WIND ENERGY CONVERTERS CONCEPTS

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INTRODUCTION

Any natural or artificial physical configuration which produces an asymmetric force in a wind stream can be made to rotate, translate or oscillate a surface, and power can be extracted from the wind. This simple notion has been used by many bright and inventive minds leading to the invention of a large number of wind machine concepts. Some of these ingenious ideas, maybe with modifications, await the availability of appropriate materials, control systems or special needs or circumstances to be placed into future use.

Since a larger amount of potential energy exists in the wind than kinetic energy, devices that depend on pressure differentials may offer innovative approaches to future wind energy conversion.

We consider some of these concepts since they provide a promise for innovative future applications of wind machines.

HORIZONTAL AXIS WIND TURBINES, HAWTs

In this type of design the axis of rotation is parallel to the wind direction. This includes the Dutch mills, American Water Pumps and most of the modern wind generators (Fig. 1).

Fig. 1: Aerodynamic and impulse or drag horizontal axis wind turbines.

Horizontal axis machines can catch the wind in an upwind fashion, and need in this case a rudder or electronic systems to direct them towards the prevailing wind direction. If they catch the wind in a downwind fashion, they become self orienting and do not need a rudder. However, the blades suffer vibrations from rotating within the shadow wake created by the support tower (Fig. 2).

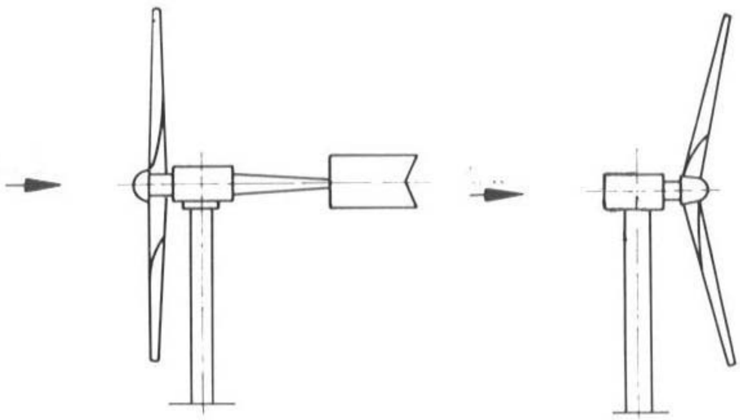

Fig. 2: Upwind and down wind designs of horizontal axis wind generators.

The rotor blades designs can be solid made out of wood, fiberglass, metal, or constructed out of fabric in the form of a sail (Fig. 3).

Fig. 3: Sail wing rotor design.

The rotors can be single bladed with a counter weight, double bladed, or multiple bladed (Fig. 4). The three blades design is considered to offer an aesthetic appeal and is widely used.

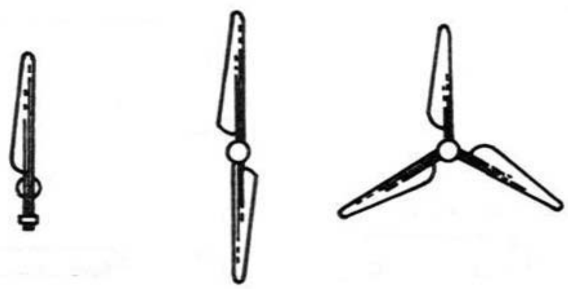

Fig. 4: Single, double and three bladed rotor designs.

Fig. 5: Single blade with counterweight wind rotor design.

VERTICAL AXIS WIND TURBINES, VAWTs

Vertical axis wind machines offer the advantage of being capable of catching the wind from all directions without a need to orient the blades in the wind direction. Some designs are though not self starting.

Another advantage is that the blade takes the shape of a jumping rope or Troposkein in Greek. It operates in almost pure tension, it becomes relatively light and inexpensive to construct.

Another noted advantage is the elimination of the need for the nacelle harboring the gears and generator in horizontal axis machines to be placed at great heights above the ground. The generator and other control and power equipment can be positioned on the ground where they are easily accessible for maintenance and inspection.

G. J. M. Darrieus introduced the Darrieus design to the USA in 1931. The National Research Council of Canada tested them in the early 1970s. Sandia national Laboratory built a 5 meters in diameter machine in 1974 and was involved in their testing.

Two versions of vertical axis machines have been proposed designated as the φ and Δ Darrieus designs. The first concept uses curved rotor blades, and the second can use straight rotor blades.

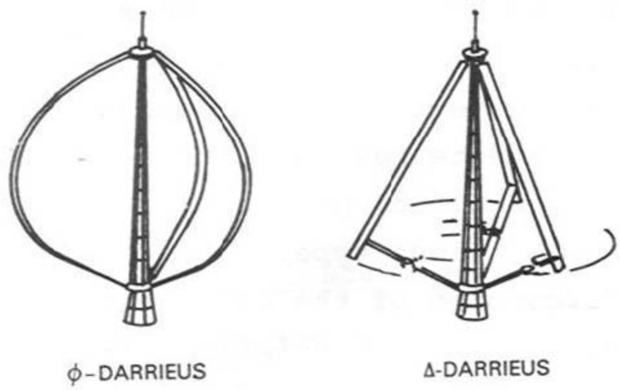

Fig. 6: Two versions of the Darrieus vertical axis wind turbines.

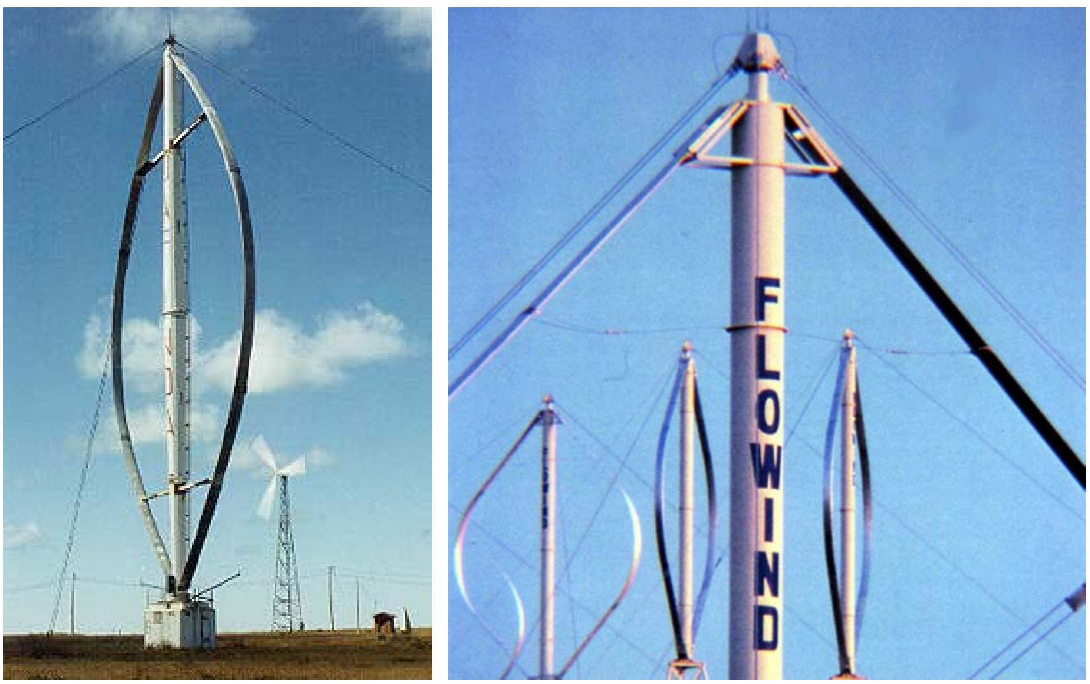

Fig. 7: Darrieus vertical axis wind turbines.

Since the Darrieus design is not self starting, a hybrid design combining one or more Savonius blades on the central axis can make itself starting (Figs. 8-10). Alternatively, an induction starting motor connected to the local utility grid can be positioned at the bottom of the axis. The same induction motor can be used as an induction generator to supply power to the grid. Induction machines are simple, rugged and inexpensive, requiring essentially no controls other than a contactor to connect it to the utility grid.

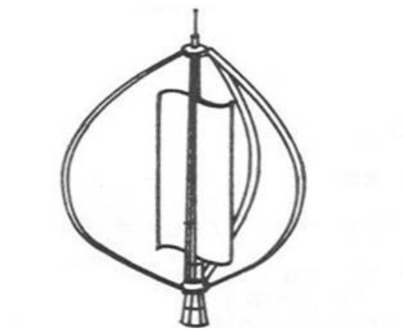

Fig. 8: Combined Darrieus and Savonius vertical axis wind turbine.

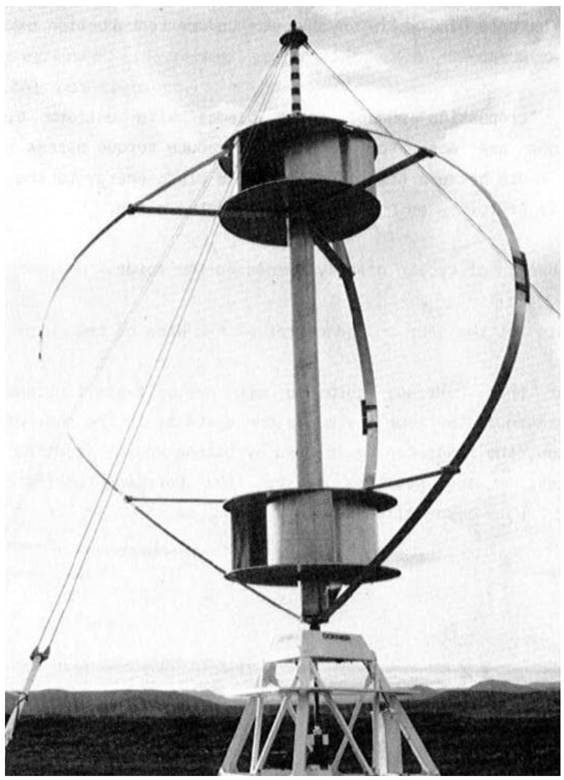

Fig. 9: Experimental Darrieus vertical axis turbine with two Savonius starters.

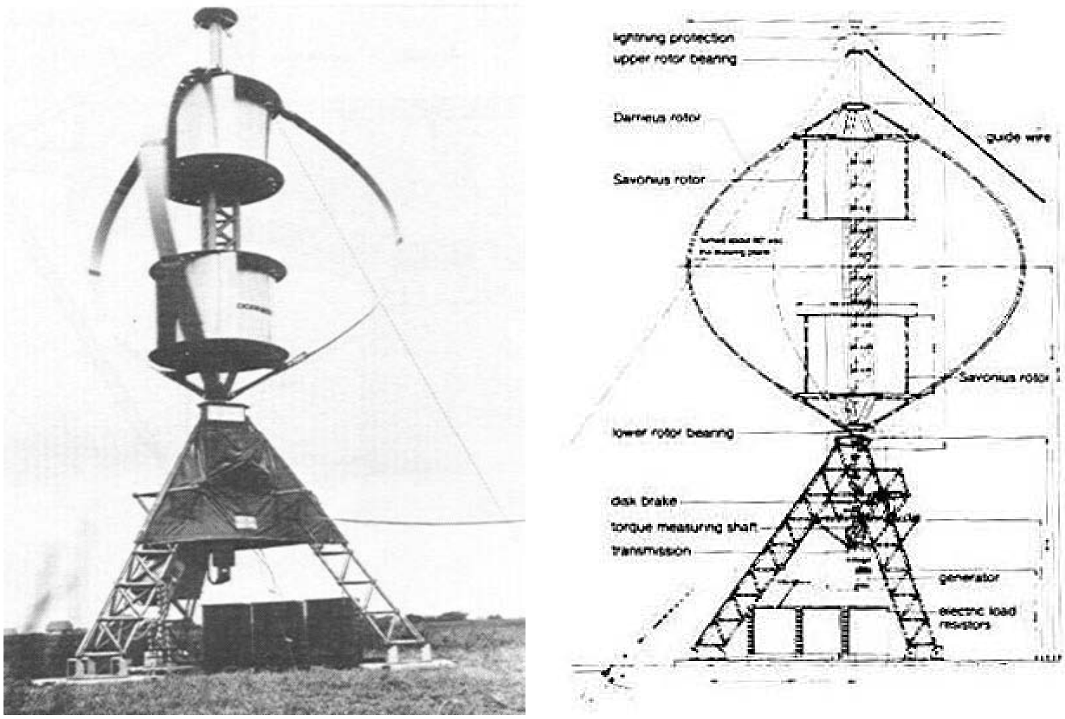

Fig. 10: Dornier design with a rated power of 4.6 kW at the Northfrisland Island of Pellworm, Germany.

