Practical experiences with a torsion based rigid blade Rotary Airborne Wind Energy System with ground based power generation

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When Loyd is just too mainstream for you…

Airfoil

Transmission

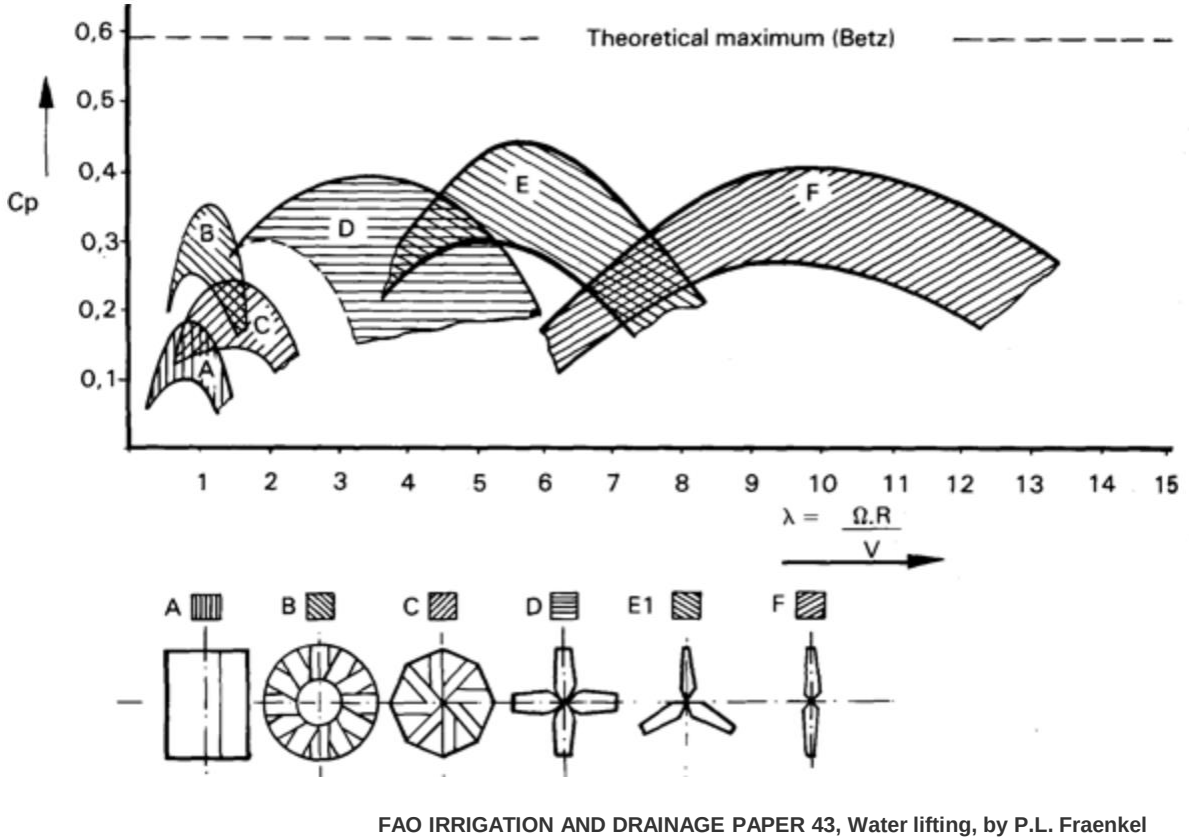
Lift

Generator

When Loyd is just too mainstream for you…

Airfoil

My Airborne Rotor (MAR1)



FAO IRRIGATION AND DRAINAGE PAPER 43, Water lifting, by P.L. Fraenkel

Goal: as small and slow as possible while still efficient
120rpm | nominal wind speed of 10m/s

$$TSR = 3 = \frac{v_{tip}}{v_{wind}} = \frac{2 * \pi * r_{rotor} m * rps}{10 \frac{m}{s}} \P$$

$$r_{Rotor} = 2.4m \P$$

FX 63-137 airfoil from
UIUC Airfoil Coordinates Database
Designed for low Reynolds number applications on small wind turbines by the UIUC Applied Aerodynamics group as part of their Low-Speed Airfoil Test program

http://www.fao.org/3/ah810e/AH810E10.htm#10.1

https://m-selig.ae.illinois.edu/ads/coord_database.html

My Airborne Rotor (MAR1)

		Wind speed	10	m/s	cp	0.1
HubDiagonal	60	1524		HubStrut	42.4	
BladeStub	22	558.8				
Blade	26.0	660				
Rotor Radius	**78.0**	**1980.8**				
	inch	mm				
HubDiagonal	60	1524		Area total	10.99	sqm
BladeStub	20	508		Area stubs	5.07	sqm
Blade	23.6	600		Effective Rotor Area	5.92	sqm
Rotor Radius	**73.6**	**1870**				
Inner Blade radius	50.0	**1270**		**Power**	**364**	W
	inch to mm	25.4				

$$A_{effective} = \pi\,(r_{tip} - r_{foot})^2 = \pi\,(1.87 - 1.27)m^2 = 5.92m^2$$

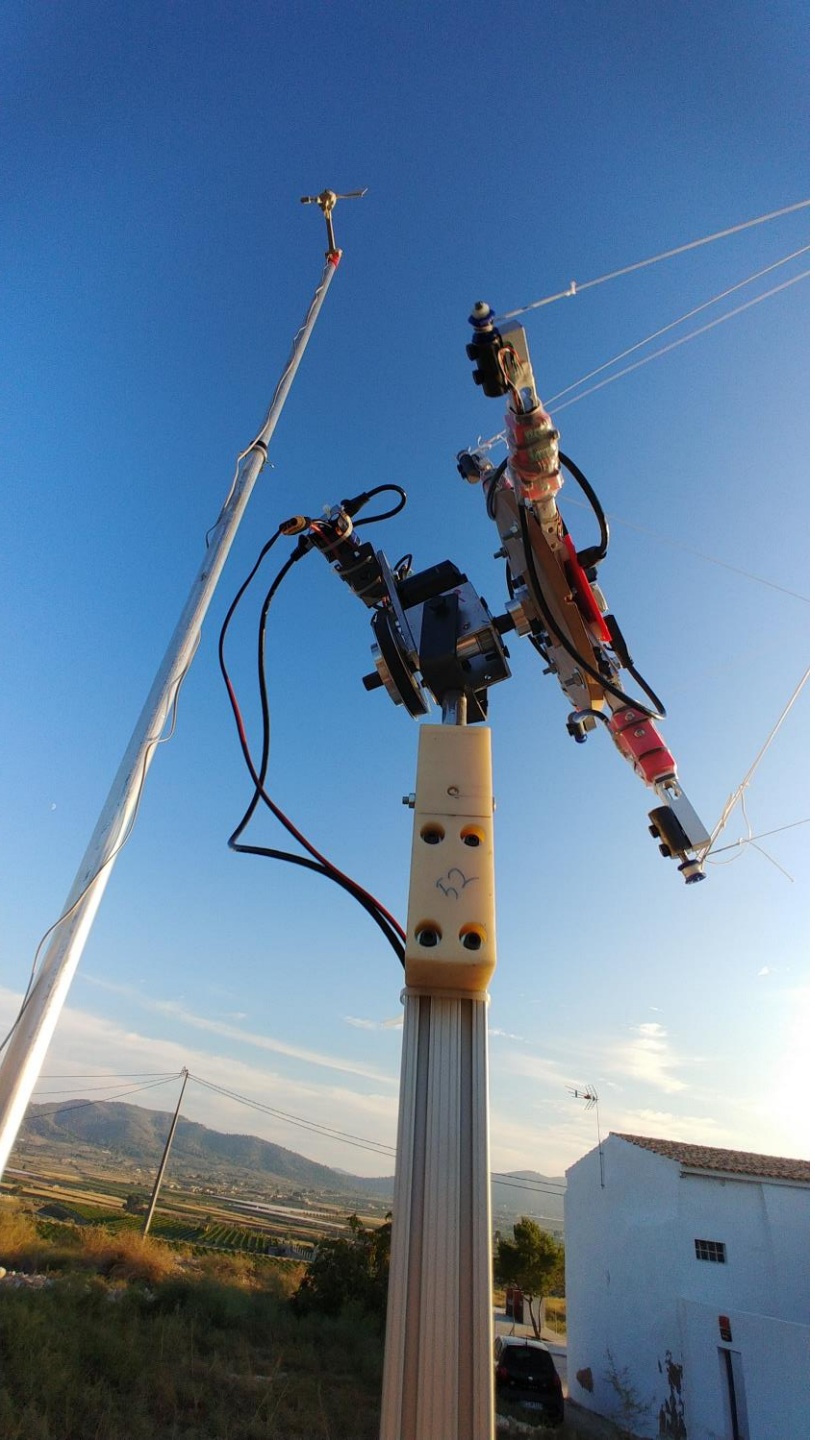
$$P = \frac{1}{2}1.23\frac{kg}{m^3}5.92m^2 10^3\frac{m^3}{s^3}\ 0.1 = \mathbf{364W}$$

My Airborne Rotor (MAR1)

Part	Description	Quantity	Weight/ Unit (LB)	Weigh/Unit (g)	Weight total (lb)	Weight total (g)
Blade	Foam core with two 0.2" carbon tube spars and Ultracote polyester covering; Foam Type: EPP; Wing Span: 24"; Airfoil: fx63137sm; Chord: 6"	4	0.175	79	0.7	318
Hub		1	0.55	249	0.55	249
Rotor total					1.25	567

