# DRAFT: Savonius wind rotor basics

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Figure 1 shows the basic parameters needed to calculate power and rotational speed of a Savonius wind rotor.

**Parameters:**
*d* – diameter of plastic pipe *[m]*
*D* – wing spread of rotor *[m]*
*e* – pipe spacing *[m]*
*h* – height of blades / tubes *[m]*
*v* – wind speed *[m/s]*
*F* – diameter of end plates *[m]*

The permanent magnet alternator from www.windbluepower.com (DC-540) produces *1A* and *12V* at only $n_a$ = *130 rpm* with an applied shaft torque $\tau_a$ *~1 Nm.*

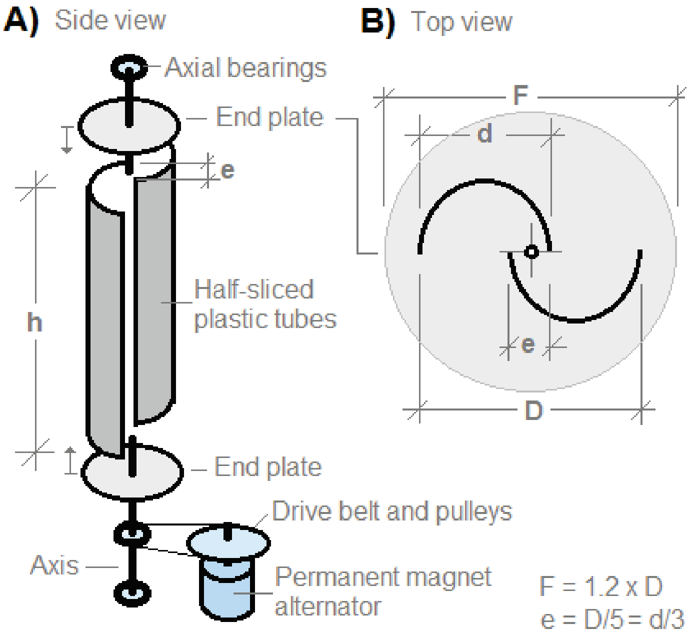

**Fig. 1.** Basic sketch of Savonius wind rotor

## Basic equations

The maximum power of the rotor is estimated according to Betz's law

$$P_s = {}^{1}\!/_{2}\ \rho \cdot A \cdot v^3 \cdot C_p = 0.36 \cdot h \cdot D \cdot v^3. \quad [W] \qquad [1]$$

$\rho$=*1.2 kg/m*$^3$ is the air density, $A = h \cdot D$ the sweep area of the rotor blade and $C_p$=*0.593* the Betz coefficient. However, there are aerodynamic and mechanical losses in the order of 50%. Our rotor shaft power equation then becomes

$$P_s = 0.18 \cdot h \cdot D \cdot v^3. \quad [W] \qquad [2]$$

The rotational speed is defined as

$$n = (60/2\pi) \cdot \omega \quad , [rpm] \qquad [3]$$

where $\omega = \lambda \cdot v/r$ is the angular velocity in units of *radians per second,* $r = D/2$ the radius of the rotor and $\lambda$ = *1* the tip-speed ratio. Furthermore, the torque at the rotor shaft is given as

$$\tau_s = P_s/\omega. \quad [Nm] \qquad [4]$$

It is now possible to calculate key parameters of the rotor using the above equations. For simplicity, the height of the rotor is *h=1m*. New power and torque values as a function of *h* is found by linear scaling of the calculated unit values. The rotor should start spinning for wind conditions defined as moderate breeze or wind start speed *v = 6 m/s.* The results are shown in Table 1.

| Rotor # | d [cm] | e [cm] | D [m] | r [m] | $\omega$ [rad./s] | n[rpm] | $P_s$ [W] | $\tau_s$ [Nm] |
|---|---|---|---|---|---|---|---|---|
| 1 | 10 | 3.33 | 0.167 | 0.0835 | 71.856 | 686 | 6.50 | 0.09 |
| 2 | 20 | 6.66 | 0.333 | 0.1665 | 36.036 | 344 | 12.95 | 0.36 |
| 3 | 30 | 10.0 | 0.500 | 0.2500 | 24.000 | 229 | 19.44 | 0.81 |