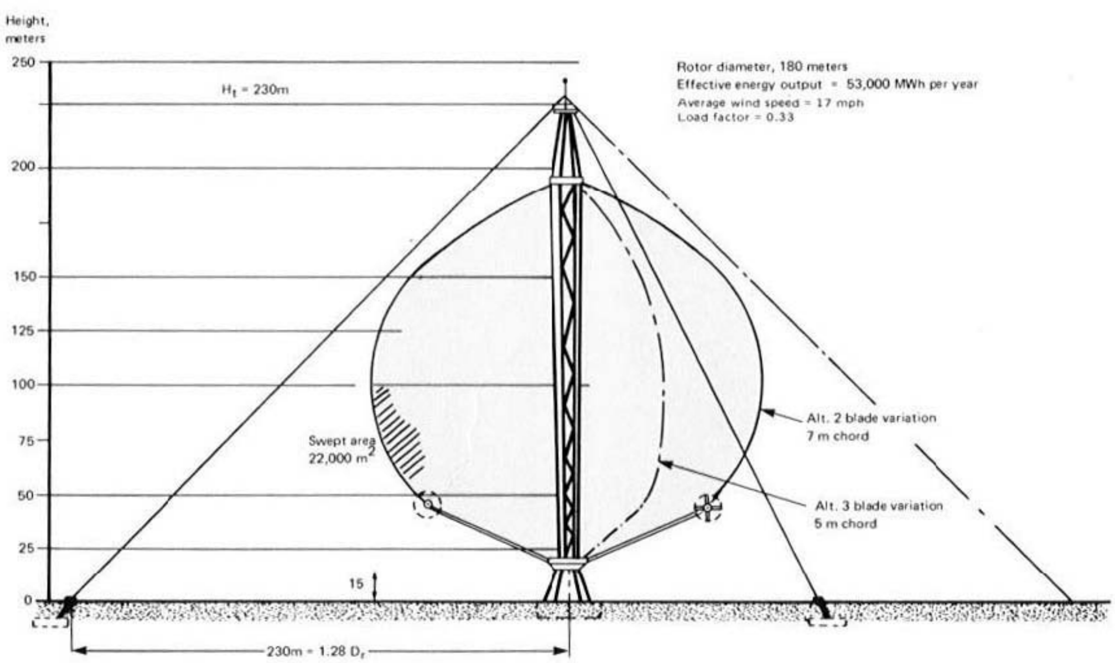

Fig. 11: Conceptual design of a Darrieus wind turbine with 180 meters rotor diameter and starting propellers on the blades.

In a larger Darrieus design, propellers can be attached to the rotating blades to provide a starting mechanism (Fig. 11).

Vertical axis machines can be built atop a structural tower to intercept higher speed winds. On a tower, stacks of vertical axis rotors can be interconnected with the double advantage of catching higher wind speeds, as well as catching the winds from all directions (Figs. 12, 13).

Large structures such as skyscrapers could be retrofitted on their outside with stacked vertical axis turbines providing them with at least part of their energy consumption at little additional cost. This is particularly interesting in large cities where the tall building create a wind tunnel effect, hence the designation of the city of Chicago along Lake Michigan in the USA as the “Windy City.”

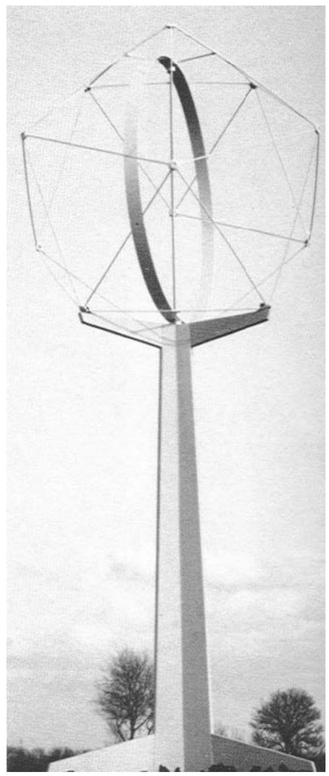

Fig. 12: Vertical tower wind turbine concept.

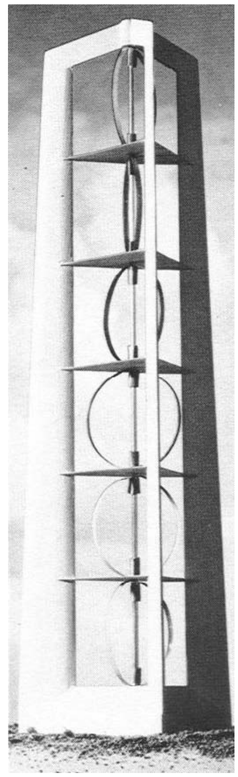

Fig. 13: Vertical tower with stacked Darrieus wind rotors.

A 230 kW Darrius turbine was built on Magdalen Island in Québec, Canada in 1977 by Dominion Aluminum Fabrication Limited Company of Ontario. The turbine operated at an average output of 100 kW for a year. A noise was heard in the gearbox and the machine was stopped for inspection. To carry out the inspection, the brakes were removed, considering that this type of machine is not generally self starting. That was a fatal mistake, since the machine did in fact self start, and without its brakes and without a load, went into a runaway mode well over its design speed of 38 rpm. The spoilers did not activate properly and when the machine reached 68 rpm, a guy wire broke and the turbine crashed to the ground.

Alcoa in the USA built a 5.5 m diameter 8 kW machine followed by 12.8 m 30-60 kW, 17 m 60-100 kW and 25 m 300-500 kW machines. The effort was plagued by accidents. A 12.8 m machine at a Pennsylvania facility developed vibrations in its central torque tube and eventually buckled down when it run above its rated speed on March 21, 1980.

A 25 m machine crashed in April 1981 in the San Gorgonio Pass east of Los Angeles. The machine worked properly at 60 rpm well above its rated speed of 41 rpm. A software error in the microprocessor controller prevented brake application in high winds. A bolt broke and allowed a blade to flare outward cutting one of the guy wires causing the machine to collapse to the ground.

The string of accidents slowed the development of vertical axis machines in favor of horizontal axis machines. With a better understanding of their operational modes, vertical axis wind machines can contribute to wind power production in the future.

POTENTIAL ENERGY PRESSURE DIFFERENCE MACHINES, ARTIFICIAL VORTEX CONCEPT

Such a machine extracts energy from pressure differences or the potential energy in the wind, rather than from the kinetic energy of the moving air. The potential energy in the air caused by pressure differentials is vastly larger than the kinetic energy at moderate wind speeds. This suggests the possibility of large energy outputs for a small tower size resulting in economical power production.

A way to concentrate wing energy is through the use of an artificial vortex. A confined vortex or tornado can be generated for mono directional winds using a spirally constructed tall shell structure with a top narrower than its base (Fig. 14). For omni-directional winds, shutters can be opened and closed on a cylindrical shell structure to create a rising vortex inside the cylindrical structure (Fig. 15). In both cases a wind turbine positioned at the bottom of the structure would extract part on the concentrated wind energy.

The augmented vortex concept was studied by James T. Yen at the Grumman Aerospace Corporation. The tower structure would use vertical vanes to direct the wind into a circular path around the inside of the tower. Wind blowing across the top of the tower would tend to pull the air inside into an upward direction through the Venturi effect. The combined action would result into the air following a spiral path and generating a vortex. A vortex is characterized by a high speed low pressure core much like a confined tornado. The pressure drop between the vortex core and the ambient outside air can be used to drive a high speed wind turbine at the base of the tower.

A modification of the concept can be thought by shaping the bottom part into an airfoil shape in the form of a horizontal nozzle and shaping the inside of the tower into a spiral airfoil eliminating the need for the vertical slits.

The tower could be painted in black absorbing solar energy and leading to air buoyancy. As a symbiotic combination of wind and solar energy extraction, the system would act optimally by generating energy from the wind on cloudy windy days and from the sun on sunny windless days enhancing the capacity factor of the plant.

An attractive feature of such a configuration is that it combines the advantages of vertical axis wind machines with the power production equipment easily accessible near the ground, and of catching the wind from all directions.

It is reported that the concept was not pursued from the fear of spawning tornadoes if the vortex becomes separated from the tower and become an actual tornado. A major difference can be noted though in that natural tornadoes and dust devils can be observed to be downdraft columns from the clouds, whereas the confined vortex would move the air in the opposite direction as an updraft.

The fear appears to be unsubstantiated since dust devils frequently occur without developing into full fledged tornadoes in areas of the Great Plains, California and in the deserts of the world. Motorists commonly drive through them in the USA, and children playfully pursue and run across them in the Middle East. One can observe two vortices forming at the wing tips of landing airplanes, which do not develop into tornadoes. Their hazard is limited to sky divers who can inadvertently run into them.

The unsubstantiated fear is reminiscent of one that arose in the 1950s to the effect that thermonuclear weapons testing at the megatons level could ignite the Earth's atmosphere turning it into a star; which obviously did not occur.

It is suspected that the vortex concept was not actively pursued due to the large capital cost involved in building the associated massive structures.

Existing wind machines as well as airplanes routinely generate vortices without their developing into tornadoes. The fear can be allayed by shutting down the machine under stormy conditions. Using a straight rising air column without the spiral action could also be attempted.

A delta wing is known to generate an unconfined vortex from its leading edge to its top. A wind turbine can be positioned on top of the wing to extract the energy concentrated in the vortex (Fig. 16).

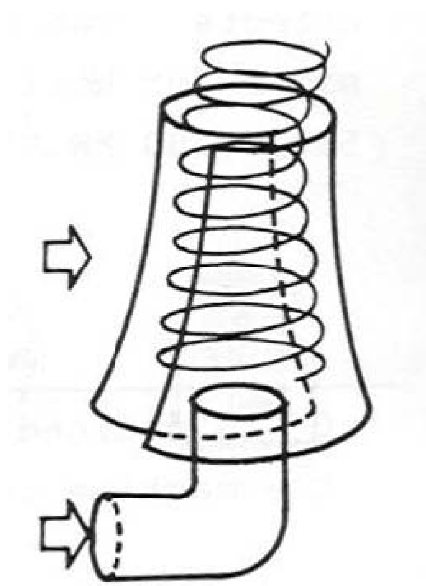

Fig. 14: Confined Vortex Concept for Mono-directional wind.

