WP1A1 - Integration
WP1B4 - Up-scaling

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SIXTH FRAMEWORK PROGRAMME
UpWind

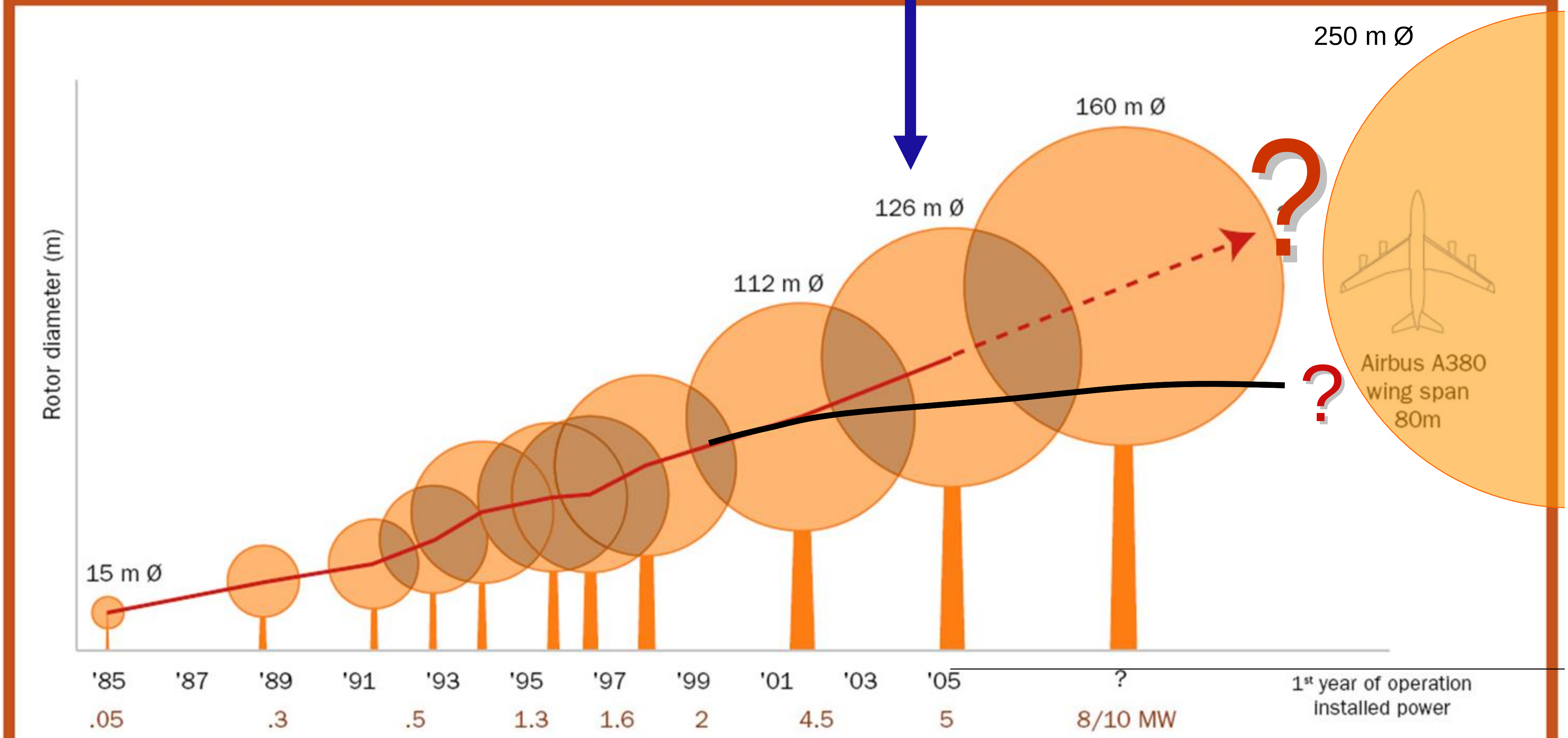
WP 1A1 & WP 1B4

Objectives:

