First published at http://www.fe.up.pt/~feliz, on the 31th of July of 2009, and registered with the Portuguese Society of Authors

Wind-Splash-Turbine[1]

J. Manuel Feliz-Teixeira

clic-to-contribute

July 2009

Physics, Modelling and Simulation
Emails: feliz@fe.up.pt, manuelfeliz@gmx.net
Urls: http://www.fe.up.pt/~feliz

KEYWORDS: wind energy, wind systems, torque, drag, lift, splash effect.

ABSTRACT

Designing a turbine usually implies the assumption that the turbine aerodynamics somehow have to blend well into the fluid flow, in order to obtain good efficiency and a low pressure operation of the overall system. The solution presented in this article points to the opposite, since it is based on the *splash* effect observed when a drop of liquid falls down on a perfectly elastic surface. Although only a small model of a wind turbine has been constructed to validate the concept, here we present and discuss such a proposal by means of mixing some *Physics* with some exercises of *intuition*.

1. **Introduction**

People who used to operate the old windmills for grinding grain used to say that one has to let the wind pass through the area of the turbine in order to allow it to turn. This idea is usually understood both for horizontal and vertical turbines, and assumes that the average direction of the flow in the plan of the turbine should remain the same as the direction of the incoming wind. So, it is also usually expected that the wind machine will induce a minimal change in the direction of the flow in its vicinity. Although the idea works, and allows around 30% efficiency, that is somehow looking at a turbine as if it was an aeroplane. There must be some sort of aperture in the collector's area through which the fluid will travel to the other side, that is, to the free space. From this, it obviously results that the effective area of contact with the fluid will be smaller than the circular theoretical area normally considered in the calculations. Since in the present context a turbine is a mechanism to collect energy with the maximum possible efficiency, we may question the advantage of loosing such an amount of energy. Even knowing that the speed of rotation helps the process of capturing the wind, wouldn't it be more interesting if all the wind reaching the turbine's surface could be used to drive it? To go further in the discussion it is important to review some aspects related to the forces driving a wind machine.

2. Wind force, drag, lift, and resistance to rotation

As said in a previous article, usually the wind turbine design is a complex process taking into account the interaction between an incompressible fluid flow and a solid structure. Frequently, the *Navier-Stokes* equation is used, which relates the various sources of force and computes a distribution of velocity. We believe, however, these equations are mostly appropriate as optimization tools, instead of being fundamental tools. Fundamental interactions may be understood based on the principles of *energy-conservation* and *momentum-conservation*, while looking at the wind as a huge field of little *wind-particles*. Lift, a typical effect from a solid moving through a fluid, can even be imagined if we

---

[1] It is the author's wish that any new ideas and systems presented in this article will be considered *anti-patent*. This means anyone has the right to use them or replicate any of the described systems for free, without the need for any special permission. If used for business, however, those interested have the duty of contacting the author in order to obtain such permission and to negotiate the appropriate compensation.

think of all those little *wind-particles* as linked to each other by a force of cohesion. The most important analysis of a turbine design may therefore relate the force of the wind with the energy captured by the machine, which highly depends on the *drag* and *lift* effects. The next figure shows the basic effects considered in a wind turbine, which design is frequently reduced to the design of its blades.

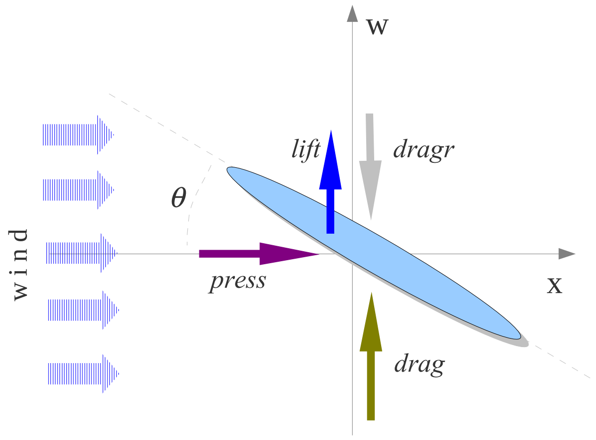

Fig. 1 Basic effects on a blade of a wind system.