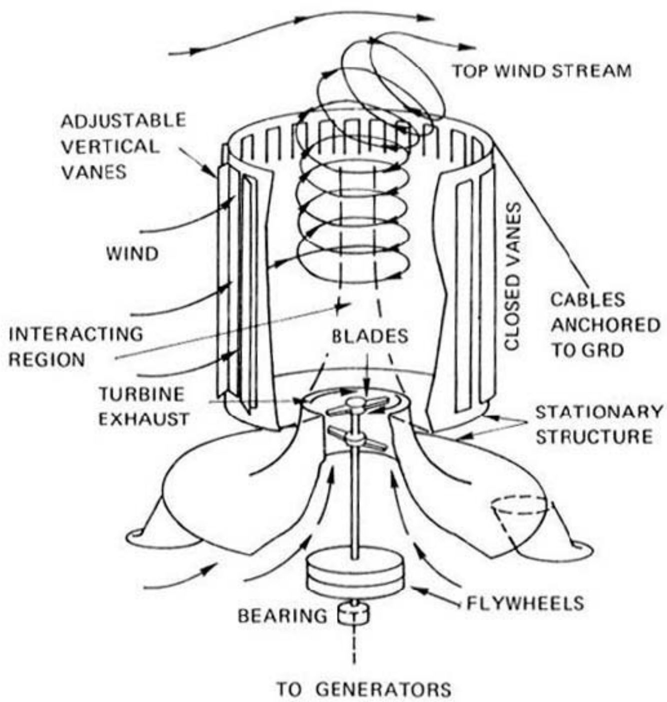

Fig. 15: Vortex Tower for Omni-directional winds.

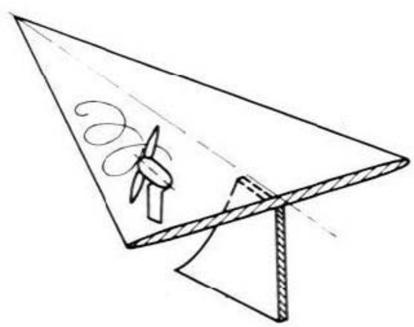

Fig. 16: Unconfined vortex on a delta wing.

One can also advance a suggestion to retrofit the cooling towers of existing fossil and nuclear power plants with vortex generators to supplement their energy production, adding to their energy production capacity.

VENTURI EFFECT MACHINES

The Venturi effect is named after Giovanni Battista Venturi (1746-1822) from Italy and refers to the decrease of gas or fluid pressure when it flows through a constriction in the flow cross section.

According to Bernoulli's law the sum of the static and kinetic pressures or the potential and kinetic energies in an incompressible flow is a constant:

$$p + \frac{1}{2}\rho V^2 = \text{Constant} \quad (1)$$

The pressure drop in a constriction would be given by:

$$p_1 + \frac{1}{2}\rho V_1^2 = p_2 + \frac{1}{2}\rho V_2^2 = \text{Constant}$$

$$\Delta p = p_1 - p_2 = \frac{1}{2}\rho V_1^2 - \frac{1}{2}\rho V_2^2 \quad (2)$$

$$= \frac{1}{2}\rho (V_1^2 - V_2^2)$$

With a Venturi effect nozzle, the wind can be directed into a nozzle to generate a low pressure region at which the blades of a wind turbine can be installed (Fig. 17). The venturi, named after the discoverer, G.B. Venturi, an 18th century physicist is a hole in the wall in front of a moving air mass. Venturi's discovery was that air moving through a venturi would gain speed. A venturi mounted in a manifold where one inlet is the incoming air and one is at static pressure the exiting air can pull the static air down close to a vacuum in the low pressure area behind the inlet.

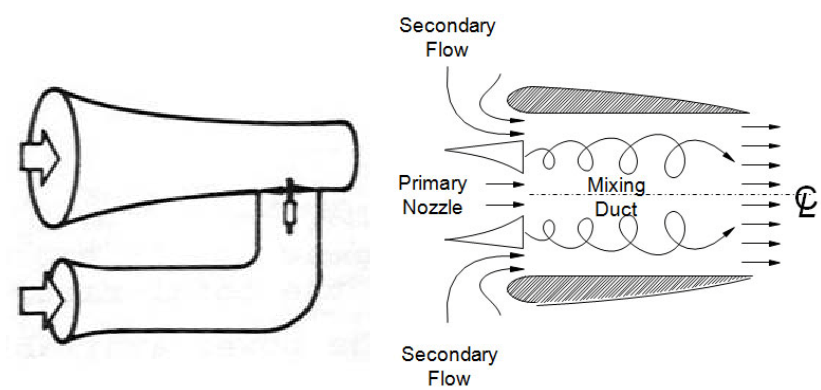

Fig. 17: Venturi Effect designs.

In the Enfield Andreau design, the rotors tips are hollow. As they rotate, they generate a low pressure region in a hollowed tower inside which a turbine would rotate.

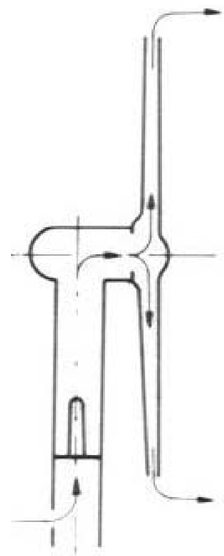

Fig. 18: The Enfield Andreau pneumatic gear turbine concept.

The simplest form of the concept is to just use a deflector into a turbine. Such designs can be placed on the roofs of tall buildings, supplementing their energy needs.

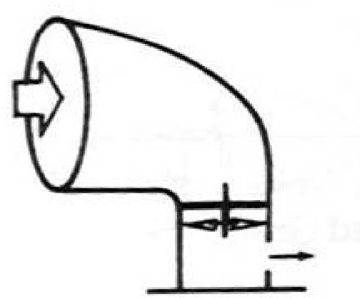

Fig. 19: Deflector turbine design.

BERNOULLI EFFECT DIFFUSER AND CONCENTRATOR WIND GENERATORS

These designs are given different names: ducted fans, shrouded turbines and diffusers and depend on the Venturi effect.

The Vortec wind turbine concept is a bare wind turbine fitted with an aerodynamically designed diffuser. A diffuser followed or a concentrator can be used (Fig. 18). Multiple diffusers can operate in tandem.

It is based on technology originally developed by the Grumman Aerospace Corporation in the USA which included extensive wind tunnel testing. Grumman ultimately produced a power augmentation of approximately six times that of the same size bare turbine in their wind tunnel tests. A small scale demonstrator turbine has been built in New Zealand to demonstrate the concept and has proved that an acceptable augmentation of wind power was achieved in actual operating conditions of a wind turbine.

The prototype Vortec 7 was used for testing and verifying the Computational Fluid Dynamic (CFD) modeling to improve and optimize the diffuser topography and technology. The University of Auckland in New Zealand published in January 1998 results on CFD studies which showed that the expected wind speedup effects, due to the diffuser, across the blade plane is not uniform as assumed by Grumman Aerospace. The speedup effect decreases towards the hub of the turbine compared with the original assumptions by Grumman Aerospace, hence the power output of the Grumman design would be less than the high values first predicted.

Several retrofits have taken place guided by the CFD modeling undertaken by the Auckland University. These included the attachment of an aerodynamically shaped nose cone, the streamlining of the nacelle and fitting of vortex generators to keep flow attached to the diffuser wall and avoid flow separation. These improvements resulted in measured site power augmentation of 3 times and high wind speeds and 4 times at low wind speeds. The best diffuser geometry may arise from CFD modeling.

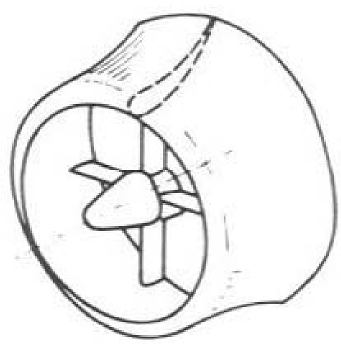

Fig. 20: Diffuser wind turbine design.

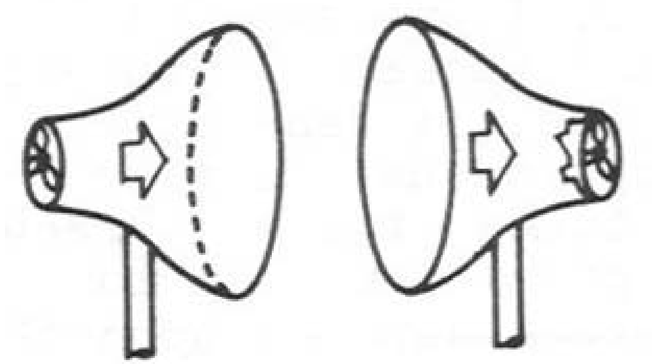

Fig. 21: Single diffuser and concentrator wind turbine concepts.

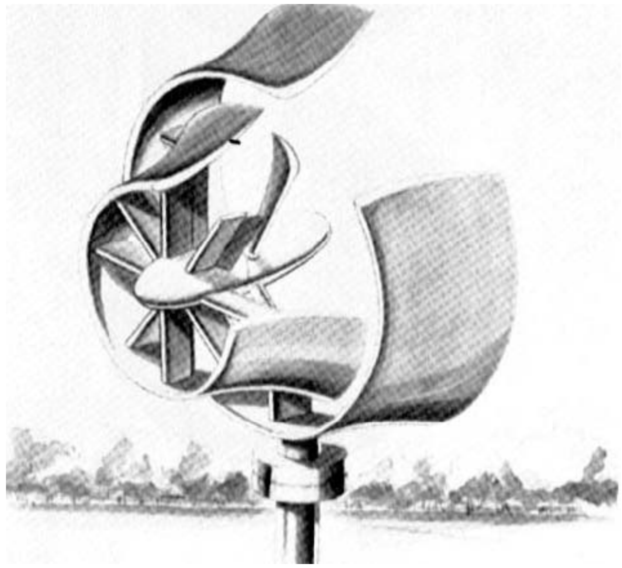

Fig. 22: Double diffuser turbine concept.

Fig. 23: Vortec prototype model, New Zealand.

Fig. 24: Conceptual design of a diffuser wind turbine.

The Vortec wind generator concept could cut the cost of wind power generation one half by using light pre-stressed concrete cowlings to concentrate the wind velocities through the turbine. The wind energy is reported to be increased at the turbine by 175 percent. Since the power production is proportional to the cube of the wind speed according to Betz's equation, such a concept could increase the power production for a given rotor size by a factor of:

$$\frac{P_1}{P_0} = \left(\frac{V_1}{V_0}\right)^3 = (1.75)^3 = 5.4 \qquad (3)$$

or about five times, by being able to generate power in a broad spectrum of wind conditions.

The diffusers can be constructed vertically on the ground, eliminating the need for structural towers. Geometrically, a stacked helical vertical rotor blade system would be more convenient for such a system instead of the shown horizontal one.

Fig. 25: Vertical air foils diffuser concept.

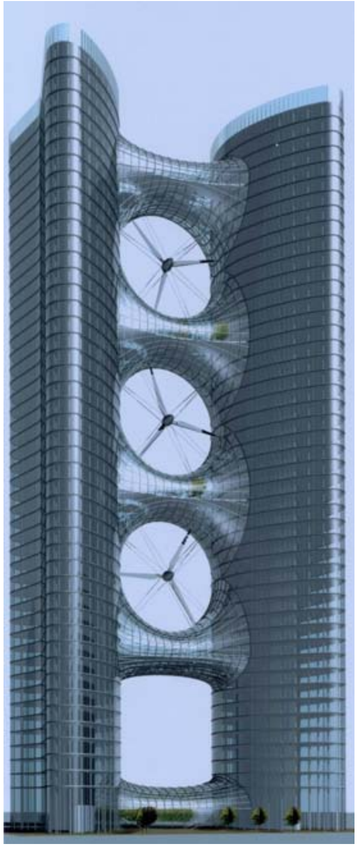

Fig. 26: Use of ducting in architectural design.

