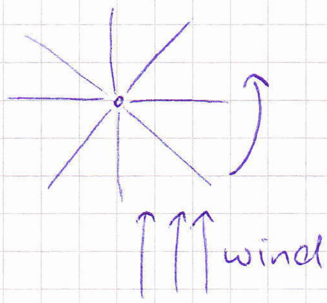
Wind energy 1 (→ lecture slides)

21.09.2010

EWEA – European Wind Energy Assosiation

Historical development of wind power

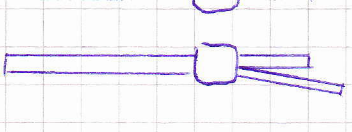
→ Persian wind mills: vertical axis
(moving because of drag)
~ 1000 b. c.



→ work only, if wind comes often out of same or completely opposite
→ blades are moving "with the wind"
→ not most efficient (comp. sailing: perpendicular gives you the fastest speed)

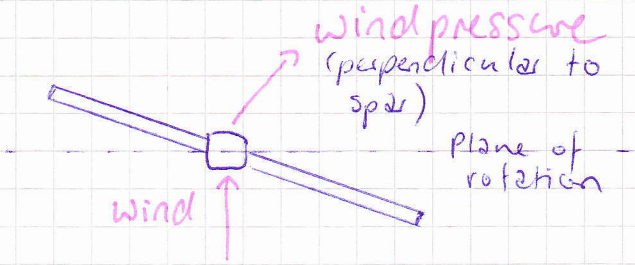
→ dutch wind mills: horizontal axis
developed somewhere in & around holland
12th century → written proof of existence
1270/5 → pictures of wind mills in belgium/cambridge (decoration of a bible)

Rotor development

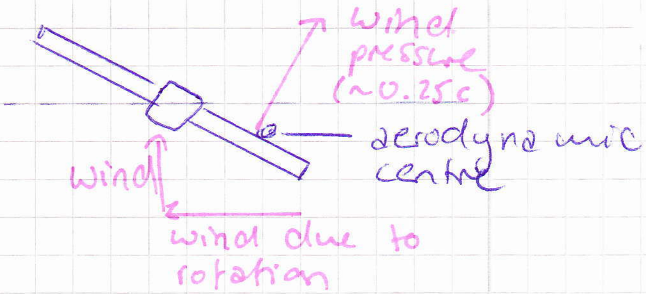


until 1400 (symmetric)
from 1400
until 1650 (0.25)
from 1650 ("cambered airfoil")

STANDSTILL



ROTATION



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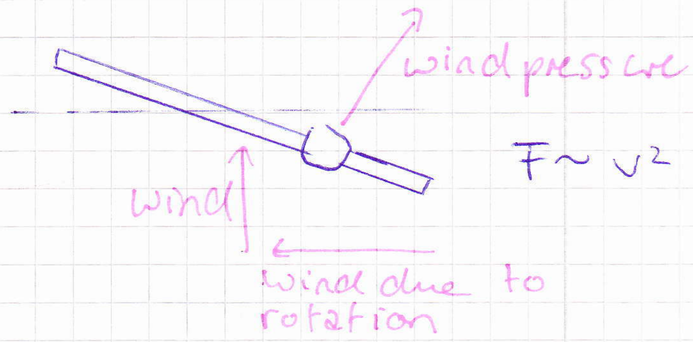
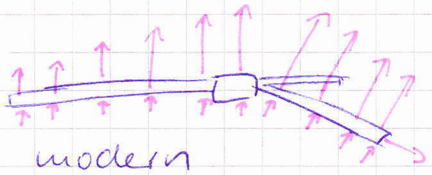


$F \sim v^2$

- Force in plane of rotation
  ↳ torque
- Force opposing the wind

adding camber:

- 1650 by Leeghwater (Noord-Holland)
- lift increases



comp. to modern airfoil: modern af: lift larger, drag lower ← main difference!

