Challenges and perspectives in future wind energy technology and the role of system engineering

Flemming Rasmussen,
DTU Wind Energy
Aeroelastic Design
Risø Campus

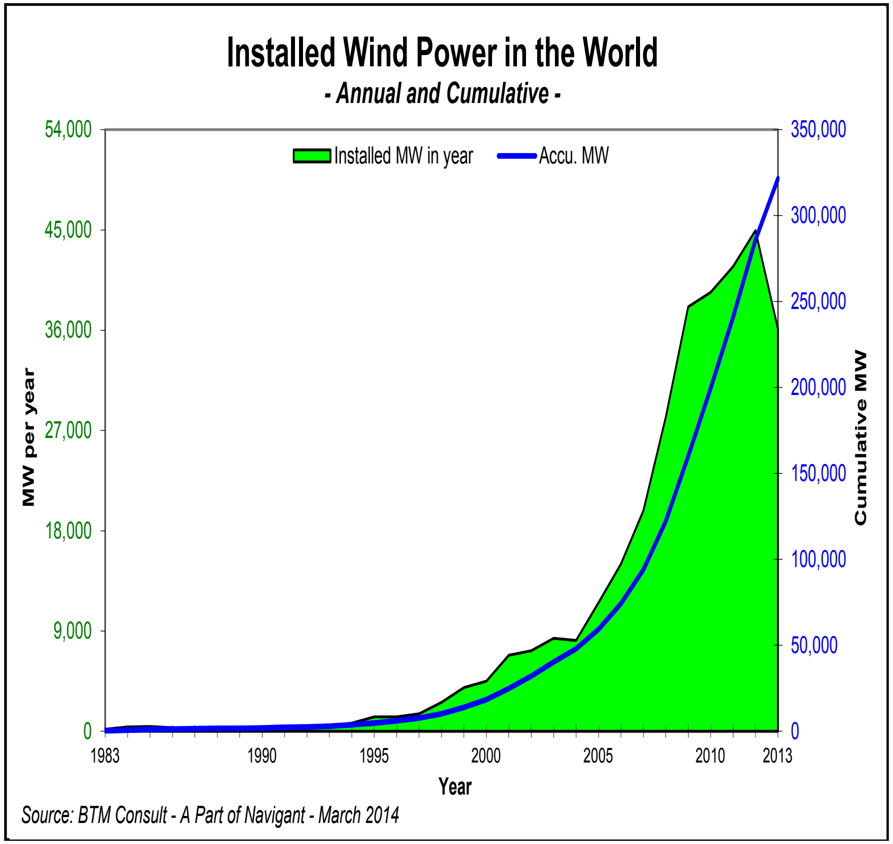
Outline

- Global market status
- Historical perspective - evolving of engineering practices, science and technology
- Status and future of wind energy technology and concepts
- Wind energy perspectives

Challenge:

- Wind energy has the potential to become the backbone of a future secure global energy supply - or wind energy as “base load”.
- It’s all about cost of energy, however, including a future perspective (not necessarily the cheapest now)

Global market status - 2014



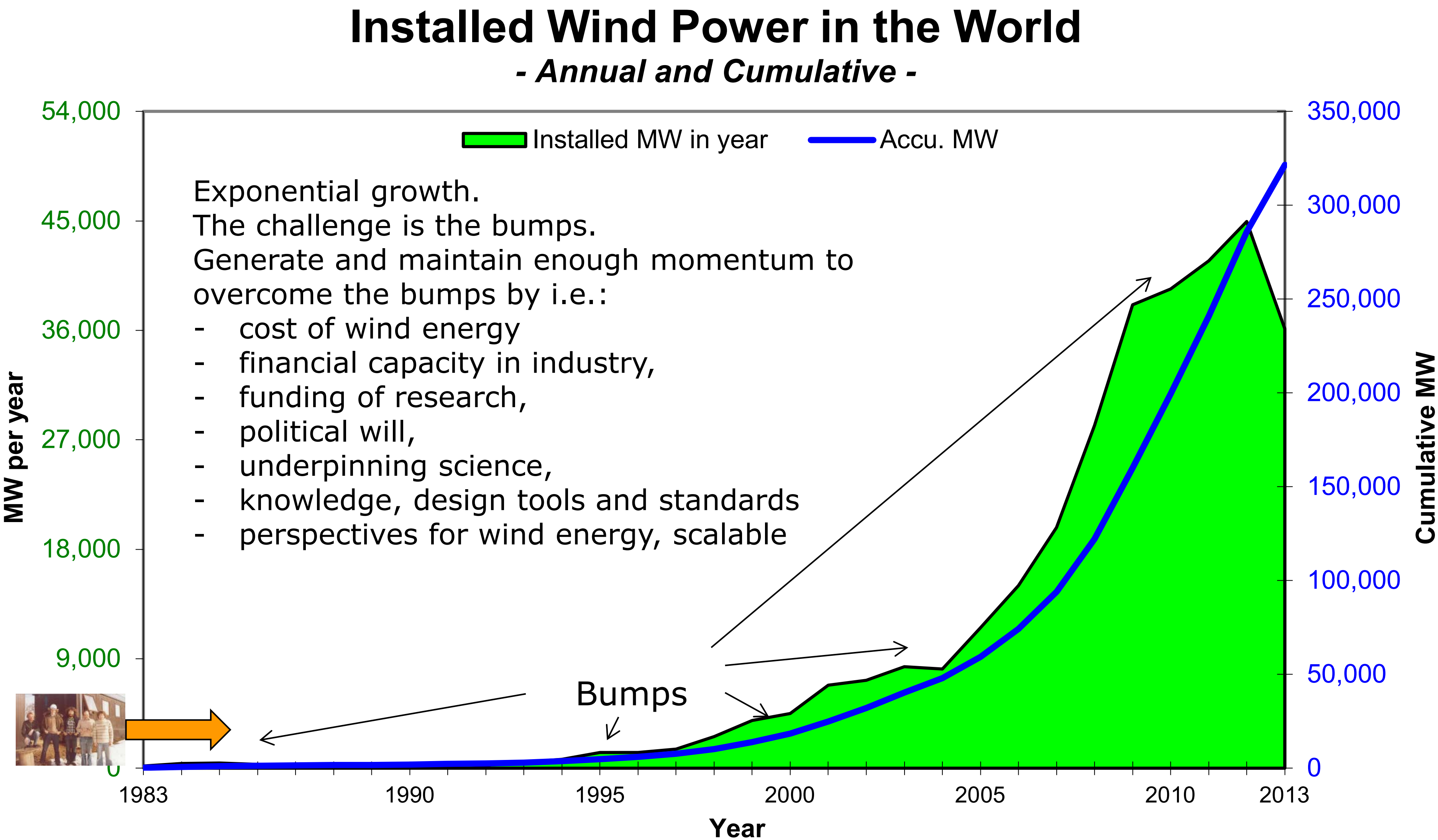
GLOBAL STATUS (early estimate by GWEC)

- ~ 47 GW installed in 2014
- ~ 369 GW installed in total
- ~ 3.5 % of global electricity
- Wind energy begins to count

STATUS DENMARK

- 39% from wind in Denmark
- 62% in January, 23% in June
- Days with more than 100%
- Energy Plan: 50% by 2020
- Plan to promote heat pumps, electric cars.....
- Electricity prices varies...

Global market development 1983 - 2014



Source: BTM Consult - A Part of Navigant - March 2014

The Test Station for Wind Turbines/Risø 1979 – a variety of concepts

Employees at The Test Station for Wind Turbines, Risø 1979

System engineering network

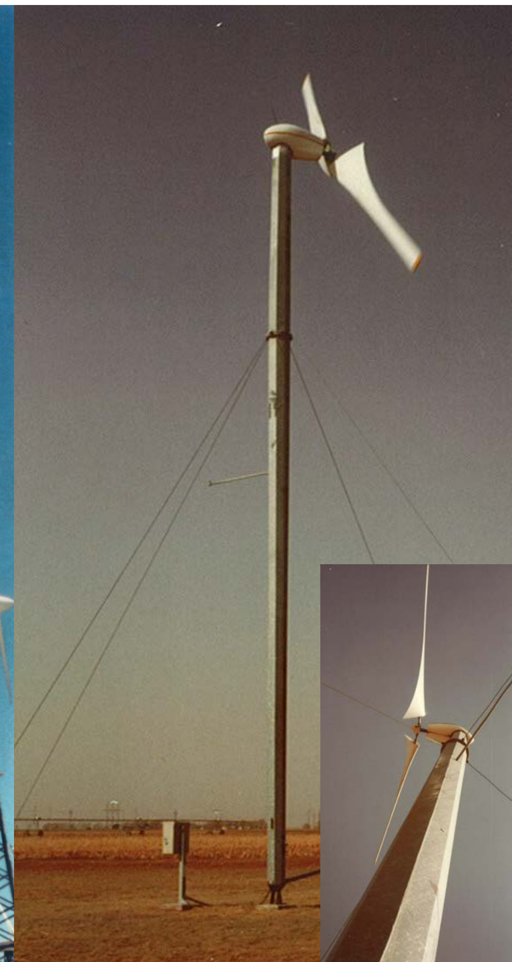
- Plans for a complete optimization tool even including manufacturing

