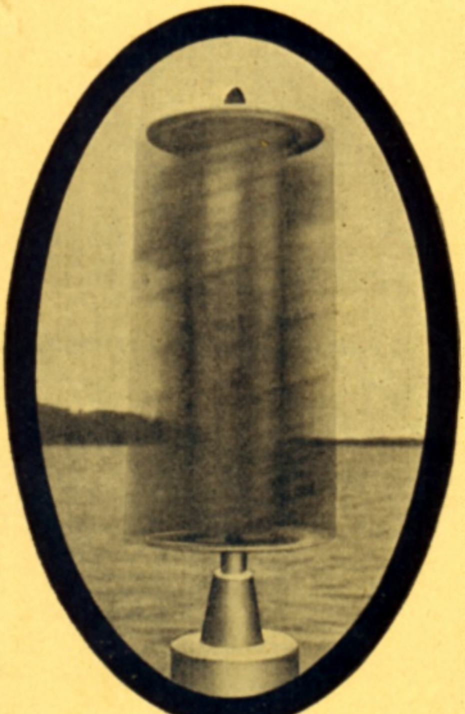
THE WING-ROTOR
IN
THEORY AND PRACTICE.



BY SIGURD J. SAVONIUS

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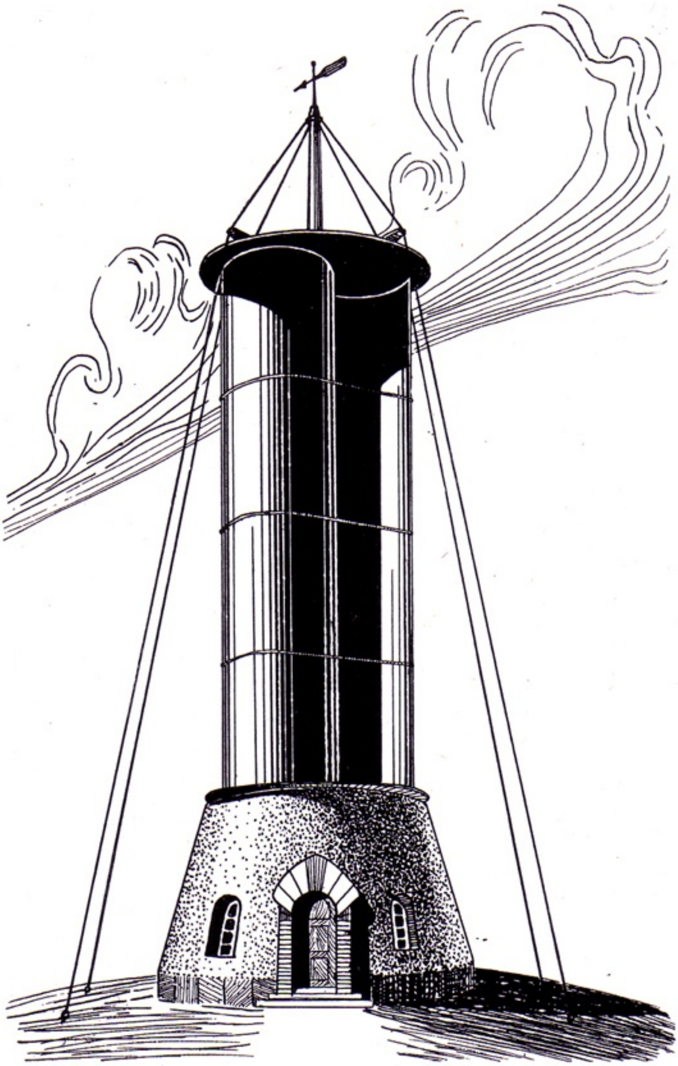
BY
SIGURD J. SAVONIUS

Patents applied for in
all principal Countries.

ELECTRO GENERATING
WING-ROTOR



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PREFACE.

Of all the powers of nature utilised by man the powers of the air are by far the mightiest. A horisontal column of air a mile wide and a mile high, moving at the rate of a gentle breeze could yield more than 200.000 horsepowers. The energy represented by the waves of the ocean and the waterfalls of all the earth are small in comparison with the giant source of power in the wind.

From the early days of human history man has been able to use this power although the means have often been crude. The dug-out of the primitive man with a leafy branch for a sail, was moved by the same power that carries the fullrigger across the seas, and the early windmills of the Egyptians and Hindues were the prototypes of the modern steel windmill. All these are only variations of the same idea; that is, of a sail moving with or across the wind.

With the arrival of the Rotor a new era has set in, opening up new possibilities of using the wind power to far better advantage than has been possible hitherto. The Rotor works on a principle altogether different from that of a sail or a windmill and a short account of its history and the phenomena connected with it will be given below. A fuller account of the cylindrical Rotor and its theory can be found in the booklet »Das Rotorschiff und seine physikalischen Grundlagen» by Dipl. Ing. J. Ackeret, published by Bandenhoeck & Rupert, Göttingen 1925.

THE CYLINDRICAL ROTOR.

When the Rotorship Buckau made its first trial runs in the Baltic in October 1924 it created a sensation hardly rivalled by that of any modern invention. In spite of this, the Rotor is not a new invention, although the honour of grasping its significance for practical use as a means of propelling ships belongs to the German inventor Dir. Anton Flettner.

In 1852 the German Professor Gustav Magnus turned his attention to the irregularities observed in the trajectory of a bullet or shell. It had been noticed, that if a shell was travelling with the wind blowing from the side, its trajectory was either lengthened or shortened from the normal, depending on whether the wind came from the right or the left side. If looking from behind, the shell is rotating clockwise and the wind is blowing from right to left, the shell is depressed and its trajectory is shortened. If on the contrary, the wind blows from left to right, the shell is elevated and the trajectory longer. The force accounting for the irregularities was surmised to be caused by the wind in combination with the rotation of the shell and this was confirmed by the experiments carried out by Prof. Magnus. Fig. 1 shows how his experiment was done.

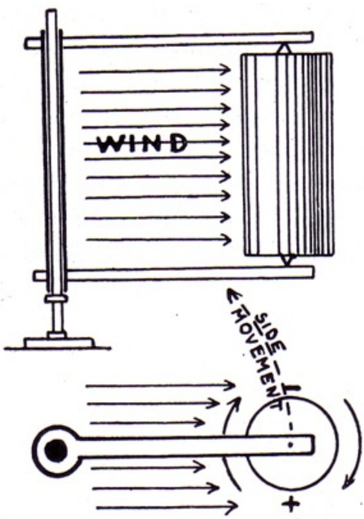

Fig. 1 The experiment of Prof. Gustav Magnus,

A cylinder was fixed to two arms, so that it could rotate freely and the arms were free to move round a vertical pivot. If the cylinder was placed in an air current and was put into rotation, the result was, that it moved sideways. If the rotation was reversed, it moved in the opposite direction.

The force causing this movement has been known under the name of the Magnus Effect and its law is expressed as follows: *If a cylinder is rotated in an air current, a force appears tending to push the cylinder across the direction of the wind.*

This phenomenon was later examined by Lafay, Dr. Prandtl, Lord Rayleigh and others. In 1912 the French scientist Lafay ascertained, that a plain rotating cylinder could exert a Magnus-force twice as big as the driving force of a wing surface, equal in size to the projection of the cylinder. In 1922 Prof. Gümbel constructed an air screw with rotating cylinders, instead of ordinary wing surfaces, and demonstrated that the Magnus Effect was able to turn the screw round in a wind. In 1923 the old experiment of Prof. Magnus was revived at the Aero-dynamische Versuchsanstalt in Göttingen with the aid of modern appliances.

From the very first trials at Göttingen with the rotating cylinder it was recognised, that the Magnus Effect was of a considerable magnitude. At this time Dir. Anton Flettner became interested in the trials and soon conceived the idea to use the Magnus force as a means to propel a ship. At his instigation the experiments were continued, and the result was so encouraging, that Dir. Flettner decided to try the Rotors on a big scale, and to this end had the 800 ton three-masted scooner Buckau fitted with two Rotors driven by a 20 h.p. motor. The Rotors were 2.8 m. in diameter and 15 m. high. In a 5 Beuf. wind the Rotorship reached a speed of 8—9 knots.

The astonishing effect of the cylindrical Rotor is offset by the drawbacks that it has to be turned round by motor power and that the Magnus Power can only be utilised if the Rotor is moving laterally, as a fixed Cylindrical Rotor can do no work.

Before going into a detailed description of the Wing Rotor, it will be necessary to explain shortly the phenomena and the curious air streaming and pressure differences produced by a Rotor.

THE THEORY OF THE ROTOR.

If a cylinder is rotating in still air, the friction between the surface of the cylinder and the air causes the air layers round the cylinder to partake in the rotation. We get what is called Circular airstreaming as illustrated in Fig. 2a and no lateral pressure is exerted. If the cylinder is stationary, but the air streaming past it, we get pressure on that side of the cylinder which is facing the wind and a vacum at the back, the result being, that the wind tends to move the cylinder in its own direction. This is known as Symetrical Streaming. Fig. 2b. If the cylinder rotates, while it stands in a wind, a new kind of stream phenomenon appears that in a way is a combination of the two former. This is the Unsymmetrical Magnus Streaming Fig. 2 c. and in the curious properties of this Stream phenomenon lie the astounding effects of both the Cylindrical and Wing Rotors.