When Loyd is just too mainstream for you…

Generator



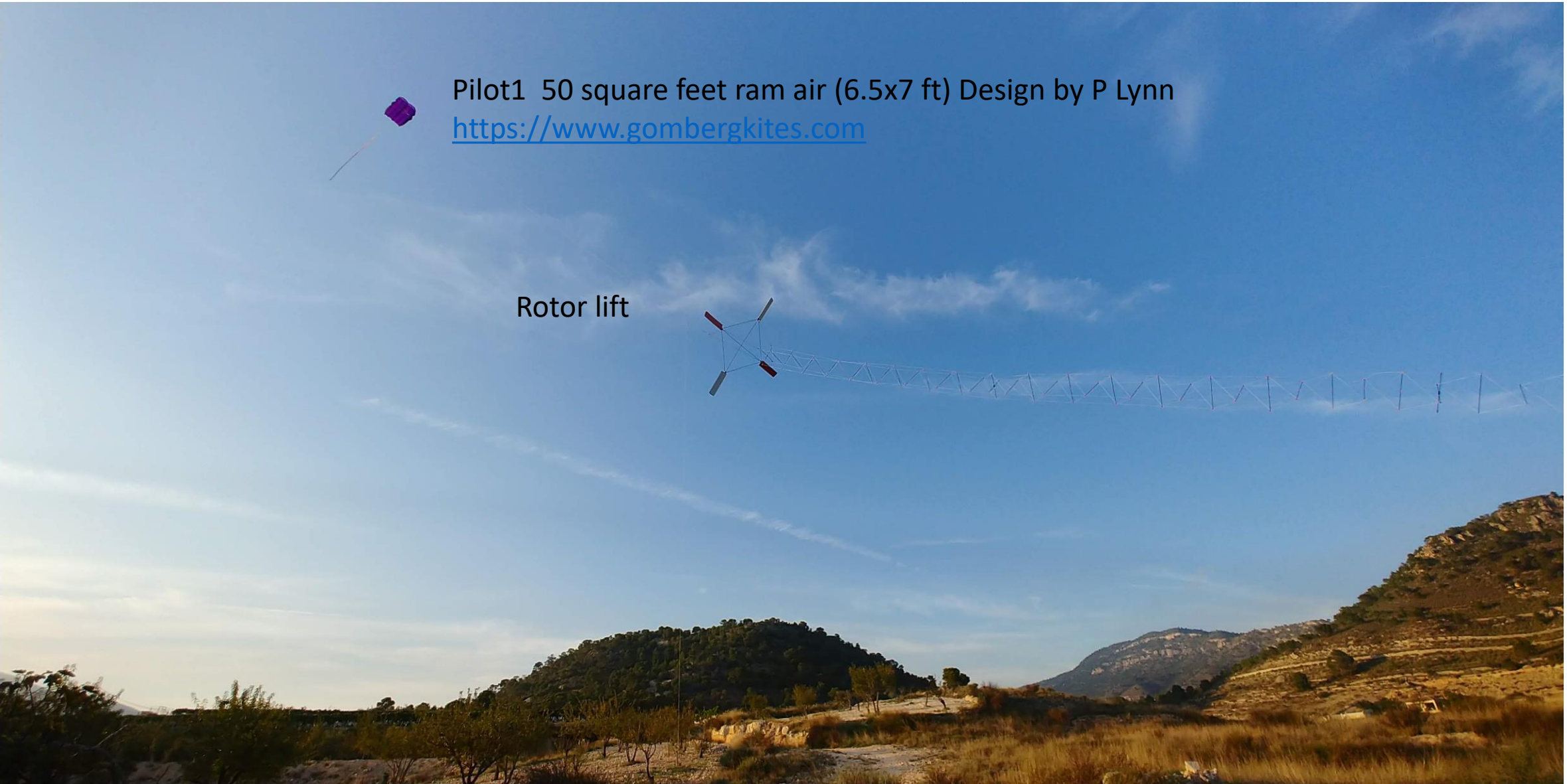
Base/Generator

- BLDC 60Kv
- 6:1 Belt drive
- VESC
- Gimbal
- 8 Load cells & amplifiers ESP32
- Power sink (battery, beer cooler, resistors)

When Loyd is just too mainstream for you…

Lift

Cheap & dumb Lift



When Loyd is just too mainstream for you…

Transmission

Coaxial multi-turbine

"Driver lines attached to the extremities of the turbines transmit this energy to the extremities of the hub structure"

R. W. Harburg, \Coaxial multi-turbine generator," 20 1991, uS Patent 5,040,948.

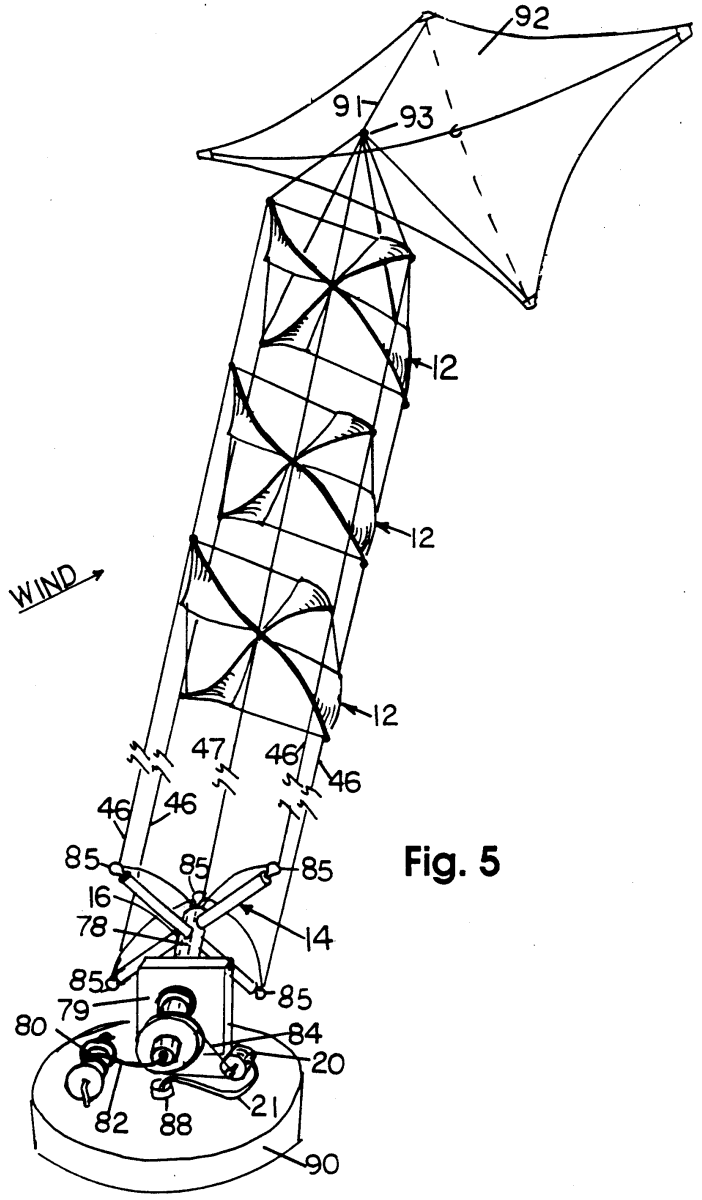
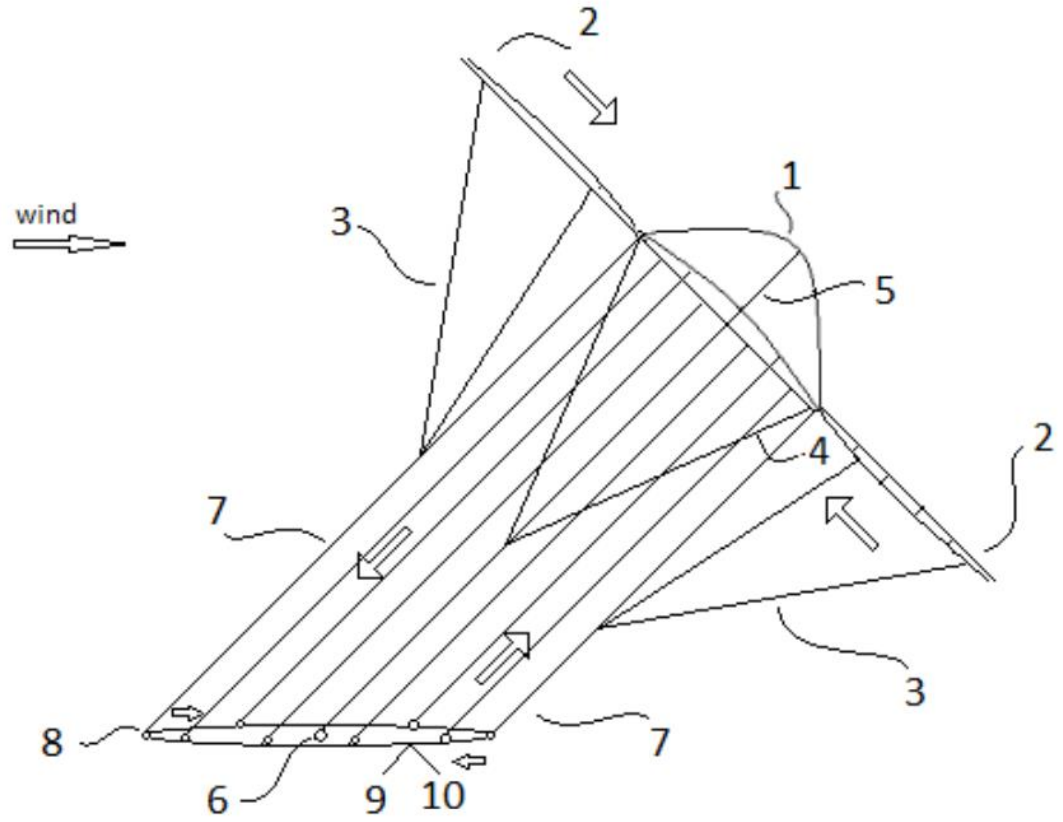


