Fremtidens vindmøllevinger -når vind globalt leverer over 10 % af vores el

Rasmussen, Flemming

Publication date:
2013

Fremtidens vindmøllevinger
-når vind globalt leverer over 10 % af vores el

Flemming Rasmussen
flra@dtu.dk

Sektionen for Aeroelastisk Design
Denmarks Tekniske Universitet
DTU Wind Energy – Risø Campus

Indhold

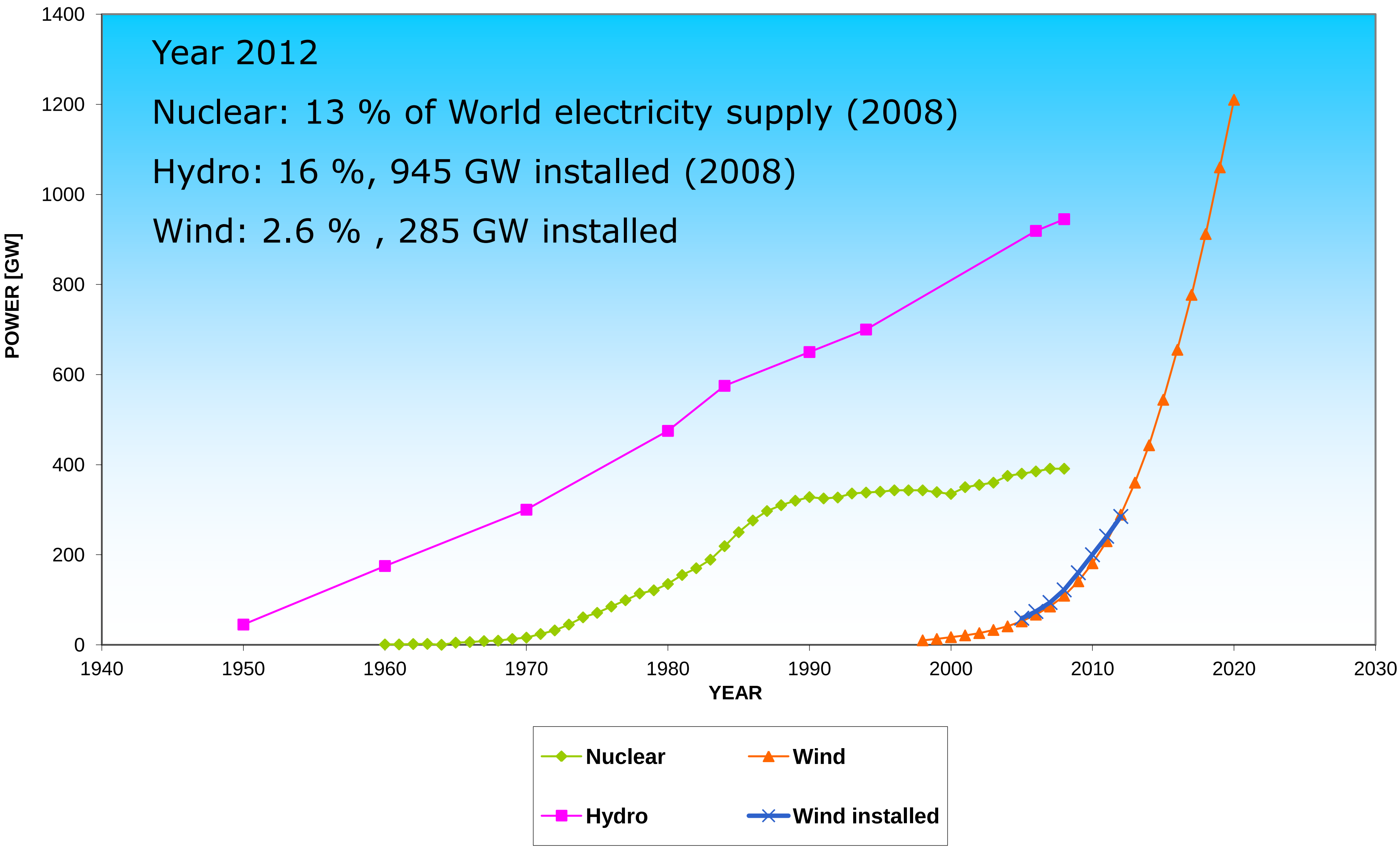
- Global status for vindkraft
- Status for teknologien og tendenser
- De næste skridt mod fremtidens vindmøllevinger (10 MW Ref. Mølle)
- Fremtidens vindmøllevinger

Antagelse:

- Vindenergi ændrer rolle til at blive rygraden i en sikker global energiforsyning, eller
  Vindenergi som ”base load”.

Prøvestationen for vindmøller, Risø 1979

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



Vindenergi som ”base load”

Verdens elforbrug

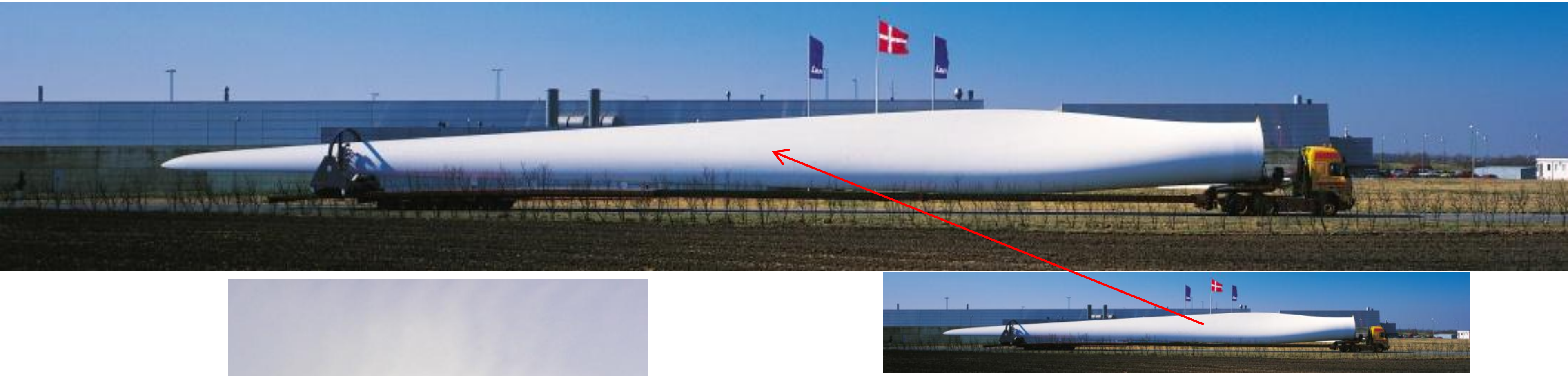
Integration er udfordringen
- **Vandkraft**
- **”pumped storage”**

en del af løsningen

Eksempel Norge:
30 GW vandkraft
2 GW pumpekraftværker
ca. 15 GW udbygningspotentiale for begge

Globalt:
Vandkraft leverer 16 % med en kapacitetsfaktor på 1/3
Kunne levere 50 %, ”hvis der var vand nok”
Samtænkning vand/vind gør det realistisk

