HyBlade
Hydroformed blades for arrays of vertical-axis wind turbines

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Main objectives of the project

- to have **built** and **field tested** prototypes of
- new light, stiff **metal blades** for optimally arranged turbines
- at a lower cost by an **innovative manufacturing process**

Project partners

and the user committee

User committee

Numeca	Hengelhoef CJ Manufacturing	Borit
SSTS	Power-Link - Greenbridge	Sirris
Laborelec	von Karmaninstituut	Beauvent
timelab	d2architecten	

Choices made before the start

Focus on...

1. H-type VAWT (giromill) for simplicity of blades
2. small wind turbine demonstrator to limit project budget
3. metals and series production technologies

Work plan of the project

1. aerodynamic and structural design of the rotor, blades
2. yield prediction of individual turbine and array
3. a sidestep to consider smart blades
4. manufacturing of the prototype rotor
5. field test of benchmark turbine and the prototype rotor

Blade geometry

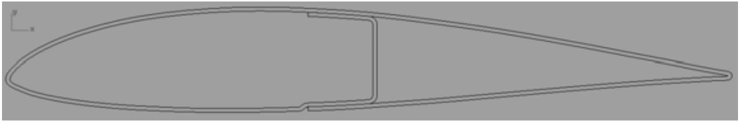
- VAWT blades are often symmetric or slightly asymmetric
  - NACA 0015 and NACA 0018 are standard choices (even 0012)
  - (Slightly) asymmetric alternatives are NACA 4418, NACA 2418, S2027, DU 06-W-200
- Typical design parameters for VAWT blades:
  - thickness of 15% to 18% (but, compromise with structural demands)
  - no or light camber (4% was highest observed value)
  - dynamic stall behaviour difficult to model and control

Blade geometry and loads

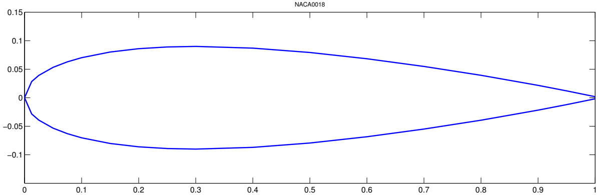
- With XFoil, we calculated aerodynamic performance data for about 100 airfoils, for various low Reynolds numbers
- With our streamtube code, we have then computed turbine power to select best airfoils
- With CFD, we have further improved our estimate of turbine power for these profiles

Blade geometry

Selig S2027 shows best theoretical performance,



The benchmark NACA0018 is chosen for the prototype rotor



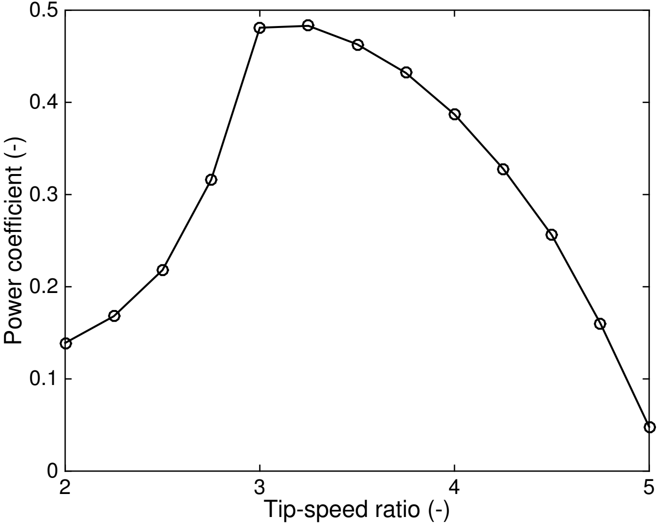
Blade geometry and loads

The prototype rotor will have

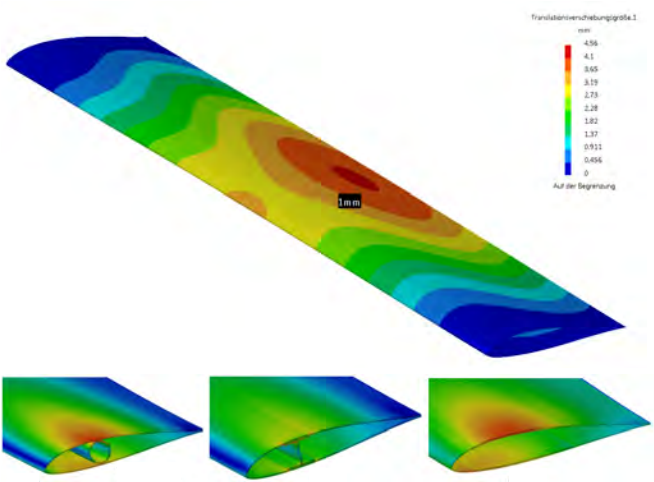
- number of blades: 3
- chord length: 0.37 m
- rotor radius: 1 m
- blade span: 3 m
- distance between struts: ca. 1.5 m
- design angular velocity: 240 rpm