- Wind turbines developed in a kind of system engineering context in a network – manufacturers, private persons, interest organizations, research community
  - open exchange of knowledge and ideas
  - setting requirements, airbrakes...
  - system approval included
  - concept selection

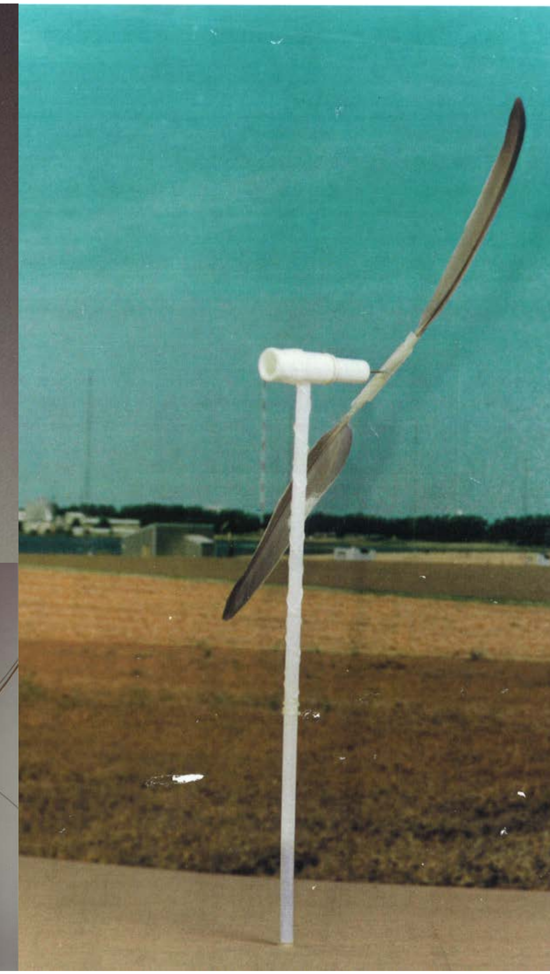
1980’s turbine concepts

Standard concept

Radical technology, Carter



Vision



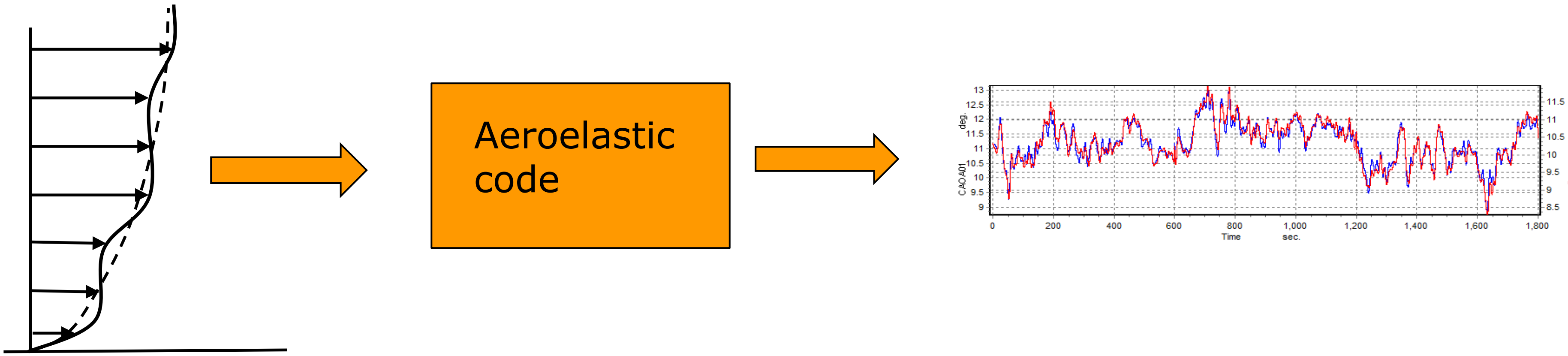
Evolving of engineering practices

- Development of specific simple design tools and rules in the beginning
- Aerodynamic model (BEM)
- Extreme design load 300 N/m2 swept area distributed on the three blades in a triangular shape for blade and tower design
- One blade full load, the two others with half load to determine yaw and tilt moments
- Main shaft 1% of rotor diameter
- Equally simple rules for fatigue
- Similarity rules and upscaling:

  $P \sim P_0 \cdot \omega^3 \cdot R^5$
- Blade testing
- Gradually supplemented by specific codes

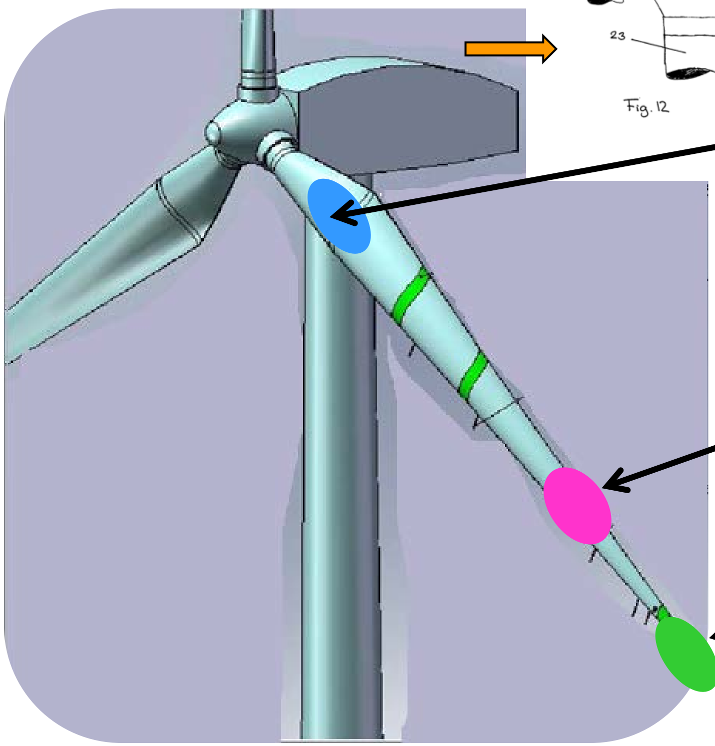
Evolving of engineering practices

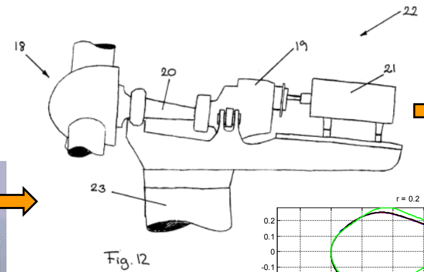
- Break through with the development of aeroelastic simulation tools

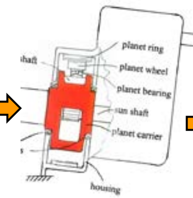


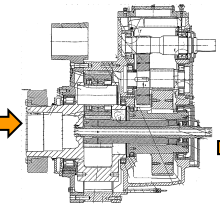
- Development of standards and certification