Opskalering

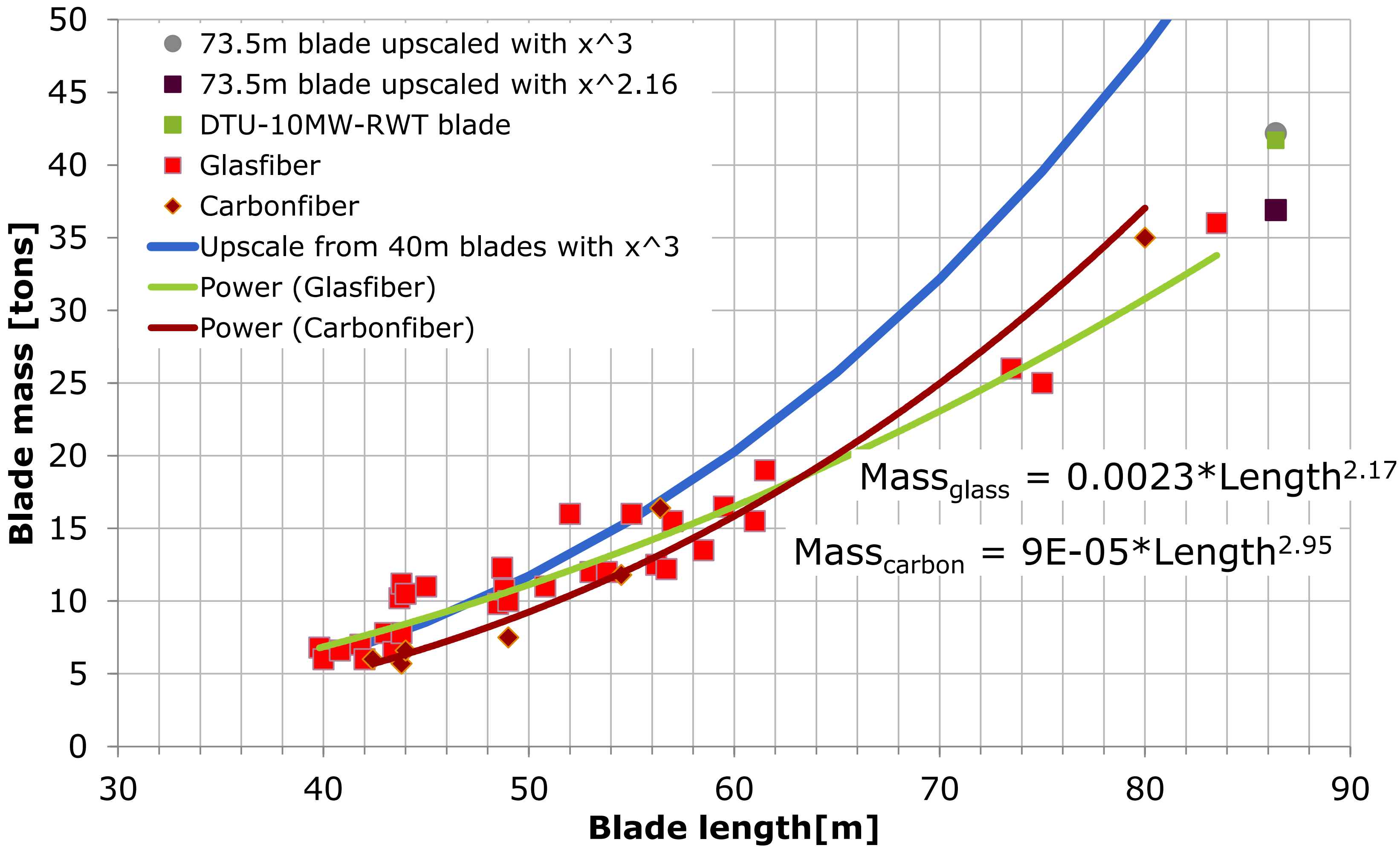


Opskalering med x 100 på 30 år

Opskalering, teori: ”Square-cube law”
- Effekten stiger med kvadratet på vingelængden
- Massen stiger med tredje potens

Bladmasse stiger kun tæt på diameteren i anden potens (eksponent 2.1-2.3) på grund af optimerede og tykke profiler og optimeret strukturelt design

Aktuel bladmasse og opskaleret til 10 MW



En materiale optimeret maskine, 6 MW

DTU Wind Energy, Technical University of Denmark

10 m/s:

- 200 tons/sek.: Luftmasse gennem rotorarealet.
- Behandler luftmasse svarende til møllens totalvægt på 5 sekunder.
- Yderste ¼ af vingerne overstryger enormt areal med meget lidt materiale

- Aksialtryk og drejningsmoment.

Typisk vindmølle 2012

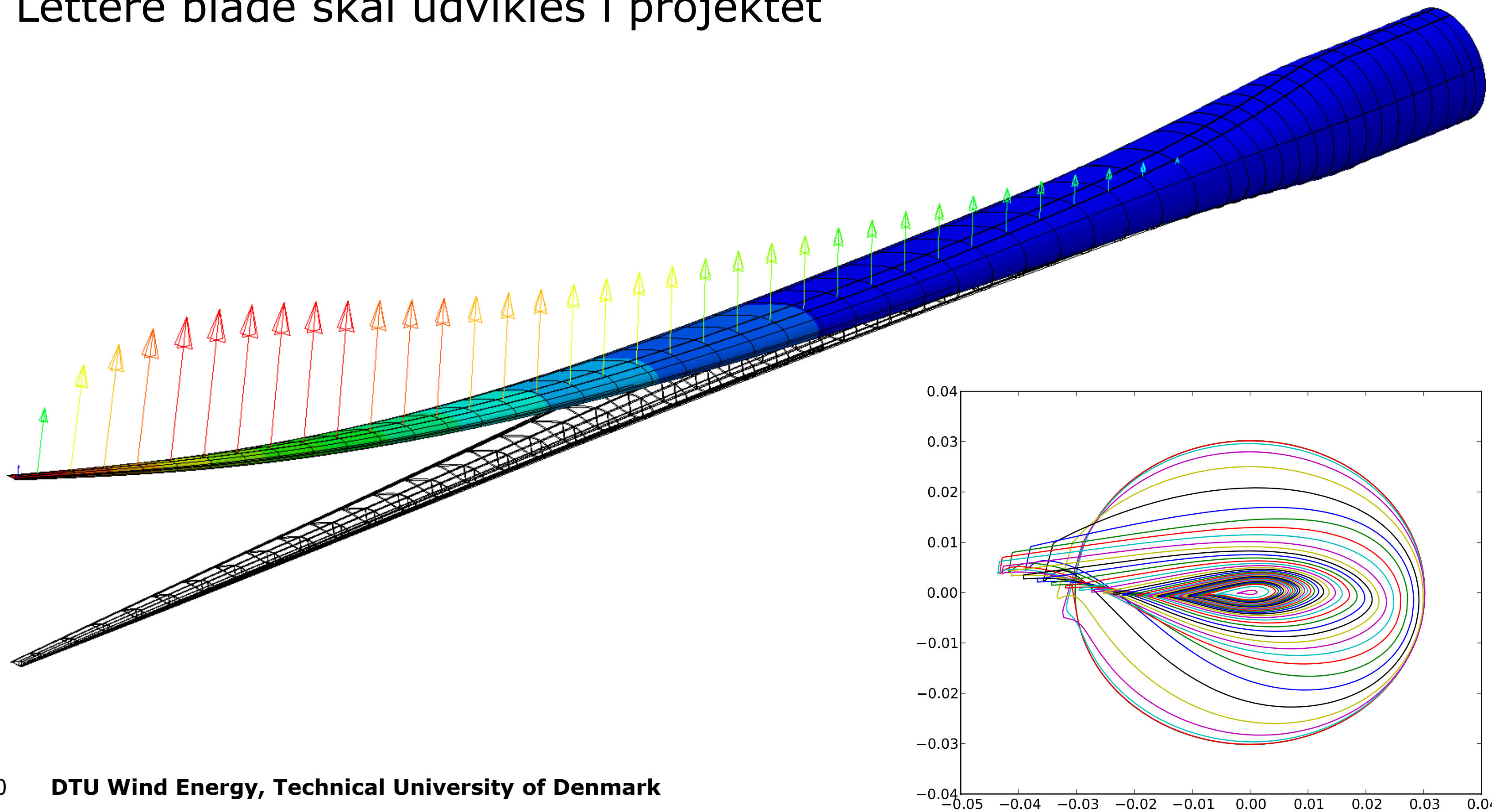
Wind turbine 2012
Resultat af 30 års optimering. Ved direkte opskalering fra 55kw ville 6 MW møllen være 10 gange tungere.

Karakteristika:

- Negativ koning
- Høj tilt
- Fra at designe for stivhed til at designe for styrke
- Mere optimeret
- Mere fleksibel
- Slanke vinger med tykke profiler

Light rotor projekt med Vestas
Blad til 10 MW vindmølle

- Det er et reference blad som er designet med eksisterende teknologi til brug også i INWIND.EU projektet
- Lettere blade skal udvikles i projektet

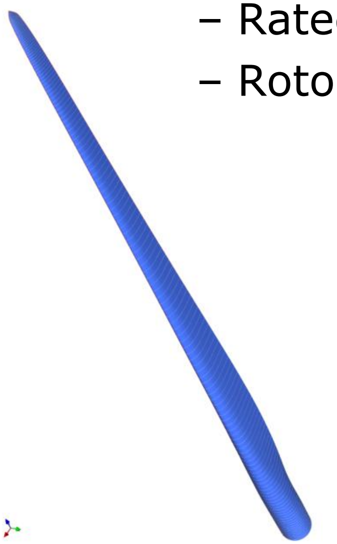


DTU 10 MW Reference rotor

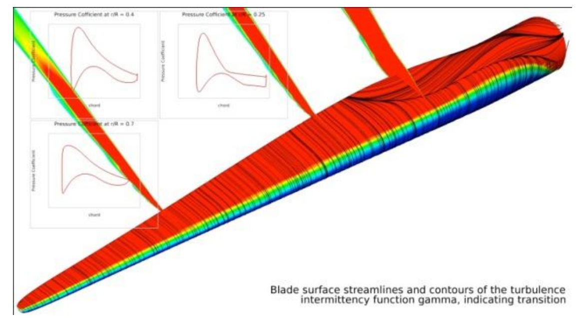
Nominal power	10.0 MW
Rotor configuration	Upwind, 3 blades
Control	Variable speed, collective pitch
Rotor diameter	178.3 m
Hub height	119.0 m
Rated tip speed	90 m/s
Blade pre-bend	3.3 m
Tower mass	628.4 tons
Nacelle mass	446.0 tons
Rotor mass	230.7 tons
Blade mass	41.7 tons