Fig. 27: Marquiss Ducted wind turbine concept.

The Marquiss vertical rectangular duct turbine design enables the turbine to continually orient itself into the wind.

The ducted design is suggested to enable the turbine to effectively accelerate the wind speed as it passes through the turbine.

TECHNOLOGICAL HURDLES

To attain significant wind acceleration, a well shaped diffuser of 7-10 rotor diameters is needed. For a shorter shroud, slots or flaps to control the inner boundary layer could be used.

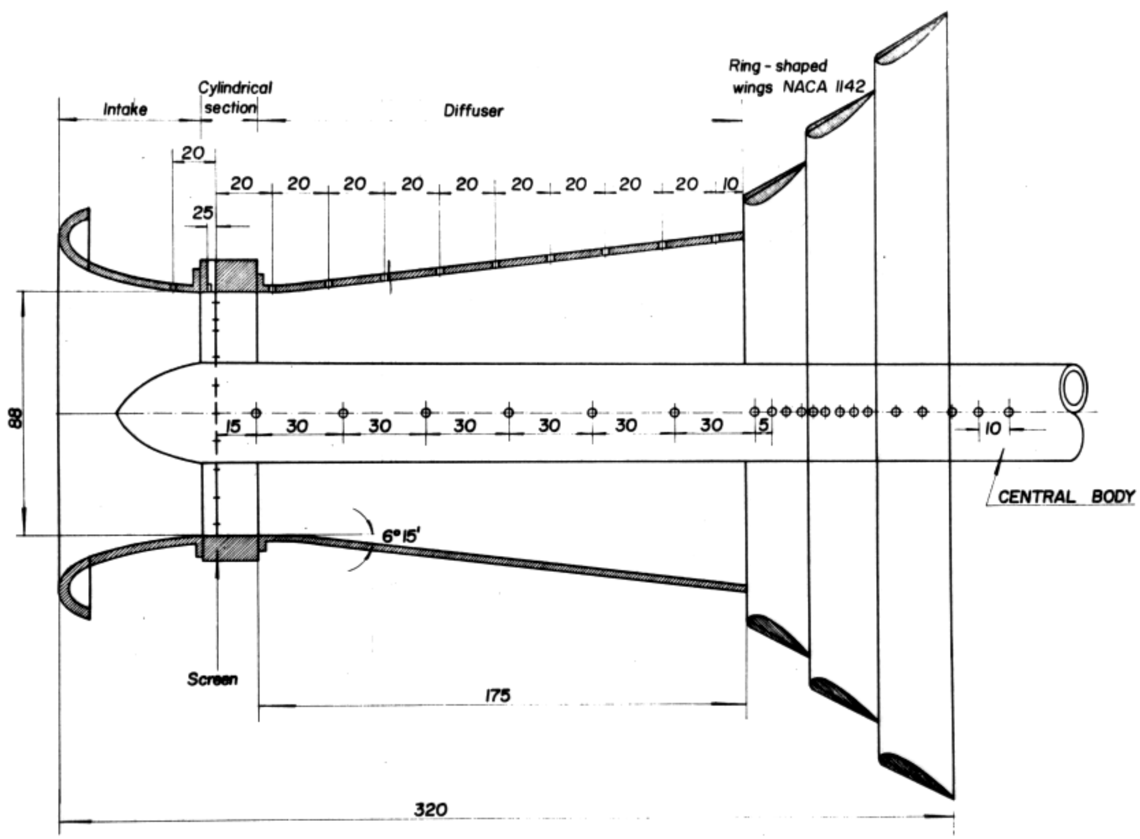

Fig. 28: Diffuser configuration. Dimensions in mms.

The intake duct must be well rounded and the diffuser smoothly and optimally flared to the end.

The rotation slot at the rotors tips should offer minimum friction.

These devices work wonderfully in the controlled environment of a wind tunnel with a homogeneous wind flow, in contrast to the prevailing random direction and turbulent flows in a natural wind stream. The wind offers a complete turbulent boundary layer of about 300 meters thickness, depending on the terrain. In fact, wind tunnel experiments with threefold rind flaps have achieved a concentration effect around 1.8.

If the yaw mechanism fails to direct the diffuser in the direction of the blowing wind large drag forces perpendicular to the diffuser axis would result that could dismantle the device.

A flow separation could occur at the inner wall of the intake resulting in the disappearance of the homogeneous flow needed for the concentration effect.

The diffuser is a large heavy structure that adds to the capital cost of the structure and making the yaw mechanism to orient the diffuser a difficult tasks.

The use of a gap between the shroud and the wing section can enhance the power ratio.

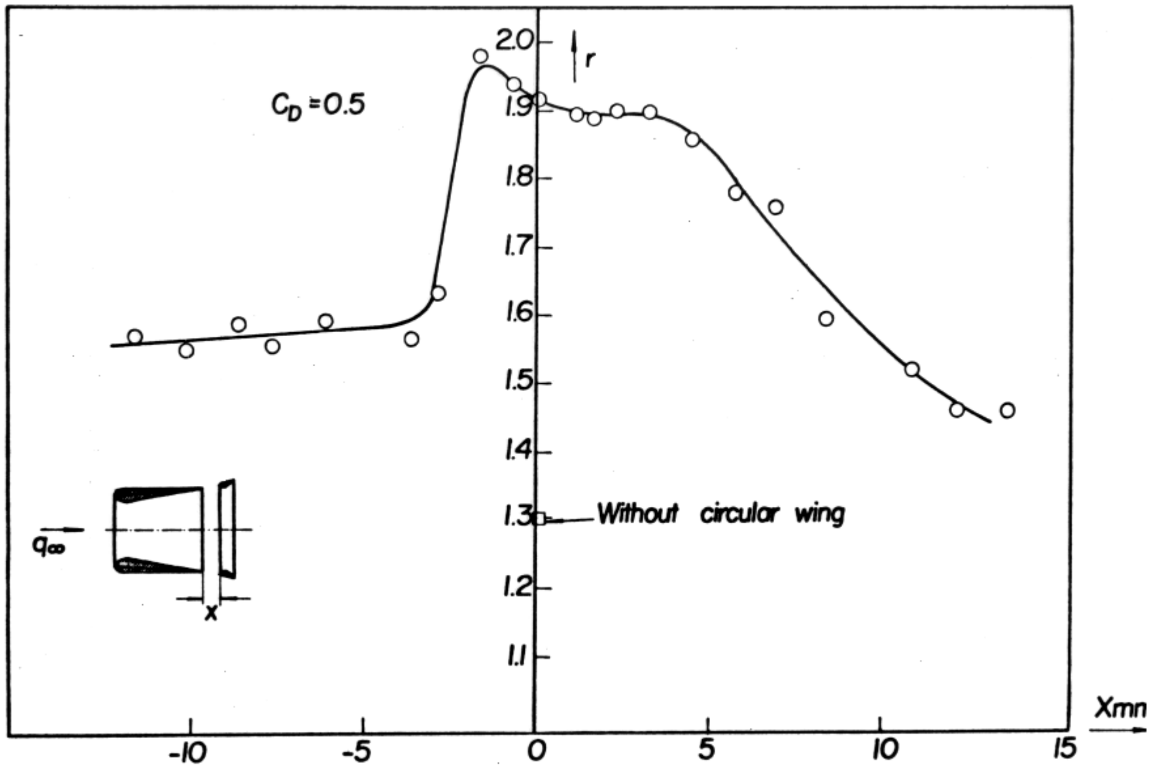

Fig. 29: Diffuser with axial gap between the shroud and the circular wing can improve the power ratio.

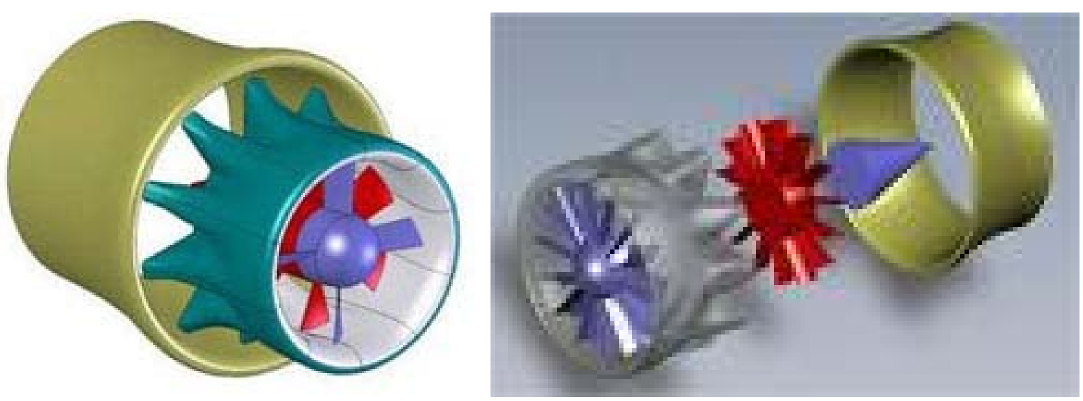

Fig. 30: Shrouded turbine design by Flowind uses vortices trains to accelerate the wind flow.

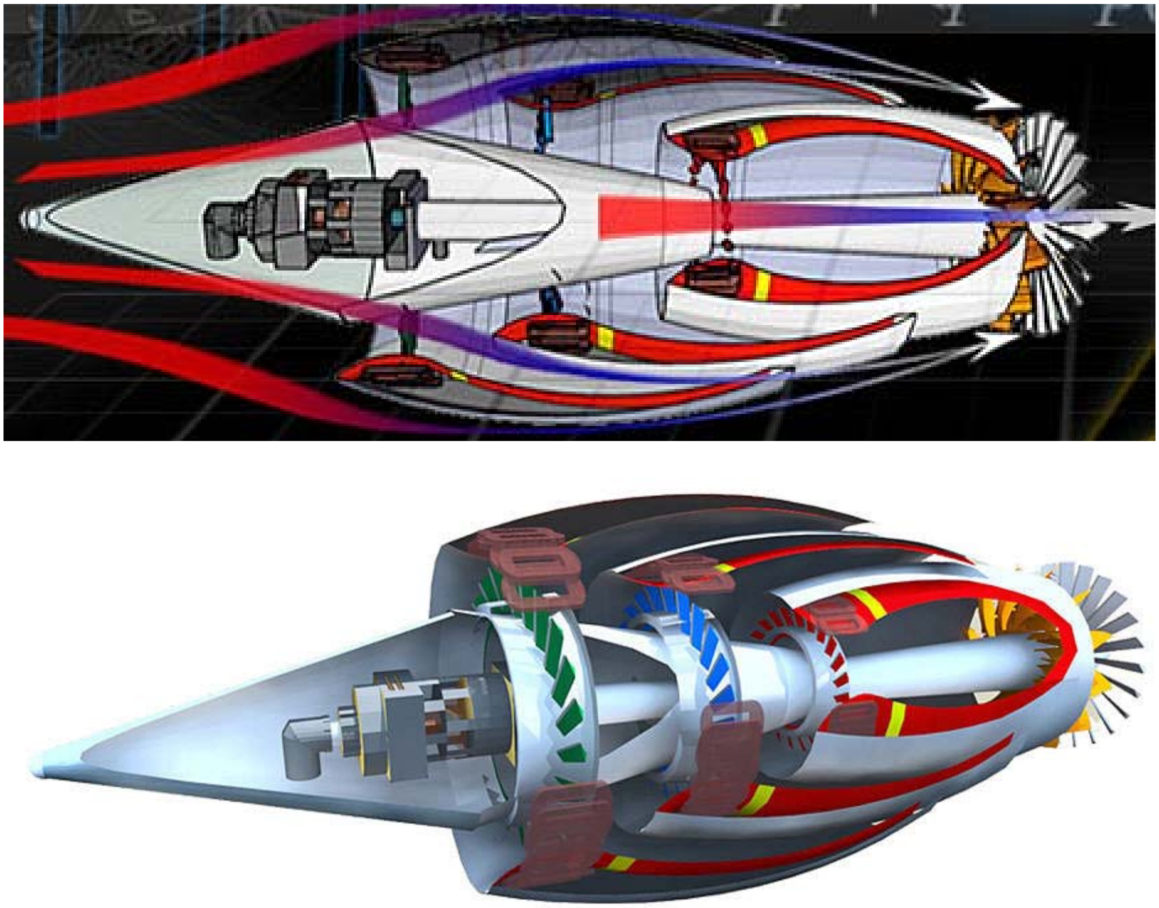

Fig. 31: Conceptual design of three stationary ducts, jet engine inspired, dragonfly system uses either an external rotating wheel at the end (top) or three inner spinners (bottom). A front conical section directs the air flow and encloses the generator inside the nacelle.