Notice that '*x*' represents the direction of the incoming wind, while '*w*' points to the instantaneous direction of rotation, which somehow can be seen as a 'circular' direction. The machine rotates along this direction. The arrows shown in the figure represent the main reaction forces to the impact of the wind in the blade. Notice that *<u>drag</u>* and *<u>lift</u>* are responsible for inducing torque in the machine, while *<u>dragr</u>*, the force produced by the resistance of air against the blade when it rotates, is in fact the main source of resistance to its movement, acting therefore as an anti-torque effect. Usually, the blade design is optimized in order to find the best possible ratio between *<u>lift</u>* and *<u>drag</u>*. The force we named *<u>press</u>* is simply the pressure imposed on the blade in the direction of the flow. It contains the direct pressure of the wind on the blade and also the projection of the original *<u>lift</u>* (which in fact is perpendicular to the blade surface) in the '*x*' direction, usually called *induced drag,* in aeronautics. The rigidity of the turbine, and also of the structure of the machine, must be able to support this force even in the worst conditions of operation.

Of course, to handle all these effects together is not an easy job, but there are, in our opinion, some directives that might be followed in order to produce a good wind machine: *maximize torque; minimize resistance to rotation; ensure resistance to storms.* For now, let us think on a horizontal circular turbine:

<u>Maximize torque</u>: this would be achieved if we would concentrate all the *drag* contributions far from the centre of the turbine, in its periphery. Standard turbines cannot do this, since this would also imply a huge increase in the overall *dragr* affect. A standard turbine would stop, in that case.

<u>Minimize resistance to rotation</u>: this would be achieved if the angle between the blade's surface and the direction of rotation (w) would be made very small, thus implying an high angle of attack (θ). In a standard wind turbine this is achieved by twisting the blades as they get apart from the centre, but this also reduces the *drag* contribution and the capture of energy.

<u>Ensure resistance to storms</u>: this is a complex issue. Due to the cubic dependency of the wind power on the speed of the fluid, this is the main problem for wind turbines. Stop the turbine (make it a wall) to avoid huge forces due to angular momentum variations, turn around the system in order to face the minimal wind power, and wait for the crisis to pass. This is what standard big turbines do, in general. Smaller turbines may also try to withstand the storm, with the generator stopped (shunted).

For the moment ignoring the third aspect, since it mainly depends on the structure of the machine and on the policy of its operation, the relevant question is: can we find a way to design a turbine in which *<u>maximizing torque</u>* will be almost independent of *<u>minimizing resistance to rotation</u>*? Or, in other words, is there any design in which *lift+drag* could be made almost independent of *dragr*?

In any standard turbine there always has to be a compromise between these concurrent and opposite effects. But, what if we think on a wall? In a compact wall of a building, for example, which can be made resistant to wind storms, what happens to the energy coming from the wind? Is it simply transformed into other kinds of energy, like heat, deformation, vibration? Probably into all these kinds, but what if we consider the surface of the wall ideally an elastic medium? *Wind-particles* going in the wind direction will reach the surface and try to reflect back in the opposite direction, but, due to the constant pressure of the next plan of *wind-particles* arriving to the wall, they are forced to change their direction of motion into a perpendicular direction. That is, they suffer the interference of *splash effect* which sends them all apart from the impact zone. Let us observe it a bit better:

3. The splash effect

Intuition is a kind of an educated common sense, we would say. It is what a previously educated mind feels as being either expectable or plausible. 3D space exercises and 3D game visualizations will of course be excellent tools to achieve a good level of intuition. One closes the eyes and then lets the "image" of the phenomenon be produced in the emptiness of the brain, and then try to study it, as a first approach. It is almost like exercising the feelings of being the system itself and not only its observer. Mathematics need to appear later, as a powerful descriptive language allowing not just a representation but also to use deduction. Let us therefore use again intuition in order to try to understand the *splash effect.*