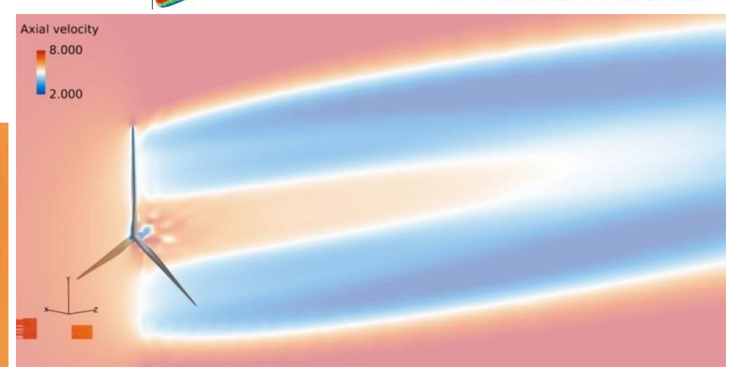
Light Rotor 10 MW Reference Rotor

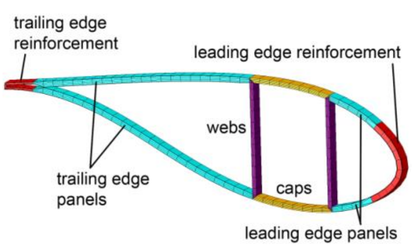
- Specs
  - IEC IA
  - Rated power=10 MW
  - Rotor
    - Radius=89.17m
    - Airfoils: FFA-W3-xxx
    - Max tip speed=90m/s
    - Optimal TSR=7.5
    - Control: PRVS
    - Upstream cone, tilt and prebend
  - Specific power=407W/m^2

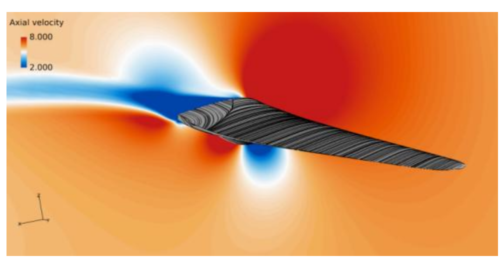


- Investigations
  - Full aeroelastic load calculations including control
  - Aeroelastic stability computations
  - Full 3D CFD rotor computations
  - Full FEM model of blade



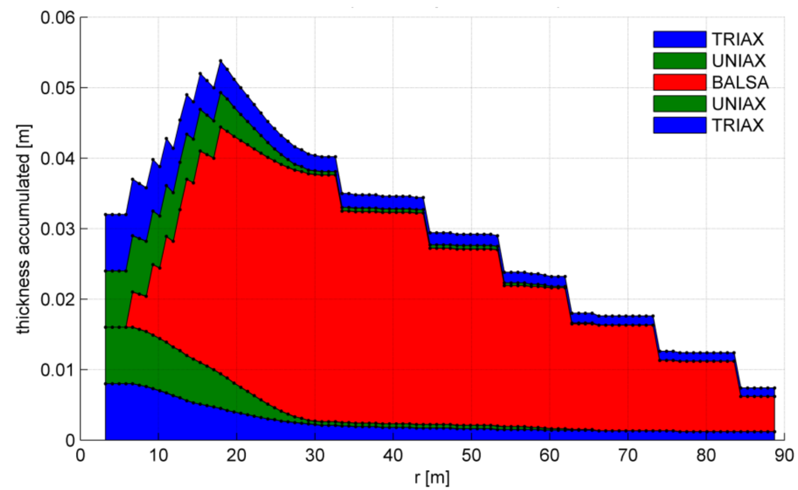


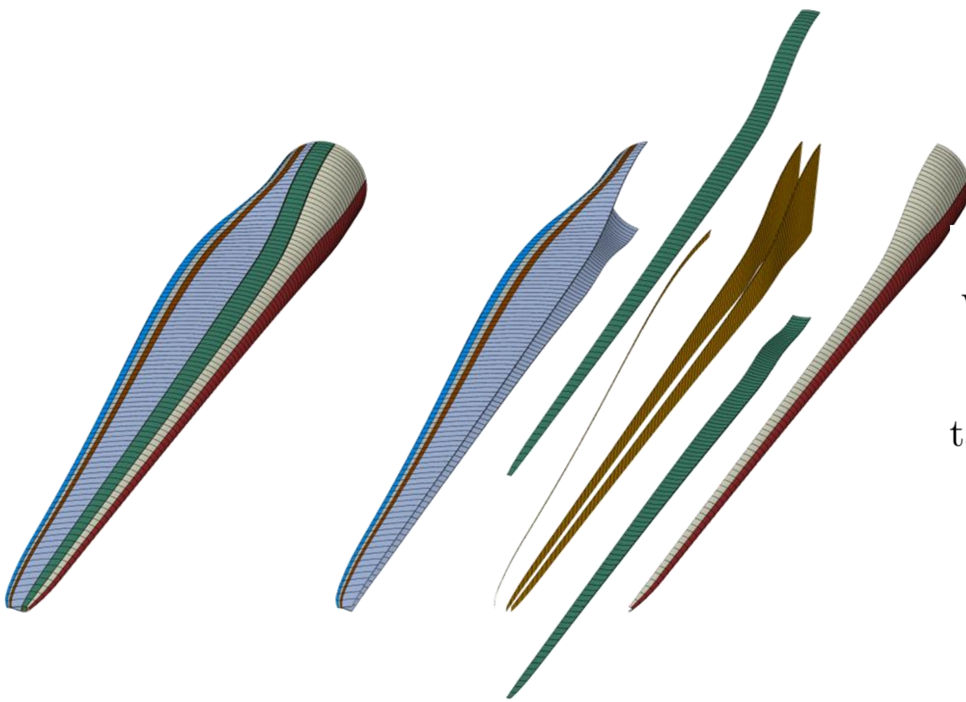


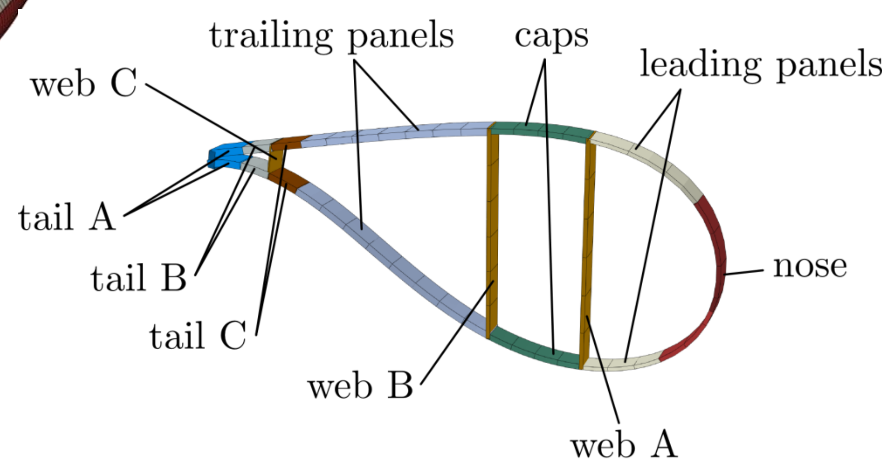


The DTU 10 MW Reference Wind Turbine Structural Design

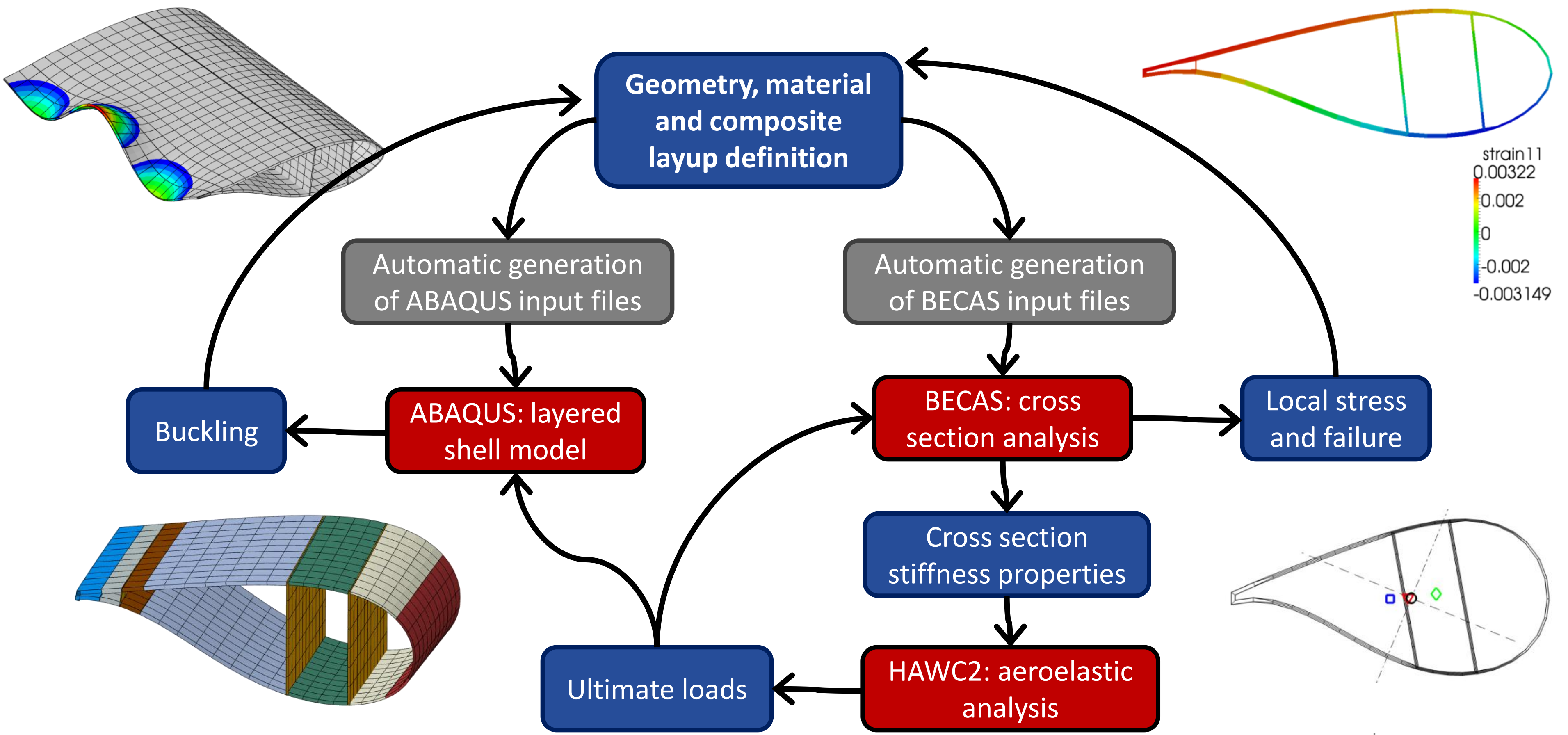
- Layup definition of the blade in 100 regions radially and 10 regions circumferentially.
- Geometry and layup is generated in a finite element shell model.



