# VERTICAL AXIS WIND ROTORS - STATUS AND POTENTIAL

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Except for a rather inventive period in the 1920's, the approach taken to extracting power from the wind has been that of using blades or vanes rotating about a horizontal axis with the plane of the blades essentially perpendicular to the wind velocity vector. The two devices shown in figure 1 were patented almost 50 years ago and have as a common element a vertical axis of rotation. The first device, patented by Msr. G. J. M. Darrieus in 1931, has received some recent study by the National Aeronautical Establishment in Canada; the second was developed and patented by Mr. S. J. Savonius in 1929. These rotors share a performance characteristic which differentiates them from the horizontal axis wind rotors, namely, their ability to operate equally well regardless of the direction of the wind. This characteristic is important because it permits the rotor to extract the energy of a given wind or gust instantaneously regardless of any rapid changes in wind direction. Considering that the energy available from the wind is proportional to the cube of the velocity, the feature of not having to take time to head the machine into the wind may well provide additional energy extraction capability over that of a horizontal axis rotor. It is also likely that the elimination of a heading control and servosystem will tend to reduce acquisition and maintenance costs and improve reliability.

Although a number of applications were developed for the vertical-axis rotor, the concept never became popular. Horizontal axis machines were improved over the years and have received substantial attention, perhaps largely due to the availability and advance of propeller theory. We believe that the time is right to take a hard look at the vertical axis machines to see if recent advances in aerodynamics, structures, and materials technology might not place these concepts individually (or perhaps in combination) in a favorable light in comparison with the horizontal axis wind rotors.

To maintain brevity, we will concentrate on the S-rotor for the remainder of the presentation. The configuration of the original S-rotor shown in figure 2 resulted from some 30 or more wind tunnel and field tests conducted by Savonius wherein he varied some of the parameters of the rotor.

Essentially, the device operates (at least during part of its rotation) as a two stage turbine wherein the wind impinging on the concave side is circulated through the center of the rotor to the back of the convex side, thus decreasing what might otherwise be a high negative pressure region. The flow is indicated in figure 2.

Savonius applied his wind rotor to water pumps, ship propulsion, and building ventilators, all with some success. In addition, he also showed the feasibility of using the energy in ocean waves to drive the rotor. This last application was developed subsequentially as an ocean current meter and is available commercially. Very good current measurement capability exists in a region of from 0.05 to 5 knots.

In reviewing the work that has been done on vertical axis rotors, we have concluded that there are a number of development alternatives that should receive some attention from the standpoint of both test and analysis. Figure 3 indicates some of these alternatives. The effects of aspect ratio (the ratio of rotor height to diameter) and the number of vanes will be discussed in detail below. The issue of the profile of the rotor has not been investigated, at least in terms of large (50 ft high or greater) machines. Questions have arisen concerning whether more of the area of the rotor should be at the top to catch the higher wind speeds or whether the area should be at the bottom to provide a more uniform torque distribution along the height. The rotor camber and thickness distribution also need to be optimized. Our own limited amount of test data have indicated that the amount of venting between the rotor vanes has a very significant effect on the rotor speed for a given wind speed.

Figure 4 presents some of the results of a preliminary analysis of the impact of rotor aspect ratio on rotor acceleration. Most of the rotors in use have relatively low aspect ratios (refs. 1 to 3). If we look at the rotor's ability to accelerate as defined by the ratio of the torque on the rotor to its polar inertia, it can be shown that this characteristic improves in proportion to the square root of the aspect ratio as aspect ratio increases. Clearly, there must be limits to this trend due to structural or other considerations. Furthermore, constant-speed performance may impose other requirements.

Test data are shown in figure 5, which indicates the static torque obtained for the two- and three-vaned rotors shown as a function of wind direction. The torque diagram for the two vaned S-rotor has a considerable irregularity that could make it difficult to start under some orientations. The addition of the third vane smoothes the torque diagram to some degree and apparently increases the torque per revolution, but also increases the polar inertia of the rotor, which may offset the increased torque when starting under low wind conditions. Whether two or three vanes will be optimum remains to be resolved. It is also likely that the torque diagram for a rotating rotor may be considerably different from that of the static case described.

The S-rotor may be located in any area where a horizontal axis rotor might be sited. However, the nondirectionality of the S-rotor may be put to use more effectively on sea coasts where the diurnal variation of the wind could be readily accepted. In considering this basic application, it occurred to us that it might be possible to generate an artificial on-shore breeze through the appropriate use of solar energy in the desert. Figure 6 shows a concept of such an artifice. A set of S-rotors are placed circumferentially around a circular area whose surface is made such that the air over it is heated to a higher temperature than the air outside of it. A flow will be established from outside of the heated area to replace the rising heated air. By locating the rotors in the throats of suitably contoured areas, it may be possible to extract considerable energy from the resulting accelerated air. It is recognized that this is an ambitious concept. In essence, we are trying to produce our own wind in sufficient quantities to make a cost-effective power system. Analysis and test techniques must be developed to verify the feasibility of this system concept.