Leeghwater / around 1600
Stevin

Golden Age of the Verenigde Provinciën

17th century

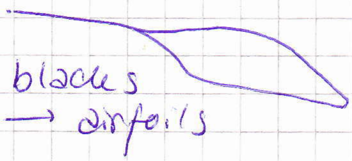
VOC → world wide trading
15.000 tall ships (Segelschiffe → wind)

→ golden age was powered by wind craft

important scientists

Hugo de Groot
x Christiaan Huygens
x Simon Stevin
x Jan A. Leeghwater
Johan de Wit
Antoine van Leeuwenhoek
x Willebrord Snellius
Benedictus Spinoza
Hermann Boerhaave

→ New "old" windmill 2006
- City of Schiedam (for 'Nolet' (company))
- should fit with the other 5
- dev. with 21st century aerodynamics by TU Delft → looks old from the outside but moder from inside



→ produces green electricity

→ Racing boat 2008 (british)
- solar cells
- "Quit Revolution" → vertical axis wind turbine based on TU Delft concept

Limits to the growth

since golden age: • increase of population (·10)
• increase in energy use (·100)

1972 Club of Rome report "Limits to the growth"
1973 oil crisis → boycott by OPEC, oil price doubled

1975 research program's on alternatives in order to become less dependant on OPEC

1987 Report "Our common future" (Def. of sustainability)

Current Facts

CO_2 concentration:	383 ppm	(2007)
population :	6.2 billion	(2000)
depletion of raw materials :	10 - 25%	(2000)

→ 21st century: age of climate change

Resources

- 200 x more wind energy available than current demand
  → no energy crisis, change of use of resources necessary

Wind potential
- available in wind >> present electricity demand
- feasable 20% of electricity demand (space is already used for other purposes)

Restriction
- planning restrictions & conflicts
- environment (noise, birds, shadows)
- grid (gitter) issues (availability, power quality → quantity)
  ↳ to less electricity grids for transporting the produced energy

Wind power → improving electricity grid
↓
transnational grid necessary

Technology

/increasing size/

1985 → 2001 → 2005 → 2010

Ø 30 m — Ø 80 m — Ø 126 m — Ø 150 m

→ = span of A 380
→ = two rotating soccer fields

→ huge wind turbines are usually offshore (transportation)
↓
high transportation and installation costs

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blade → airfoil

DU 97 - W - 300 → thickness 30%
(DU → Delft university)

→ today: 40% thickness in use

- 50% of new turbine are TU Delft airfoils

Market

Europe had 3/4 of wind power installed capacity in the whole world till 2002

30% / year
2006 → 65000 MW (World)
44000 MW (Europe) → ~ $\frac{2}{3}$

2010 → 80000 MW in Europe (EWEA)

- growth now more in North America and Asia than in Europe

China: need huge masses of energy → use all resources

Production in Europe in 2006

Capacity 2006: 44 000 MW

capacity factor: 0.2 for wind turbines

→ wind not always strong enough to prod. whole capacity ($v = 12 \frac{m}{s}$)

Production: (Europe)

∅ hours of ↓ a year

$0.2 \cdot 8760h \cdot 44000 MW$

$= 77 TWh$

electr. Consumption NL 2006: 80 TWh

Renewables in EU

Targets 2020 → 34.8% wind
28 % hydro
13.1% photovoltaic

Wind available in Europe

→ Scotland, Denmark

not that much wind in Germany, but most employees in comparison to other countries in wind industry

↳ also political issue

5% of Europe covered by wind turbines for prod. 100 000 MW (could be placed on Crete only)

→ wind is getting quite important as a renewable energy resource

→ share of windenergy in europe now: 5%
(Denmark: 23%) → 2020: 10% (EU), 50% (DK), 20% (NL)

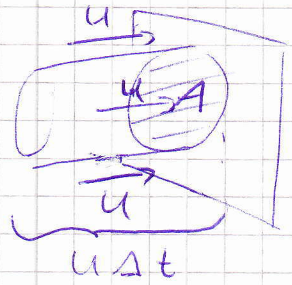
→ 50% of new capacities is wind power

Wind Energy 2

28.09.2010

Energy extraction from wind

Conservation laws



mass in cylinder: $\rho u \Delta t A$ [kg]

per second:

mass flow $\dot{m} = \rho u A$ [kg/s]