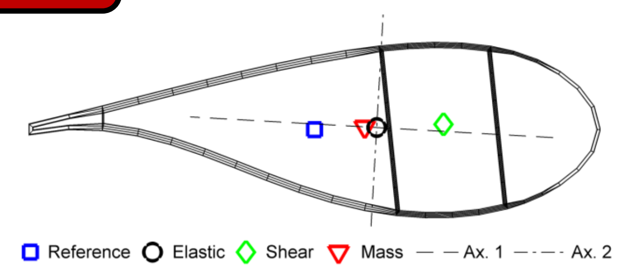




The DTU 10 MW Reference Wind Turbine Structural Design: Design loop



		Load case	γ_F [–]	F_x [MN]	F_y [MN]	F_z [MN]	F_{res} [MN]	M_x [MNm]
F_x	max	dlc5.1	1.35	0.9531	-0.2915	1.0163	0.9967	25.2834
	min	dlc1.3	1.35	-0.8724	0.3672	2.2653	0.9465	-8.9863
F_y	max	dlc1.3	1.35	0.4949	1.6055	2.4138	1.6801	-52.9810
	min	dlc6.1	1.35	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]



Næste skridt mod fremtidens vindmøllevinger: Videreudvikling af DTU 10 MW Ref.-rotoren

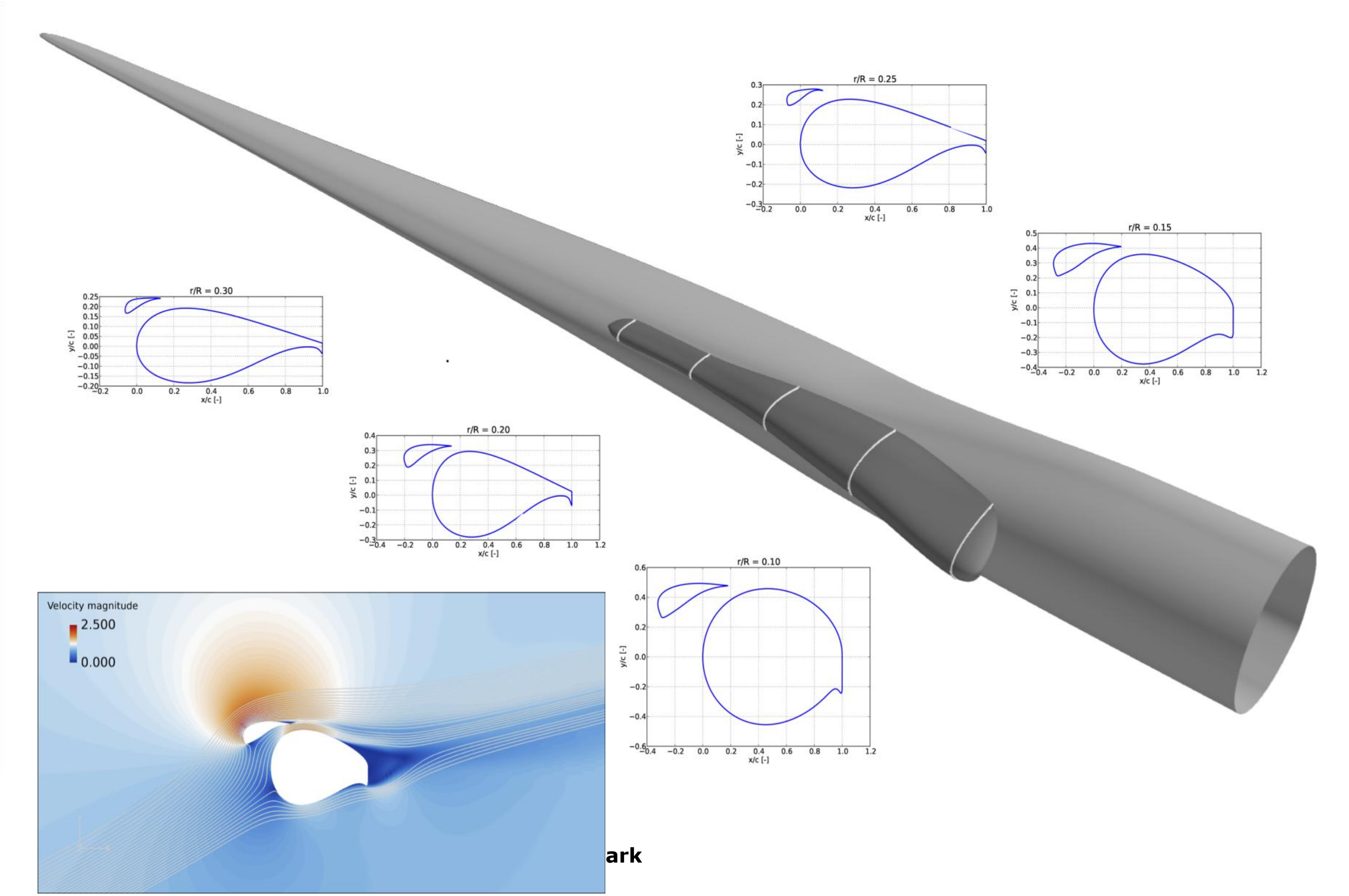
Parameterstudier:

- Passivt indbygget kontrol, herunder flow-kontrol
  - Gurney flaps
  - Vortex generatorer
  - Slats
  - Tipudformning
  - Flap/twist kobling
  - Flap/profilkrumning kobling

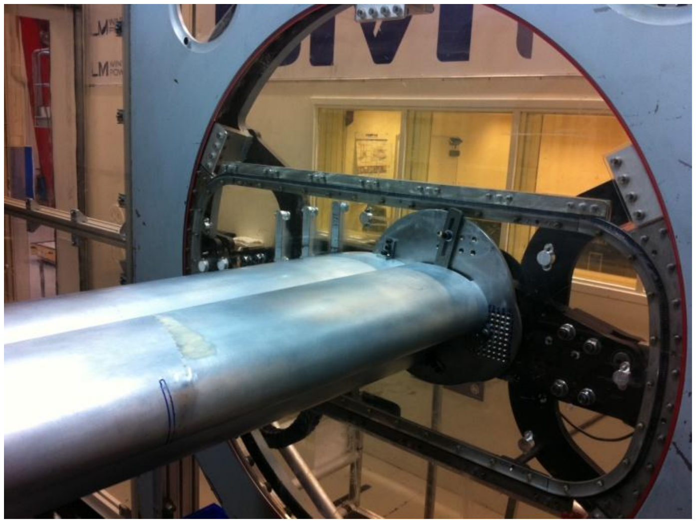
- Aktiv kontrol
  - Kombineret pitch og aktiv bagkant-flap kontrol

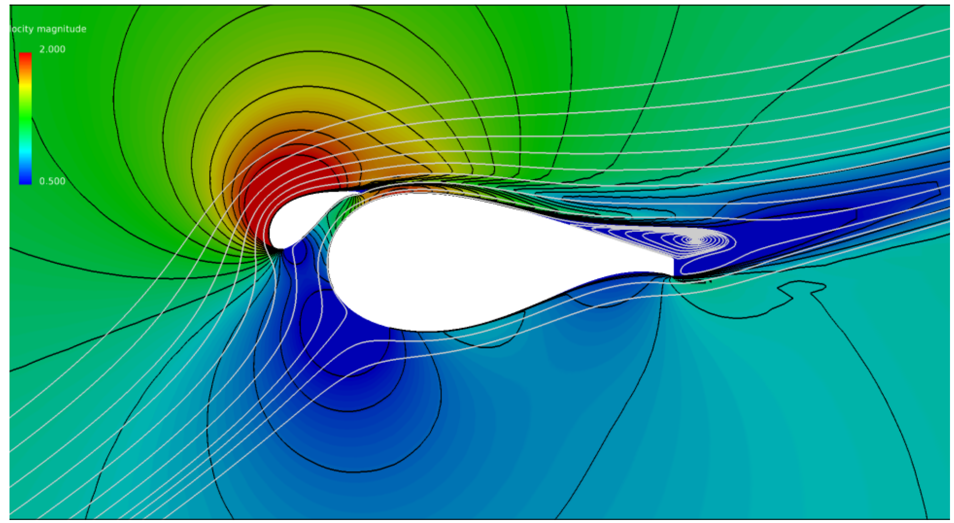
- Øget tiphastighed
- Længere vinger
- Antal blade
  - Trebladet/tobladet

