W I N D P O W E R :

The Utilization of Wind Rotors for the Generation of Power in Underdeveloped Areas.

Erol İnelmen

June 1965

" Ye kürküm, ye ... " (N.H.)

Thesis submitted in partial fulfilment

of the requirements for the degree of

Master of Science in Mechanical Engineering

from the Graduate Engineering School of

Robert College, İstanbul, Turkey.

Candidate for M.S. in M.E. :

Erol İnelmen

İstanbul, June 18 1965.

" Pehlivan güreşi ... "

Comprehensive Examination Committee:

Prof. Otto Davidson (ME)

Prof. Harry H. Nickle (Physics)

Prof. Turgut Noyan (Chem. E)

Prof. Joseph Panarelli (Math)

Prof. Necmi Tanyolaç (EE)

Prof. Stanley A. Thompson, Chairman (ME)

May 24, 1965

" Fincanları kırmadan ... "

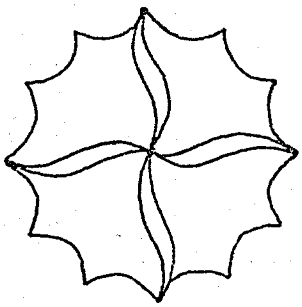
" Uyarma ... "

A C K N O W L E D G M E N T

I remain in debt to my advisor
Prof. Adnan Halet Taşpınar,
who not only gave me very valuable advice for this thesis, but
showed me the way through life.

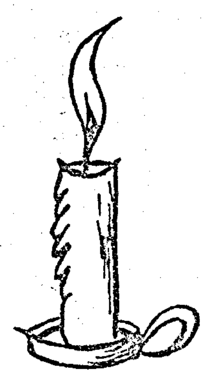
E. I.

" İyi niyet ... "



" Pervâneye zulm-i bîhisâb eyler şem'
Zulm odına bağrını kebâb eyler şem'
Gûyâki bilir zulm ser-encâmı nedir
Bîhûde değil ki ıztırâb eyler şem'."

Fuzûlî



" Damla

damla

göl olur. "

Anneme.

' Kurda: "Ensen neden kalındır?" demişler "Kendi işimi kendim görürüm" demiş.'

P R E F A C E

1. The subject matter
2. Method of analysis
3. Method of work
4. Physical and mental health
5. Related activities
6. Results
7. Comments on the work accomplished
8. Recommendations
9. Acknowledgments

1. The subject matter.

The actual work for this thesis started in February 1964, when the author was given the responsibility of the Investigation work in the Energy Generation course offered by Prof. Adnan K. Taşpınar at Robert College.

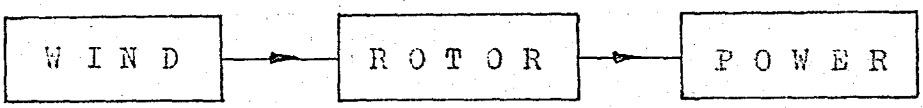
A survey made in the Engineering Index 1960 to 1963, showed that there was plenty of information available on "wind power". A topic had to be selected for an engineering project during that semester among modern methods of power generation, such as: direct conversion, solar energy, geothermal power, atomic power, wind power, etc. The subject of wind power was considered by the author to be the most interesting.

The encouraging results of the preliminary experiments and the suggestions given by Prof. Taşpınar, moved the author to decide on Wind Power as the subject for his thesis, and abandon the first idea on the subject of "Cotton Standardization", for which he had started early in January 1964.

The preliminary project concluded showing that there was a large field for the research of "wind rotors and their application in underdeveloped areas", and this was taken as the specific subject matter for this thesis.

2. Method of analysis.

Throughout the whole work, the author attempted to separate the problem in three main interrelated items:



For this reason the:

- Survey
- Theory
- Design

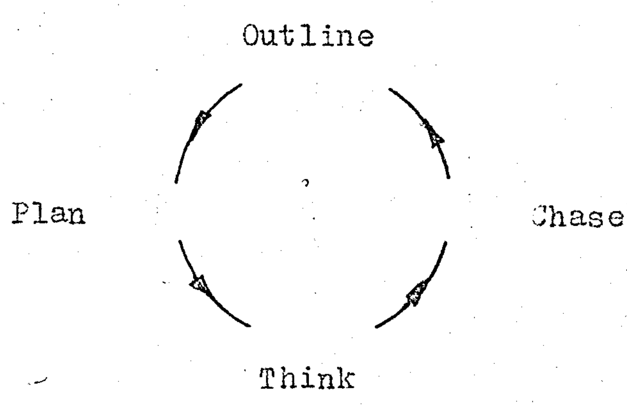
ere analyzed taking into consideration this basic classification.

3. <u>Method of work</u>.

Following the suggestions made by the advisor, Prof. Taşpınar, a ystem was developed to handle the work, based on the items:

a) Gantt's chart
b) Agenda
c) Diary

In this way it was possible to develop a system, that can be sum- arized with the following scheme:



4. Physical and mental health.

It was found out by experience, that health influences creativity d efficiency. In order to be productive it is necessary to be in od mood and this is only possible through a balanced diet, physical ercises and spiritual recreation. For this purpose the following ints were considered as essential:

- Cod lever oil
- Carlsbad Sprudelsalt
- Dried yeast
- Gelé Royale
- Yogi
- Walking
- Gardening
- Decorative arts
- Classical Turkish music and poetry
- Turkish proverbs
- Religion
- Admiration of Nature

5. Related activities.

Besides the work for the thesis, the author was engaged in the fo- owing studies:

a) Engineering Education

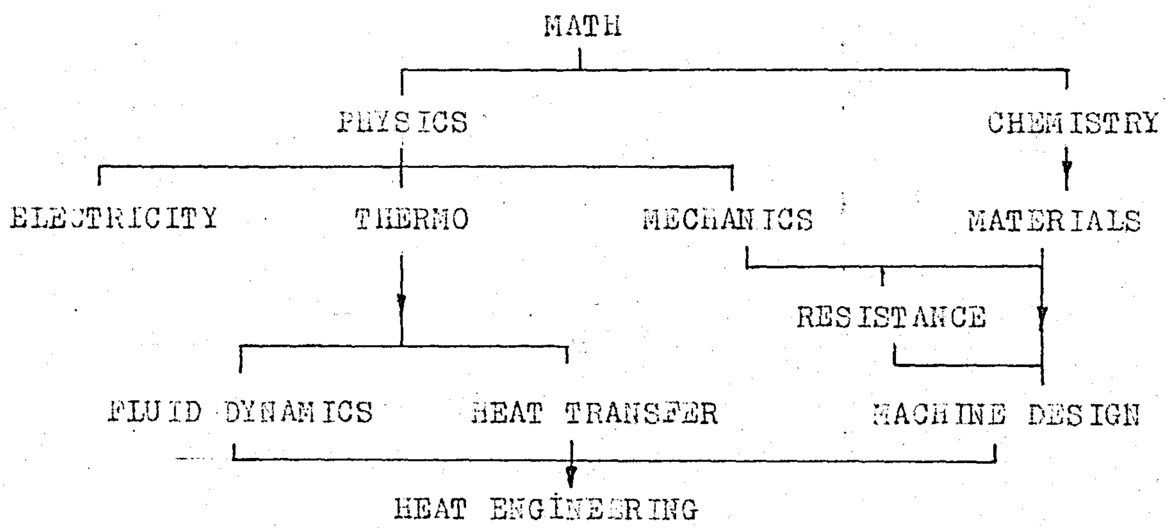
b) Hydraulic Machinery and Fluid Mechanics Notes

c) Rehabilitation Plans

d) Review of undergraduate courses.

It was possible in this way to alternate the work for the thesis ;h other activities, and at the same time these studies helped in proving the methods and information for the thesis.

The following scheme was applied in reviewing the undergraduate urses:



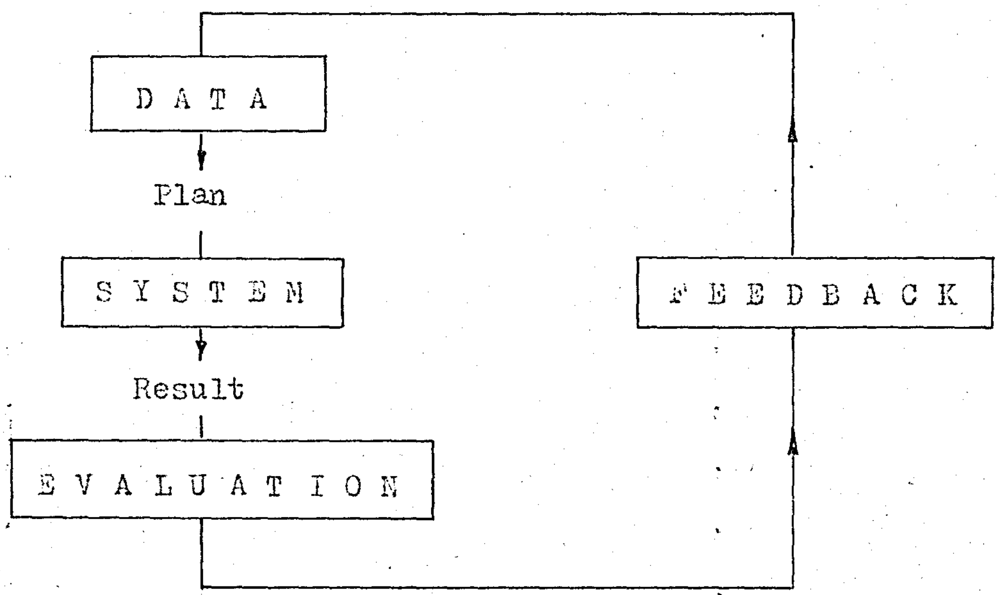
6. Results.

The development of the thesis made it necessary to deal with seve- al basic engineering sciences:

- Fluid Dynamics (airfoils, circulation, etc.)
- Machine Design (bearings, rotor balancing, etc.)
- Engineering Economics (cost estimation, economic analysis)

ich together with Heat Transfer are the cornerstones of Mechanical gineering.

Besides this, the author was forced to develop a systematic work order to accomplish something efficiently, and the method of tackng en engineering problem, is in the author's opinion his greatest ofit. This can be summarized with the following diagram:



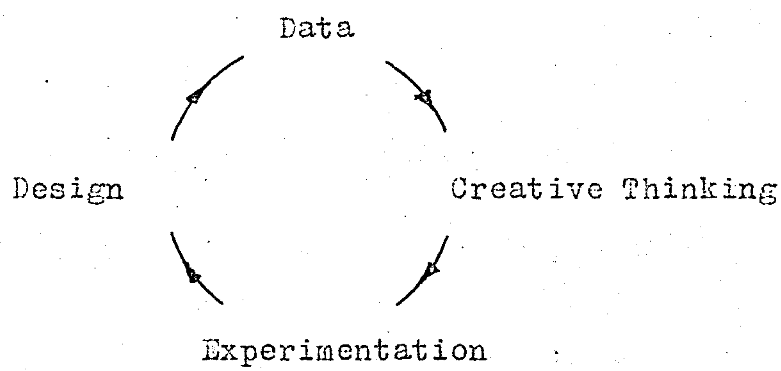
7. <u>Comments on the work accomplished</u>.

Although the author attempted to make his work as complete as posible, the lack of the necessary engineering background prevented his to be the actual case. As a whole the following items may be ommented:

a) Content of the report

As a whole the thesis is the result of compiling a large amount of nformation and not as the author intended : the result of the deveopment of an idea, the survey, theory and design planned in such a ay as to bring light to this idea. In other words, the work should ave been developed in the form of a cycle, repeated several times eading to the development and improvement of an original idea. The eport is more of an "introductory work" and not a complete project.

A suggested scheme for this cyclic work is as follows:



b) Survey data

The survey on the available data was made in order to show the rend in the development of wind power, and not to give a complete dea about the subject.

c) Experiments

The experiments are not sufficient, more accuracy and further work eing still necessary.

8. Recommendations.

During the development of the project the author was faced with se- ious technical difficulties that he could not always solve satisfac- orily. For this reason the author wishes to present here an outline f what he considers should be done to improve the conditions and elp graduate students to be more efficient in their work.

- Clear definition of regulations related with thesis ork.

- Graduate students meetings with the teaching staff to iscuss problems related to their thesis. Work in common between staff ıd students may help to solve minor details and even to select the ıesis topics.

- Seminars with teaching staff to help students to make-) for their undergraduate defieiencies . These seminars should also ɜal with the basic principles of Engineering Design.

The author feels that the following items may help in the develop-ɜnt of a thesis:

1. Select the topic for the topic from a real need of he community in which you live.

2. Isolate variables very carefully.

3. Try to make research with the materials and equipment vailable.

4. Avoid becoming saturated with the subject, alternate he work of the thesis with other work.

5. Time should be allowed for new concepts and ideas to ecome mature. It is not always possible to understand something the irst time it is read.