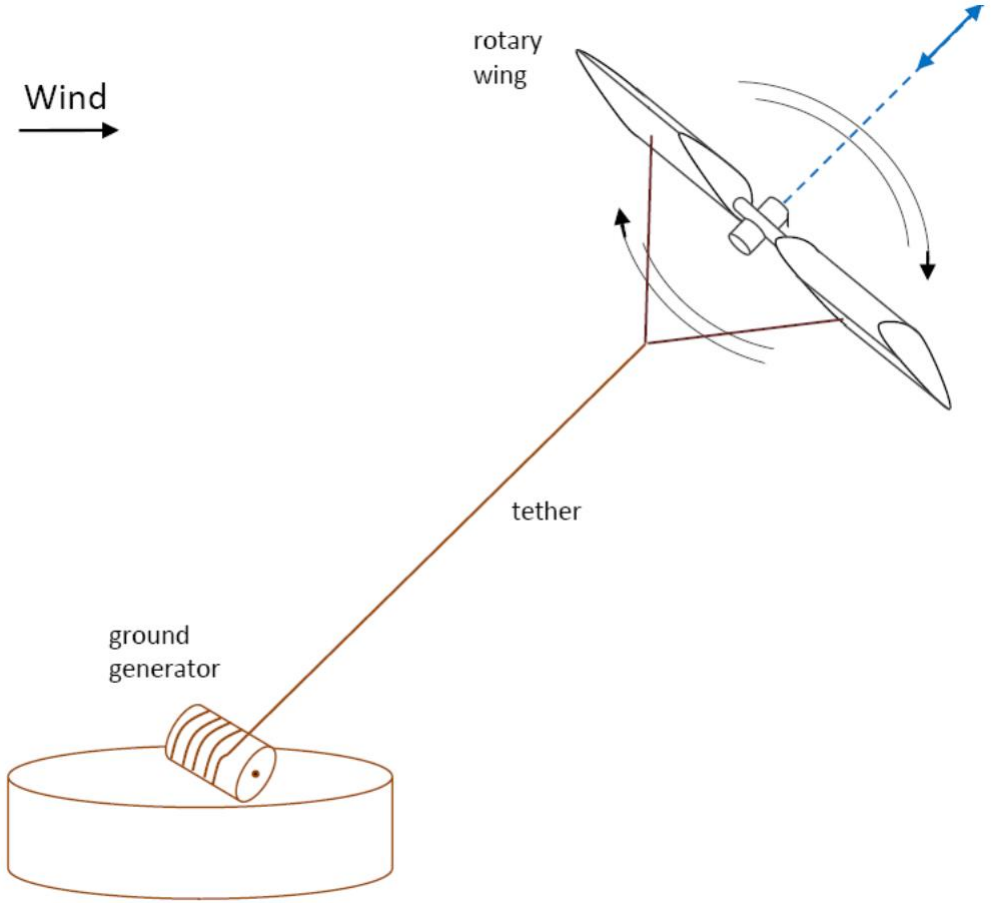
Fig. 5

Rotating Reeling



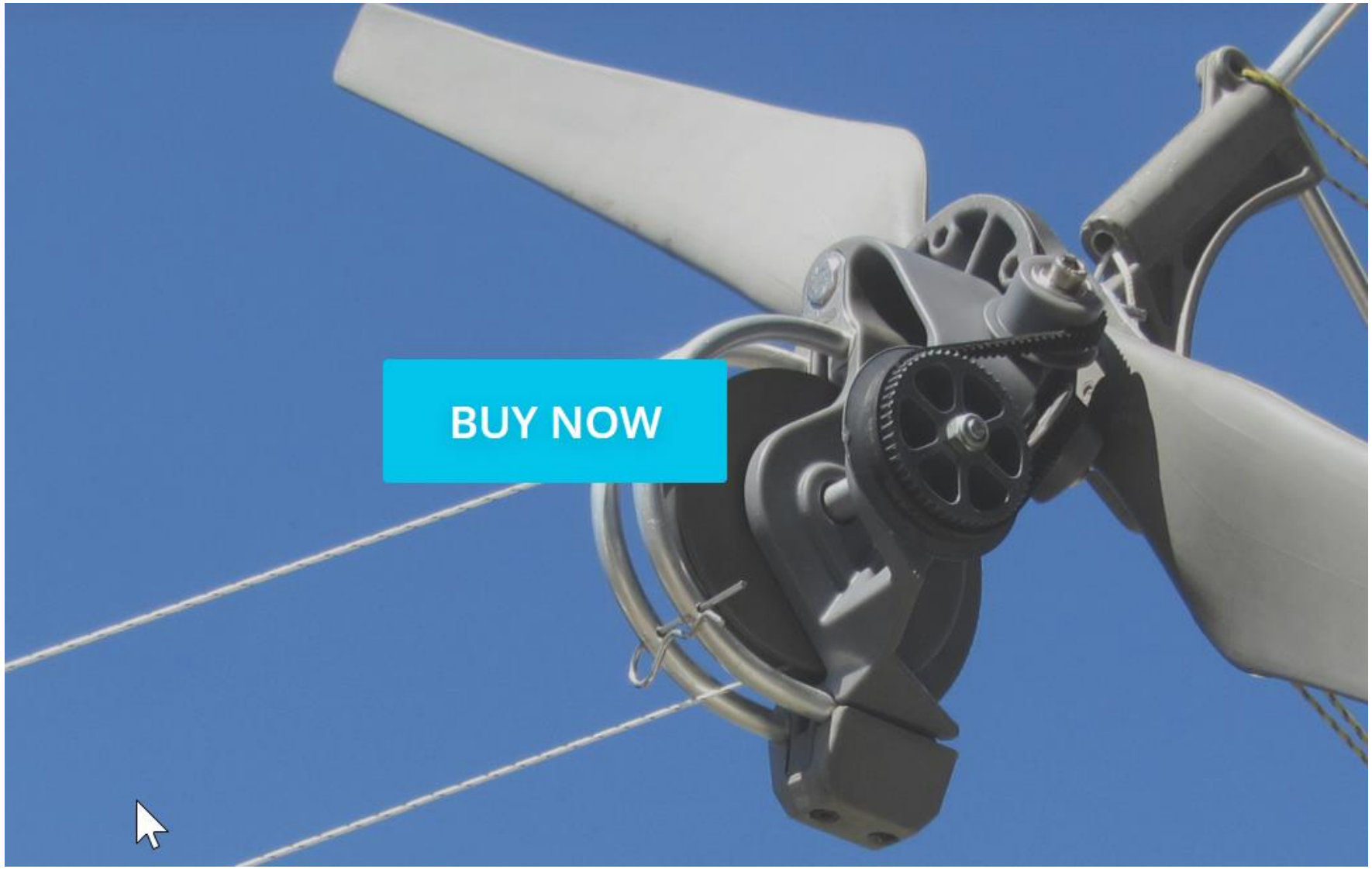
Pierre Benhaïem pierre-benhaiem@orange.fr AWEC 2015

Reel in/out



Leo Goldstein - Airborne Wind Energy Systems with Rotary Wing and Ground Generator