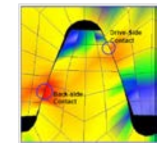
System approval, optimising reliability

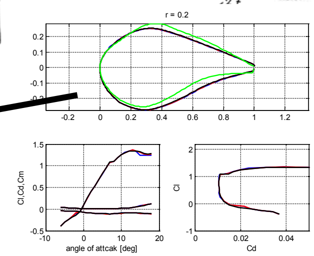






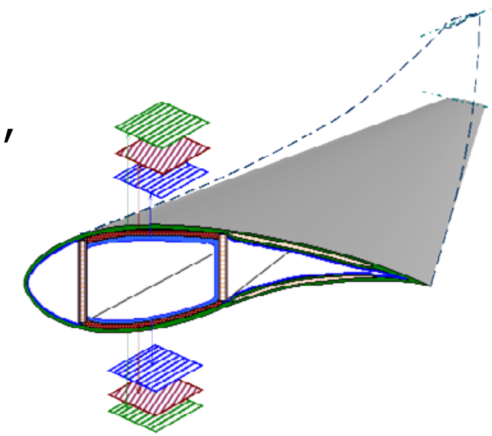




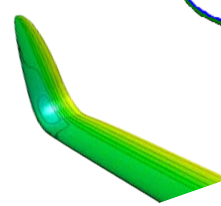


Root section, 3D
rotational effects, deformations

Mid span, 2D,
structure



Tip, 3D



Airfoil data
Mode shapes
Edgewise vib.
Flutter
Couplings

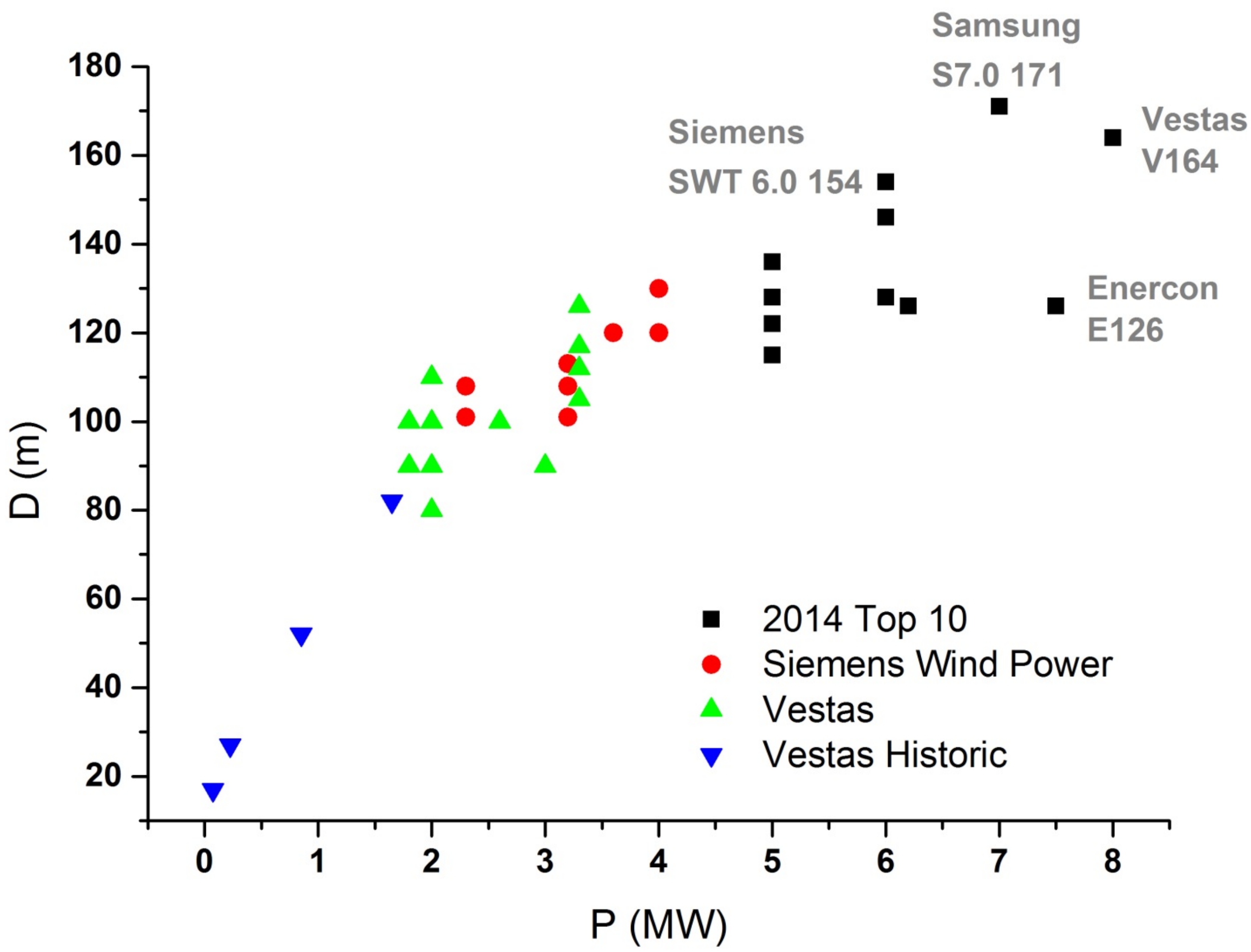
Evolving of engineering practices

- Science, research and development on track - in global interaction.
- Progress on research and development, refinement and coupling of codes.
- Change from open to closed environment. Competition in industry.
- New perspectives in System engineering <> Crowd sourcing, crowd funding also used in 1750’s.

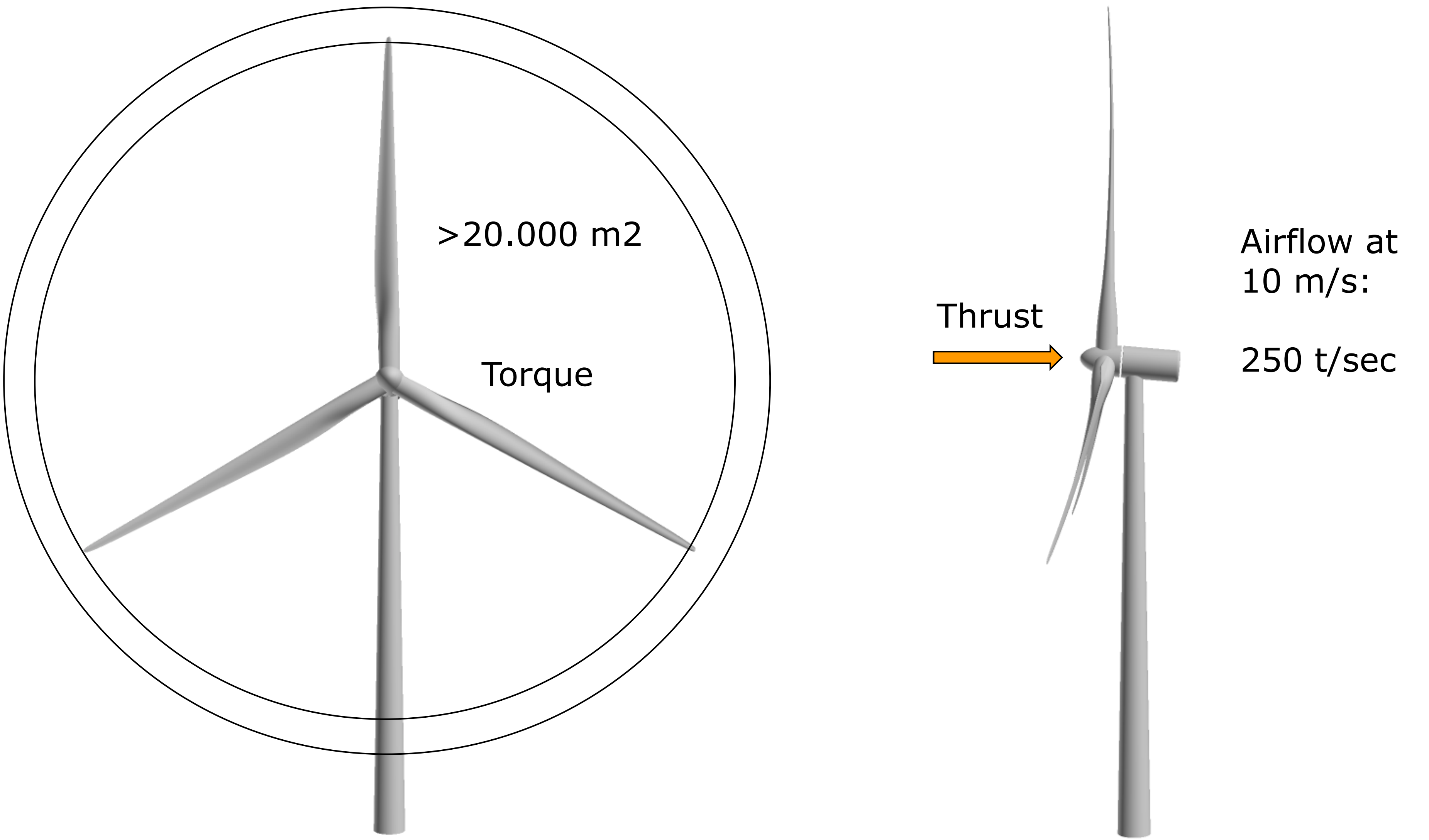
- Our goal is cost efficiency and sustainable development. Not the same as the cheapest right now.

- System engineering to help develop new insight and maintain knowledge. Increase crowd intelligence.