LightRotor 10 MW RWT blade with multi-element airfoils

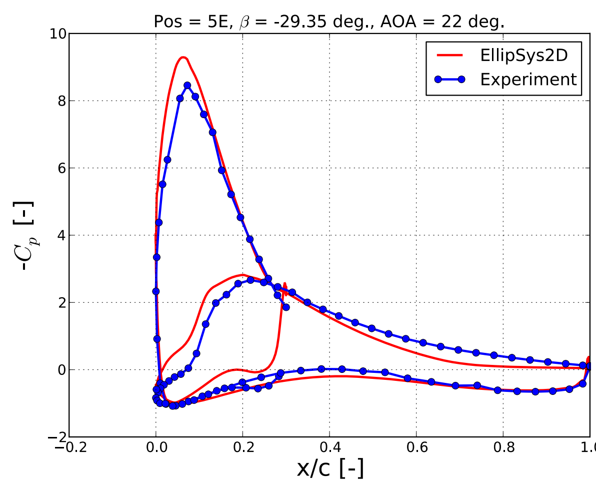


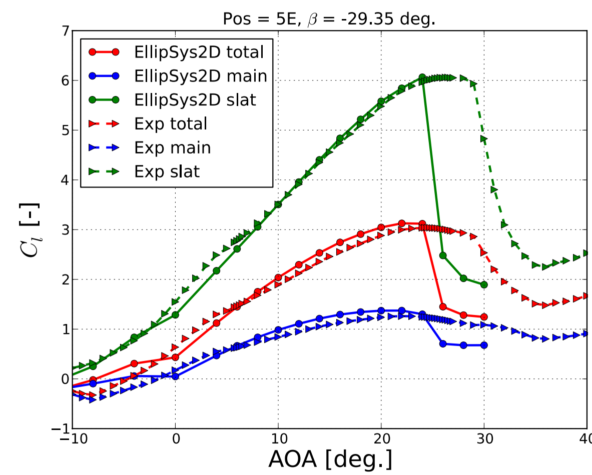
Thick flat back airfoil with slat



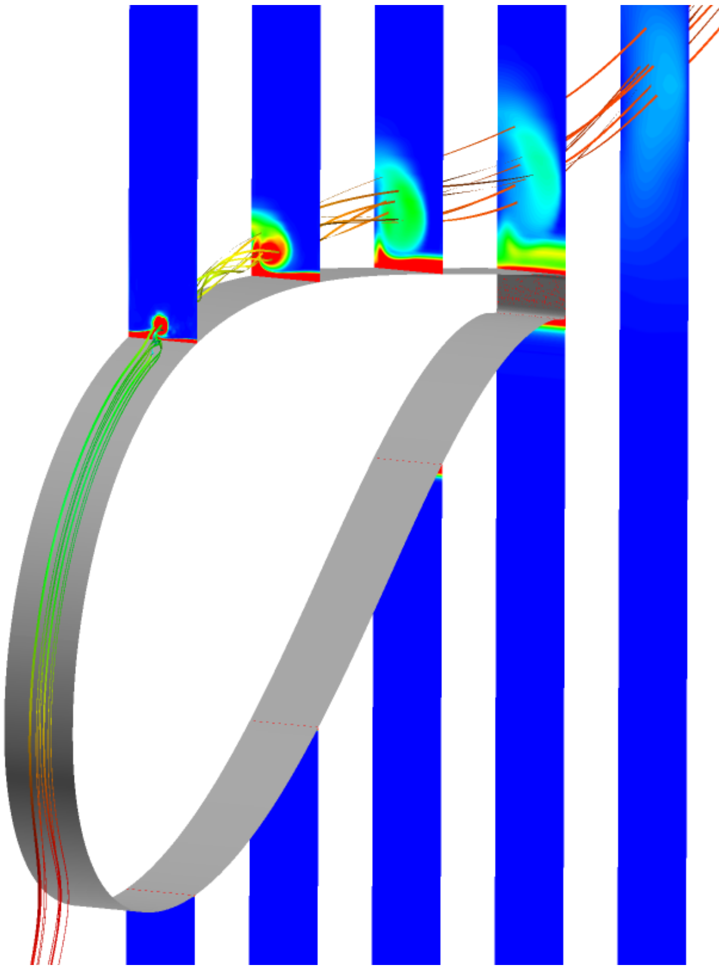


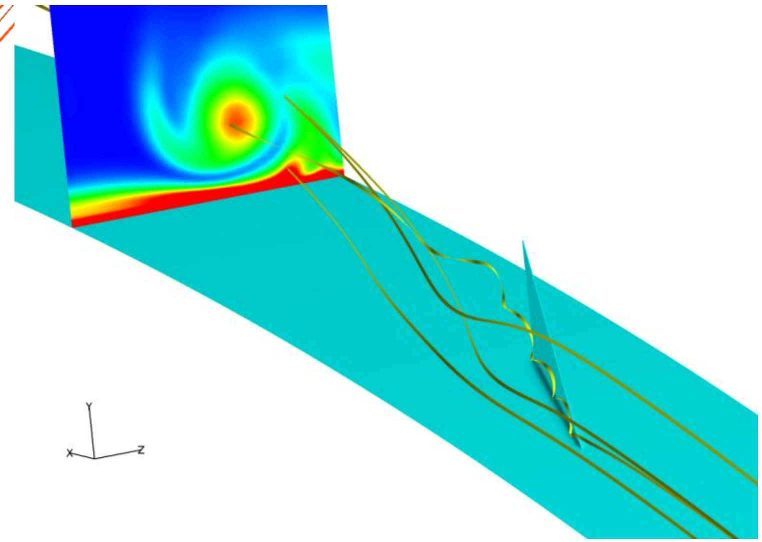
- A multi-element airfoil was designed and tested
- The slat was designed using an optimization tool coupled with EllipSys2D.
- 2D CFD succeeded to a large extent in predicting the correct characteristics.