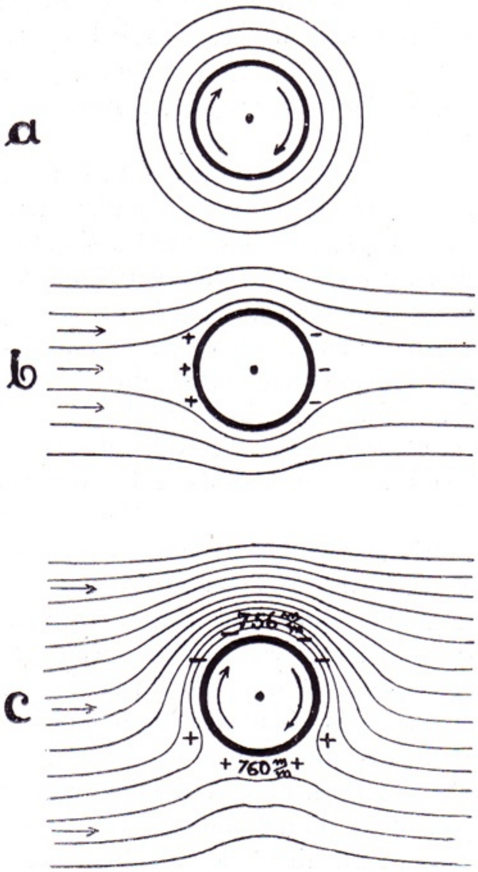

Fig. 2. Different air streaming round a cylinder. **a**:circular streaming, **b**:symetrical streaming, **c**:unsymmetrical Magnusstreaming. Note the wide air field affected.

The air jacket participates in the rotation of the cylinder, as explained above, and this causes a disturbance in the air current flowing past. The pressure differences, which in the case of the non-rotary cylinder in Fig. 2b. are at the front and back, now appear at right angles to the direction of the wind, and increase in magnitude. The result of this is that the Rotor is pushed by the high pressure + towards the low pressure – causing a movement across the wind. This is known as Magnus Pressure. The air jacket rotating with the Cylinder is on one side moving against the wind, and throws the air back obliquely across the front of the Rotor, causing a pressure on the side moving against the wind. On the other side the air jacket is moving with the wind, and the »volume» of air being bigger on this side the speed of the wind is increased, while the pressure is reduced. If the cylinder is rotating in a 10 meters per sec. wind and its peripheral speed being 20 m. p. sec., the difference in pressure amounts to 3–4 m/m. mercurypillar. The difference in air speed is big, the speed of the air on the – side, is increased twofold or more. This is graphically shown in Fig. 2c., the stream lines on the – side being much closer together than on the + side. This in short is the explanation of the phenomena of the unsymmetrical Magnus Streaming.

During the trials at Göttingen it was found, that a much greater effect could be obtained if the rotating cylinder was equipped with endplates. These endplates keep the air from streaming over the ends of the cylinder from the + to the – side. Flettner also used endplates on the Rotors of his Rotorship Buckau, the diameter of the endplates being about 1 1/2 times the diameter of the Rotor. The Magnus force of the Rotor in this form was 6–8 times bigger than the driving force of a sail of equal size.

At first sight it seems impossible that the Magnusforce could reach such magnitudes, as the power of the wind seems much less than the Magnus-force exerted by the Rotor. This apparent incongruity is explained by the fact, that the Rotor really reacts on an air field many times wider than its own diameter and according to the third fundamental law of physics: »actio est par reactioni», the magnitude of the acting wind force is equal to the reaction on the air set up by the Rotor. The force field in Fig. 2c. is in reality much bigger than shown in the figure.

The inventor of the Wing Rotor has tackled the problem from another quarter, and succeeded in producing a new type of Rotor, giving both torsional pover and lateral Magnus Effect and using only the power of the wind.

THE WING-ROTOR.

If the Cylindrical Rotor in Fig. 2 is cut and the two halves are moved sideways, a two- winged Rotor is formed, in cross section resembling the letter S. Fig. 3. It is obvious that a Wing-Rotor of this description will rotate under the influence of the wind, but it is less obvious that even here the Magnus Pressure and Unsymmetrical Streaming will be of any magnitude. This is nevertheless the case. If we look at Fig. 3, we see that the wing *a* moving against the wind throws the air back, causing an increased windspeed on the side of the wing *b*. We get in this way a high pressure + on the wing *a* and a low pressure – on the wing *b*.

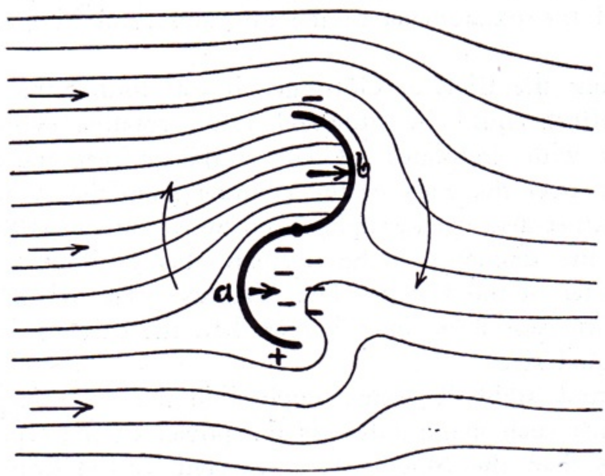

Fig. 3. The air streaming and pressure differences caused by a Wing-Rotor with wings closed in the middle.
Note the vacuum at the back of the wing a.

If a Wing-Rotor of this description is rotating idly in the wind, its peripheral speed is almost equal to the windspeed. If the wings are moved further apart, the speed decreases considerably as the increased windspeed on the — side now escapes unutilised through the opening between the wings. This is the common form of the cup cross used in anemometers, in which the wings, four in number are halfspherical, the peripheral speed being about half of the windspeed.

When a body is moving through the air, the resistance is composed of head resistance or pressure and rear resistance or vacuum. Of these two the latter is of far greater importance than the former. As exemples of the truth of this we can mention the blunt nose and tapering tail of the modern airship. The body of an aeroplane and a racing car, follow the same lines. The modern stream-line bullet with a tapering tail is known to have a trajectory 50 % longer than an ordinary bullet, etc. If we glance again at Fig. 3 we see that at the hollow back of the wing *a*, moving against the wind is formed a considerable vacuum, which acts as a brake. If this vacuum can be counteracted, the rotary movement is at once relieved of its greatest resistance and the speed and torsional power will in consequence increase considerably. The solution of the problem is shown in Fig. 4, and this is the real form of the Wing-Rotor.

We see that the wings are arranged so that an opening exists in the middle between the inner edges of the two wings, through which opening the air has a free passage. When the wind strikes the inner surface of the wing *b* the air does not lose its living force, air being very elastic, but streams through the middle opening and strikes the inside of the wing *a*. The vacuum tendning to form here is

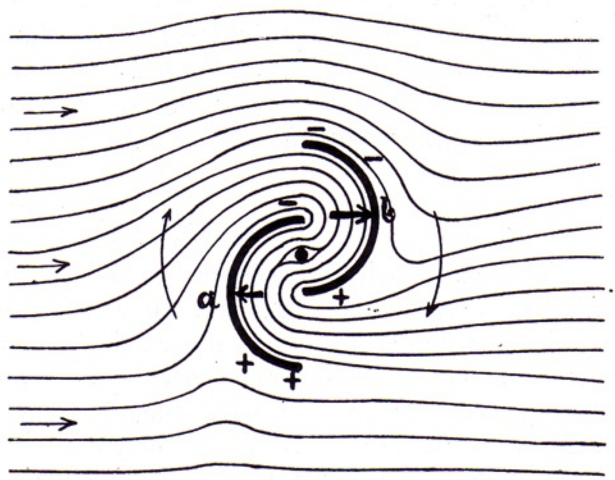

Fig. 4. The air streaming and pressure differences caused by a Wing-Rotor with opening between the wings. Note the smooth air flow and absence of vacuum at the back of the wing a.

counteracted by the air streaming through the opening but causes a further increase in the speed of the air striking the wing b.

The effect of this seemingly small alteration is in fact most astonishing. The pheripheral speed of the Wing-Rotor now increases to 1,7 times the windspeed and the torsional power grows 3 times bigger than in a Wing-Rotor of equal size but without middle opening and 5 times bigger than in a Wing Rotor with wings still further apart.

It might be suggested, that an even better result could be secured if the oncoming wing was screened, so that the wind-pressure on this wing could be removed, but a nearer reflection shows, that the Unsymmetrical Magnus Streaming and the increased wind speed on the other side are affected if this is done. Tests confirm that this is the case. The same thing holds true if the wings are equipped with opening flaps, as in the case of the old vertical »air wheels» of Beatson, Jackson, Rychlowsky and others.

