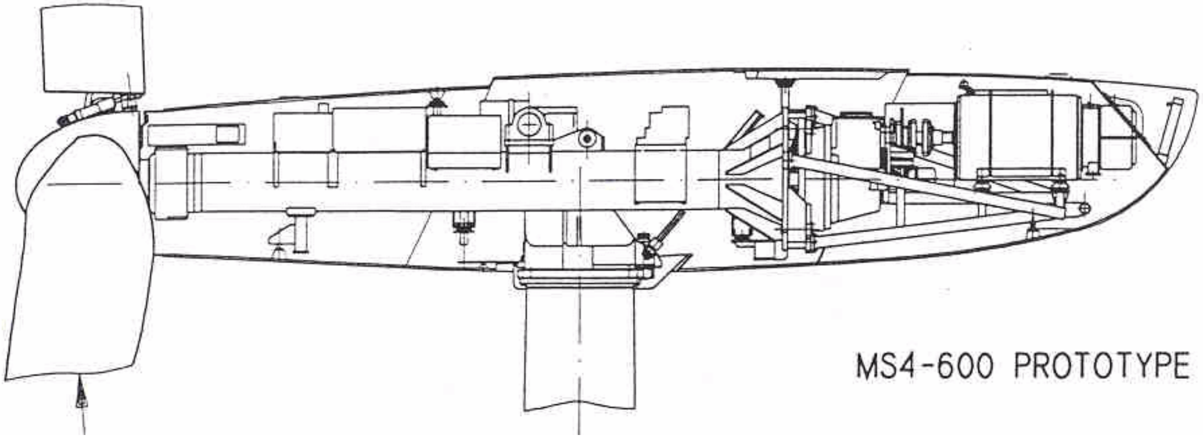
- Has been a “holy grail” of wind turbine cost reduction
- Myth of the Carter wind turbine design
- Lessons and insights
- Natural path to more flexible blades

Structural Flexibility – Impact on Tower Top Mass



Carter 300 and WEG MS4 Wind Turbine





Carter Design Concepts

- Stimulated interest in routes to lower mass and lower cost rotors and turbines
- Not the most commercially successful wind turbine but way out front in – engineering discussion hours/rated kW
- Widespread confusion about the influence of structural flexibility on system mass

More Flexible Blades

- Useful potential cost reduction in downwind flexible rotors but easily overestimated
- Popular fallacy that free yaw saves significant cost in the yaw system
- Avoid cost centre of “extreme” flexibility which requires Carter-like solutions of spar/shell composite hinge
- Glass is an automatic choice for flexible blades because of its high strain capability but, surprisingly, carbon may be the more logical material for very flexible downwind rotors

Future

1. Bigger blades but only if offshore market grows as predicted

2. More carbon – but in what form?

3. More adaptable rotors