Upscaling and longer blades -evolving of technology

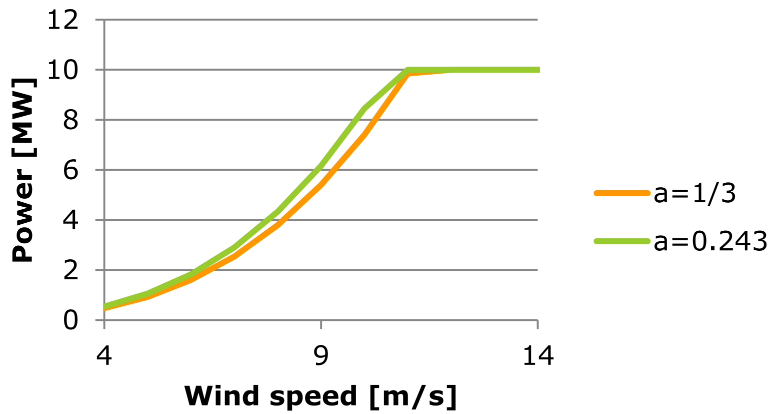


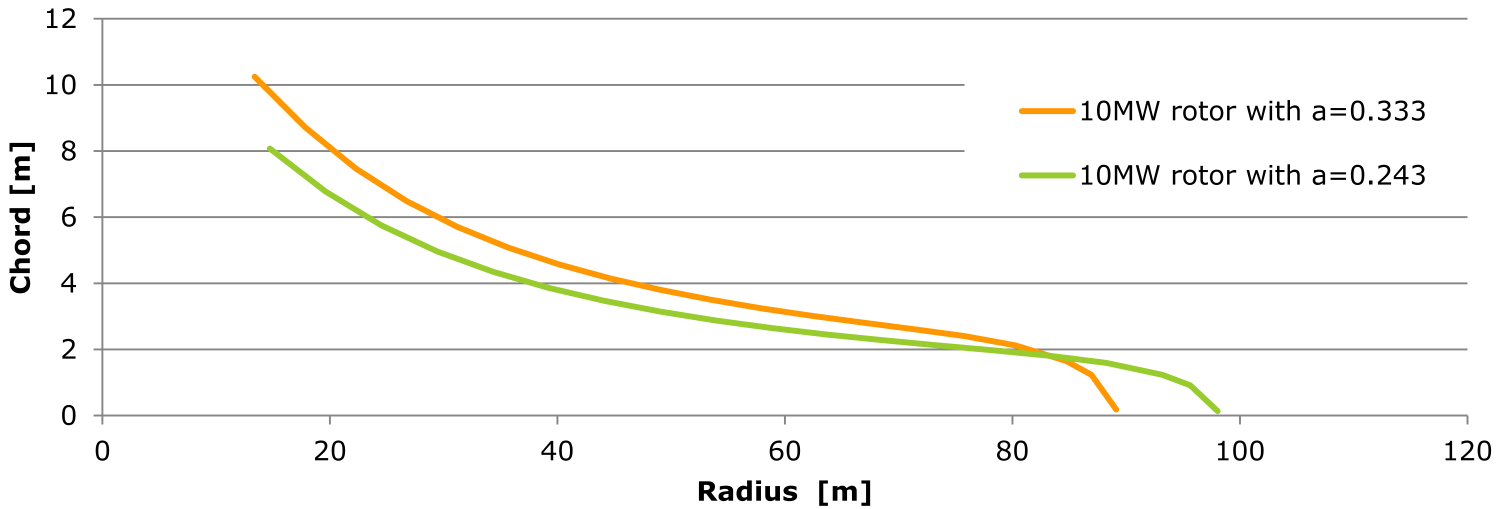
Standard three-bladed turbine, DTU 10 MW



Low induction rotors

- Two rotors designed by simple means and maintaining thrust:
  - Radius=89.166m, a=0.333, TSR=8.0, CP=49.5%
  - Radius=98.083m, a=0.243, TSR=8.8, CP=46.7%
- Area increase=21%, CP reduction=5,6%
- Total power increase at low wind speed=14%
- AEP increase ~7%





Wind turbine concepts

Envision 3.6 MW

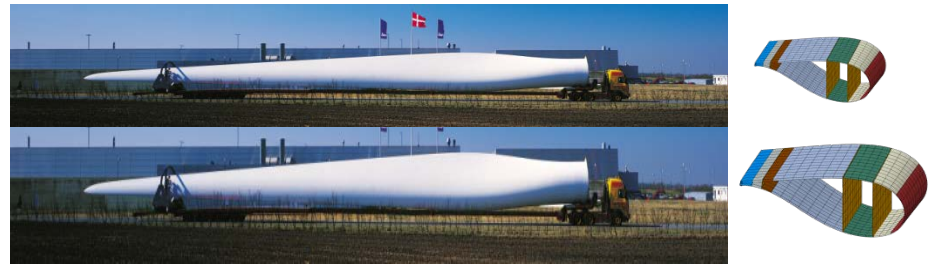
DeepWind

Multi-rotor

Number of blades: 2-bladed/3-bladed

The 2-bladed has:

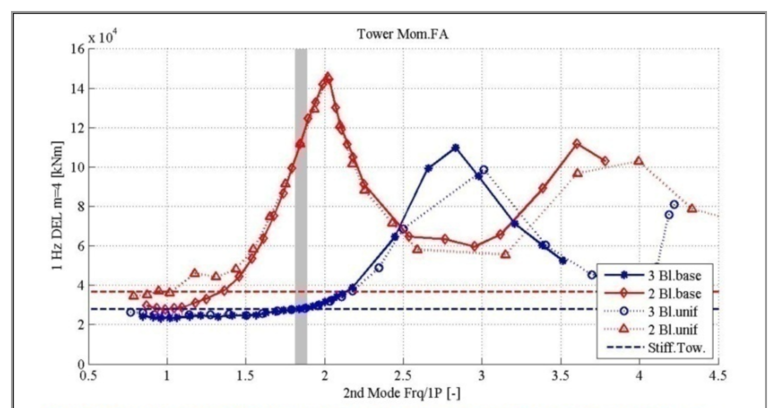
- 50% larger chord
- 4% lower efficiency
- 15 % larger turbulence load input (as 2p<3p)
- App. 2/3 rotor weight



With teetering hub:

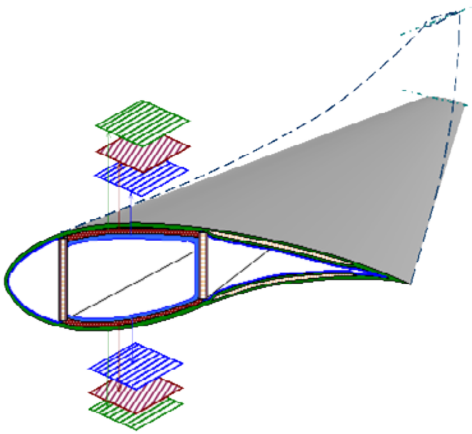
- App. 50% rotor weight
- Blade load ~ blade load for 3-bladed
- Possibility for larger diameter

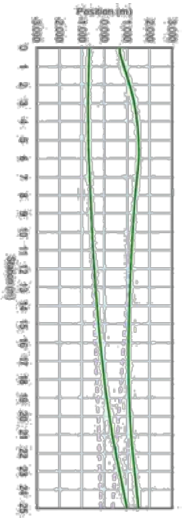
- Tower natural frequency has to be lower (down towards 1p, or lower)



Coupled deformations

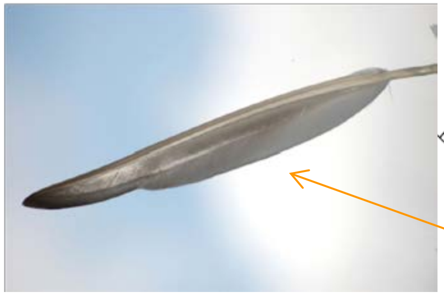
Flap-torsion

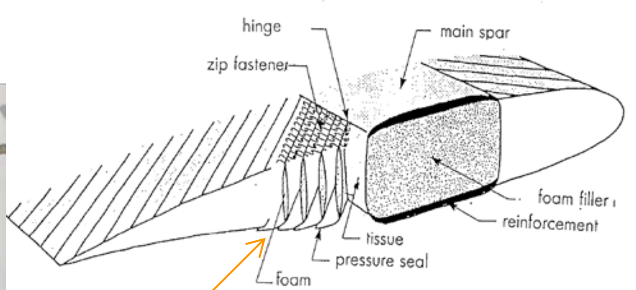




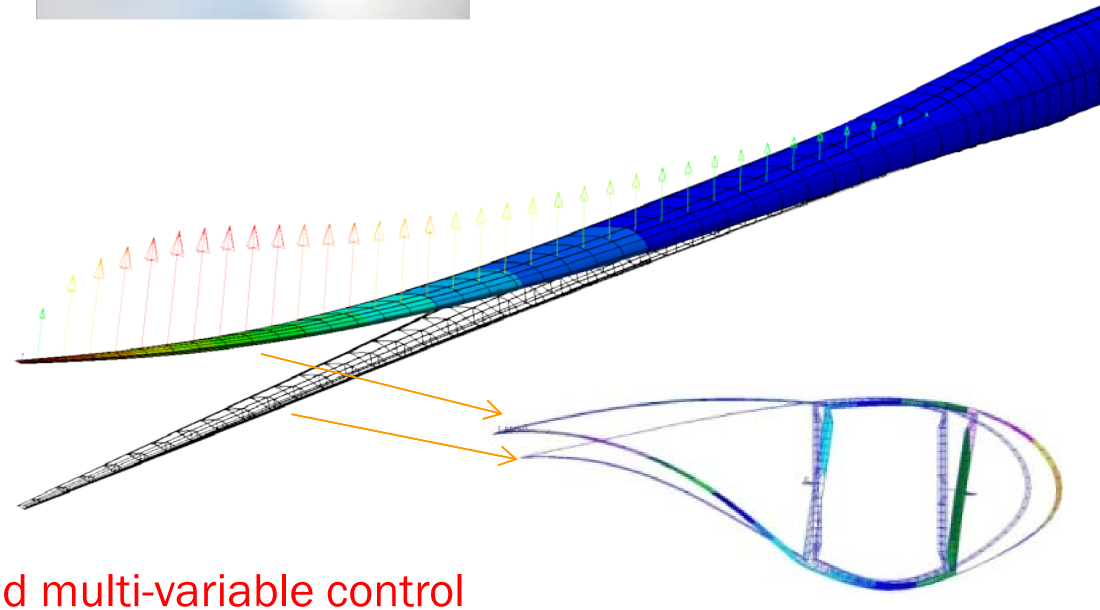
A Twist–flap Coupled Blade Design to Alleviate Fatigue Loads (on the left with material coupling and on the right with a curved blade (Sandia)