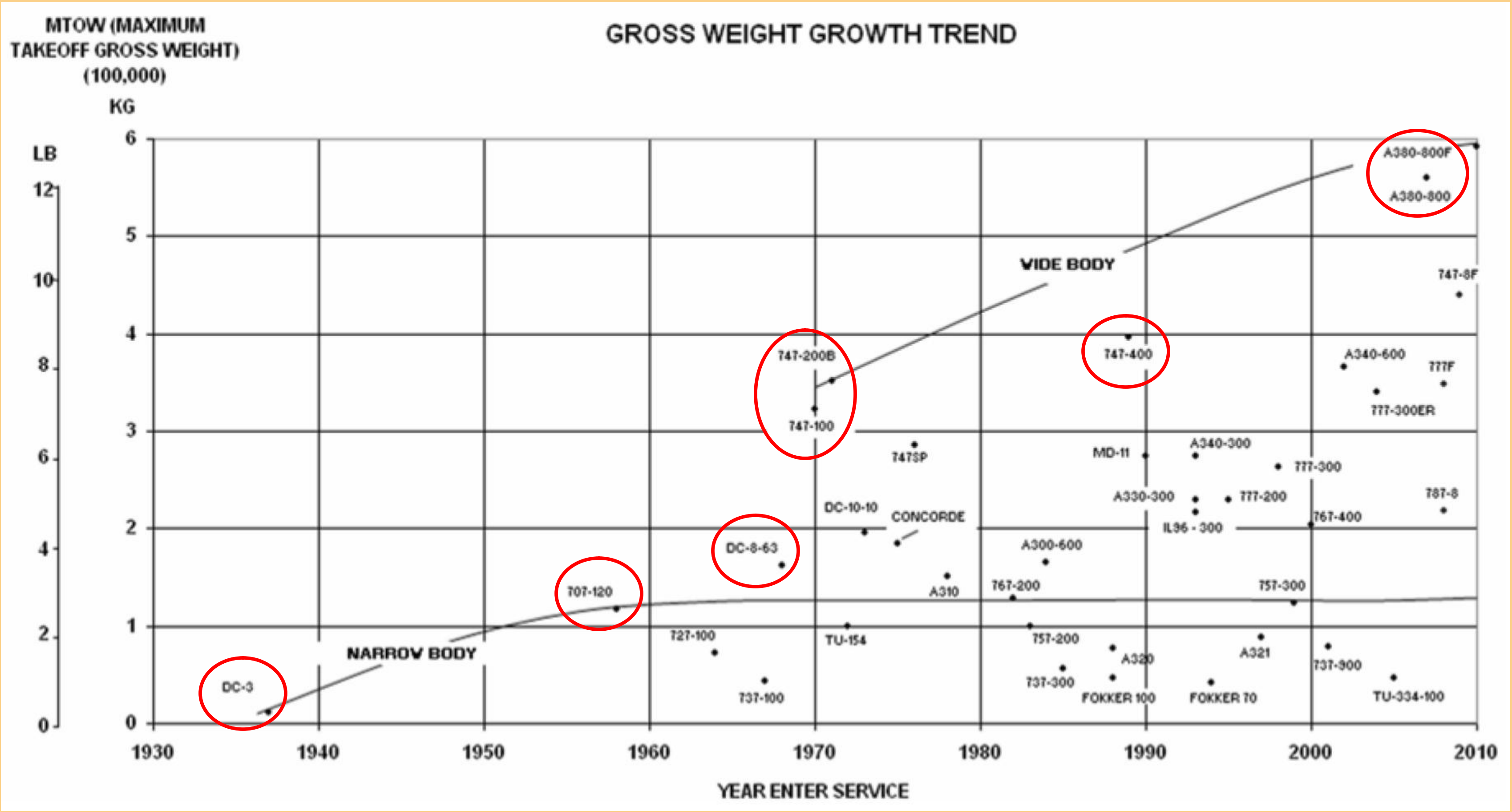
- *Development of integral design approach methodology*
- *Development of (pre)standards for application of the integral design approach*

- Develop cost models for application in other WP for comparisons and for demonstration of potentials and benefits of design developments
- Evaluate pros and cons of different design options by calculation of cost of energy
- Define the technological bottlenecks for successful up-scaling of wind turbines to **20MW**

