ROBIPLAN

SCIENTIFIC SURVEY, TECHNOLOGIES AND OUTPUTS

February, 15th 2009

SYCOMOREEN
SYstems for COnversion of MOtions and REnewable ENergies
systèmes pour la conversion de mouvements et d'énergies renouvelables

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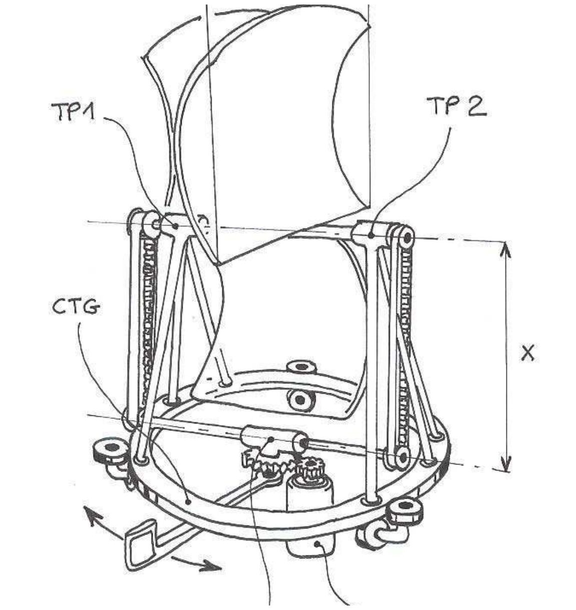
The Rotary Bi-Plan (ROBIPLAN) wind turbine, original invention of *Pascal HA PHAM*, is likely to be used on the dwellings, out in the country or in urban environment to generate a mechanical, then electric power. The invention is very simple to manufacture and has a big ability to start under very weak winds, as well as to support strong winds.

<u>The Inventor has already built and tested 2 very simple and improvable prototypes, called **Robiplan :**</u>



The ROBIPLAN exploits a whole range of wind speeds, but its output, defined as the ratio between the recovered power and the incidental kinetic power is not even known. The present survey aims to estimate an order of size of it: as the fluids dynamics is especially complex, *it will be necessary to confirm these evaluations thereafter by finite elements analysis of out-flows, and of preference and especially, by measures in bellows.*

A lot of information and links about Pascal HA PHAM's inventions available on :
http://sycomoreen.free.fr/syco_annonces.html
http://www.econologie.com/forums/turbine-eolienne-rotative-bi-plan-robiplan-vt4872.html

SUMMARY

I. Problematics of this scientifique survey

I.1. Legal aspect

The present survey is written by *SYCOMOREEN* SARL on Pascal HA PHAM's demand, as friendly collaboration and without reciprocal engagement.

I.2. The context

I.2.a) Story of the wind power

The Man would have begun to tame wind with *veils gone up on rafts in sea since 4000 before J-C.* Since a long time, wind energy has fascinated the men. In Europe, the *first windmills are built toward 1100 to the Middle-Ages* and used to pump water and to grind wheat. From the antique to recent times, the wind engines converts it into mechanical energy for multiple uses :

- Grain grinding
- Water pumping and irrigation / drainage of too dry / humid zones
- Livestock drinking
- more lately, electric power.

In 1888, Charles F. Brush builds in the United States a small wind turbine to supply his shops in electricity, with a storage by battery of accumulators. It included 144 blades and a rotor of 17 m of diameter.

The first "industrial" wind generator of electricity is developed by the Dane Poul The Court *in 1890*, to produce hydrogen by electrolysis. In the following years, he creates the Lykkegard wind turbine, of which he sells 72 engines in 1908.

The first turbine with alternating current dates of thirties. An experimental wind turbine of 800 kVA runs from 1955 to 1963 in France, at Nogent-le-Roi in the Beauce. It had been designed by the Office of Scientific and Technical studies of Lucien Romani and had been exploited for the account of EDF. Simultaneously, two Neyrpics wind turbines of 130 and 1 000 kW were tried by EDF in Saint-Rémy-des-Landes (English Channel). There was also a wind turbine connected to the heights of Algiers area (Dély-Ibrahim) in 1957.

Until the middle of the XXth century, the wind is essentially used in isolated sites. *It is briskly competed by coal (steam-powered machine), the internal combustion engine and the expansion of the centralized electric networks*. In the seventies, with the first oil crisis, *wind power knows a new flight, and especially these last 15 years: the very fast development of more and more powerful and effective tri-blades wind turbines* is essentially due to the European industries (Denmark then Germany). The worldwide capacity raise from 4800 MW in 1995 to 74 000 MW in 2006 with yearly growth rates oscillating between 30 and 45%.

I.2.b) The energy issues in 2009 and after : quid of the wind ?

Wind energy and electric grids

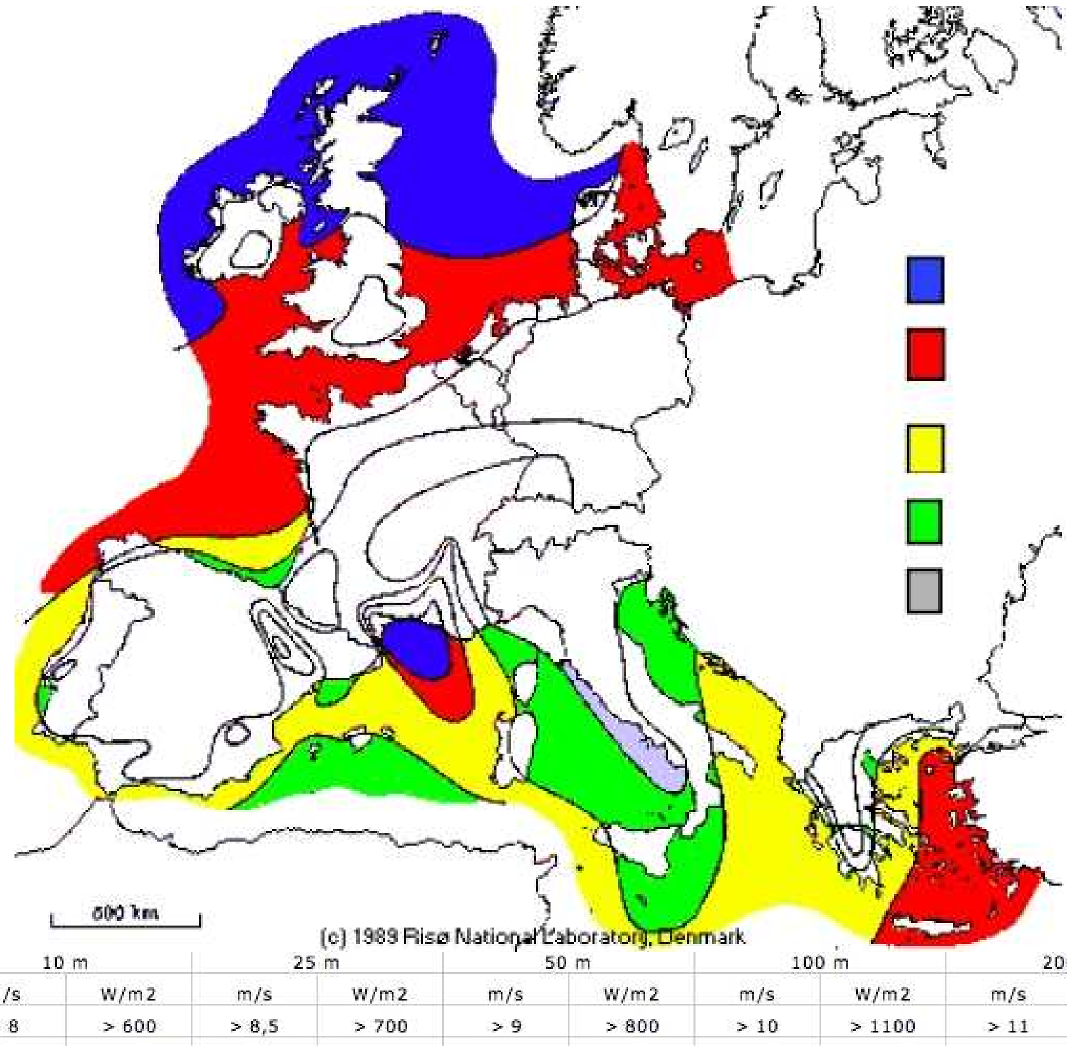
The wind energy was handicapped for a long time by its very little foreseeable intermittence and the costs of the electric batteries necessary to store temporarily the production. However, nowadays, big interconnected electric networks, notably in Europe and in the United States, are linking power stations based on renewable energies with irregular power. The fields of wind turbines currently have the strongest progression.

The present part of the wind in the electric mix

This very meaningful flight of the wind must not conceal its marginal use in the world electric mix (about 0,5%), although the wind energy is **enough abundant and renewable** (generated by the Sun). **To this title, the wind engineering is one of the key-technology to reduce the greenhouse effect while encouraging an energizing independence** in relation to all fossil energies, as well the hydrocarbons (coal, oil and gas) that the ore of uranium.

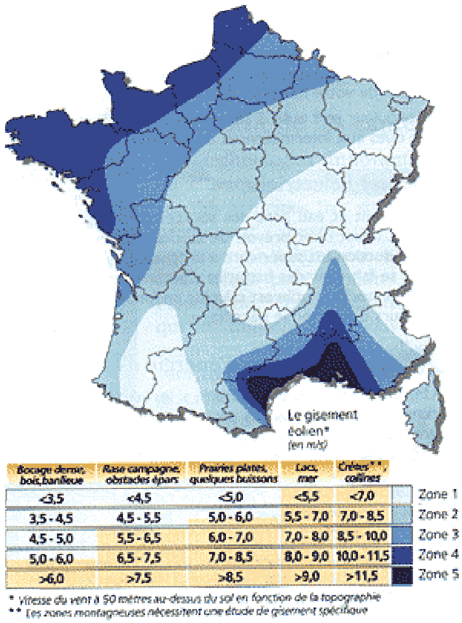
France and Europe : great under-exploited resources

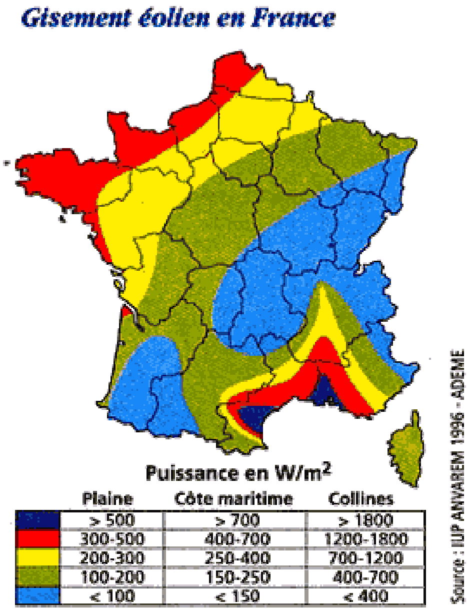
Europe and especially France benefit from a very favorable situation because they have abundant resources in biomass, in wind and in hydraulic strength with a strong culture of sciences, industry and engineering : progress in the storage / unstorage of the energy (by various ways), the hydroelectric pumping and turbining power stations (dam of heavy hydraulics, STEP), the capacity of regulation of the other fueled power stations (decrease then resumption of production), and the emergence of intelligent decentralized networks (Smart Grid) opens the way to *the injection of clean and intermittent productions in synergy* (as those which already exits for the wind) *into the grid with economically acceptable costs, but especially* ***strategically*** *indispensable.*



	10 m		25 m		50 m		100 m		200 m	
	m/s	W/m2	m/s	W/m2	m/s	W/m2	m/s	W/m2	m/s	W/m2
	> 8	> 600	> 8,5	> 700	> 9	> 800	> 10	> 1100	> 11	> 1500
	7 à 8	350 à 600	7,5 à 8,5	450 à 700	8 à 9	600 à 800	8,5 à 10	650 à 1100	9,5 à 11	900 à 1500
	6.0 à 7.0	250 à 300	6.5 à 7.5	300 à 450	7.0 à 8.0	400 à 600	7.5 à 8.5	450 à 650	8.0 à 9.5	600 à 900
	4.5 à 6.0	100 à 250	5.0 à 6.5	150 à 300	5.5 à 7.0	200 à 400	6.0 à 7.5	250 à 450	6.5 à 8.0	300 à 600
	< 4.5	< 100	< 5.0	< 150	< 5.5	< 200	< 6.0	< 250	< 6.5	< 300

marine et terrestrial Wind resources of Europe area





Maps of terrestrial wind resources in France

The hydrocarbons and the nuclear: the dangerous illusions

In spite of trendy speeches on reserves which are judged abundant, and of the extracting technologies claimed as always more effective, the oil productions in all regions of the world stagnated and often decreased in 2007/early 2008 (and this before the economic crash of the 2008 fall) whereas the demand didn't stop intensifying and that the rise never seen before of the barrel's price strongly incited to extract more oil in order to get exceptional profits.

