Hochschule Düsseldorf
University of Applied Sciences
HSD

Fachbereich Maschinenbau & Verfahrenstechnik
Faculty of Mechanical and Process Engineering

Institute of Sound and Vibration Engineering
ISAVE

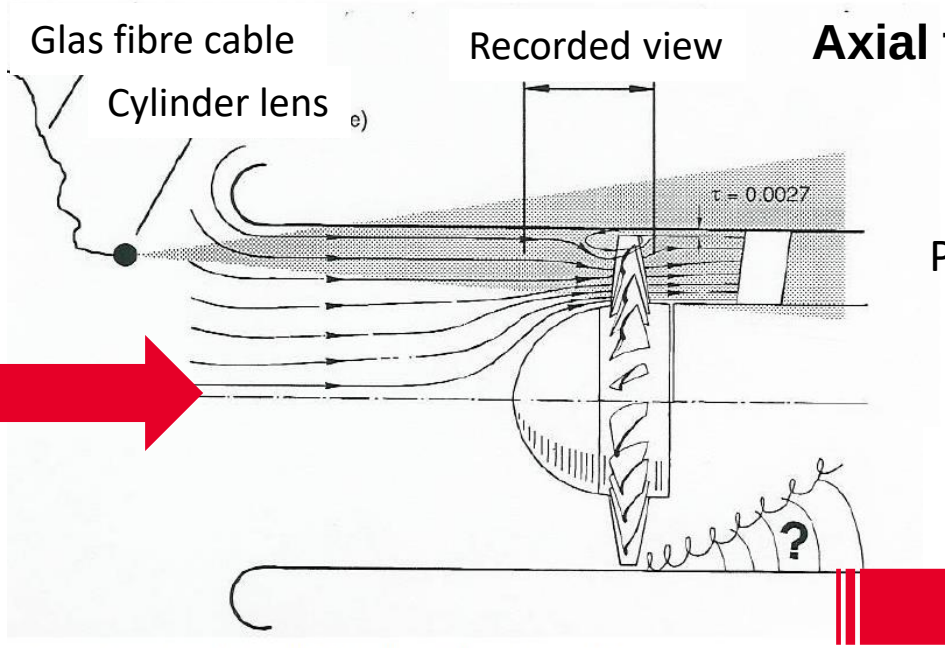
European Congress on Renewable Energy and Sustainable Development
November 16-17, 2023, in Rome, Italy

Blade tip vortex noise of wind turbines and infrasound

https://www.dlr.de/content/de/artikel/energie/forschungsthemen/windenergie.html

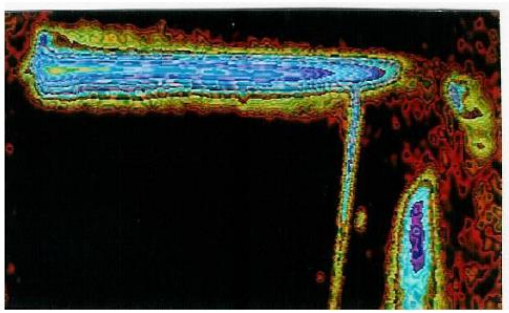
Frank Kameier # Professor for Fluid Mechanics and Acoustics

Axial fan – experimental flow visualisation



Position of the laser light sheet in the flow machine

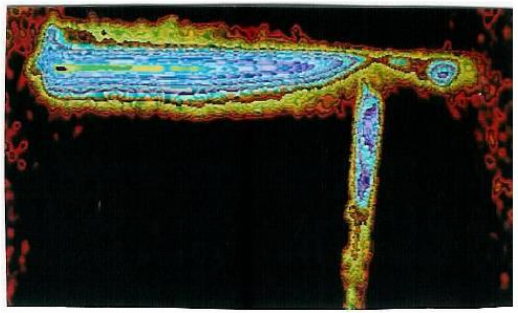
PhD Blade tip **vortex** noise … 1994



Vortex

Impeller blade

Only rotor-synchronus visualisation available



Vortex

Impeller blade

http://stroemungsakustik.de/old.mv.fh-duesseldorf.de/d_pers/Kameier_Frank/c_veroeffentlichungen/Dissertation_kameier220405d.pdf

Axial fan – averaging methods

PhD Blade tip **vortex** noise … 1994

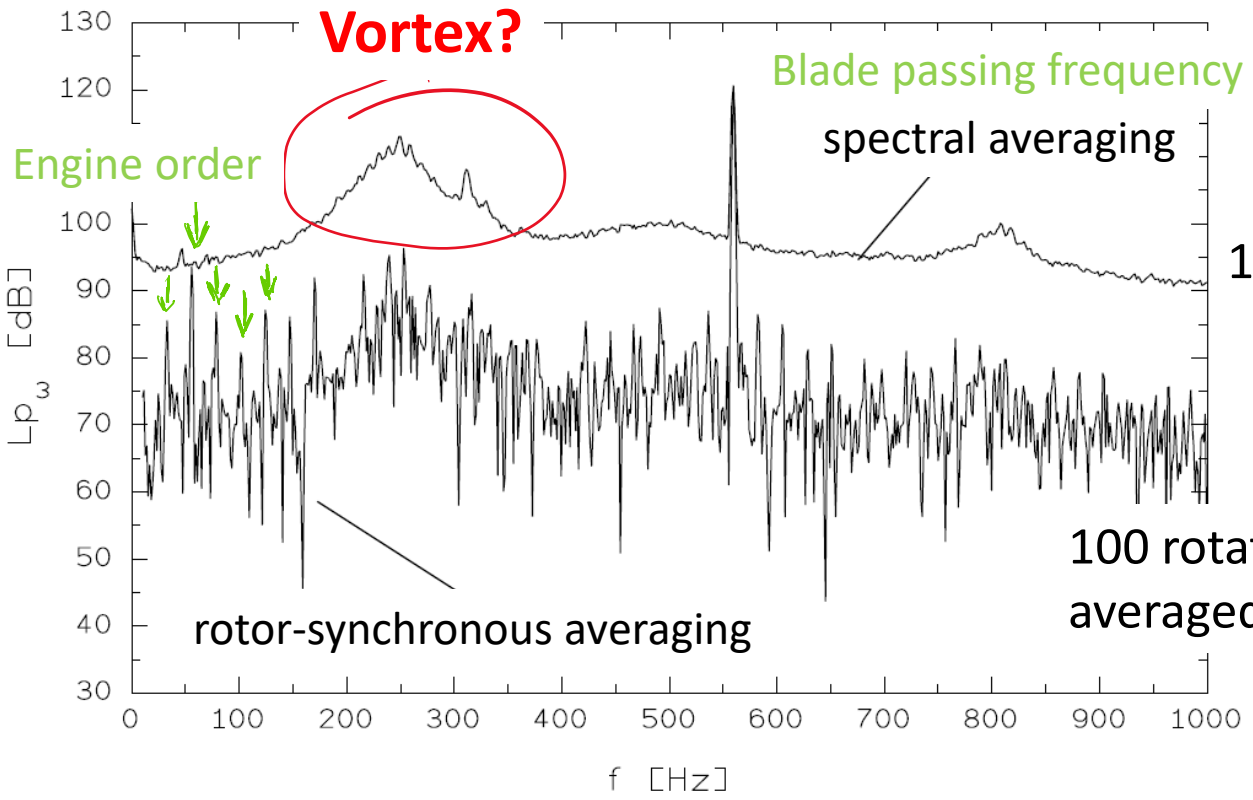
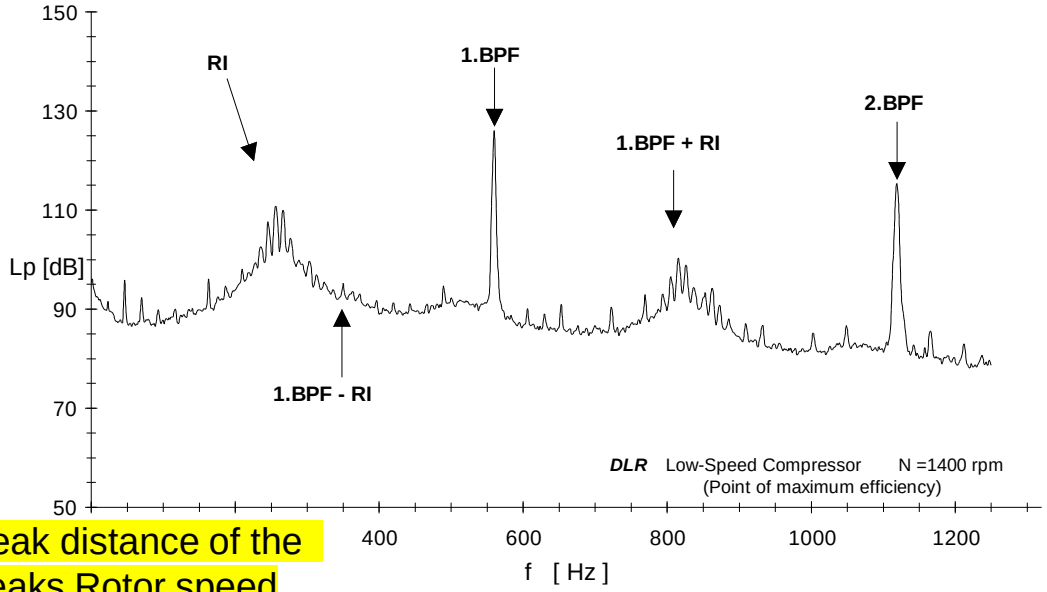


Bild 3-35: Vergleich der Spektraldichtepegel der Wanddruckschwankungen für verschiedene Mittelungsarten, ζ=-0.007, τ=0.0053, $\Phi/\Phi_{Opt.}$=0.93, n=1400 U/min.

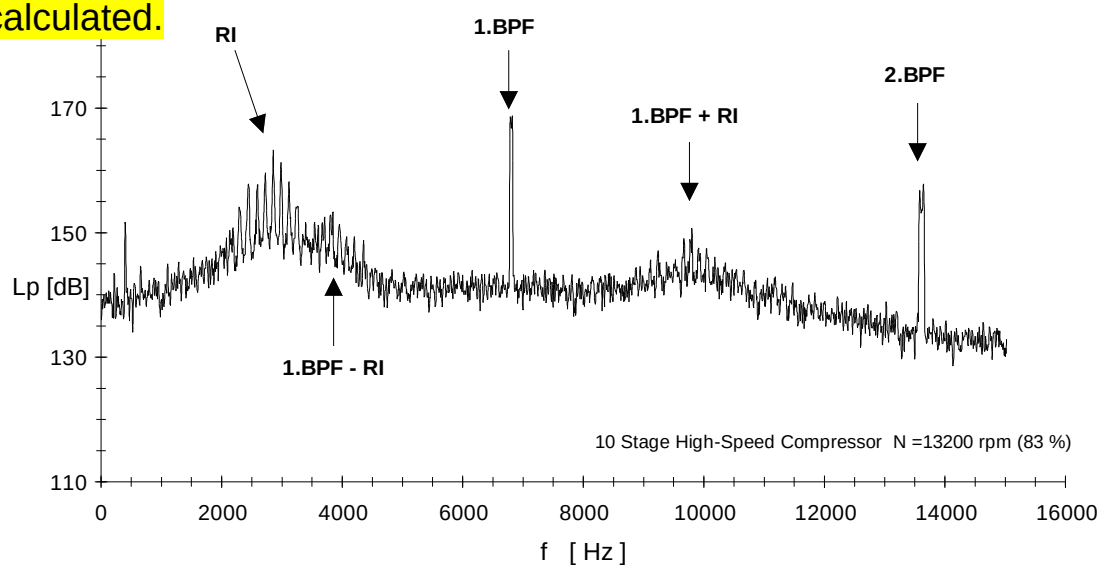
http://stroemungsakustik.de/old.mv.fh-duesseldorf.de/d_pers/Kameier_Frank/c_veroeffentlichungen/Dissertation_kameier220405d.pdf

Blower 1200 1/min
(Tip clearance effect)



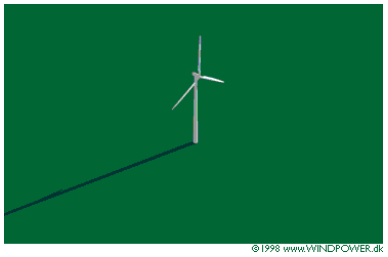
With the peak distance of the Doppler-peaks Rotor speed Could be calculated.