Belt

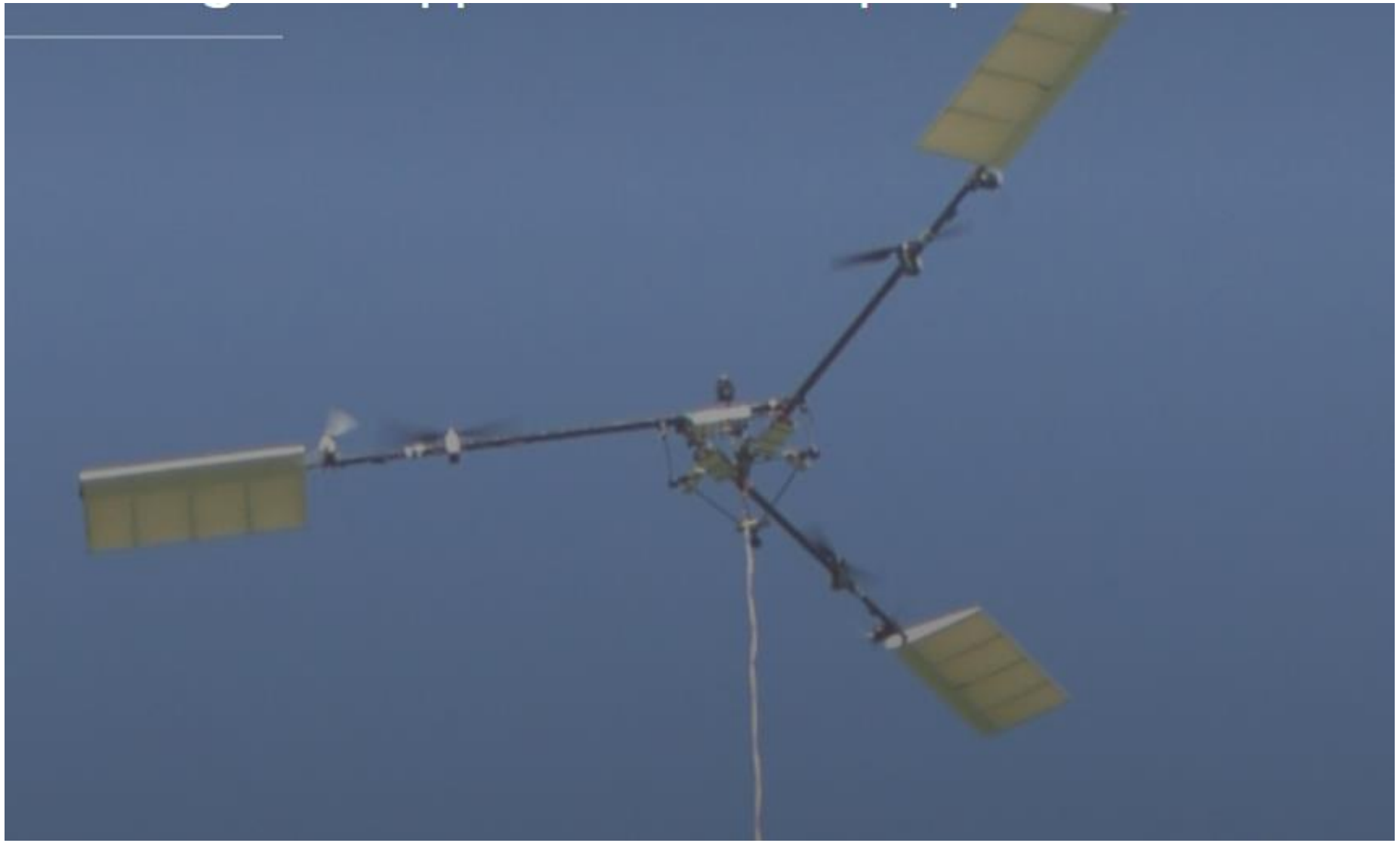


http://kitewinder.fr/

Flygen / Multirotor / Autorotation

https://www.skywindpower.com

Flygen



http://bladetipsenergy.com

Torsion / Shaft

http://www.selsam.com/

TRPT - Tensile Rotary Power Transmission

Rod Read
https://windswept-and-interesting.co.uk/

Torsion

US4708592A Helicoidal structures, useful as wind turbines

“A collapsible structure comprising a non-rigid helicoidal sheet braced by light-weight members”

“flexible fabric sheet (21) is reinforced by wires (42) sewn into its edges, and may be further reinforced by ribs or battens (30) sewn crosswise into the sheet”

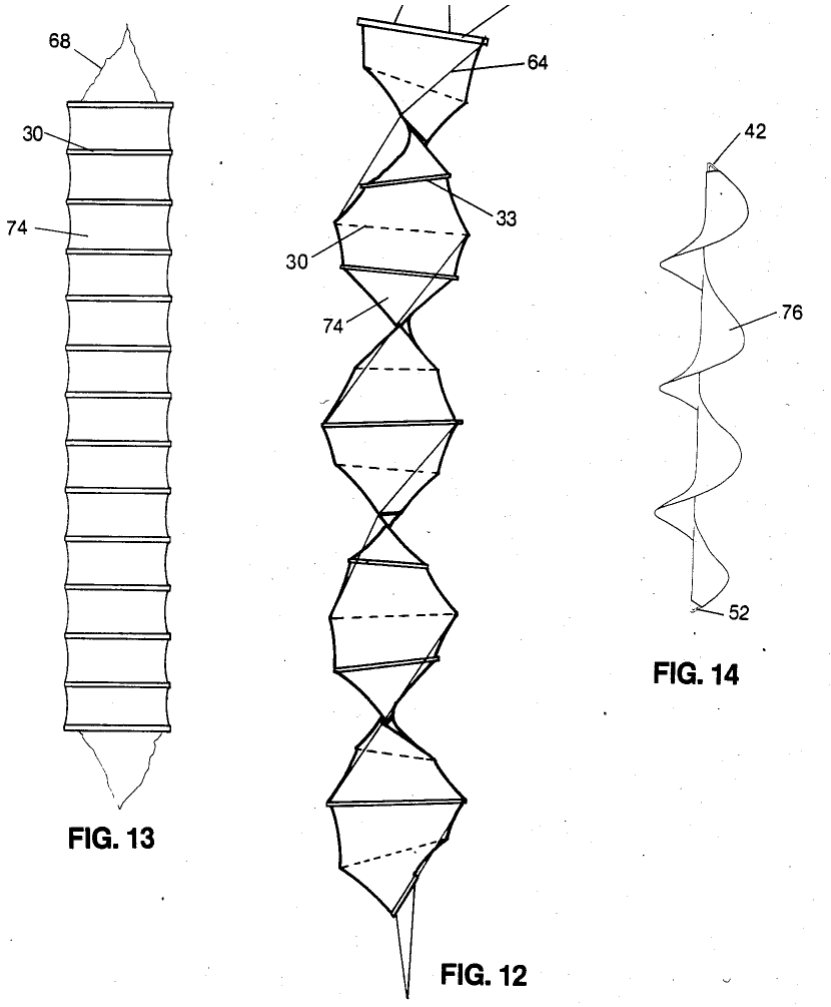


FIG. 13

FIG. 12

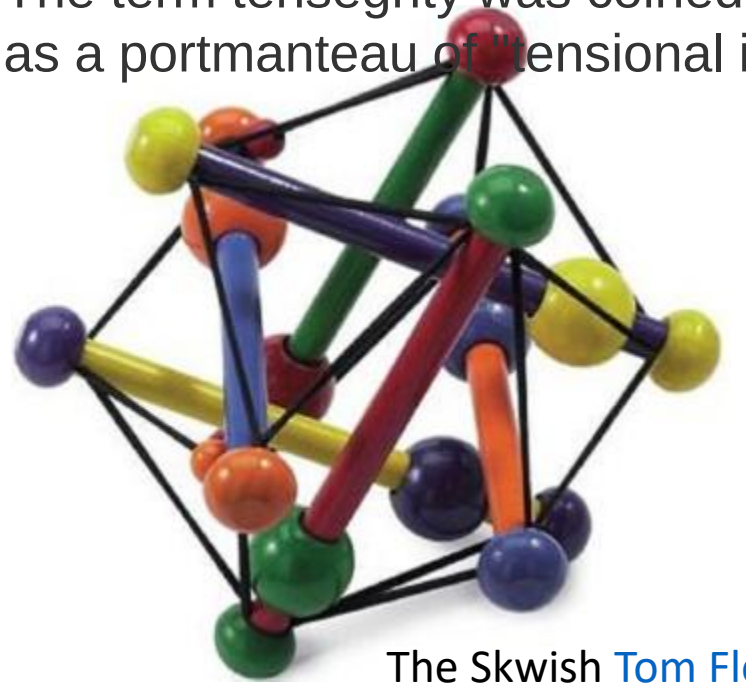
FIG. 14

US4708592A Krolick et al. ”Helicoidal structures, useful as wind turbines”

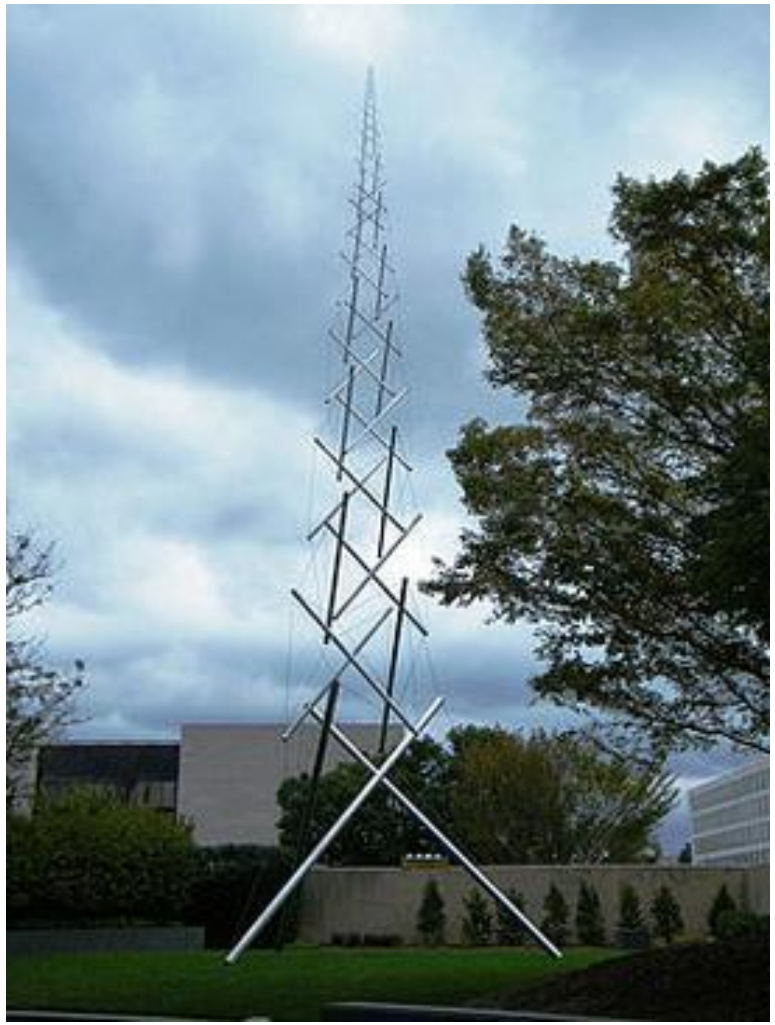
Tensegrity

Tensegrity [...], is a structural principle based on the use of isolated components in compression inside a net of **continuous** tension, in such a way that the compressed members (usually bars or struts) do not touch each other and the prestressed tensioned members (usually cables or tendons) delineate the system spatially.[1]