SOLAR WIND TURBINE CONCEPT

A shell structure similar to the cooling towers of fossil and nuclear power stations would be constructed of solar energy absorbing material. With a lower opening, the buoyancy generated in the heated air creates a chimney effect. The inlet air from the bottom part would exit at the top transferring its energy to the blades of a wind turbine.

This suggests that the cooling towers of existing conventional power plants can be retrofitted at their top with wind turbines for added energy production from the heat rejected in the rising steam.

A hybrid variant of the concept would have the shell structure covered on its southern side with photo voltaic cells for a combined solar and wind electricity generation.

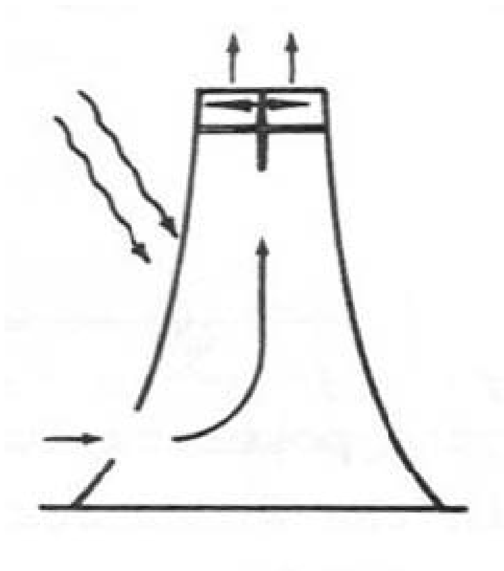

Fig. 32: Solar wind turbine concept.

MAGNUS EFFECT AND AIRFOIL VEHICLES

MAGNUS EFFECT

The Magnus effect was described by Heinrich Magnus in Germany in 1853 and refers to the force produced on a rotating cylinder or sphere in an air or fluid stream. The rotating object creates its own boundary layer and whirlpool around itself and experiences a force perpendicular to the direction of the wind stream. An example of the Magnus effect is the curve ball thrown by a pitcher who imparts a spinning action with his fingers on a baseball. The same effect is observable in volley ball, tennis, golf, baseball soccer and especially ping pong because of the light weight of the ball.

For a rotating cylinder in a fluid the lift force is given by:

$$F = \frac{1}{2}\rho S V^2 \ell \tag{4}$$

where: ρ is the fluid density

S is the cross sectional area

ℓ is the lift coefficient

V is the relative speed between fluid and cylinder

If a cylinder is spun in the direction of wind flow, the cylinder would experience a lift force designated as the Magnus force. A drag force also occurs in the direction of wind flow. The resultant force will move the cylinder in its direction.

MADARAS VEHICLE

Using movable rotating cylinders or airfoils mounted on closed tracks can extract wind energy from the high rotational speed acquired by the wheels. In this case no gearbox is required like in the classic unconfined wind turbine design.

Julius D. Madaras conducted studied over the period 1929-1934 on a large cylinder that is spun in the wind by an electric motor.

If the cylinder is mounted on a special kind of railroad car and the wind speed perpendicular to the railroad track is strong enough, the lift force would be adequate enough to overcome the frictional resistance of the wheels and tracks, and move the car along the tracks. Power can be extracted from the kinetic energy of the system by electrical generators attached to the wheels of the tracked vehicle. The system must be sturdy enough not to be overturned by a strong wind.

The cars would rotate around a circular race track. When the wind becomes parallel to the track, the cylinders rotation would be stopped and reversed in the opposite direction.

Madaras design consisted of 27 m high and 6.8 m diameter cylinders vertically mounted on flat cars. The cars formed an endless train of 18 cars around a 460 m diameter closed track. Generators geared to the cars axles would produce 18 MW of power when moving at a track speed of 8.9 m/s in a wind speed of 13 m/s.

More ambitious studies considered a racetrack 18 km long and 3 km wide oriented perpendicularly to the prevailing wind direction. The cylinders were 39.1 m in height and 4.9 m in diameter. The cars had a length of 19.2 m and a width of 17.4 m. The track width was 11 m between the rails. Each car would weigh 328 metric ton and each cylinder would be spun with a 0.45 MW, 500 Volts DC motors. Each of the 4 wheels on a car would drive a 0.25 MW generator for a total of 0.25 x 4 = 1 MW per car. An overhead trolley bus operating at 4.16 kV, 500 A three phase, would extract power from the system.

Wind tunnel and field tests were conducted to prove the feasibility of the system. Hurdles in the aerodynamic, mechanical and electrical losses and the system's reliability remain to be solved.

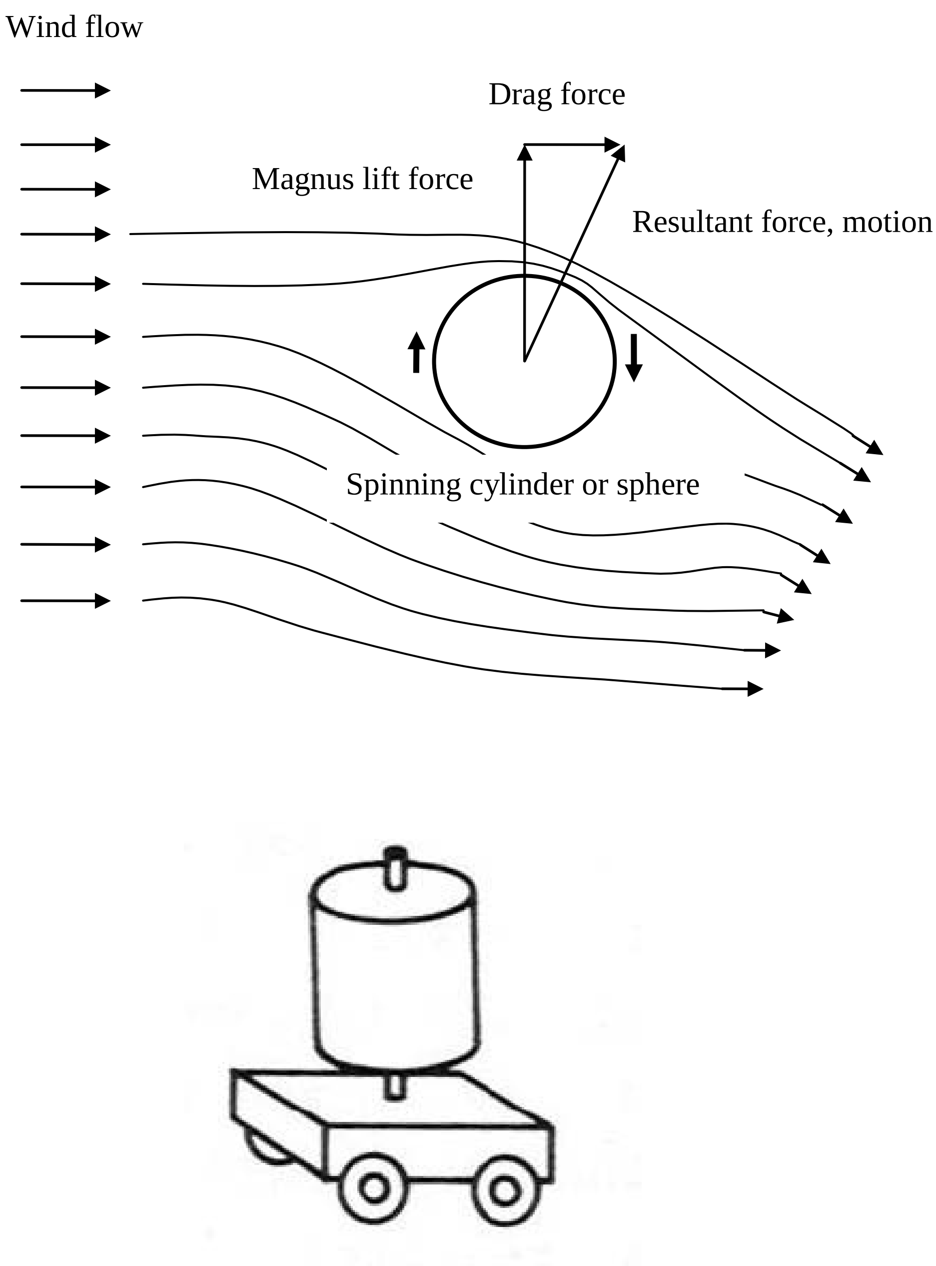

Fig. 33: Magnus effect on a rotating cylinder or sphere, and its adaptation to a tracked vehicle.

A Magnus design with a rotating cylinder would catch the wind from all directions.

The cost of the vehicle tracking system must be balanced against the savings in the gear transmission that is used in blade driven wind turbines where they are used to increase the low rotational speed of the blades to the high rotational speed required by the electrical generator.

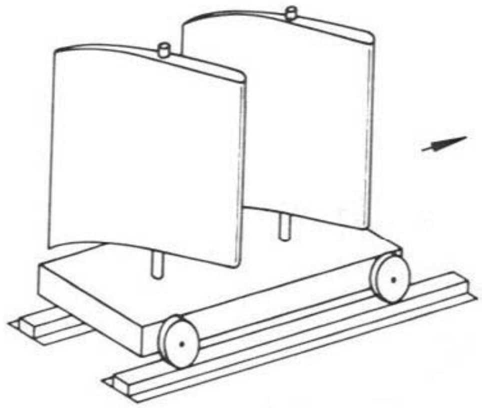

Fig. 34: Vehicle mounted airfoil on tracks.

MAGNUS FLETTNER TURBINE

Anton Flettner built two sea-going ships, the first named Buckau, then renamed Baden-Baden crossed the Atlantic in 1926. The Magnus Flettner rotors allow a sailing vessel to turn about its own axis, apply brakes and go directly into reverse. They allow self-reefing at a chosen wind speed.

With a wind on her quarter, a ship would heel into the wind. The only disadvantage of these vessels is that they have to tack to move downwind. Energy has to be provided for electric motors to spin the rotors, but this was typically 5–10 percent of the engine power for a conventional ship of the same thrust.