Up-Scaling


250 m Ø
160 m Ø
126 m Ø
112 m Ø
15 m Ø
?
?
Rotor diameter (m)
Airbus A380
wing span
80m
'85 '87 '89 '91 '93 '95 '97 '99 '01 '03 '05 ?
.05 .3 .5 1.3 1.6 2 4.5 5 8/10 MW
1st year of operation
installed power

Up-Scaling
Development in airplane size –MTOW



From: “Commercial Aircraft Design Characteristics” International Industry Working Group *Fifth Edition R1, 2007*

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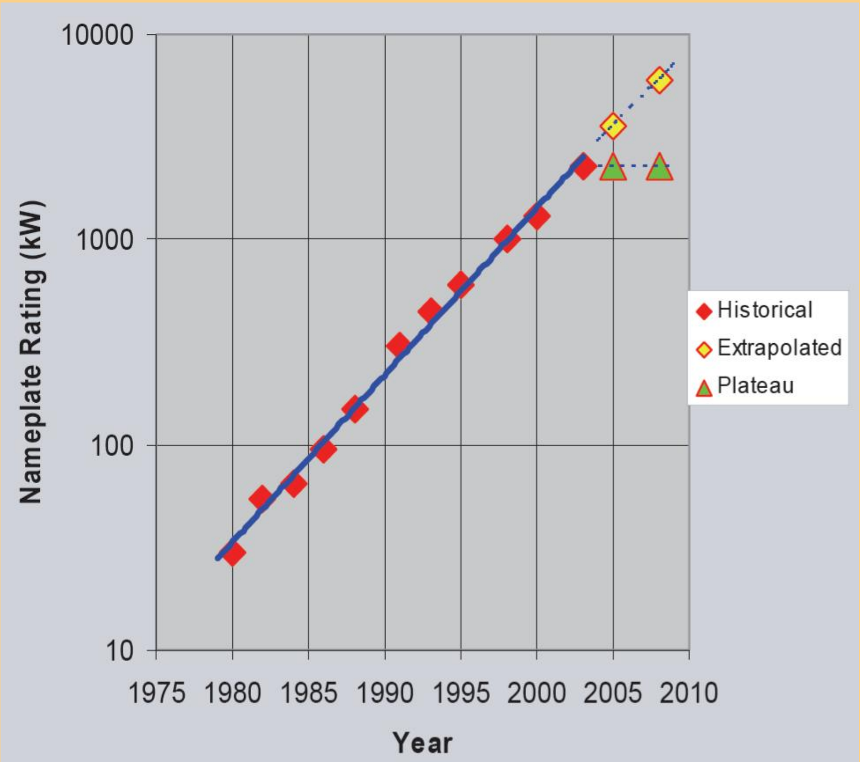
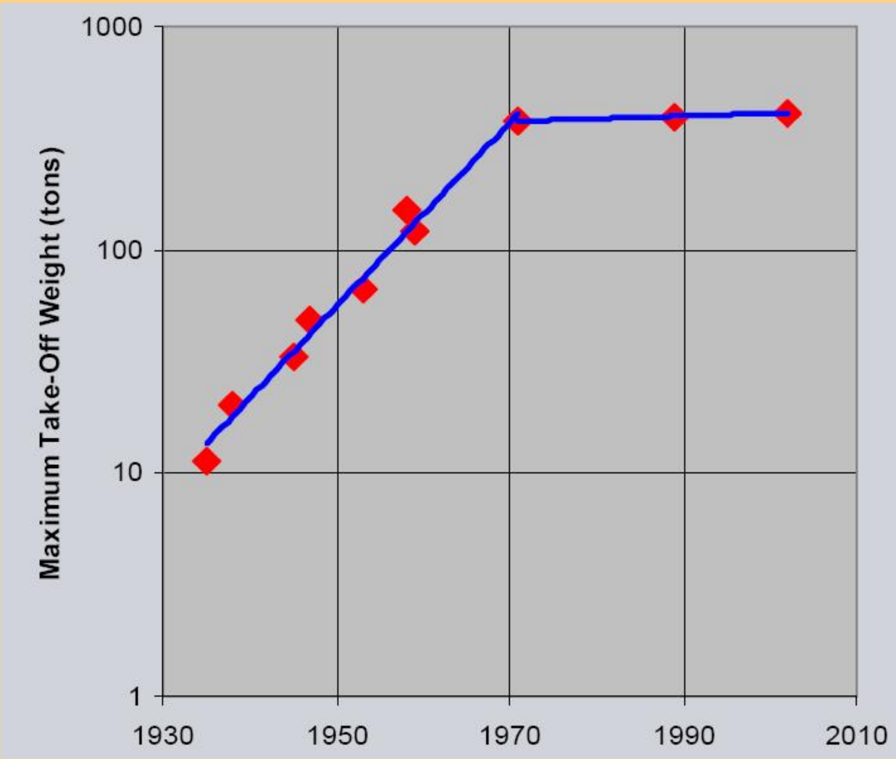
UpWind