Another application of S-rotor might be in remote areas such as the one depicted in figure 6. In the Arctic and many other places in the world, empty oil drums might be used for rotor vanes. In some underdeveloped countries it may be possible to construct the rotor from indigenous materials. The actual siting of the rotor in a village or base camp would depend on knowing where strong winds persisted without regard to their direction. This simplification coupled with low costs (for the rotor) might make the S-rotor a valuable asset to the community. It should also be noted that vertical axis rotors might be of considerable value in meeting instrumentation and power needs for research on the surface of other planets.

In conclusion, we believe that the potential of vertical axis rotors has not been exploited in recent years and that a comprehensive program including design, analysis, and test could yield devices of equal (if not better) cost-effective performance than that of horizontal axis rotors. We further believe that applications of these rotors should be considered simultaneously with their development to ensure the practical utility of the wind machines.

## DISCUSSION

COMMENT: There are two units currently being manufactured in Switzerland which use this principle. One is a 50 watt unit; the other is a 250 watt unit. The design is a slight variation of the Savonius rotor principle. The larger unit has been in production now for about 5 years. They are being used very successfully, particularly on top of radio towers where a little power is needed for a booster amplifier to take the signal down to the house. They worked very well for that purpose.

COMMENT: The company, Electro GMBH Company, also produces the 6-kilowatt standard generators. The man that runs that company is very interested in vertical axis design. He has experimented a lot with them. He has come up with, it seems, a quite successful unit for a small-scale, very simple in design and virtually no maintenance whatsoever, and no problems with regulations in high wind, and so on. There has been one built as a matter of fact, out in the Scripps Institute of Oceanography not too far north of where we are.

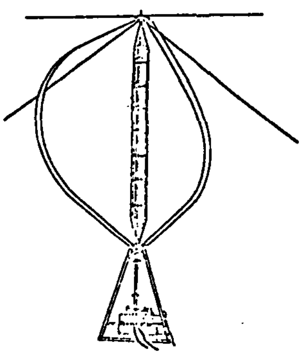
Q: You speak of one of these machines being 100 feet high. What is the largest model you know about?
A: I haven't heard of any near that size. An important question is whether this type of rotor be scaled up to larger sizes? My answer is: I don't know.

Q: How big you have seen any size.
A: About 15 or 20 feet high.

Q: In the thirties one about 100 feet high was constructed in New Jersey.

VERTICAL AXIS WIND ROTORS

DARRIEUS ROTOR



BACKGROUND

PATENTED IN 1931 (US AND FRANCE)

CURRENTLY UNDER STUDY AT NATIONAL AERONAUTICAL ESTABLISHMENT, OTTAWA, CANADA

CHARACTERISTICS

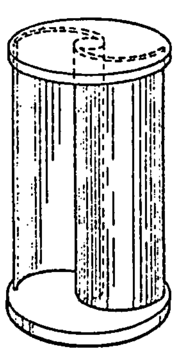
EFFICIENCY ~ 35%

TIP SPEED TO WIND SPEED ~ 6 TO 8

POTENTIALLY LOW CAPITAL COST

CURRENTLY NOT SELF STARTING

S-ROTOR



BACKGROUND

PATENTED IN 1929 (US AND FINLAND) BY S. J. SAVONIUS

CURRENTLY USED AS AN OCEAN CURRENT METER

OTHER APPLICATIONS SHOWN FEASIBLE

CHARACTERISTICS

TIP SPEED TO WIND SPEED ~ .8 TO 1.8

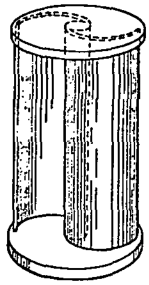
EFFICIENCY ~ 31%

SELF STARTING

| |
|---|
| VERTICAL AXIS ROTORS OPERATE INDEPENDENTLY OF WIND DIRECTION AND THUS HAVE A POTENTIAL FOR HIGH EFFICIENCY IN CHANGING WINDS |

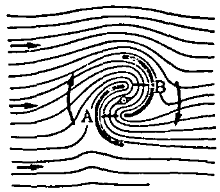
FIGURE 1

## S-ROTOR DEVELOPMENT



### CONFIGURATION

- END PLATES PROVIDE
  - STRUCTURAL MEMBERS
  - CONDITIONS FOR 2 DIMENSIONAL FLOW
- COMMON ASPECT RATIOS < 3
- SHEET METAL VANES