After the Atlantic crossing, Flettner obtained orders for six more ships. He built one named Barbara, but had the rest cancelled as a result of the 1929 depression.

Flettner used drums of steel and, later, aluminium. Today much lighter ones could be built with Kevlar or carbon-reinforced epoxy materials.

The main problem was to find bearings capable of taking the large aerodynamic forces at high velocities despite the geometric distortions of heavily loaded structures.

The wind turbine manufacturer, Enercon, was said to be launching a Magnus Flettner rotor ship in 2008 with four rotors, 4 m in diameter and 27 m tall.

The lift forces of a spinning cylinder are higher than those of a textile sail or an aircraft wing having the same projected area. Potential theory predicts that the lift per unit length of rotor should be 2π times the product of the surface speed of the rotor and far-field wind speed.

For a constant rotor speed, it will rise with the first power of wind speed rather than with the square. If the rotor surface speed and wind speed are kept in proportion, square law equations can be used as in aircraft design for comparison with wings and sails.

The spin ratio, defined as local rotor speed over far-field wind speed in a frame moving with the vessel, acts such as the angle of incidence of the airfoil section of an aircraft wing.

Fig. 35: Magnus Flettner rotor equipped ship first named Buckau then renamed Baden-Baden. Source: Popular Mechanics.

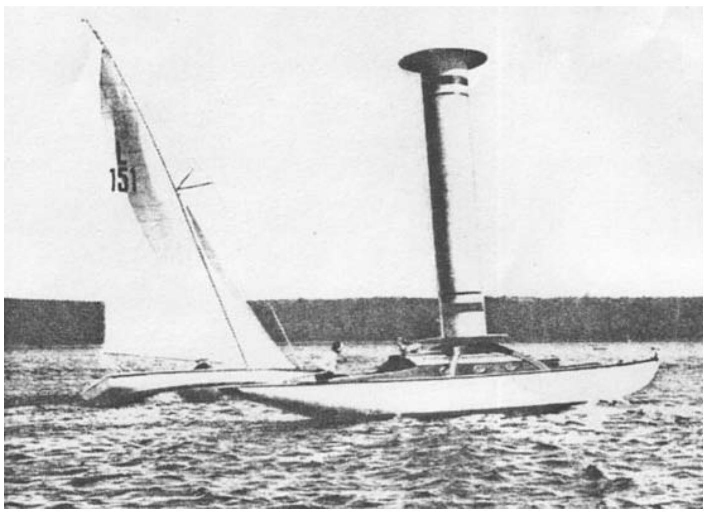

Fig. 36: Magnus Flettner rotor equipped boat in a race with a sial boat. Source: Popular Mechanics.

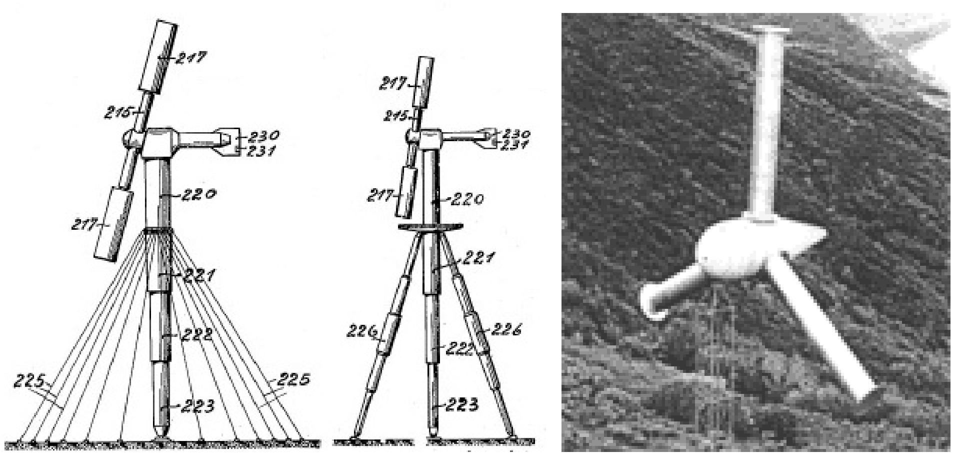

Fig. 37: Use of Magnus Flettner rotor in a wind turbine concept. Barrel blade

experiment, USA, 1983.

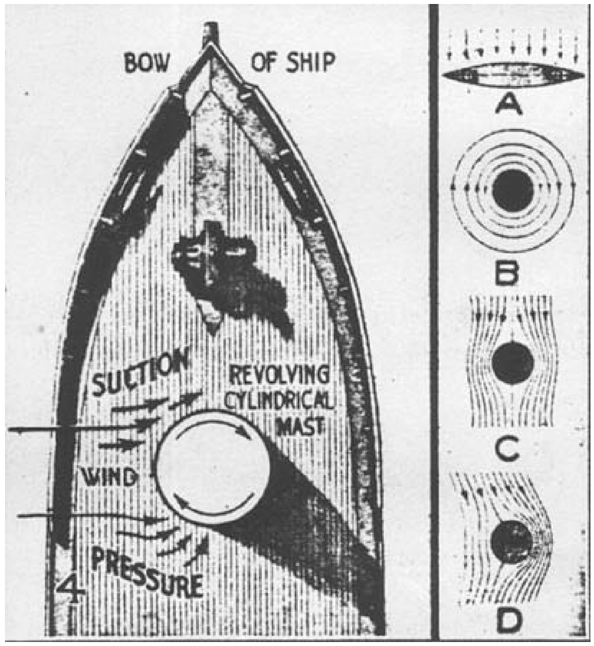

Fig. 38: Operation of Magnus Flettner Rotor.

ENERCON E-SHIP 1

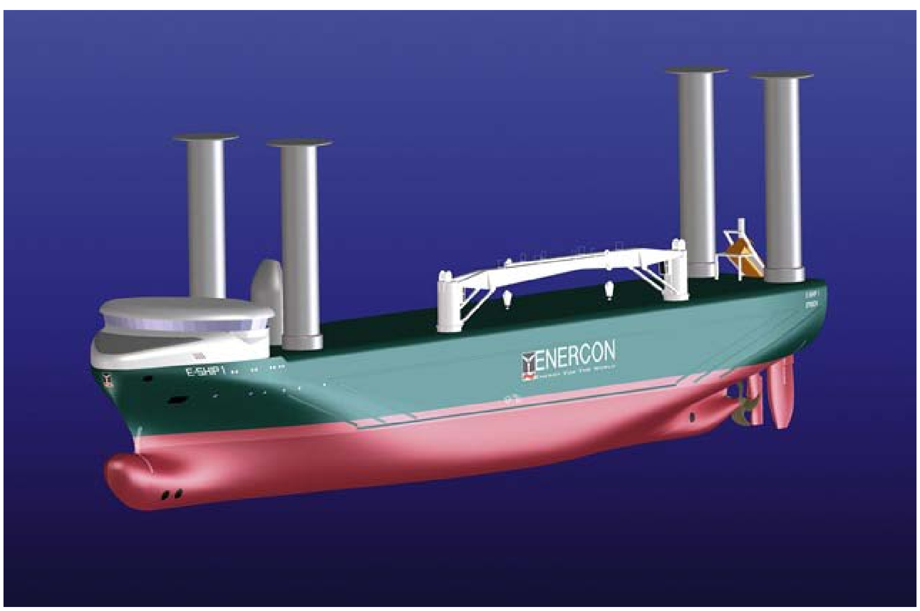

Fig 39: E-Ship 1 uses four giant 25 m high, 4 m in diameter, rotating, vertical metal sailing Magnus-Flettner rotors positioned two fore and two aft to harness wind energy.

The name E-Ship 1 E stands for: Enercon, and is also claimed to represent Electro-technology, Environment, Economy, Ecology Energy, Earth, Endurance, Encouragement, Experience, and Experiment.

The ship was constructed at Lindenau GmbH shipyards, Kiel and was launched on August 2, 2008. Its main components such as sailing rotors, the highly efficient main engines, and the ship's streamlined silhouette above and below the water line. It has been designed to cut down fuel costs by 30 percent.

Table 1: Technical specifications of E-Ship 1.

Length	130.0 m
Width	22.5 m
Draught	6-9 m
Tonnage	10,500 tdw /9,700 tdw
Speed	17.5 knots
Engine power	2 x 3.5 MW
Capacity, 3 holds below deck	20,580 m^3
Ice class	E3

Enercon plans on using the vessel to transport wind turbines and components worldwide by 2009.

THOM ROTOR

Part of the drag on an aircraft wing is due to the permanent tip vortex generated by the positive pressure on the under surface driving air to the negative pressure on the upper surface. The effect can be minimized by high aspect-ratio wings, such as those of the albatross, and by tip fins. For this reason, Flettner added discs to the tops of his rotors.

As a further design development, Thom in 1934 experimented with multiple discs or fences and found that they produced very much higher lift coefficients and sometimes even negative drag coefficients.

The negative drag coefficients imply that some forward drive power is being taken from the rotor drive.

Fig. 40: Cloudia catamaran with Thom rotor.

Fig. 41: Conceptual design of cloud seeding autonomous ship with Thom rotors.

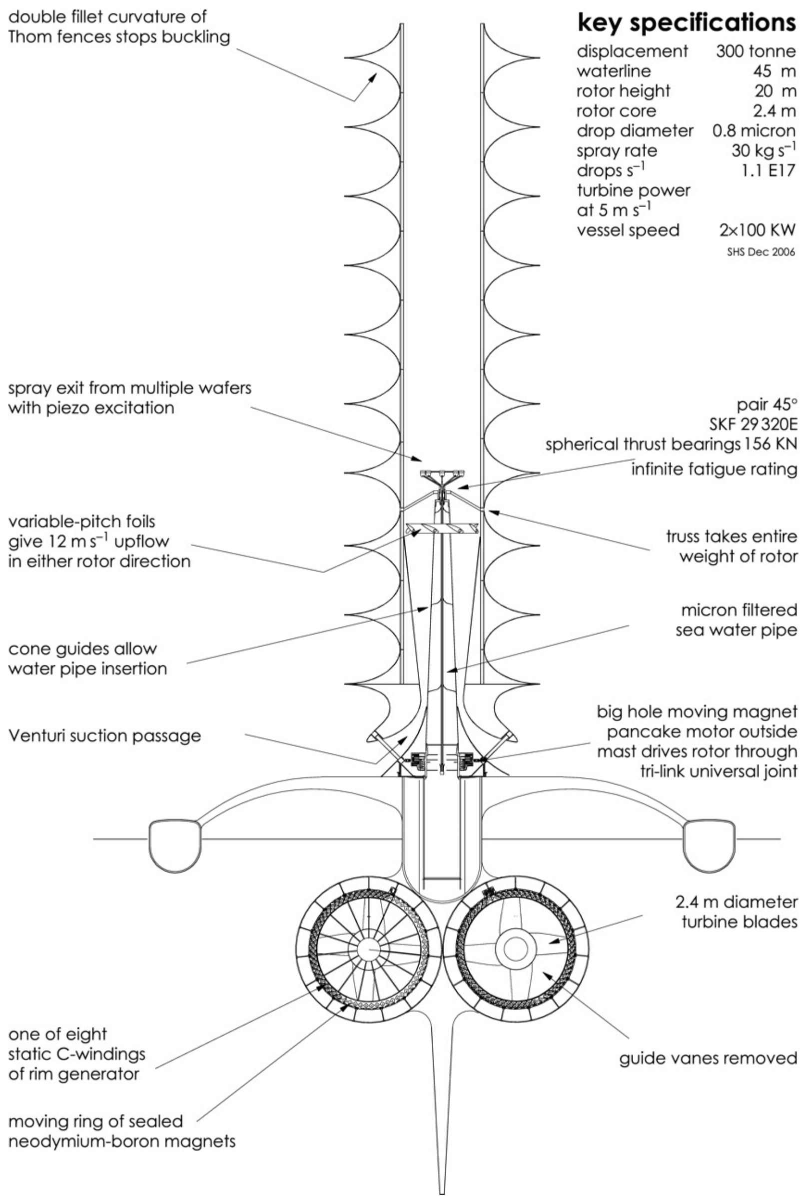

Fig. 42: Details of the Magnus Flettner rotor with Thom fences for cloud seeding.