6. When dealing with other persons to get their help be s polite as possible.

7. Try to make the design as flexible as possible so as o be able to change variables whenever needed.

8. Be always ready to receive new inspirations.

9. The work should be undertaken for personal satisfaction.

9. Acknowledgments

To:

- Prof. Adnan Halet Taşpınar for his patience and advice hat made this thesis possible.

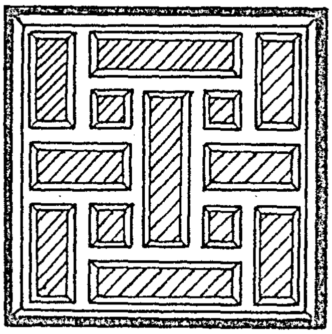
- Mr. Alexandre Nadolsky for teaching me the secrets of ogi.

- Prof. Necmettin Halil Onan for showing me the beauties f Turkish classical music and poetry.

- Prof. Godfrey Goodwin for pointing me out the architec- ural beauties of İstanbul in his mos unforgetable tours.

- Bay Yusuf Sakallı (dear Yusuf Usta) for his patience nd help in the work shop.

- My mother for encouraging me to take the M.S. degree.



YENİ CAMİİ

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" Sel önünden kütük kapmak. "

Zurnada peşrev olmaz, ne çikarsa bahtına. "

1. I N T R O D U C T I O N

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1.2 Description of the sciences used

1.3 Available facilities

1.4 Description of advices and comments

1.5 Method of procedure

1.6 Units and abbreviations

1.7 Progress time chart

1.8 Outline of the report

1.1 Statement of the problem

The aim of this work is to study the possibilities of the utiliza-
.on of wind rotors for the generation of power in underdeveloped areas.

Today there are around 50.000 wind charges in service in the United
;ates, with an average rating of almost 2 kw; and aproximately
)0.000 windmills in service developing an average of 0.25 h.p. In
enmark 88 wind turbines generate from 30 to 50 kw. (1)

This gives an idea about the importance of the subject, and the need
f developing more efficient methods of wind power generation.

The work is divided into the following items:

a. Survey on the research work carried up to date.

b. Study of the basic theoretical principles involved in windmill design

c. Experimentation on different wind rotors to analyze their performance characteristics.

d. Economic analysis in the design of wind machines.

1.2 Description of the sciences used

The following sciences we used during the work:

1) E.Ayres and C.Scarlott "Energy Sources - The Wealth of the World" Mc Graw Hill Book Co. Inc. 1952 pp 255-263.

a) Meteorology

b) Fluid Dynamics

c) Machine Design

a) Meteorology

The careful design of wind machines requires knowledge of e characteristics of wind the forces that generate them. Meteorology lps in predicting wind regimes. ( )

MARK'S Handbook p. 9-12, 13.

b) Fluid Dynamics

The basic principles of aerodynamics are very important thematical tools in the study of rotors and airfoils.

c) Machine Design

The knowledge of the properties of materials and machine rts are a prerequisite for satisfactory design.

1.3 Available facilities

The following equipment available in the Mechanical Engineering boratory at Robert College were used in the performance of the experiments:

- Tachometer
- Fan
- Wind tunnel
- Water flow channel (ME Thesis 1961)
- Soldering equipment
- Anemometer
- Vibrodyne for balancing of machinery

- Variac

he following apparatus was used in the Physics Laboratory:

- Optical bench
- Lenses

1.4 Description of advices and comments

A. Advices given by Prof. Adnan H. Taşpınar

1. Study of wind rotors (Flettner rotors)
2. Selection of an airfoil profile for the Impala rotor
3. Study of the wind stucture
4. Study of the performance characteristics of different wind rotors
5. Study of multi-stage Impala rotors
6. Use of airfoil discs
7. Study of rotor balancing techniques
8. Study of source and sink principles
9. Study of circulation principles
10. Visualization of steamline formation around stationary wind rotors.
11. Design of a wood pattern for the manufacture of blades
12. Use of plastic materials to manufacture rotors
13. Measurement of torque by means of springs
14. Design of a new stand
15. Importance of rotor balancing (efficiency, wear, etc.)
16. Visualization of the eddy formation in multi-stage rotors.

17. Utilization of the rotor in other fields.
18. Analysis of the power output of a rotor from theoretical considerations
19. Improvement of stand to reduce yawning of rotor
20. Circulation models
21. Improvement of the visualization techniques
22. Measure of torque by prony brake.

B. Comments by Prof. Stanley Thompson

1. Place of windmills in the power economy of a particular country.
2. Importance of windmills today.

C. Comments by the Comprehensive Committee

1. Proof of the relation : $P = k \cdot v^3$ in wind power
2. Use of stainless steel as a raw material
3. Aproximate power developed
4. Joukowsky condition in the design of airfoils
5. Calculation of torque developed
6. Type of generator to be used.

1.5 Method of procedure

February 1964 - June 1964 :

1. Engineering Index survey
2. Survey on L.Vadot articles
3. Survey on Encyclopedya Britanica : rotorship
4. Meccano model of a wind rotor

5. Impala rotor 20 cm in diameter
6. Wind theory
7. Circulation theory
8. Preliminary survey on Putman and New Delhi Symposium
9. Contact with E.Golding
10. Preliminary survey of World Power Conference
11. Printing thesis paper
12. New 12 mm shaft
13. Express type Impala rotor
14. Multi-stage Impala rotor.

September 1964 - January 1965

1. Survey of thesis regulations
2. Survey of ME articles on rotors
3. Survey of World Power Conference 1962, New Delhi Symposium, Golding, Putnam.
4. Thesis outline
5. Rotor balancing stand
6. Use of plastic materials
7. Progress report I
8. New 20 cm diameter Impala rotor
9. Savonius S-rotor

February 1965 - June 1965

1. Visualization of fluid flow
2. Interview on Prof. Taşpınar's research work
3. Wind theory

4. Fixing wood stand
5. Vibrodyne experiments
6. Wind measurements
7. Visualization of flow techniques
8. Bearing selection
9. Design of new stand
10. Experiments with new rotor
11. Progress report II
12. Soldering techniques
13. Manufacture of new rotors
14. Testing of new stand in the wind tunnel
15. Performance characteristics of the Impala rotor with different angles of attack of blades.
16. Aerodynamic principles
17. Experiments with new rotors
18. Final report writting.

1.6 Units and abbreviations

The large variety of sources from where information was surveyed for this work, forced the author to unify the terminology as much as possible, and include a glossary to define the most important terms used in the report.

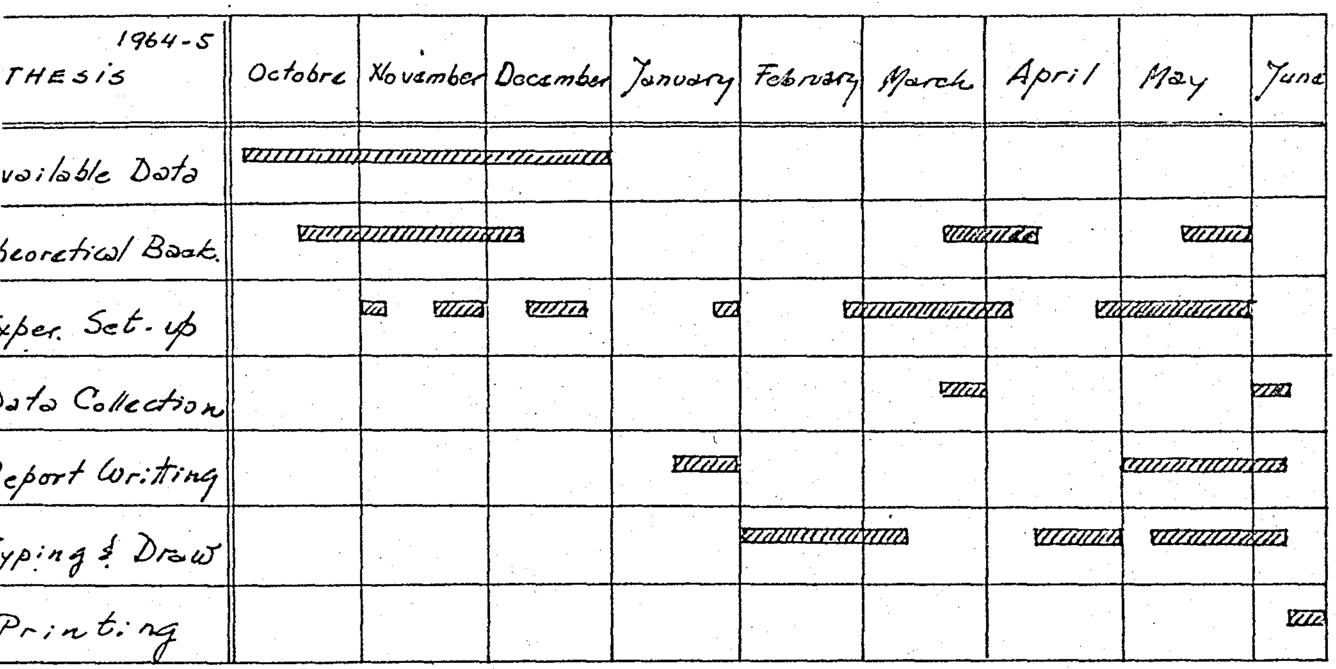
The metric system was used throughout the whole work for uniformity.

The nomenclature used in the theory is given in the form of a table at the begining of each section.

The references are given at the end of each section.

1.7 Progress time chart

A total of around 550 hours were used in the preparation of this esis over a period of one and a half years, with an average of 10 urs per week. A simplified progress time chart is given below arting on October 1964 till June 1965.

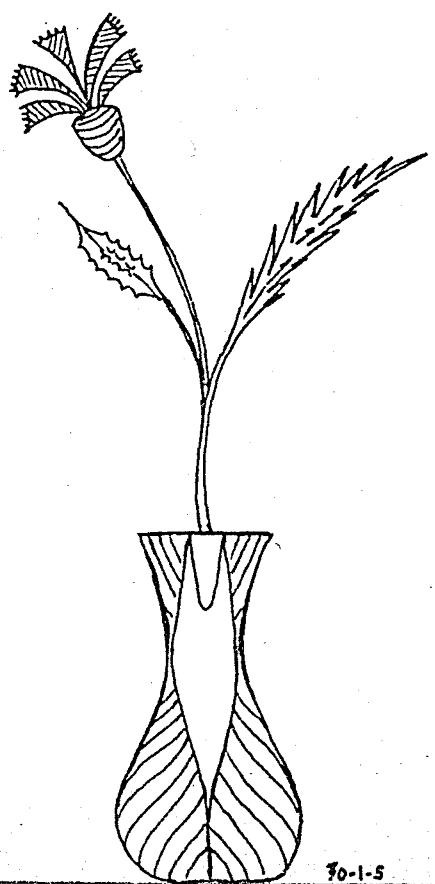


1.8 Outline of the report

1. Introduction
2. Survey on the Available Data
3. Theoretical Background
4. Practical Considerations
5. Experimental Set-up

" Tavsîfi mûsıkîye bırakmak diler Kemâl
Bulmaz lisanda nağme senâ-hân olan sana."

Y.Kemâl



Bildiğinizi öğretin, öğretirken kolaylaştırın, güçleştirmeyin;
.jdeleyin, nefret verip kaçırmayın ve biriniz kızdı mı sussun."(Hadis)

2. SURVEY ON THE AVAILABLE DATA

2.1 Historical Background

2.2 Main Engineering Projects

2.3 Design Considerations

2.4 Conclusion

1 The history of the windmill

t seems very probable that the Mesopotamia is the cradle of the dmill, towards 1500 BC. Although there is no information about se machines, it is possible to imagine that they were vertical-s mills. It was thought that the Crusaders introduced the wind-l to Europe, but it now seems that the Mediterranean countries d them much before the year 1100. From there it was spread to the rth of Europe: windmills are mentioned in the archives of Croyland ey in England from the year 1000. In France some documents about ndmills appeared in the 13th century; in Germany in the 14th cen-ry. In general european windmills had a horizontal axis with 4-aded rotor in the form of a cross. These machines were used to ind corn.