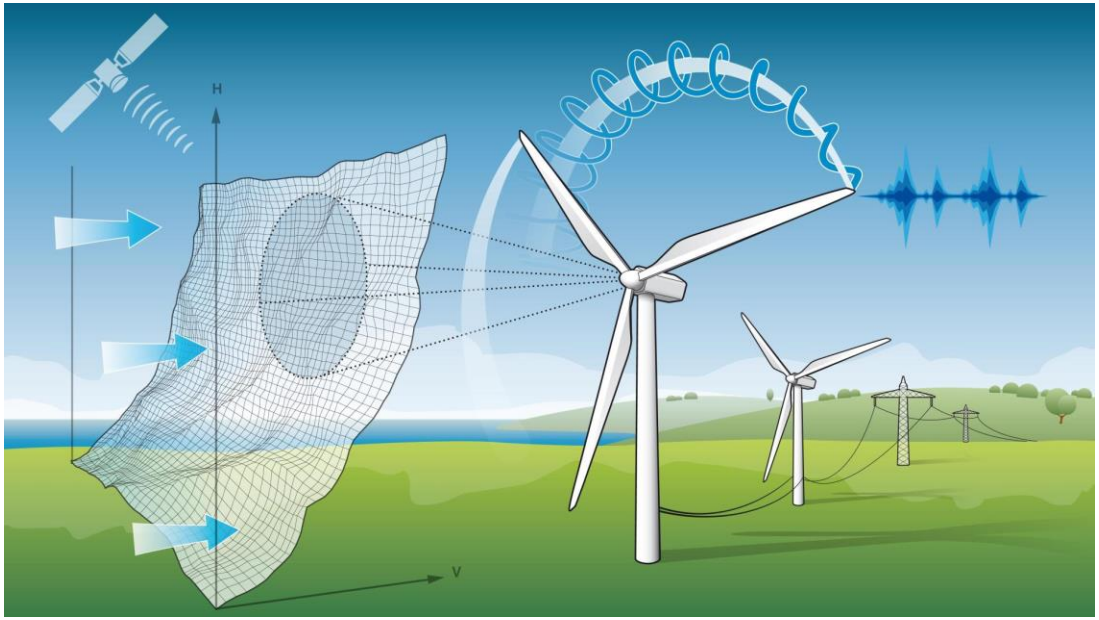
High-pressure compressor
13200 RPM
(Overload
with negative incidence)



Baumgartner et al. 1995

… origin of a research idea 2022






[From Oerlemans, 2009]

https://www.dlr.de/content/de/artikel/energie/forschungsthemen/windenergie.html

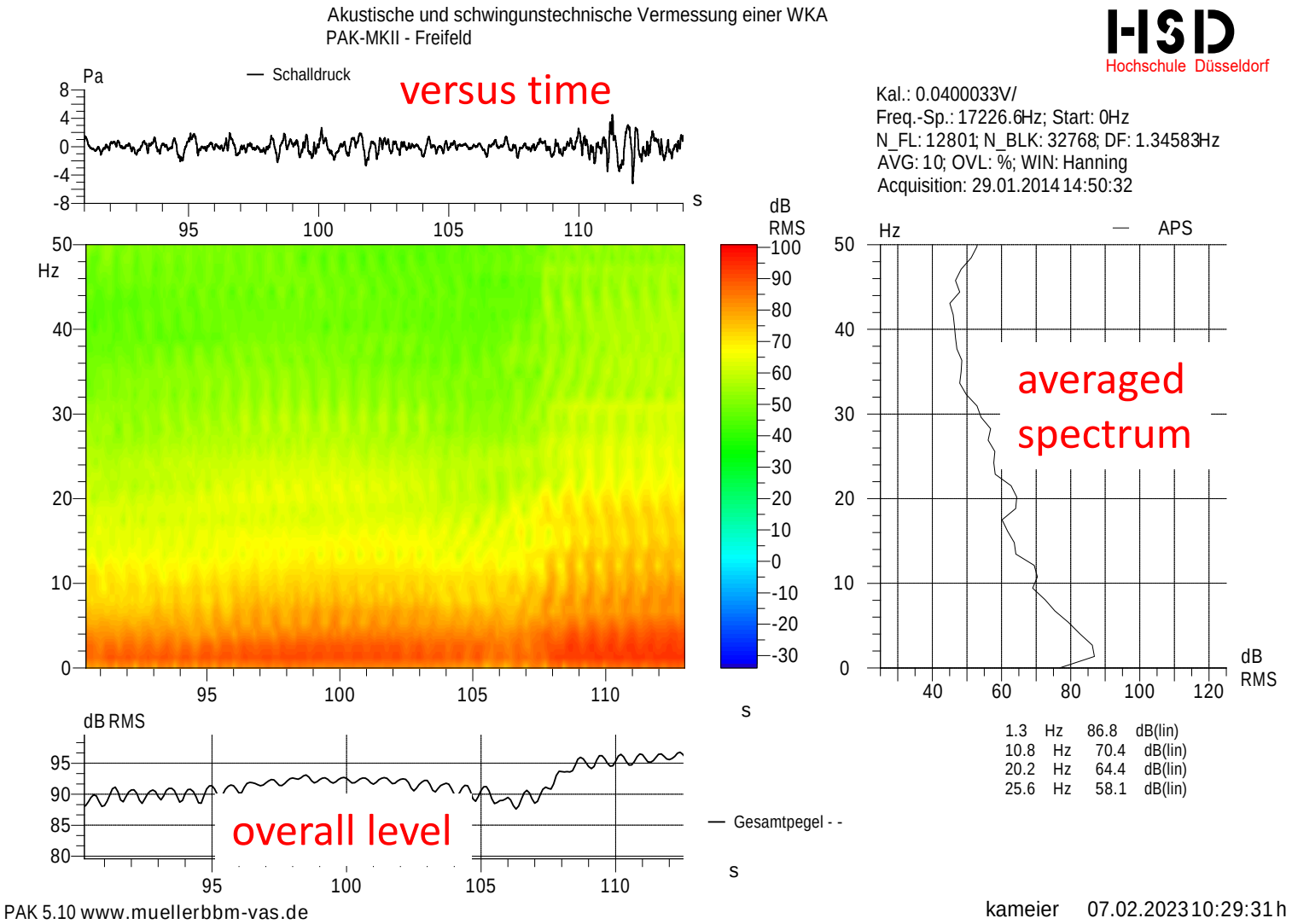
https://www.dhv.de/medien/dhv-info/dhv-info-2016/dhv-info-199/

Blade tip vortex

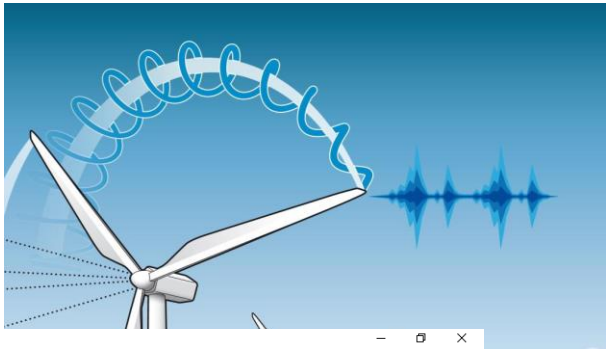
Multi-Copter and smoke generator placed on a rope

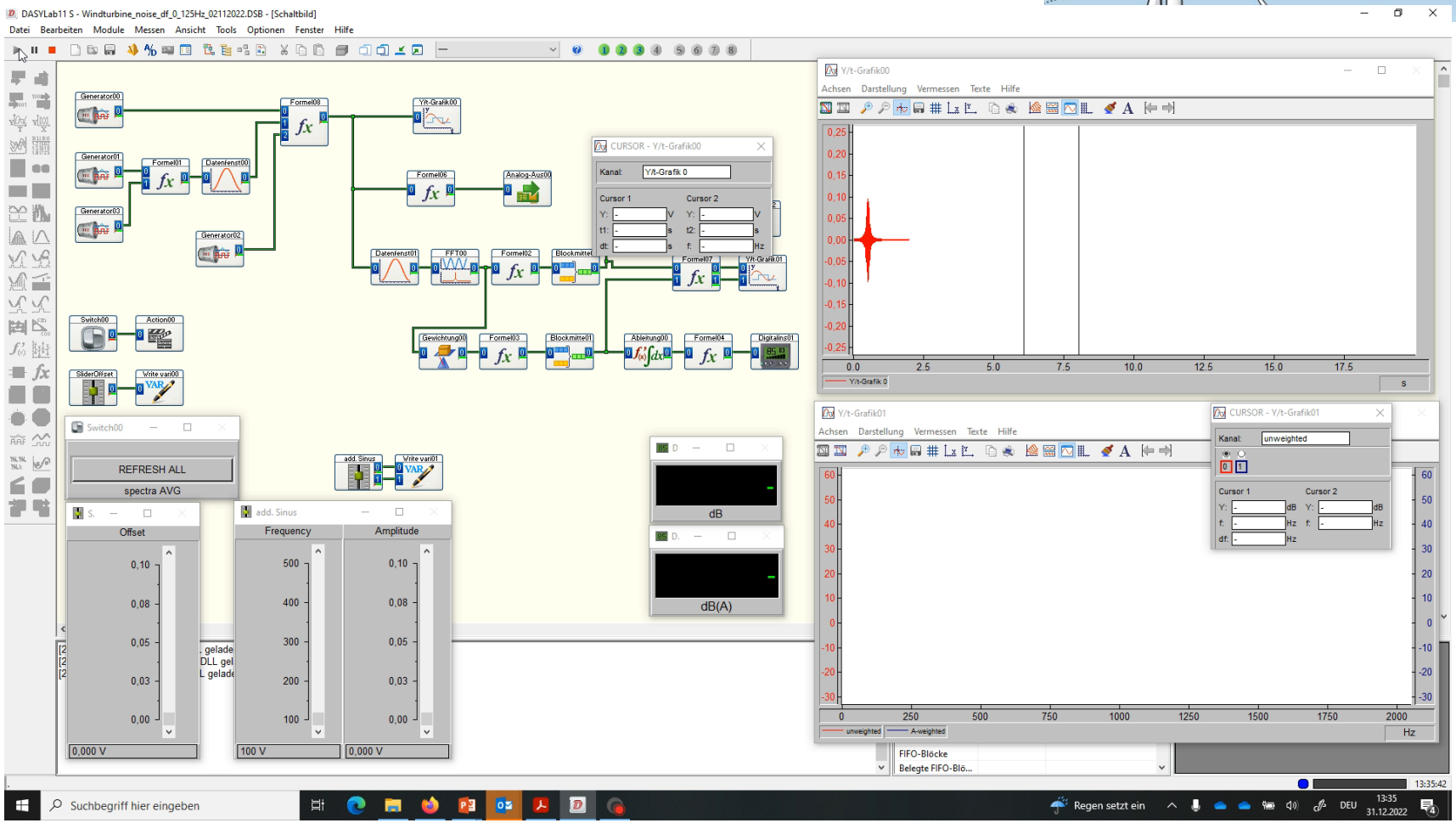
Test-pilot in the lee of the wind turbine

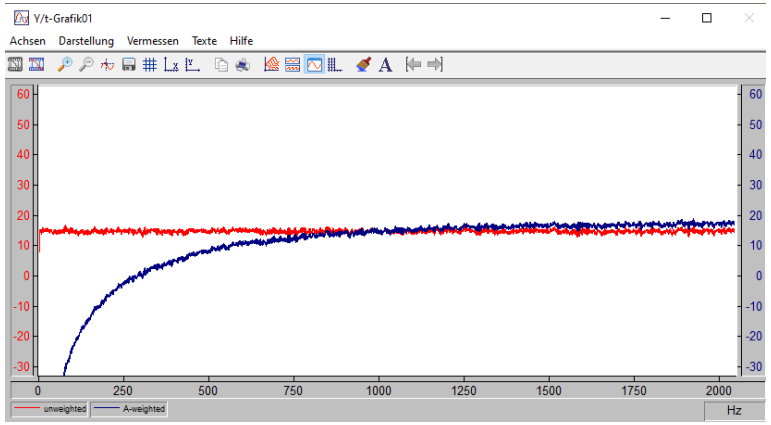
Sound pressure versus time – measurement (distance 100 m)



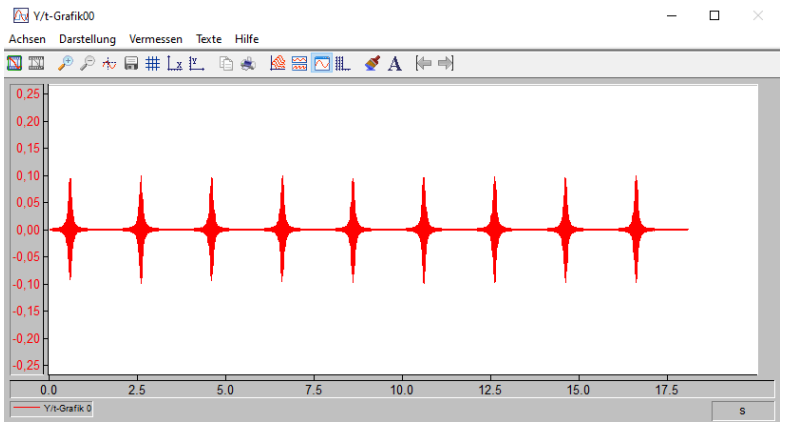
Simulation of the noise of a wind turbine –
modulation of the amplitudes of a white noise