Already, the overconsumption of the developed countries (USA, Europe, Persian Gulf, Russia) and the *economic flight of very densely populated countries* (China, India, South America) *comes up against the implacable rarefaction of easily exploitable hydrocarbons*, and for the future, simply extractible. The markets were not of it mistaken with $ 150 the barrel in summer 2008 : historic record which only wants to be soon pulverized.

It is precisely these financial stakes that make highly likely the combustion of the remaining reserves in hydrocarbons, notably the conventional and non conventional oils (sands bituminous, deep offshore), then the whole gas and coal fossile stocks. *In spite of the contempt to plunge the Earth in the dangerous unknown of a world warming up of more than 6°C to the scale of one century, or even 10°C for the following century*.

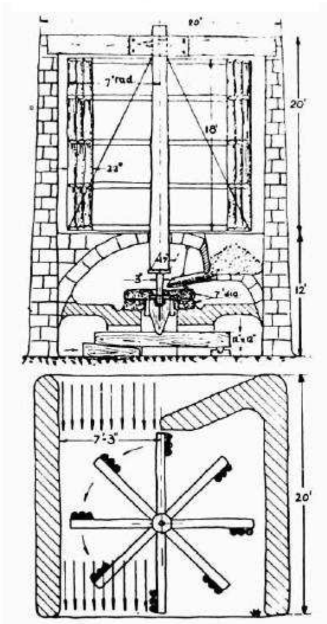
One hears in echo *the sirens of the nuclear "decarbonated" energy: it will only assure a very ephemeral and restricted transition in the technologically developed and politically steady countries*. Otherwise, the nuclear is an eminently fossil resource : if the French electric mix (more of 80% nuclear) were spread worldwide, the story known for the hydrocarbons would reproduce fatally to medium-term (< 50 years), more precisely :

1. Fast weariness of uranium resources (+ risk of the proliferation of the atomic bomb)
2. Wars for the appropriation of ore by the the greatest military powers
3. Ecological disasters (nuclear incidents and accidents, storage of the radioactive garbage).

The present world is post-peak-oil : it is the moment **to draw the Future**. A best future – economic, social and ecological – can't avoid **an energizing mix with dominant renewable contributions**. *Therefore the wind energy must be part of this Future, among the other renewable ones* (hydraulic, solar, biomass, geothermics, tide / surge).

I.3. The current technologies of wind turbines

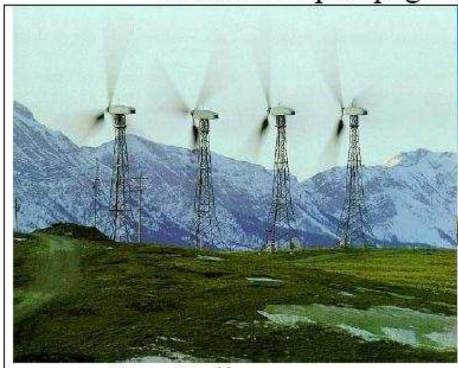
Persian windmill - 700 before JC



Moulin Perse (Antiquité)
VII$^{\text{éme}}$ siècle AV-JC

Pumping windmills in polders (Holland)

Moulins de pompage dans les polders (Hollande)



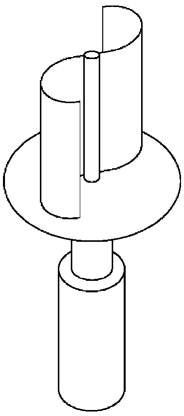
Parc Eolien
Californie (début 1980)
Eolian farm, California, early 1980's

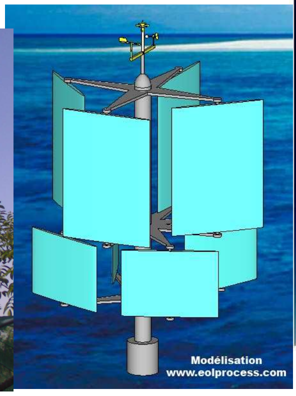
Pompage
pumping typical of USA

Eolienne Nordex
(années 90)
Nordex windturbine 1990's

The pictures *above* are drawing the major evolutions of the wind technology. Currently, the tri-blades wind turbines with horizontal axis impose themselves, generally disposed in wind fields.

Nevertheless, in parallel, technologies with vertical axis are developed themselves to smaller scales :





The Savonius 'marine' wind-turbines
(Lahor on the left, Eolprocess on the right)

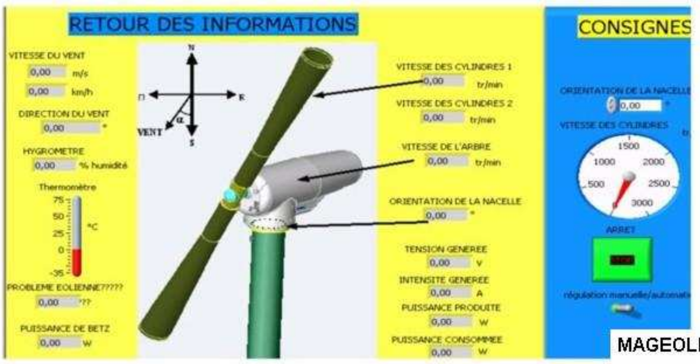
Darrieus (Québec)
Haut : 110 m, 4 MW
Height

AG Windrotor
kW

Ecotools
100 W à quelques kW
from 100 W to some kW

But also rarer wind turbine running on the Magnus effect (*at the opposite*).

Other projects propose various floating and rotary contraptions at high altitudes, retained by cable...



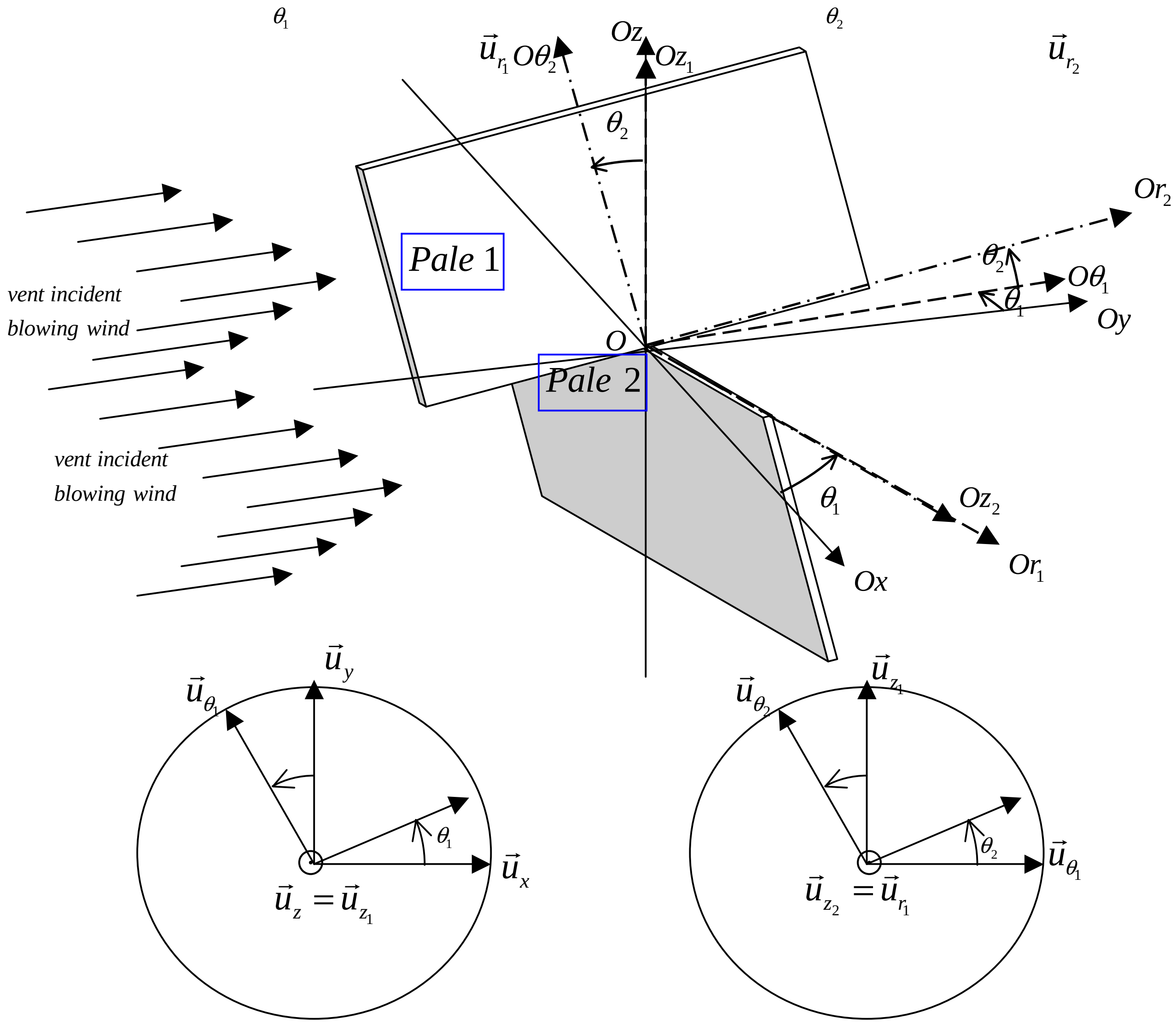
MAGEOLE (Polytech Clermont Ferrand)

II. ROBIPLAN's modelling

II.1. Kinematics

II.1.a) Motion's parametrization

The motion of the ROBIPLAN's blades results from the composition of 2 pure rotations with uniform velocity around 2 orthogonal axes requiring the following parameterization :



One deducts from it the projected relations between the following unit vectors :

$$\vec{u}_{r_1} = \cos\theta_1\,\vec{u}_x + \sin\theta_1\,\vec{u}_y \qquad \vec{u}_{r_2} = \cos\theta_2\,\vec{u}_{\theta_1} + \sin\theta_2\,\vec{u}_{z_1}$$

$$\vec{u}_{\theta_1} = -\sin\theta_1\,\vec{u}_x + \cos\theta_1\,\vec{u}_y \qquad \vec{u}_{\theta_2} = -\sin\theta_2\,\vec{u}_{\theta_1} + \cos\theta_2\,\vec{u}_{z_1}$$

$$\vec{u}_{z_1} = \vec{u}_z \qquad \vec{u}_{z_2} = \vec{u}_{r_1}$$

with the laws $\theta_1 = \omega t = \theta_2$ where *t* is the time and ω the rotary velocity of the ROBIPLAN.

From these relations, one can express the coordinates of any point on the blades as well as the instantaneous rotary vector of the blades.