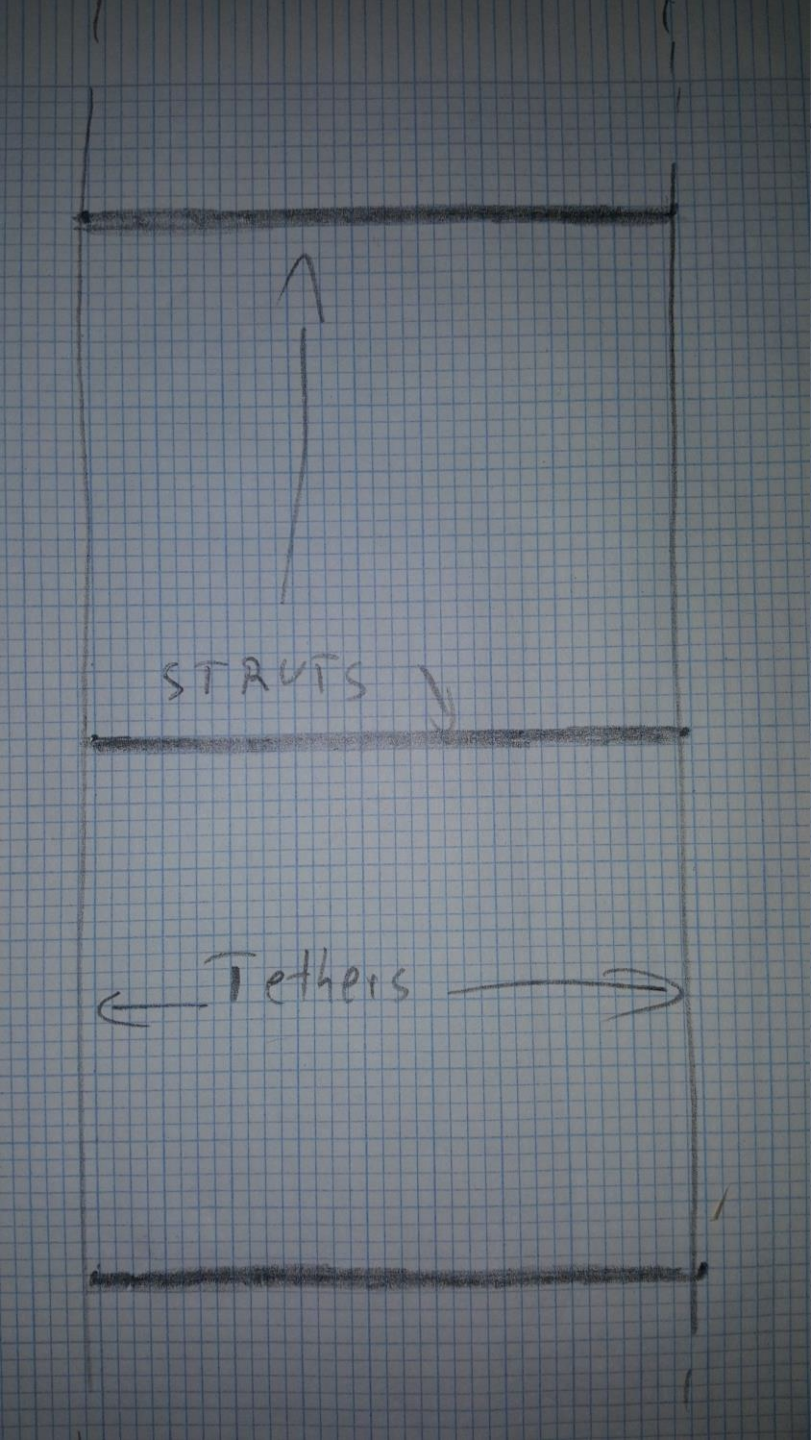
The term tensegrity was coined by Buckminster Fuller in the 1960s as a portmanteau of "tensional integrity". [2]