As with the cylindrical Rotor the effect is heightened by the use of endplates, the same holds true of the Wing Rotor. Owing to the shape of the Wing Rotor the endplates can be much smaller, their diameter need only be $^1/_3 - ^1/_4$ bigger than the wingspread.

From the foregoing it is clear, that the principle of the Wing Rotor is related to that of the Cylindrical Rotor, with this difference, *that the Wing-Rotor gives both Torsional Power and Magnus Pressure, while the Cylindrical Rotor absorbs Torsional Power and gives Magnus Pressure.*

THE TRIALS.

The trials with the Wing-Rotor were carried out from the middle of November 1924 till June 1925, partly in natural wind of different velocities, and partly in artificial air currents. The number of Wing-Rotors tried was over 40, representing various sizes, forms and wing types. Some of these models are shown in Fig. 5 & 13. Comparative tests were also made with cylindrical Rotors, aeroplane wings, sails, windmills and modern windmotors. A full account of the trials is not given here, but only a short description and summary of results of the most important tests.

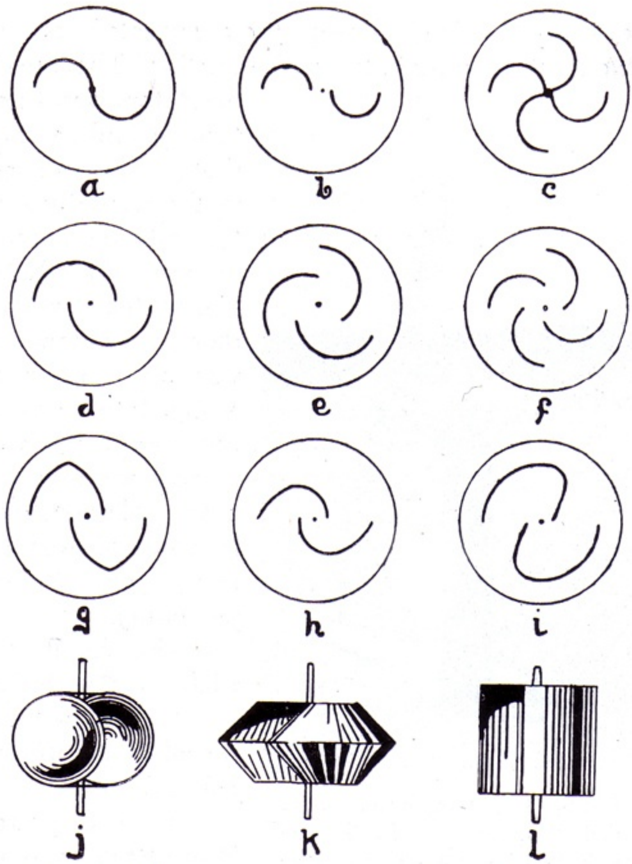

Fig. 5. Different wingforms tested during the trials.

I. THE FORM AND NUMBER OF WINGS.

The trials were carried out in the following manner: — See Fig. 6.

The Wing-Rotors to be tried were mounted, coupled together rotating freely on an axis. The direction of rotation being contrary for each of the Rotors, the more powerful one turned the other round which gave an indication as to which wingform etc. was likely to give the greatest torsion.

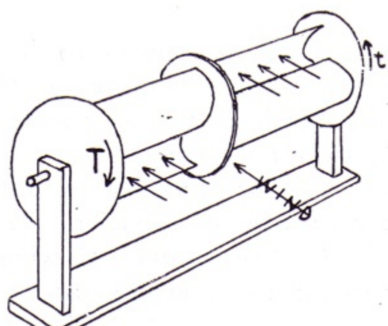

Fig. 6. Testing the torsional power of two Wing-Rotors.

After this the Wing-Rotors were mounted as in Fig. 7 on an arm, both rotating in the same direction. The arm on which the Rotors were fitted could turn round a horizontal shaft. The pair were kept in the wind by a vane. If the rotation speed of one of the Wing-Rotors was bigger than that of the other, the Magnus pressure was also bigger and this Wing-Rotor was able to turn round the arm, overcoming the resistace of the other. The tests were made in winds of from 2--15 meters per sec. ($2^1/_2$—30 miles per hour).

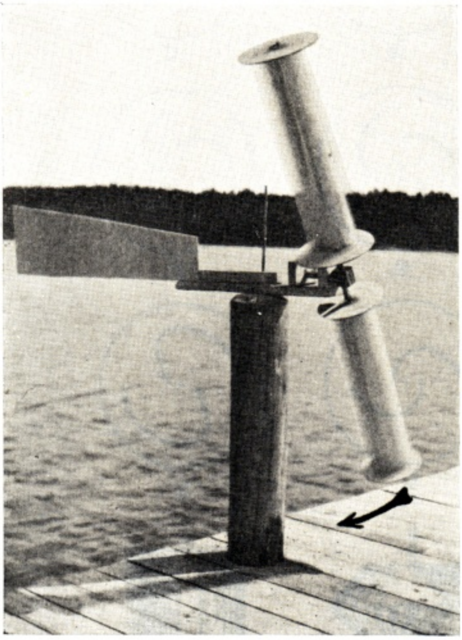

Fig. 7. Testing two Wing-Rotors as to their Magnusforce. In the picture the smaller Wing-Rotor gave the bigger power, turning the arm in the direction of the drawn in arrow.

The results of these trials were as follows:

1. The best wing form for all round efficiency was half cylindrical.

2. The power of a Wing-Rotor was in direct proportion to its projected area.

3. The opening between the wings had to be $^1/_4$—$^1/_5$ of the spread of the wings to obtain the greatest torsional power. The greatest Magnus pressure and least reistance was obtained if the opening was increased to $^1/_3$—$^3/_5$ of the spread of the wings.

4. The diameter of the endplates had to be 20—30 % bigger than the spread of the wings.

5. The number of wings giving greatest torsional power and Magnus pressure was found to be two.

II. THE TORSIONAL POWER.

Another series of trials were now undertaken to ascertain the relative magnitude in power of 2, 3 and 4 winged Rotors and Wing-Rotors with wings open and closed in the middle. These trials were carried out with models of bigger size and the power given off was measured by brakeing. The Wing Rotors to be tried were placed side by side on stands as shown in Fig. 8.

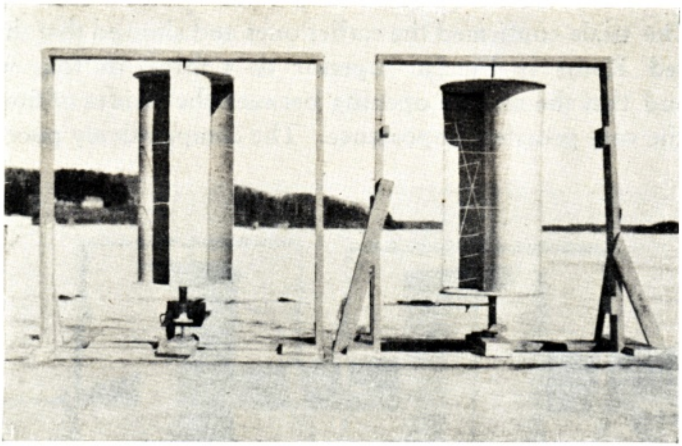

Fig. 8 a. A two winged and a three winged Rotor on the testing stand.

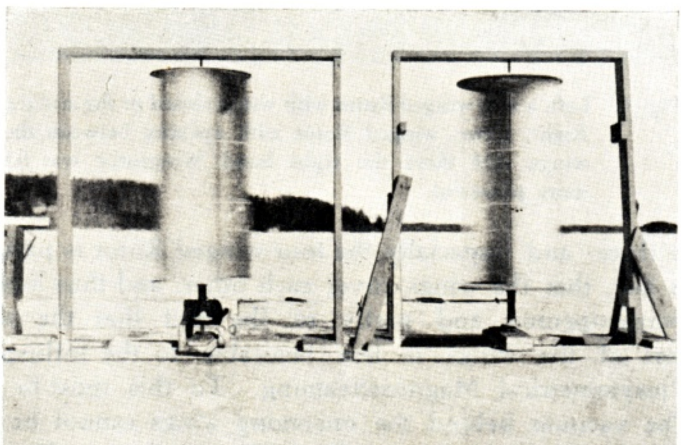

Fig. 8b. The two and three winged Rotors working.