### FLOW CONDITIONS

- PERFORMS SOMEWHAT LIKE 2 STAGE TURBINE
- FLOW TO BACK SIDE OF ADVANCING VANE REDUCES NEGATIVE PRESSURE
- SUBSTANTIALLY CONSTANT AREA FOR AIR FLOW

### DEMONSTRATED APPLICATIONS

- WIND DRIVEN WATER PUMP
- WIND DRIVEN SHIP PROPULSION
- BUILDING VENTILATORS
- OCEAN WAVE DRIVEN WATER PUMP
- OCEAN CURRENT METER

FIGURE 2

## DEVELOPMENT ALTERNATIVES

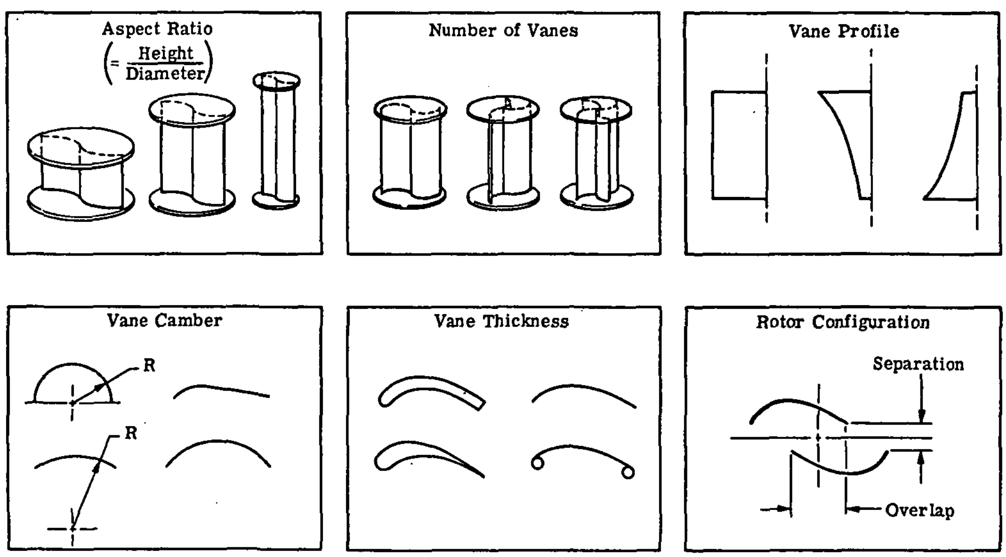



FIGURE 3

EFFECT OF ASPECT RATIO ON ROTOR ACCELERATION

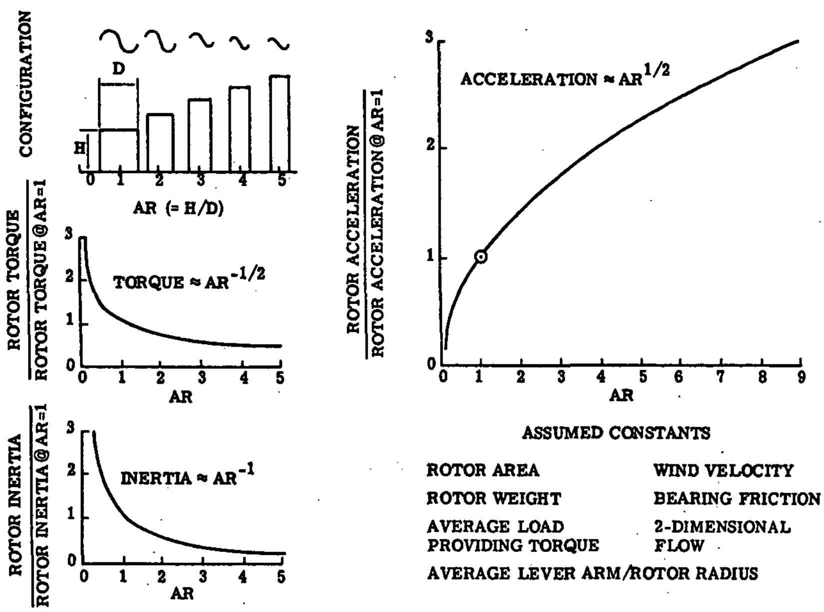



FIGURE 4

STATIC TORQUE PROFILE

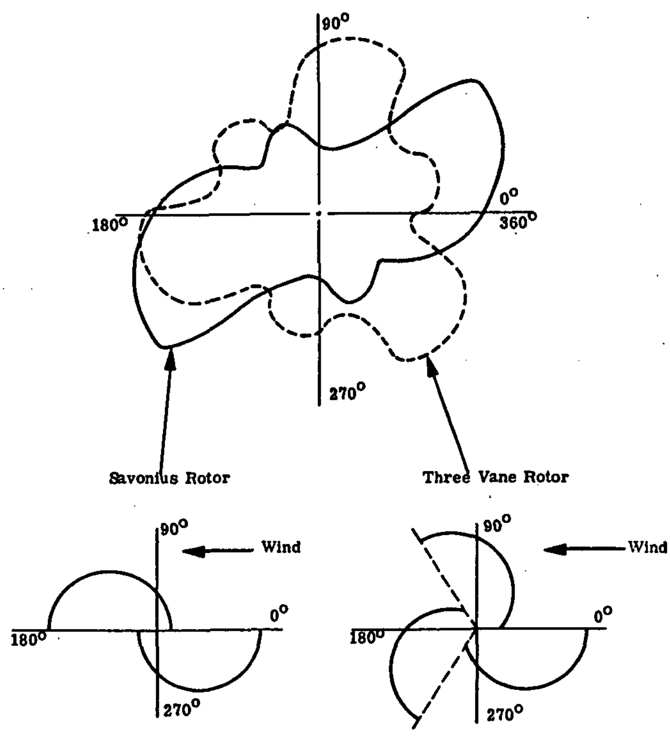