About the year 1350, in the Low Countries mills were first used r pumping water, with the object of draining the land situated be-w sea level. A special design was developed for this purpose in 30 in Schoonhaven (Holland), and soon they spread all over the untry. Windmills soon were extended all over Europe for irrigation feeding fountains. An article published in 1588 by Agostino melli " Le Diverse e Artificiose Machine ", shows the use of ndmills to carry water by vessels tied by chains to feed a foun-in (Fig.2.11-1). In 1686 Andre Brockler proposed a new type of ndmill in the " Theatrum machinarum novum ". It uses a chain pump th double gear train.(Fig.2.11-2). In 1578 Jacques Besson in the

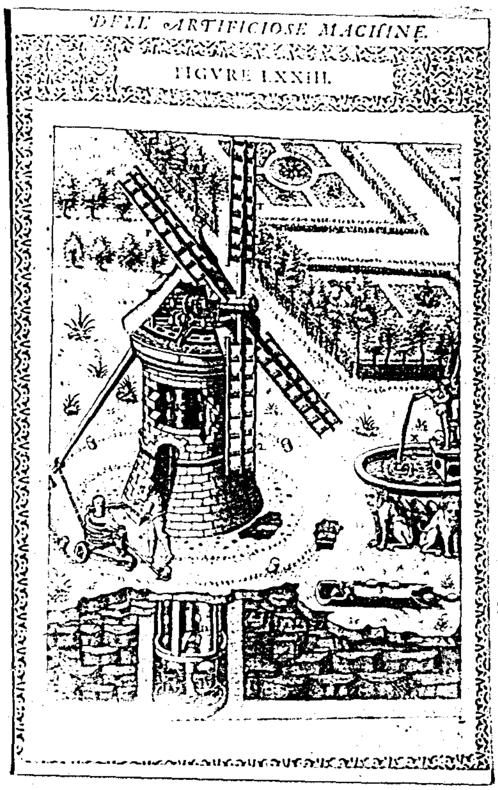
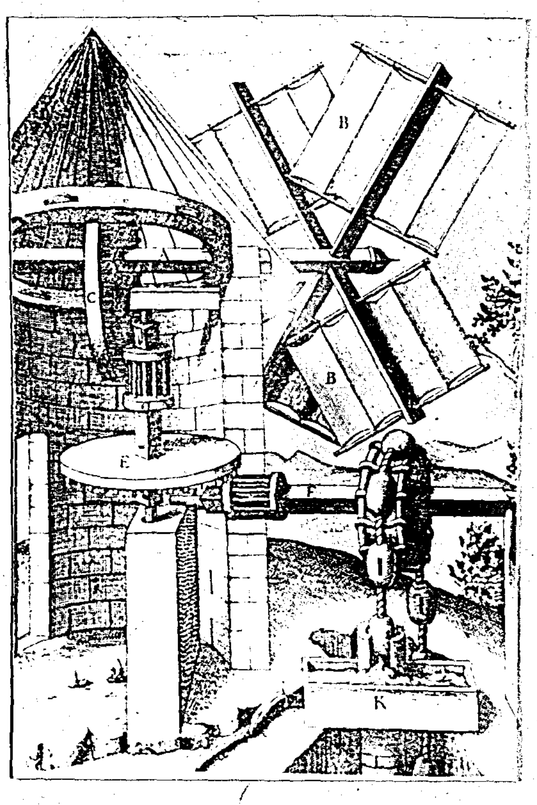


Fig 2.11-1
Windmill driving a chain pump, from Agostino Ramelli 1588. (1)



g. 2.11-2
ndmill driving a chain
mp via a double gear
ain, yawning mounted
rollers, from André
öckler, 1686 (1)

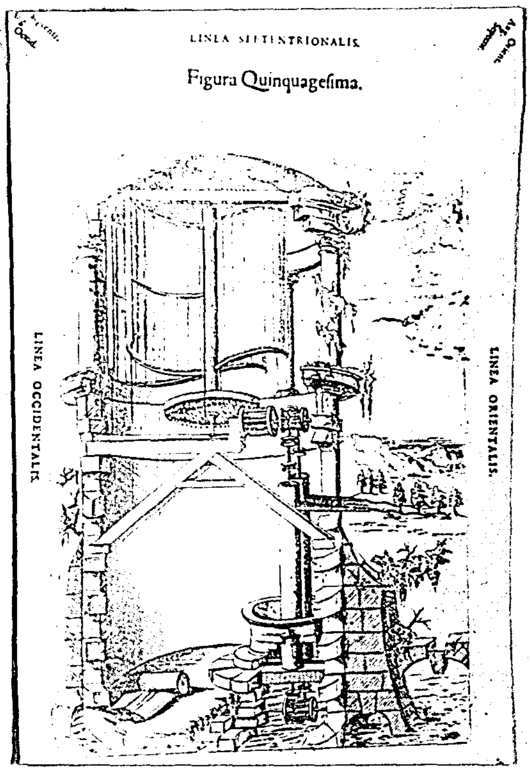
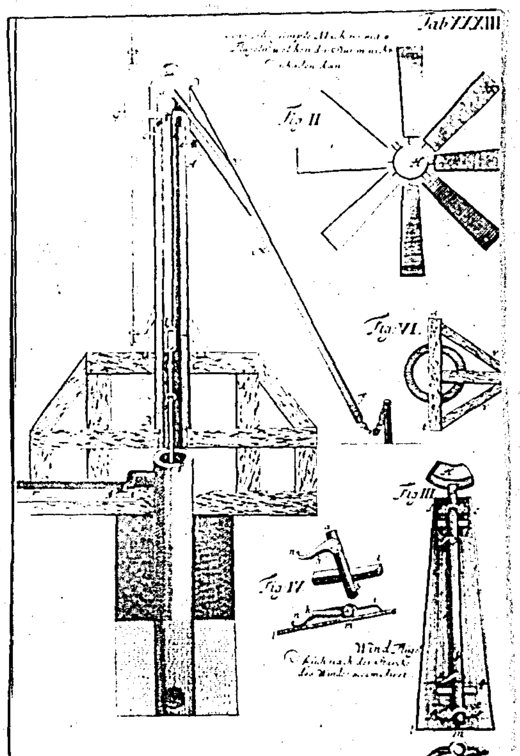


Fig 2.11-3
Vertical windmill which does not require a yawning mechanism, driving a chain pump, from Jacques Besson 1578, (1)



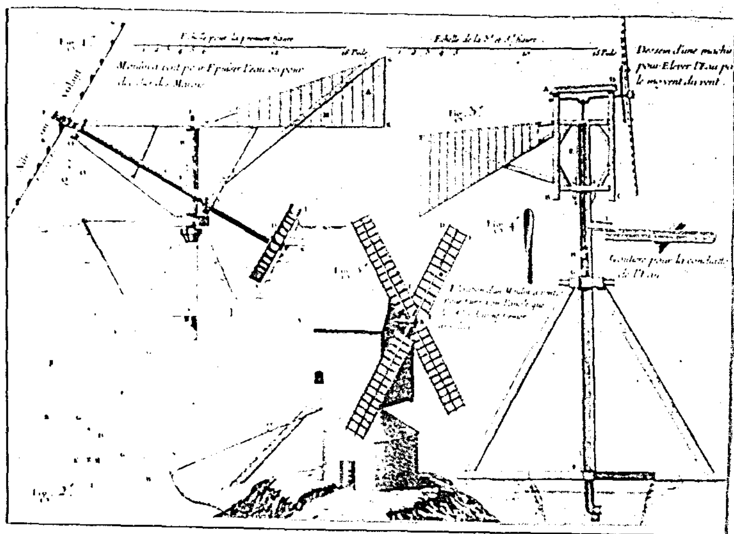
. 2.11 - 4
f-governing windmill with
atable paddles having
ing return, driving
ingle action pump,
n Jacob Leupold, 1724

heâtre des instruments mathématiques et mecaniques ", describes
ertical windmill which recalls the modern Savonius rotors.(Fig2.24-6)

n the 17th century engineering principles developed and more ra-
cal and practical designs were made. The evolution led to construc-
ns so durable that they still survive in their main outlines. The
t interesting application was made in Holland, about 1630 when
Lake of Schermeer, near Alkmaar in North Holland, was drained
windmills working in series according to the plans of Leeghwater.
area of about 11710 acres was recovered by means of 50 windmills.
most interesting machine was proposed by Jacob Leupold in his
heatrum machinarum hydraulicarum " printed in Leipzig. An 8 bla-
rotor drives by means of a crankshaft and a tie rod, a single-
ing pump. The machine has special mechanisms for self-regulation.
g 2.11-4).

n 1739 Belidor published in the " Architecture hydraulique " se-
al windmills. Among others, one had an inclined axis, on one side
wheel was supported, and on the other an elevating wheel was
nged directly into the water. Another windmill made use of a ro-
very similar to modern high speed propellers with twisted bla-
(Fig 2.11-5 and Fig 2.11-6). Towards 1745 Edmund Lee patented
auxiliary wheel or fantail, used to turn the mill into the wind
omatically, a device still used today. In 1759 Smeaton presented
the Royal Society a report " On the construction and effects of
dmill sails ", which describes experimental study to measure
rque at different speeds. (1)

2.11-5
mill driving a tread-
directly, and a wind-
with a piston pump,
Belidor 1739 (1)



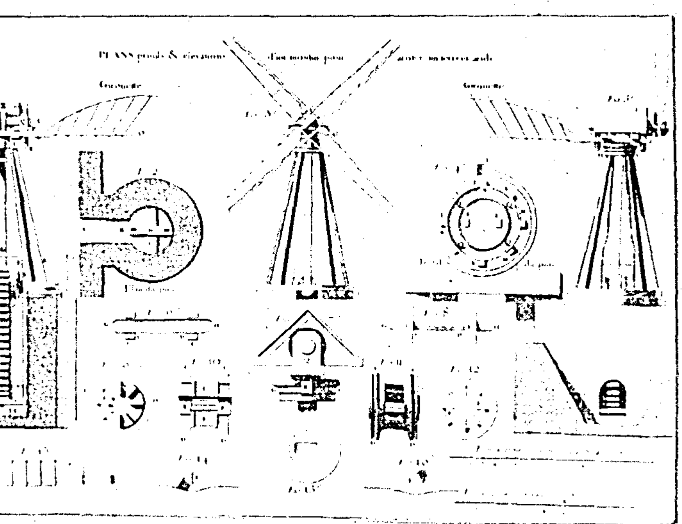


Fig 2.11-6
Windmill driving a chain pump through a cable transmission, from Belidor 1739 (1)

vidence exist of the utilization of windmills during the last tury in Denmark. Seventy or eighty years ago practically all farm k in Denmark was performed by men and animals. Danish farms are a rule 100 to 150,000 m^2 large, and the country is divided in ms of such size. Grain was ground in industrial mills mainly dri- by wind power (Fig 2.11-7). The windmills as a rule were of the ch type with four sails and a swept area diameter of 20 to 22 m, h providing 30 kw. Sails had to be renewed every 15 to 20 years. development of the Danish agriculture forced farms towards the of the century to build their own house-mills, that were very mitive in construction. Several manufacturers soon started the duction of house-mills made of iron and steel.

bout 1890 Professor P. La Cour, a teacher of physics and chemistry, h the financial help of the Danish Goverment started a research k on windmills. (2) In 1898 W.H.Mooreland started some experi- ts in Meerut (India) on the use of windmills for well irrigation.(3) red Chatterton, Professor of Engineering in Mardas (India) con- ted some experiments in 1902 on the use of windmills for irriga- n. The windmill had a diameter of 5.2 m, was placed 23 m above und level, water being raised to a level of 8 m. He made some sug- tions obout the power obtainable from the wind and the best lo- ion of wind power plants. (4)

fter the World War I , towards 1920, Joukowsky, Drzewiecki, ssosky, Sabinin from Russia; Prandlt, Betz from Germany; Constantin, fel from France became interested in the design of more interes- g and efficient windmills. Kumme from Germany built in 1920 a

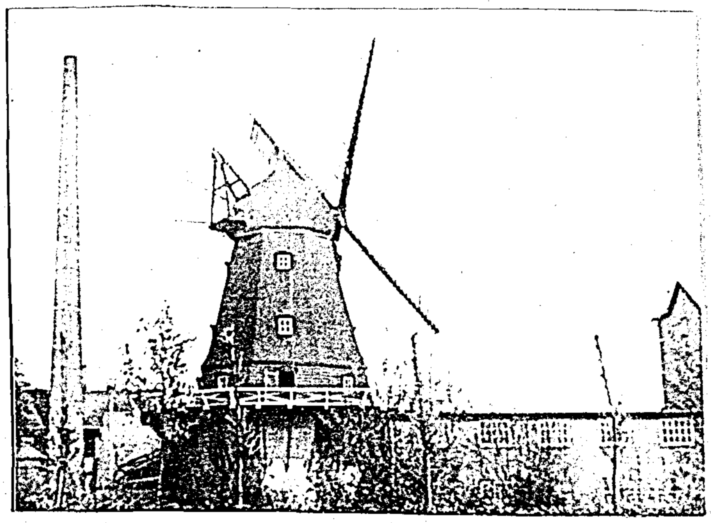


Fig 2.11-7
Industrial mill in
Denmark (19 th cent.)
(2)

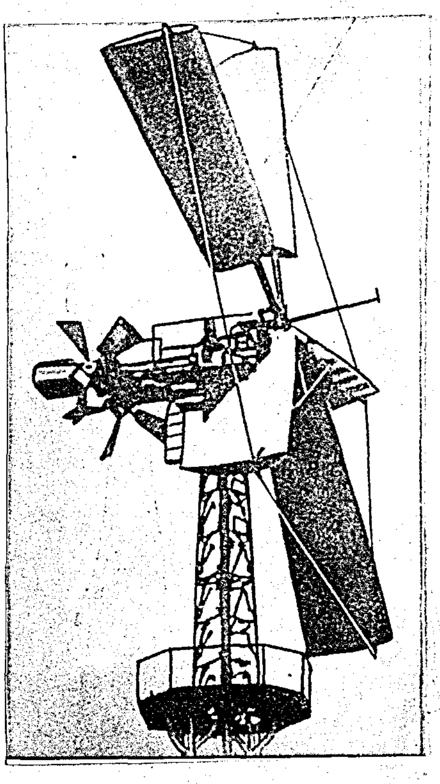


Fig 2.11-8
The Kumme wind turbine built
in Germany ,1920 (5)

6 blades, moderate tip speed ratio, windmill (Fig 2.11-8). In 1924 Flettner started his work on the wind rotor, making use of the Magnus effect; in 1925 he crossed the ocean with his rotorship Baden-Baden (Fig 2.23-1), followed by the second ship Barbara. The same year in Finland, Savonius built his S-shaped rotor. (5) In 1929 the Madras Department of Agriculture in India set up a windmill at Coimbatore, 4 m in diameter and 13 m above ground level, with a daily average output of 60 litres. (4) In 1929 Darrieus in Bourget (France), biult a two-bladed unit 20 m in diameter and a ratio of tip speed of 10 (Fig 2.11-9).