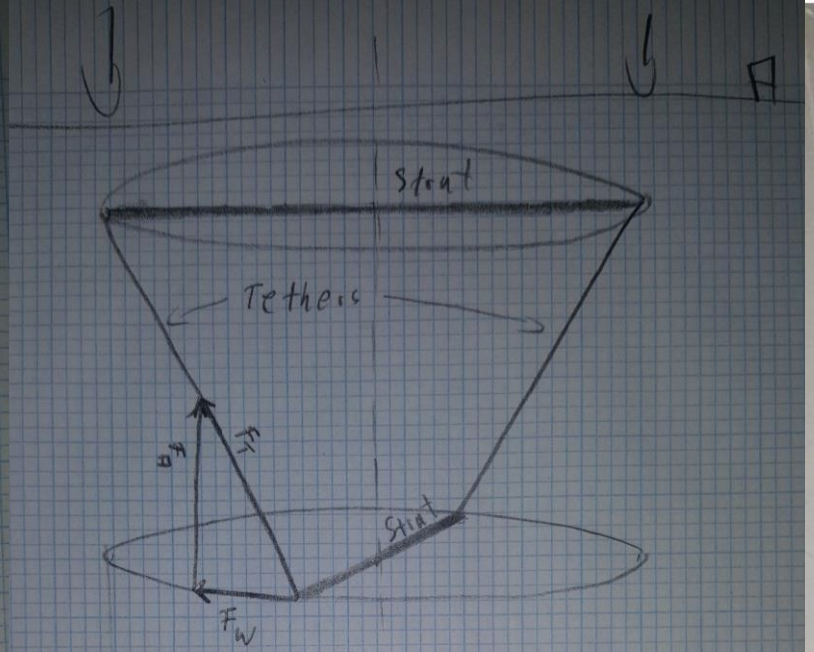


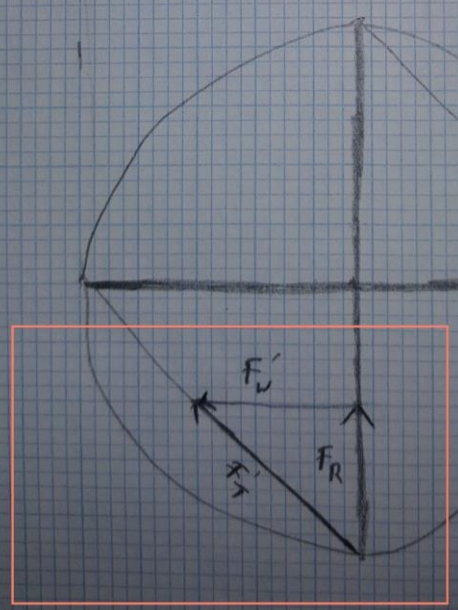
The Skwish Tom Flemons

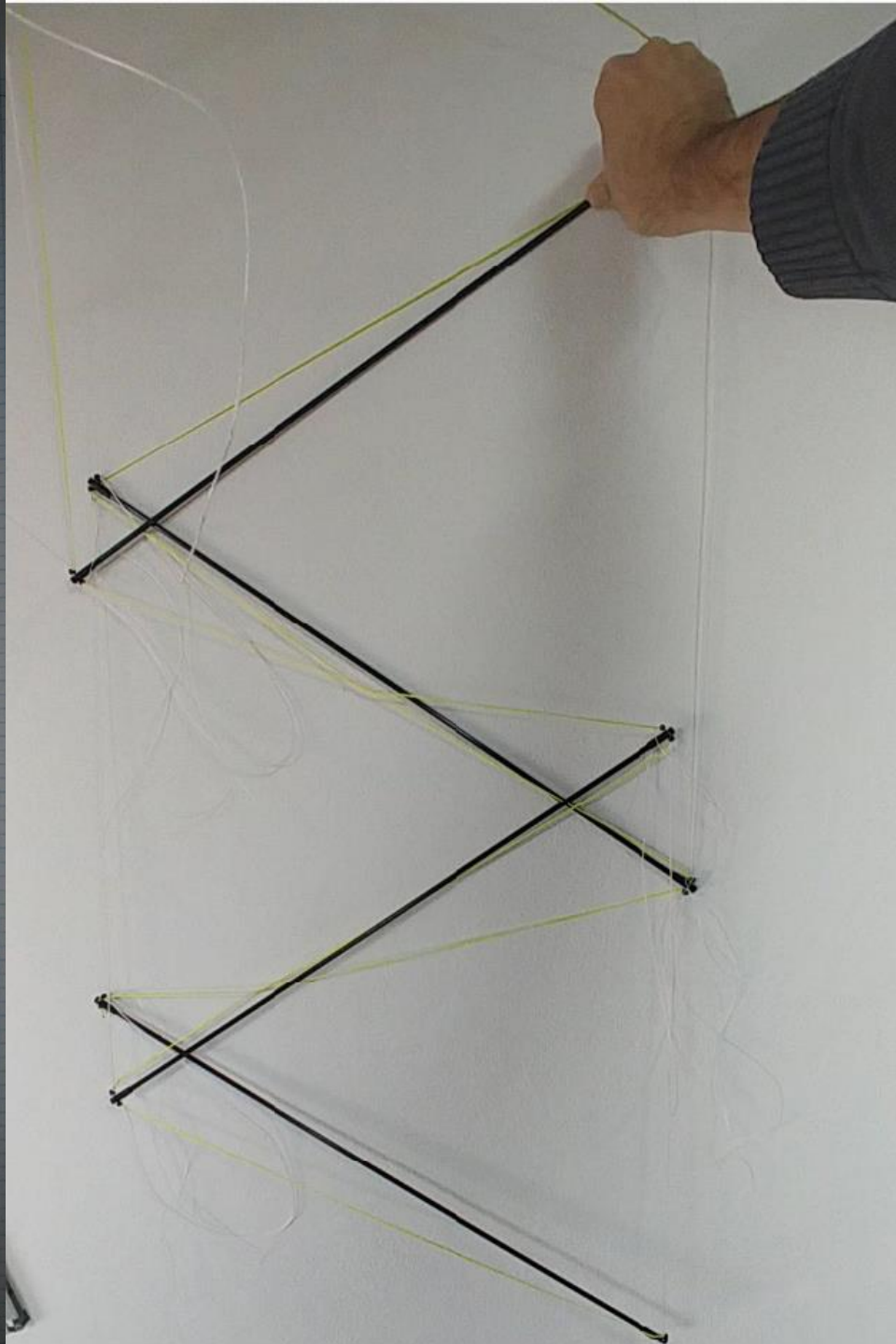


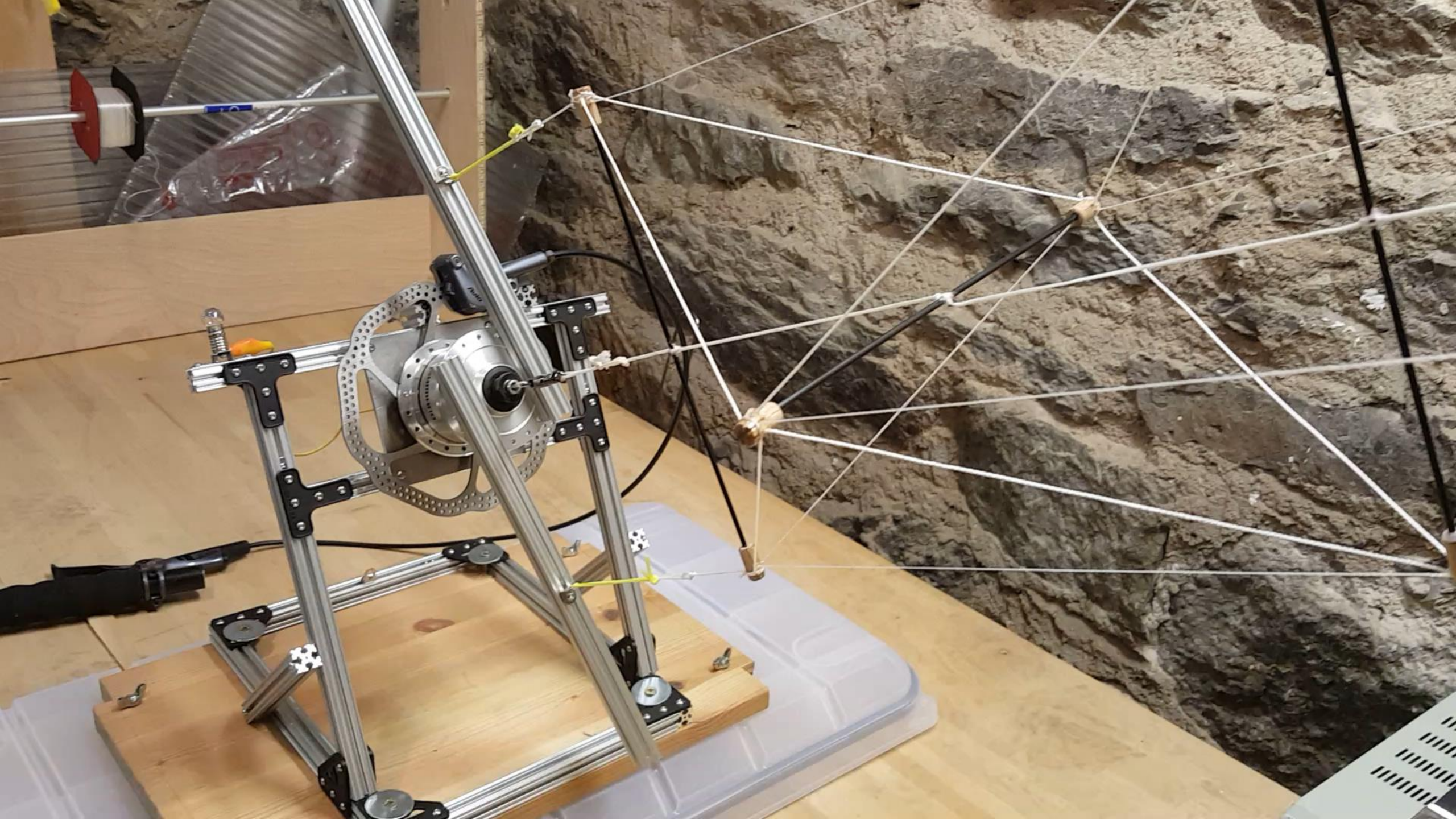
Kenneth Snelson https://en.wikipedia.org/wiki/Needle_Tower


STRUTS
Tethers


Strut
Tethers
Strut
F_W


F_W'
F_R





Open Tensegrity Shaft (OTS) “Helix”

Tensegrity […]

Open Tensegrity is a structure that fulfills the definition of Tensegrity except for the "*continuous tension*" part. An Open Tensegrity structure allows for an external force to be applied to delineate the system spatially. In AWE this force would likely be a lift force generated by an airfoil.

Shaft/Driveshaft is “a long cylindrical rotating rod for the transmission of motive power in a machine”[3].
We remove the "*cylindrical*" requirement. We define any rotating three-dimensional long structure for the transmission of power a “Shaft”.

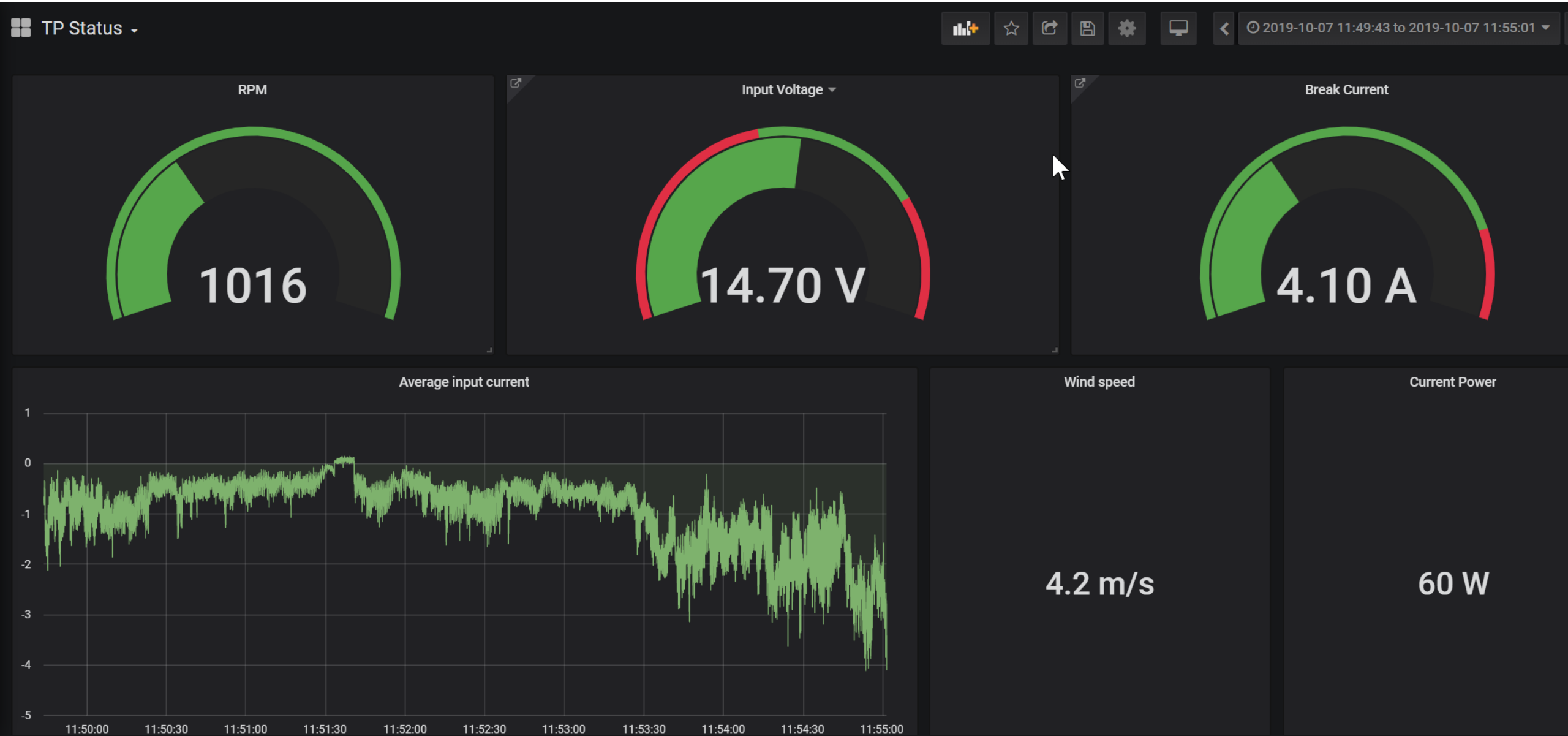
Open Tensegrity Shaft / OTS Combining the definitions of “Open Tensegrity” and “Shaft” an OTS is defined as a:

Rotating three-dimensional long structure made of components in compression (struts) and tension (tethers) for the torsion based transmission of power.