LESH ROTOR

Unlike the Magnus Flettner rotor which needs to be rotated by an electrical motor, Laurence J. Lesh uses vertical boat that would start spinning in a blowing wing. They contine spinning until the wind dies out or the brakes are applied. It is suggested that such a configuration would give four times the propelling power of ordinary sails. Rotors can be covered with canvas, plywood or polished aluminum.

The rotor can spin equally well in either direction compared with a Savonius which would require a mechanism to shft the halves of the rotor when a ship heads in the opposite direction.

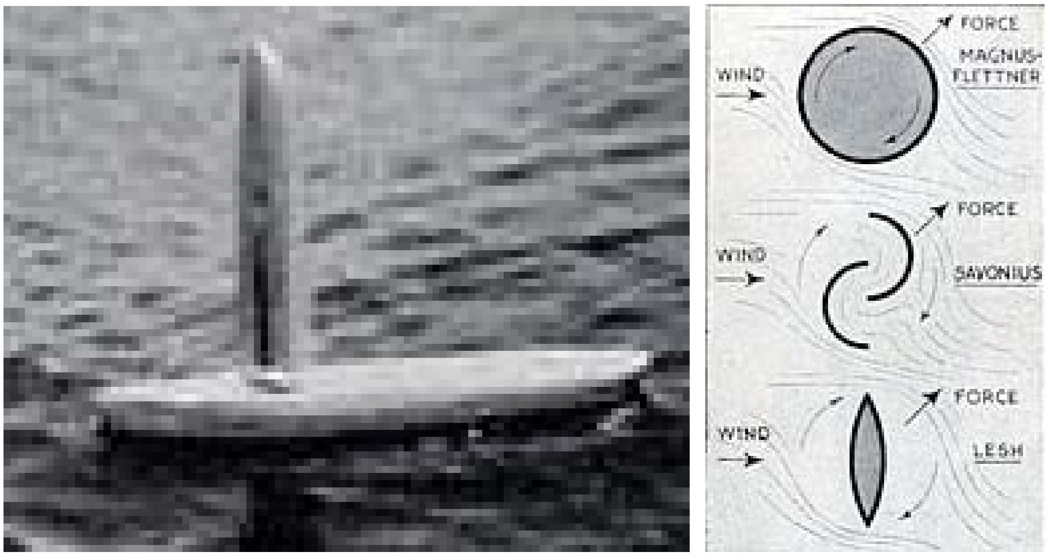

Fig. 43: Lawrence J. Lesh Rotor compared with Magnus Flettner and Savonius rotors.

SPIRAL MAGNUS

The Spiral Magnus Wind Turbine does not make use of common propeller-type rotor blades. Instead, the technology makes use of cylinder-shaped blades with spirally-arranged fins attached around the cylinders.

The result is a wind turbine that claims higher efficiencies in lower wind speeds than traditional wind turbines. Because the rotational speed is about one-sixth of common propeller types, these turbines are relatively quiet and gale winds resistant. The Magnus Effect lift turns the turbines by spinning cylinders in a wind stream.

Each of the five blades in the form of cylinders spins driven by a built-in electrical motor and wind blowing through the cylinders rotates the rotor.

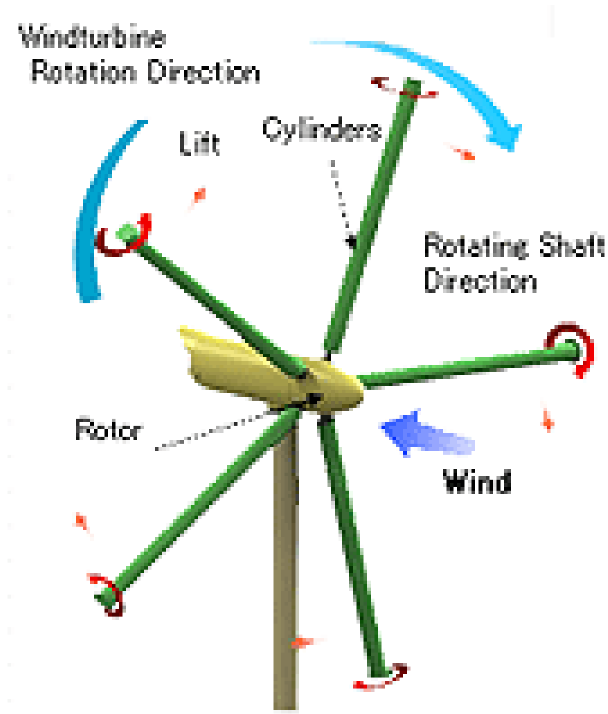

Fig. 44: Spiral Magnus wind turbine. Source: Mecaro.

WIND TURBINE DRIVEN BOAT

A wind turbine has been incorporated into a catamaran design, Revelation II. The power from the wind turbine is transmitted to propeller. The design must overcome both the wave resistance and the wind drag on the turbine.

Fig. 45: Revelation II wind turbine powered catamaran.

IMPULSE, DRAG CROSS WIND, SAVONIUS DEVICES

These impulse or drag concepts do not use airfoils and have been used in rugged circumstances by tinkerers using available material supplies such as oil drums split in half lengthwise then welded the two halves together with an offset from each other to catch the wind, in a concept developed by S. J. Savonius in Finland, or even simpler cross wind paddle designs.

Savonius reported an efficiency of 31 percent in a wind tunnel test and 37 percent in free air. He did not specify in detail his configurations to be duplicated by others.

The advantages of the Savonius design is its great construction simplicity and high starting torque. The disadvantages are the weight of the materials and the need to design the rotor to withstand high winds.

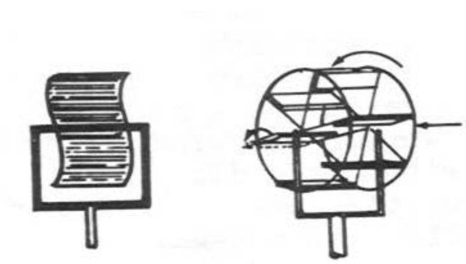

Fig. 46: Cross wind paddle designs.

The Savonius concept includes single and multi bladed wheel designs.

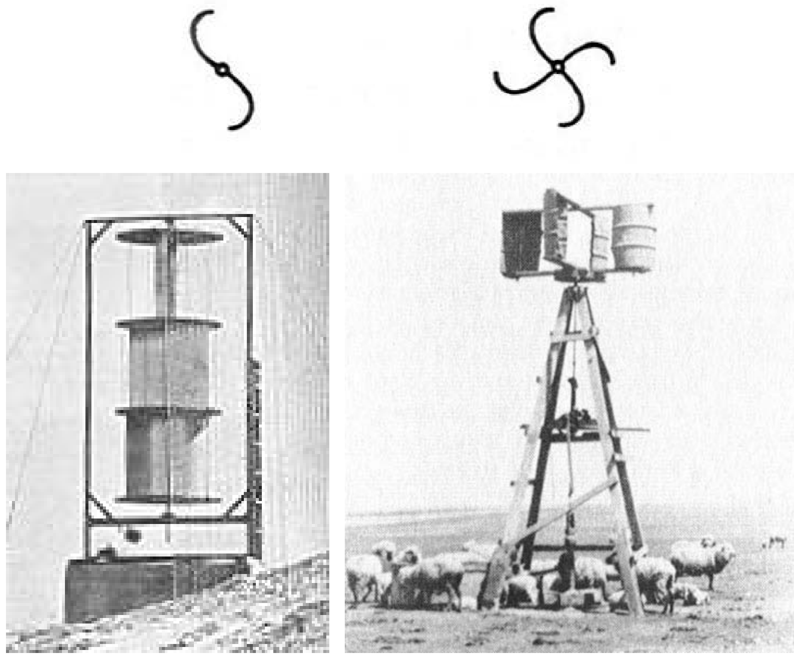

Fig. 47: Single and multi bladed Savonius wheels.

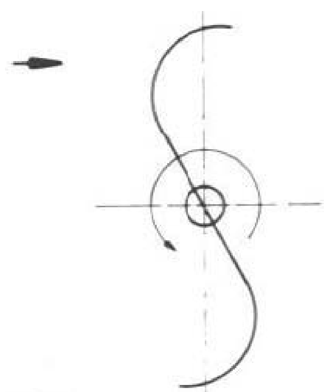

Fig. 48: Drag force rotation of single bladed Savonius wheel.

Fig. 49: Split Savonius blades use mixed lift and impulse drag forces.

A variant of the concept is the offset split Savonius blades configuration which uses mixed drag and lift forces.

The best representative of impulse drag systems is the multi bladed American farm wind mill design.

Another drag design uses rotating cups as in the case of a wind anemometer. Still another uses drag plates, but its efficiency is enhanced by using a shield. An evolution of this concept is the gyromill design. An example of it is the Stephan Hooper 1816 design.

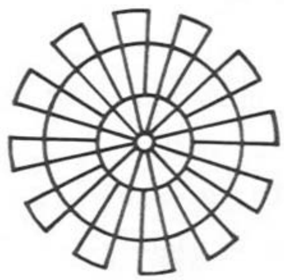

Fig. 50: American farm windmill multi bladed impulse drag turbine design.

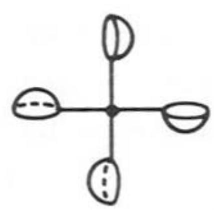

Fig. 51: Impulse drag cupped turbine.

Fig. 52: Plates impulse drag turbine with a shield.

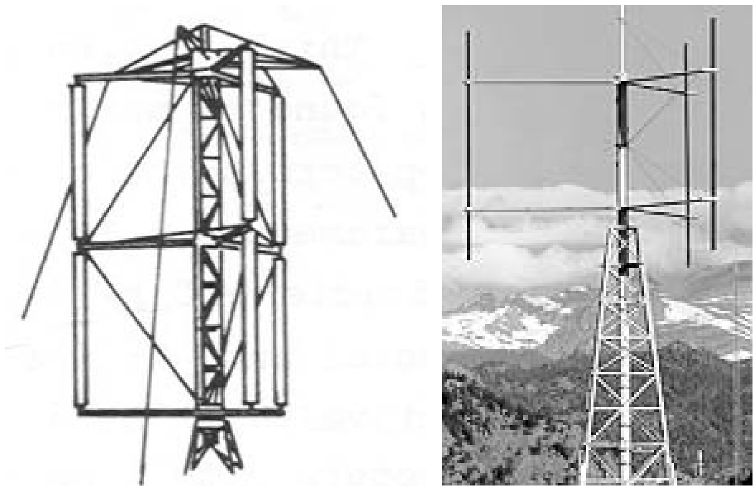

Fig. 53: Gyromill design.