Flap-camber





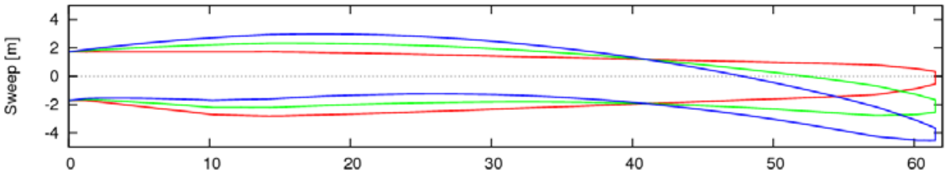
Feather



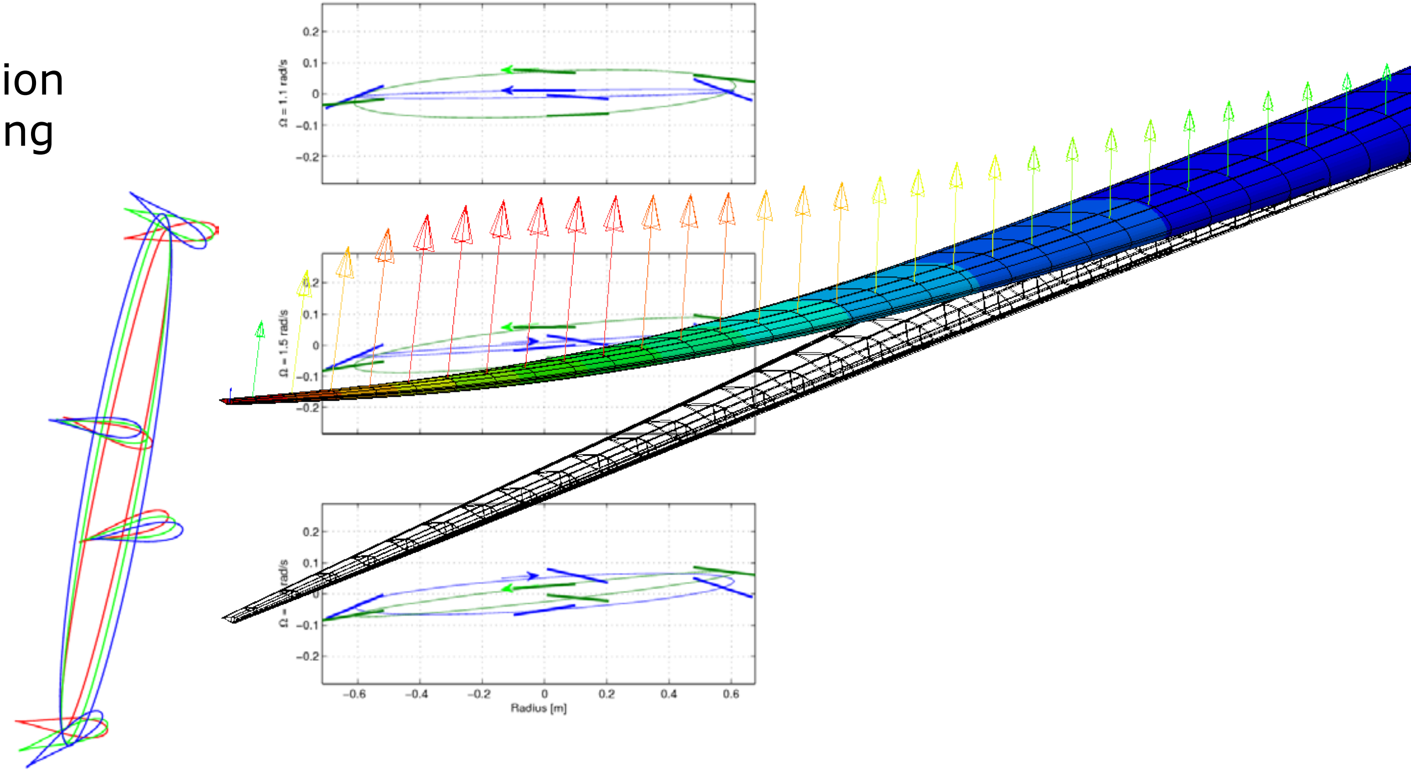
Combined passive built-in coupling and multi-variable control - an optimum design

Aeroelastic stability

Example: Swept blades



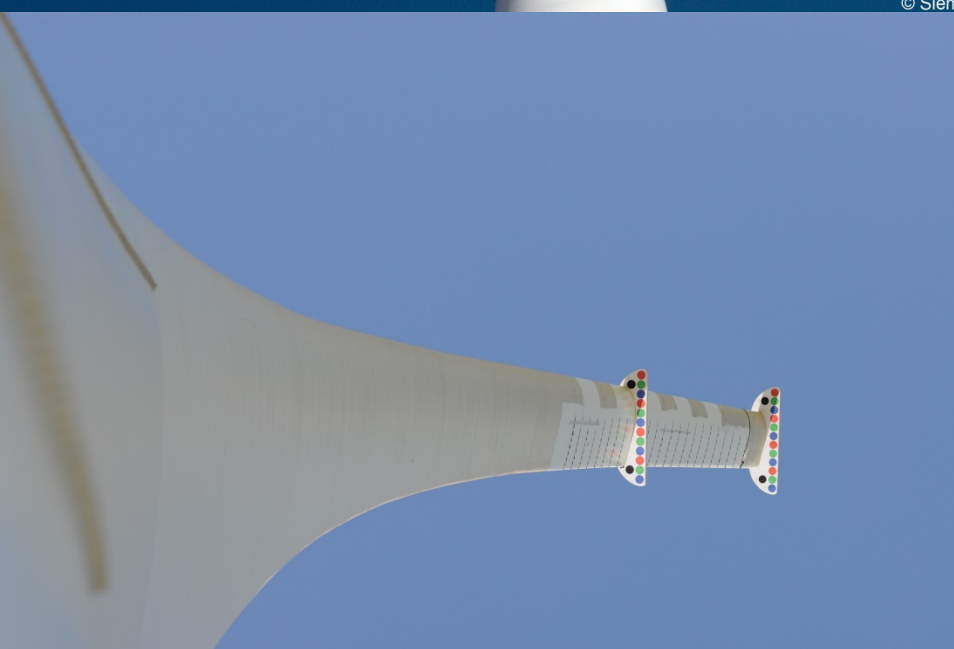
Different section motion gives different damping and load alleviation