If the power of the Two Winged Rotor with the opening between the insides of the wings is put down as 100, the result of the tests were:

a. Two Winged Rotor with inside opening .... 100 %
b. Two » » » wings closed in middle .. 30 »
c. Two » » » opening between outsides of wings.. 20 »
d. Three » » » inside opening .... 80 »
e. Four » » » » » .... 30 »

The trials confirmed the earlier ones and showed that the Two Winged Rotor is by far superior to a three- or four winged one and that the middle opening between the insides of the wings is of the very greastest importance. The comparatively poor result

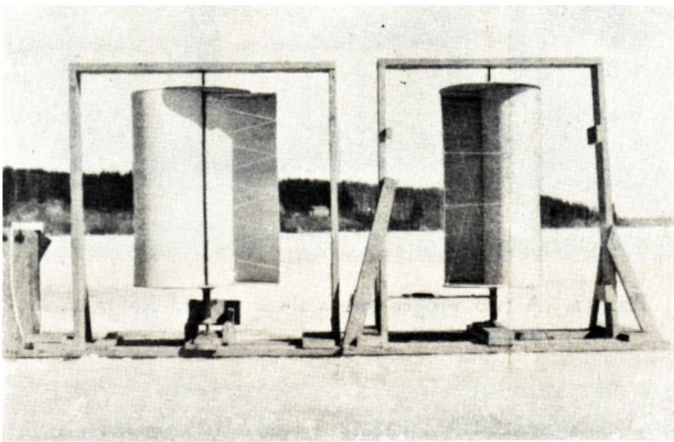

Fig. 9. Left, a two winged Rotor with wings closed in the middle. Right, a two winged Rotor with opening between the wings. Of these the right hand Wingrotor was far more powerful.

of the three- and -especially the four winged Rotor is partly due to the fact, that the wings cover each other, and thus lessen the free wing-opening and partly to the fact that the relative position of the wings is less favorable to the influence of the Umsymmetrical Magnusstreaming. To this must be added that the vacuum behind the oncoming wings cannot be counteracted so effectively as in a Two Winged Rotor. The speed of the Two Winged Rotor was greatest and the starting load bigger than for any of the others, except the Three Winged Rotor, which started with the same load. In connection with these trials, Wing-Rotors with screened wings and Twin Rotors in which the oncoming wings alternately screened each other were tried. Such a Rotor is shown in Fig. 10, while in Fig. 13 on the extreme left is a Rotor with wings having a sharp front side. Both the screened and the sharp wings gave a much smaller effect due to the causes explained on page 2.

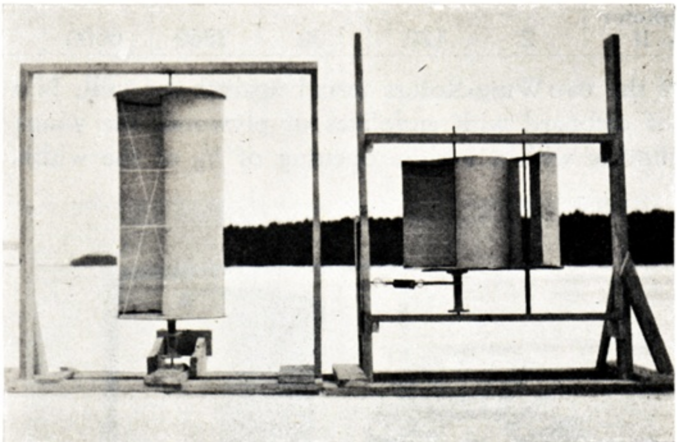

Fig. 10. Right, a two winged Rotor. Left, a twin Wingrotor, with oncoming wings screening each other. The twin Rotors were connected by a pair of gearwheels just under the wings. The Twinrotor gave 50% less power than the ordinary Wingrotor.

III. WING-ROTOR VERSUS WINDMILL.

The foregoing tests had shown that the torsional power developed by the Wing-Rotor was considerable. Now it was to be seen how the power given off by the Wing-Rotor compared with the power of a windmill. Several model windmills were made and compared as to their power output. The greatest power for area of the wingcircle was given off by an 18 winged mill designed on modern formulae. The windmill had a diameter of 70 cm., the wings of thin brass sheeting were fixed to an outer and inner ring. The wings had a curved surface, the angle at the outer tip was 15° and at the base 44°.

Sizes and weights of test Models

	Number of wings	Projected wingarea cm².	Diameter of wingcircle cm.	Working windarea cm².	Weight. grams
Wind mill	18	2475	70	3840	3800

	Number of wings	Hight cm.	Width cm.	Working windarea cm².	Weight grams	Diameter of Endplates cm.
Wing-Rotor n:o I	2	80	48	3840	3600	54
Wing-Rotor n:o II	2	120	32	3840	6600	40

Of the twoWing-Rotors tested against the mill, N:o I was made of carboard with endplates of plywood, the wings being semicylindric with a middle opening of $^1/_5$ of the width.

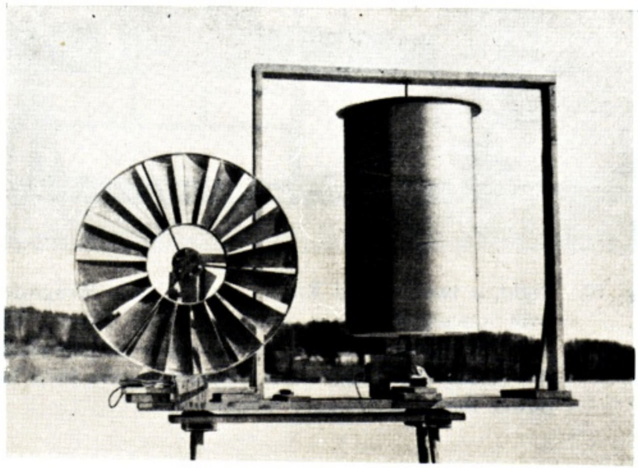

Fig. 11. A Windmill and a Wing-Rotor on the testing stand. See also Fig. 20 b.

Wing-Rotor N:o II was made of galvanized steel sheeting, with wings of 165o of a cylinder surface. The middle opening was $^1/_4$ of the width. Compared to the small size, the latter Wing Rotor was made of unnecessarily heavy material, as sheeting only half as heavy would have been strong enough. In spite of this the Wingrotor ran as easily as n:o I due to the fact that the weight of a Wing-Rotor is supported by a thrust bearing, while the weight of a Windmill has to be carried in horisontal bearings having a greater friction.

The area of the wingcircle of the Windmill was equal to the projected area of the Wing-Rotors.

Over one hundred separate tests were made during the months Januari—May 1925, in winds of varying speed. The power was measured by brakeing directly on a drum fixed to the shaft. A number of data were thus collected and tabulated. A summary of the results is given in the table below.

Table N:o I.

Comparative values of:	Load	Rotation Speed	Work	Power %
18 Winged Windmill	1,3	390	507	75
Wing Rotor N:o I	1,3	520	676	100
Wing Rotor N:o II	0,9	705	634	93

The results show that the Wing-Rotor gave about 30 % more power than the 18 winged windmill. In reality, under ordinary working conditions, the power of the windmill is reduced considerably, as it has to be carried down through gear wheels, levers, rods etc., causing frictional losses, which normally are reckoned to be 20—30 % of the power output. In the Wing-Rotor the power is carried down directly by a rotating vertical shaft and nothing is lost in transit. Under actual working conditions the useful power of the Wing-Rotor is thus 50—60 % greater than the useful power of a windmill of equal size. The trials also showed that the Wing-Rotor starts under load from any position, even in a feeble wind. In spite of the greater weigt, the Wing-Rotor n:o II gave almost the same power as n:o I, which shows that the greater weight had no adverse effect.

IV. THE MAGNUS FORCE OF THE WING-ROTOR.

The trials described below were carried out partly in natural wind and partly in an artificial air current. The former part of the trials were conducted as is shown in Fig. 12. A Wing

Rotor and a wingsurface or sail were fitted to a moving arm in such a way that the Magnus Force of the Rotor and push of the sail tried to turn the arm in opposite directions. The wing or sail was fixed so, that the angle presented to the wind

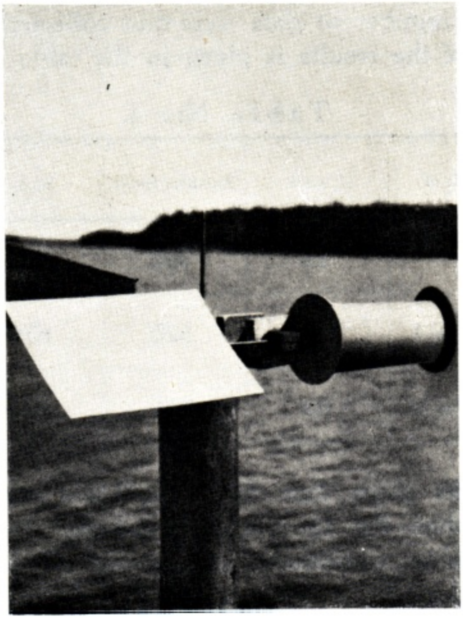

Fig. 12. A small Wing-Rotor running at full speed balances a wingsurface $2^1/_2$ times bigger.

could be altered. It was found that the Magnus Force of the Wing Rotor was equal to the driving force of a wing surface 2,2 times bigger or a sail 3 times bigger in area than the projection of the Wing Rotor, when the sail or the wing stood in an angle of 35°—40° to the wind, this position giving the greatest driving force.

After this two windmills with a wingspan of 2 meters were built. These are shown in Fig. 13 and 14. One mill had four curved wings constructed acording to Prof. La Cours formula. The other mill had four Wing-Rotors made of metal sheeting with endplates of plywood, the projected area being equal in size to the wings of the other mill. The torsional power was measured by brake on a drum fixed on the horisontal main shaft. Several tests were made and the results are tabulated below.