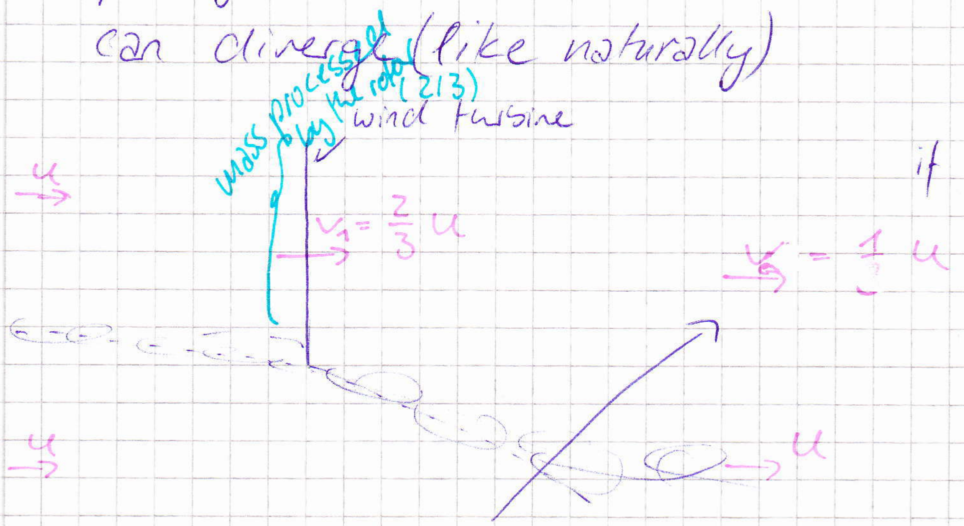
momentum flow $\dot{m} u = \rho u^2 A$

energy flow $\frac{1}{2} \dot{m} u^2 = \frac{1}{2} \rho u^3 A$ [W]

momentum $\hat{=}$ m · v

· Wind turbine model in open jet wt

- open jet wind tunnel because flow can diverge (like naturally)



if $v_e = 0$ → mass flow = 0
↳ sim. to solid block situation
→ less energy generated

turbine slows flow down

mass flow: prop. $\sim \frac{2}{3} u$

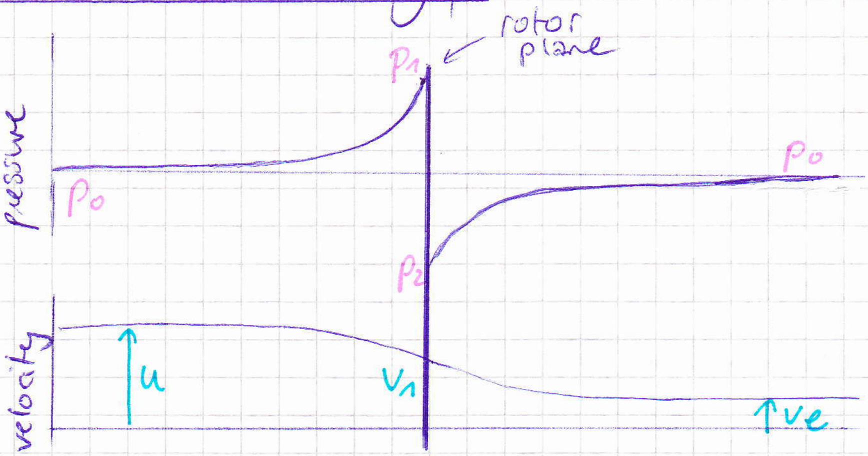
energy loss: $\sim \left(u^2 - \left(\frac{1}{3} u\right)^2 \right) = \frac{8}{9} u^2$

↓

$\frac{2}{3}$ of the mass

↳ extract $\frac{8}{9}$ of the energy ($\sim \Delta u^2$)

Pressure & velocity relations (axial momentum theory)



Bernouilles law: valid on left & right hand side of rotor plane but not while crossing! (where energy is extracted)