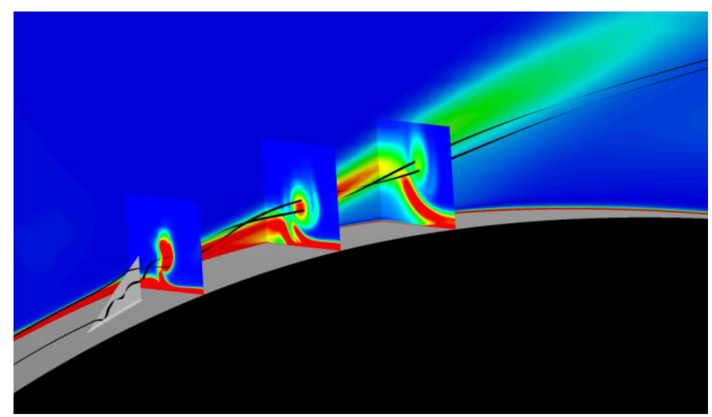




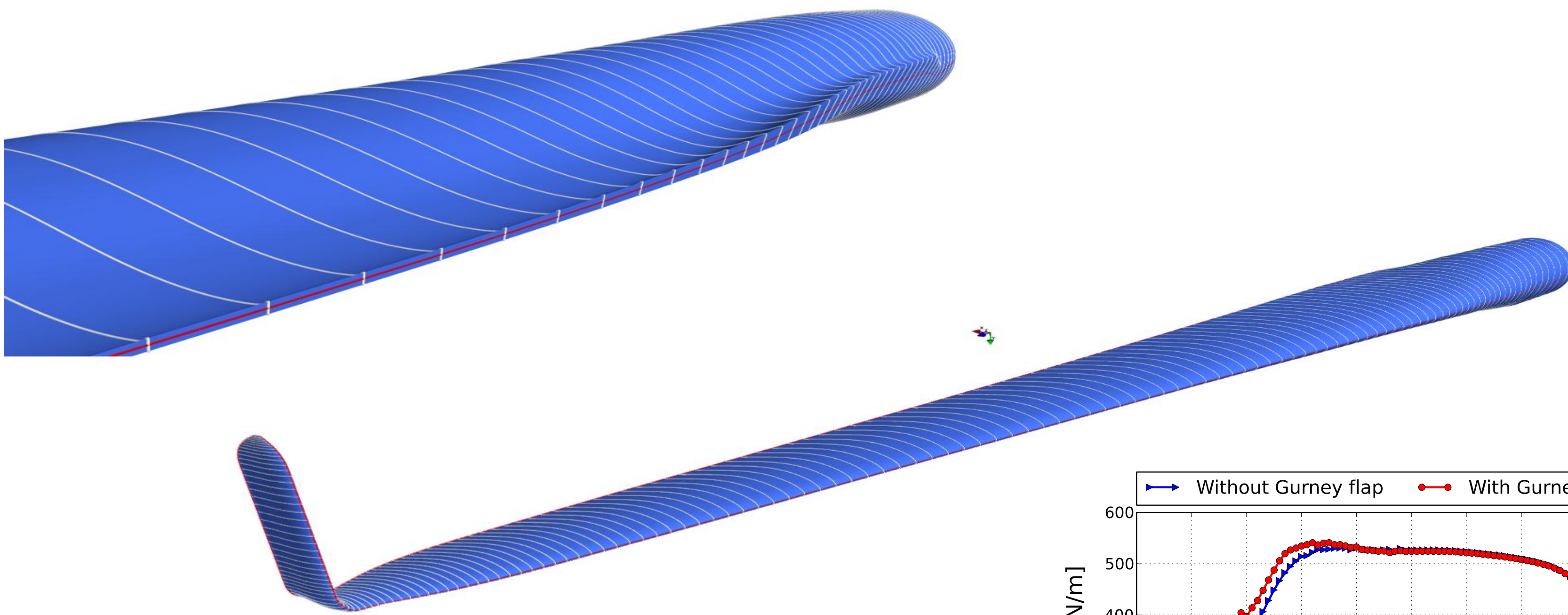
Flow kontrol med vortex generatorer

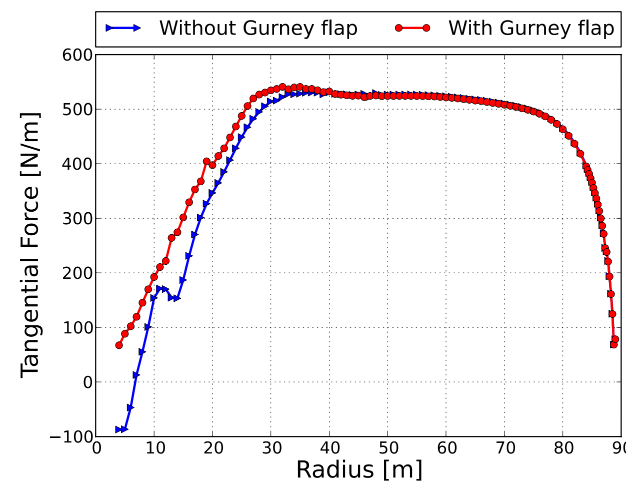






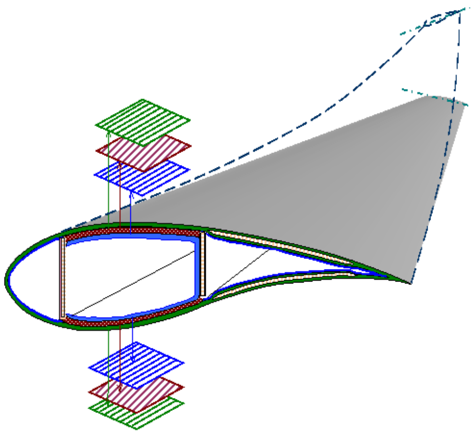
LightRotor 10 MW RWT blade with winglet and flat-back airfoils at root with Gurney flap

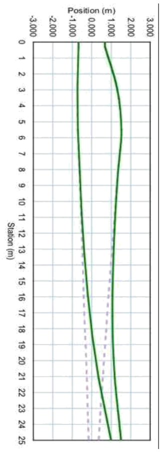


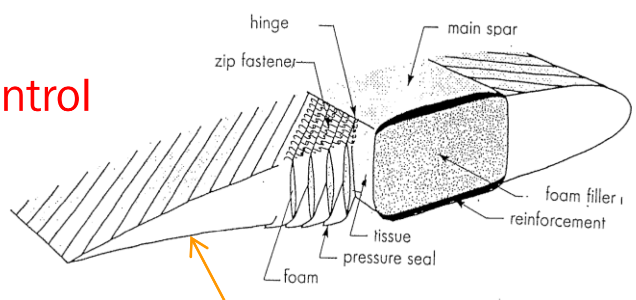


Flap-torsion coupled blade

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



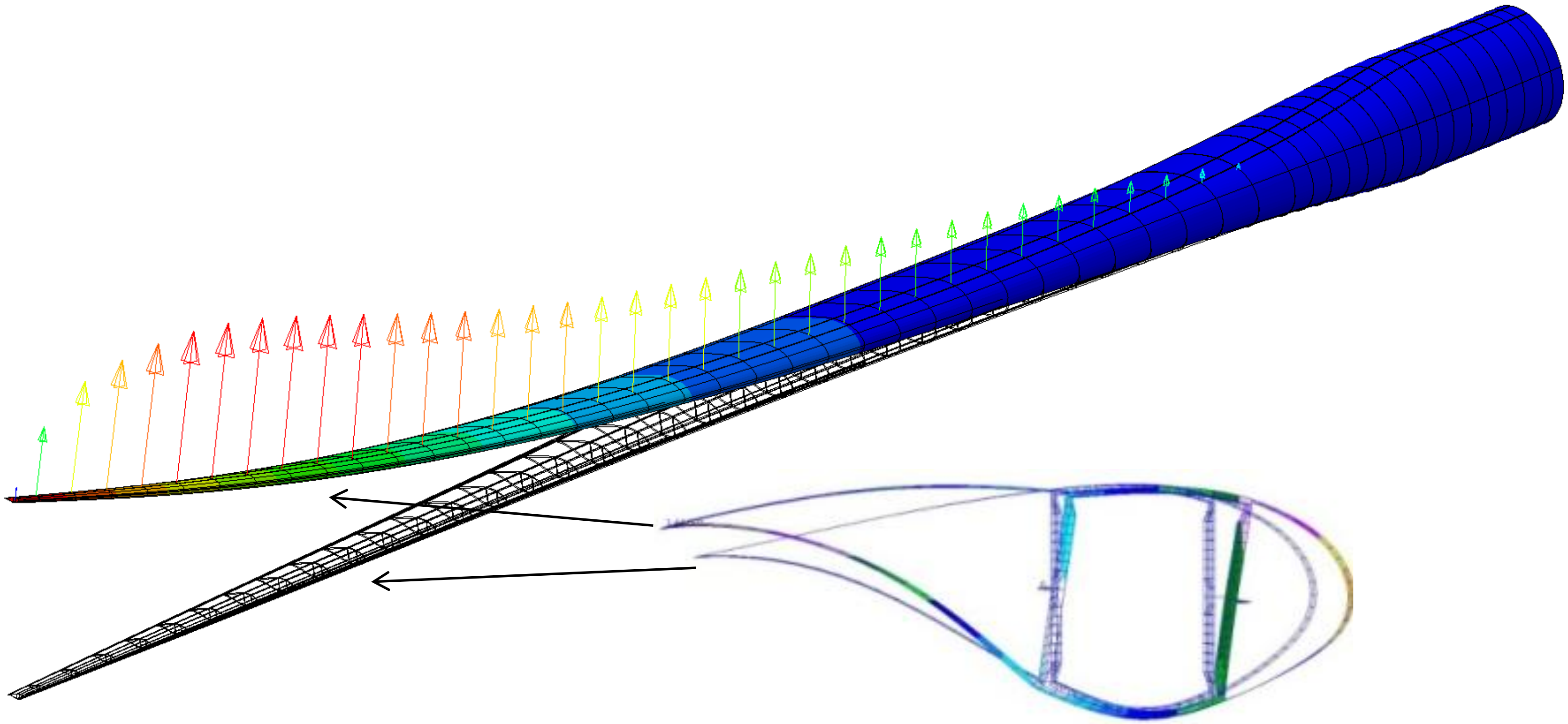




Feather

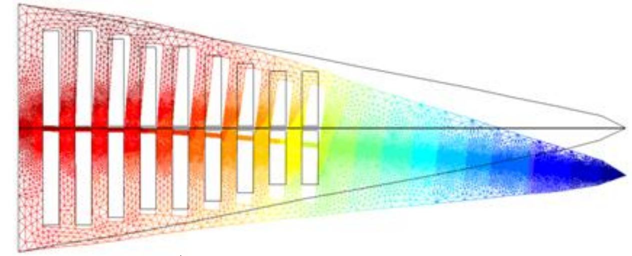
A Twist–flap Coupled Blade Design to Alleviate Fatigue Loads (on the left with material coupling and on the right with a curved blade

Possible flap-camper coupling?