II.1.b) Coordinates of the blades' points

The blade n°1 occupies the space along the axes $\vec{u}_{r_2}$ *and* $\vec{u}_{\theta_2}$. We call *a* the demi-width of blade and *b* its height. Thus, any point M_1 of the blade n°1 has a positionning vector :

$\overrightarrow{OM}_1 = x_1\vec{u}_{r_2} + y_1\vec{u}_{\theta_2}$, which once intended in the stationary basis $\left(O;\vec{u}_x;\vec{u}_y;\vec{u}_z\right)$, gives :

$$\boxed{\overrightarrow{OM}_1 = \left(-x_1\cos\theta_2\sin\theta_1 + y_1\sin\theta_2\sin\theta_1\right)\vec{u}_x + \left(x_1\cos\theta_2\cos\theta_1 - y_1\sin\theta_2\cos\theta_1\right)\vec{u}_y + \left(x_1\sin\theta_2 + y_1\cos\theta_2\right)\vec{u}_z}$$

for x_1 and y_1 respectively varying from *–a* to *a* and from *0* to *b*

The blade n°2 occupies the space along the axes $\vec{u}_{r_1}$ *and* $\vec{u}_{\theta_2}$. We call *a* the demi-width of blade and *b* its height. Thus, any point M_2 of the blade n°2 has a positionning vector :

$\overrightarrow{OM}_2 = x_2\vec{u}_{r_1} + y_2\vec{u}_{\theta_2}$, which once intended in the stationary basis $\left(O;\vec{u}_x;\vec{u}_y;\vec{u}_z\right)$ gives :

$$\boxed{\overrightarrow{OM}_2 = \left(x_2\cos\theta_1 + y_2\sin\theta_2\sin\theta_1\right)\vec{u}_x + \left(x_2\sin\theta_1 - y_2\sin\theta_2\cos\theta_1\right)\vec{u}_y + \left(y_2\cos\theta_2\right)\vec{u}_z}$$

for x_2 and y_2 respectively varying from *–a* to *a* and – *b* to *0*

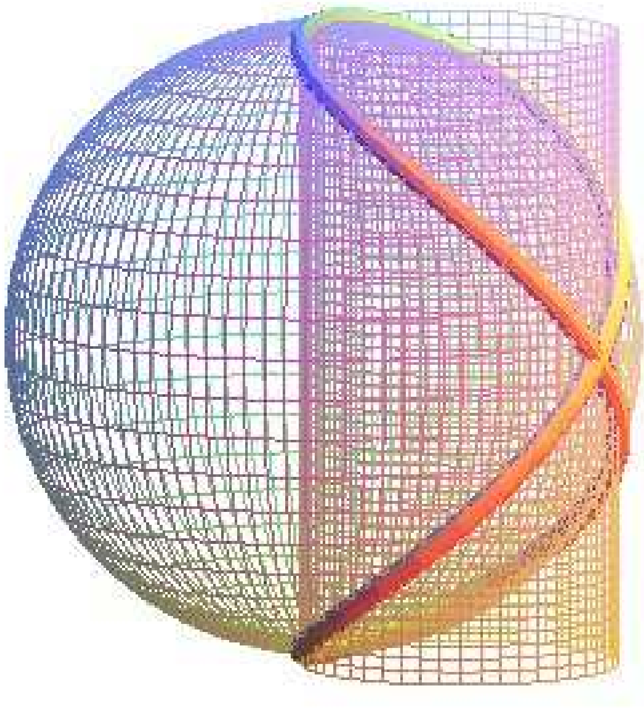
The trajectories of the blades' points are *Viviani's curves* since the ROBIPLAN's kinematics is based on the *equality between the angle of latitude and the one of longitude to constant radius*.

<u>*Some history :*</u>

The trajectories of Viviani were studied in 1692 by the mathematicians ROBERVAL and VIVIANI. They can have several mathematical definitions ; one of them is "*spherical curve of which the angle of latitude is equal to the one of the longitude*". Before the ROBIPLAN, one didn't know any of technological application in the wind world.

With an independant research in 2007, Pascal HA PHAM imagines to make work 2 orthogonal blades facing the wind and joined in one stationary point placed in the middle of their long side. While rotating around this stationary point, the blades periodically face the wind and fade away, never slowing down the motion. Pascal HA PHAM chose a synchronization by strap and conical couple.

Thus, the generated kinematics is *spherical and keep the equality between the latitude and the longitude* of the blades' points : it discovers again *the Viviani's kinematics*.



A Viviani's curve
(<u>source :</u> the *excellent* website
http://www.mathcurve.com)

II.1.d) Instantaneous rotary vector of the blades

It results from the composition of 2 rotations of angles : θ_1 around $\vec{u}_z$ and θ_2 around $\vec{u}_{r_1}$, thus ;

$\boxed{\vec{\Omega} = \frac{d\theta_1}{dt}\vec{u}_z + \frac{d\theta_2}{dt}\vec{u}_{r_1}}$ in projection on the stationary basis : $\boxed{\vec{\Omega} = \frac{d\theta_2}{dt}\cos\theta_1\vec{u}_x + \frac{d\theta_2}{dt}\sin\theta_1\vec{u}_y + \frac{d\theta_1}{dt}\vec{u}_z}$

II.1.e) instantaneous speeds of the blades' points

As O is is fixed point, we have them directly from the vectorial product :

$$\boxed{\vec{v}(M_1) = \vec{\Omega} \wedge \overrightarrow{OM_1}} \text{ and } \boxed{\vec{v}(M_2) = \vec{\Omega} \wedge \overrightarrow{OM_2}}$$

II.2. Relative speeds of the wind in relation to the blades' points

II.2.a) Absolute speed of the wind

The wind is supposed blowing uniformly along the Oy axis with a speed *w* facing the ROBIPLAN.

Therefore, the wind vector before any impact on the blades is : $\boxed{\vec{w} = w\,\vec{u}_y}$

II.2.b) Orthogonal unit vectors facing the wind

For the blade n°1, the orthogonal direction facing the wind is not constant during the motion :

When $\theta_1 \in [0;\pi]$, it is $\vec{N}_1 = -\vec{u}_{z_2} = -\vec{u}_{r_1} = -\cos\theta_1\,\vec{u}_x - \sin\theta_1\,\vec{u}_y$

When $\theta_1 \in [\pi;2\pi]$, it is $\vec{N}_1 = +\vec{u}_{z_2} = +\vec{u}_{r_1} = \cos\theta_1\,\vec{u}_x + \sin\theta_1\,\vec{u}_y$

For the blade n°2, the orthogonal direction facing the wind is constant during the motion

Whatever are θ_1, θ_2 , it is $\vec{N}_2 = -\vec{u}_{r_2} = (\cos\theta_2\sin\theta_1)\vec{u}_x - (\cos\theta_2\cos\theta_1)\vec{u}_y - (\sin\theta_2)\vec{u}_z$

II.2.c) Deviation's modelling of the veins of fluids

The goal is to find the leading vector of the fluid after its deviation for any point of impact on the blades. *Therefore it's necessary to make choices and deliberate simplifications,* ***but including the essential physical phenomena of impact of the fluid on the blades.*** The out-flow is very strongly subsonic: even for conditions of storm at 50 m/s, the number of Mach remained lower than *Ma = 50/340 < 0,15*. To consider the out-flow as incompressible means to make a relative mistake of $100\left(1 - \frac{1}{\sqrt{1+Ma^2}}\right) \simeq 1\%$. Thus the Navier Stokes' equation is valid :

$$\rho\left[\frac{\partial\vec{v}}{\partial t} + \left(\vec{v}.\overrightarrow{grad}\right)(\vec{v})\right] = \vec{f}_v - \overrightarrow{grad}(p) + \eta.\Delta\vec{v}$$

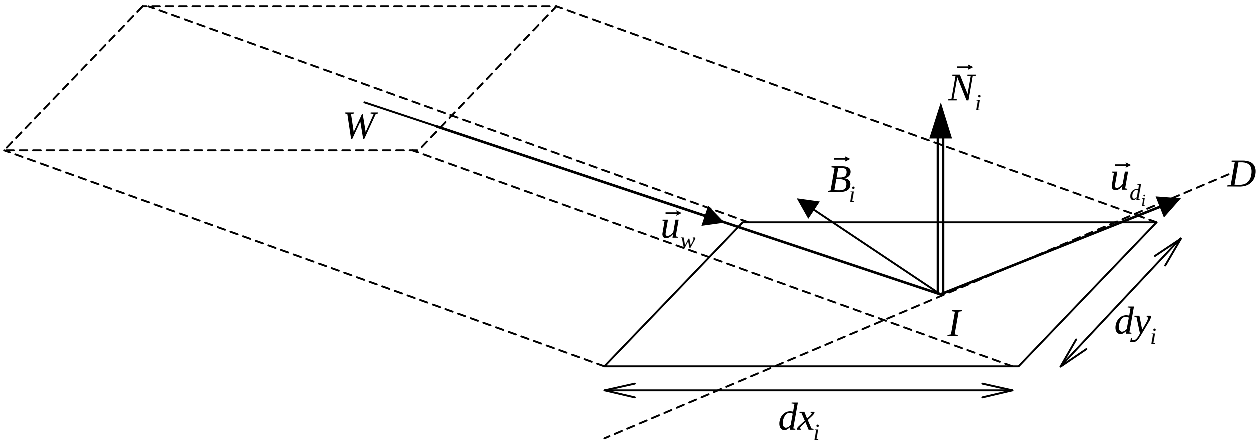
The Reynolds' number $\mathrm{Re} = \frac{\rho_{air} v_{air} L_{blade}}{\eta_{air}} \simeq 5\ 000\ 000$ is high. Moreover, the pressure is quite uniform and the volumic strengths of weight are negligible compared to the strengths of impact. Therefore one can delete all the terms on the right of the equation which becomes : $\rho\left[\frac{\partial\vec{v}}{\partial t} + \left(\vec{v}.\overrightarrow{grad}\right)(\vec{v})\right] \simeq \vec{0}$

Even in temporal stationary situation, the previous equation remained non linear. It is not here about to finely foresee the deviations of the veins of fluids (it would require a CFD code (*Computing Fluid Dynamics*) very heavy in time of computing, in particular if one wants to simulate the motion of the blades, the detachment of the fluid and the turbulences). **On the contrary, one tries to find an intrinsic vectorial model** (independent of all system of coordinates) **of deviation**.

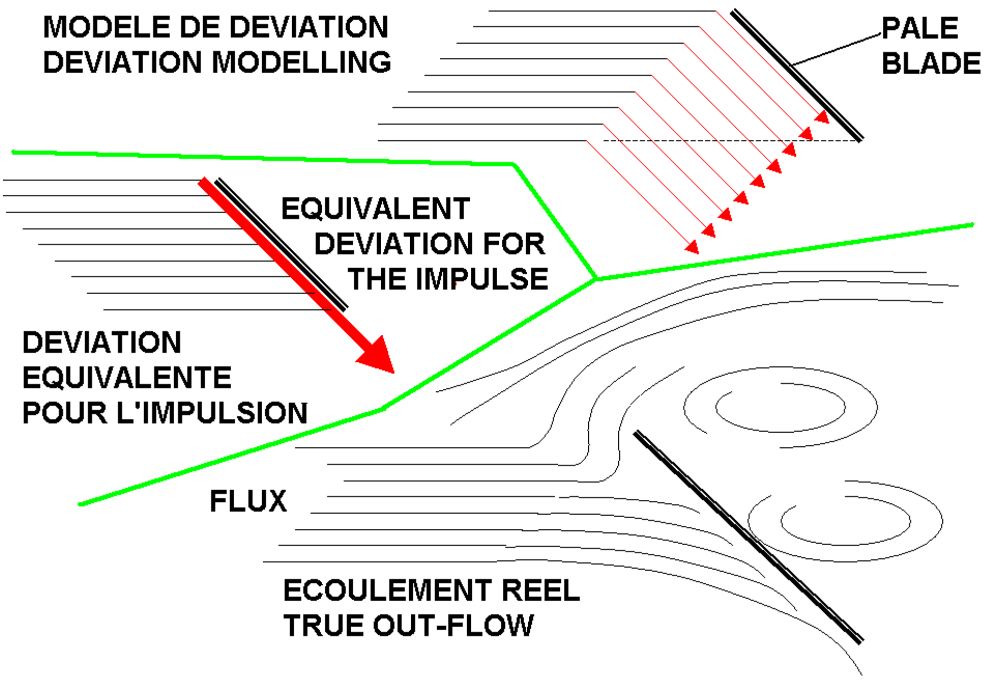
Thus, in the schema below :

1. The incidental fluid's vein is WI
2. The deviated fluid's vein is est ID
3. The orthogonal local unit direction to the blade is $\vec{N}_i$ as defined in II.2.b with *i* taking the values 1 or 2
4. One considers an elementary surface centered on I of blade $dx_i dy_i$: $\left(x_i ; y_i\right)$ are the coordinates of blades' points as defined on II.1.b

The choice is coming from the following idea (**which is a necessary approximation**) ;



Wind is coming on the blade n°i along the WI direction and **its inertia entails a least possible change of direction : one proposes therefore that the going away vein of fluid (ID) is in the plan of impact defined by** $\left(\overrightarrow{IW} ; \vec{N}_i\right)$ (natural extension of wind if one were looking at the blade facing its orthogonal direction).