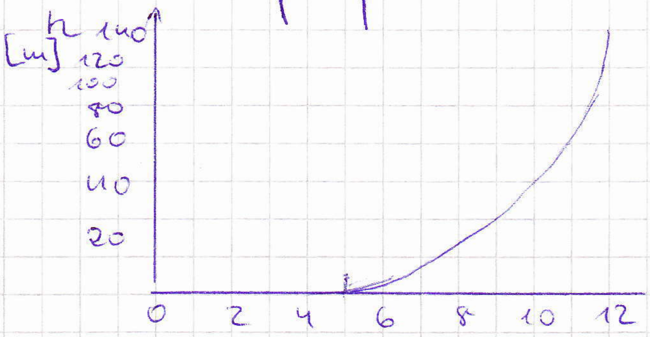
Power P: mass flow · kin. energy loss
→ $P_{available}$

Betz 1926: non dimensional max

power coefficient → $C_p = \frac{2}{3} \cdot \frac{8}{9} = \frac{16}{27} \approx 0.593$

where $C_p = \frac{P}{\frac{1}{2} \rho u^3 A}$

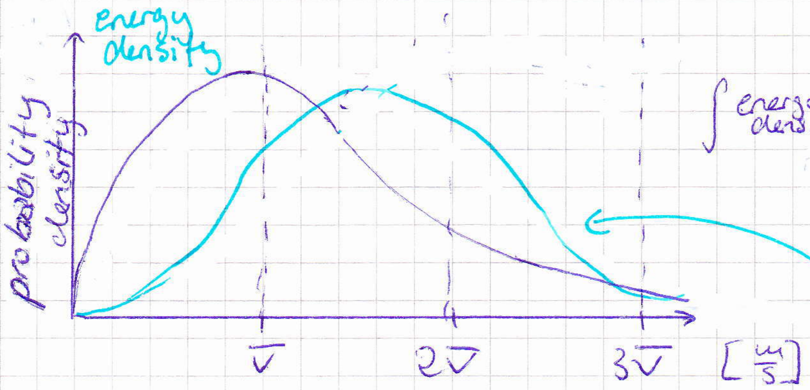
Wind profile



vertical wind profile
~ log h
→ mechanical friction (the higher the less bilding, gras, waves, ... are there)
→ depends on "roughness length" of surface
"height" of surface

Wind speed distribution

- average windspeed of ten minutes, measured for many times during 1 year → bars, (occurance per year)
  several years → line



$\int \text{energy dens.}(v) = 1$ (%)

speed → energy distribution

energy ~ u^3

→ v^3, $(2v)^3$, $(3v)^3$, ...

Technology of wind turbines

Components

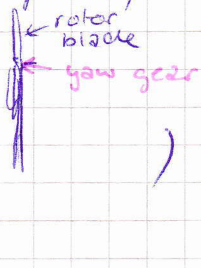
rotor (~25 u/min) – main shaft – gear box – high speed shaft with brake – generator (typ. 1500 u/min) –

brake: not able to stop rotation but to keep wind turbine at rest

- cooling system – control cabinet & power conversion – yaw gear

(↗ slide 18/53)

yaw gear: with wind direction sensor; moves rotor in direction due to wind (yaw gear located on top of the tower:



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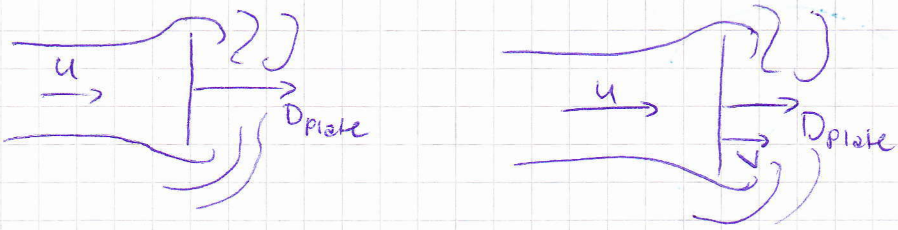
Primary conversion process

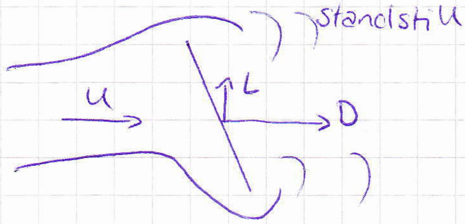
→ Drag driven devices (vertical axis (e.g. persian) windmills):

