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Proposal for the Use of a Controlled Tornado-like Vortex to Capture the Mechanical Energy Produced in the Atmosphere from Solar Energy

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Abstract

The energy of the wind could be harnessed by controlling the atmospheric process so that wind energy is released at high intensity, at selected locations. An engine consisting of a controlled tornado-like vortex is proposed.

Mechanical energy, the kinetic energy of the wind, is produced in the atmosphere because the atmosphere is an engine where solar radiation is partly transformed into mechanical energy. Solar energy is received at low intensity but the mechanical energy produced in the atmosphere from solar radiation is occasionally released at high intensity. The existence of storms and particularly of tornadoes proves that low intensity solar radiation can result in high intensity mechanical energy.

The mechanical energy is produced where the heated air rises and expands and not necessarily where the solar radiation is received. It is proposed to capture the mechanical energy produced in the atmosphere by forcing the expansion to take place at a selected location by means of a controlled vortex similar to a natural tornado.

The vortex would be established above a station consisting of a ring of deflectors. The proposed vortex power station is shown in Fig. 1. The vortex would be started by heating the air within the station with fuel. Once started, the vortex would persist without further heating with fuel because the air at the bottom of the atmosphere is heated by solar radiation. Some of the mechanical energy produced by the expansion of the rising air would be harnessed by expanding some of the air surrounding the station into the low pressure zone produced by the vortex via turbines installed under the deflectors. The station would be 100 to 1000 m in diameter.

Mechanical energy is produced when heat is convected upward. Conditionally unstable air is in a metastable state in the sense that when it is lifted sufficiently it becomes less dense than ambient air, and then continues to rise from its own buoyancy. It is well known that warm rising air is diluted by the air through which it rises and that this is a factor which inhibits convective heat transport. One might use a large chimney to prevent rising air from being diluted by ambient air. An upward flow could be established in a large chimney by heating the air within the chimney with fuel. The upward flow in the chimney would persist after the heating with fuel stops when conditional instability exists.

The use of a large chimney to promote convection and to produce precipitation is an old meteorological concept. Recently Starr *et al.* (1974) proposed the use of a vertical tube called an aerological accelerator to produce precipitation. Ley (1954) has described a proposal by Dubos in 1925 of a power station involving a large chimney.

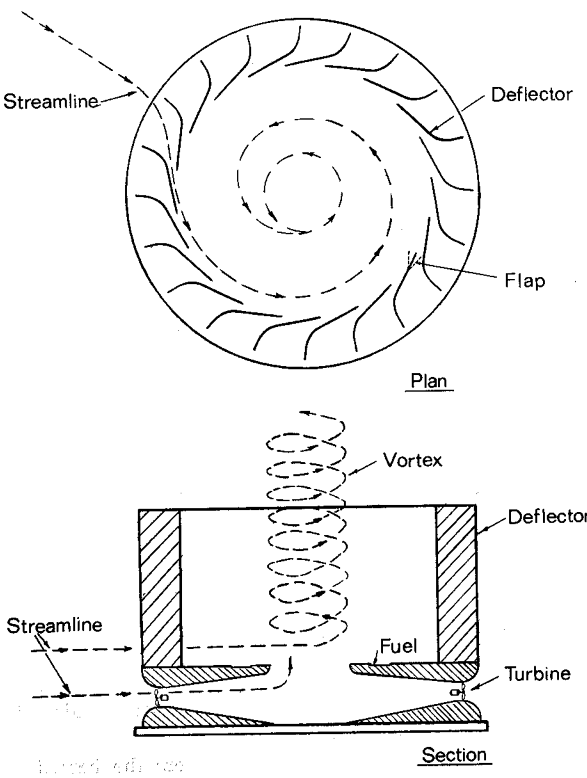

Fig. 1. Vortex power station.

The operation of a natural draft chimney depends on the fact that a chimney is a cylinder in radial compression which prevents convergence in the horizontal plane in spite of the fact that at any given level the pressure is less inside than outside. The puffy appearance of hot smoke coming out of a chimney shows how rapid is the ingress of ambient air into the rising smoke once the protection provided by the chimney stops. A solid chimney could be replaced by a cylinder of air rotating about the vertical axis. The centrifugal force produced by the rotation of a mass of air can prevent horizontal convergence just as well as the solid wall of a chimney.