In 1931 a Russian design was tested, after two years of wind measurements. The unit was 33 m in diameter, 100 kw output, 220 volt induction generator, connected to a 6300 volt line, to the 20,000 kw peat burning steam station at Sevastopol, 30 km distant (Yalta). Regulation was by pitch control and an automatic yawning system (Fig 2.11-10). In 1932 Madaras tested his 30 m high, 9 m diameter wind rotor with success (Fig 2.23-12). In 1933 Honnef proposed a design with 5 turbines (85 m in diameter each) mounted on a 350 m high tower, the generators being built in the turbines, generating a total of 5000 kw. (Fig 2.11-11).(5) In 1936 the Mysore Department of Agriculture (India) set up a windmill at Hibbal near Bangalore, 13 m in diameter, 17 m from the ground level, producing 100,000 litres per month. (4)

In 1941 the Smith-Putnam wind turbine was installed on the Grandpa's Knob in Vermont (USA). It was a two blade, 58 m diameter wheel, on a 41 m high tower developing 1000 kw in favorable winds (Fig 2.25-3),

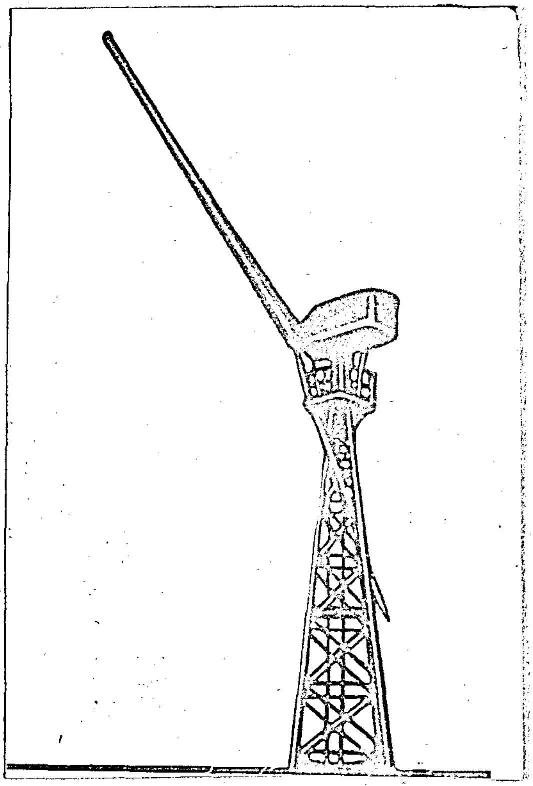


Fig 2.11-9
The 20 m Darrieux wind turbine, 1929 (5)

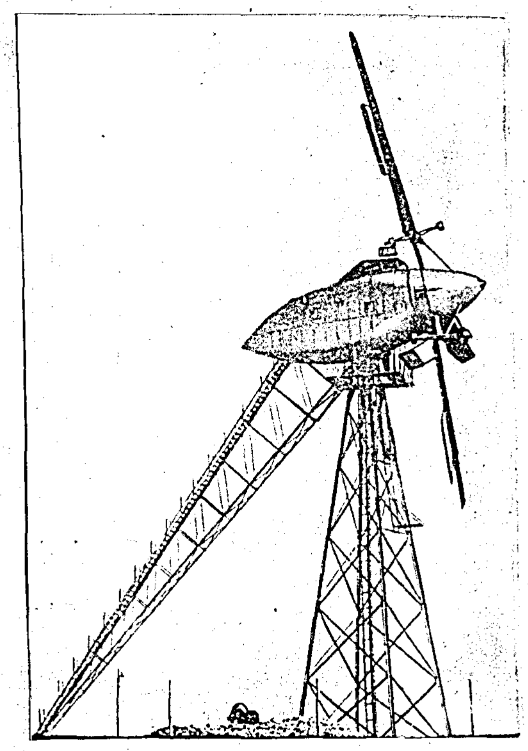


Fig 2.11-10
The Russian wind turbine, 33 m in diameter built in Yalta, 1931 (5)

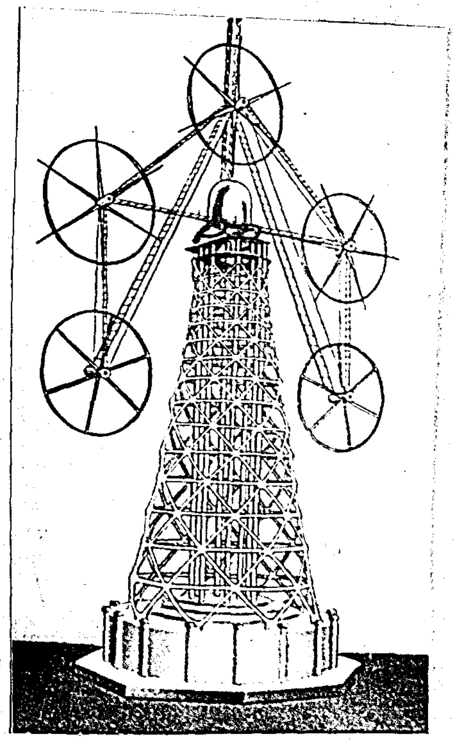


Fig 2.11-11

Design proposed by Honnef , 1933 (5)

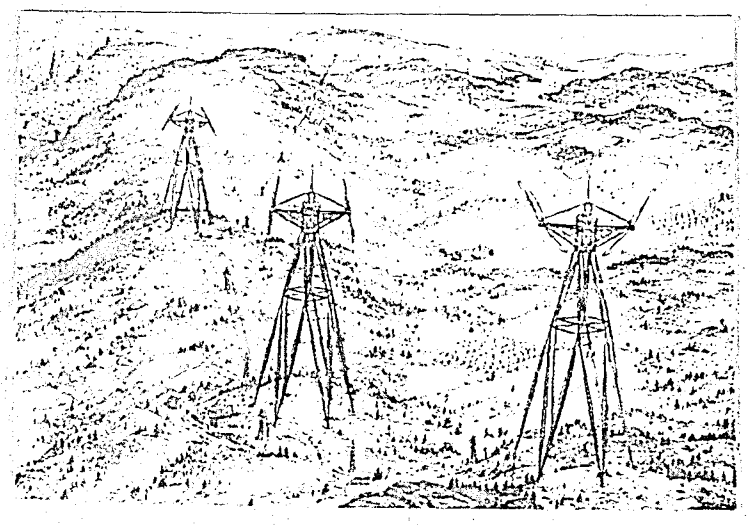


Fig 2.11-12

Wind turbine system visualized by Percy H.Thomas 1945 (6)

Based on the results obtained from this first commercial experimental unit, Percy H. Thomas engineer of the USA Federal Power Comission designed in 1945 two special units: one a two blade turbine for 7500 kw., the other for 6500 kw. with three blades (Fig 2.11-12).(6) In 1947 research on experimental windmill and wind tunnel investigation started at the township of Haslev in Denmark under the SEAS organization (Fig 2.26-3). (2) In 1949 the British Electrical and Allied Industries Research Association (BEAIRA), conducted by E.W.Golding started the research on wind turbines and ordered the erection of an experimental unit on Costa Head Hill on the Orkney coast one of the windiest spots on earth, to generate 100 kw. (6) This was followed by other two 100 kw. units (Fig 2.27-1 and Fig 2.27-2). (8)

In 1951 the Research Council of Israel established a Wind Power Committee, in order to study the potentialities of wind power in the country. (8) In 1952 J.M.Still published his results on the windmill in Poona (India). He reported that the plant was not efficient the use being limited to places of plenty wind. (4) During the same period, U.Hütter at the Allgaier Werke Gmbh at Ubingen, Germany his 7.8 kw., 220/380 volt, 10 m propeller diameter wind turbine, which turned a 3 phase, 50 cycle generator (Fig 2.11-13).(9) In 1953 a 3 kw. unit was put into operation at Eilat, working at 110 volts DC.(10) In 1954 Australia starts a program of erection of 27 wind survey stations in various parts of the south. Statistical data was gathered in order to study the economics of wind power generation. (11) In 1956 L. Vadot, consultant engineer at Seypric, France, reported manufacture of several wind turbines ranging from 6 to 21 m in diameter. (12) (Fig 2.29-1 to Fig 2.29-4). In 1957 W.A. Harrison reported

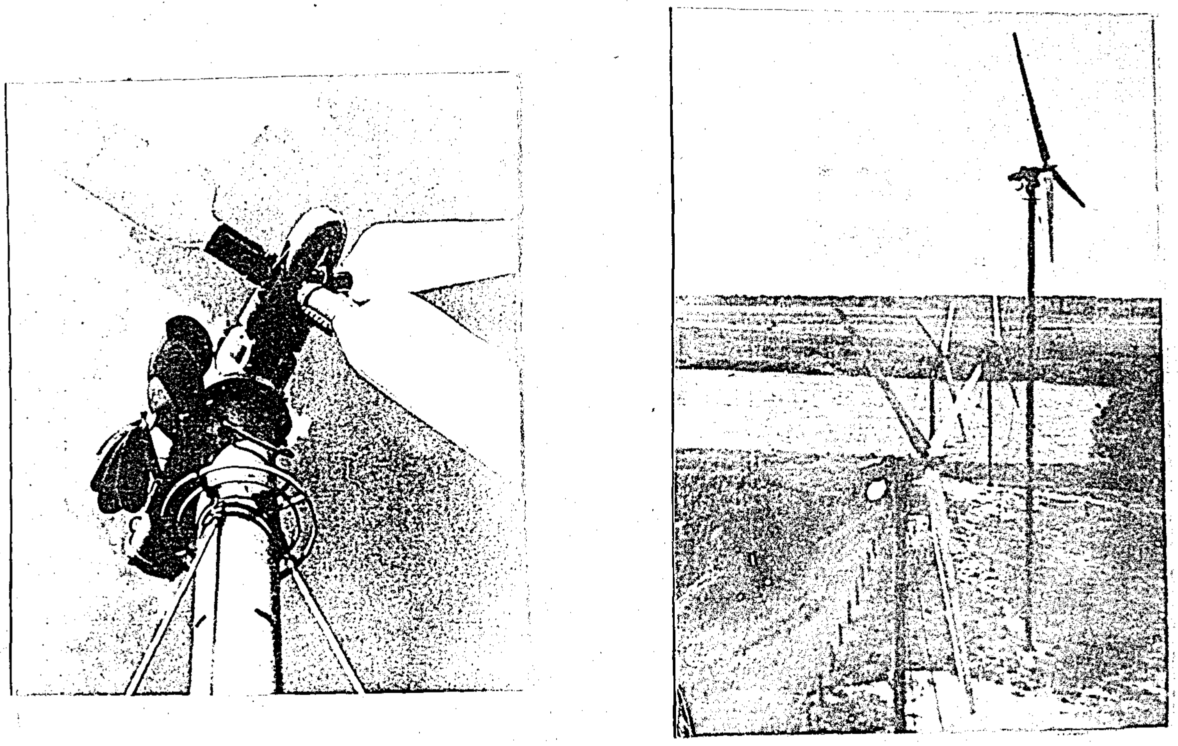


Fig 2.11-13

Allgaier small power generator designed by Hütter, 8 kw. (12)

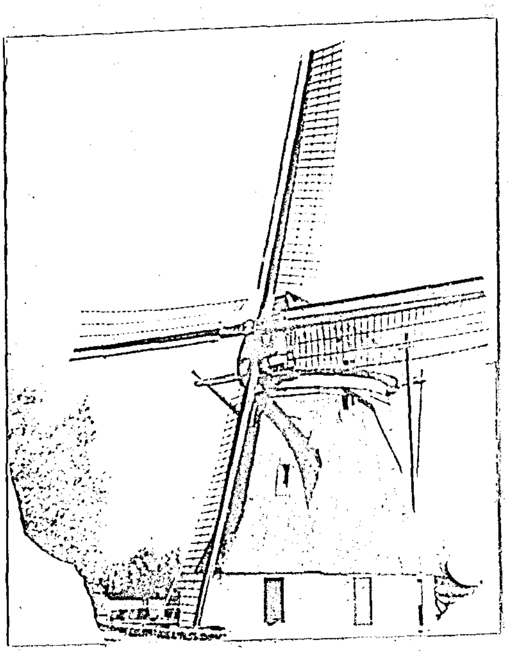


Fig 2.11-14

Windmill at Utrecht, Holland

experiments carried satisfactorily on a 1 watt wind rotor (Fig 2.210-1) (13).