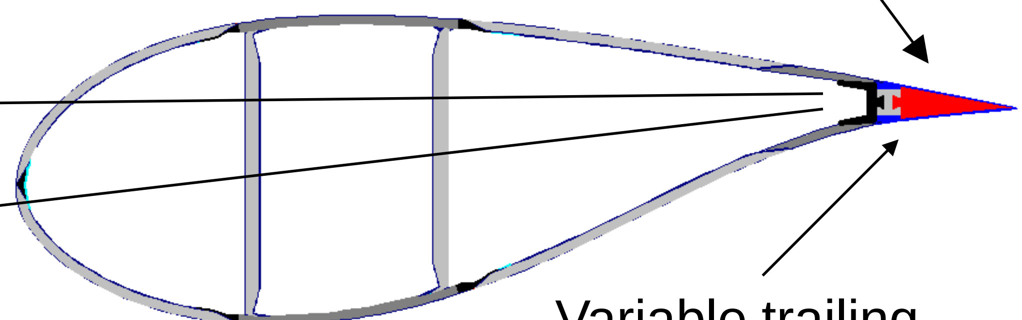


Blade pitch and trailing edge control

Elastomeric controllable flap
activated by pressure in voids

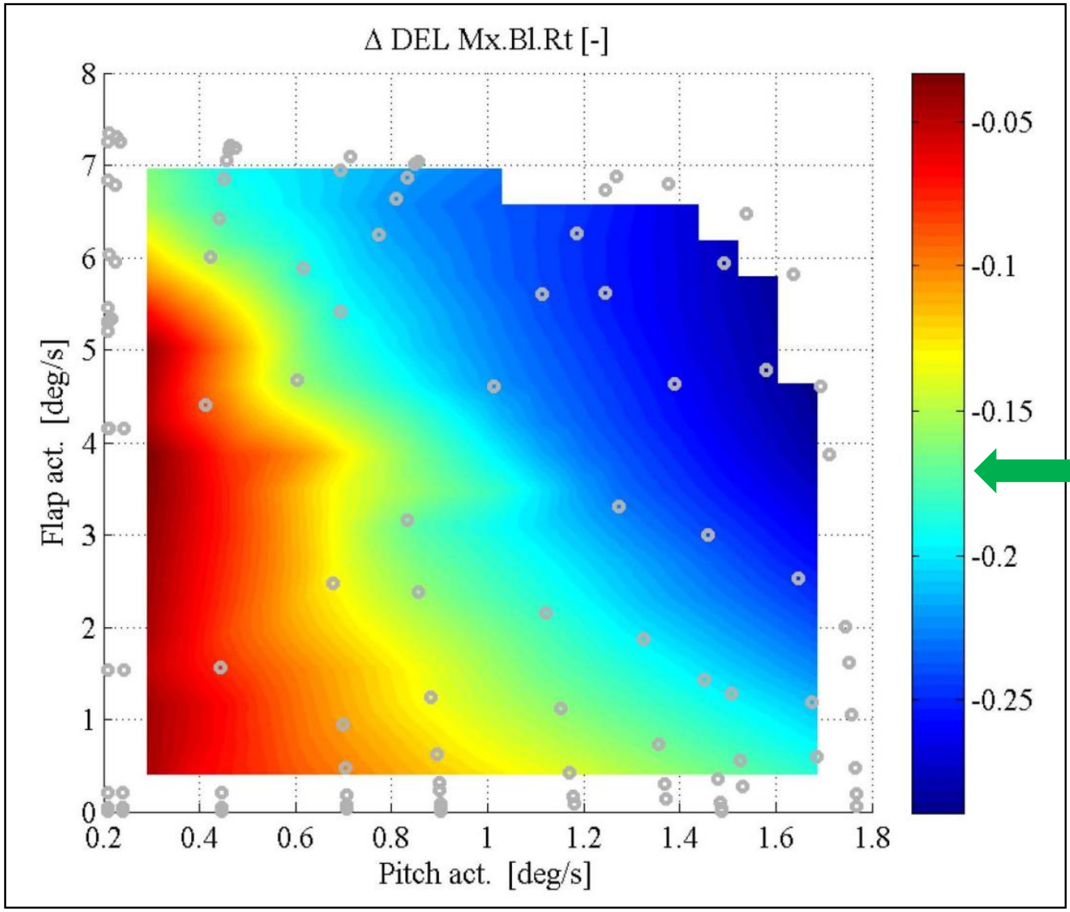


20-40% reduction in blade- and tower fatigue loads



Variable trailing edge flap

KOMBINERET PITCH OG FLAPKONTROL BASERET PÅ MÅLING AF FLAPMOMENT I RODEN



CONTROL OBJECTIVE:
Reduce the pitch activity and alleviate the loads using the same sensors as for the pitch system

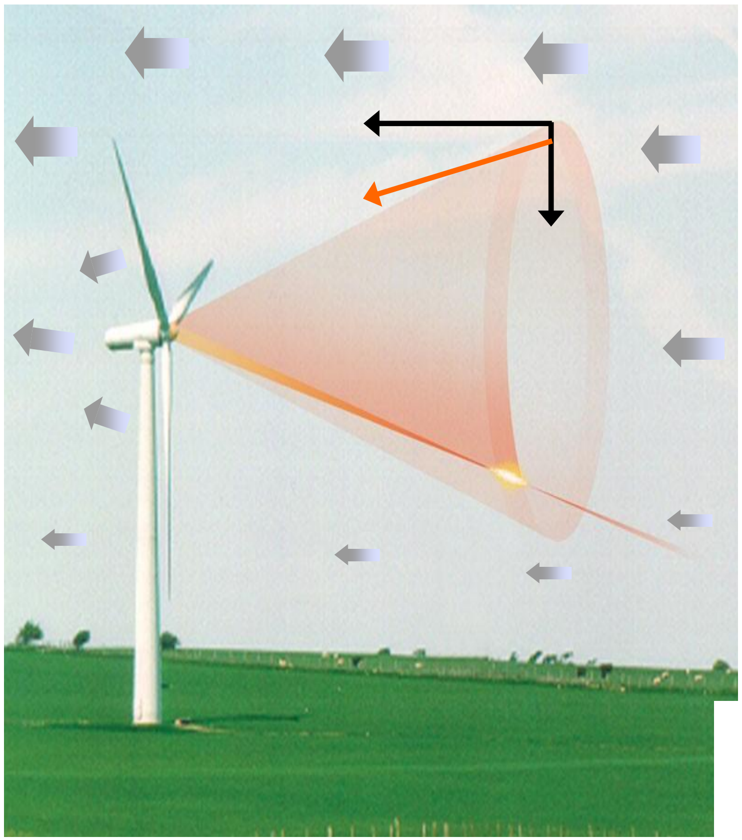
Fatigue Damage Equivalent Loads (DEL)

% alleviation at root flapwise bending

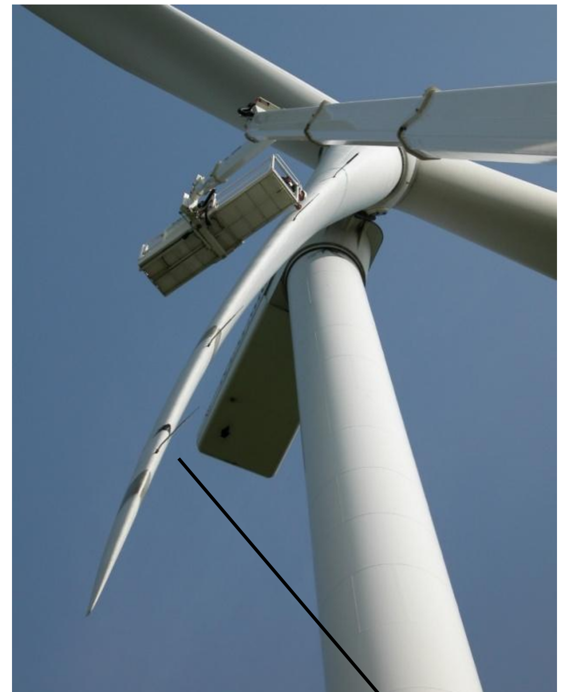
IEC class IA
18m/s

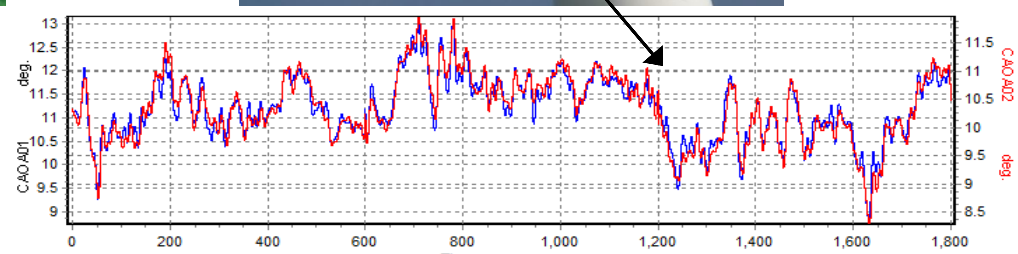
Measuring inflow for pitch or flap control

Lidar technology

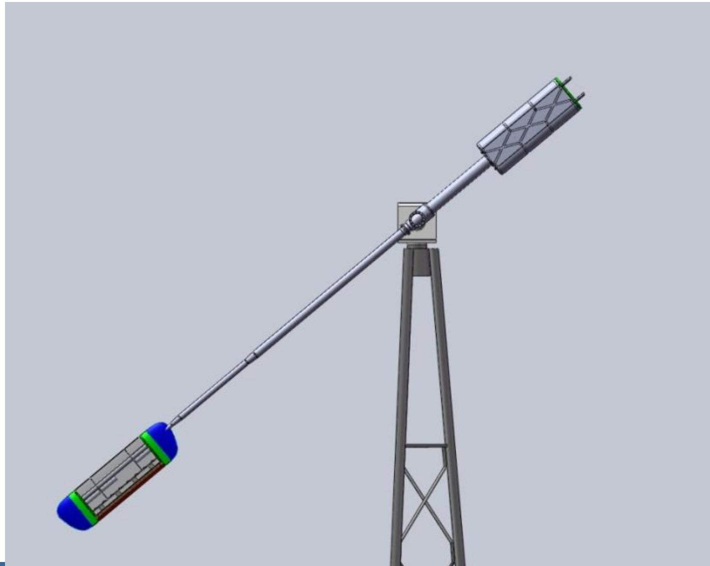


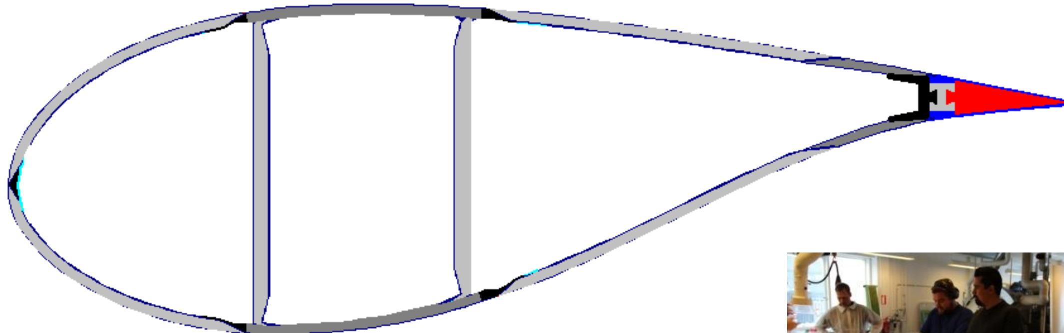
Inflow measured with four five hole pitot tubes