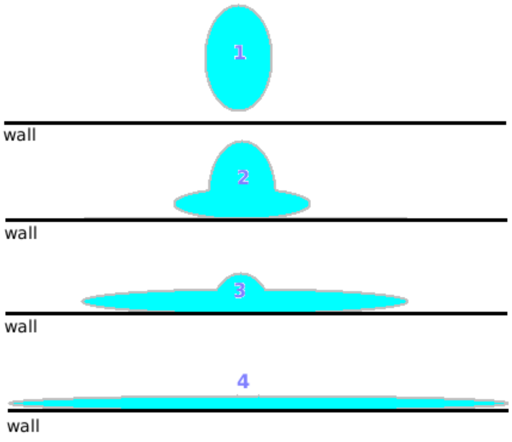

Fig. 2 Basic splash effect, in a drop of liquid under gravity.

Figure 2 shows, in a simplistic way, what happens when a drop of a fluid under the forces (pressure) of gravity falls onto an elastic surface. Considering we are dealing with an incompressible fluid, which means that the ration between its *volume* and its *mass* is a constant, we can see that practically all the mass which in the instant 1 was moving down, along the gravity pathway, was finally spread through a perpendicular direction in the instant 4.

This was due to the "pressure" of gravity, of course. Thus, instead of collecting the energy contained in the drop directly in the midpoint of contact with the wall, one may also collect practically all that energy with sensors located around and apart from that point, where mass is already moving parallel to the wall's surface (see wind example in Fig. 3).

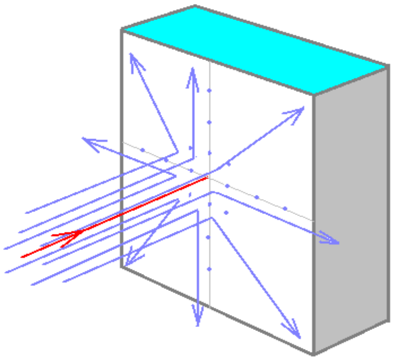

Fig. 3 Basic splash effect: wind "crashing" into a rigid wall.

This is obviously a promising result in the sense that it let us achieve the possibility of maximizing torque, as previously mentioned, and so we would at this point consider fulfilled the first of our directives for the design of an efficient turbine. Figure 3 shows how the wind will flow when in contact with a rigid wall perpendicular to the wind's direction. We may imagine that this energy could simply be collected by means of a circular system of blades properly positioned at the periphery of the wall. Notice that the efficiency of such a method will be highly dependent on the wall's surface. Ideally, this surface should not absorb any energy from the wind, but only scatter it radially and to the periphery of the obstacle. Thus, in reality the wall must not only be rigid, but also well-polished and made of an appropriate material. Both plastic for cheap turbines and carbon fibre for the more challenging and expensive ones could be some of the materials to be explored. But, while thinking on a very simple and robust solution, one may even use a concrete wall into which a rotating system will be fixed, similarly to what is presented in the next figure, for example.

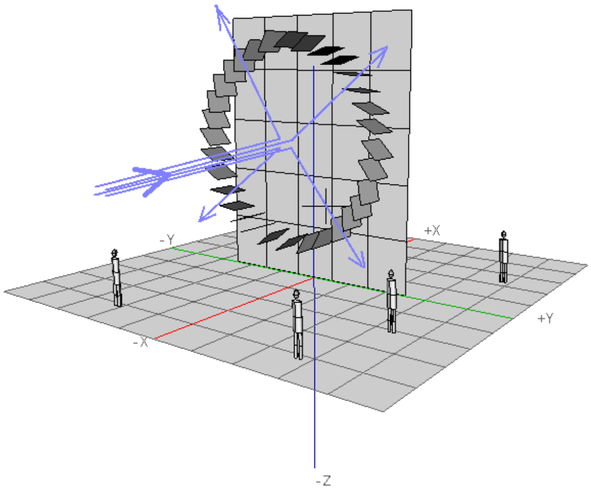

Fig. 4 Collector for the energy scattered by a rigid wall.