Thus a unit vector $\vec{B}_i$ bi-orthogonal both to $\vec{N}_i$ and $\overrightarrow{IW}$ is defined :

$$\boxed{\vec{B}_i = \frac{\vec{N}_i \wedge \overrightarrow{WI}}{\left\|\vec{N}_i \wedge \overrightarrow{WI}\right\|}}$$

Then the unit directing vector of the deviated flux is obtained by : $\boxed{\vec{u}_{d_i} = \vec{B}_i \wedge \vec{N}_i}$

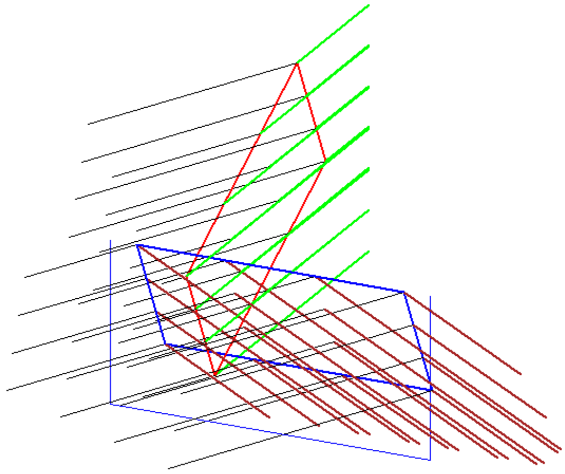
Finally : $$\boxed{\vec{u}_{d_i} = \frac{\vec{N}_i \wedge \overrightarrow{WI}}{\left\|\vec{N}_i \wedge \overrightarrow{WI}\right\|} \wedge \vec{N}_i}$$

When the wind is coming exactly facing a blade, an arbitrary direction has to be imposed, because in this case, $\vec{N}_i \wedge \overrightarrow{WI} = \vec{0}$: one will choose a deviated flux centrifuge along Ox or Oz.

$$\boxed{\vec{N}_i \wedge \overrightarrow{WI} = \vec{0} \Rightarrow \vec{u}_{d_i} = \vec{u}_z or\, \vec{u}_x}$$

The whole of the kinematic modelling described before has been programmed on a computing software and the 3D-rendering gives the picture at the opposite.

thin black features :
incidental veins of fluid on the blades (facing the ROBIPLAN)
strong green features :
deviated veins of fluid by the red blade (n°1)
strong brown features :
deviated veins of fluid by the blue blade (n°2)



Animations are available on the following urls :

http://www.econologie.info/share/partager/12316848546AX4XU.gif

Published in the ROBIPLAN's topic ;

http://www.econologie.com/forums/post111526.html#111526

II.2.d) Relative speed of the wind in relation to the blades' points

A particularity of the ROBIPLAN stays in the fact that *each point of blade has its own speed* : thus, ***every point of blade produces a different impact resulting from an unique relative speed*** *between this point of impact I and the incidental local wind* $\vec{v}_{RI}$. One has thus :

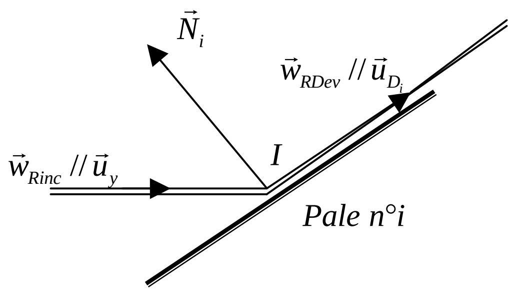
$$\boxed{\vec{v}_{RI} = \vec{w} - \vec{v}_I = \vec{w} - \vec{\Omega} \wedge \overrightarrow{OI}}$$

One supposes <u>a stationary and incompressible local out-flow</u>, what implies that ***in the referential of the blade n°i, the norm of the speed is unaltered between the incidental wind and deviated wind (only the direction changes)***. So :

The 'incidental relative wind' vector in relation to the blade n°i is : $\boxed{\vec{w}_{Rinc} = \|\vec{v}_{RI}\| \vec{u}_y = \|\vec{w} - \vec{\Omega} \wedge \overrightarrow{OI}\| \vec{u}_y}$

The 'deviated relative wind' vector in relation to the blade n°i is : $\boxed{\vec{w}_{RDev} = \|\vec{v}_{RI}\| \vec{u}_{D_i} = \|\vec{w} - \vec{\Omega} \wedge \overrightarrow{OI}\| \vec{u}_{D_i}}$

These 2 vectors are key-elements to calculate the strength produced on the blades by the deviation of the wind, then the power resulting from it.



II.3. Extracted power

II.3.a) Calculation of the induced strength by the deviation of the out-flow

One considers the vectorial infinitesimal element of surface $dx_i dy_i \vec{N}_i$ of the blade n°i centered on *I*.

Let call ρ the volumic mass of air (about 1,3 kg/m^3)

This blade's element is receiving a massic debit of fluid $\delta D_m = \rho \, dx_i dy_i \left| \vec{w} . \vec{N}_i \right|$ in kg/sec

Locally, the infinitesimal element of blade is a referential *R* non Galilean (because rotating around the stationary referential) . In this referential, the out-flow is supposed stationary and incompressible.
Therefore, the fundamental relation of the dynamics applied to the mass of fluid $d^2 m = \delta D_m dt$ flowing out in an incompressible and stationary way on the blade's referential gives :

$$\frac{d\vec{p}_R}{dt} = \delta^2\vec{F}_{blade\to fluid} + \delta^2\vec{F}_{inertia} \Leftrightarrow \delta D_m dt\,\frac{\left(\vec{w}_{RDev} - \vec{w}_{Rinc}\right)}{dt} = \delta^2\vec{F}_{blade\to fluid} + \delta^2\vec{F}_{inertia}$$

The strengths of inertia in the blade's referential are :

- the engaged strengths of inertia : $\delta^2\vec{F}_{ie} = -d^2m\,\left(\frac{d\vec{\Omega}}{dt}\wedge\overrightarrow{OM} + \vec{\Omega}\wedge\left(\vec{\Omega}\wedge\overrightarrow{OM}\right)\right)$
- the Coriolis' strength of inertia : $\delta^2\vec{F}_{ic} = -2\;d^2m\,\vec{\Omega}\wedge\vec{v}_{RI}$

These 2 strengths are negligible compared to the impacting strength because it makes itself on a time nearly 0 ; the demonstration in order of size gives at an almost constant angular velocity :

On the one hand $\left\|\delta^2\vec{F}_{ie}\right\| = d^2m\;\left(0 + r\vec{\Omega}^2\right)$ and on the other hand $\left\|\delta^2\vec{F}_{ic}\right\| = 2\;d^2m\;\Omega\;v_{RI}$

Otherwise, so that most of the points of blades have an absolute speed equals to the half of the one of the incidental wind, and that no point of blade goes as quickly as the wind (to have the best output),

We need : $\boxed{\omega = \frac{w}{a+b}}$

Thus $\frac{\left\|\delta^2\vec{F}_{ie}\right\|}{\left\|\frac{d\vec{p}_R}{dt}\right\|} \simeq \frac{d^2m\;r\;\omega^2}{d^2m\frac{\left\|\vec{w}_{RDev}-\vec{w}_{Rinc}\right\|}{dt}} \simeq \frac{dt\;r\;\omega^2}{w} \simeq \frac{dt\;r\;w}{a+b}$ <<1 because dt is about 0

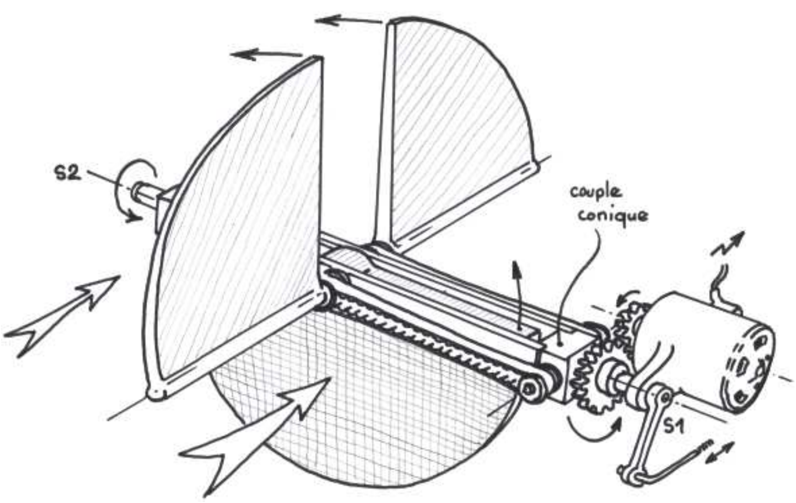
(almost instantaneous impact on I)

Thus $\frac{\left\|\delta^2\vec{F}_{ic}\right\|}{\left\|\frac{d\vec{p}_R}{dt}\right\|} \simeq \frac{2d^2m\;\omega\left\|\vec{v}_{RI}\right\|}{d^2m\frac{\left\|\vec{w}_{RDev}-\vec{w}_{Rinc}\right\|}{dt}} \simeq 2\frac{dt\;\omega\;w}{w} \simeq 2\frac{dt\;\omega}{a+b}$ <<1 because dt is about 0

One deducts from it : $\boxed{\delta D_m dt\,\frac{\left(\vec{w}_{RDev} - \vec{w}_{Rinc}\right)}{dt} \simeq \delta^2\vec{F}_{blade\to fluid}}$

And with the principle of the reciprocal actions : $\delta^2\vec{F}_{fluid\to blade} = -\delta^2\vec{F}_{blade\to fluid}$

either $\boxed{\delta^2\vec{F}_{fluid\to blade} = \delta D_m\left(\vec{w}_{Rinc} - \vec{w}_{RDev}\right) = \rho\;dx_i dy_i\left|\vec{w}.\vec{N}_i\right|\left(\vec{w}_{Rinc} - \vec{w}_{RDev}\right)}$



A variant of ROBIPLAN

II.3.b) Power on the blade's element

$$\boxed{\delta^2 P_i = \delta^2 F_{fluide \to pale}.\vec{v}_I = \rho \, dx_i dy_i \left|\vec{w}.\vec{N}_i\right| \left(\vec{w}_{RDev} - \vec{w}_{Rinc}\right).\left(\vec{\Omega} \wedge \overrightarrow{OI}\right)}$$

II.3.c) Total power

We have to add the powers collected by every blade : $P_{tot} = \iint_{I \in Blade1} \delta^2 P_1 + \iint_{I \in Blade2} \delta^2 P_2$

$$\boxed{P_{tot} = \iint_{I \in Blade1} \rho \, dx_1 dy_1 \left|\vec{w}.\vec{N}_1\right| \left(\vec{w}_{RDev} - \vec{w}_{Rinc}\right).\left(\vec{\Omega} \wedge \overrightarrow{OI}\right) + \iint_{I \in Blade2} \rho \, dx_2 dy_2 \left|\vec{w}.\vec{N}_2\right| \left(\vec{w}_{RDev} - \vec{w}_{Rinc}\right).\left(\vec{\Omega} \wedge \overrightarrow{OI}\right)}$$

II.4. ROBIPLAN's mechanical torque

The power of the blades is given to a first rotary shaft, dragging a strap or a chain, which transmits the motion to a conical gear. Let call η_{strap} et η_{gear} the mechanical outputs of the strap and the gear.