The lattest report available on wind power is given in the 6 th World Power Conference held at Melburne during 1962. Research is still being carried in England in the British Electrical and Allied Industries Research Association and in Israel by the Research Council. (14)

(1) L.Vadot " Water Pumping by Windmills " Houille Blanche. Septembre 1957. pp 524-529.

(2) J.Juul " Wind Machines " Wind and Solar Energy. Proceedings on the New Delhi Symposium.UNESCO 1958. pp 56-73.

(3) 5 th World Power Conference. Wien 1956. pp586-587.

(4) R.V.Ramiah " Some Problems in the Utilization of Wind Power in India ". Wind and Solar Energy. Proceedings on the New Delhi Symposium.UNESCO 1958. pp 102-105.

(5) Palmer C. Putnam "Power from the Wind " Van Nostrand 1948.pp 98-108.

(6) E.Ayres and C.Scarlett "Energy Sources - The Wealth of the World" Mc.Graw Hill Book Co.Inc. 1952 pp 255-263.

(7) E.W.Golding and P.J.Montagnon "Development of a 100 kw. Wind Power Plant in the United Kingdom" Comision Nacional de Energias Especiales. Madrid June 1960.

(8) 5 th World Power Conference. Wien 1956. pp 313-314.

(9) U.Hütter "Planning and Balancing of Energy of Small Output Wind Power Plants" Wind and Solar Energy. Proceedings of the New Delhi Symposium. UNESCO 1958. pp 76-89.

(10) J. Frenkiel "Wind Power Research in Israel" Wind and Solar Energy Proceedings of the New Delhi Symposium. UNESCO 1958 pp 108-114.

(11) 5 th World Power Conference 1956, Wien. p 185.

(12) L.Vadot "The Production of Electrical Energy by the Wind" Houille Blanche. Octobre 1958. pp 503-525.

(13) W.A.Harrison "A Wind Operated Electric Power Supply" Electrical Engineering.Vol 76 No.5 May1957 pp 418-422.

(14) 6 th World Power Conference, Melbourne 1962. pp 375-376 and 450.

2.12 Experiments on a new wind rotor.

The following information was obtained from an interview with Prof. Adnan Halet Taşpınar, professor of Mechanical Engineering at Robert College and advisor for this thesis, held on March 24, 1965.

The purpose of the interview was to find out the development of a new idea for the utilization of wind power, carried out by Prof. Taşpınar that made it possible the invention of a new wind rotor.

Prof. Taşpınar, showed since early childhood great interest for machinery. He still remembers with pleasure, a trip to Anatolia where he saw a simple water wheel turning, used to scare birds from the fields. When he started teaching Fluid Mechanics and Hydraulic Machinery at Robert College, he was involved in the design of propeller turbines as an assignment to the senior class. He was then interested on the lattest developments made in the field of hydrodynamics and specially on the principles of flow. During his graduate work in M.I.T., he planned to prepare his thesis on "Three dimensional balancing apparatus". There he was introduced to Prof. Spannhake, professor of Hydraulic Machinery. Prof. Taşpınar assisted him in the erection of the Cavitation Laboratory, cavitation being the subject matter for his thesis. During their work, Prof. Taşpınar suggested Prof. Spannhake an idea about scavenging ICE, which the latter developed afterwards when he returned back to Karlsruhe, Germany. Prof. Spannhake was the Director of the Research Institute for Hydraulic Machinery.

Prof. Taşpınar had also the opportunity of working with Prof. Th. Rehbock, from Karlsruhe, Director of the Research Laboratory on

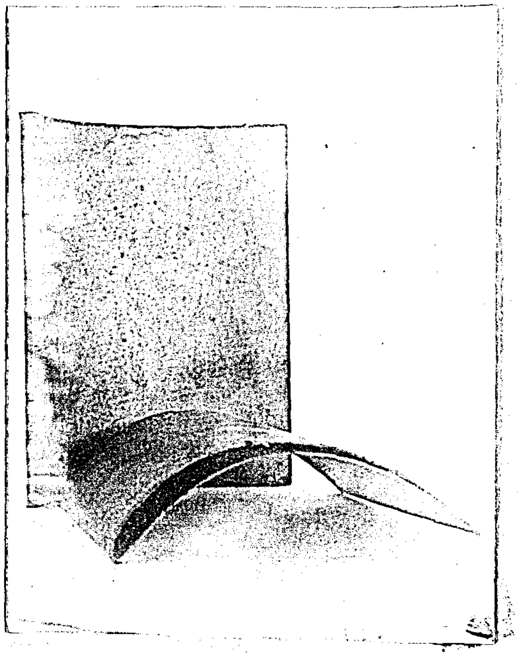


Fig 2.12-1

Blades manufactured by Adnan H. Taşpınar.

Fig 2.12-4

Paper model by Prof. Taşpınar

River Regulation and Land Reclamation, specially in the drainage projects of Zudersee in Holland and river Rhein in Germany.

After his return to Turkey, Prof. Taşpınar gave a lecture at Robert College on Modern Fluid Dynamics and Cavitation. He soon started his experiments on a new wind rotor, basing his ideas on the basic principles of Hydrodynamics. Fig 2.12-1 shows a pair of wings used for his experiments. The outline of the experiments carried is as follows:

1. Experiments to study the flow conditions around the stationary wind rotor, using paper strips attached to the wings. This made it possible the analysis of the blade profiles and stream tubes in the wheel.

2. Torque measurements to study the power characteristics of the wind rotors.

3. Study of different blade profiles.

4. Study of the performance characteristics of different models varying the diameter to height ratio:

- one to one ratio
- one to two ratio
- one to four ratio (Express type)
- four to one ratio
- two to one ratio.

5. Study of the performance characteristics of three stage rotors, placed 120 degrees out of phase from each other.

The most interesting characteristic of the rotor is it reversability, that is to say the ability to turn in clock and counterclockwise

16.2.58.
Jet Pala Dolabı

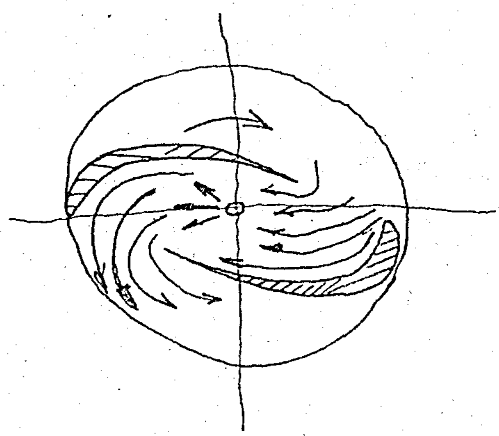


Fig 2.12-2

Principles of the Impala Rotor

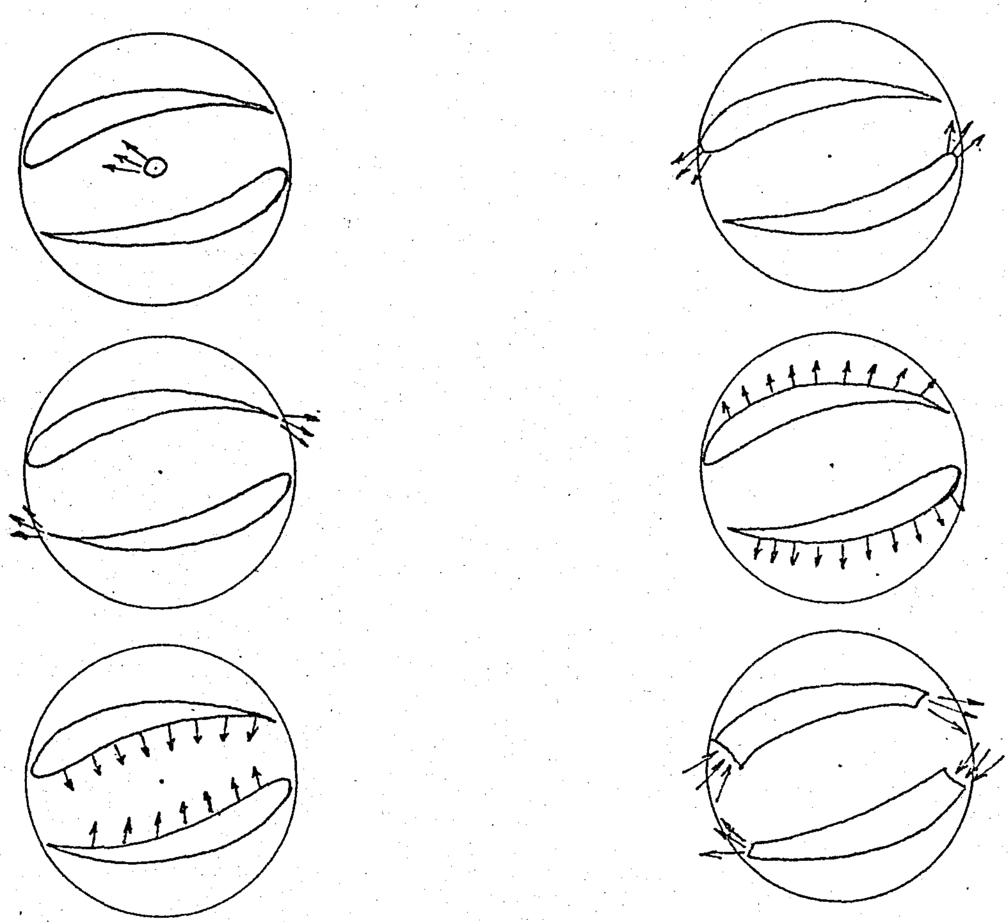


Fig 2.12-3

Different applications of the rotor

lirection. The idea was finally patented by the Turkibh goverment. The peculiar characteristics of this rotor makes it possible its applica- :ion in other fields of energy generation such as water turbines, steam turbines and also gas turbines, and as ship propeller.(Fig 2.12-2)

Prof. Taşpınar has also prepared a program for the implementation of the invention, taking into consideration the existing conditions in underdeveloped countries. The aim of the program is to utilize the wind rotor in small communities with water scarcity to pump well or ground water to be used for irrigation. The plan envisages the pobsi- bility of financing the project in such a way as to accept payment of the cost of the equipment and its installation only after water has been pumped out.

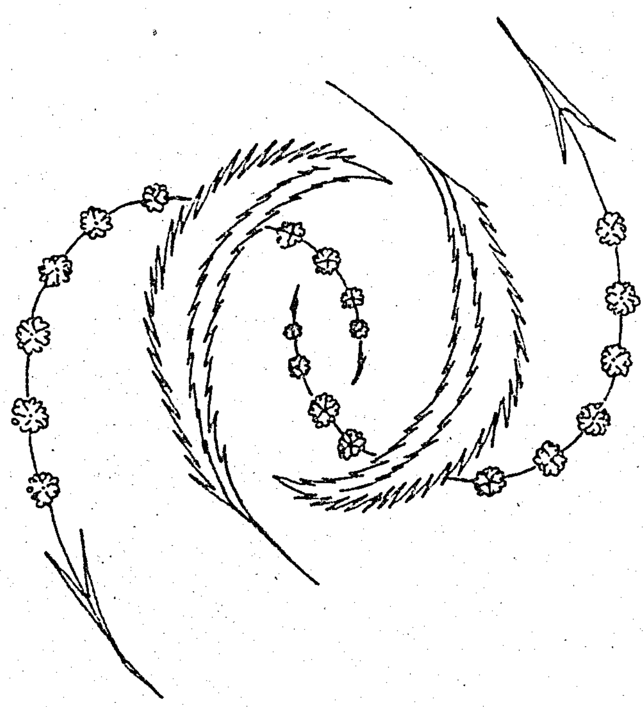
A field of application of this rotor than ban have still further development is the one of the gas turbine. The gases produced in a combustion chamber may be injected in the rotor through nozzles pla- ced in the:

- main axis of the rotor
- nose of the blades
- tip of the blades
- upper chamber of the blades
- lower chamber of the blades

Another possible application may be the use of two ram jets in the form of airfoils, placed instead of the blades, developing in this way an extraordinary torque. (Fig 2.12-3)

In February 1964, Prof. Taşpınar brought to his Graduate class at Robert College, a paper model of the "Impala rotor" to explain the basic principles involved in such a rotor. (Fig 2.12-4). From this model, the author of this thesis started his preliminary work.

" Ciğeri kaptın ama, tarifi bende ... " (N.H.)



SOKOLLU C.

Her yiğidin bir yoğurt yiyişi var".