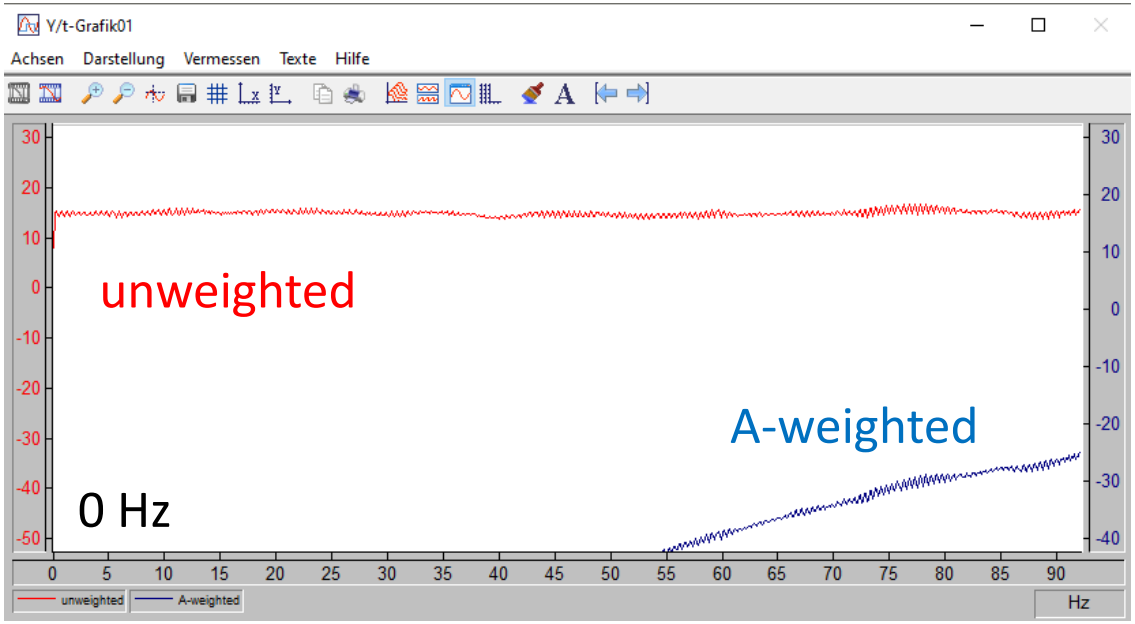


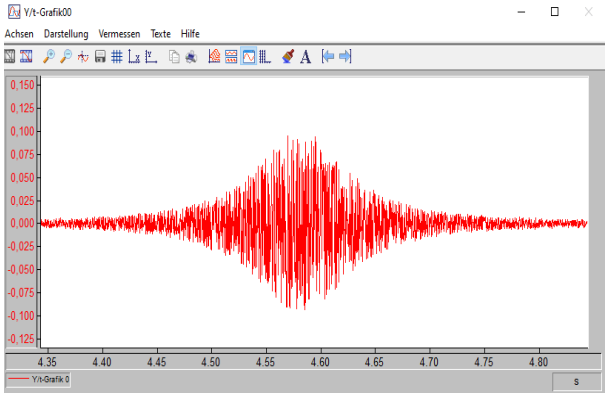
0 Hz 2000 Hz



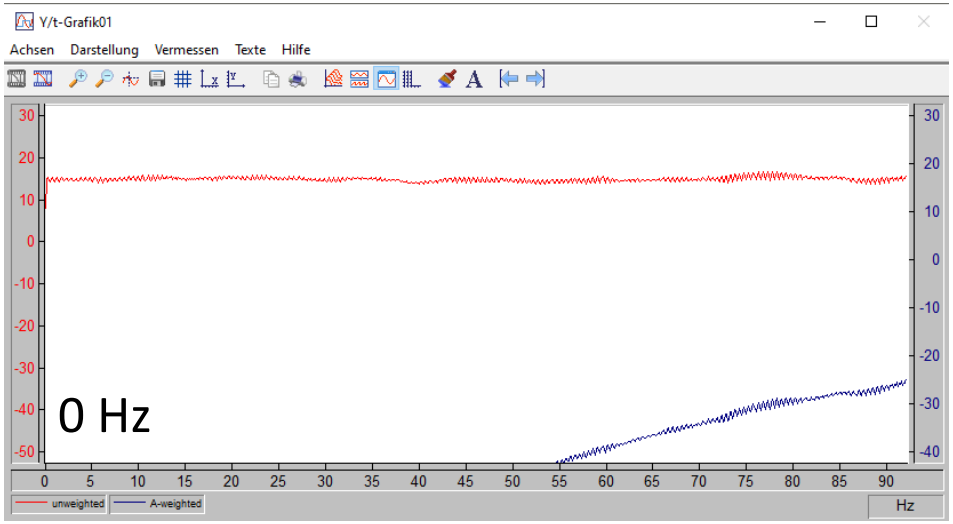
variation in time

spectra – with several averages …

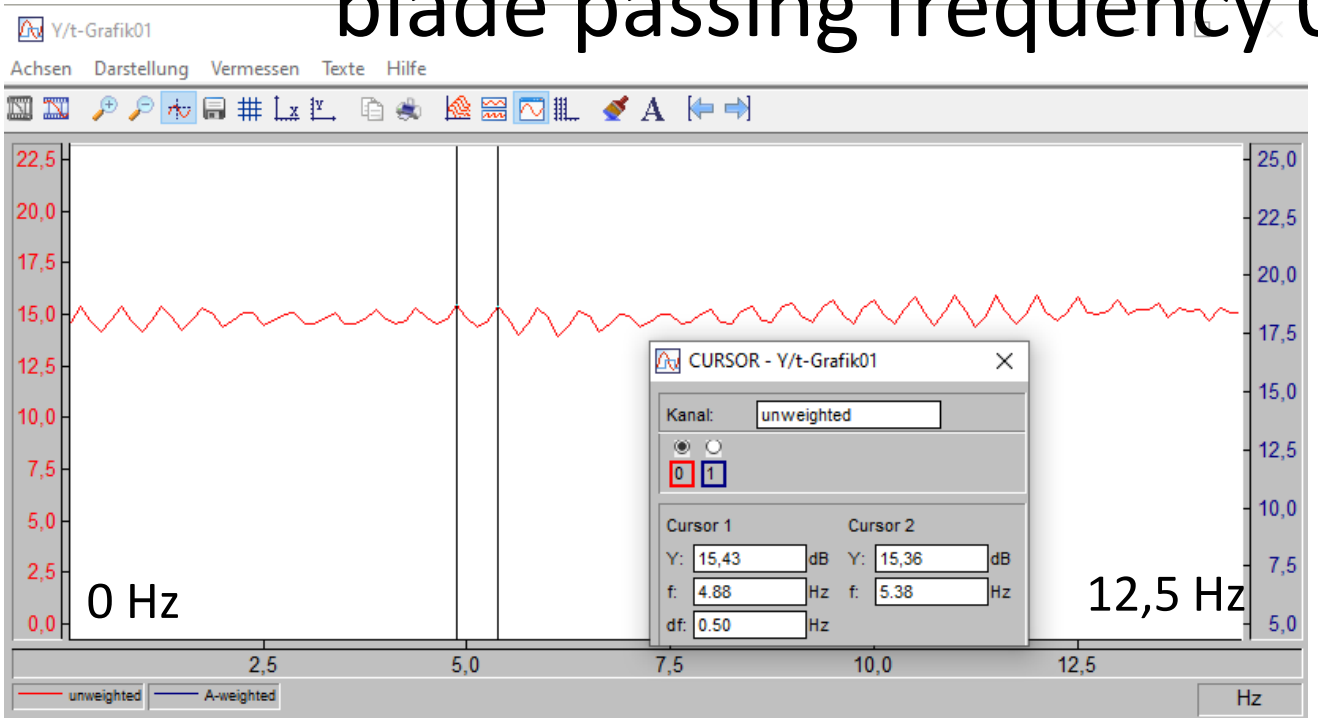




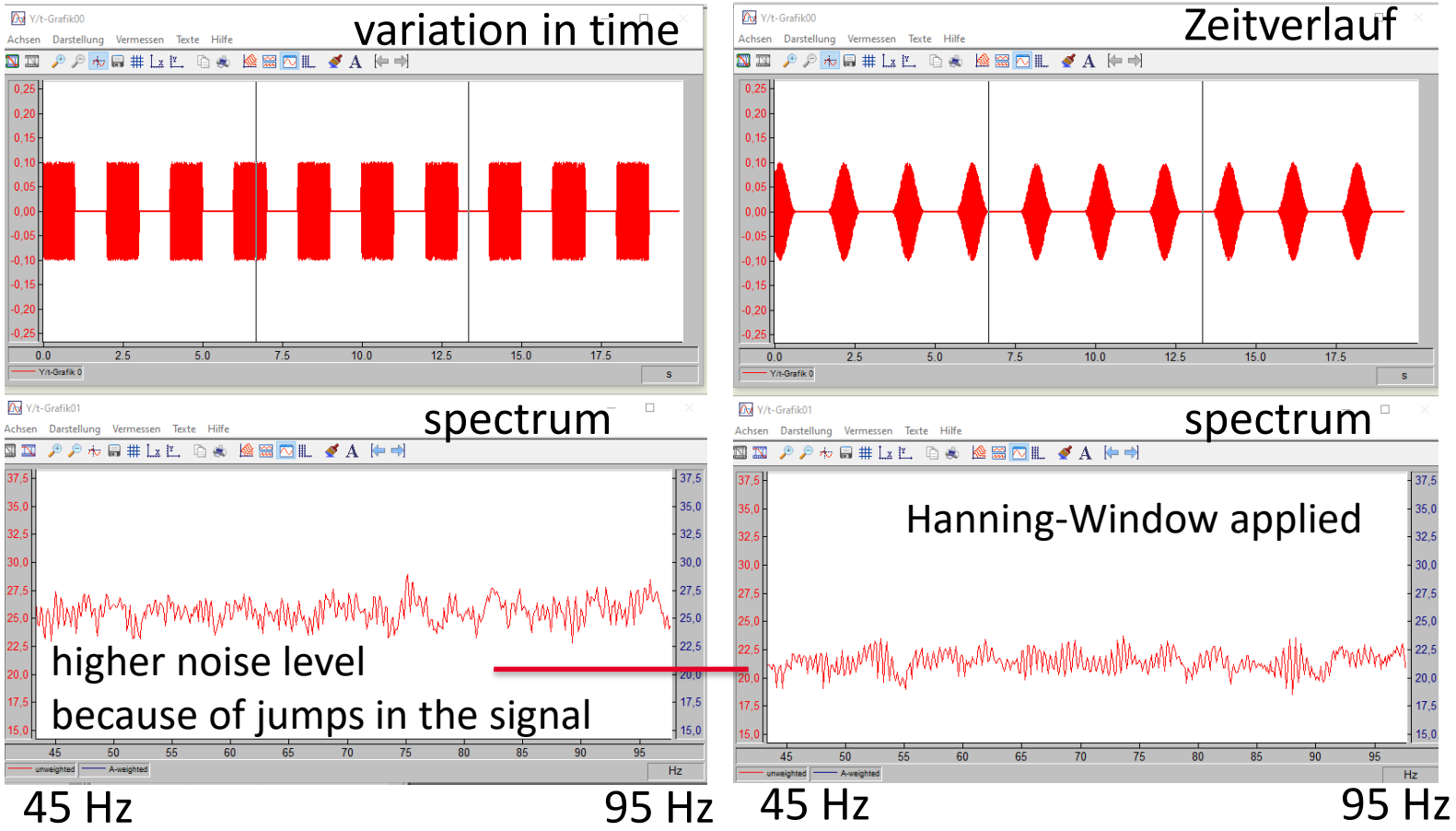
90 Hz



blade passing frequency 0,5 Hz

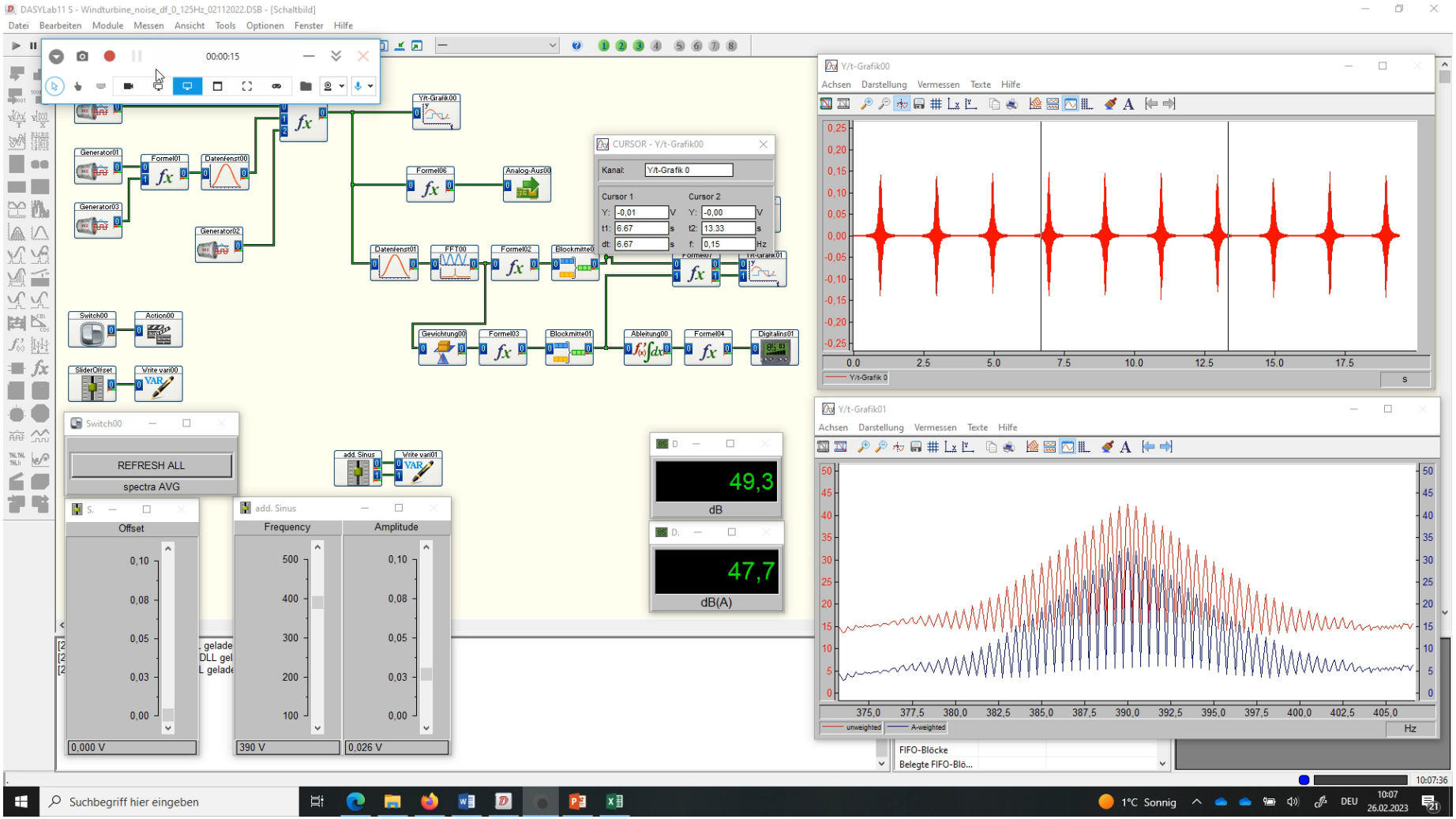


Window- or smoothing-influence