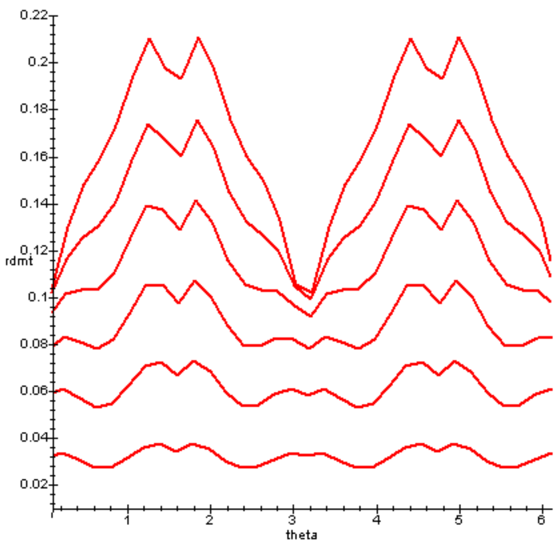
The ROBIPLAN's torque C_z around the axis Oz respects : $\eta_{strap}\eta_{gear}P_{tot} = C_z \omega$

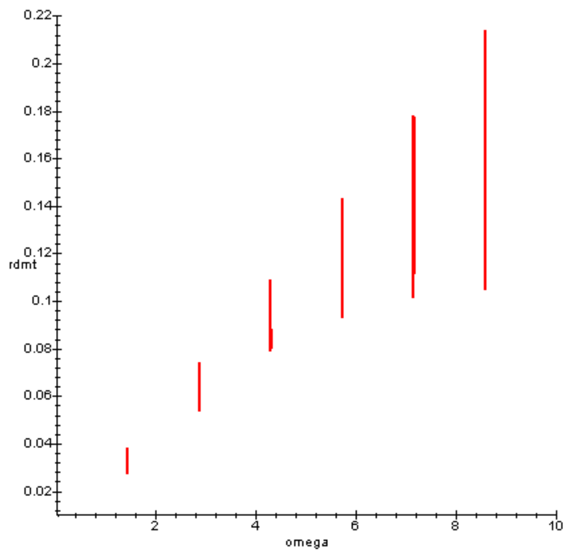
$$\text{Soit } \boxed{C_z = \frac{\eta_{strap}\eta_{gear}P_{tot}}{\omega}}$$

III. Results from the computings

The results below are showing maps of the wind output in relation to the angular position θ (rad) of the ROBIPLAN and of the angular velocity ω(rad/s). The instantaneous power recovered by the turbine only depends on these 2 parameters. These outputs don't include η_{strap} η_{gear}

III.1. Only one ROBIPLAN wind turbine

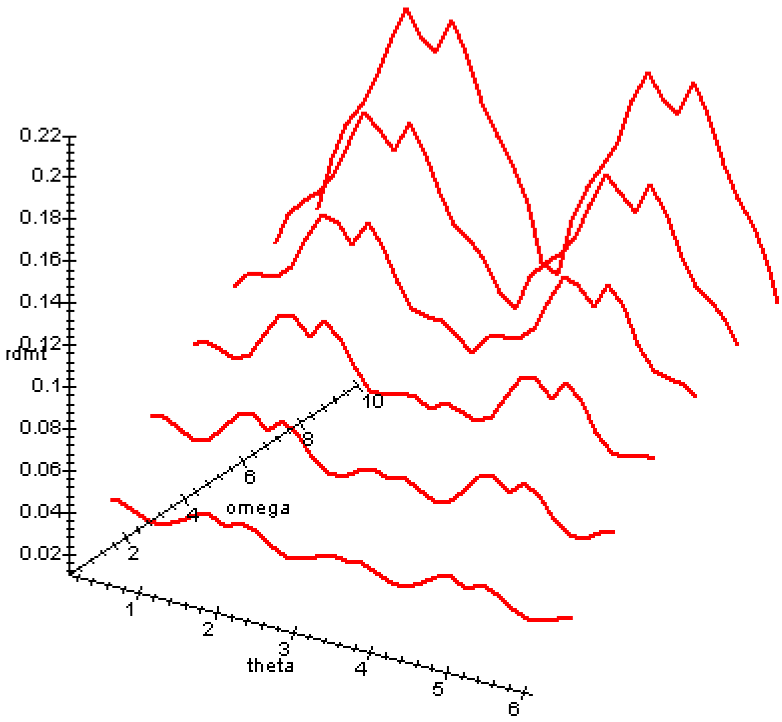




The graphics above and below are coming from a simulation with the following parameters :

- Volumic mass of the air : at 10°C , $\rho_{air} = 1.25 \; kg/m^3$
- incidental wind speed $w = 20 \; m/s$
- Half-Span of the blade : $a = b = 1$ m ;
- Kinetic incidental power : 1745 W

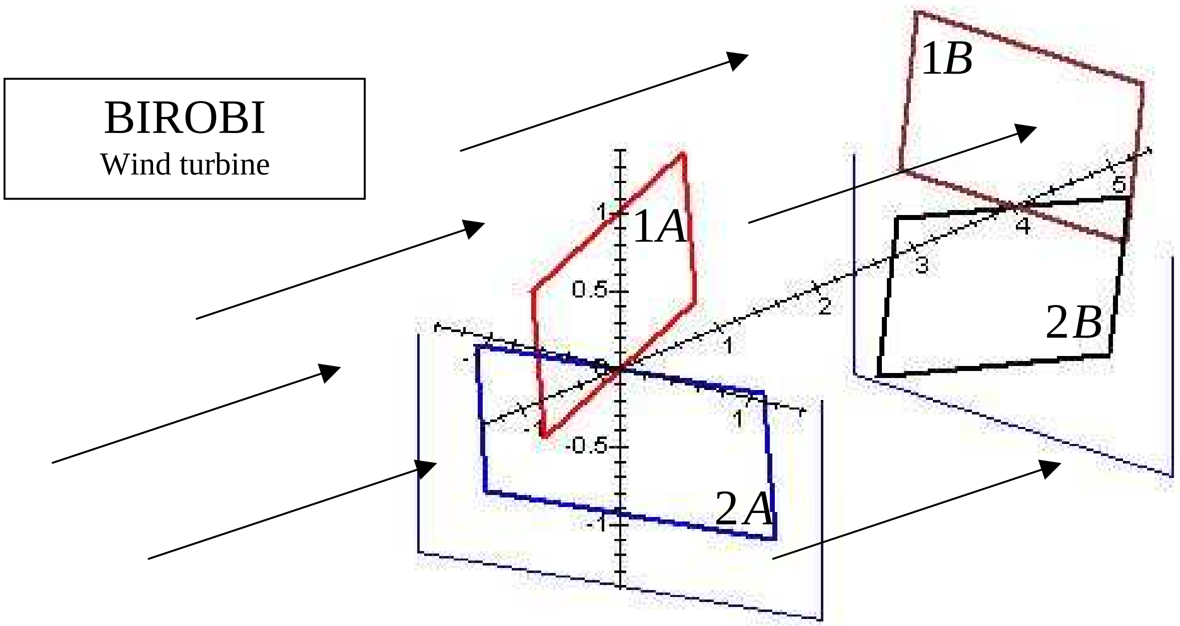
The essential key-points of the ROBIPLAN's behaviour are :



- output proportionnal to the angular velocity between 0 and $\omega = \dfrac{w}{a+b}$
- then linear decrease, because from this speed, the extremites of blades become faster than the wind and are brewing it instead of being knocked by it.
- The positions 0, π and 2π are the bottom output positions : the blades are facing the wind, but its effect is recovered through the strap and the conical gearing.
- The positions π/2 and 3π/2 are the top output positions : the blades are facing the wind, and its effect makes directly turn the ROBIPLAN's structure.
- The output is never zero (there is always a powering strengths on the blades)
- **The average output at the optimal angular velocity** $\omega = \dfrac{w}{a+b}$ **is 19,3% (around 20%)**
- **Thus, for this output, the recovered power from the wind is 336 W ;** but while assuming 15% of global losses due to the strap and the conical gearing : 286 W .

III.2. Two ROBIPLAN wind turbines

The ROBIPLAN wind turbines must be used ideally by couple (version "BIROBI") so that the non deviated wind by the first ROBIPLAN knocks the second and vice versa.



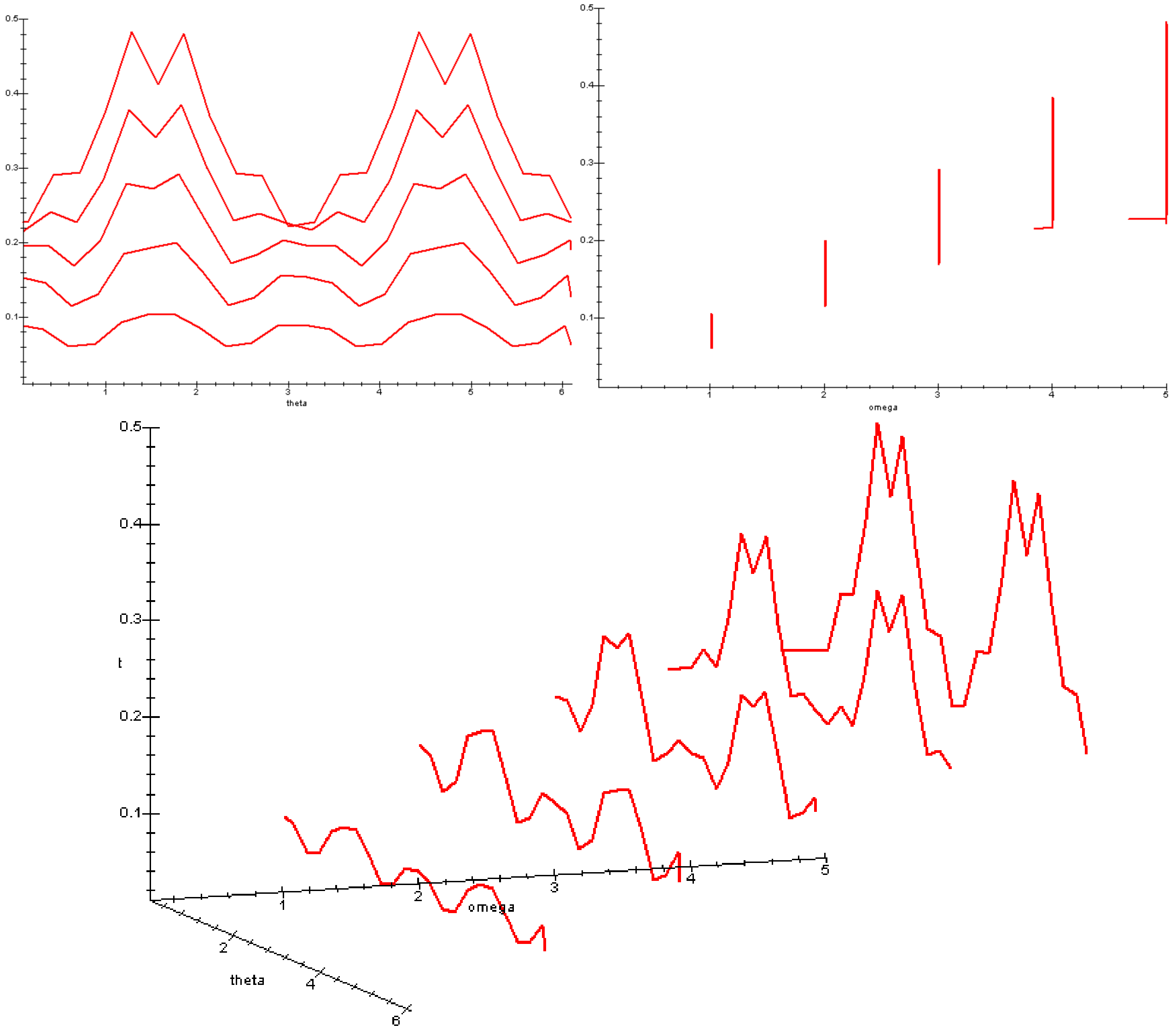
BIROBI's animations are available here : http://www.thewindpower.net/forum/topic851-30.html