(Based on the Aeolos-V 1 kW turbine, see further)

The efficiency of the rotor was predicted to peak around a tip-speed ratio of 3



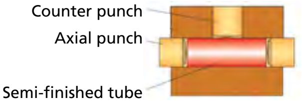
Structural design of the blade performed by IWU Fraunhofer



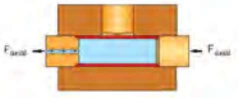
What is hydroforming?

Principle / process steps

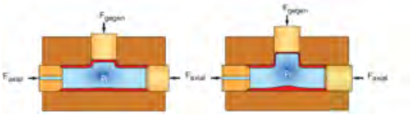
(1) Insertion of the part in the tool



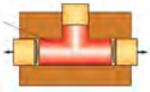
(2) Filling with active media



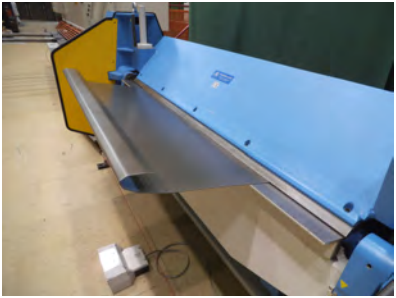
(3) Forming process + calibration



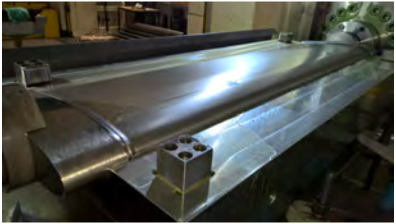
(4) Release of the part



First, the metal sheet is bent in a pre-form, then welded

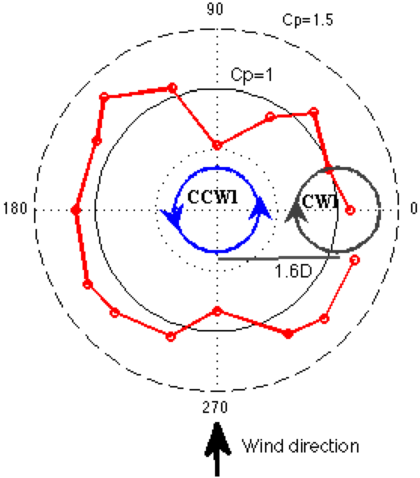
Then the profile is hydroformed into its final shape



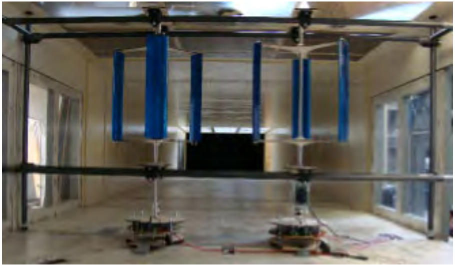
A short movie of the laser welding

Closely-spaced VAWTs have been shown theoretically to mutually increase the power output

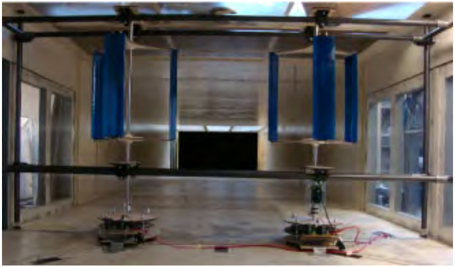
Seminal work by prof. Dabiri (CalTech), which we verified



Our tests of the efficiency of arrays of VAWT farm



(a) 1.25D



(b) 1.5D

A pair of VAWTs

A short movie of the experimental tests

Can this mutual power increase be extrapolated to VAWTs or VAWT pairs in a (very) large farm?