Tornadoes, water-spouts, and dust devils are rising currents of air which rotate about the vertical axis as they rise and which owe their existence partly to centrifugal force preventing dilution. The reason why the air that rises in a tornado rotates is that when the air which is at the bottom of the atmosphere converges, its angular velocity must increase to conserve angular momentum. And the reason why the air converges towards one point is that at this point there is a vortex chimney.

It is proposed to produce a controlled atmospheric vortex above a station consisting of a ring of deflectors. The station could be as shown in Fig. 1, the lower section containing the turbines is not essential. The deflectors could be similar in construction to aircraft wings. The vortex would be started by burning some fuel on the bottom of the station. The air within the station would rise as a result of the heating, and the air surrounding the station would converge towards the center of the station to replace the rising air. The converging air would acquire angular momentum when it passes between the deflectors, and as it continued to flow towards the center of the station its angular velocity would increase to conserve the acquired angular momentum. This air would rotate when it rises and centrifugal force would prevent its dilution by the air through which it rises. Once established, the vortex should persist after the heating with fuel has stopped, and should remain inside the station; provided that the station is large enough, that the atmosphere is sufficiently unstable, and that the horizontal wind is not excessive.

I verified part of the hypothesis on a small model in my back yard. I produced vortices that looked like small tornadoes by burning some fuel spread on the ground inside a circle of deflectors. See Fig. 2. These vortices did not persist after the heating with fuel stopped because the tests were on too small a scale. The largest test was done with deflectors 1 m high placed on a circle 1.5 m in diameter. The largest vortex produced was approximately 10 m high by 0.1 m in diameter.

Substituting high intensity heating with fuel for low intensity solar heating makes it possible to produce vortices using a small station. The fact that a given quantity of fuel burned much more rapidly and completely with deflectors than without deflectors was interpreted as proof that a vortex has an effect similar to that of a chimney.

The tests indicated that the base of the vortex would remain in the center of the station. A ring of fuel outside the ring of deflectors was ignited just before the fuel inside the ring of deflectors burned out, and the vortex remained in the center of the ring of deflectors even after the fuel inside the ring of deflectors had burned out.

The thermodynamic cycle of the proposed process is shown in Fig. 3. For the purpose of thermodynamic calcula-

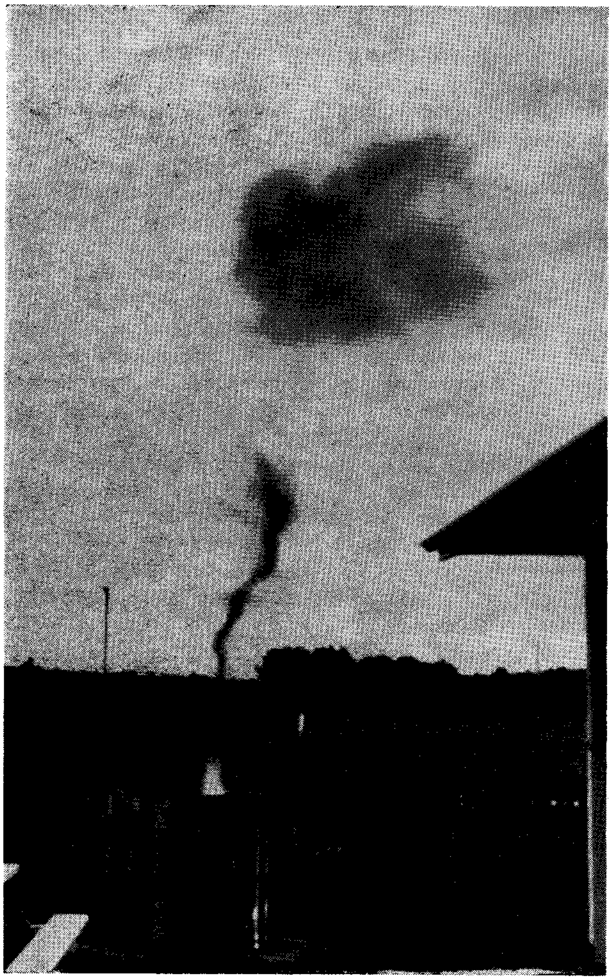

FIG. 2. Vortex produced by burning fuel inside a circle of deflectors.

tions the cycle can be considered independently of the atmospheric process. The cycle is very similar to the standard gas turbine power cycle. The gas is compressed by being lowered instead of in a conventional compressor, and the work of compression is supplied directly by the work of expansion. The pressure differential across the turbine results from the difference in weight between a column of cooled gas and a column of uncooled gas. A standard gas turbine power cycle cannot operate across a small temperature differential because of the low efficiency of mechanical compressors, but using gravity to compress a gas as it is lowered is very efficient, so that the cycle is practical for small temperature differentials. The engine must be several kilometers high to achieve even a small temperature differential.