This would enable the construction of very cheap wind sites on the top of hills, for example, or in some places by the sea, promontories, or even offshore. The next figure represents one of these possibilities, something like a concrete building with a big *splash-turbine* placed on it, for capturing the dominant winds. Notice that the "*scatterer*" (splashing surface) does not have to be fixed to the "*collector*" (blades' system), which greatly reduces the weight of the rotating parts of the machine. Another possibility could perhaps be to install one of these turbines on the windiest wall of certain skyscrapers, as long as noise, vibration and people's safety would be seriously addressed.

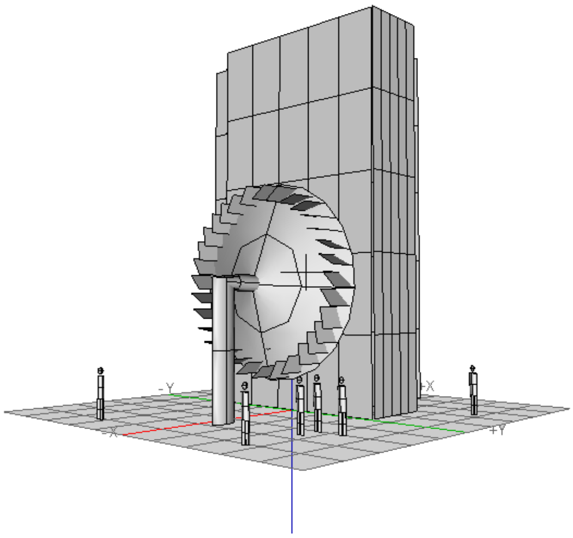

Fig. 5 An example of a possibility for a wind-splash-turbine.

4. Efficiency and the blades design

The fact that most of the energy will be collected and transformed into torque at the periphery of the turbine, seems a good indication that this may result in a system with high efficiency. On the other hand, the mass coming in the wind will be "processed" by the blades of the collector, and this, however, must be done in a way that ensures the minimal resistance to rotation and the maximum capture of forces. Let us try to use figure 6 to represent the effects involved in a collector made of several blades, which then will be mounted in a circle.

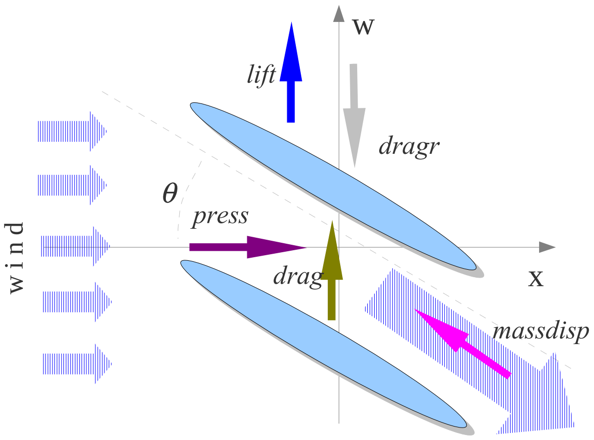

Fig. 6 Basic effects in an almost parallel blade array.

Now, the wind forces coming from the left of the figure represent the mass scattered radially into the collector. In this *collector*, which may be understood as a circular array of almost parallel blades, as shown in figures 4 and 5, now act the effects of *press*, *drag lift* and *dragr*, but also a new effect (*massdisp*), known as *mass displacement,* which is related to the change of linear momentum on the fluid. This is the effect used for propelling rockets, for example, and it is usually feeble in wind turbines, but it may increase if the blades' proximity do not allow a straight escape of the fluid into the open air. This effect also increases with the pressure inside the turbine, and so with the speed of the wind. It will basically be added to the *drag* effect and oppose the *press* effect, which seems an interesting result, since it also contributes to the forces responsible for the rotation of the machine. We expect, therefore, that by increasing the angle of attack (θ) one can reach a good situation where *dragr* is small when compared with the summation of *drag+lift+massdisp*. Since the overall blade area is also very small compared with the area that receives the energy from the wind, we certainly expect this to be another efficient design. Although it is not altogether new, this design is in effect new as a proposal for a horizontal wind machine. A similar concept is frequently found in vertical ventilators and air exhauster turbines (Fig. 7), for example, which normally are quite efficient and able to operate at very low pressure regimens.