Up-Scaling
Development in WT and airplane size



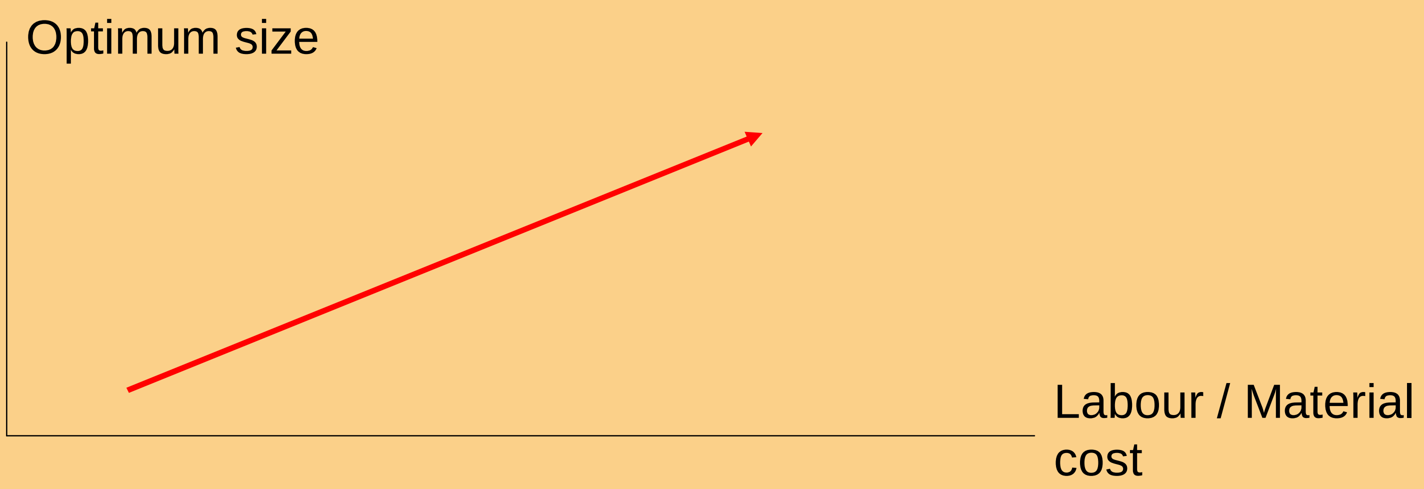


From: Siemems Wind Power, *2007*

Up-scaling

The optimum size depends on:

- Chosen concept
- Installation method
- O&M costs
- Ratio of Labour / Material cost



Cost model –Life cycle approach

- Life cycle approach - using expected
  - Benefits –production of energy
  - Planning costs
  - Fabrication & installation costs
  - Operation & maintenance costs
  - Inspection & repair costs
  - Demolition costs

- Optimal design:

  Minimum expected total costs during lifetime per MWh

Cost model - Main design parameters

Power	**5 MW**	10 MW	15 MW	**20 MW**
Rotor diameter	**126 m**	178 m	218 m	**252 m**
Tip speed	**80 m/s**	80 m/s	80 m/s	**80 m/s**
Hub height	**90 m**	116 m	136 m	**153 m**

- Wind turbine type: reference WT (based on NREL 5 MW)

Cost model - Design parameters

Detailed list of decision parameters –on component level:

- Wind fam layout

- Height and cross-sections of tower
- Length and cross-sections of blades
- Design parameters for nacelle
- Type and size of foundation
- …
- Monitoring methods and maintenance strategy
- …