Cycle calculations are carried out by applying the energy balance equation in the following form to each process of the cycle (see list of symbols at end of note):

$$Q - W_s = \Delta H + \Delta gz + \Delta v^2/2. \qquad (1)$$

The calculations show that if the cycle is assumed to be reversible the net cycle work is equal to the work that would be produced if the heat transfer was accomplished via Carnot engines, irrespective of the quantity of heat transported per unit mass of air and irrespective of whether the heat is transported as sensible or latent heat. The effect of irreversibilities can be investigated by replacing the turbine with a restriction where an amount of irreversible work to heat reversion equal to the net cycle work takes place. The restriction can be lumped or distributed around the cycle to investigate various effects. An interesting feature of the cycle is that the net cycle work is released at the point where there is the most resistance to flow; the turbine could be located anywhere around the circuit.

The efficiency of a Carnot engine transferring heat from a temperature of 15°C at the bottom of the troposphere to a temperature of −50°C at the top of the troposphere would be 23%. According to Gray (1973) the convective heat flux is a maximum at the bottom of the troposphere and gradually decreases to zero at the top of the troposphere. Taking the average temperature of the cold source as −15°C, the amount of mechanical energy produced in the atmosphere is 10% of the convective heat flux at the bottom of the atmosphere. Taking the average upward convective heat flux, both sensible and latent, at the bottom of the atmosphere as 100 W/m^2, the amount of mechanical energy produced in the atmosphere is 10 W/m^2. Kung (1966) calculated that the amount of mechanical energy that must be produced to support large scale circulation is 7 W/m^2. Based on the value of 10 W/m^2, the amount of mechanical energy produced for an area of 1000 km^2 is 10 000 MW. The fact that large quantities of mechanical energy are produced is recognized; capturing this energy is the problem.

Starr *et al.* (1974) have concluded that an aerological accelerator cannot supply a significant amount of power. Starr's conclusion is based on the fact that the kinetic energy of the air leaving the top of the tube is lost. This conclusion is valid for an aerological accelerator but not for a vortex. There is a zone of divergence at the top of a vortex where the vertical velocity of the air reduces to zero and where the kinetic energy of the air is recovered. A similar effect could be obtained by flaring the top of the aerological accelerator, a technique commonly used to reduce exit losses.

Starr *et al.* used the following equation:

$$gL\frac{(\rho_e - \rho)}{\rho_t} = \frac{2L}{R}\frac{\rho}{\rho_t}C_D w^2 + w_t^2. \qquad (2)$$

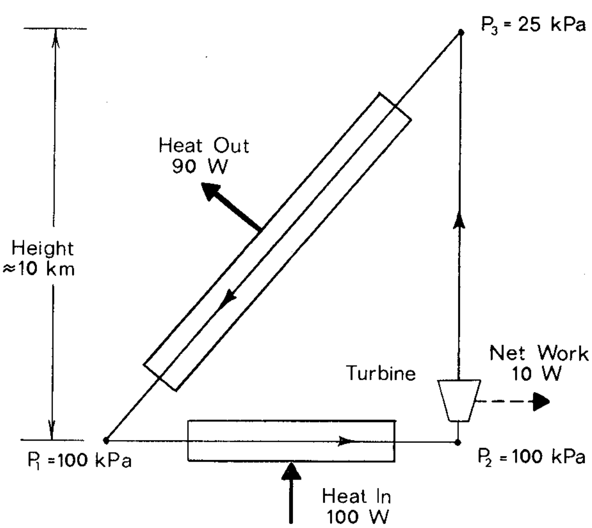

FIG. 3. Vertical power cycle.

The left hand term represents the energy available from buoyancy forces, the first term on the right represents the energy required to overcome viscous friction in the tube, and the second term on the right represents the kinetic energy of the air leaving at the top of the tube. When the effect of divergence at the top of the vortex and the consequent reduction in vertical velocity is considered the last term drops out of the equation.