However in some positions, the first ROBIPLAN shades the second meaningfully. Thus, the output of a BIROBI wind turbines in relation to a simple MONOROBI doesn't double, but increases very meaningfully. *This shadiness has a period 2 times more quick than the one of the angular velocity and is in opposition of phase between the blades 1 and 2.* The functions of shadiness chosen for the simulations are thus with the following conventions (see previous fig.) :

- The Robiplan **firstly facing the wind is marked as A** with its blade 1 and its blade 2 as defined at II.1.a and which supply the respective powers P_{1A} and P_{2A}
- The Robiplan **secondly facing the wind is marked B** with its blade 1 and its blade 2 as defined at II.1.a and which supply the respective powers P_{1B} and P_{2B}.
- The powers P_{1A} and P_{2A} are the computed powers in MonoRobi's situations.
- The powers P_{1B} and P_{2B} are therefore :
    - o $P_{1B} = P_{2A}\, O_{1A\to 1B}$ where $O_{1A\to 1B} = (1+\cos 2\omega t)/2$ is the shading function of the blade 1B by the blade 1A
    - o $P_{2B} = P_{1A}\, O_{2A\to 2B}$ where $O_{2A\to 2B} = (1-\cos 2\omega t)/2$ is the shading function of the blade 2B by the blade 2A

The results below are computed from an incidental wind speed at 10 m/s

BIROBI's outputs



Thus, one foresees that the BIROBI reaches an average output of 35%, the A wind turbine providing 20%, and the B wind turbine 15%**, this whatever is the *w* wind's speed** under the condition to put the ROBIPLAN on their optimal angular velocity $\omega = w/(a+b)$

III.3. Comparison to current technologies of usual wind turbines

III.3.a) relative to multi-blades wind turbines with horizontal axis

The wind output $C_{PR} = P_{eolienne} / P_{cin}$ is defined as the ratio between the wind power *on* the turbine and the kinetic incidental wind power (see page 1 and III.3.b). This output varies with the angular velocity of the turbine because the power is the product of a strength by a speed on each element of blade, therefore :

- if the blade is fix, the strength is maximal, but speed is zero
- if the blade is as quick as the wind, speed is maximal, but strength is zero
- **the research of a compromise on the blades' speed gives the optimum to recover**.

For the wind turbines with horizontal axis, one often defines *the standard speed of rotation :*

$$\boxed{\lambda = \frac{R\Omega}{V}}$$

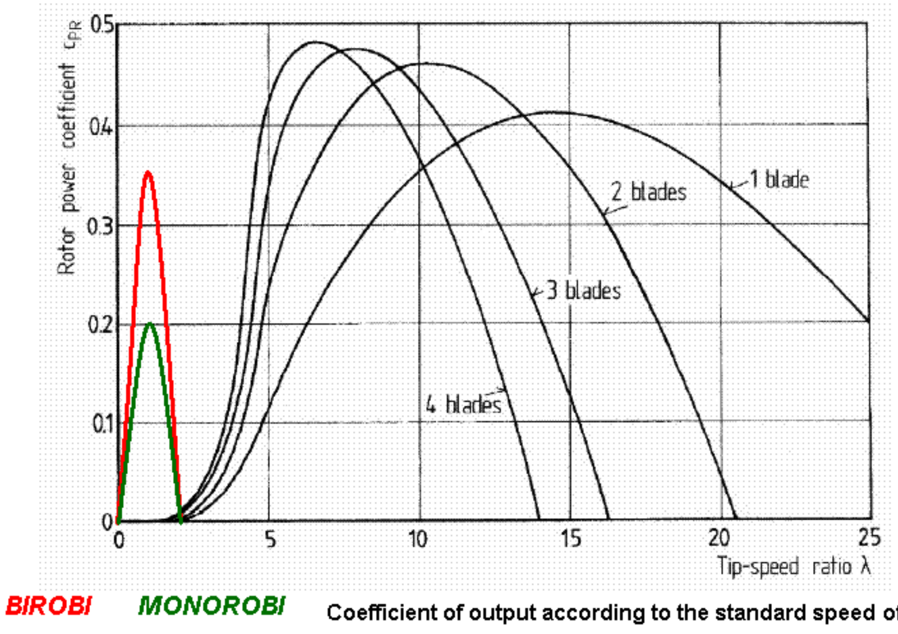
where : R is the radius of the blade,
Ω the angular velocity of the shaft
V the absolute speed of the incidental wind.

This standard speed is linked to the speed of the blades' extremities, as well as instantaneous and average. One will define for the *ROBIPLAN the same idea* ***on the maximum speed of the fastest corner of a blade*** :

$$\boxed{\lambda \simeq \frac{(a+b)\,\omega}{V}}$$

where : a is the half-length of the blades
b is the width of a blade,
ω is the angular velocity of the ROBIPLAN
V is the absolute speed of the incidental wind.

Assuming these definitions, the MONO and BIROBIPLAN take place on the following picture :



Coefficient of output according to the standard speed of rotation

Coefficient aérodynamique de puissance en fonction de la vitesse de rotation normalisée λ

The optimum of ROBIPLAN corresponds to $\lambda = 1 \Leftrightarrow (a+b)\,\omega = V$ because it allows the incidental flux to knock a maximal surface appreciably at the half of its incidental speed. When $\lambda = 2$, there is no power because the center of blades is as quick as the incidental wind.

One notices that **the optimal output of ROBIPLAN is a litle smaller than the one of multi-blades, but it is obtained for standard speed a lot smaller**, advantaging its **ability to convert very fast wind, thus very powerful**. We will speak again about it in III.4.d.

III.3.b) relative to 'american' pumping, Savonius & Darreius turbines, and wind mills

From the following notations :

- ρ the volumic mass of the fluid
- S the swept area by the turbine
- V the absolute speed of the incidental wind
- P_R the recovered power on the shaft

One defines the wind output C_{PR} with $\boxed{P_R = C_{PR}\dfrac{\rho S V^3}{2}}$

One defines also the torque coefficient C_{QR} with the torque M of the turbine by $\boxed{M = C_{QR}\dfrac{\rho S V^2}{2}R}$

Definition which will be so adapted in the case of the ROBIPLAN : $\boxed{M = C_{QR}\dfrac{\rho S V^2}{2}a \simeq C_{QR}\dfrac{\rho S V^2}{2}b}$

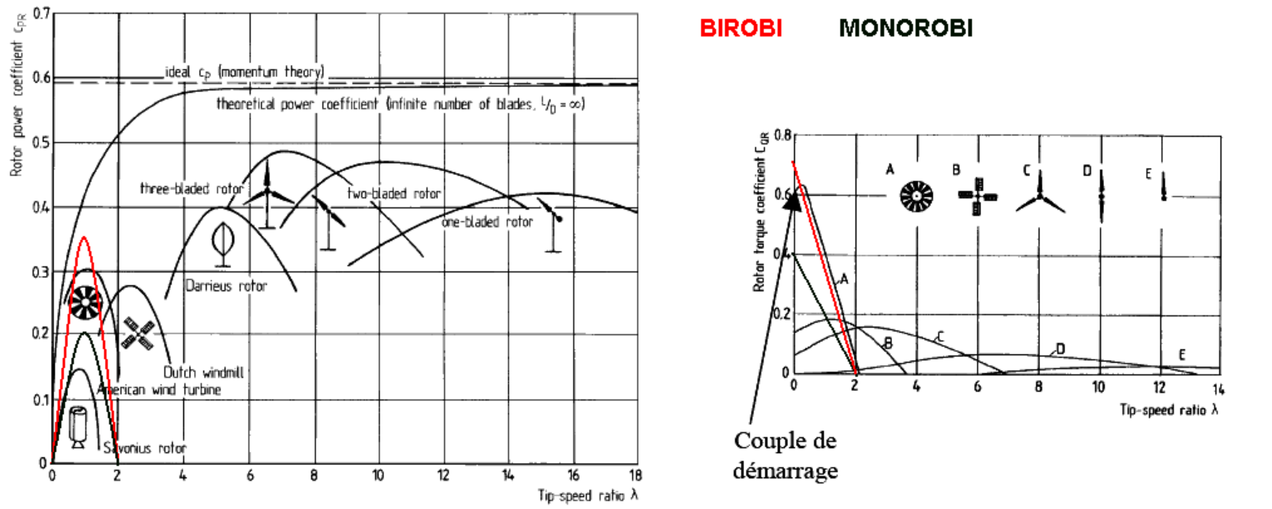
The C_{PR} coefficient reflects the *energetic quality of a turbine* and *the* C_{QR} *coefficient is drawing its running range :*

- if C_{QR} is *weak, the engine finds the power in high angular velocity*
- if C_{QR} is *strong, the engine finds the power in low angular velocity*
- C_{QR} measures also *the starting ability* of the turbine.

As $\boxed{P_R = M\Omega}$, one can demonstrates that $\boxed{C_{PR} = \lambda C_{QR}}$

For a ROBIPLAN, $C_{PR} \simeq C_{PR}^{\max}\lambda(2-\lambda)$, thus $\boxed{C_{QR} = (2-\lambda)C_{PR}^{\max}}$

With $C_{PR}^{\max} = 20\%$ in MONOROBI and $C_{PR}^{\max} = 35\%$ in BIROBI (Cf. III.1. et III.2.)



Coefficients de puissance et de couple en fonction de la vitesse normalisée λ pour différents types de turbines

Power and torque outputs' coefficient relative to the standard speed of rotation for several technologies of wind turbines

Therefore, the ROBIPLAN wind turbines are clearly near the 'american' pumping turbines, logically, because they're running on the wind's impact. **The ROBIPLAN turbines have the best torque coefficient at the slowest speed, what means :**

1. **that they spontaneously start at very low wind speed** (1 m/s already experimentally seen on Pascal HA PHAM's prototypes),
2. **that they don't need to rotate as quickly as the other wind turbines** to extract the same power from the wind (approximately 7 times slower than tri-blades).

III.4. Yearly productions

III.4.a) Statistics of wind

One generally agree with the Weibull's density of probability $f(V)$ for the wind speed :

$$\boxed{f(V)=\frac{k}{V}\left(\frac{V}{c}\right)^{k}\exp\left(-\left(\frac{V}{c}\right)^{k}\right)}$$ where :

- k is a shaping parameter changing the repartition of the speeds
- c is parameter launching the power on the high (c high) or low speed (c small)

So the probability dp to find a wind speed V staying between V et $V+dV$ is :

$$dp = f(V)\,dV$$

The average wind speed is givent by $V_{avg}=\int_{V=0}^{\infty} f(V)VdV=\int_{V=0}^{\infty} k\left(\frac{V}{c}\right)^{k}\exp\left(-\left(\frac{V}{c}\right)^{k}\right)dV$

The values on windy sites show that in general, $k = 2$ well describes the wind speeds.
The c parameter depends on the site and its altitude, and when $k = 2$, the average wind speed verifies :

$$\boxed{V_{avg}=0.88c}$$

III.4.b) Incidental kinetic power

$$\boxed{P_{cin}=D_m\frac{\rho V^2}{2}=\frac{\rho SV^3}{2}}$$ with $D_m=\rho SV$ the massic debit of fluid on the swept area.