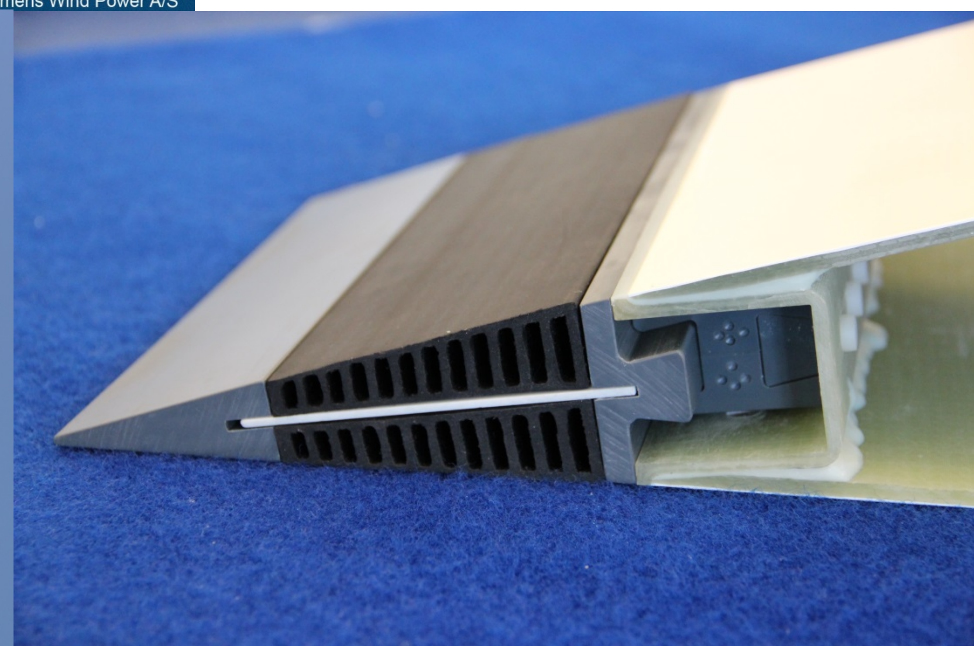


Combined blade pitch and trailing edge flap

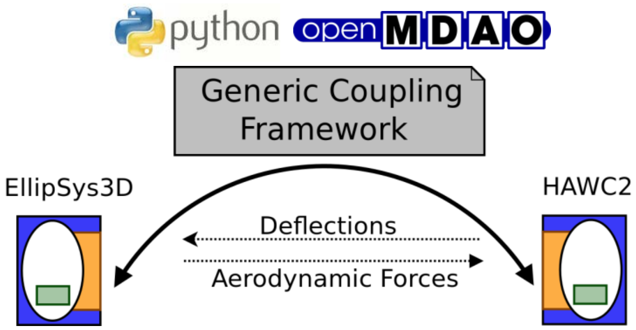
Load reduction

- Cyclic pitch: 15%
- Flaps: 14%
- Combined: 24%

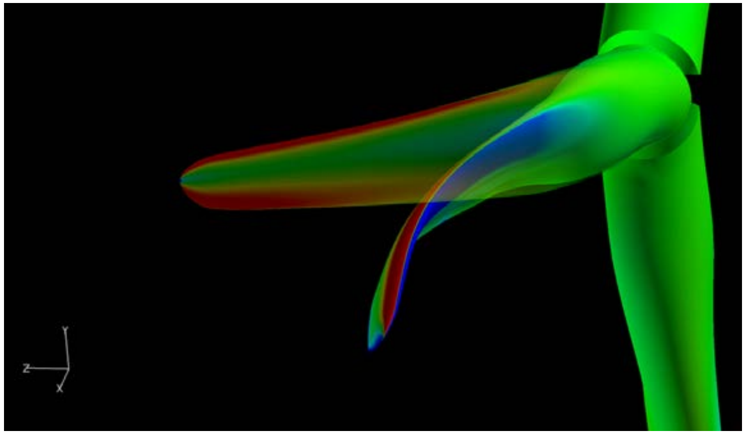


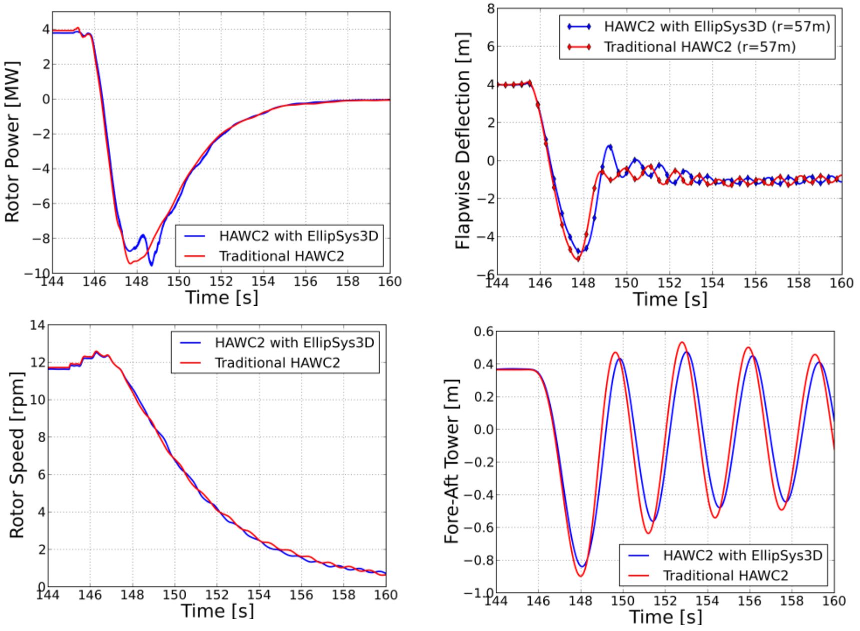


Fluid-Structure Interaction Simulations Using CFD

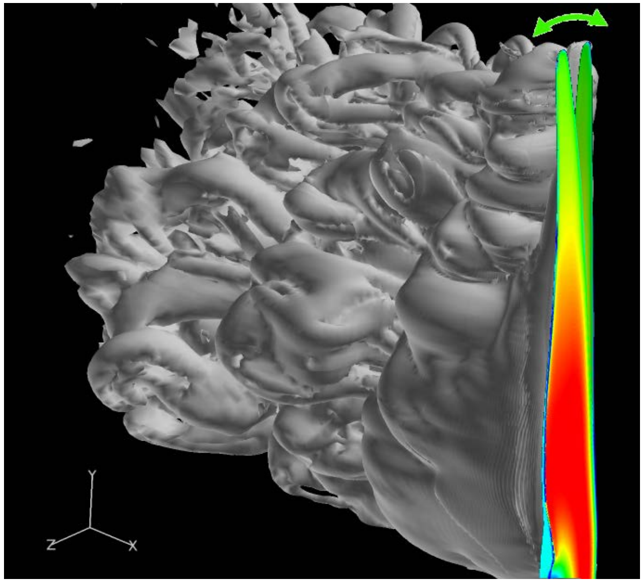


Emergency Shutdown



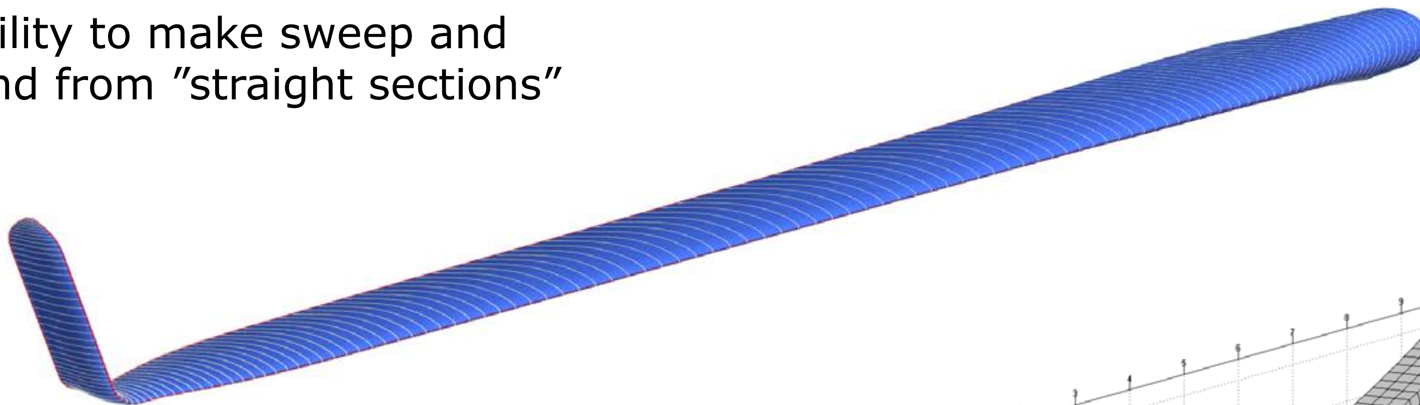


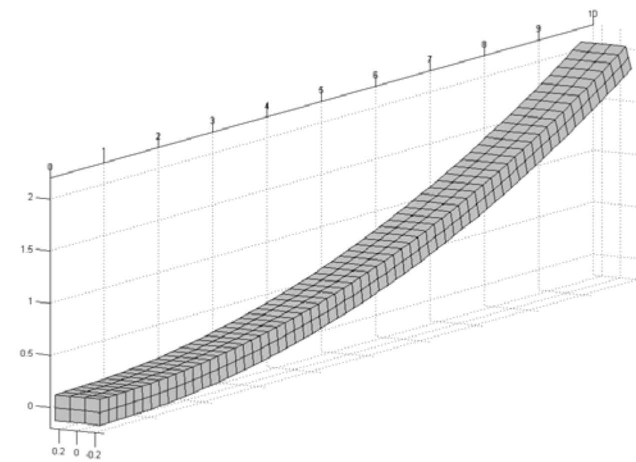
Standstill Vibrations

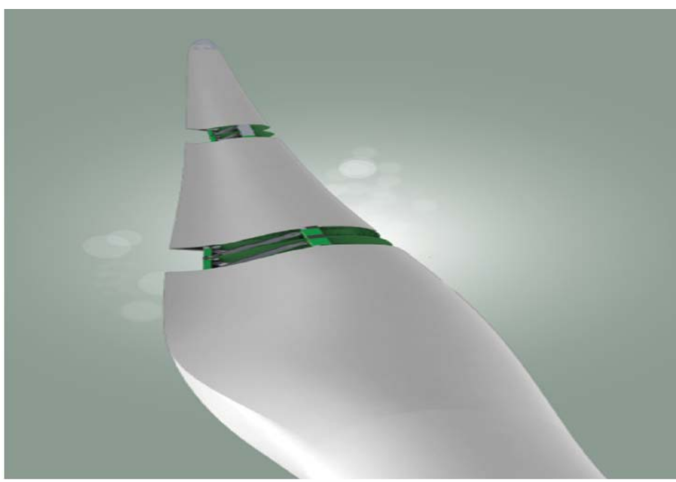


Segmentation of large blades ?

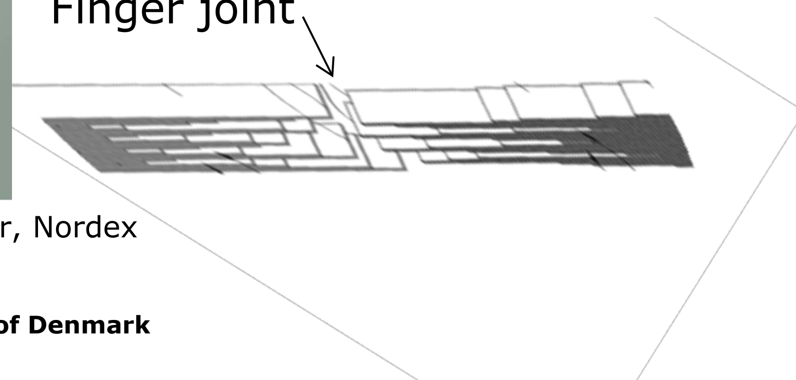
Possibility to make sweep and
prebend from ”straight sections”