The effect of dropping the last term plus the increase in height and diameter possible with a vortex can increase the amount of energy released from 5 MW calculated by Starr *et al.* to several thousand megawatts. A further effect of vortex flow is that centrifugal force prevents the flow from becoming turbulent even though the Reynolds number is high. At high Reynolds numbers the value of the friction factor, C_D, is much lower for laminar flow than for turbulent flow. The value of the friction factor could therefore be two orders of magnitude less for a vortex than for a tube. This reduction in friction factor plus the increase in diameter with height would further increase the amount of mechanical energy that can be produced.

The differential pressure developed at the base of a tornado indicates that only a small amount of the energy released is required to overcome friction in the tuba. Most of the energy released is required to overcome the resistance to the flow of converging air at the base of the vortex because convergence is only possible in approximately the bottom 10 m of the atmosphere where friction reduces the angular momentum of the converging air. As far as resistance to flow is concerned, a tornado 50 m in diameter at the base may be equivalent to a vertical tube 10 km high by 0.5 km in diameter at the base and 5 km in diameter at the top, with a passage only 10 m high between the bottom of the tube and the Earth's surface.

In the proposed engine the turbine is effectively placed in parallel with the point of the cycle where there is the greatest resistance to flow. It is expected that it will be possible to extract energy with the turbines without excessively reducing the intensity of the vortex because with a vortex station it is possible to raise the base of the vortex and to reduce the amount of energy dissipated in the convergence zone. For the same reason it may be possible to sustain a vortex when atmospheric conditions are less unstable than found in tornadoes.

An atmospheric vortex must have a minimum size to be self sustaining because the air at the bottom of the atmosphere must be lifted enough to become appreciably less dense than the overlying air, and because the amount of energy required to overcome viscous friction per unit mass of flow decreases with size. I estimate that it would be possible to produce a self sustaining vortex with a station 10 m in diameter, under optimum conditions, when instability is pronounced. A power station would have to be 100 to 1000 m in diameter. The deflectors could be 20 to 100 m high. The capacity of the station could be 1000 MW of mechanical energy. There could be 400 turbines of 2.5 MW capacity by 10 m in diameter around the perimeter of the depression chamber. The turbines could be similar in construction to aircraft propellers. The pressure differential across the turbines could be from 0.01 to 10 kPa. Heating with fuel for 5 min would be sufficient to establish the vortex. The diameter of the vortex and the quantity of air flowing could be controlled by adjusting flaps on the tips of the deflectors. Increasing the amount of deflection and the amount of jetting between the deflectors would increase the diameter of the vortex. There might be locations where it would be possible to operate such a power station most of the time.

The use of a circle of deflectors to produce a vortex and to promote convection and precipitation was proposed by Dessoliers (1913). He proposed to use a black heat absorbing surface to start the vortex. In the 1950s H. Dessens, as reported by J. Dessens (1962, 1969), produced tornado-like vortices over 1 km high by using gas burners oriented tangentially on the arms of a spiral. H. Dessens was attempting to produce convection and precipitation by the use of heat; he did not use deflectors; the vortex formed downwind of the heating device. Recently, Nazare (1973) proposed a 1000 MW power station consisting of a 600 m high chimney similar to a natural draft cooling tower, with a large turbine at the throat. He proposed using deflectors in his tower to produce a cyclone.

More extensive study of feasibility of the proposal and of many related problems is required. There might be beneficial uses for this process other than the production of energy. The process could be used to produce precipitation or to otherwise influence weather. The possibility that adverse weather conditions might be created would have to be considered.

It is generally recognized that the amount of energy produced by man is small compared to the amount of energy produced in storms. Based on an average of 10 W/m² the amount of mechanical energy produced in the atmosphere is 5100 TW. The total amount of energy produced by man is 10 TW. Control of the atmospheric engine could make the vast amount of mechanical energy being produced in the atmosphere available to do useful work. Weather control is a potential source of energy.

The calculations on which this proposal is based are given in a companion manuscript (Michaud, 1974) oriented toward the engineering community.

Definition of Symbols

W_s	heat (kJ/kg)
Q	shaft work (kJ/kg)
H	enthalpy (kJ/kg)
g	acceleration of gravity (9.8 m/s²)
z	elevation (m)
v	velocity (m/s)
L	height of tube (m)
ρ_e	average density of environment (kg/m³)
ρ	average density in tube (kg/m³)
ρ_t	density at top of the tube (kg/m³)
R	radius of the tube (m)
C_D	friction factor (dimensionless)
w	average vertical velocity in tube (m/s)
w_t	vertical velocity at top of the tube (m/s)

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