Power: $P = D_{plate} \cdot (u - v)$



$c_p < 0.15$

→ Lift driven devices   Lift ⊥ wind

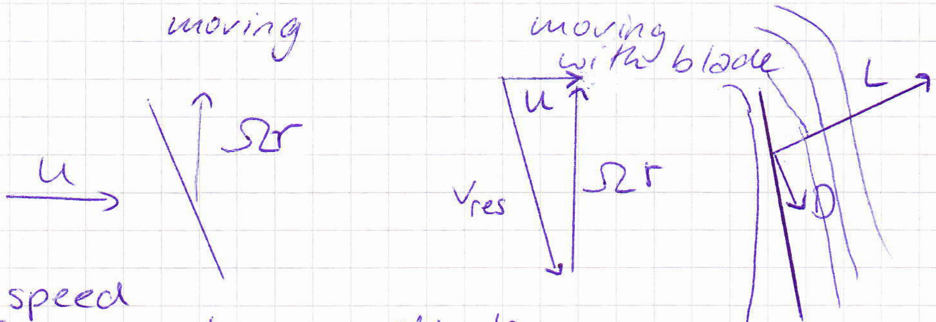


$c_p \approx 0.45$

if $\Omega r >> u$

then $v_{res} >> u$

thus $L >> D$



Ωr – speed component perpendicular to the wind → r: radius (c of rotor)
Ω: rotational speed [°/s]

v_{res} – acting wind speed

the higher v_{res} the higher Force ($\sim v^2$)

→ less material → slender blade

2, 3 or multiple blades?

2 blades	3 blades	multiple blades
- low torque	- higher torque	- high torque
- high RPM (← rotational speed)	- lower RPM	- low RPM
Same	Power	
- more noise	- less noise	- no noise
- less esthetic	- esthetic	- esthetic
- cheap (2 rotors, small gearbox)		- expensive rotor

2 blades	3 blades	multiple
→ future offshore?	onshore	windpumps
→ 2 blades → easier installation	→ less noise	→ high torque
→ noise/esthetic do not matter	→ esthetic	

Round up of conversion principles

→ Power in the wind

$$P = \frac{1}{2} \rho u^3 A$$

→ Aerodynamic efficiency

c_p 0.45 - 0.5 (always < 0.593)

→ conversion efficiency

$\eta \approx 0.95$ (large machines)

Control

- main concept (since 2003):

  variable speed → pitch controlled (angle of rotor surface due to wind)

(↗ slides 30/31)

Electrical energy yield

P[kW]

E[kWh]

from wind speed distribution:

≈ 825 h with 4 m/s, ...

→ 61 875 kWh (4 m/s)

\+ 142 500 kWh (5 m/s)

\+ 237 500 kWh (6 m/s)

\+ 382 500 kWh (7 m/s)

\+ ⋮

\+

~ 3 500 000 kWh / year

("1000 families")

↑ average dutch electricity consumption of one family per year

Costs of wind energy

1980 - 2005

decrease (38 ct/kWh - 5 ct/kWh)

2010 ≈ 2005

Offshore wind power

→ 8 areas of 100 km · 100 km offshore wind farms can produce 3000 TWh ≈ present electricity use in EU per year

Offshore wind farms

- Egmond aan Zee (NL), 2006
  8-12 km offshore
  108 MW (36 × 3 MW)
- Princess Amalia (NL), 2008
  18-23 km offshore
  120 MW (60 × 2 MW)

- realised offshore projects up to 2008:
  → 1423 MW
  2010 → ~2400 MW
- size of wind farms is increasing

why offshore?

- onshore space is getting limited (DK, D, NL)
- large farms possible
- Some countries don't want onshore (UK)
- production 1.6 - 2 times higher (more wind)
  lower roughness

but! - investment costs 2.5-3 times higher
- maintenance costs 3-5 times higher
- accessibility difficult
⇒ reduced availability
→ offshore wind is currently much to expensive
100 MW ~ 300 million €

Scroby Sands (UK)
→ wind farm 3-4 km offshore
↳ wind turbines with "entertaining area" → not a problem to have them that close to the coast

~1500 turbine visits per year

still accessibility problems (waves, storms)

capacity factor ~ 0.25-0.3

"Ampelmann"
- offshore platform is "fixed" (independant from waves → pistons are moving to keep the platform in the same position with respect to the horizon)