**Table 1.** Moderate breeze wind conditions: *v = 6 m/s and h = 1 m*

Let us now select rotor no. 2 due to the relatively compact size and the power of ~12W at moderate breeze conditions. Table 2 shows the calculations as a function of wind speed.

| v [m/s] | 6 | 11 | 17 | 22 | 28 |
|---|---|---|---|---|---|
| n [rpm] | 344 | 630 | 975 | 1262 | 1606 |
| $\omega$ [rad./s] | 36.04 | 66.07 | 102.10 | 132.13 | 168.17 |
| $P_s$ [W] | 12.95 | 79.78 | 294.46 | 638.34 | 1315.80 |
| $\tau_s$ [Nm] | 0.36 | 1.207 | 2.884 | 4.831 | 7.824 |

**Table 2.** Power and torque as a function of wind speed for rotor no. 2 with wingspread *D = 33.3 cm* and gap *e = 6.66 cm*. The height of the rotor is *h = 1 m*. Wind values are from moderate breeze to near gale conditions.

The power transmission between rotor shaft and alternator should be preserved $P_a = P_s$. Fig.2 shows the belt drive configuration. Since diameter times angular speed of the shafts are the same, $\phi_s \cdot n = \phi_a \cdot n_a$, the applied torque to the alternator shaft is found by using equation [3] and [4]

$$\tau_a = \left(\frac{n}{n_a}\right) \cdot \tau_s = \left(\frac{\phi_a}{\phi_s}\right) \cdot \tau_s. \qquad [5]$$

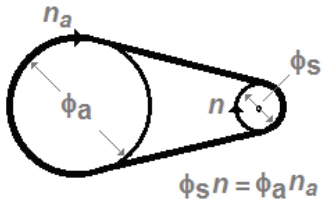

**Fig. 2.** Belt drive

The mechanical advantage factor in equation (5) is $MA = (\phi_a/\phi_s)$. If we for simplicity assume that *MA = 3,* then $\tau_a$ *~ 1 Nm* for moderate breeze wind conditions. The alternator shaft should then spin at $n_a$ *~ 115 rpm*. Both values are close to the alternator data given by the manufacturer.

**STEP 1: The 3D printed rotor**

The next step was to construct a 3D printed rotor to test the above equations and assumptions. The web based program from www.tinkercad.com was used to draw the parts needed. Fig. 3 shows the printed parts necessary to produce one rotor. The wingspread of the rotor is *D=70 mm* and the height is *h'=130 mm* with the top mounted with super clue. The pipe spacing equals *e=14 mm*. The walls or thickness of the printed rotors is ~*3 mm*.

The Replicator 2 from the company MakerBot was used to print the parts using black Polylactic acid (PLA) thermoplastic. The infill was set to *10%* with *2* numbers of shells and a layer height of *0.20 mm*. This is the standard setting / profile used by the printer.

Two rotor sets were printed, and stacked on top of each other. The top rotor is rotated an angle of 90 degrees to the bottom one. This was done to prevent any dead angle or non-favorable attack angle of the rotor to the wind direction. A center axial metal shaft penetrated the two rotors.

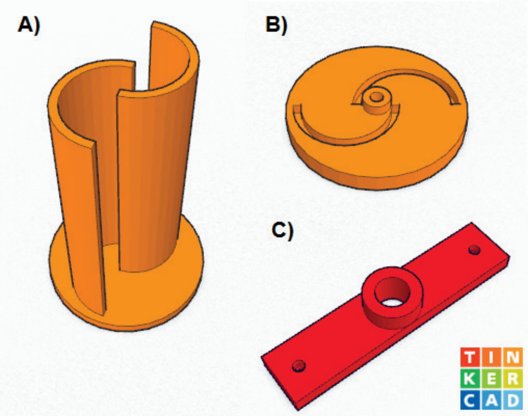

**Fig. 3.** 3D visualization of Savonius rotor parts: (A) rotor blade, (B) top lock, and (C) bridge to hold top bearing.

The assembled system is shown in Fig. 4. One top and bottom bearing is used to spin the rotor relative to a fixed frame. The frame is constructed by the use of a gun cleaning set with 3 equal length metal rods. The rods, bearings and the 3D printed top bridge are mounted to the lid of a square metal box. The latter serves as base mount of the system.