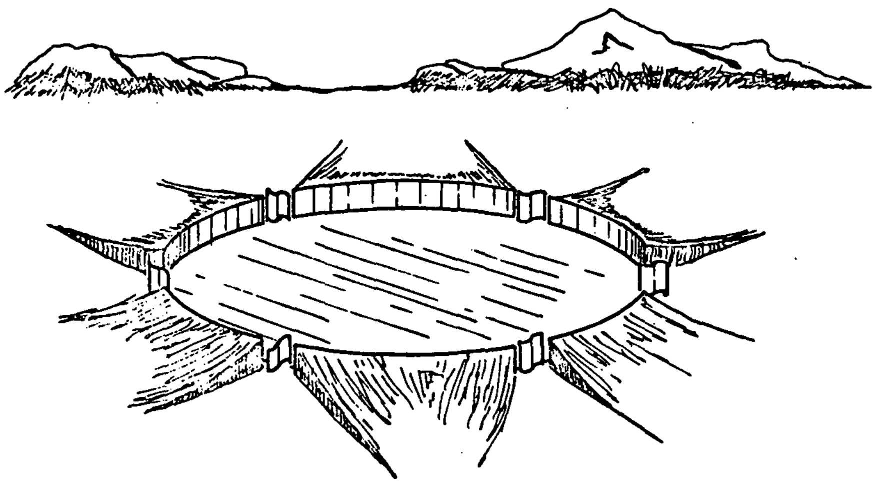



FIGURE 5

# POTENTIAL IMPLEMENTATIONS



## SOLAR/WIND CONCEPT

- LARGE RADIATING SURFACE TO HEAT AND RAISE AIR

S-ROTORS ARRANGED TO EXTRACT ENERGY FROM INCOMING REPLACEMENT AIR

FOR EQUILIBRIUM FLOW:

$$V_x \simeq \frac{\text{AREA OF RADIATING SURFACE}}{\text{(NUMBER OF ROTORS) (ROTOR DIAMETER)}} V_y$$

POTENTIAL HYDROGEN PRODUCER

## REMOTE AREA CONCEPT

SIMPLE VANE REQUIREMENTS PERMIT CONSTRUCTION USING
- OIL DRUMS
- INDIGENOUS MATERIALS

SITING REQUIREMENTS SIMPLIFIED
- DEPENDS ON WIND SPEED -
- NOT DIRECTION

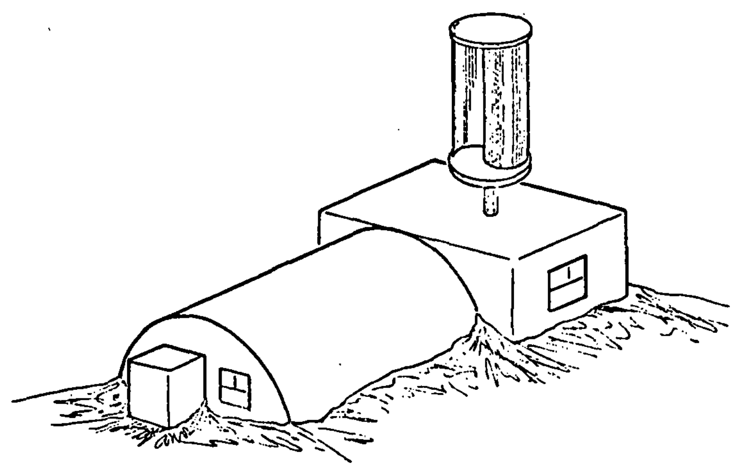


FIGURE 6