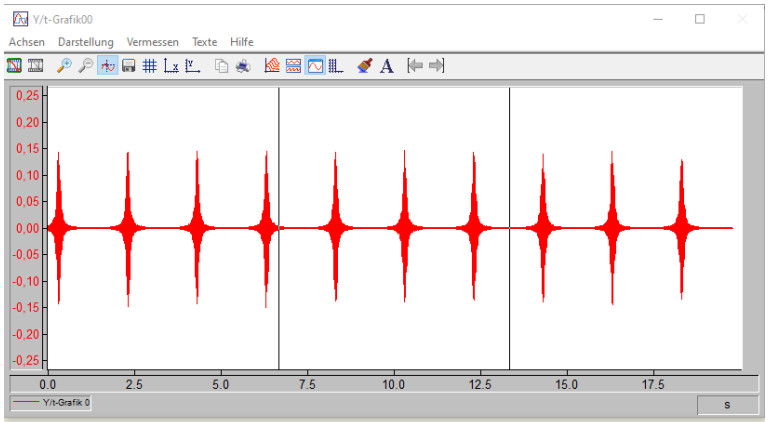


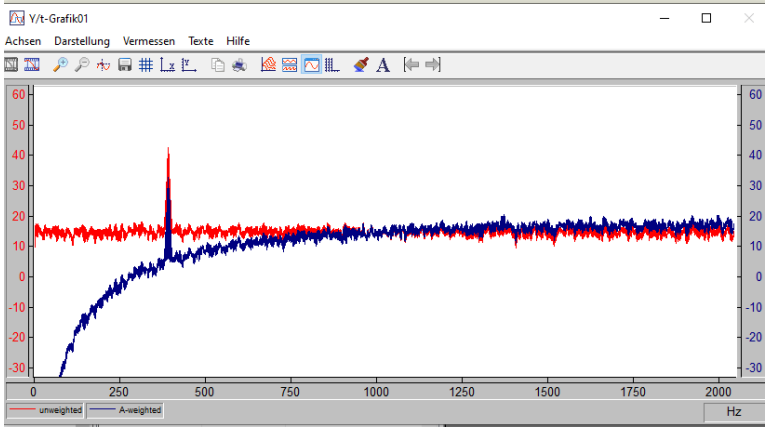
Modulation – with/without windowing – not dominant visible

Modulation with a single frequency component

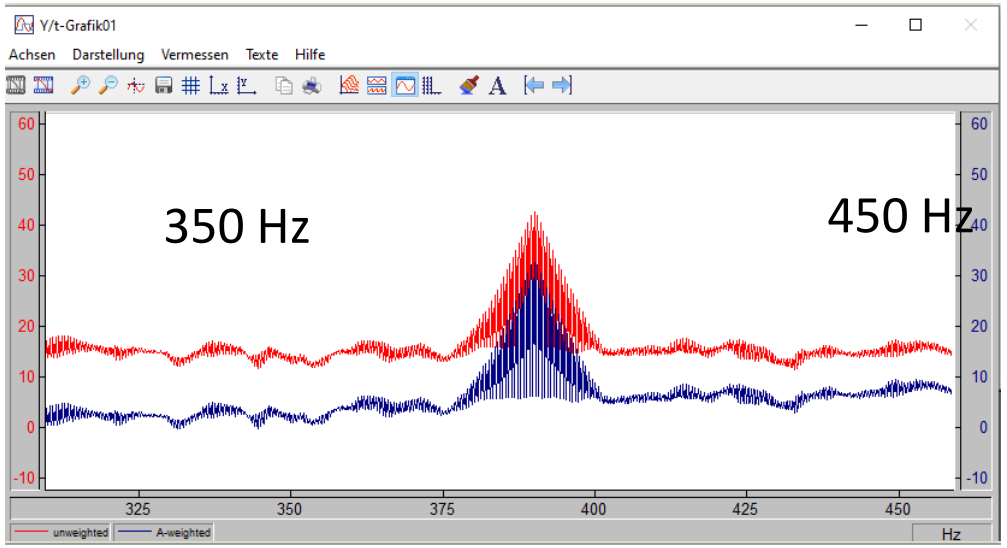


Modulation – single frequency





0 Hz 2000 Hz



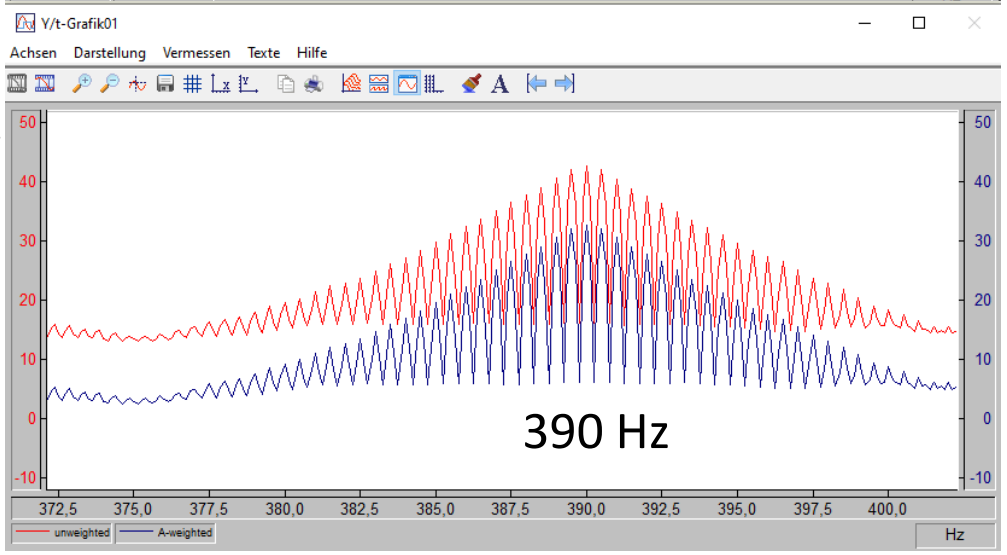
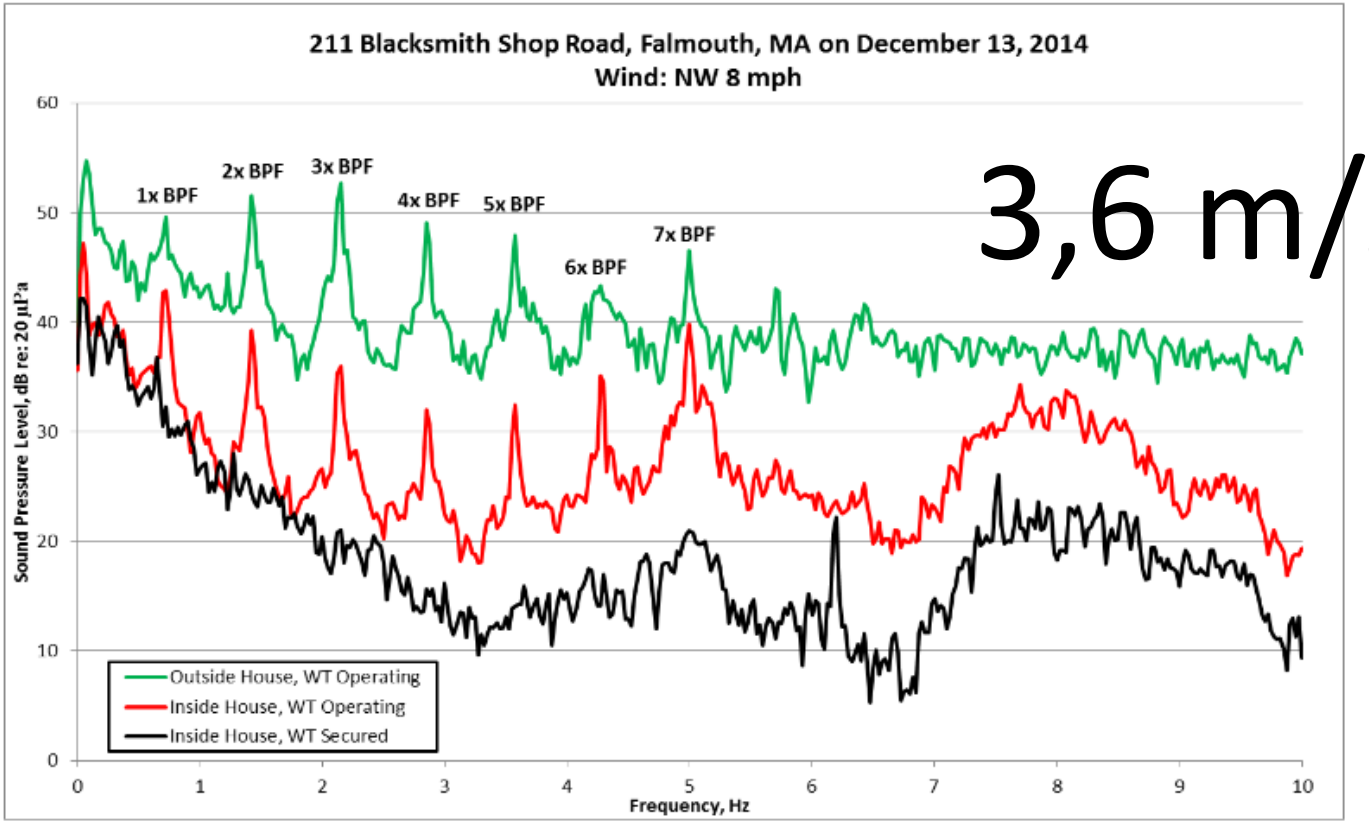


FIGURE 4

Extreme low incident flow velocity!