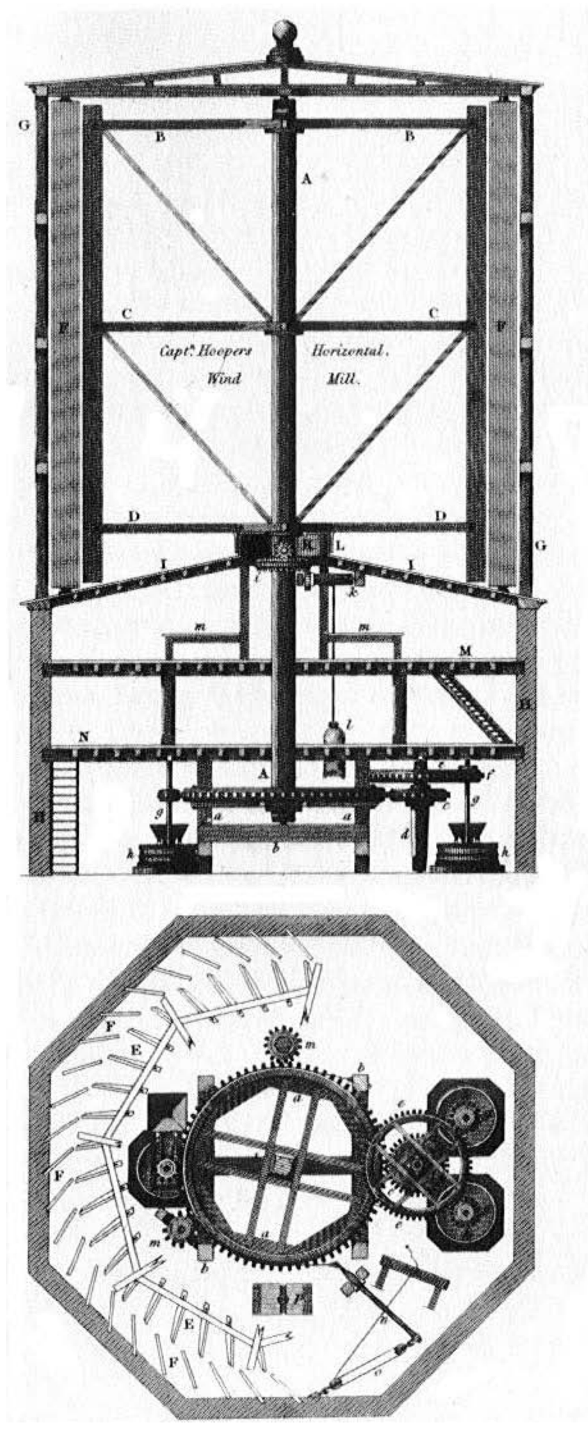

Fig. 54: Stephan Hooper vertical wind mill design, 1816.

MULTI ROTORS DESIGNS

Counter rotating rotors would lead to the cancellation of some of the torsional loading of single bladed systems.

Another unexplored advantage is that an electrical generator with counter rotating stator and rotor would constitute a direct drive system eliminating the need to use a gear box.

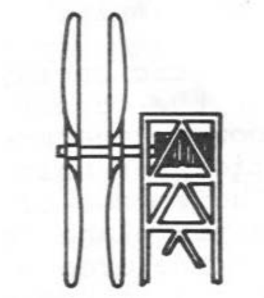

Fig. 55: Counter rotating rotors turbine.

The relative costs of the structural towers and the rotors assemblies may justify the positioning of multiple turbines on a single tower structure.

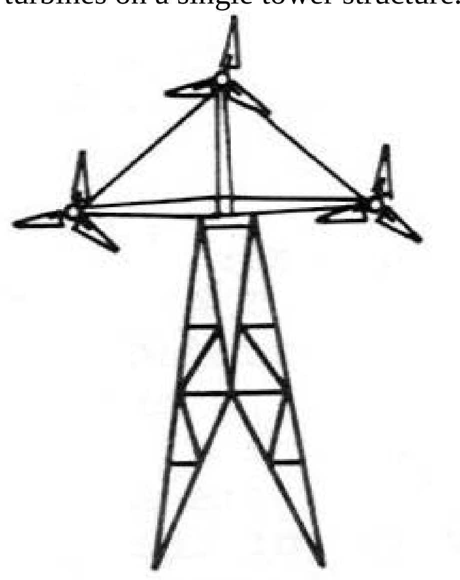

Fig. 56: Multiple turbines sharing a common structural tower.

Multiple blades on a single rotor shaft can also be considered.

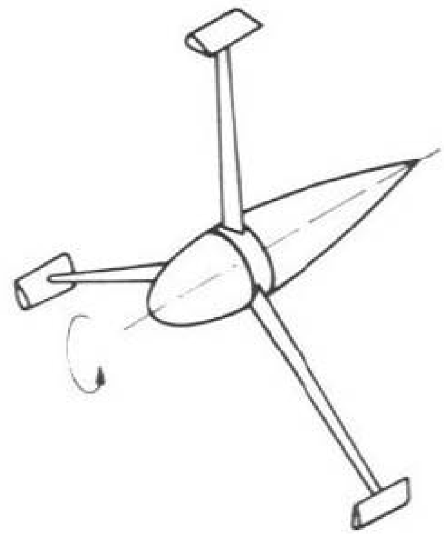

Fig. 57: Multiple blades on a single shaft.

Bicycle wheels turbines have been offered as providing higher vibrational stability.

Multiple rotors enclosed on outside rims can use a single structural tower and feed a single electrical generator with their outside rims in the bicycle looking device of Fig. 59.

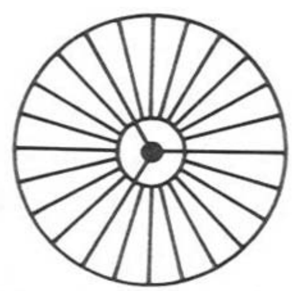

Fig. 58: Bicycle rim turbine.

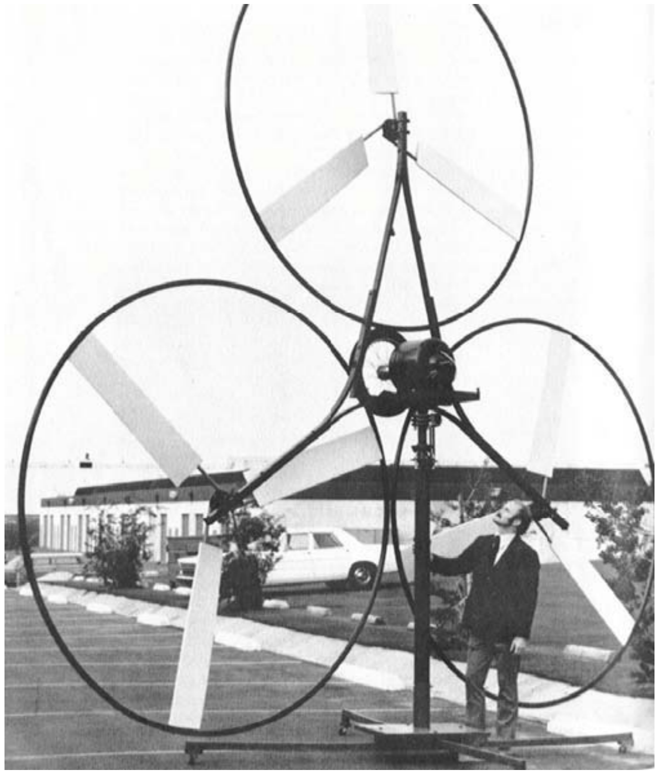

Fig. 59: Multiple rotors sharing a single tower and feeding a single electrical generator with their outside rims.

TURBINE BLADED DESIGN

Instead of rotors or cups a turbine bladed design has been suggested. It has been implemented as a vertical helical turbine system for small applications.

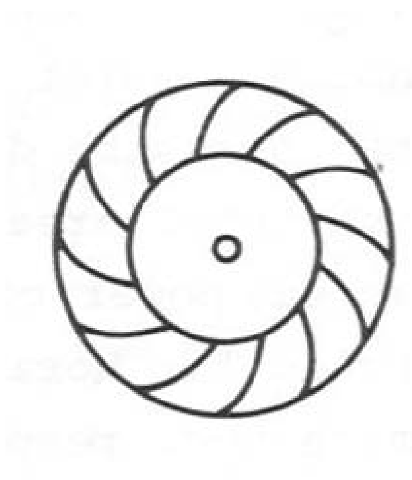

Fig. 60: Turbine bladed design of a wind generator.

Fig. 61: Horizontal helical turbine.

Fig. 62: Vertical helical turbine.

HORIZONTAL AXIS SPIRAL

This concept would use spiral rotors extended between two vertical towers or poles, taking advantage of the higher wind speeds at higher elevations above the ground. At one end a generator would convert the rotational energy induced by wind breezes into electrical power. The spiral rotor could extend between two buildings in the urban environment and between electrical poles in the rural environment.

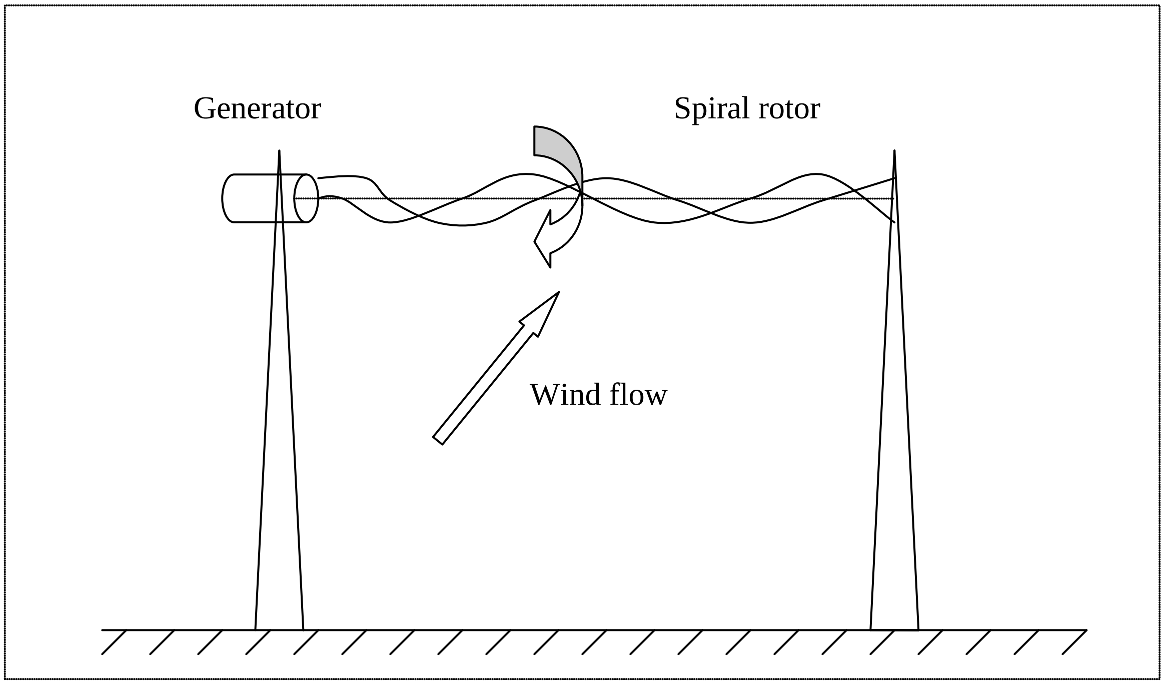

Fig. 63: Spiral rotor turbine extended between two towers.

DISCUSSION

Extracting energy from the wind will continue to challenge the ingenuity and the imagination of the human mind both through the invention of new devices or the re-invention of the older concepts using newly available materials or control systems.

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