Cost model - External conditions

- 500 MW (1000 MW) offshore wind farm
- Separation: 7 x 7 rotor diameters
- Design lifetime: 20 years
- Wind speed and turbulence –class I B at 90m height + wake turbulence
- Wind shear: see IEC 61400-3 –normal wind shear

- Water depth: 30m and 60m
- Wave height: North Sea
- Ice loading: not included
- Current: not included
- Soil conditions: sand / clay
- Distance to shore: 25 km and 100 km (30m and 60m water depth)

Cost model –Components

Component	**WP**
Benefits	1A1
Project development	9
Blades	1B4 + 1B3 + 1B1 + 2 + 3
Nacelle: generator, gear/drive train, ...	1B2
Support structure	4
Wind farm costs: (Internal grid, Central platform, Connection to land)	9
Installation (incl. transportation)	1A1
Operation & Maintenance	7
Removal / demolition after end of use	1A1

Cost model

Generalised cost model:

$$C(sf,T)_{\text{comp}} = C(1,T_0)_{\text{comp}} \cdot \boxed{\frac{c(sf,T)}{c(1,T_0)}} \cdot \boxed{sf^{\alpha_{\text{comp}}(T)}} \cdot \boxed{r(T)}$$

changes in **cost per mass unit** due to changes in materials, manufacturing process,..

up-scaling of mass using the same technology using 'similarity rules'

effect of **technology improvement on mass** with same size of the component

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Up-Scaling

Similarity rules

(Takis Chaviaropoulos

*2.4. **Blade structural properties***

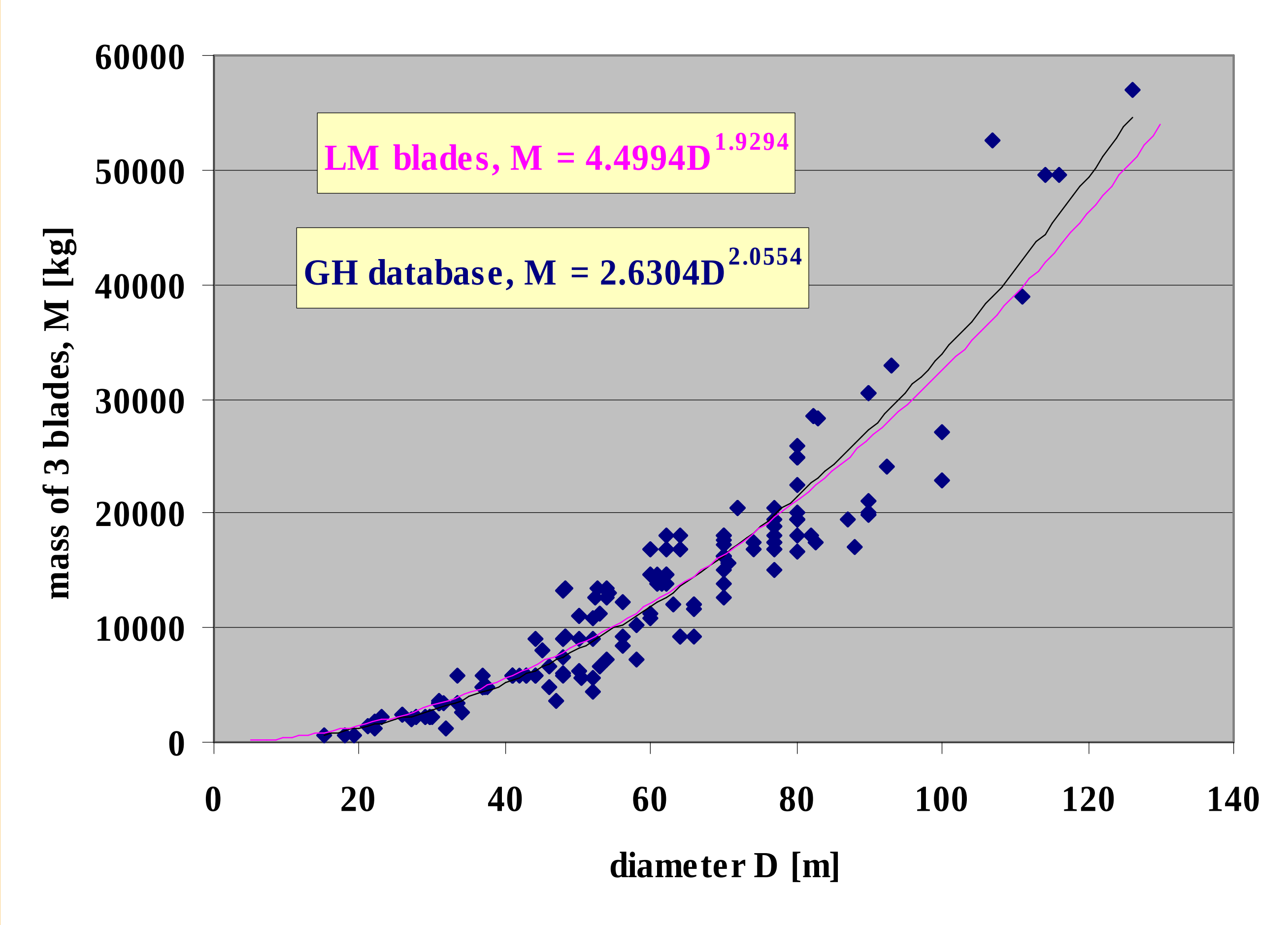
Assuming the geometric up-scaling of the internal blade structure (dimensions scale-up with R, increasing proportionally the number of layers of the same material) and ignoring possible second order effects, the following table results for the sectional properties.