50dB



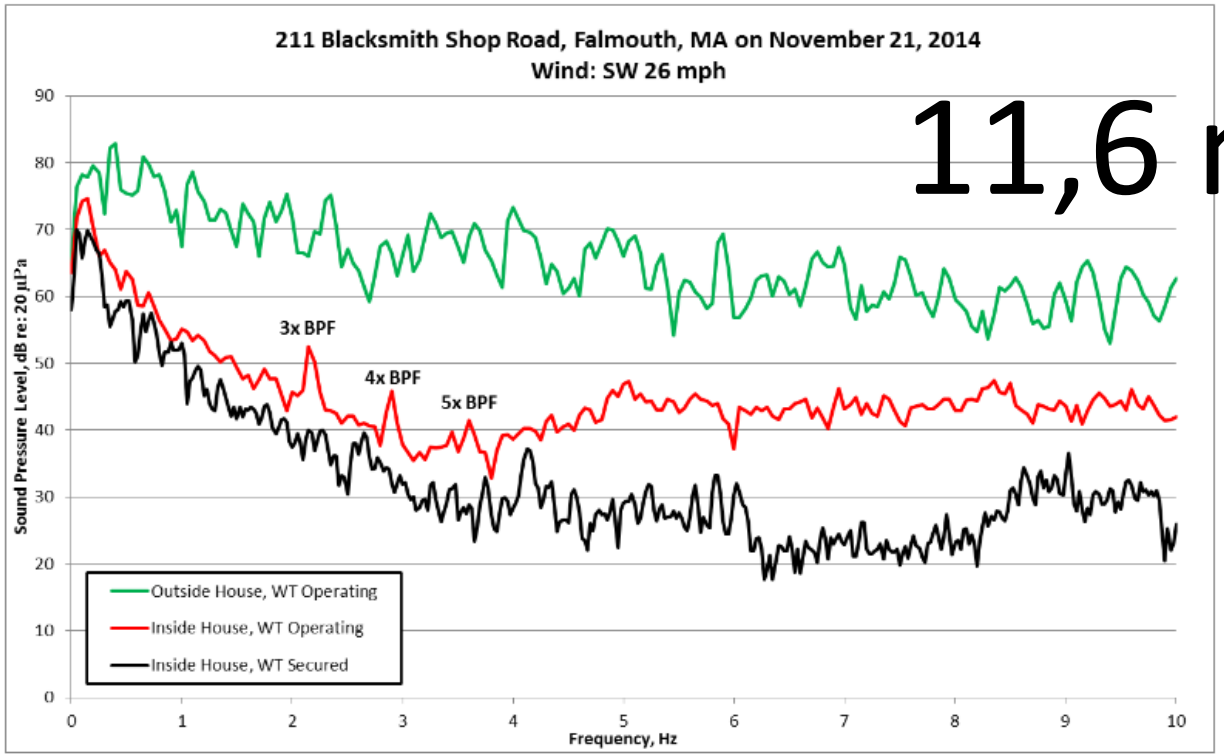
3,6 m/s

Infrasound Measurements of Falmouth Wind Turbines
Wind #1 and Wind #2
Michael Bahtiarian, INCE Bd. Cert.
Allan Beaudry
February 27, 2015
https://www.edockets.state.mn.us/EFiling/edockets/searchDocuments.do?method=showPoup&documentId=%7B30F8E75E-0000-CD1E-88E8-0966487DEEBF%7D&documentTitle=201710-136092-01

Heavy incident flow velocity!

80dB

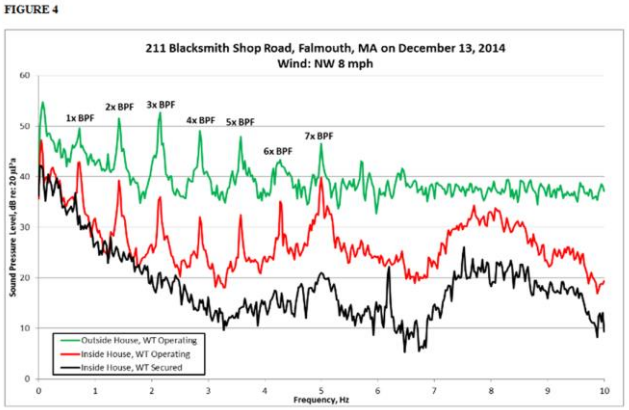
FIGURE 3



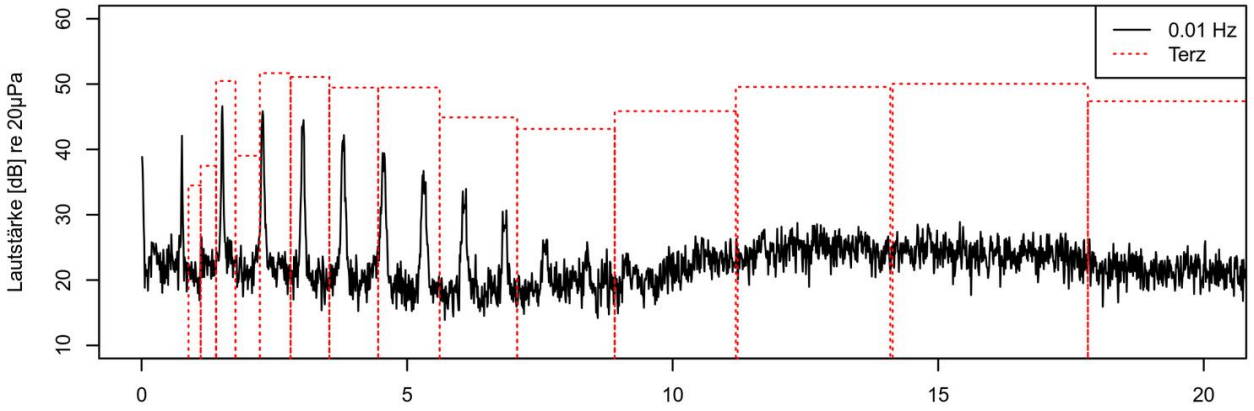
11,6 m/s

Infrasound Measurements of Falmouth Wind Turbines
Wind #1 and Wind #2
Michael Bahtiarian, INCE Bd. Cert.
Allan Beaudry
February 27, 2015
https://www.edockets.state.mn.us/EFiling/edockets/searchDocuments.do?method=showPoup&documentId=%7B30F8E75E-0000-CD1E-88E8-0966487DEEBF%7D&documentTitle=201710-136092-01

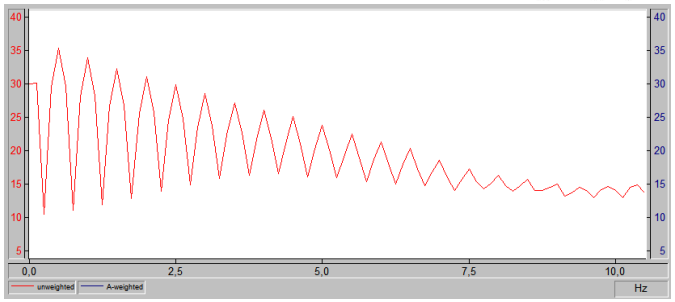
Measurements USA



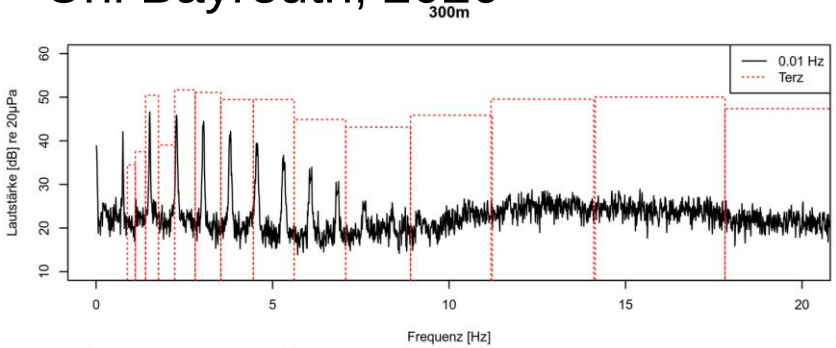
Measurements Germany Holzheu, Uni Bayreuth