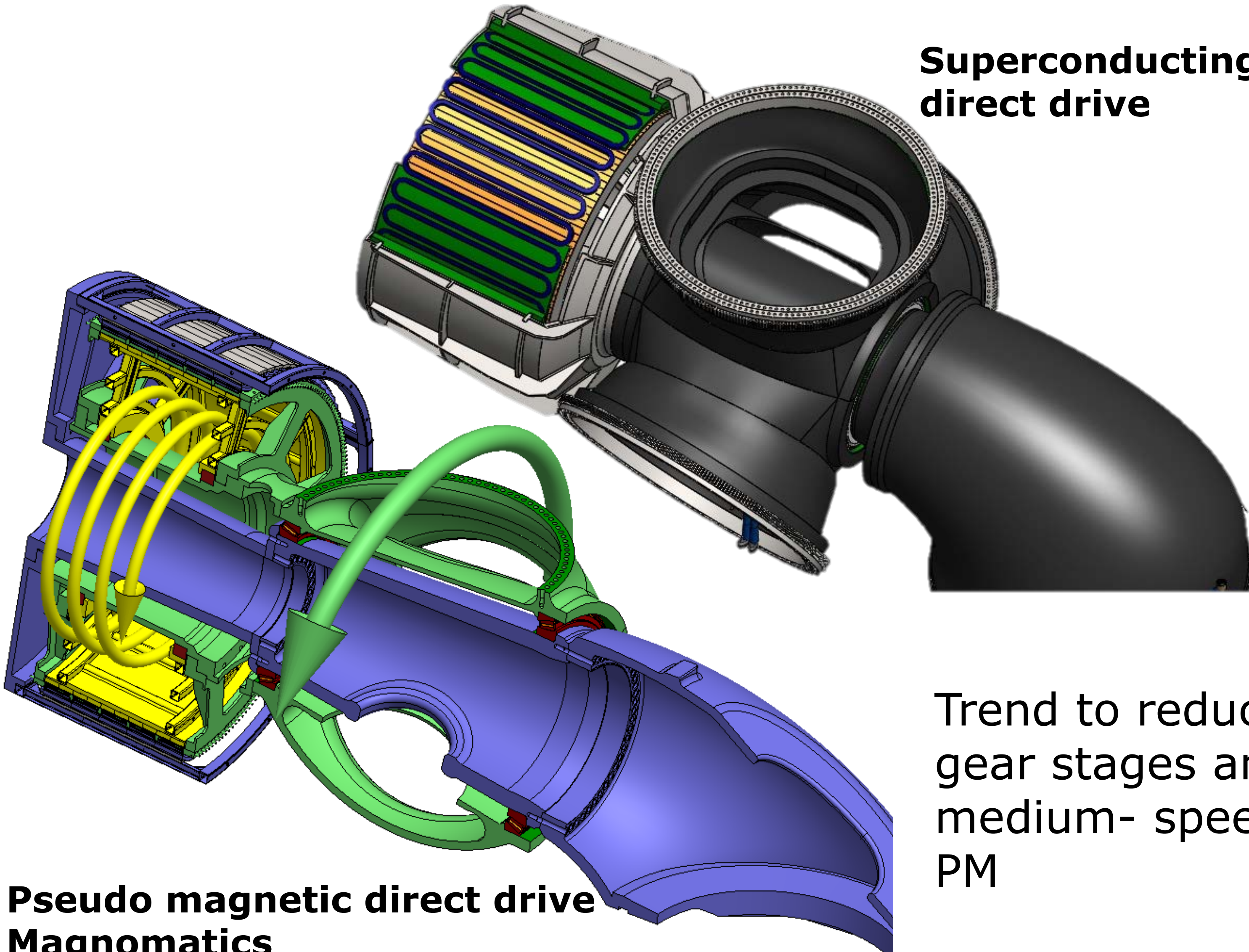




Source: Lutz Beyland, Dr. Jochen Birkemeyer, Nordex



Electro-mechanical conversion

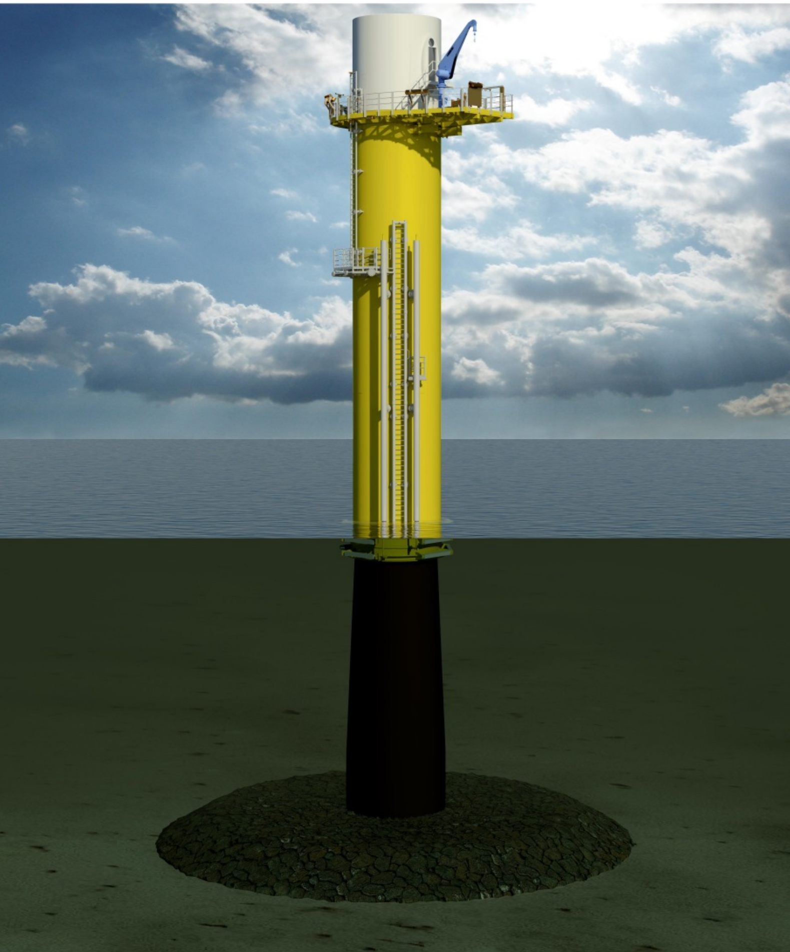


Superconducting direct drive

Pseudo magnetic direct drive
Magnomatics

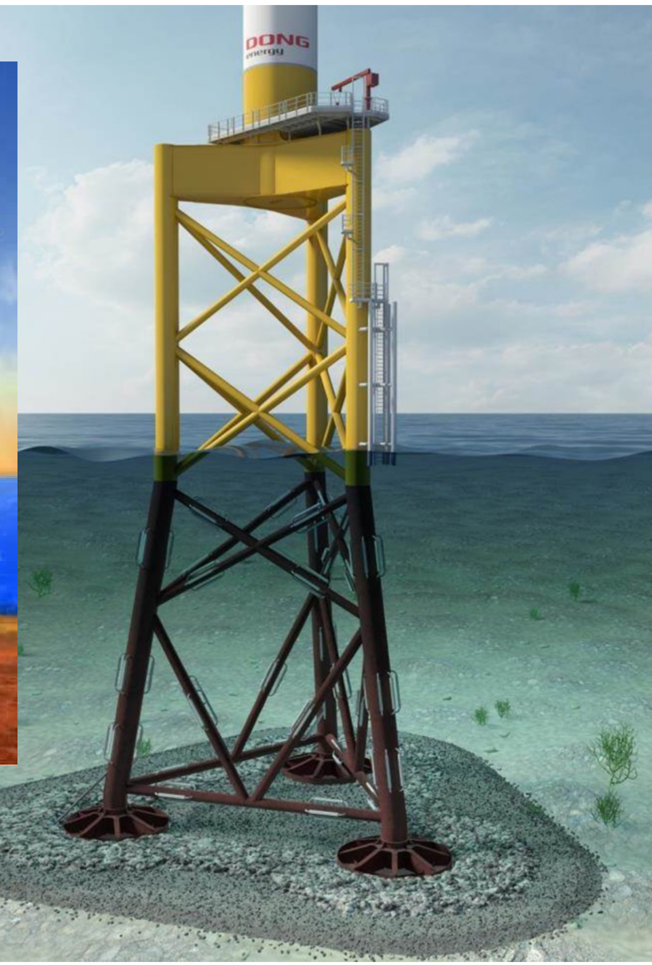
Trend to reduce number of gear stages and use medium- speed multipole PM