2.2 MAIN ENGINEERING PROJECTS

2.21 La Cour Project (Denmark, 1890)

2.22 India Research Project (1898)

2.23 Flettner Wind Rotor Experiments (1924)

2.24 Savonius Wind Rotor Project (1925)

2.25 Smith-Putnam Experimental Project (1941)

2.26 SEAS Research Project (Denmark, 1947)

2.27 BEAIRA Research Project (England, 1949)

2.28 Israel Research Program (1951)

2.29 Experimental Program in France (1956)

2.210 Wind-Rotor Research Project (USA, 1957)

2.21 La Cour Project (Denmark , 1890)

Windmills are an important factor in the development of the Danish agriculture. Before the end of the last century, grain was ground in industrial mills driven mainly by wind, as a rule of the Dutch type, with four sails and a swept diameter of 20 to 22 m . At that time there were about 3000 windmills producing each 30 kw., their sails having to be renewed each 15 to 20 years. The development of the Danish agriculture towards the end of the century forced many farmers to build their own house-mills, that were very primitive in construction. Soon several manufacturers started the production of house-mills of iron and steel. This mills worked very satisfactorily at about 7 m/sec wind speeds or more. About 35 years ago, 30,000 of these house-mills were working producing about 100,000 kw. (Fig 2.11-7).

About 1890 Professor P.La Cour, a teacher of physics and chemistry at the Askov Folk High School, became interested in the utilization of wind power. He had previously worked at the Royal Institute of Meteorology in Copenhagen, where he had started studying the problem. The Danish Goverment granted him a sum of money for the erection of an experimental mill at Askov. A wind tunnel and a laboratory was also erected near the experimental mill (Fig 2.21-1). This mill produced enough electricity for light and power to the township and high school of Askov. About 1900 La Cour presented his design of a windmill for supplying electricity for farm use. During the following 10 years several of this windmachines were erected in Denmark generatingeach 5 to 25 kw., 110 or 220 voltage,supplied with a 100 to 300 amper-hour battery for periods of calm wind.

Utilization of electricity soon became very common in Denmark, and the conventional type of diesel engines were introduced to the country. After the World War II, an interconnected network between Denmark, Sweeden and Zealand was established. The large amount of available electricity in Denmark made it possible the utilization of electric power for cooking, heating, poultry, farm work, etc., with the consequent rise in the living standards. (1)

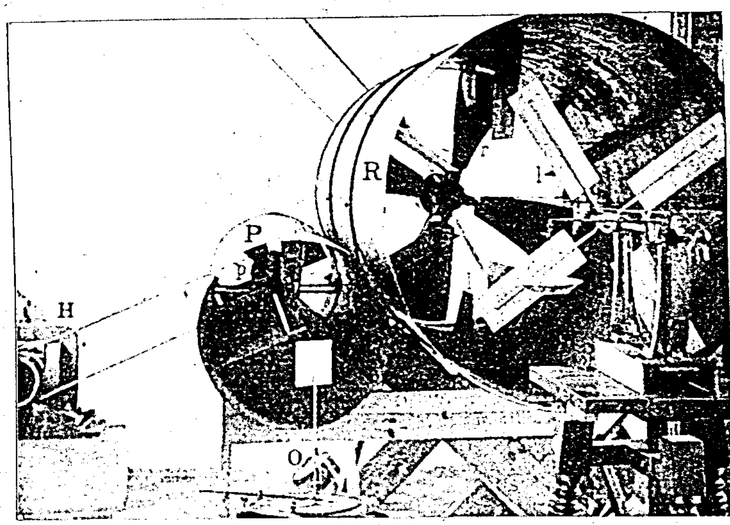
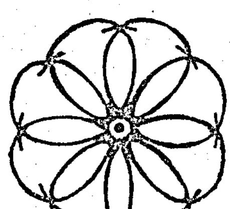


Fig 2.21-1

Wind tunnel at Askov, 1896 (1)



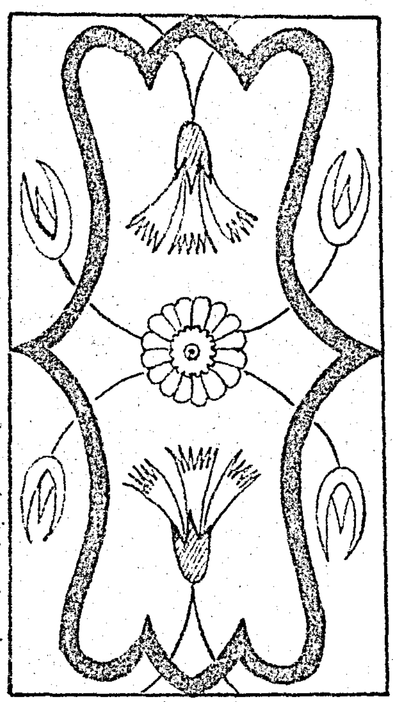
(1) J. Juul "Wind Machines". Wind and Solar Energy Proceedings of the New Delhi Symposium. UNESCO 1958. pp 56-73.

2.22 India Research Project (1898)

In 1898 W.H. Mooreland started some experiments in Meerut on the use of windmills for irrigation. n 1902 Alfred Chatterton conducted some experiments on the same subject. In 1952 J.M.Still published his results on the windmill in Poona. esides the above mentioned experiments, some individual attempts for exploting wind power were made in Madras, Mysore, Coimbatore, and were useful in identifying the problem. The Indian Goverment became interested in the problem and started a research program.

The Indian Meteorological Department (IMD), mantains regular observations of wind velocity and direction at more than 200 places scattered all over the country. Data relating the average monthly and annual mean hourly wind velocities at these stations were published in 1948. These data provided useful information on areas where windmills may be set up, but thel are of little value for estimating the available wind power. More recently the IMD has installed recording anemographs at selected 24 places, and a proposal for installing anemographs in 15 more places was considered. An estimate of the available energy for windmills at 20 selected places has been made by Bhatia. Considerations to be taken into account in the measurement of wind power have also been analyzed by Venkiteshwaran, and they constitute the preliminary approach to practical large scale projects. The surveys reveal that prospects for wind power exists in various regions of Rajasthan and the West Coast. The Second Five Year Plan envisages the possibilities of setting up 5000 small units and 100 medium sized units for irrigation and rural electrification purposes. (1)

The Indian Goverment has established a research group for this purpose, with the support of UNESCO. (2)



RÜSTEMPAŞA C.

(1) 5 th World Power Conference. Wien 1956. pp 586-587

(2) E.W.Golding "Energy from Wind and Local Fuels". The Problems of the Arid Zone. Proceedings of the Paris Symposium. UNESCO, 1960. pp 249-258

.23 Flettner Wind Rotor Experiments (Germany, 1924).

In 1926 Anton Flettner in his book on the rotorship: "Mein Weg um Rotor" (Leipzig), emphasized the importance of finding an economical solution to make use of the enormous amount of wind power available on land and on sea. He had started making some research on the aerodynamic Laboratory of the University of Göttingen (Germany) in 1922, to improve the existing methods of utilizing wind power. By means of these experiments he was able to confirm his flow theories and estblish the coefficients which made it possible to decide on the proportions of his famous rotorship.

He had discovered a clear cut analogy between the airplane wing and a rotor. In both cases streamlines are deflected to one side of the body, where an acceleration of the fluid takes place, with a reduction of pressure, while on the opposite side, the fluid is retarded with an increase in pressure, causing a lift upon the projected area of the body. In the case of the airplane wing the deflection of the stream lines is affected by means of a special profile section. The rotor is revolved about a fixed axis, therefore offering a new surface to the wind making the action continuous. This action receives the name of "Magnus effect", which first made investigations on the subject.

1. Development of the experiments

The first application of the rotor for ship propulsion was the Buckau - later named Baden Baden. This rotorship proved that the application was technically feasable. (1) The ship was 3 masted, 960 tons, equipped with 200 hp auxiliary motor. Two story mast were erecd 14 m high, provided with bearings. The cylinders were fitted by scs, rotated by motors at a speed of 125 rpm with a tip velocity 20 m/sec, using 9 hp power. (2) In wind and sea such as she countered in the North Sea in midwinter, as well as on the Atlantic, ere she also passed through terrific storms, the rotors proved to entirely safe, reliable and efficient. The rotors accomplished actly as much power as sails of about 10 times the area it formely d. In place of a crew to handle the sails, there was only an elecic controller on the bridge for each rotor. (Fig 2.23-1) The second torship, was the 3000 tons Barbara - the first rotorship actually ilt for commercial service - whose performance agreed with the pectations of designers and owners.(1) It was built in 1927, consisd of 3 vertical rotating cylinders, 7.5 m in diameter, 32 m high. e maximum rotating speed of each rotor about its vertical axis s 150 rpm. (3)

Although windmills had been used very extensively during the last ntury, there was no significant engineering development on the sic designs until the first decades of the 20th century. Flettner udied this problem for years and carried on extensive experiments. s a result he had come to the conclusion that a wheel with wings ilt on the plan of the current would be superior to all existing ypes in efficiency and ability to start at low wind velocities, and ithstand the highest wind pressures. The successful operation of he Baden Baden confirmed his conclusions and a windmill based on this rinciples was soon designed and erected. The wheel of the windmill ad a diameter of 22mm; the tower was 35 m high. The four rotors ach had a diameter of 14 cm at the outer end and 11 cm at the inner

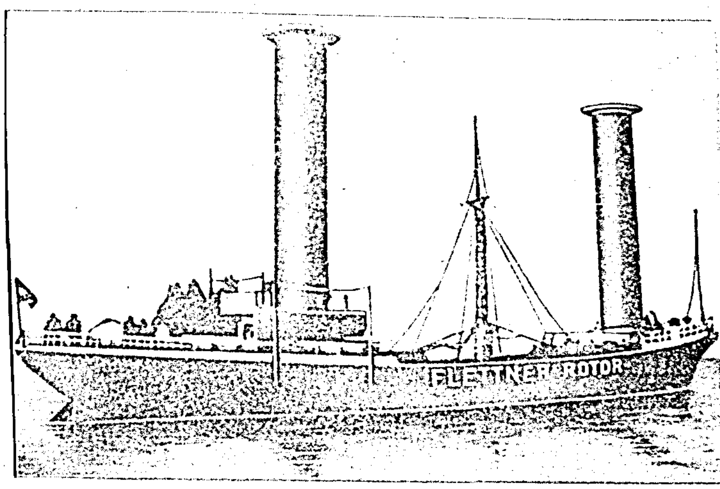


Fig 2.23-1
Baden Baden rotorship
(1925). from Putnam.

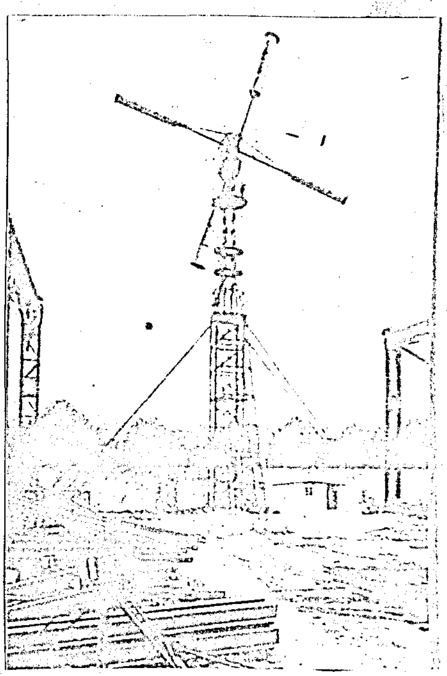


Fig 2.23-2
First large rotor windmill
to be built (1)

, and 5.3 m long. The shells were made of 0.8 mm aluminium alloy. ı rotor was driven by a small rotor built into the inside of the ıl. The top housing contained the electric generator which was dri- by the wheel through a 1:100 transmission. The generator was of pecial design giving constant voltage at widely varying speeds g 2.23-2 and Fig 2,23-3).

ı the basis of the experience gained with the first wind power nt, it was proposed to build a 35 m wheel. This design did not electric motors to turn the rotors - whose regulation was an im- tant factor for best operating conditions - but Savonius rotors ached at the ends of the main rotors. The regulation was arranged meens of pivoted flaps in the wings of the auxiliary rotors which n and check the speed increase as soon as the wind speed exceeds ertain amount, the opening being resisted by springs (Fig 2.23-4). Savonius rotors were 2.6 m high, 1.6 m in diameter. The main ttner rotors were 8 m long and 1.5 m in diameter at the inner l and 1.95 at the outer end. The tower was planned to be 88 m height. characteristic curve of the rotor shows a maximum output of 136.5 at the wind velocity of 36 km/hr. (Fig 2.23-5).