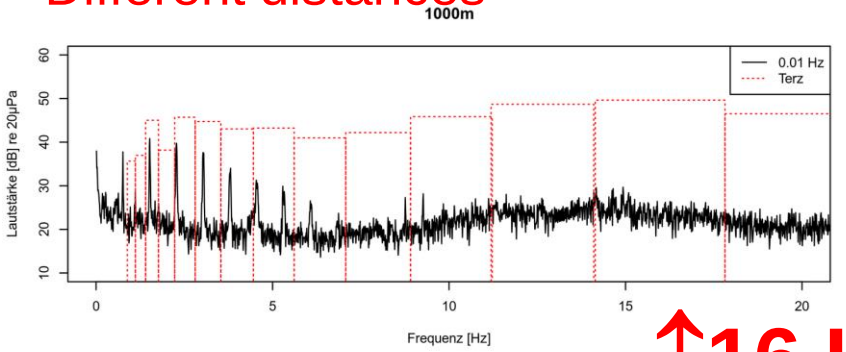
Simulation



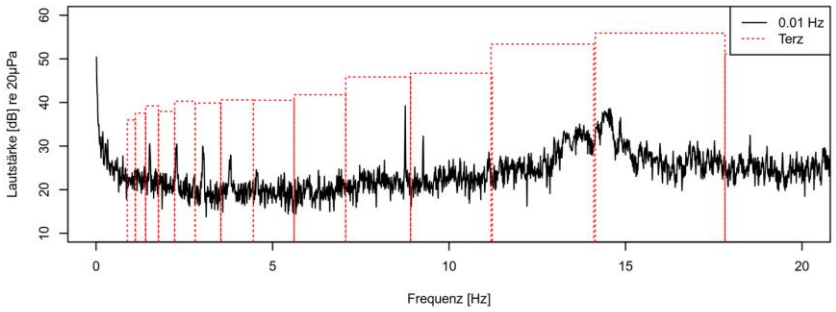
Holzheu,
Uni Bayreuth, 2020



Different distances

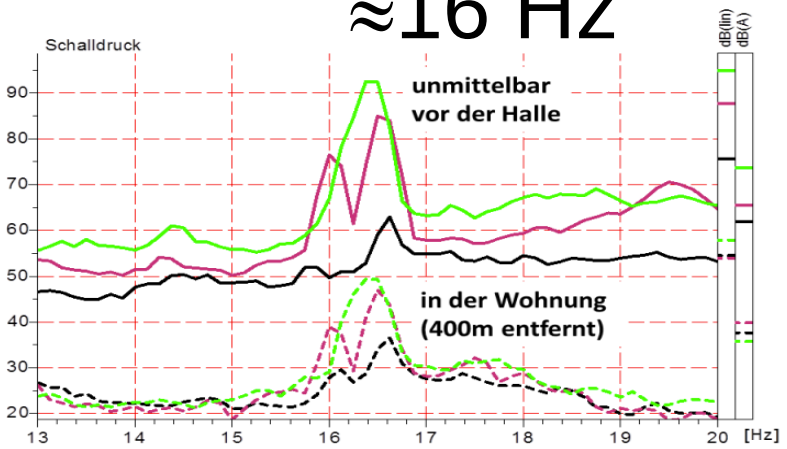


↑16 Hz



Kameier 2015

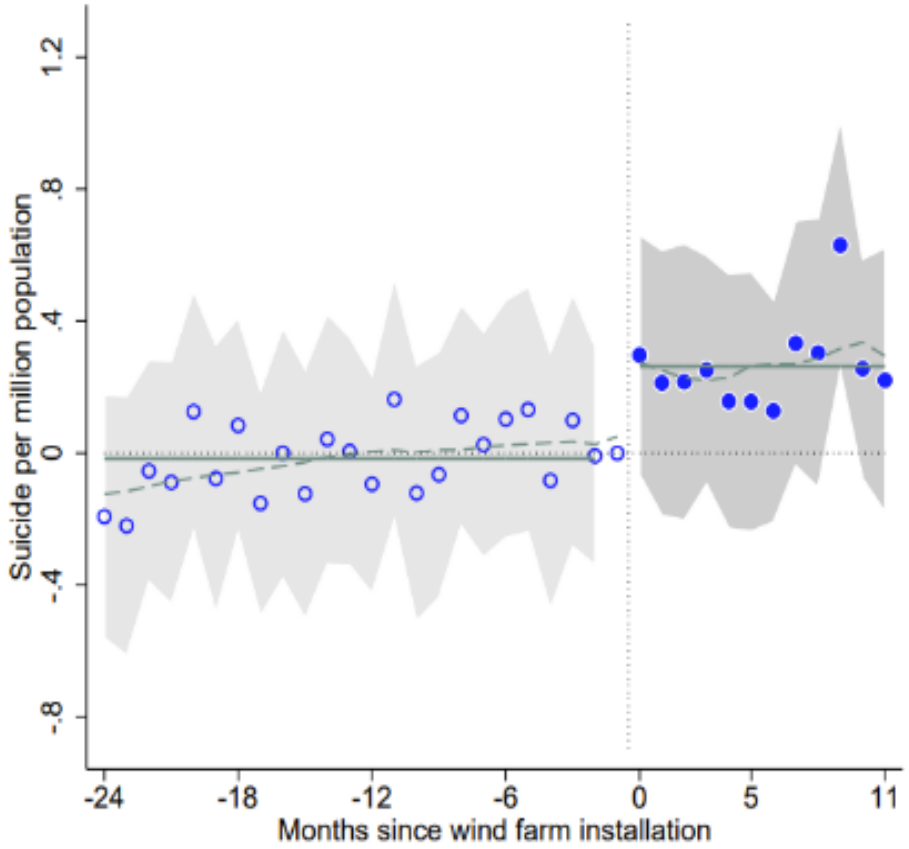
≈16 Hz



… humans are reacting sensible

Eric Zou, Oregon, 2017

Figure 4: Event Study: Suicide



Notes: Graph plots suicide rate (per million population) by months relative to wind farm installation month, using all installation events from 2001-2013. The estimation uses a balanced panel of counties from 24 months before to 12 months after wind farm installations. The month immediately before the installation is the omitted category. The regression is weighted by county×year population and is conditional on 12 month-of-year dummies. Dots show monthly point estimates. Solid lines show before vs. after averages of the point estimates. Dashed lines show lowess smooth of monthly point estimates. Shades show 95% confidence interval constructed using standard errors clustered at the wind farm level.

Physical model ... with open questions

Tragflügel

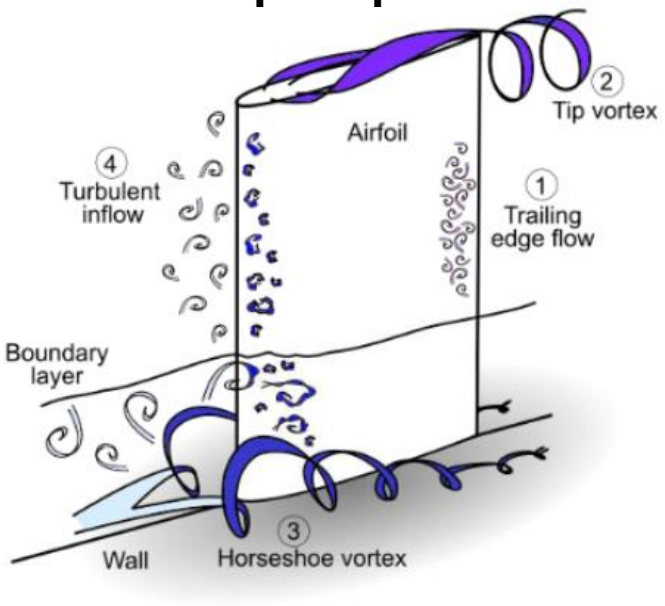
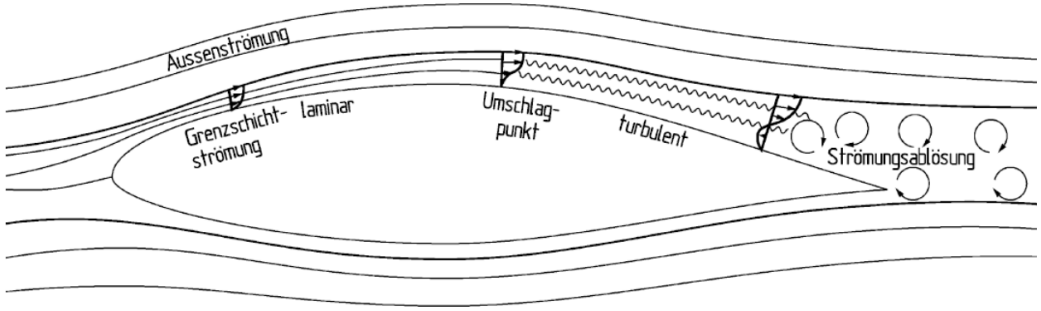


Figure 1: Flow-induced noise mechanisms of a wall-mounted finite length airfoil.

D.J. Moreau, Australia

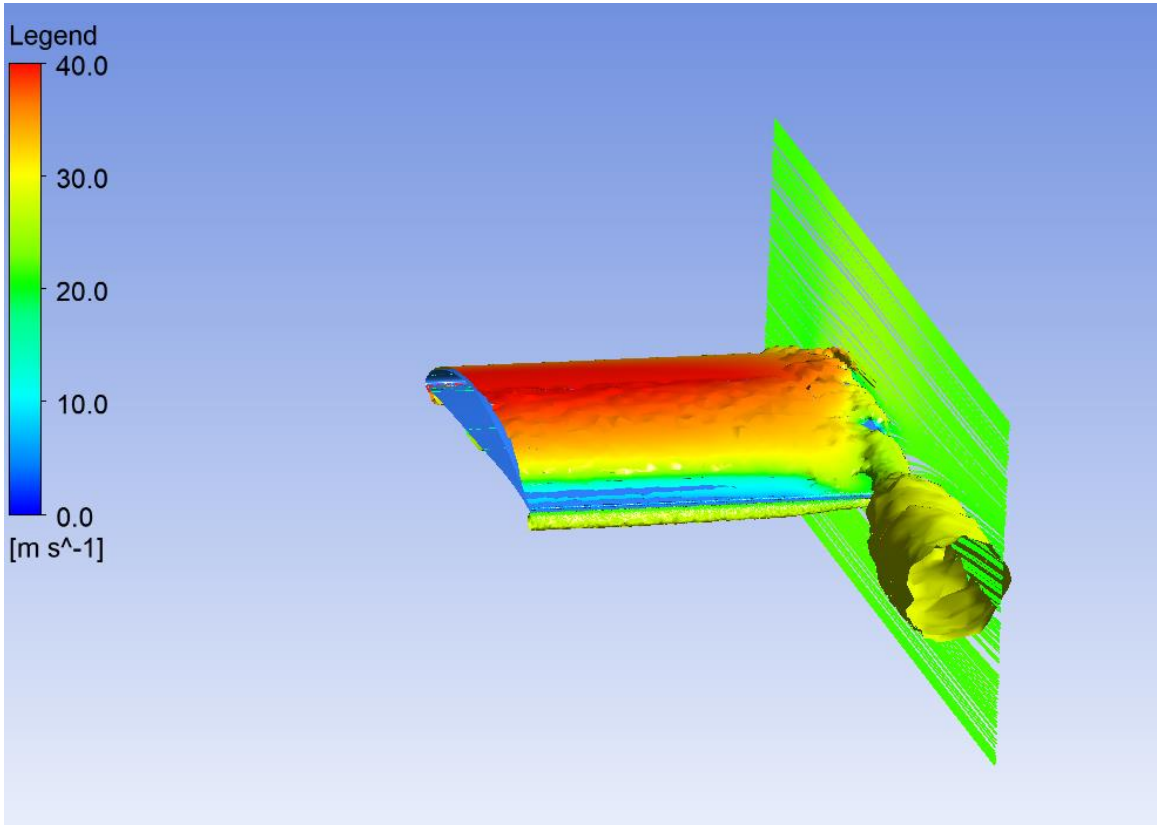
Acoustics 2021

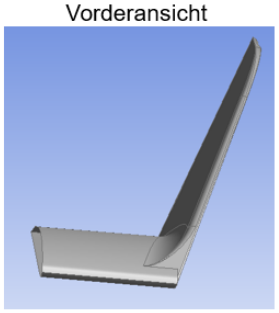
Wind turbine

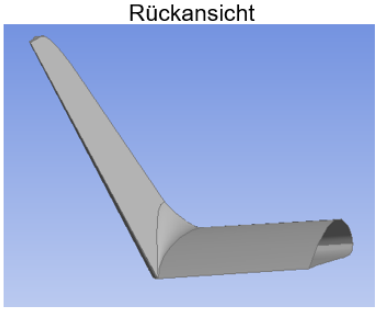


Hau E., Windkraftanlagen,1988

CFD on an airfoil (3rd semester Fluid Mechanics)

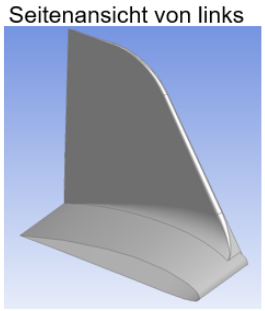


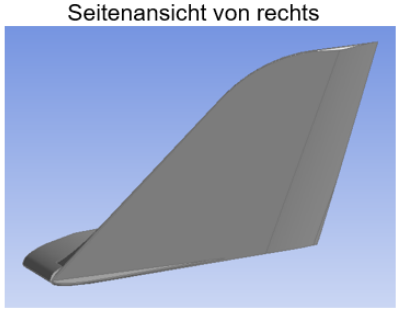


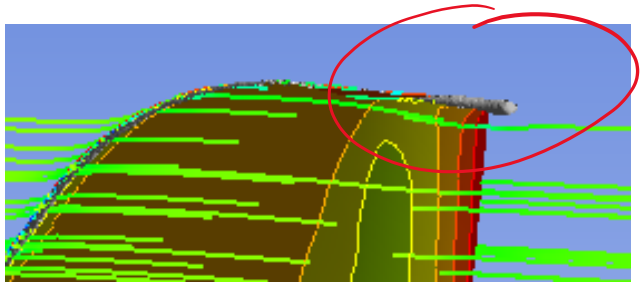


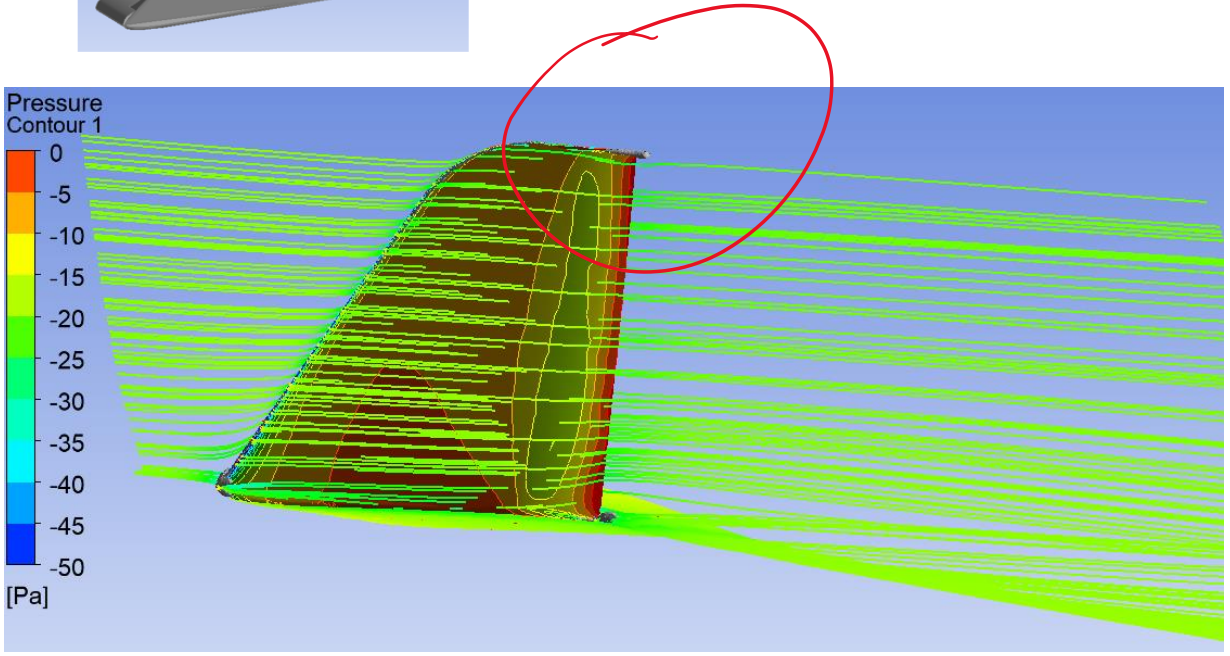
Winglet

- small vortex





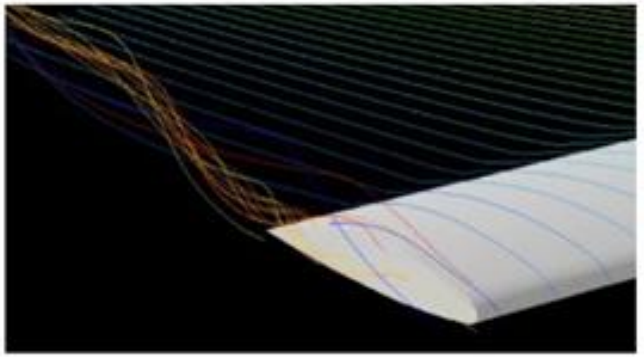




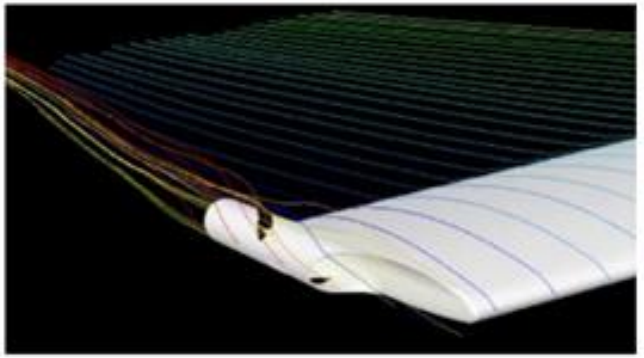
3rd semester
practical course
in
Fluid Mechanics