Symbol	***Defining Formula***	***Description***	***Size-Dep.***
$A(x)$	$= R^2 \int ds^* = R^2 . A^*(x)$	*Effective Area*	R^2
$\underset{\approx}{I}(x) = \begin{pmatrix} I_{yy}(x) & I_{yz}(x) \\ I_{zy}(x) & I_{zz}(x) \end{pmatrix}$	$= R^4 \begin{pmatrix} \int z^{*2} ds^* & -\int y^* z^* ds^* \\ -\int z^* y^* ds^* & \int y^{*2} ds^* \end{pmatrix}$ $= R^4 . \underset{\approx}{I}^*(x)$	*Moments of Inertia - Tensor*	R^4
$I_p(x)$	$= R^4 . I_p^*(x)$	*Polar Moment of Inertia*	R^4
$J(x)$	$= R^4 . J^*(x)$	*Torsion Constant*	R^4
$W_y(x)$		*Section Moduli – Y Bending*	R^3
$W_z(x)$		*Section Moduli*	R^3

Up-Scaling

Trend data

(Peter Jamieson, Garrad Hassan)



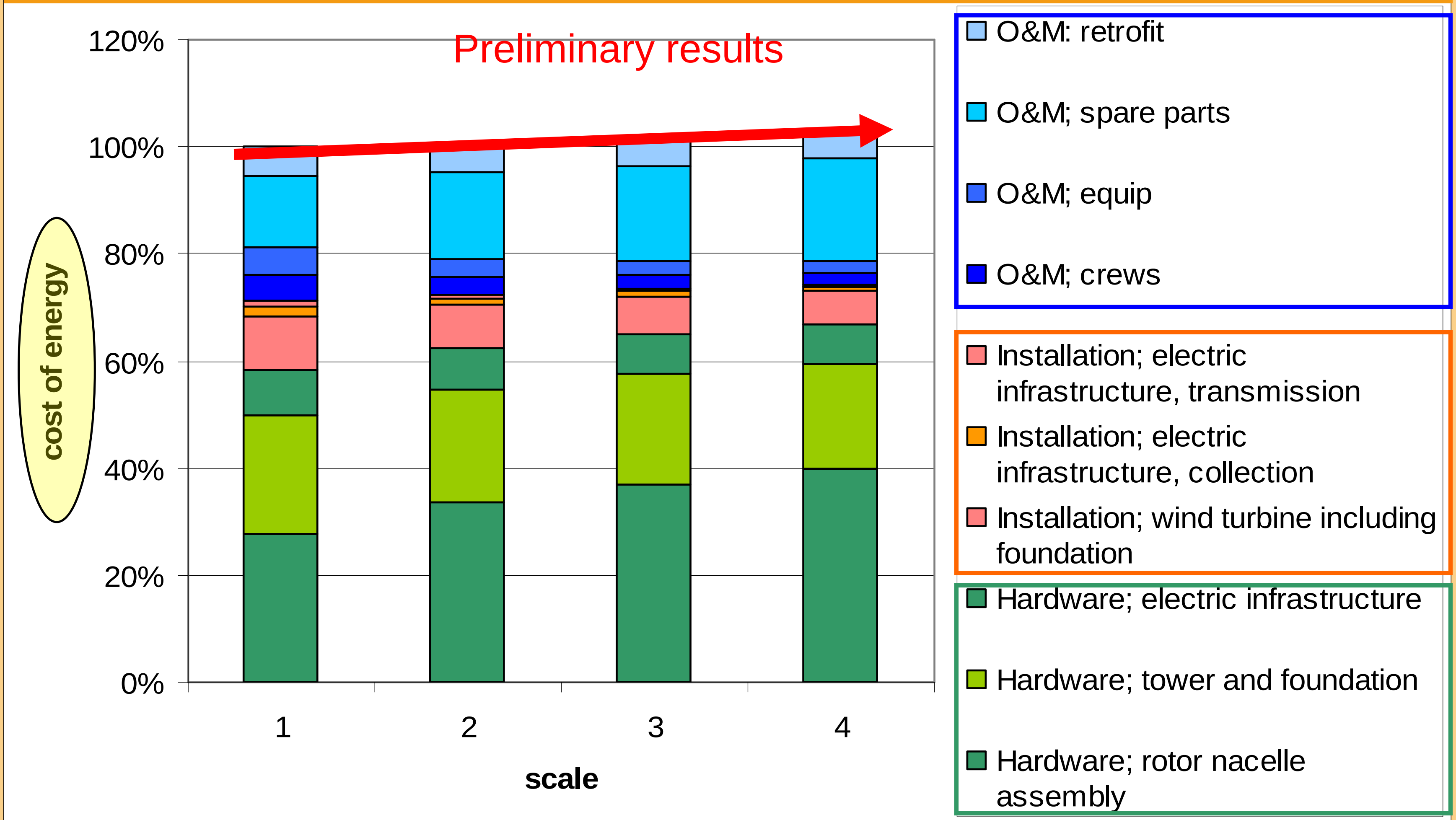
Up-Scaling

Upscaling, preliminary results for blades:

- Classical similarity rules : mass of blade ~ R^3
- Trend data : mass of blade ~ R^2

$$C(sf,T)_{\text{comp}} = C(1,T_0)_{\text{comp}} \frac{c(sf,T)}{c(1,T_0)} \cdot sf^{\alpha_{\text{comp}}(T)} \cdot r(T)$$

Up-Scaling –cost of energy –wind farm



Up-Scaling –cost models

- Uncertainties:
  - Costs and yield are site dependent and uncertain
  - The scaling rules are uncertain
  - The learning curve, and the introduction of new technologies and new concepts will bring the costs down

- Unlikely that up-scaling of present wind turbine designs is optimal for future offshore wind energy
  - *higher tip speed?*
  - *active boundary layer control?*
  - *advanced materials?*
  - *advanced control?*
  - *....*

Component	WP
Benefits	1A1
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Blades	1B4 + 1B3 + 1B1 + 2 + 3
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Operation & Maintenance	7
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Challenges

Are 20 MW turbines technically possible:

- Can they be **manufactured?**
- Can they be **transported?**
- Can the turbines be **installed?**

Not feasible?