The effective height of the assembled rotor is $h = 2xh'=260\ mm$, which gives a theoretical power of only $P_s = 0.7W$ for moderate wind $v = 6\ m/s$. The rotor should then spin at 1637 rpm.

Note that the bearings are not sealed. Therefore, the construction is not suited for outdoor use, especially for snowy and icy conditions. The mount box top surface easily collects snow and ice. The box also enhances rotor noise, since it is empty. Our frame could also be strengthened with a more rigid metal construction to resist vibrations.

Nevertheless, tests will be conducted outside to see how the rotor performs.

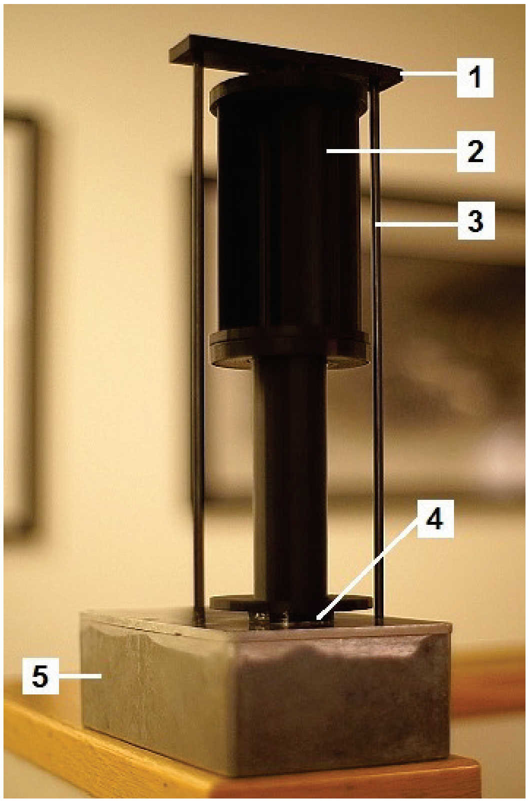

**Fig.4.** Assembled Savonius wind rotor: (1) top bridge with bearing, (2) rotor, (3) support rods, (4) bottom bearing holder, and (5) mount base.

### STEP 2: First test of 3D printed prototype

The rotor was mounted on the 10th of November 2015 to the porch railings of apartment 561, road 232 in Longyearbyen, Svalbard. The average wind conditions reported by the