Niklas Uebbing

MINIX - french idea – Patent WO02083497 (A1) — 2002-10-24 – 20 years old = open for everyone

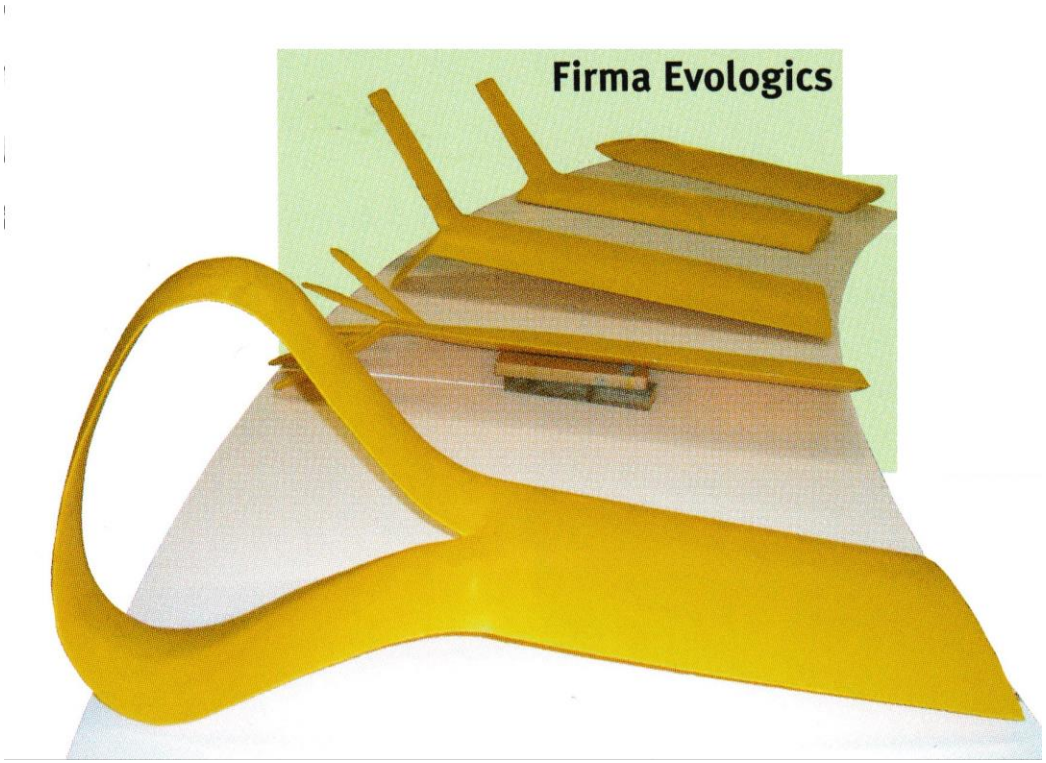


Above: regular wing tip showing turbulent vortex



https://www.minix.fr/english/sub_shows.php?im=../images/expos/2009/le_bourget/06.jpg

https://www.minix.fr/english/minix_and_wind_turbines-results.php
https://worldwide.espacenet.com/publicationDetails/biblio?II=0&ND=3&adjacent=true&locale=de_EP&FT=D&date=20021024&CC=WO&NR=02083497A1&KC=A1#

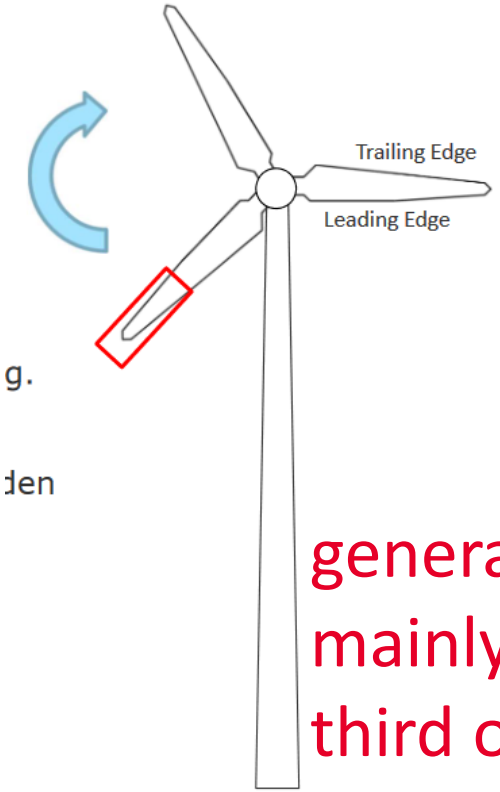


Bionik – was ist was – 2006

Children book!

Serrations here: leading …

additional kinetic energy
is able to reduce
flow separation



g.

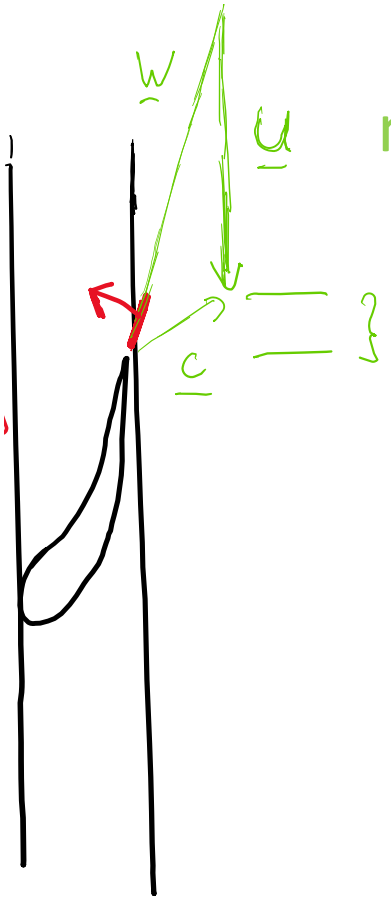
den

generation of noise
mainly in the outer
third of the blade (???)

risk of flow
separation

https://windenergietage.de/wp-content/uploads/sites/2/2017/11/26WT0811_F7_0935_1_TES_DNVGL.pdf

more redirection increases c_{2u}



negative twist

$$y = u(c_{1u} - c_{2u})$$

Future versus today

Energy

electric
- **conversion**
- **generation (?)**
- **production (?)**

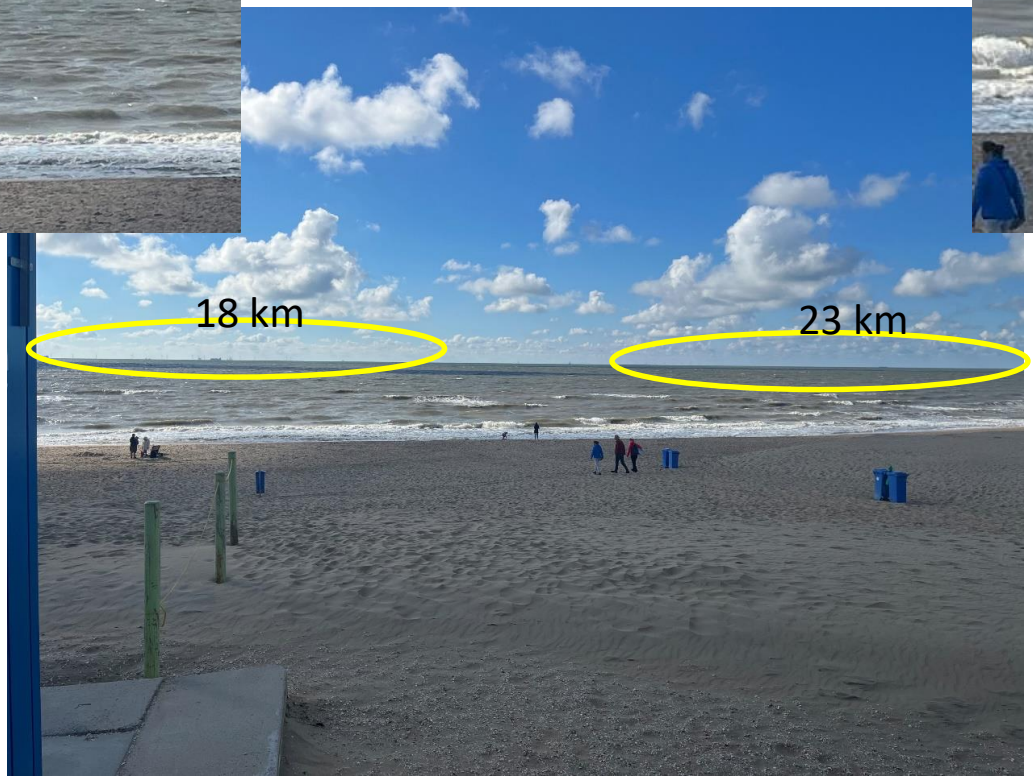
Energiequelle Strömung: Wind, Wasser, Wellen

2021:
Habour of Hafen Rotterdam

GE Renewable Energy,
HaliadeX,
12 MW,
107m blade length = 214m in diameter

Photo: GE Renewable Energy

2023



Insgesamt 140 Windkraftanlagen mit je knapp 11 MW-Leistung will das schwedische Unternehmen Vattenfall rund 18 km vor der Küste installieren.
Siemens Gamesa ∅ 200m
https://www.energate-messenger.de/news/213546/baubeginn-beim-weltweit-groessten-offshore-windpark

43 stuks
Type: Vestas V112
Ashoogte: 81 meter
Bladlengte: 55 meter
Vermogen: 3 MegaWatt
https://www.eneco.nl/over-ons/wat-we-doen/duurzame-bronnen/windpark-eneco-luchterduinen/

Frank Kameier 06/2022
stroemungsakustik.de

https://www.erneuerbareenergien.de/technologie/offshore-wind/videos-die-groessten-windturbinen-der-welt

Offshore

CSSC Haizhuang Wind Power mit 18 MW, ∅ 260 m (?)

China Three Gorges Corp: 16 MW, ∅ 252 m

Vestas V236 mit 15 MW, ∅ 231 m

Siemens-Gamesa SG 14-236 mit 15 MW, ∅ 236 m(?)