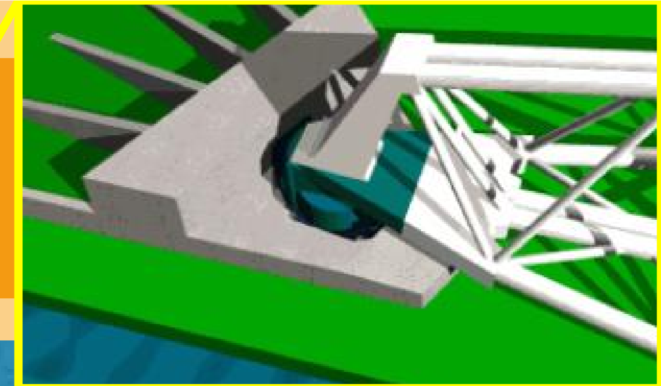
- …we were able to build this in 1889 …

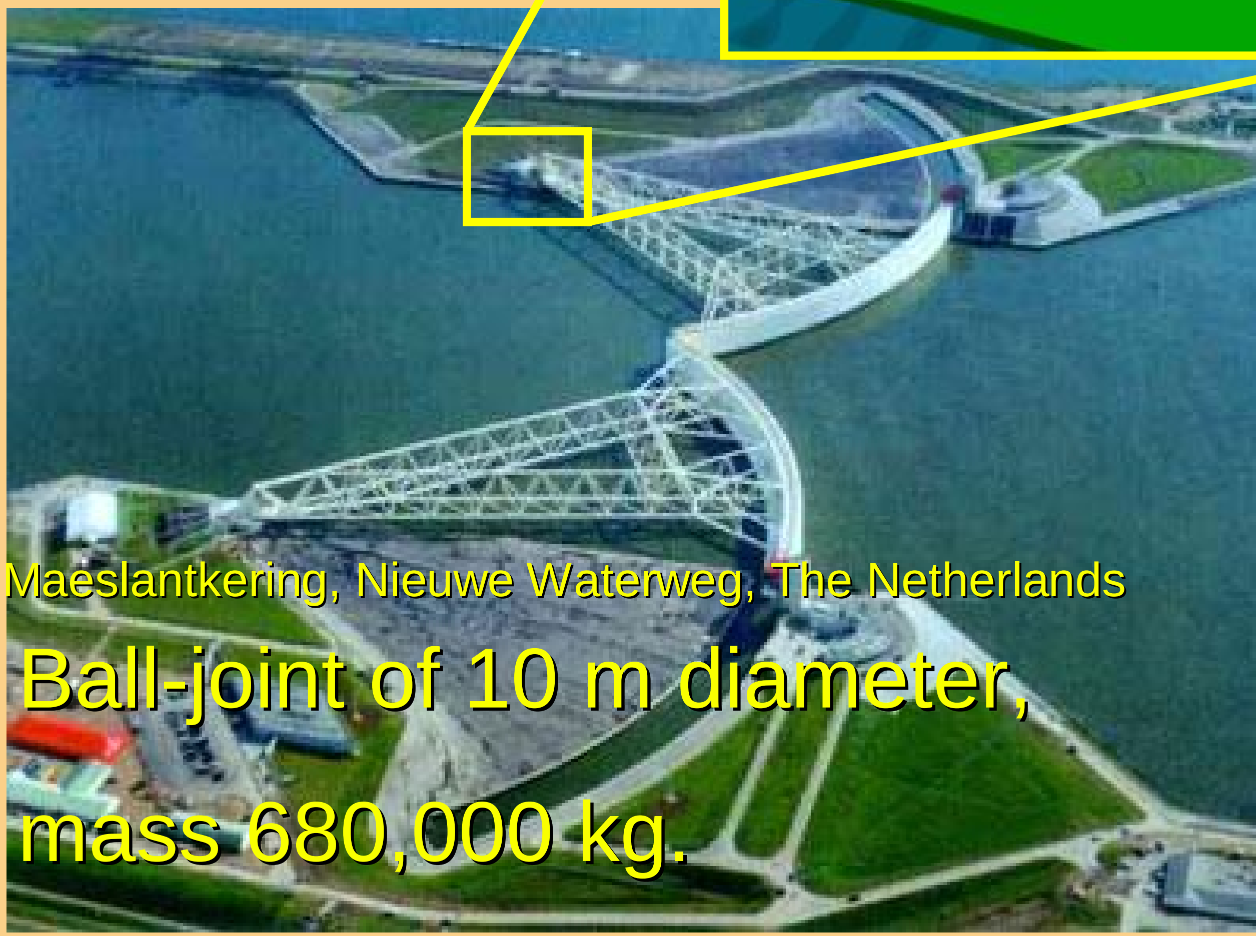
Not feasible?

- …we were able to build and transport this some decades ago …

Not feasible?

- …we were able to design and manufacture this some years ago …





Not feasible??

- …we were able to design and manufacture this some years ago …

Not feasible?

- So can we build a 20 MW turbine?

So, what is determining the erection of 20 MW turbines?

It's the Economy, stupid!

Thank you!