- Pairs of turbines should be spaced about 4–8 D apart, which is smaller than for HAWT farms (8–15 D)
- Theoretical studies of 5×6 VAWT farms at 2.5 D and 3–4 D apart predict 50–100 % power increases
- Based on our wind tunnel tests, we confirm a power increase of about 5–10%, possibly more at higher TSR
- The extension to very large farms (> 1 km in length) has not been studied for VAWT farms

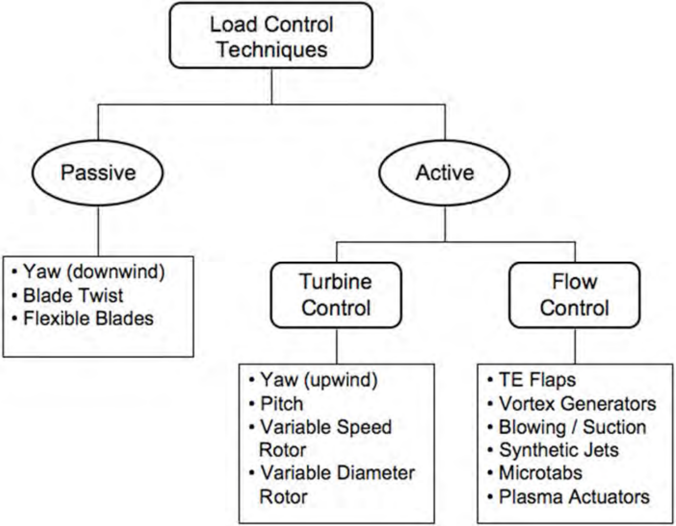
What about smart blades?

Smart blade = active or passive device for *flow control*, to

- delay/advance transition
- suppress/enhance turbulence
- prevent/promote separation

for load alleviation, lift enhancement, . . .

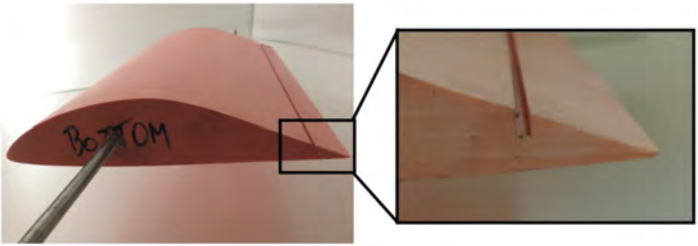
What is flow control?



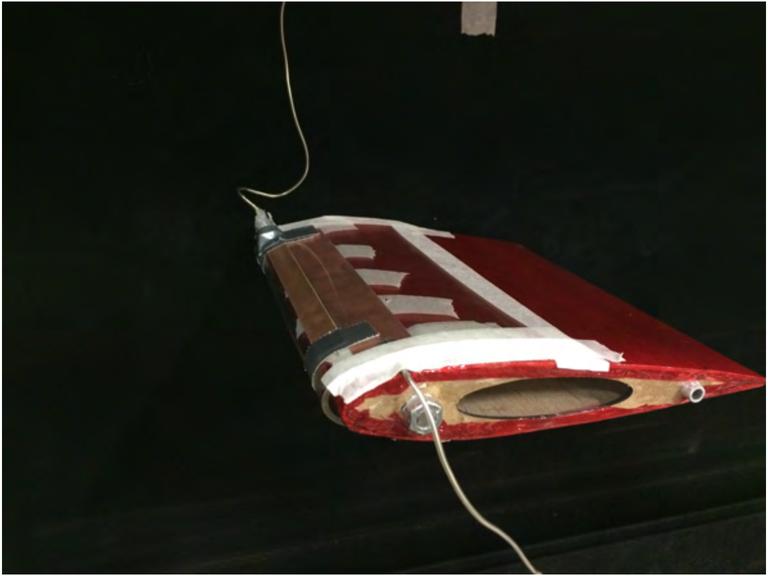
Smart blades offer options

Our suggestion for VAWT turbine: microtabs for lift enhancement:

- Loads for VAWT are predominantly centrifugal
- Lift varies greatly over one revolution, thus could benefit from periodic lift optimization