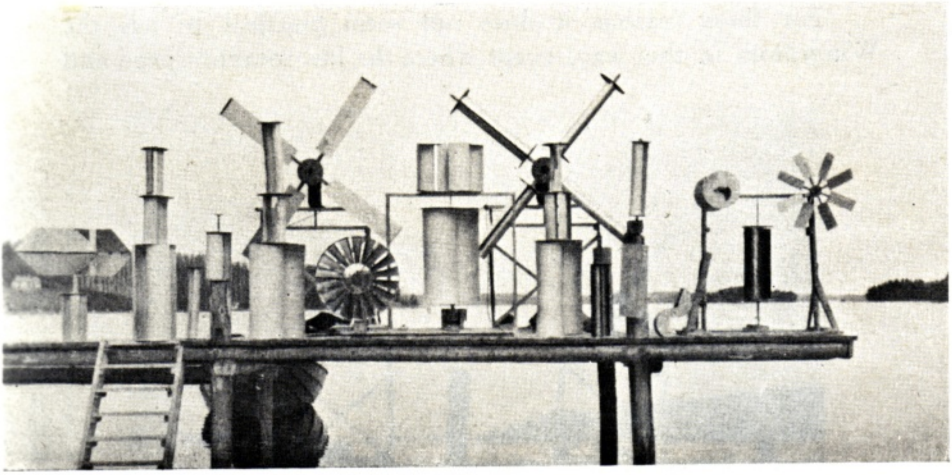

Fig. 13. Some of the models used during the trials. Only about half of the models tried are in the picture.

Table N:o 2.

Comparative values of:	Load	Rotation Speed	Work	Power %
La Cours Windmill	30	110	330	72
Wing-Rotor Windmill	120	38	456	100

The tests gave the result that the mill with the Wingrotors had a starting torsional power 4 times bigger than the other mill. If the loads put on were as 4:1 the Rotormill gave an aggregate power output about 40 % bigger than the other mill. The speed of the Rotormill was very much lower. This is due to two causes. The first is, that the direction of the driving Magnusforce, wich at standstill is at right angles to the wind, moves more to the front according to the direction of the apparent wind when the mill is working, thus lessening the driving force. Secondly the gyroscopic effect of the wingrotors acts as a brake at higher speeds, counteracting the driving force. The case is exactly the same if cylindrical rotors are used, with the added complication of the artificially driven rotors, and their still greater gyroscopic effect.

For these reasons it does not seem practical to use the Wingrotors in this way, exept where the low rotation speed and

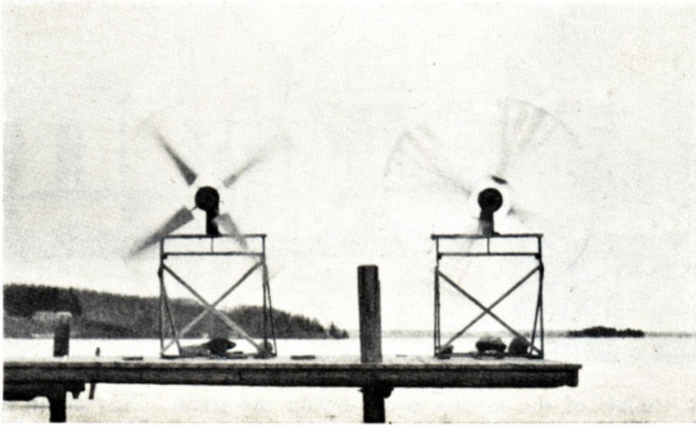

Fig. 14. The la Cour Mill on the left and the Wing-Rotor Mill on the right working.

great starting torsion can be of advantage, for instance for direct driving of slow speed pumps etc.

Some trials were now undertaken in artificial wind to compare the Magnusforce and resistance of Wingrotors and artificially driven cylindrical Rotors.

For these tests a set of Wingrotors, cylindrical Rotors and model aeroplane wings were made. These are shown in Fig. 16. Fig. 15 shows how the trials were carried out. The artificial wind was created by a big centrifugal blower driven by a 10 H. P. motor. Windspeeds from 4—12 meters per sec. were used.

These tests gave the result that *a cylindric Rotor and a Wing-Rotor with equal length and surfaces gave equal Magnuspressure at equal r. p. m.* Compared to the lifting force of the aeroplane wing 1 in Fig. 16, the Wingrotors 4 and 6, gave a Magnusforce of 2,3:1 if running naturally only under windpower. If the speed was increased by aid of the small motor to 3000 r. p. m. the periphereal speed of the Wing-rotor was 30 meters per sec. and measuring the Magnus-force exerted in a 10 m. per sec. wind it was 3,4:1 as compared to the aeroplane wing. At this same r. p. m. of 3000 the periphereal speed of the cylindrical rotor was 20 m. per. sec. or twice the windspeed, and the Magnusforce equalled 3,4:1

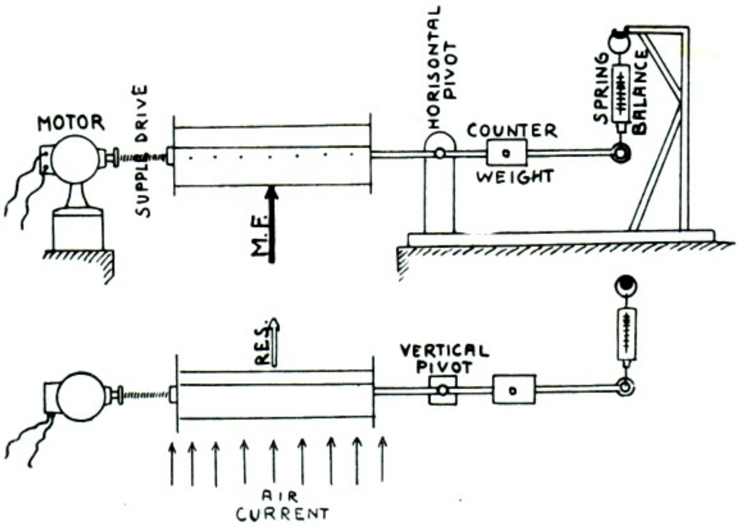

Fig. 15. Testing the Rotors in artificial air current. The small electro motor on the left was used to drive the cylindrical rotors and also the Wingrotors in high speed tests.

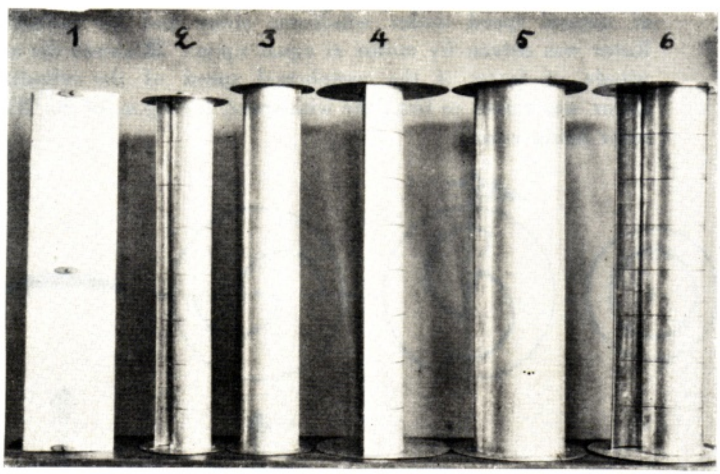

Fig. 16. The models used on the testing stand shown in Fig. 15. 1: Aeroplane wing 20×80 cm. 2: Wingrotor 13×77 cm. 3: Cylindrical Rotor 13×80 cm. 4 & 6: Wingrotors 20×80 cm. 5: Cylindrical Rotor 20×80 cm. Of there models the cylindrical Rotor 3 and the Wingrotors 4 & 6 had the same surface area and gave equal Magnusforce.

According to the tests at Göttingen a cylindrical rotor if run at a periphereal speed of twice the windspeed exerts a Magnusforce of 3,8:1 if compared to a aeroplane wing and 5,3:1

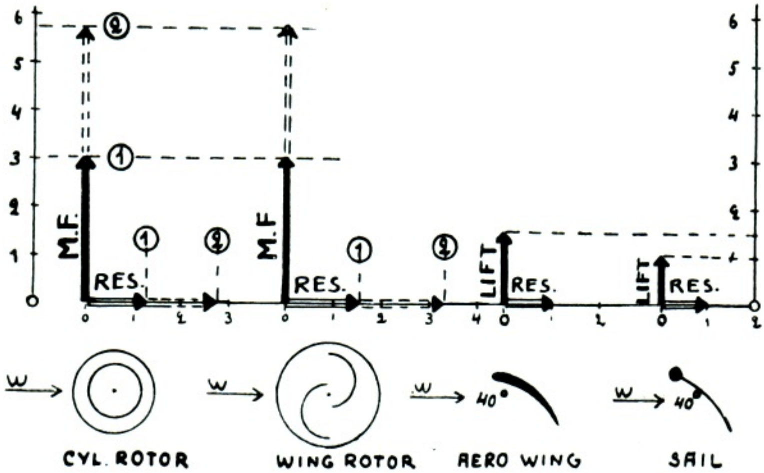

Fig. 17. Diagram illustrating the comparative forces of a cylindrical Rotor, a Wing-Rotor, an aeroplane Wing and a sail. **1**: shows the magnitude of Magnusforce and Resistance if the Wingrotor ran at natural speed under windforce alone and the cylindrical Rotor was driven by motor at equal r.p.m. **2**: shows the magnitude of forces if the periphereal speed of the cylindrical Rotor was raised to twice the windspeed, the r.p.m. of the Wingrotor being equal.