MingYang Smart Energy, MySE 16.0-242 i, 16 MW, ∅ 242 m

Goldwind, 13,6 MW, ∅ 252 m

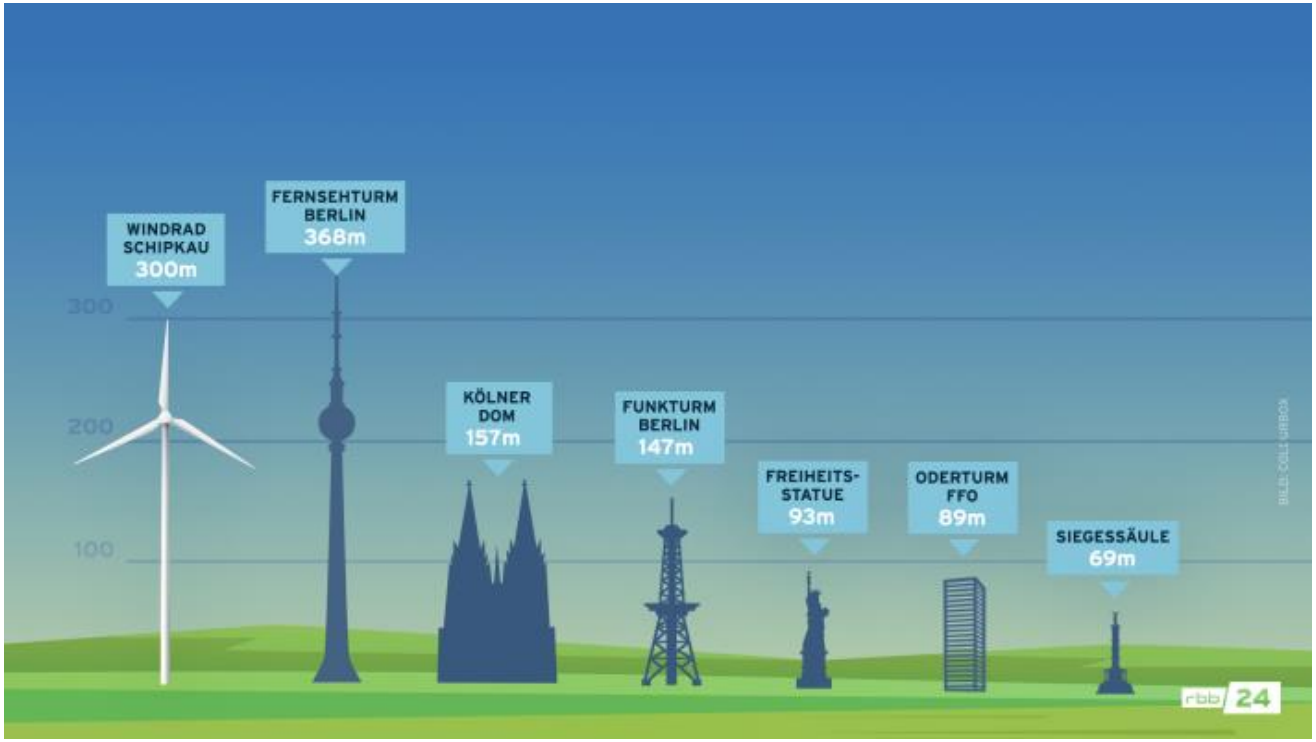
Limits?

Onshore

Up to 7,2 MW and diameter of more than 170 meter

... without guarantee, the internet information is not really precise and many prototypes and projects are in planning ...

… challenge for the largest turbine in 2023 …



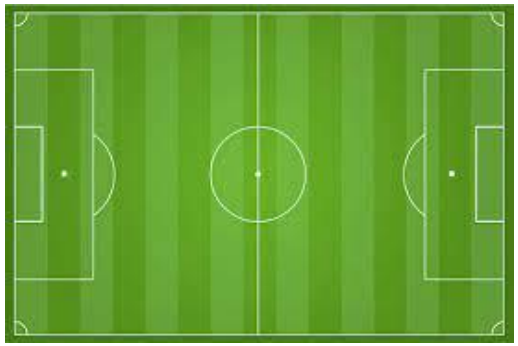
Overall height 300m, hub height app. 240m, rotor diameter 120m
80% or 40% more wind because of the height – different given values found

https://www.rbb24.de/studiocottbus/panorama/2022/05/300-meter-windrad-schipkau-vorbereitungen.html

Rotating „fooball fields“

ca. 105 m

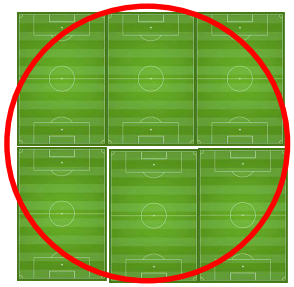
ca. 70 m



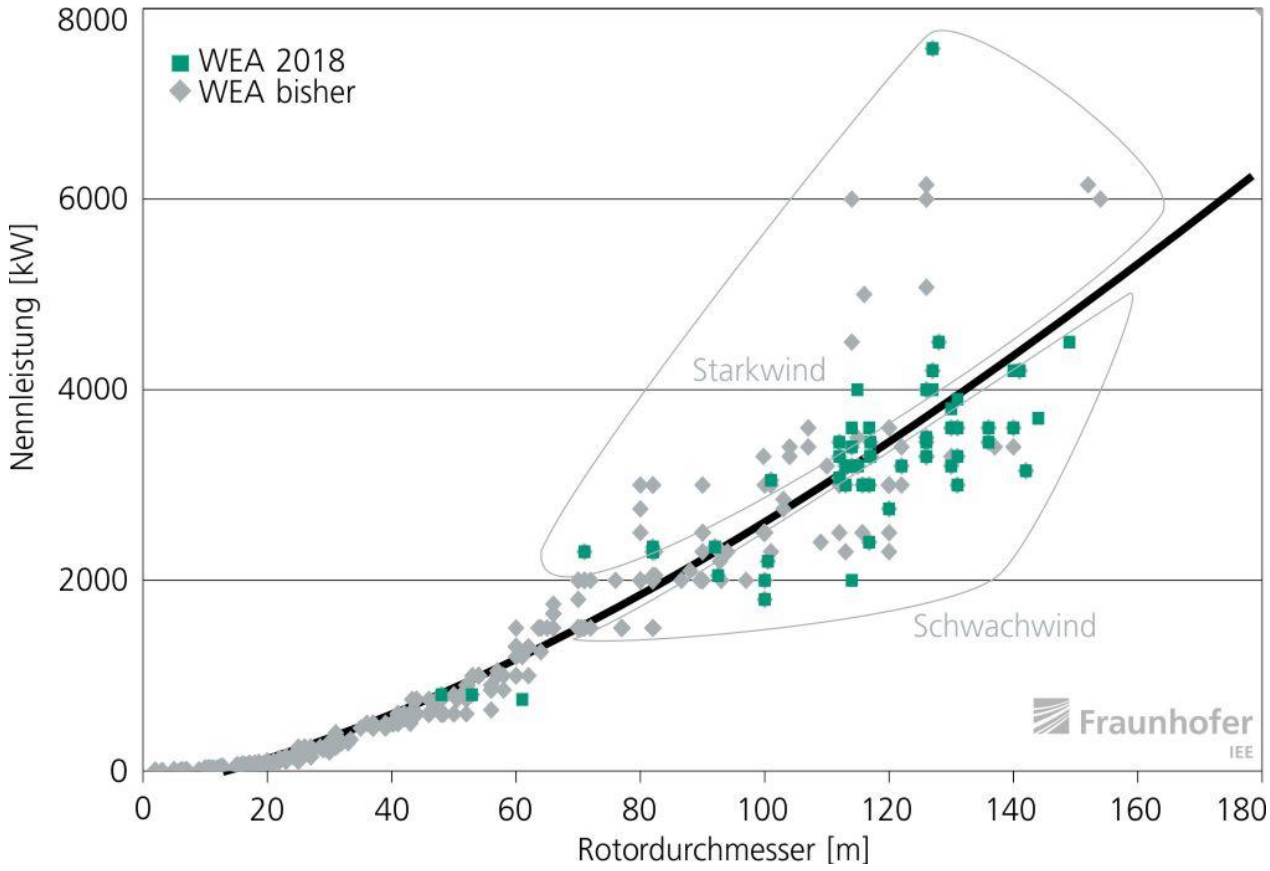
7350 m^2

https://www.igwindkraft.at/?mdoc_id=1048852

Wind turbine	∅120m	∅ 220m	∅ 260m
Results to	1,5	5	7 football fields



Trend 2018 +



https://windmonitor.iee.fraunhofer.de/windmonitor_de/3_Onshore/2_technik/4_anlagengroesse/

Trend 2018 +

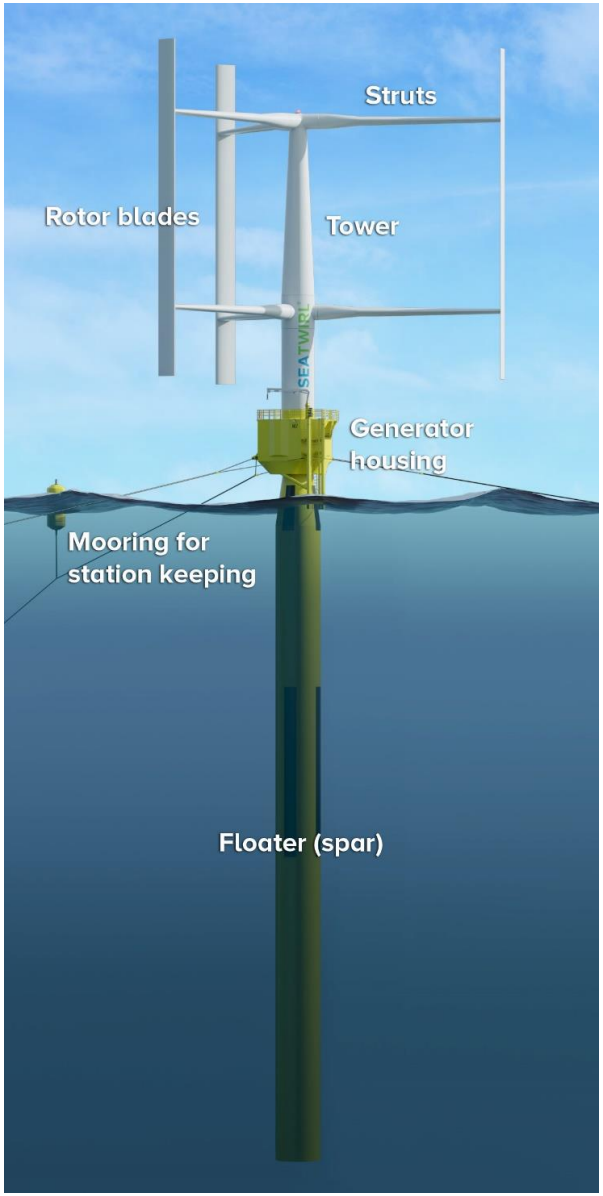
30 kW existing

vision in 2023:

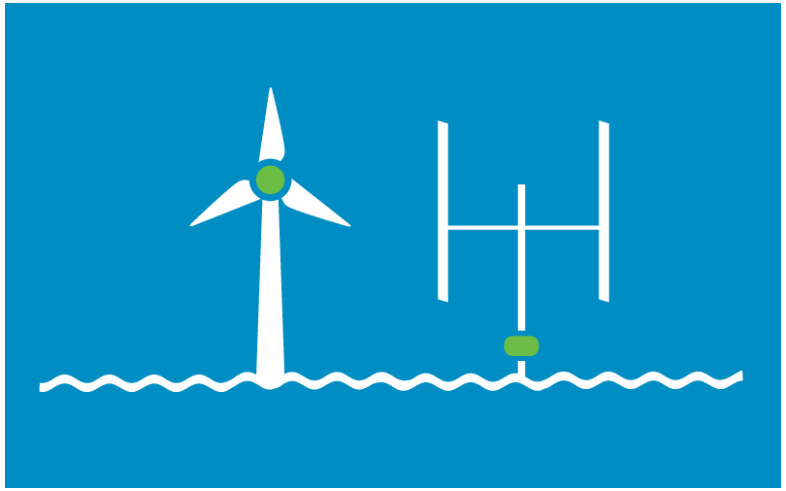
1 MW

… Windpark Norway (?)

https://seatwirl.com/products/



Trend 2018 +



30 kW existing

vision in 2023:

1 MW

… Windpark Norway (?)

- possible with deep see conditions,
- Simple maintenance
- direction of the wind plays no role

https://seatwirl.com/products/

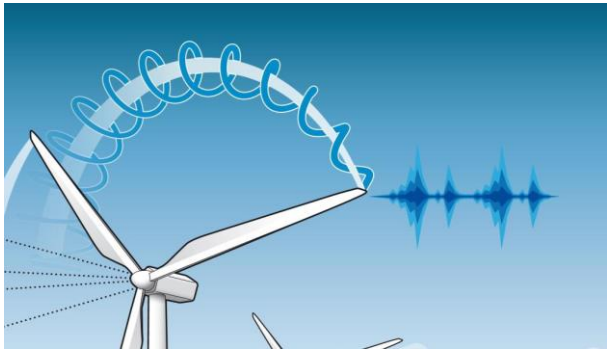
Summary / open questions

- **Flow separation shows stochastic behaviour**
  (… only cylinder wake with Kárman vortex street is periodic).

- **The modulation of noise (flow separation) together with a strong periodic component (blade passing frequency) results in a tone for a wind turbine sound**
  (… distríbutated along the whole frequency range, with low amplitude levels and relevance for infrasound).

- **There is no certain physical modell of blade tip (vortex) noise.**


[From Oerlemans, 2009]



? Not in this way!