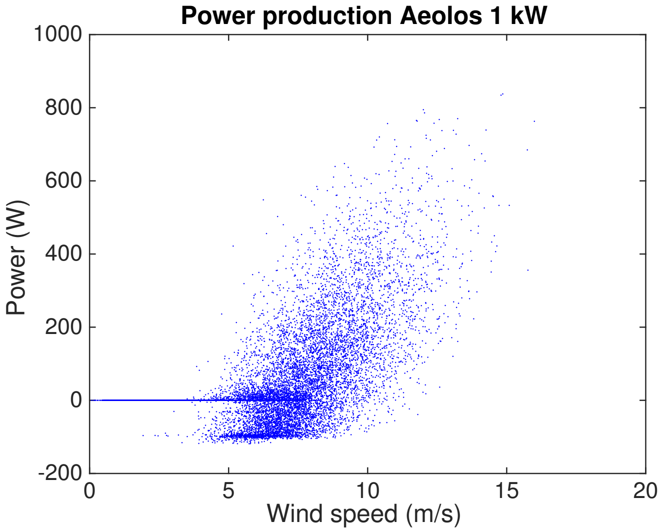
Also plasma actuators are considered, to delay stall with no moving parts

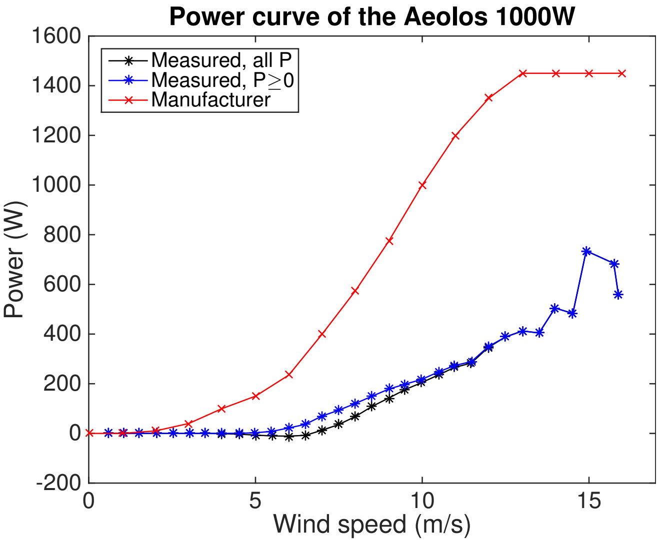


A short movie of an experimental test

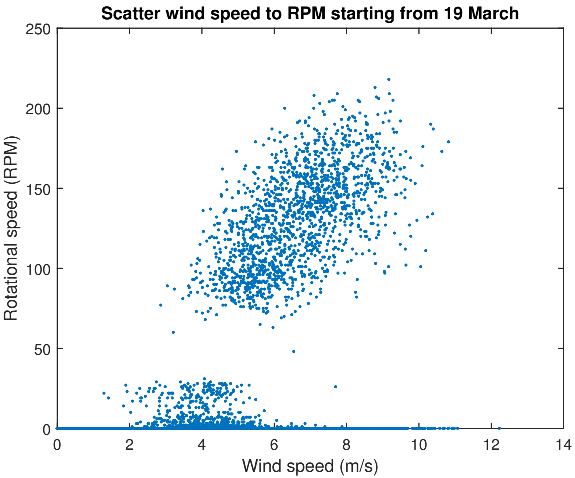
Field tests of benchmark turbine

- We have installed the Aeolos turbine on 20 August 2014
- Testing began 16 February 2015
  (after much inverter problem solving)
- With (very) limited electricity production:
  - Max. overall power obtained was 850 W
  - After a while, only 10 W was produced, even at speeds > 10 m/s
- We also installed an rpm sensor (max. recorded was 240 rpm) and an electronic drive to start the turbine


Power production Aeolos 1 kW
Power (W)
Wind speed (m/s)
1000
800
600
400
200
0
-200
0
5
10
15
20



Power curve of the Aeolos 1000W
Measured, all P
Measured, P≥0
Manufacturer
Power (W)
Wind speed (m/s)
1600
1400
1200
1000
800
600
400
200
0
-200
0
5
10
15


Scatter wind speed to RPM starting from 19 March
Rotational speed (RPM)
250
200
150
100
50
0
0
2
4
6
8
10
12
14
Wind speed (m/s)

Turbine failure

The turbine broke down on 25 March 2015.