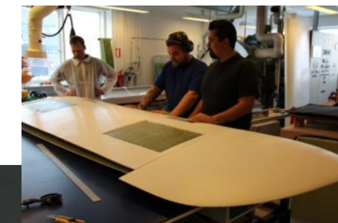


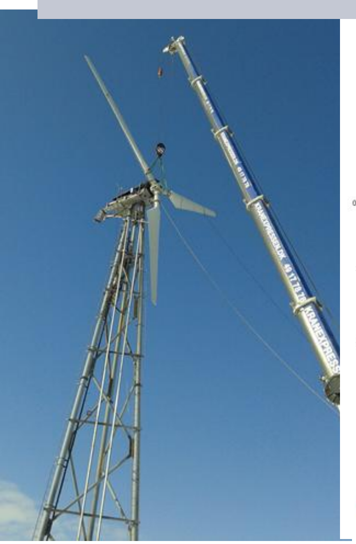


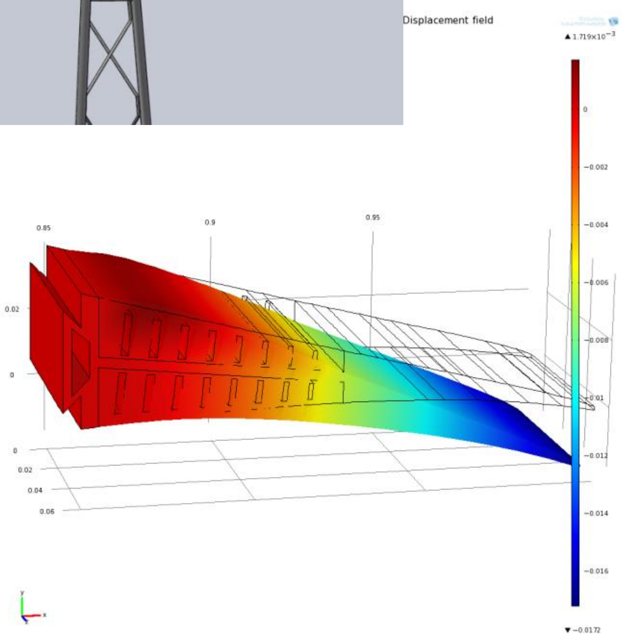
Rotating test rig and rubber trailing edge flap

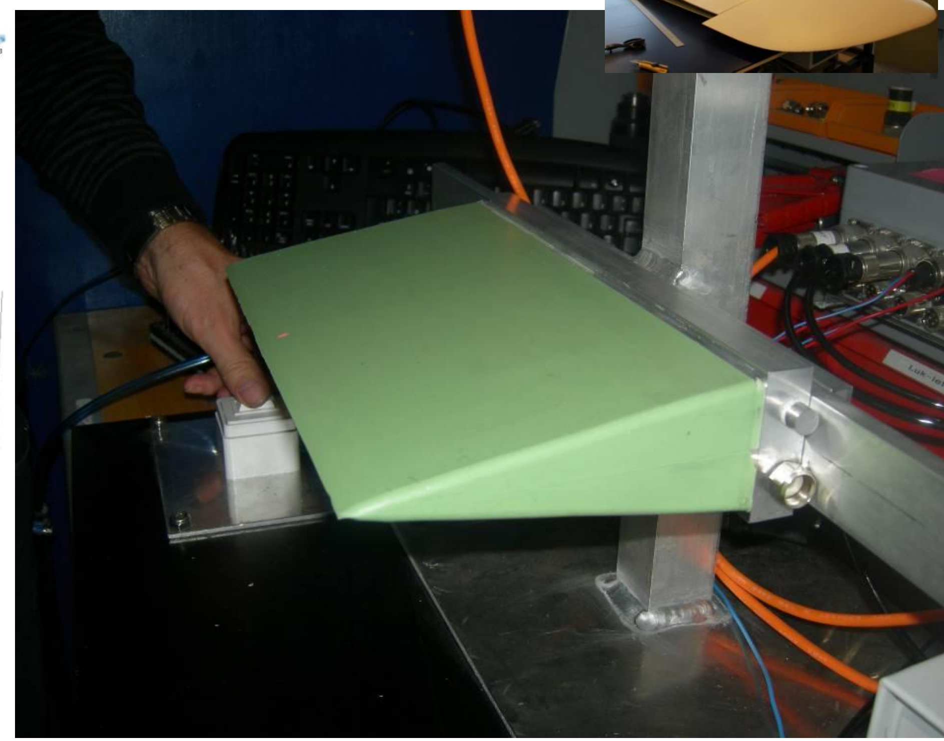










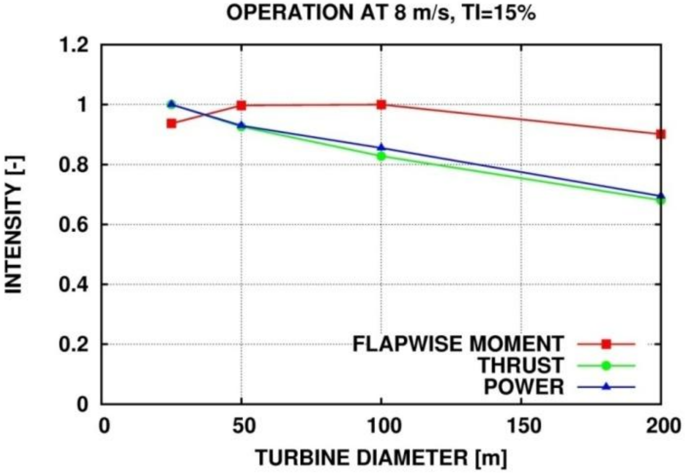


Forhold ved opskalering

- Stigende Reynoldstal en fordel op til 10 Mio. (ca. 10 MW). Derefter en ulempe?

- Øget tiphastighed (Mach nr.) en ulempe efter 90 m/s

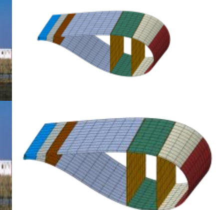
- Turbulens: Filtrering fra roterende sampling giver relativt mindre laster



Antal blade: 2-bladet/3-bladet

Den 2-bladede har:

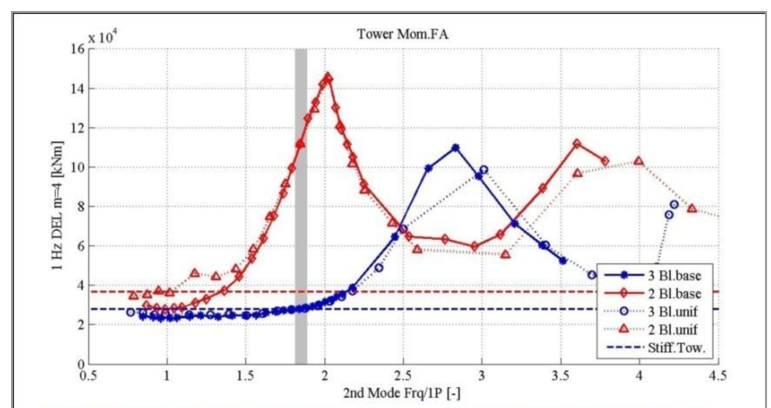
- 50% større korde
- 4% mindre virkningsgrad
- 15 % større turbulenslastinput (fordi 2p<3p)
- Ca. 2/3 rotorvægt



Med vippenav:

- Ca. 50% rotorvægt
- Bladlast ~ bladlast for 3-bladet
- Mulighed for større diameter

- Tårnegenfrekvens skal være lavere (ned mod 1p)



Perspektiver

- Er lavt belastede rotorer (som kører lavere belastet end det optimale) og derved giver mindre wakeeffekt i parker kost-effektive?

- Kan man forestille sig, at passiv og aktiv kontrol ud langs vingerne kan regulere effekten så hurtigt, at man igen kan køre med fast omdrejningstal?

- Opskaleringen har igen taget fart, og 10 MW er realistisk. Vil den fortsætte til 20 MW?

- **Fremtidens vinger bliver længere – både relativt og absolut.**