2. Characteristics of Flettner rotors

The Flettner rotor can be considered as a mechanism which, when aced in the current of fluid produces a force nearly at a right gle to the direction of flow, with two components: the lift (Perpen- cular to the direction of flow) and the drag (Parallel to the flow). "Magnus effect" developed when a circular cylinder is rotated in streamline can be expressed mathematically by the equation:

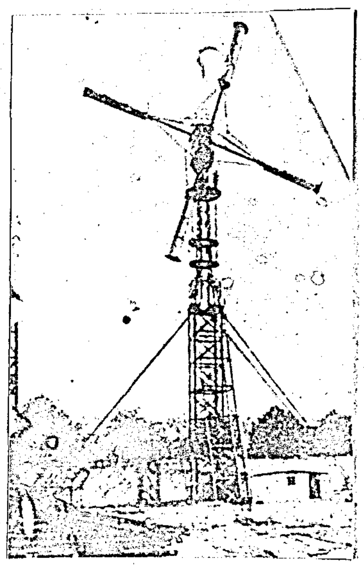
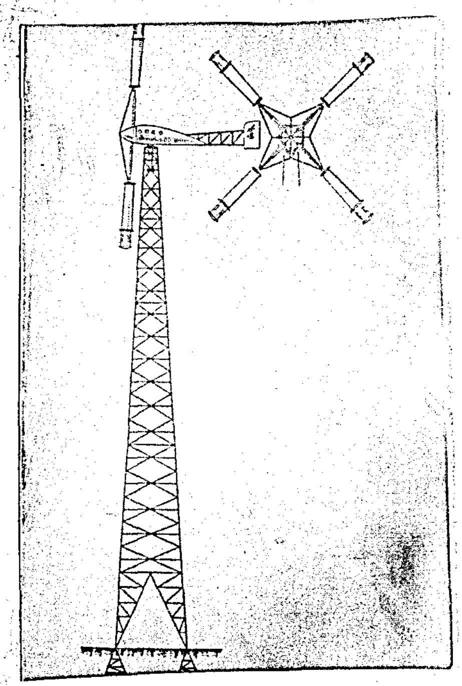


Fig 2.23-3
Another view of the rotor windmill. (1)



ig 2.23-4
roposed wind power plant
f 135 kw. (1)

$$R = 1/2\ C \rho A V^2$$

here A is the projected area, ρ the density of the fluid, V the elocity of the fluid with respect to the body, and C a coefficient epending upon the characteristics of the body. In the case of the irplane wing, this coefficient depends upon the angle of attack and he aspect of the profile, while for the rotor it also varies with he ratio of peripheral velocity to fluid velocity. In a airplane ind the vacuum on the upper side is responsible for 60 to 80% of the otal lift, the same is true for the rotor (Fig 2.23-6), while the est is furnished by the pressure increase on the opposite side where he cylinder surface moves in a direction opposed to that of the urrent.

There are three characteristic diagrams of the Flettner rotor, which have been published and their action expained:

a) The first one gives the lift and drag coefficiens of a rotor, for constant wind velocity and varying peripheral speed (Fig 2.23-7). The value of the lift coefficient for a sail under the best conditions does not reach the value of 1.

b) The second one gives the lift as a function of the peripheral velocity and wind velocity ratio (u/v). The curve illustrates how rapidly the lift increases as the cylinder accelerates and reaches a maximum where the peripheral speed is about 3.5 to 4 times larger than the wind velocity (Fig 2.23-8).

c) The third one gives the total pressure against the two rotors of the Baden Baden, plotted against the wind velocity. The upper curve represents the conditions when the rotors are turning at a constant

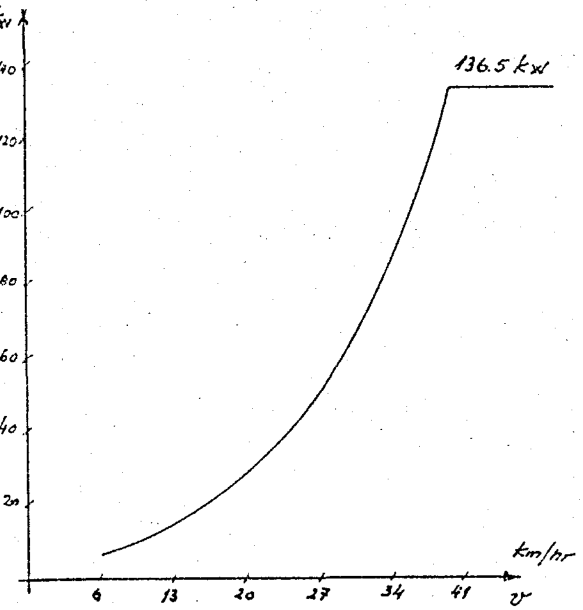


Fig 2.23-5

Power curve for the proposed 135 kw. power plant. (1)

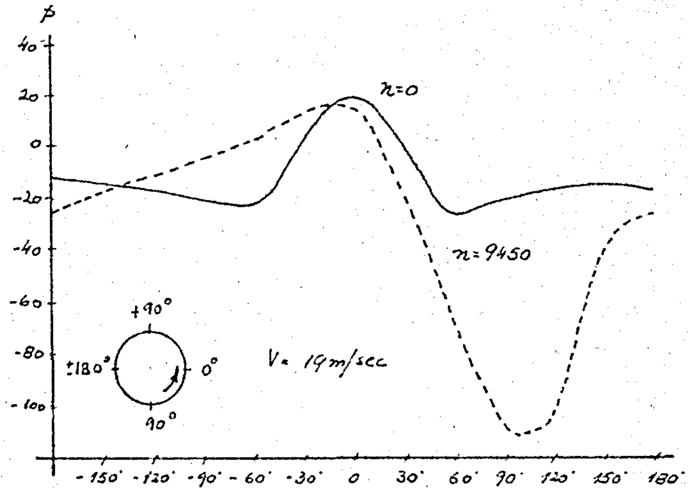


Fig 2.23-6

Distribution of pressure around a Flettner rotor. (1)

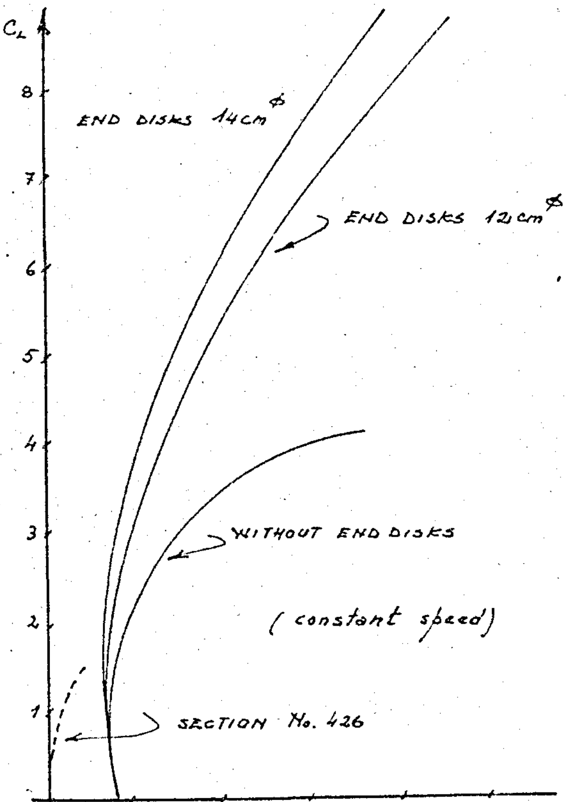


Fig 2.23-7

Typical polar diagram of a Flettner rotor. (1)

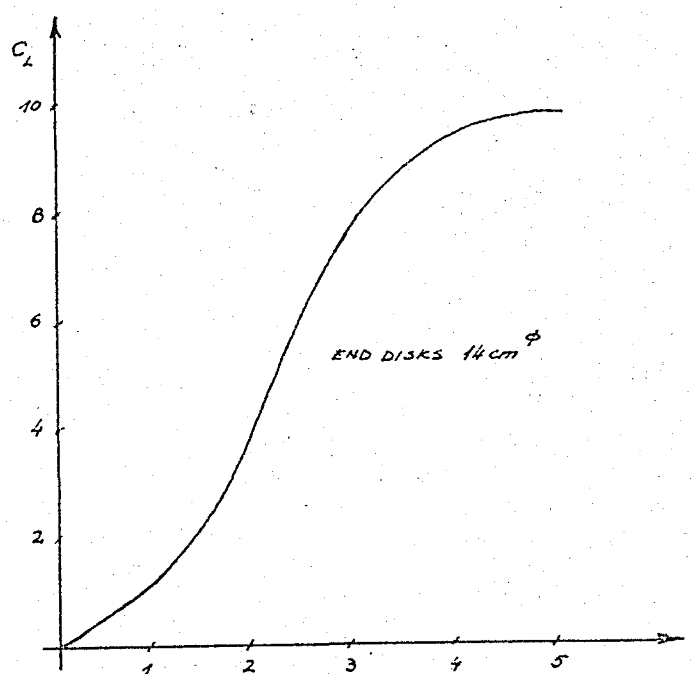


Fig 2.23-8

Lift ploted against ratio of peripheral speed to wind velocity. (1)

speed, and the lower one when they are stationary. For this particular conditions, the pressure against the rotors ceases to increase after the wind has reached a velocity of about 43 km/hr (Fig 2.28-9).

The study of this characteristics can be summarized as follows:

1) the lift coefficient of a rotor is much larger compared with a curved surface - such as a sail - or the best airfoil profile.

2) the resistance in the direction of the wind - the drag - is much larger than for an airfoil, and the lift -drag ratio is relatively low, but the resistance is not excessive when dealing with natural wind.

3) the total pressure exerted by the wind upon the rotor at any given wind velocity, when changing the speed of rotation, vary between a minimum when the rotor is not revolving and a maximum which depends on the ratio of the peripheral speed and wind velocity.

4) the power required to revolve the rotor at the velocity giving maximum lift is less than 10% of the energy abstracted from the wind. This figure was obtained from laboratory and practical experience, but improvement is possible by changes in the design.

The main advantages of the wind rotors are:

- ability to start at low wind velocities.

- ability to generate power even when the wind velocity exceeds the value for which it was designed. It reaches a maximum and then remains constant.

- ability to run with winds coming in all directions.

3. Applications of Flettner rotors

The Flettner rotor can be used as

a) a windmill to pump water or generate power,

b) a means of ship propulsion

c) a water turbine

d) a ventilator (1)

The only important commercial attempt to utilize the principles of the Flettner rotor was made in West Burlington, New Jersey (USA) in 1932, by six large light and power companies: Public Service Electric and Gas Company, Middle West Utilities, Detroit Edison, Standard Gas and Electric, United Gas Improvement and United Light and Power companies. The original design consisted of 15 to 40, 50 tons vertical rotors mounted on trucks which circle around a 10 m gage track about 1000 m in diameter. Each rotor consists of an aluminium shell braced and supported by a duralumin framework. The rotating system is given its initial rotation by means of a motor. The wind propels it around the track and drives a generator coupled to the rotor, and at the same time gearing maintains the requisite rotation of each cylinder about its axis. The generators are operated in parallel, feeding their output through trolleys to an overhead bus. In order to provide for continuous rotation of each rotor twice during a complete circuit of the track, otherwise the torques produced on opposite semicircles would neutralize each other. Each rotor unit was expected to produce 1000 kw. under the most favoroble wind velocities (Fig 2.23-10). At West Burlington a full size rotor was erected on stationary foundations for the purpose of confirming the results obtained in wind tunnel test on a small working model. (4)

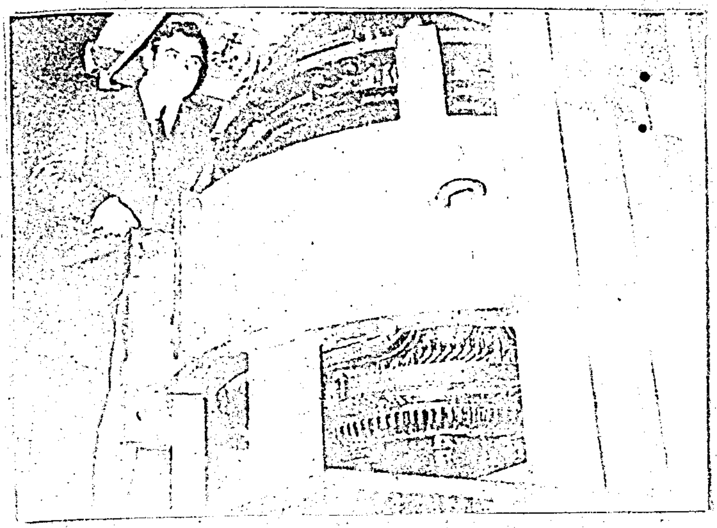


Fig 2.23-11
Wind rotor generator at
West Burlington. (5)

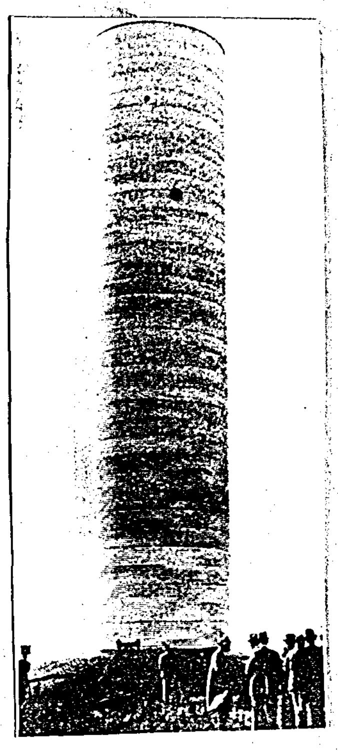


Fig 2.23-12
Wind rotor testing at
West Burlington. (5)