III.4.c) Outputs of the turbines

For the tri-blades turbines , the output depends on the speed :

- Phase I : if $V<V_D$, then the output is zero because the engine doesn't start due to its internal frictions : $C_{PR}=0$
- Phase II : if $V_D<V<V_n$, (absolute wind speeds between the start and the nominal run), then the output, as a first favorable approximation, is the optimum : $C_{PR}=0.48$
- Phase III : if, $V_n<V<V_M$ (absolute wind speeds between the nominal and the maximal run), the turbine is forced to change the pitch of its blades to limit the flexions of it. In practice, it limits the power to the previous nominal value for an output $C_{PR}=0.48\left(\frac{V_n}{V}\right)^3$
- Phase IV : if $V_M<V$, (absolute wind speeds higher than the maximum allowed), then the output is zero again because the turbine has to be stopped for security reasons (the centifugal strength is likely to break the blades) : $C_{PR}=0$

The following schema summarizes thes tri-blades behaviours ont the blackcurve.

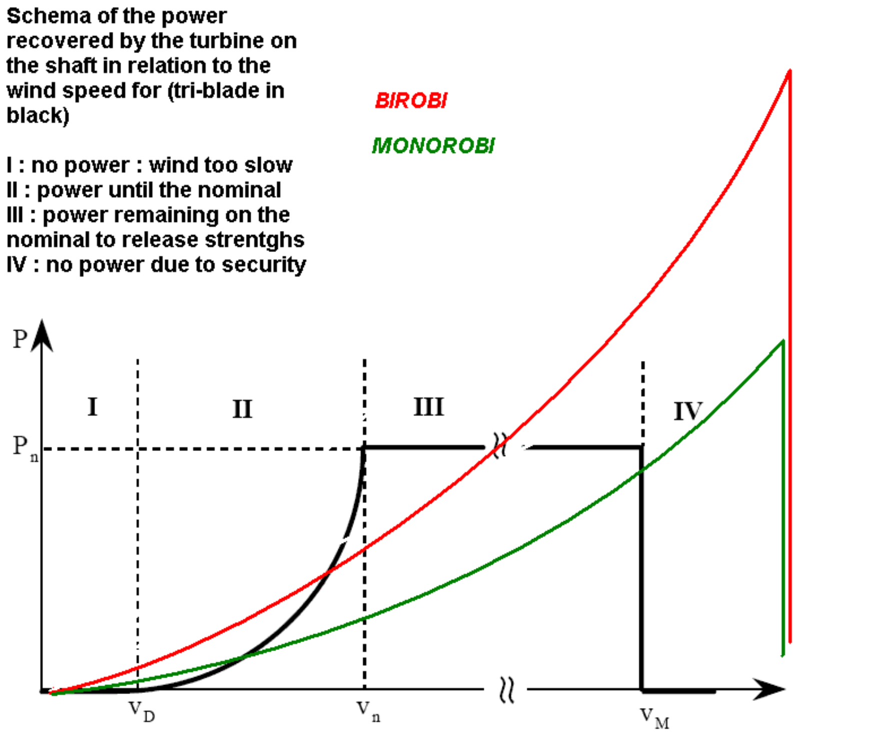


Diagramme de la puissance utile sur l'arbre en fonction de la vitesse du vent

Par rapport aux tripales, les éoliennes ROBIPLAN démarrent plus vite, n'ont pas de phase III puisque leur pas est fixe, et tolèrent une vitesse maximale de vent plus grandes. Ainsi, leur puissance croît sensiblement comme le cube de la vitesse absolue du vent incident. Elles ont aussi un rendement constant sur la phase II : 20% pour le MONOROBI, et 35% pour le BIROBI

Pour ROBIPLAN, le rendement dépend donc aussi de la vitesse :

- Phase I : if $V < V_D$, then the output is zero because the engine doesn't start due to its internal frictions : $C_{PR} = 0$
- Phase II : if $V_D < V < V_M$, (absolute wind speeds between the start and the maximum run), then the output, as a first favorable approximation, is the optimum : $C_{PR} = 0.35$
- Phase III : absent.
- Phase IV : if $V_M < V$, (absolute wind speeds higher than the maximum allowed), then the output is zero again because the turbine has to be stopped for security reasons (the centifugal strength is likely to break the blades) : $C_{PR} = 0$

Usual values

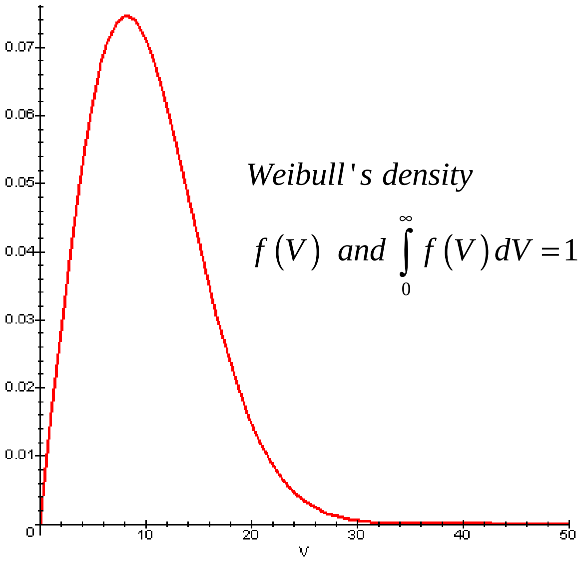
	Tri-blades wind turbines	ROBIPLAN
Starting wind speed V_D	5 m/s	1 m/s
Nominal wind speed V_n	16 m/s	//
Maximal wind speed V_M	28 m/s	More than 50 m/s **
Top output $C_{PR}^{\max}$ for phase II*	0.48	0.35 BIROBI 0.20 MONOROBI

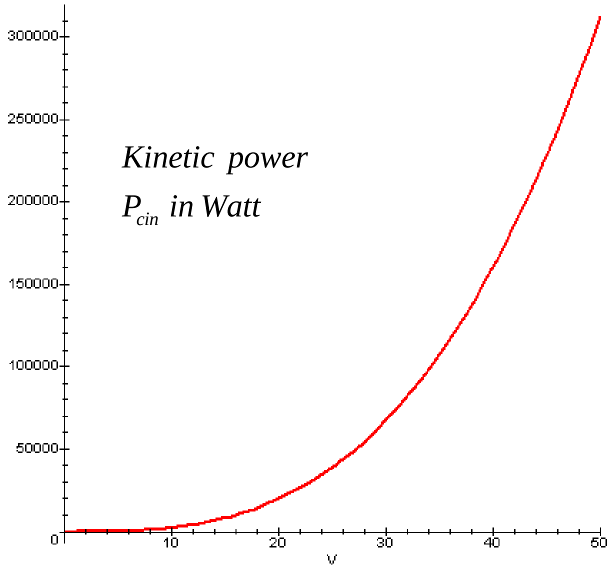
* at the optimal angular velocity (electric regulation like MPT (maximum power tracking))
** as it turns about 6 times slower for the same incidental power

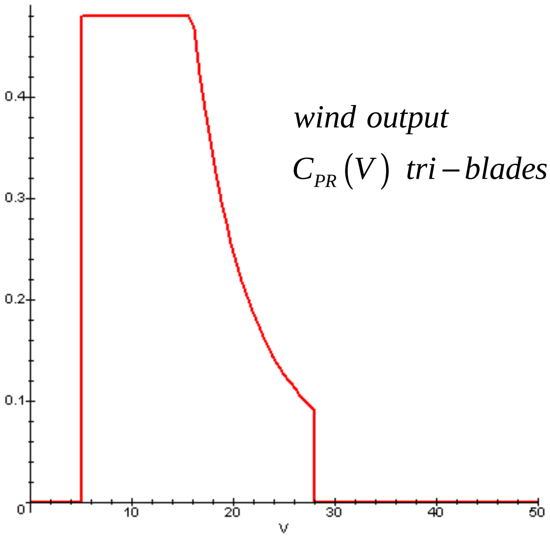
The following simulations and calculations keep this parameters <u>for a BIROBI wind turbine</u>.

III.4.d) Yearly production

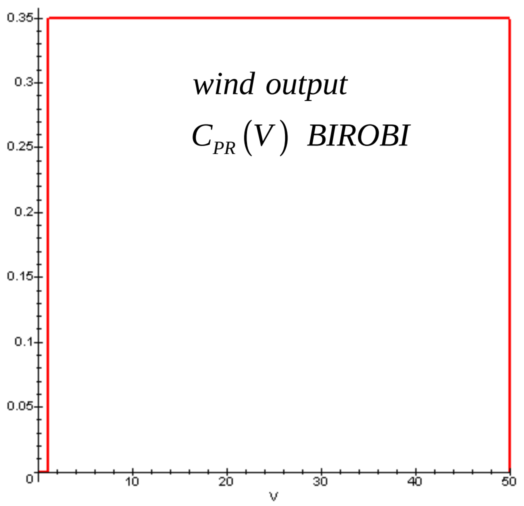
It results from the product of the four following curves :

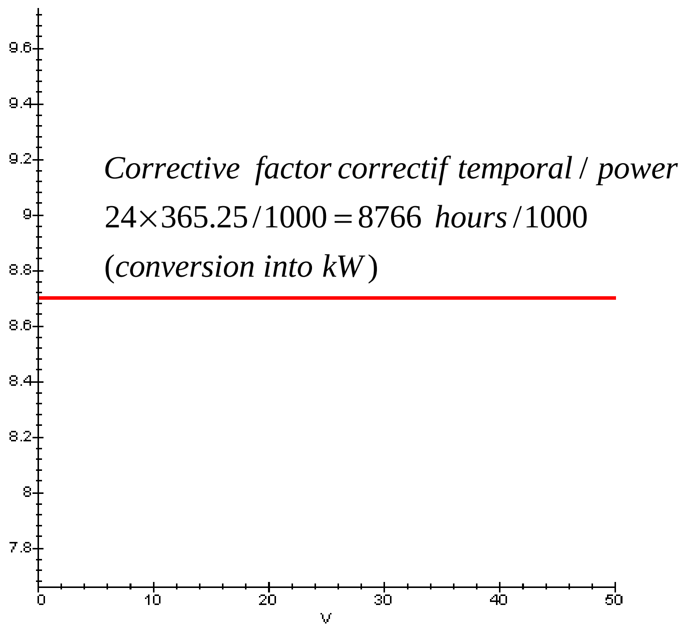






OR

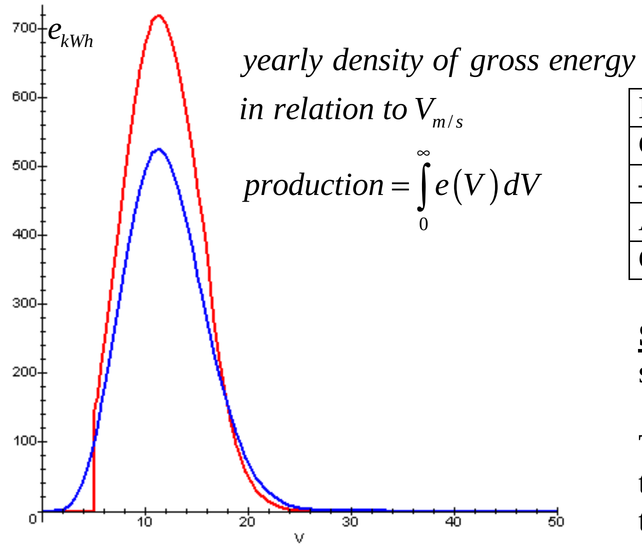




Then one gets the graphic below of which thearea l’aire sous les courbes représente l’énergie annuelle produites en kWh : en rouge l’éolienne tripale, en bleu le BIROBIPLAN:

According to 3 scenarios of yearly average wind speed :

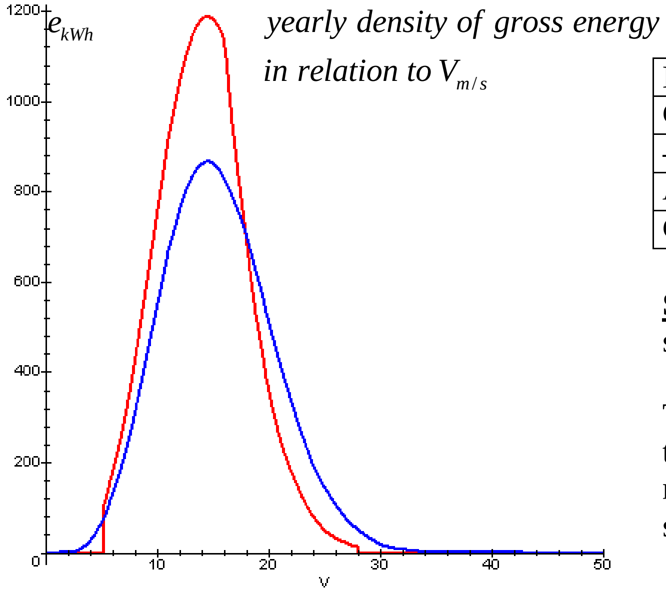
	7	9	and	11 m/s
with the respective values of *c* :	7,95	10,22	and	12.5 m/s



Hyp 0.06 €/kWh	BIROBI	Tri-blades
Gross production kWh	5 123	6 560
– meca/elec losses 15%	4 355	5 576
Average power W	497	636
Gains €	261	394

<u>Scenario 7 m/s</u> of yearly average wind, 4 m² of swept area.