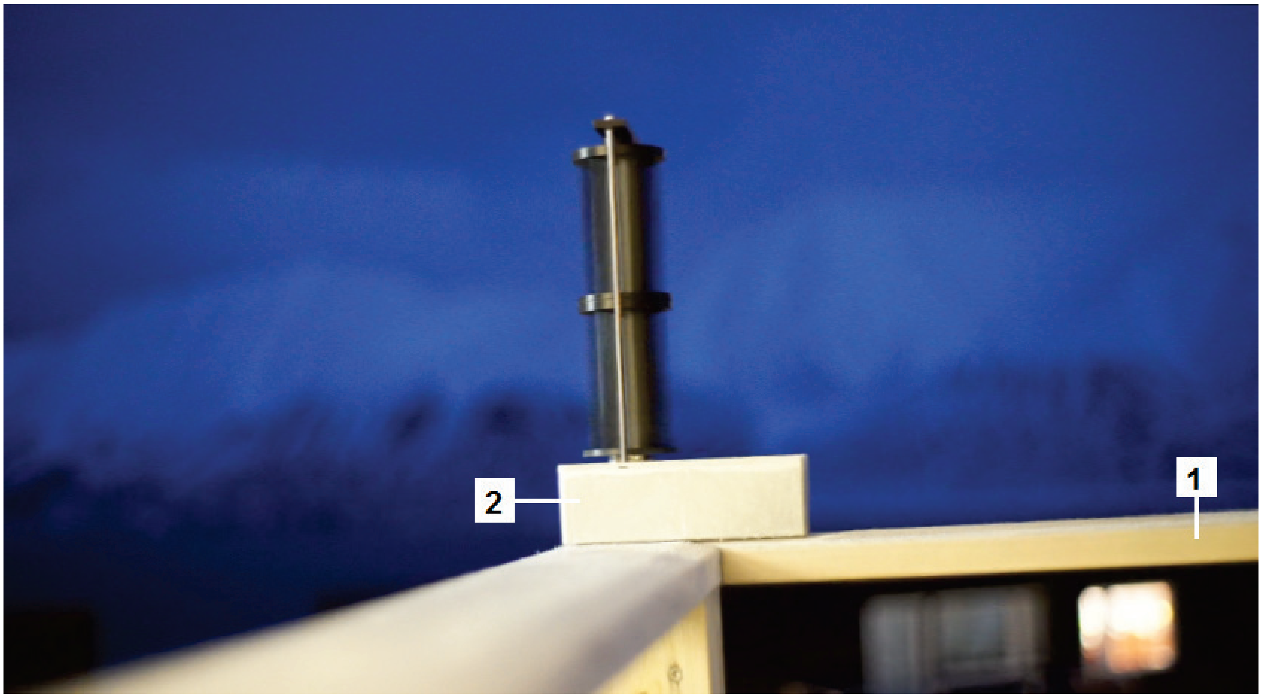

**Fig.5.** Experimental setup of 3D Savonius printed rotor on 10.11.2015 at 07:30 UT. (1) Porch railings of apartment 561, road 232 Longyearbyen, Svalbard, and (2) Savonius rotor.

Meteorological Institute of Norway at 07:30 UT was $v = 7.5\ m/s$ South – East. Fig.5 shows the experimental setup.

A short .avi film of the test can be downloaded here.

In this first experiment the rotor spins at an unknown rotational speed. Both wind and rotational speed need to be measured before any further conclusions. The first test just verifies that the system actually spins quite easily.

### STEP 3: Full size prototype

Based on the above, a full size prototype is constructed using a 200 *mm* diameter PVC pipe, two pillow blocks with self-aligned spherical bearings, a 12 *mm* steel axis, brass fittings, and ~5 *m* of square 25 *mm* steel bars for the frame.

The construction is shown in Fig. 6. The frame has a dimension of 60 x 150 *cm* and is painted green. Two support legs are bolted to the frame to keep it vertically. The rotor is mounted in the center of the frame using two pillow blocks with self-aligned spherical bearings (Model UCP204-20 TR). The bottom bearing is bolted to a 60 *cm* steel bar aligned parallel to the top bar at a distance of 102 *cm*.

The rotor blades are mounted by bolts to four 5 *mm* thick aluminum bars that each are 500 *mm* long and 40 mm wide. The bars are separated by a gap of *e = 40 mm* with the axis running parallel through in the center of the aluminum slit construction. This cap between the rotor blades is close to the optimum cap reported by Sheldahl et al. (1978) testing Savonius rotors in a wind tunnel.

The rotor in Fig. 6 will turn clockwise independent of wind direction. The height of the rotor is *h = 1 m* and the wing spread is *D = 35 cm*, which is close to rotor #2 in Table 1.

Note that the key challenge in the above was to make the bearings spin freely with low friction. One protective ring of the bearing was taken out to remove all grease and replace it with a nano based oil (Orapi Nano Spray Lubricant). This is not optimum and will cause the bearings to wear out fast. The latter mainly due to leakage when exposed to weather and harsh outside conditions. Therefore, a study to find more suitable bearings than steel based ones has to be initiated. One candidate could be ceramic or hybrid ceramic bearings.