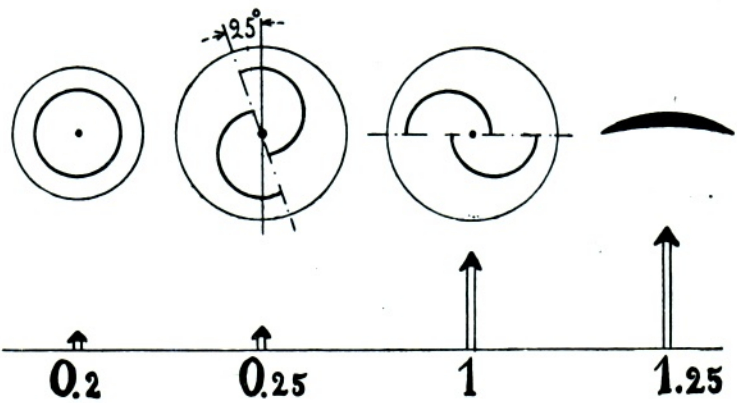

Fig. 18. Relative magnitude of Resistance to the wind of a Stationary cylindrical Rotor. Wingrotor at least and greatest position of resistance. A wingsurface facing the wind.

if compared to a sail. The comparative tests described above are in fair agreement with the results arrived at in the Aerodynamic Research Institute at Göttingen. The result of the tests is illustrated in the diagram Fig. 17, while in Fig. 18 are shown the comparative magnitudes of the Resistance, for a cylindrical Rotor, a Wingrotor and a wingsurface.

As the Magnusforce of the Wingrotor was found to be 3 times bigger than the driving force of a sail of equal size, it was decided to try the effect of the Wingrotor in a boat. A small hull of 5 meters length and 1,8 m. beam was fitted with two Wingrotors made of galvanized sheeting with a projected area of 1.87 sq. meters each. The Rotors had a width of 67 cm. and a height of 280 cm. The endplates were 88 cm. in diameter. The wings were pivoted on the endplates and their position could thus be reversed.

The best point of sailing was with the wind just abaft the beam. In a breeze of 7 m. per sec. (about 15 miles p. h.) the boat reached a speed of 5 Knots. In a 10 meters per. sec. wind the speed averaged 6 Knots, the two Wingrotors developing a driving force equal to 3—4 H. P. Tacking was done by reversing the wings in going round on the other tack. The boat wore 45° to the wind. Going with the wind the Rotors could be stopped, then acting as ordinary sails. Eventually the Rotors could be rotating in opposite directions, the stern Rotor deflecting the wind so that the Magnusforce acted in a more favorable direction on the bow Rotor. The boat could be reversed by altering the direction of rotation of the Rotors. By aid of a wire running round the wings, these could be pulled together either partly or altogether. Pulling them partly diminished the free wingopening, causing a decrease in speed, corresponding to the reefing of an ordinary sail. If the wings were pulled close together the Rotors remained stationary.

Compared to the speeds of 9 Knots reached by the Flettner Rotor-Ship Buckau, the speed of the small Wingrotor boat reaching 6 Knots is quite good. It seems as if the Wingrotor in a natural wind should give a comparatively better driving effect than a cylindrical Rotor. This can be explained by the fact that the speed of the Wingrotor being determined by the speed of the wind, increases if the wind increases, thus always giving its maximum force according to the momentary windspeed. An artificially driven cylindrical Rotor, has its constant speed which cannot be altered from instant to instant as the wind varies. As a consequence the cylindrical Rotor does not give off its maximum effect, exept in a steady unvarying wind, and the small side resistance is rather a drawback as the ship rolls violently in a sea. Due to its form and greater side resistance the Wing-Rotor steadies the ship much better, counteracting violent rolling.

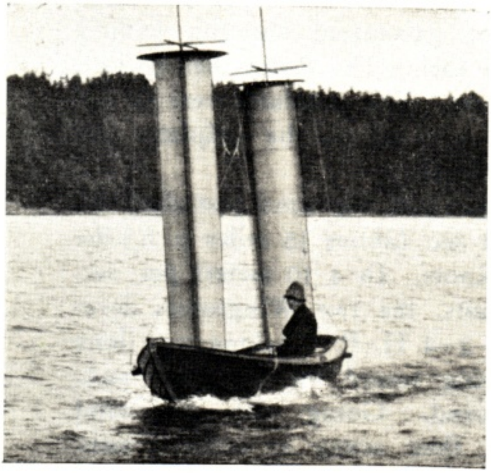

Fig. 19. The Wingrotorboat sailing on different courses and at rest with wings sloced.

The question whether the Rotor eventually will find use in ships, must be left open, as the trials still are at their beginning. There seem to be possibilities that the Wing-Rotor can with advantage be used on motorships as an additional source of power under favorable wind conditions. The regulation of speed the reversing and reefing of the wings, can be secured with simple means and is done practically automatically with aid of the brakeing arrangement used by the inventor. When not in use the wings of the Rotors can be closed up, and in this position make very little resistance to the air, when the ship is moving under motorpower alone. Eventually the Wingrotor can be lowered into a horisontal position.

Another way to use the Wing-Rotor in a ship is to utilise its torsion power to drive cylindrical Rotors. A ship can for instance have 3 Rotors, a Wingrotor amidships and cylindrical Rotors in bow and stern. Besides supplying the power needed to turn the cylindrical Rotors the Magnusforce of the Wingrotor also adds to the aggregate driving power.

It is also possible to use a direct combination of a Wing-Rotor and a Cylinder-Rotor, by having a smaller Wing-Rotor directly on the top of the cylinder, the former rotating the latter. The altering of the direction and speed of rotation is secured by having the wings reversible as usual.

In comparison with the cylindrical Rotor the Wingrotor has two decided advantages. One is that it supplies its own rotation power, needing no complicated and expensive power plant with motors, dynamos, driving electromotors and wiring. Another is, that the wingrotor has quite an appreciable driving force even when sailing with the wind, on which point of sailing the cylindrical Rotor has practically no effect. Against these advantages must be set the disadvantages, a bigger size for equal power and a more complicated construction of the Rotor proper.

It is of course also possible to drive the Wingrotor artificially thus securing a greater Magnusforce. When the wind is stronger the Wingrotor runs by windpower alone, the driving Magnusforce increasing with the square of the windspeed.

THE USES AND ADVANTAGES OF THE WINGROTOR.

As a result of the various tests and trials described on the foregoing pages, one fact is patent. Quite apart from other possible uses, the Wingrotor is eminently suitable as a windmotor or air turbine. Compared with any other kind of windmill now used it is of very simple construction. This simplicity naturally has a most important bearing on its utility. Compared to the power produced, ordinary windmills are not only delicate and complicated but even expensive, while a Wingrotor obviously can be built at a cost amounting only to a fraction of the price of a windmill of equal power output. The Wingrotor has very few wearing parts, in fact in its simplest form only two bearings, preferably ball or roller bearings. The frictional losses which in an ordinary windmill are considerable, due to the multitude of moving parts, bearings, gearwheels etc., are in a Wingrotor practically nil, and no power is lost in transmissions, as the power shaft is a direct continuation of the vertical axis of the Wingrotor. The Wingrotor needs no vane to keep it to the wind, as it is not affected by changes in the wind direction. This fact makes it possible to dispense with the usual tower as the Wingrotor it just as well placed on the end of a staged pole or tubular mast. Oiling can be arranged from the ground and there is thus no necessity to climb to the top of a crazy and greasy tower.

The rotation speed of the Wingrotor can be chosen within wide limits. A short and broad Wingrotor has a lesser speed of rotation than a tall and narrow one of the same area, the r. p. m. standing in inverse proportion to the width of the wingspan. The form of the Wingrotor is such that the construction is strong and stabile.

In localities where no high obstacles obstruct the wind the Wingrotor can be placed on the roof of a house or on a low base. Instead of using a tower the rotor can be built narrow and tall to reach the greater windvelocity higher up, and the addition of a few extra feet in height inceases the cost little, while the building and erection of a tower is fairly dear.

Finally it is obviously possible to construct Wingrotors of a size far greater than ever attempted with Windmills at a cost that is comparatively low. This opens out quite new possibilities to use air power for producing electricity on a big scale and at a low cost. On the other extreme the Wingrotor can be produced to a very low price for small power purposes such as pumping work, charging radioaccumulators etc. and thus find extensive use for purposes where any other kind of motor would be too expensive.

CONSTRUCTIONS.

The stresses to be reckoned with in a Wingrotor are caused by the windpressure and by the centrifugal force. The working stresses caused by windpressure are not bigger than in ordinary wind mill practice. The stresses set up by the centrifugal force are taken by suitably placed stays in such a way that practically no stress comes on the wings. The small Wingrotor N:o 2 in Fig. 16 with a diameter of 13 cm. only was run at a speed of 3000 r. p. m., without showing any deformations due to centrifugal strains. In Wingrotors of bigger size the centrifugal force is less, its magnitude decreasing in inverse ratio to the diameter.