Fig. 7 Mechanical ventilator based on a vertical blade array.

This is also the kind of design used in some vertical wind turbines, which, unfortunately, have the disadvantage of operating with only half of the wind stream, due to obvious issues of geometry.

5. **The wind-splash-turbine**

Based on what was previously said, several types of wind-splash machines may now be constructed. The art is in the ability to reduce the weight of the rotating part of the turbine, and in ensuring that the collision with the "*scatterer*" will be as elastic as possible and channelling the wind stream into the "*collector*". In the solution presented in figure 8, for example, which is a fixed system, we would think on using thin blades of fibreglass, for example, to build the "*collector*", and perhaps a similar material for the "*scatterer*", this with a slightly conic design for helping scattering the wind flow. All this structure, with roughly 4m diameter, would have to be supported by a strong structure in order to sustain the impact of the wind during any conditions of operation. By its dimensions, we would say this is a machine to be exposed to 7,5KW@10m/s of wind power. If operating with 40% efficiency, that would mean capturing 3,0KW@10m/s. Considering 50% of efficiency on the injection of this power into the electric grid, by means of a generator and an inverter, we finally may deduce this would be a 1,5KW@10m/s machine, in practice. In terms of resistance to storms, in the challenging conditions of 56m/s wind speed (200Km/h), the maximum force acting on the turbine overall would be of around 4800Kg, which seems not to be so difficult to sustain with good engineering.

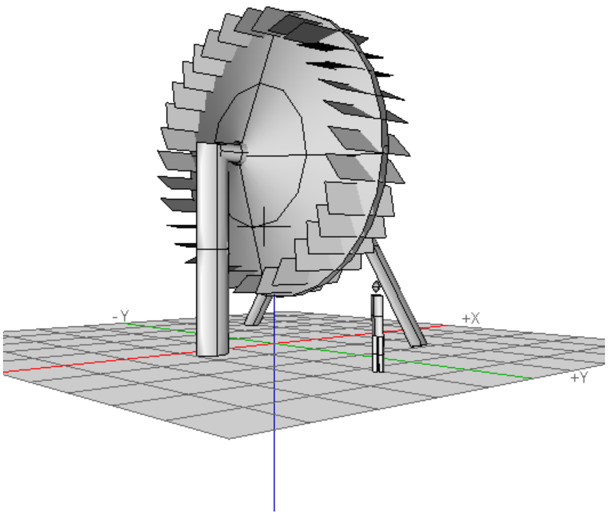

Fig. 8 A proposal for a *splash-turbine* of 1,5KW@10m/s.

But this design has another advantage: it will always rotate to the same side, no matter the direction the wind is blowing from (see next figure). And this is a very interesting feature, since it allows a continual and steady capture of energy as long as the wind blows. Of course this machine will be most effective in places where there is a preferential direction of the wind, like in mountains or near the sea, for example.

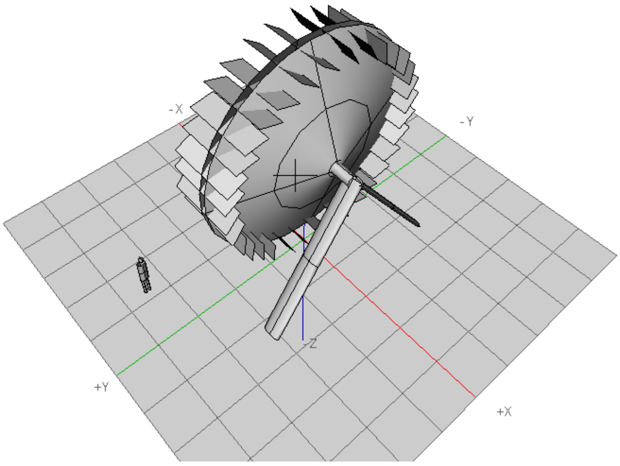

Fig. 9 Birds-view of the rear part of the same machine.

Another interesting aspect is the easy way for connecting a generator with a high gear ratio to this machine. As suggested in figure 10, this generator could simply be positioned inside the turbine, thus also being protected from atmospheric conditions.