AEOLOS

Our plan B to continue with the field tests

- We bought a new (European-built) 3 kW PMSG
- We cut the mast in half to reduce risk
- We installed a wind measurement mast nearby
- The rotor was shipped to Ostend and installed on the test field on 10 July 2015

We tested the rotor on 29 July and 4 August 2015

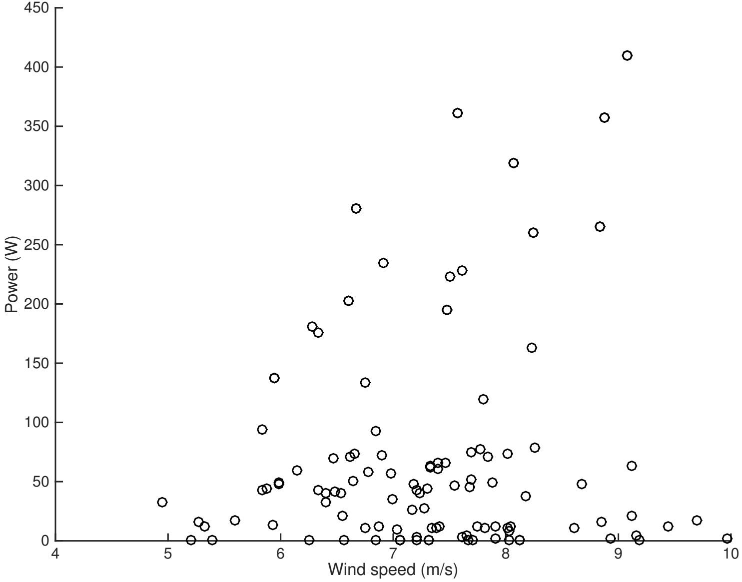
We varied the resistive load applied to the generator, meanwhile measuring

- wind speed (m/s)
- rotational velocity of the rotor (rpm)
- generator voltage (V)

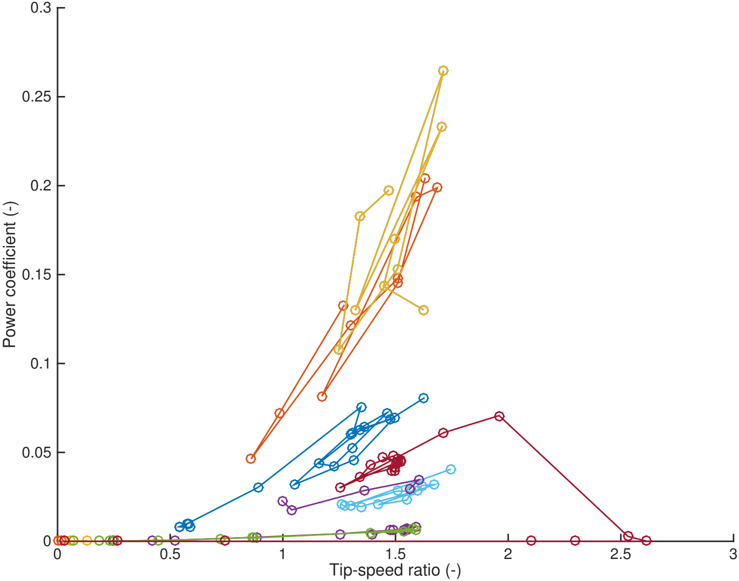
- These data were sampled and stored at 5 Hz using Labview
- We post-processed the data into one minute averages according to IEC 61400-12-1

The first tests of the prototype rotor

A short movie of the field test



450
400
350
300
250
200
150
100
50
0
Power (W)
4
5
6
7
8
9
10
Wind speed (m/s)


Power coefficient (-)
Tip-speed ratio (-)
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.5
1
1.5
2
2.5
3

We measured a solidly performing turbine

- with maximum power coefficient of 0.257
  (at TSR 1.7 and 6.7 m/s wind speed)
- and a maximum power of 409 W
  (at C_P of 0.149 and 9.1 m/s wind speed; the TSR was 1.5)
- the overal power coefficient is above 0.2
  for wind speeds between 6 m/s and 8 m/s.
- but more measurements are needed to find the optimum

(To compare, the Fairwind 10 kW turbine reaches a maximum power coefficient of 0.263 at 7 m/s, and stays above 0.2 from 5 m/s till 10.6 m/s, according to the SEPEN test report).

Breakdown of manufacturing costs, per blade span, for metal and GFRP series production.

	Cost in €/m blade		
	Metal prototypes	Metal series	GFRP series
R&D, Tooling cost	40	7	2
Material cost	14	3	14
Manufacturing cost	11	2	70
Total cost	66	21	86

This is about a four-fold reduction in blade cost,
and a 25 % reduction of the turbine cost
(assuming the blade amounts to 1/3 of the total cost)

I would like to thank. . .

- IWT Vlaanderen, AiF Germany, the CORNET framework
- IWU Fraunhofer, EFB
- All the companies of the user committee
- My colleagues and researchers on the project

for the succesful realisation of an inspiring project

Vrije Universiteit Brussel