For small Wingrotors the proportion of width to height can be 1:1—1:2, in case the Rotor is fixed on the top of a pole or mast. A Wingrotor standing on the ground or on a basement rotating round a centrally placed mast can have a height 3—5 times the width. The endplates on a short Rotor have a diameter of 125—130 % of the width of the wingspan, in a tall Rotor the endplates can be even smaller. The Wingrotor can be built of different materials, the trial models were made of cardboard, plywood, aluminium, brass- and galvanized sheeting. In ordinary practice galvanized steel-sheeting is most suitable. For the wings corrugated sheeting is eminently suitable giving great strength combined with lightness.

The wings are stayed from edge to edge across the wing opening, and the centrifugal stresses are taken up by circumambient stays. The edges of the wings are stiffened by a rolled in wire.

Wingrotors of very big size will have wings built of double sheeting on an inside framework, in the same way as aeroplane wings are built. The endplates can be level with a strenghtening outer ring of flat or L iron, or in bigger sizes a double construction with an inner level and outer conical surface can be used.

A Wingrotor with fixed wings needs some arrangement with which it can be stopped and kept stationary when not working. In small sizes up to 4 sq. meters a simple spring-loaded brake is enough. This locks the Wingrotor, but should the wind change in direction the brake gives slightly so that the wings automatically take up the position of least resistance (See Fig. 18) the common diameter of the wings standing at 25_o from the wind.

In the case of bigger sizes with fixed wings a vane can be used in conjuntion with the brake. This vane is coupled in after the Wingrotor has been brought to a standstill, and when the brake is released the vane keeps the wings in the right position to the wind.

The vane must be so big that its area multiplied by its leverage from the Rotor axis, gives a product which is twice as big as half the projected area of the Rotor multiplied by $^1/_4$ of its width. As will be seen from the diagrams Fig. 18 the head recistance of the rotorwings when standing at an angle of 25° from the wind is only slightly greater than the resistance of the cylinder formed by the two wings. If the wings are of 165° only, the resistance is equal to the resistance of the cylinder. This resistance is about $^1/_5$ th. of the corresponding resistance of a surface of the same area. In a hurricane of 12 Beuf. the windpressure on the Wingrotor would thus be 50 kg. per sq. meter of the smallest projection of the rotor-wings. If the Rotor has a greatest projected wingarea of 3 sq. meterst the smallest projected area will be 2 sq. meters, giving a pressure of about 100 kg. on the Rotor, which strain is easily provided for.

A PUMPING WINGROTOR.

Fig. 20 a and b. show a pumping Wingrotor. The height between the endplates is 196 cm. the wingspread 96 cm. giving an projected area of 1,88 square meters. The diameter of the endplates is 120 cm.

The wings are of 0,75 m/m iron sheeting, the edges wired with a 10 m/m wire. The wings have 4 stays each of 3 m/m wire in addition to which 4 circumambient stays of the same thickness are provided. The endplates are of 12 m/m plywood, the wings being fixed to these with wood screws. The rotating axis is formed by a 2″ steel tube fixed to the upper

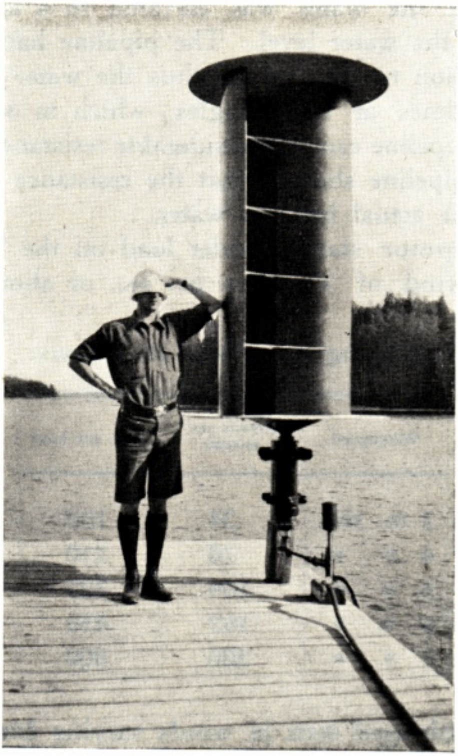

Fig. 20 a. The pumping Wingrotor erected on a pier., note its small size.

and lower endplates by conical supports of 1 m/m sheeting. The axis runs in two ball bearings fixed inside a tubular support, the lower one taking the weight of the Rotor. The weight of the rotor proper (the moving parts) is 50 kilos. At the lower end of the axis is a circular plate in which a tappet can be fixed in different positions giving a shorter or longer stroke at will. A short connecting rod is moved by the tappet actuating the plunger of the pump. The pump could be given

3 different stroke lenghts giving 35—43 and 50 cm^3 water per stroke, the diameter of the plunger being 34 m/m. The longest stroke was used during the tests.

The pumping Wingrotor was erected on a pier about 2½ meters over the water level. The water from the pump was led into a 3/4″ pipe joining an existing pipeline from a well on the shore. The lenght of the pipeline was 110 Meters (366 feet), and the water was elevated to a tank, 15 meters (50 feet) over the water level. The pipeline had 8 right angle bends in addition to two valves, thus the water had to change direction 12 times at right angles, which in addition to the lenght of the pipeline caused considerable resistance. A pressure gauge in the pipeline showed that the resistance was 15—25 % greater than the actual head of water.

The Wingrotor started under load on the longest pump-stroke in a wind of 3 meters per sec. or about 6 3/4 miles an hour.

The actual pumping result was as follows:

Windspeed	Strokes per minute	liters per hour
3 m. sek.	34	100
4 » »	70	210
5 » »	109	325
6 » »	152	455
7 » »	200	600

During prolonged tests in winds varying from 4—6 meters per sec. (9—13½. Miles an hour) the pump delivered water at a rate of 300—330 liters per hour. If during a lull in the wind the Wing-Rotor stopped, it started again as soon as the wind freshened, independent of the position of the wings. Stoppage occured only if the windspeed fell under 3 meters per second.

The result must be regarded as very good. In Fig. 22 a diagram is given in which Curve 1. shows the amount of water given at different windspeeds. Curve 2. in the diagram shows the water delivered by a 6 ft. steel windmill. This curve is based on figures given by the makers of two of the best

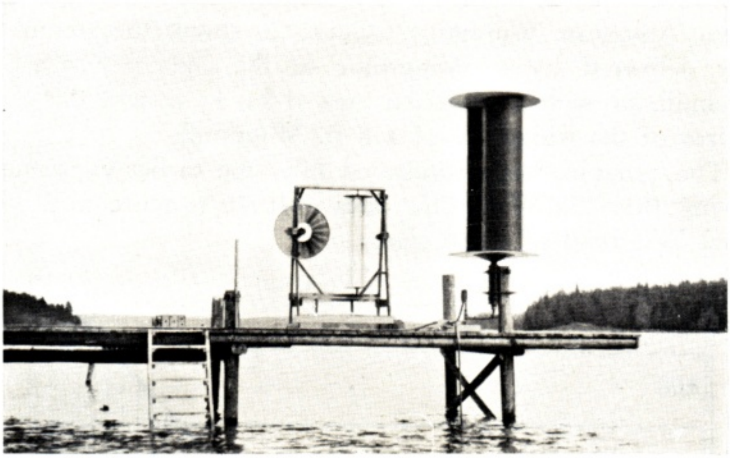

Fig. 20 b. The pumping Wingrotor working. To the left a model Wingrotor and Windmill on testing stand.

Fig. 21. A Pumping Wing-Rotor fixed to the top of a tubular mast The two ball bearrings are in the short tube clamped to the mast. The brake is situated under the lower endplate, the wire nearest the mast actuating the brake. The other four wires are stays.

known American Windmills. Curve 3. shows the amount of water delivered by a Wingrotor of the same size as a 6 ft. Windmill, or with a projected area of 2.62 sq. meters, this being the area of the wingcircle of a 6 ft. Windmill.

The pumping tests confirmed fully the earlier experiments showing that the Wingrotor does over 70 % more work than a steel Windmill of equal size.