Our Helix

- 5*500mm: smallest wound CFK tubes available
- Spacing between rods: Tetrahedron =1/sqrt(2) ~70% (“because it feels right”)
- Length 30m - because Tüddeln is hard

DATA


TP Status
2019-10-07 11:49:43 to 2019-10-07 11:55:01
RPM
1016
Input Voltage
14.70 V
Break Current
4.10 A
Average input current
1
0
-1
-2
-3
-4
-5
11:50:00
11:50:30
11:51:00
11:51:30
11:52:00
11:52:30
11:53:00
11:53:30
11:54:00
11:54:30
11:55:00
Wind speed
4.2 m/s
Current Power
60 W

TPLog: Overview

tp_core (ESP32)

tp_ vesc

tp_ log

tp_ wind

tp_ gui

tp_ rotor

tp_rotor (ESP32)

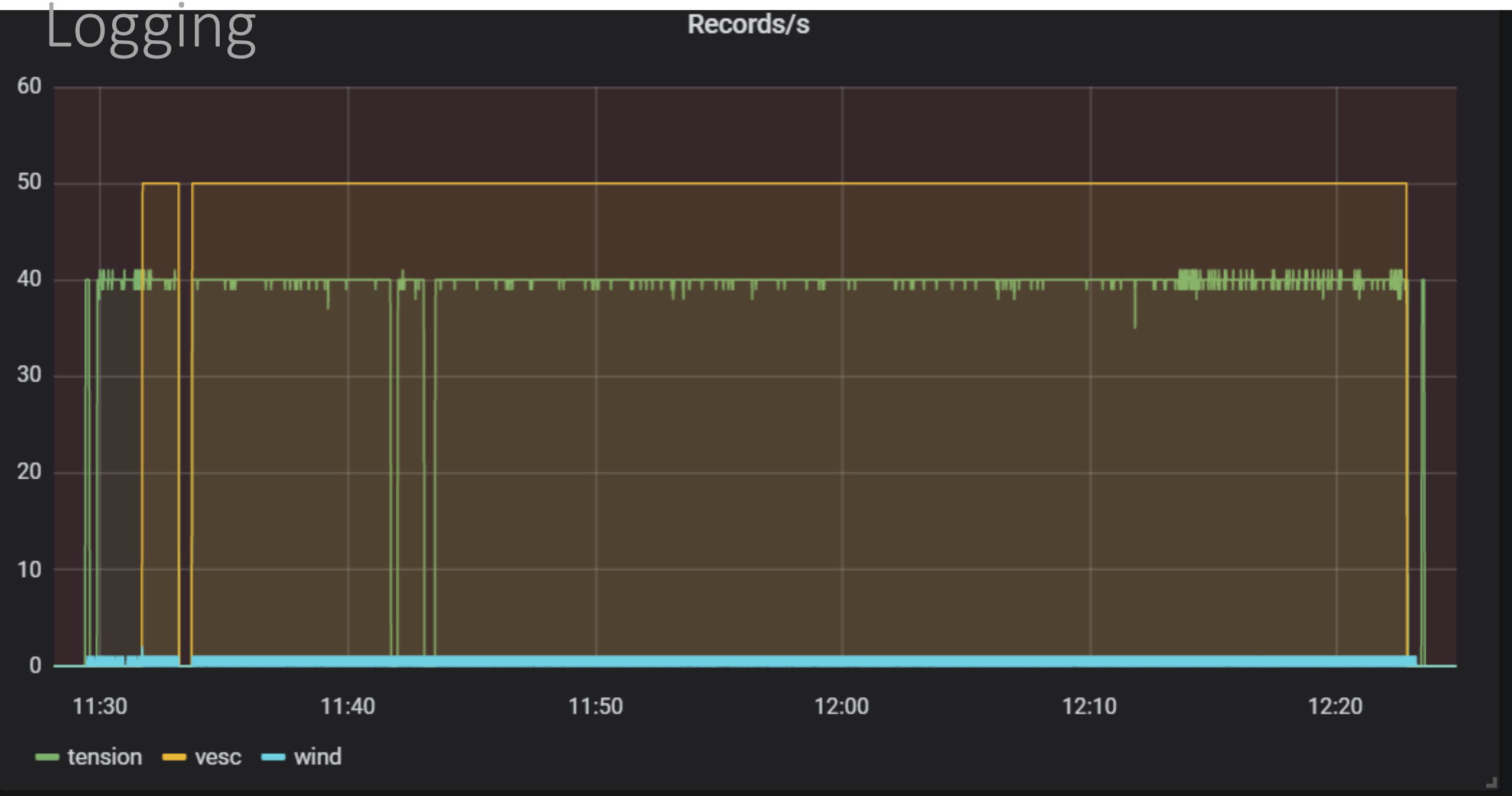
influxdb

Grafana

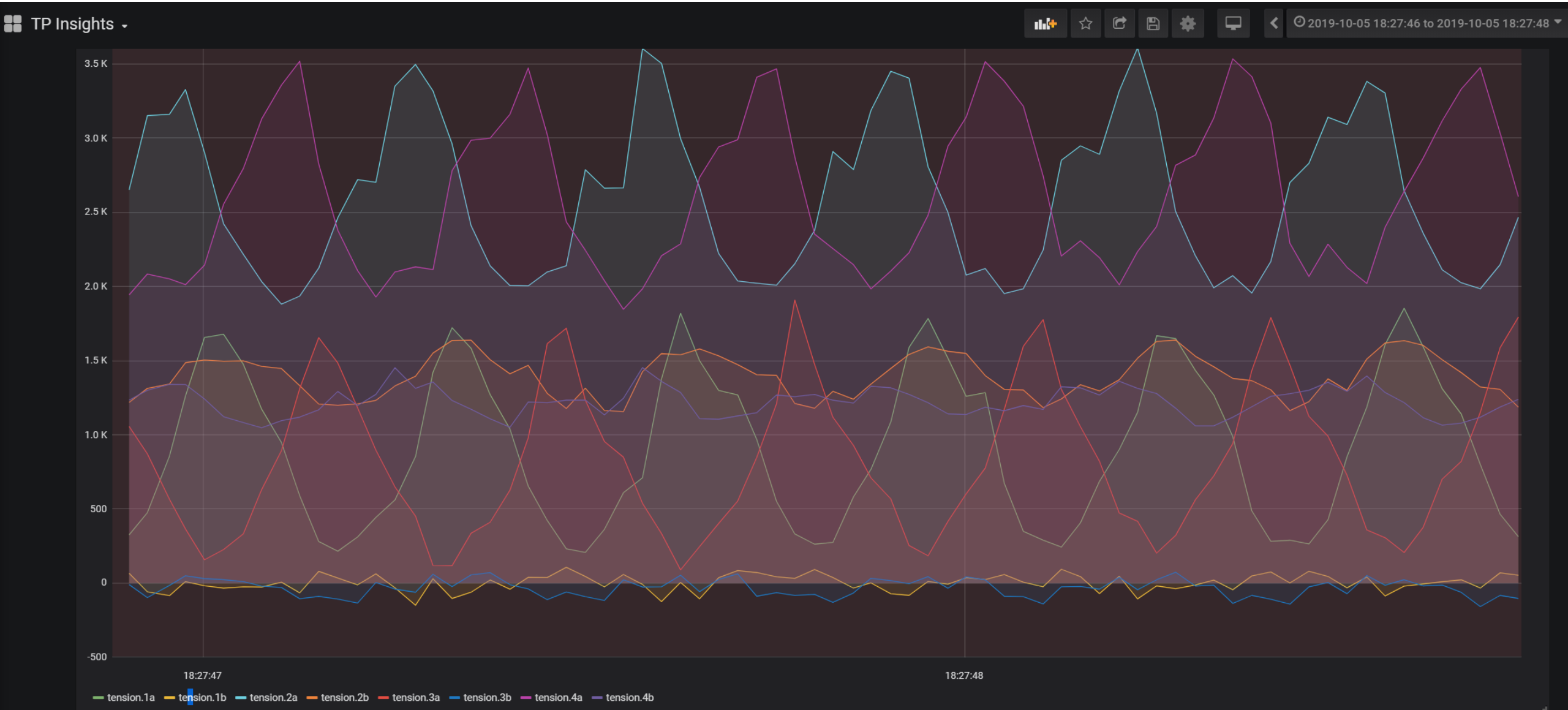
tplog.de (Docker, Amazon AWS)