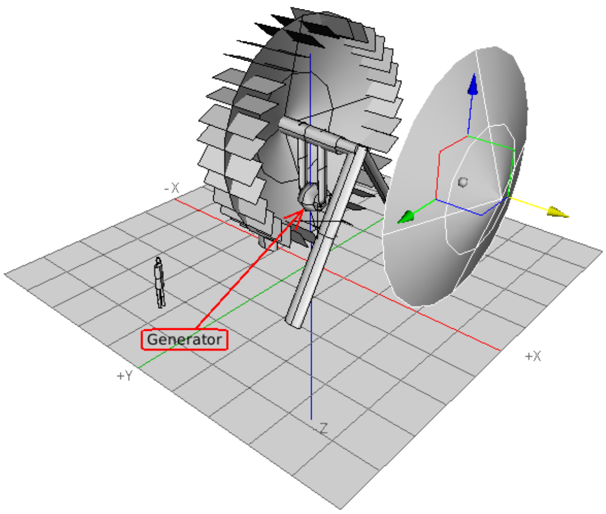

Fig. 10 The generator mounted inside the turbine.

Apart from these constructions for big turbines, which we defend should be static, or quasi-static, to avoid catastrophic effects during storms, due to the huge torque forces produced by changing their high angular momenta (we are convinced that blades of big turbines crash mainly due to these forces, which are produced even during small storms) other kinds of constructions could be tested, in particular the ones using the idea of an “array” of turbines to achieve a better resistance on handling storms. In effect, it is theoretically advantageous to “disperse” such wind power into several small elements that collect it and transform it into electrical energy (see figure 11). We usually call each of these elements a “*wind-cell*”, but they simply are mini-turbines, each one driving a little generator. They may be mounted in the form of an “array” in order to collect the desired amount of energy. Each *wind-cell* can be either fixed or allowed to search for the wind direction. For example, a *wind-cell* of around 0,25m radius (medium bicycle wheel), would receive on its surface during a big storm (@200Km/h (56m/s)) a wind force of around 75Kg. It is not so difficult to build a device capable of handling this. It would be exposed to 0,1W@1m/s and 100W@10m/s.

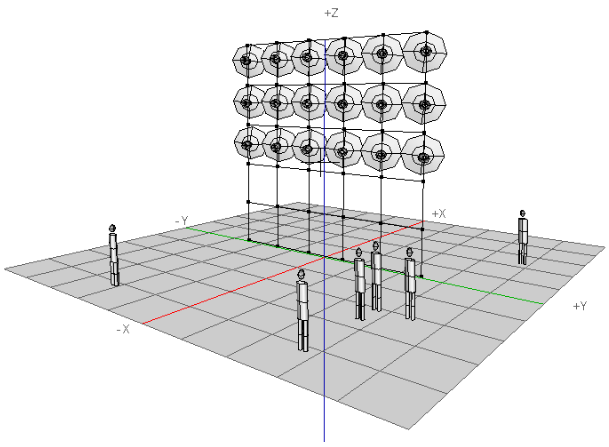

Fig. 11 Example of an array of 18 wind-cells.

Thus, if the system of figure 11 would be built of 18 *wind-cells* of this type, and if we suppose 40% efficiency for each *wind-cell* (too optimistic, maybe), we could say that this system would capture the mechanical power of 0,4x18x0,1=0,72W@1m/s and 720W@10m/s. Half of this could be injected into the grid!

6. Conclusions

Very interesting, but somehow disappointing due to the amount of energy that small scale systems may be able to collect from the wind. The ideas exposed are to be considered *anti-patent*.

Author's Biography:

J. Manuel Feliz-Teixeira graduated in Physics in the Faculty of Sciences of University of Porto, Portugal, and received an MSc and PhD from the Faculty of Engineering of the same university. His work has been related to various matters, from optical communications, solar energy and seismology, to, more recently, the simulation of complex systems in management science, like warehouse and supply chain. His PhD thesis is on “Flexible Supply Chain Simulation”. Lately he is also dedicated to researching new approaches for renewable energy.