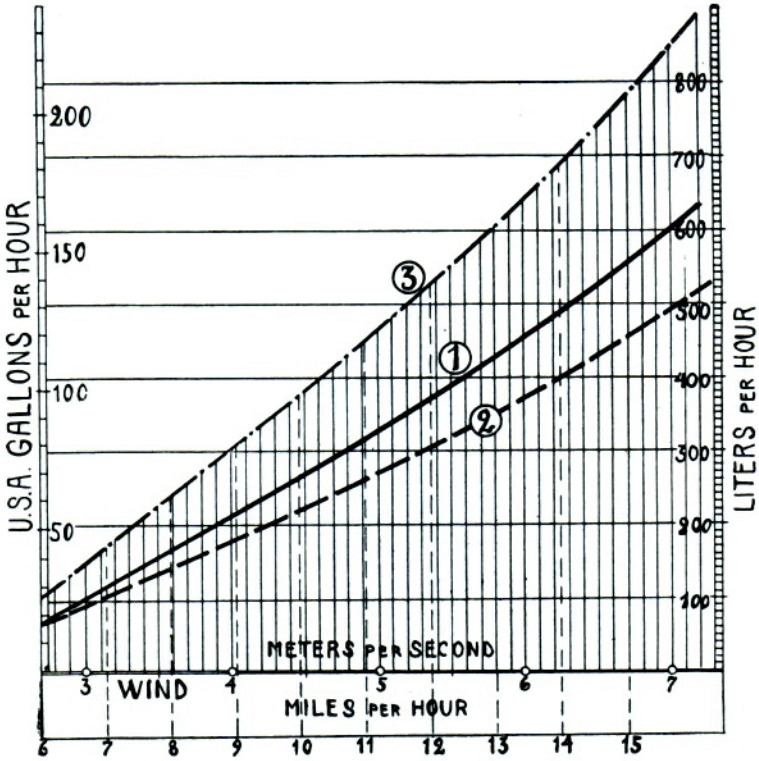

Fig. 22. Diagram illustrating amout of water pumped to a height of 15 meters (50 feet).

1. Curve for the Wingrotor of 1.88 sq. meters area.
2. Curve for a 6 ft. Windmill of 2.62 sq. meters area.
3. Curve for a Wingrotor of 2.62 sq. meters area.

A REGULATING WINGROTOR.

One of the most difficult problems in connection with windmills is the regulation of the speed. In many cases a regulation is not necessary, but where the windmill has to actuate a long pumping rod or drive machinery some regulating arrangement has to be used. While the pumping Wingrotor described needs no regulation, as the pump in this case can work at any speed, it may in other uses be desirable to have a constant speed. Even in this respect the Wingrotor is superior to any other air motor as it can be regulated to a nicety.

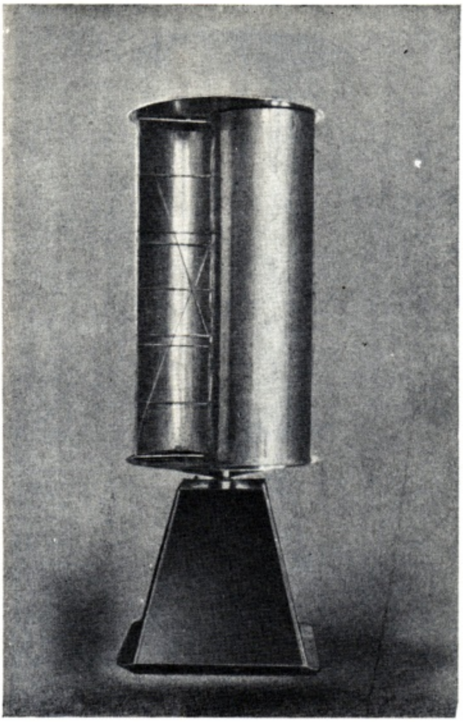

Fig. 23. Regulating Wing-Rotor, rotating in feeble wind, wingspan fully open.

Fig. 23—25 show a regulating Wingrotor. The two endplates are joined together by a steel tube. This tube also forms the axis of the Rotor and runs in two ball bearings in the support or engine house underneath the Rotor. The wings are pivoted on tappets in the endplates. The edges of the wings are connected by the tension rods which are privoted at the edge of the wing. Two pairs of springs are fixed to the wings pulling them apart. Finally, a chain fixed to one wing runs down over pulleys through the hollow axis to a windlass.

Rotating at a normal speed the wings keep the position shown in Fig. 23. If the speed increases even slightly above the normal, the centrifugal force acting on the wings begins to pull them round against the springload, so that less of the free

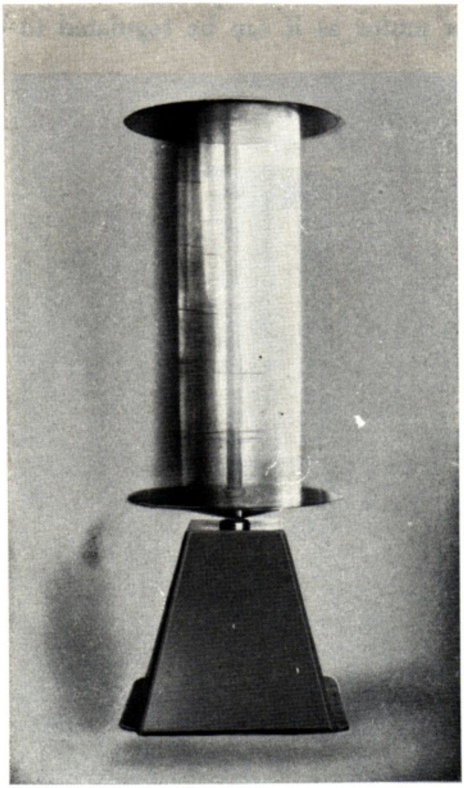

Fig. 24. Regulating Wing-Rotor, rotating in strong wind, wingspan contracting.

wingsurface is exposed to the wind. If the speed again decreases the springs pull the wings back in their original position. The tension rods take up and equalize the centrifugal forces relieving the wings of all strains and cause the wings to move together and to an equal degree. The Rotor is stopped by hauling the wings in neutral position with the aid of the chain and windlass.

The speed regulation is, according to tests with models, excellent. From a wind of 3 meters per sec. to a wind of 10

v. m. per sec. (6—20 miles pr hour) the speed of the regulating Wingrotor increases only 10—15 %. No matter how gusty the wind, is the Rotor works like a clock, the regulation answering instantly to an increase in the windspeed. The regulating arrangemet hardly adds any complications or wearing parts as

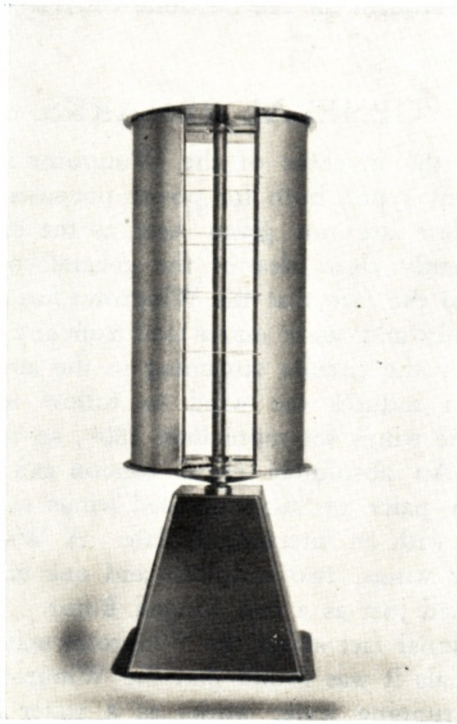

Fig. 25. Regulating Wing-Rotor at rest.
Wings in neutral, facing each ether.

tappets and rods have only a very slight movement and are stationary most of the time. For this reason no oiling of these parts is required. Standing idle with the opening facing the wind, the Rotor swings gently to alterations in the direction of the wind as if it should have an invisible vane. Resistance in this position is also quite small, so that the Rotor standing idle is not stressed even in a storm. If the regulating Wing-rotor is built tall it is equipped with a stayed mast inside the tube joining the endplates and the bearings are fixed round this central mast. The regulating Wingrotor is from every point of view an ideal air motor combining simplicity of design, with strength and excellent speed regulation.

If the Wingrotor is used for generating electric current the benefit of having the gearing, dynamo and wiring down on the groundlevel instead of on the top of a tower is obvious, as repairs and adjustment can be done conveniently.

GENERAL REMARKS.

Although the inventor of the Wingrotor has constructed several different types, both for power purposes and ship use, designs of these are not given here as the examples shown give a sufficiently clear idea of the general construction.

In spite of the fact that the Wingrotor has only two wings it runs smoothly and starts under load from any position. This is explained by the circular streaming in the air set up by the rotation which induces the wind to follow round, exerting pressure on the wings for more than 180°, so that there is no dead point. An absolutely equal torsion can be secured by arranging two pairs of superimposed wings standing at 180° to each other with an intervening plate. A Wingrotor of this form has four wings, two endplates and one middle plate. It can be regulated just as a two winged Rotor.

An additional fact about the Wingrotor may be mentioned. During the trials it was found that the Wingrotor if altogether immersed in running water works as a water wheel. At the time this pamphlet is published trials with the water Wingrotor have just begun so it is not yet possible to give any definite statements as to its efficiency as a water turbine. If the efficiency would he satisfactory its field of use is limited to slow rivers or tidal currents.

CONCLUSION.

From a scientific point of view the Wingrotor offers a very interesting study and the full explanation of its startling qualities still needs research. The theoretical explanation of the Wingrotor given in these pages is not supposed to be complete, many facts and sidephenomena have been left unmentioned as being of lesser importance from a purely practical point of view.

Several months of experimental work and tests conducted under actual working conditions have shown that the Wingrotor offers a new and simple means to utilise the windpower efficiently in various ways.

PRICE:

Shilling........	1 s. 2 d.
Doll.	25.
Rmk	1:—
Sv. Kr.	1:—
Fmk	10:—