christof.Beaupoil@gmail.com

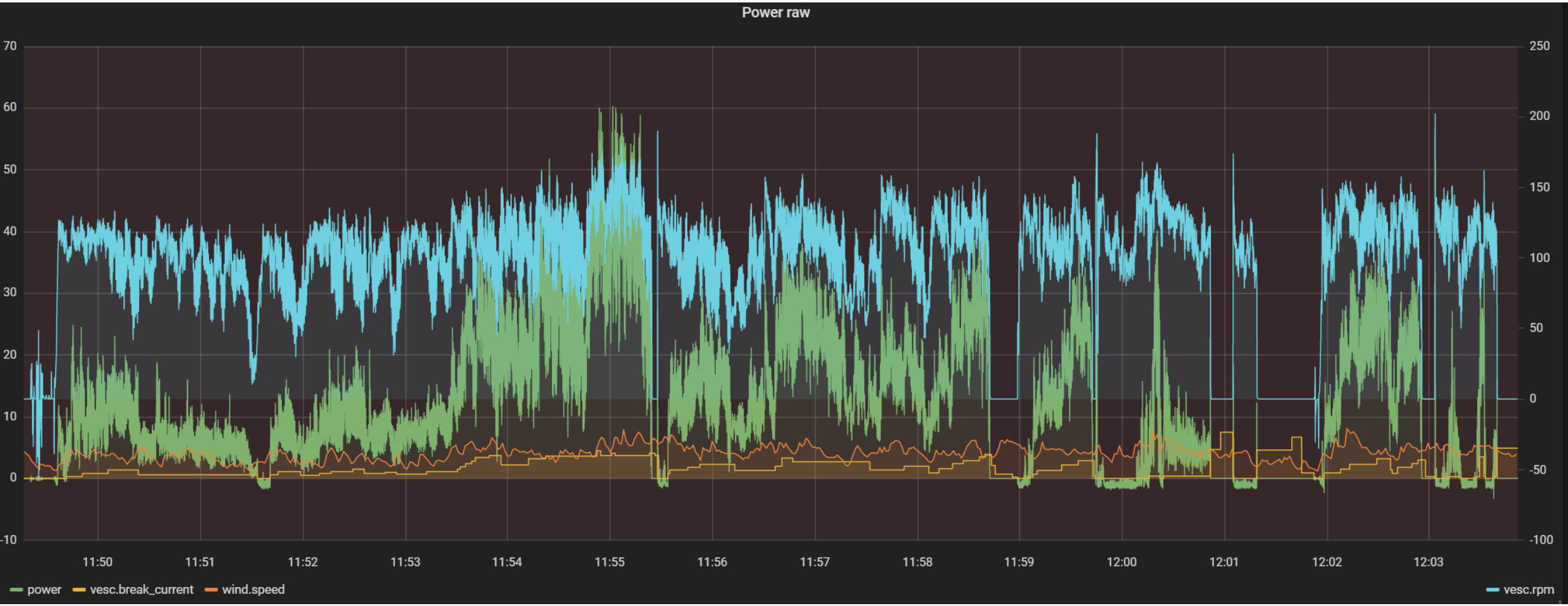
Logging


Records/s
60
50
40
30
20
10
0
11:30
11:40
11:50
12:00
12:10
12:20
tension
vesc
wind

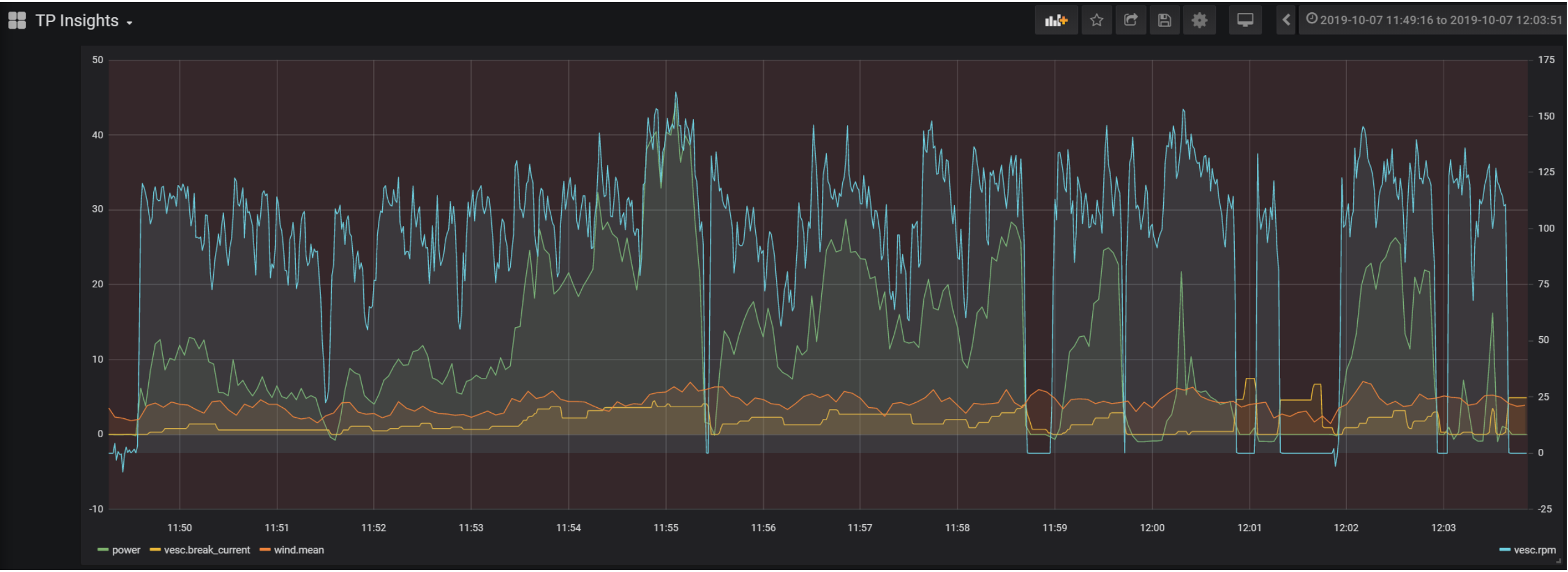
The Wobble (on testbench)



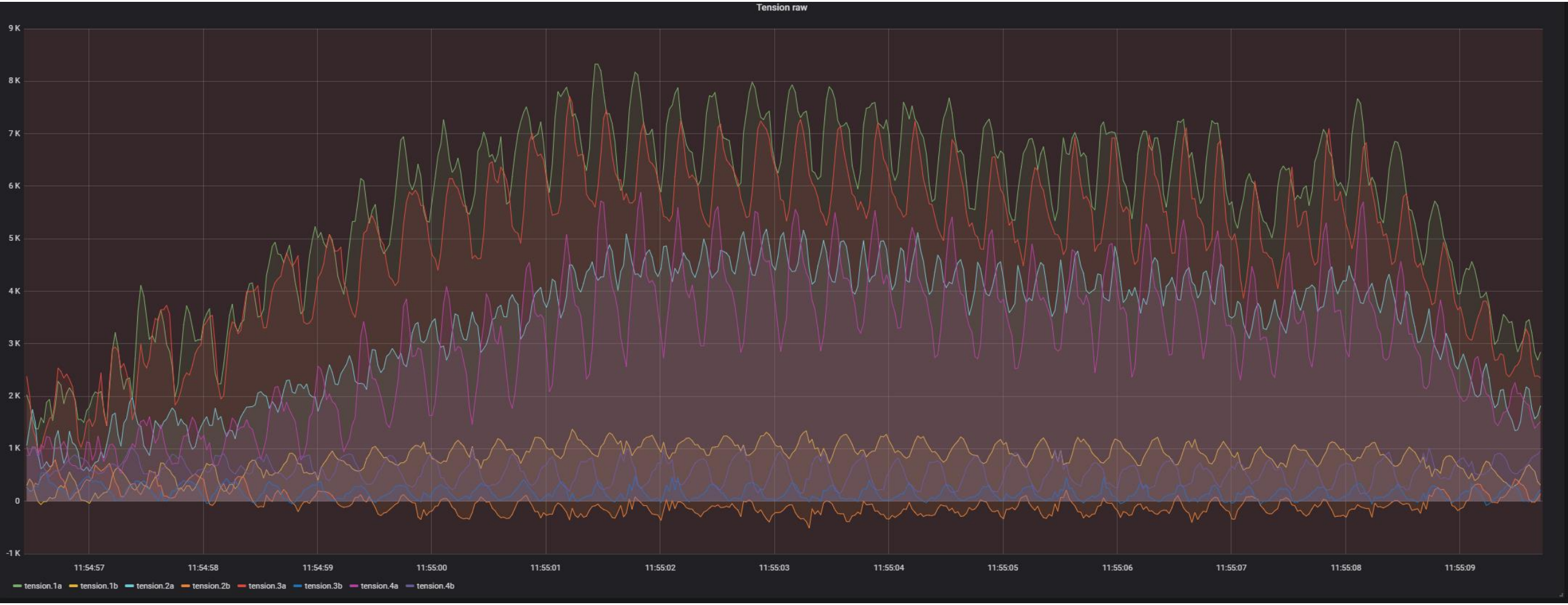
Power over wind – raw data



Power over wind



Forces @ peak power



Technology Road Map

- Measure OTS efficiency&optimise f(length, RPM, torque, diameter)
- Understand OTS dynamic behavior (wobble & skipping)
- Build & document 500W @ 100ft
- Add launch and retrieval capabilities

Anybody wants to build a model of the OTS?

someAWE’s secret masterplan

Open Source Business model Linux / Red Hat or RepRap / Prusa i3

Build something useful that works -> have people copy and improve it

The machine is & will be 100% open source

The machine that builds the machine is not

someAWE S.L. will start by distributing components

https://reprap.org/wiki/Prusa_i3

Team Tüddelpower

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@someAWE_cb

plattdeutsch: tüdern = binden, wickeln, haspeln, **verwirren**
etwas (auf unprofessionelle Weise) befestigen
english: to knot & **entangle & fix in an unprofessional manner**

https://www.youtube.com/watch?v=HjZbnF8jmjc