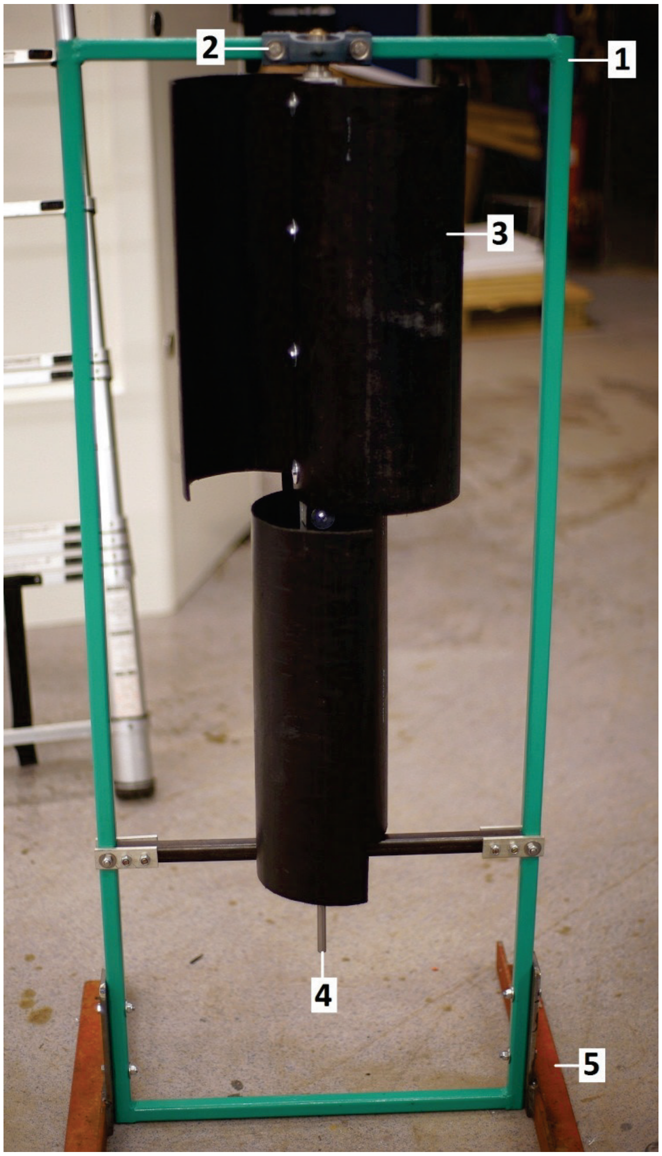

**Fig. 6.** Prototype Savonius rotor: (1) Steel frame, (2) self-aligned top bearing house, (3) rotor blades, and (4) 12 mm steel axis.

The initial test of the prototype was conducted at the roof of UNIS 26th of April 2016. The *200W* permanent magnet generator from Jiangsu Naier Wind Power Technology Development Co., Ltd (model NE-200SP) was mounted to the rotor and tested. The startup Torque of this generator is only *0.12 Nm*.

The experimental setup is filmed here.

**Next:** An experiment to obtain data of rotational speed as a function of wind velocity will be conducted. Charge voltage and current must also be monitored.

## Conclusion so far …

The wind rotor described is not as efficient as commercial wind mills, but the compactness and simple construction makes it a possible candidate that could survive arctic weather winter conditions.

## Acknowledgement

I like to thank the following persons in Longyearbyen for supporting this so far zero budget project: Frank Pettersen at LNS, Odd Jostein Sylte at the Power plant, Kåre Johansen at UNIS, Geir Hekne at the Fire station, Knut Flå at Jensen Elektriske AS, Prof. Yngvar Gjessing and my Dad Ulf for numerous technical questions and discussions. The advice and experience of Prof. Marc Lessard at UNH in the US is deeply appreciated.

## References

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