Offshore & foundations bottom mounted



Rambøll

NREL

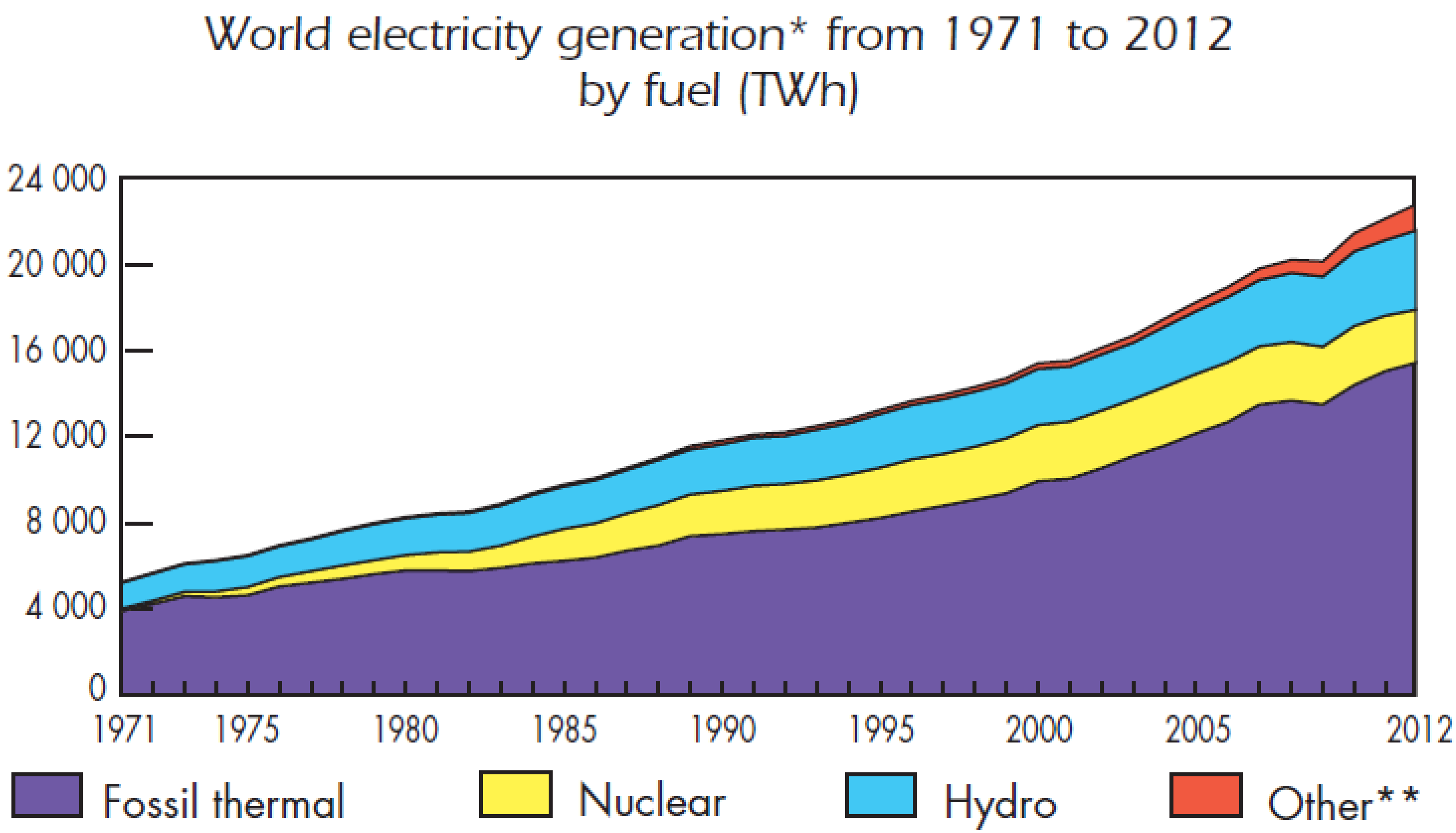


DONG Energy

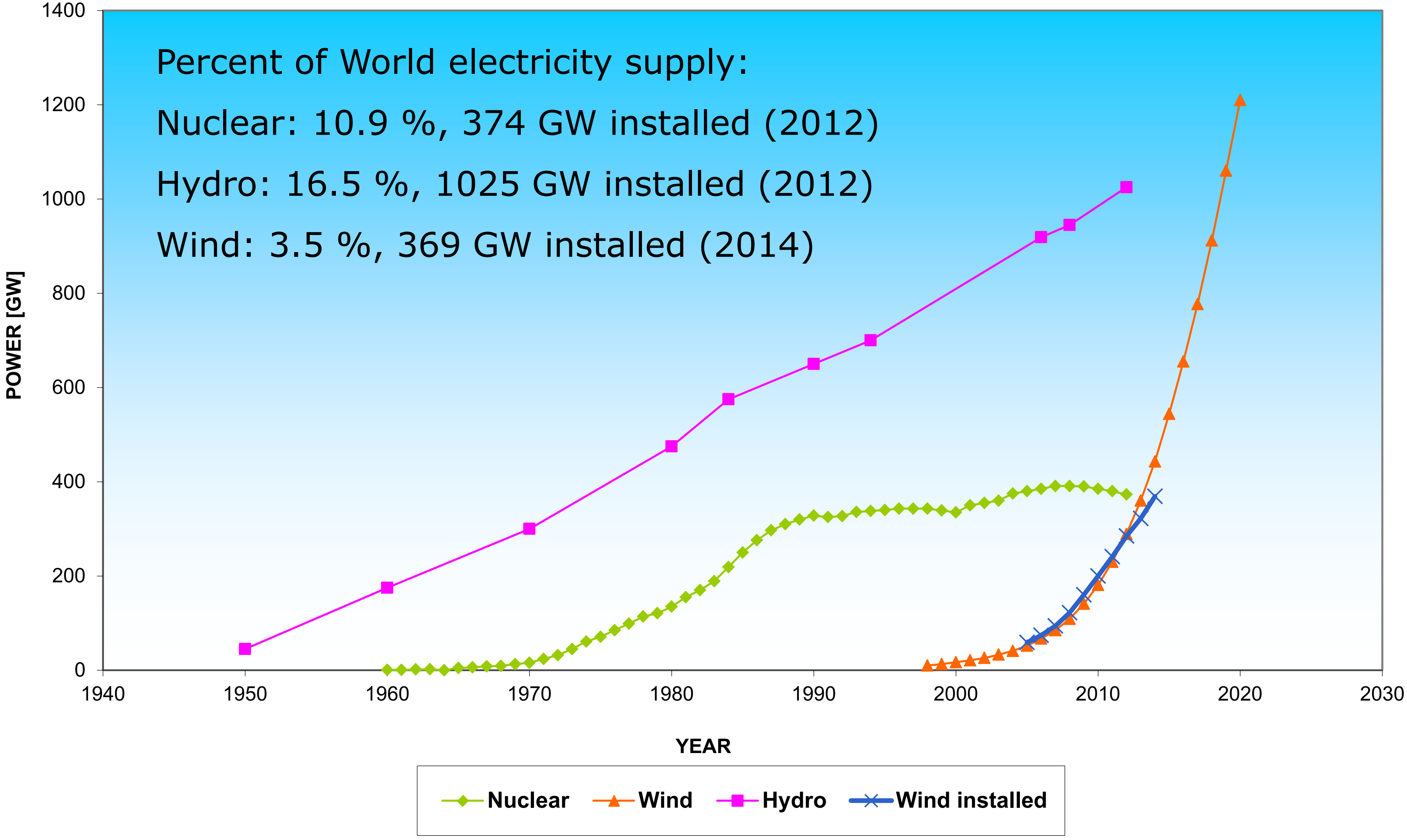
Technology perspectives

- Upscaling - 10 MW is within reach.
- Aeroelastic tayloring and distributed control. Future blades will become longer, more coupled and more flexible (in the tip). Possibly made in sections.
- Great perspectives for emerging technologies.
- Getting more complex.
- Turbine in the power plant in the energy system.
- Lots og benefits in a more integrated system approach – and in more integrated turbine and plant design.
- Conversion of new concepts into mainstream is a challenge.

Wind energy perspectives - World electricity generation



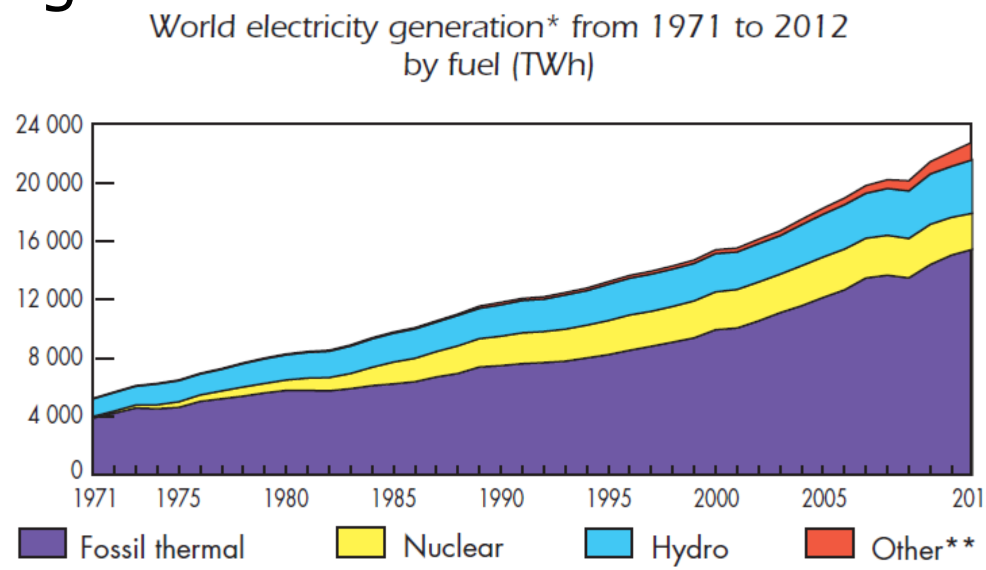
Accumulated power in the world, 2014
10 % Wind energy-scenario (1998)



Outlook for wind electricity generation

Integration is the challenge
Wind-Hydro-pumped storage
part of the solution

Example Norway:
30 GW hydro power
2 GW pumped storage
15 GW potential for both



Global:
Hydro power supply 16.5% with a capacity factor of 1/3
Could supply 50 %, ”if there was enough water”

Thank you for your attention!