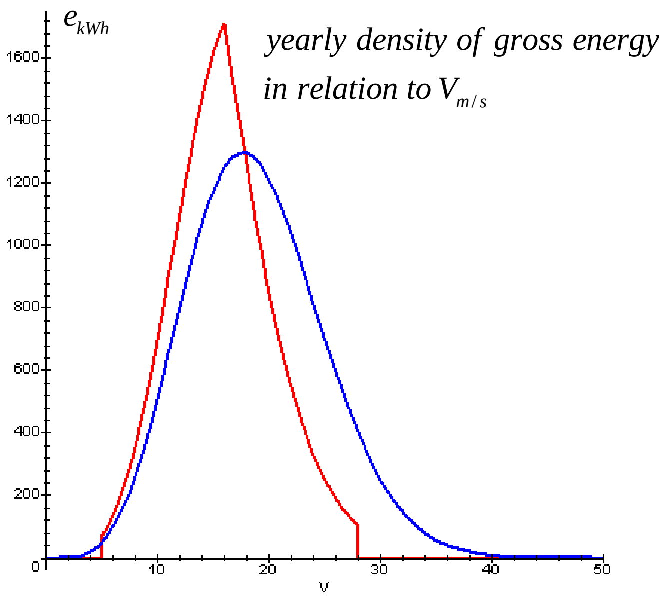
The BIROBI reaches 80% of the performance of a tri-blades. Although it starts earlier, the tri-blades takes the advantage on the moderate speeds.



Hyp 0.06 €/kWh	BIROBI	Tri-blades
Gross production kWh	10 884	12 123
– meca/elec losses 15%	9 251	10 304
Average power W	1 055	1 175
Gains €	555	618

<u>Scenario 9 m/s</u> of yearly average wind, 4 m² of swept area.

The BIROBI reaches 90% of the performance of a tri-blades. It starts earlier, remains back at the moderate speeds, but takes the advantage for the strong winds.



Hyp 0.06 €/kWh	BIROBI	Tri-blades
Gross production kWh	19 915	17 368
– meca/elec losses 15%	16 927	14 763
Average power W	1 931	1 684
Gains €	1 016	886

<u>Scenario 11 m/s</u> of yearly average wind, 4 m² of swept area.

The BIROBI reaches 115% of the performance of a tri-blades. It starts earlier, remain back at the moderate speeds, but finds the essential of its performance for the very strong winds, where the tripale is restrained, or even stopped.

This tendency intensifis with more and more windy sites in altitude or crest.

Regarding the computations, the yearly average speed where BIROBI and tri-blades are equivalent is around 10 m/s

CONCLUSION

Forecasts of simulations

- The *typical output of a single ROBIPLAN wind turbine is 20%*
- The *typical output of a double ROBIPLAN wind turbine* managed and turning as shown in this survey (BIROBI) is *35%*
- The optimal output is obtained when $\omega = \frac{w}{a+b}$. The output *decreases in a quite linear way* around this angular velocity.
- Under the condition to pilot ω according to the absolute wind speed *w* regarding this previous formula, *the output remains identical whatever the wind speeds are because the ROBIPLAN is running only in impact*.

Orientation facing the wind

The ROBIPLAN turbine must stand facing wind. According to the Inventor Pascal HA PHAM, this adjustment is greatly facilitated by a central piloting which acts on the angular position of the fixed central gearing of the conical gearing couple ; it encourages the reactivity of the turbine to automatically follow-up when wind imposes frequent changes of direction.

Pursuit of the scientific research on the ROBIPLAN

As claimed in introduction, these forecasts would deserve to be simulated numerically by CFD codes, (computing fluid dynamics) but especially, the ROBIPLAN is an emergent and promising technology of which *the behaviors and performances would have quickly to be confirm in bellows*.

Regardless of these considerations, it doesn't exist currently – in relation to the state of the known art – no other technology having the features of the ROBIPLAN ; the mechanics of the fluids is complex, and one lacks experimental data such new concepts, but which have real potential.

The energizing asset of the ROBIPLAN

Although the output of a ROBIPLAN, especially if it is single, is lower than the optimum of a tri-blades helix, *its output clearly keeps itself at all wind speeds because the Robiplan starts better at the weak winds and is not non limited by the strong winds* : therefore as the wind speed is very uncertain, *it allows to extract more yearly average energy, especially for greatly windy sites.*

The ROBIPLAN wind turbines : domestic or industrial ?

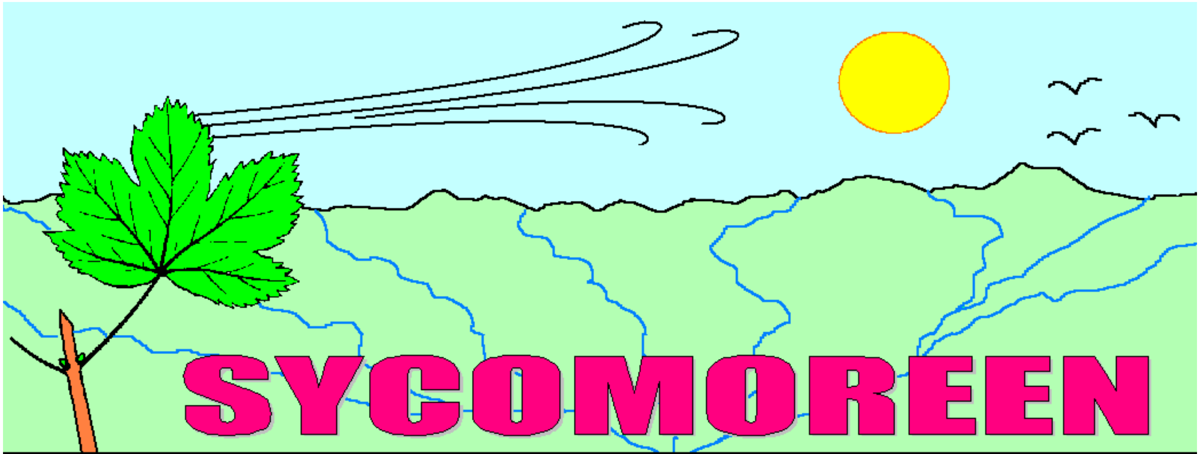
The ROBIPLAN has *big assets to enter on the domestic wind turbine market*. Its strong starting torque combined to its very correct output at all wind speeds allows him *a more regular and more important production than the small tri-blades wind turbines*. Otherwise, it is mechanically extremely simple (parts and assemblies), very robust and easily repairable.

For the industrial turbines (1 MW, height 100 m, swept area of several score of m²), complementary studies, as well on the chosen architecture that for the building issues would be necessary.

Under the condition to overcome the building challenges and resistances of the materials on high power ROBIPLAN turbines, these would be more effective than the big wind present tripales.

TO FINISH, a small note of humor giving matter to think.

« Concerning wind,
the essential is to have the breath
and not to lack any air »



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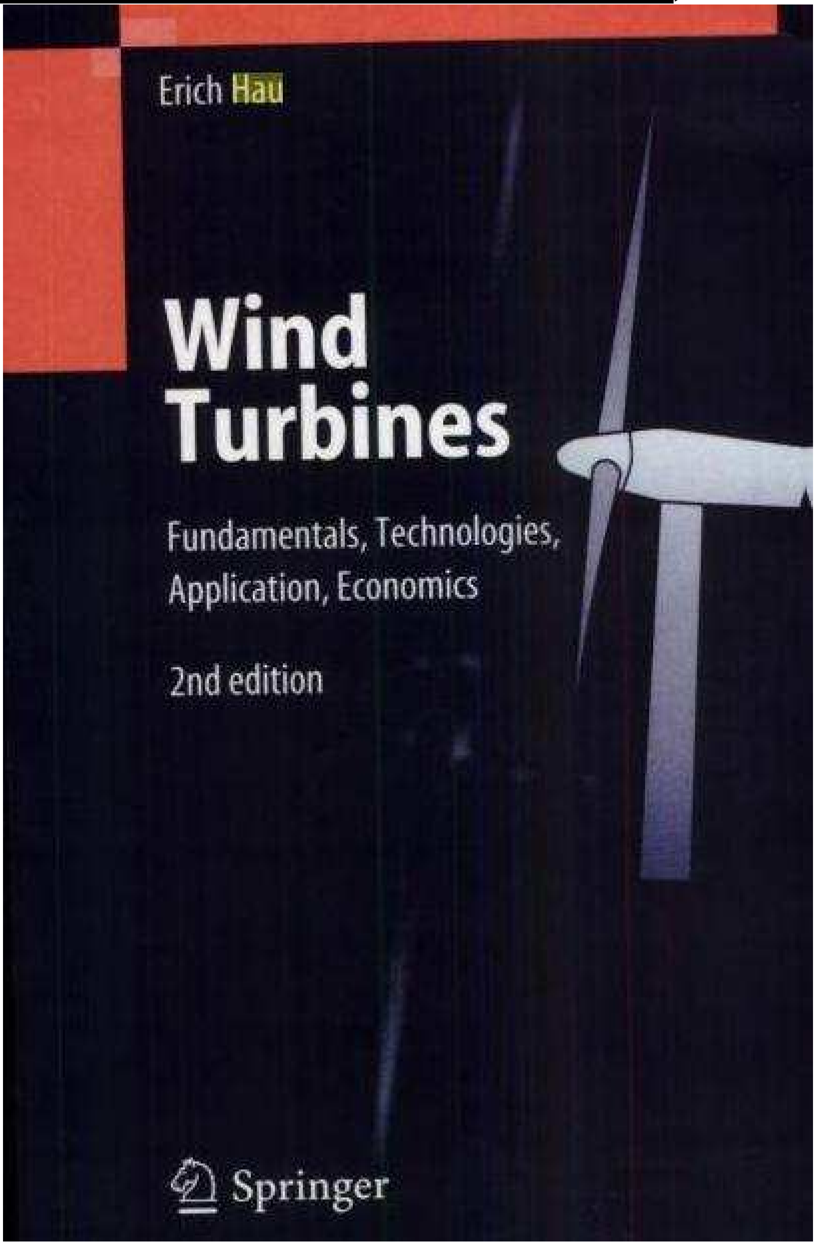
RELATIVE DOCUMENTS

The diagrams of this survey are extracted from :

Wind Turbine Fundamentals, Technologies, Applications, Economics, Erich HAU, Springer Edition



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See also a good ***state of the art of Bernard MULTON,***
Professeur des Universités à ENS Cachan, Agrégé de Génie Electrique (French)

File (14 Mo) Downloadable on this page http://www.geea.org/article.php3?id_article=316

General overview on current and future wind turbines and their issues (French Powerpoint)
http://www.iufmrese.cict.fr/catalogue/2007/Strasbourg/Keiflin/EE-Eoliennes_PPT2000v2.ppt
by Denis KEIFLIN, lycée Louis Armand de Mulhouse (FRANCE)

Doug Selsam's realizations and designs *(USA)*
about multiple wind-turbines on the same axis : www.selsam.com