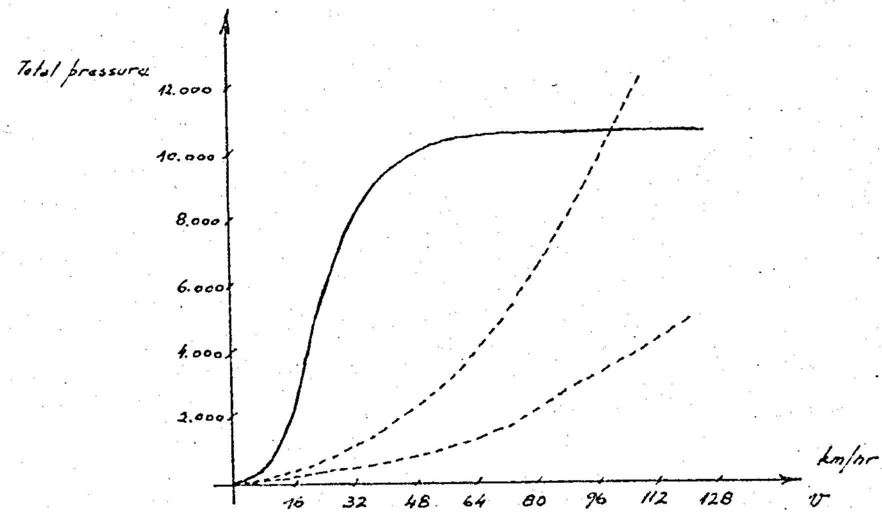


Fig 2.23-9

Total pressure on the two rotors of the Baden Baden rotorship, plotted against wind velocity. (1)

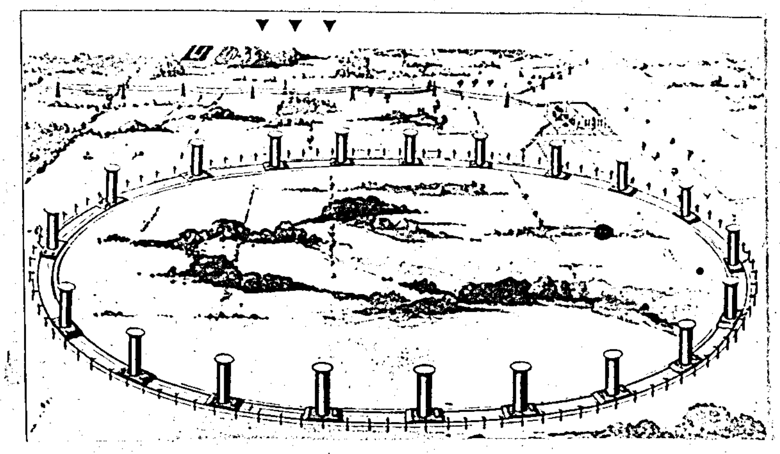


Fig.2.23-10

Wind rotor plant proposed for West Burlington, in New Jersey

(6)

The results of this first experimental wind rotor was reported by Julius D. Madaras as satisfactory. The tower was about 30 high, 9.3 m in diameter and developed a peripheral velocity of as high as 24 km/hr. With 16 km/hr wind the tower showed a translational force of 4000 kg at right angles to the direction of the wind (Fig 2.23-11 and Fig 2.23-12). (5)

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(1) F.O. Willhofft "Industrial Applications of the Flettner Rotor" Mechanical Engineering. Vol 49 No. 3 1927 pp 249-253.

(2) Encyclopidia Britanica "Rotorship"

(3) Richard H.F. Pao "Fluid Mechanics" John Wiley end Sons 1961 p 441

(4) - "Six Large Light and Power Companies Back Experimental Wind Rotor Plant". Electrical World. October 3, 1931 p 574.

(5) - "Wind Rotor Experiments Decidedly Satisfactory" Electrical World, October 28, 1933 p 548

(6) - "Will Towers Like These Dot the Land" Electrical World. May 28, 1932. p 914.

2.24 Savonius Wind Rotor Project (Finland, 1925)

1. Development of the project.

S.J. Savonius, from Helsingfors, Finland, became interested in aerodynamic problems in 1924 when the Flettner first rotorship Baden Baden was tested. He had then asked to himself if it were not possible to substitute the electric motor needed to turn the cylinder rotors by wind power. He made some experiments by cutting a Flettner cylinder from top to bottom into semicylindrical surfaces, moved these sideways along the cutting plane, forming a rotor which in cross section resembled the letter "S", placed a shaft in the center and closed in the surfaces between the two circular end plates. He tested this model in a windy day, an unmistakable pull manifested itself, which tended to press the shaft sideways. The next step was to make another similar structure and to mount both on the ends of a common shaft, to the middle of which he fixed another shaft at right angles. This resembled a two-bladed propeller or windmill, with S-rotors instead of ordinary vanes. Holding this structure in the wind the rotors spinned around while the whole propeller revolved at a fair state.

In this way Savonius was able to make use of the Magnus effect and at the same time avoid the need for an external power to turn the rotors. The problem was then to find a way to increase the speed of rotation of the rotor: this was accomplished by moving the half cylinders slightly back towards each other and the central axis, having in this way a gap or air passage in the middle of the rotor. It was found that the wind striking the cup of one vane would flow through

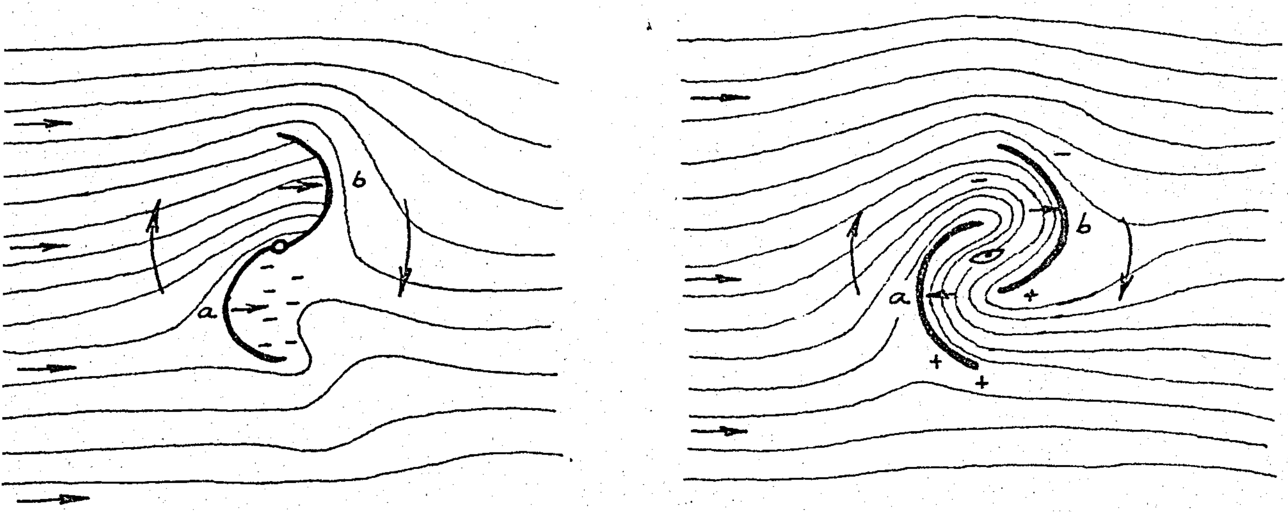


Fig 2.24-1

a) Wing rotor with closed passage (vacuum at concave side of wing a.)

b) Wing rotor with open passage. (2)

Fig 2.24-2

Boat equipped with Savonius rotor, sailing at 11 km/hr (2) the central gap into the other vane, replacing with pressure there the vacuum which caused the drag. (1) The torque is increased in this way by 3 times and the peripheral speed increased by a factor of 1.7. (2) There is also an increase in the side pressure caused by an improvement in the Magnus effect (Fig 2.24-1).

Savonius applied his device for the same purpose as Flettner had. He equipped a 5 m small boat with two metal S-rotors of about 10 m^2 area each. The vanes were made reversible, so as to allow sailing f with wind from either side. The results of this experiments were very satisfactory (Fig 2.24-2). The next application to undergo tests was a rotor of 2 m^2 for pumping waetr. The results obtained were very encouraging, comparing the output with that of a 2 m windmill of American manufacture, the S rotor prooved to be 70% better.

After this preliminary experiments, Savonius realized the need of more scientific research to determine the best vane form and to study the influence of size and shape of the central openning, end plates, and also other details on the speed and power output. For this purpose, he redisgned and enlarged the wind tunnel he had used and equipped it with the necessary recording instruments. The test models were made comparatively large, with a wind area of 2.300 cm^2. In all some 50 different models were made and tested in the wind tunnel. These models included several aeroturbines and windmills of the ordinary horizontal type, several models of vertical airwheels of older construction, and finally more than 30 different models of S rotors.

2. Testing of the S rotors

According to experiments carried up to the first decades of the 20th century the highest efficiency reached with modern designs of windmills was 40% (wind tunnel at Göttingen, Germany). The most common range of efficiencies runned from 10% for the older wooden windmills, to 15-20% for average multi-vened steel windmills, the highest value reached for the last ones being 30-32% . The 4 vaned windmill of La Cour developed an output of 21%. This results were obtained from wind tunnel experiments, conditions in natural wind being somewhat different. It was estimated that in actual conditions 10% of the power obtained in wind tunnels could be developed. This difference is due to two main factors:

a) a windmill provided with a fanetail cannot instantly follow the frequent changes of wind direction.

b) losses due to turbulence and resistance due to friction are larger by a factor of 1.6 in nature (after Bilau).

Professor Betz had calculated the efficiency of vertical windmills compared with the common type horizontal windmills and estimated that only 20% of the theoretical maximum could be developed with the vertical windmills (1/3 of that for horizontal windmills). In practice only an efficiency of 5-10% was allowed for this type.

Savonius confirmed in his experiments most of this estimations, and found for the La Cour wheels for example 20 to 22% efficiency (for a peripheral speed wind veloçity ratio of 2.25). Using a 12 curved vane turbine model of German design he found an efficiency of 32.5% (for a ratio of 1.25). With the multi-vaned turbines of the vertical type the best result obtained was 14% and this with a 3 vaned wheel very similary to a S rotor with the addition of one vane. This vanes were closed by circular end plates; when these were removed the power dropped to 7%. The corresponding power output with wheels having 4, 6, or more vanes wab between 8 and 10% with endplates and 4 and 5% without them. The best of the rotor models gave 31% (for a peripheral speed wind velocity ratio of 1.74), the best output being at a ratio of 0.85.

The comparative study of the 12 vaned wheel, the La Cour wheel and the S-rotor, shows that the characteristics of the power curve of the S-rotor and the 12 vaned wheel are similar, while the La Cour has the characteristics of a high speed wheel, with the consequent low starting allowable torque. Savonius proved by his experiments that 30% efficiency could be obtained with his S-rotor against what was predicted by Betz (only 20% theoretical and 10% practical). Of course Betz had neglected alltogether the Magnus effect which accounts for the big difference (Fig 2.24-3 a)

Savonius became also interested in the torque problem for the S-rotor, which apparently was not constant around the rotor. He compared his rotor with the 12 vaned and the La Cour wheels, and found that while the last two were constant, the torque of the S-rotor reached a value of 100% greater than the 12 vaned wheel at its maximum point and 61% smaller at the minimum point. The 90%position does not, as might be expected, give the greatest torque, the maximum occuring at the angle of 40. In the 150 position when the turbine presents its smallest area to the wind, there appears another maximum, equal to the torque of the 12 vaned wheel, though in this position the wind is blowing over the back of the advancing vane. If area is also taken into consideration the torque is at its maximum in this position. The relative sum of torque for one complete revolution for the wheels

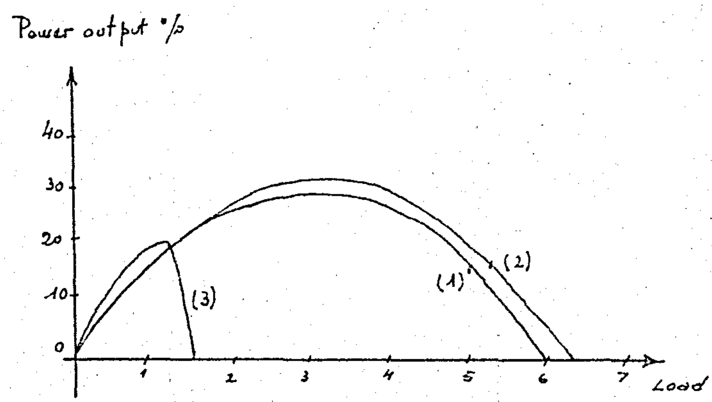


Fig 2.24-3 a

Power diagrams taken in wind tunnel (power output in per cent of total wind power)

1) S-rotor, 2) 12 vaned mill, 3) 4 vaned La Cour mill. (1)

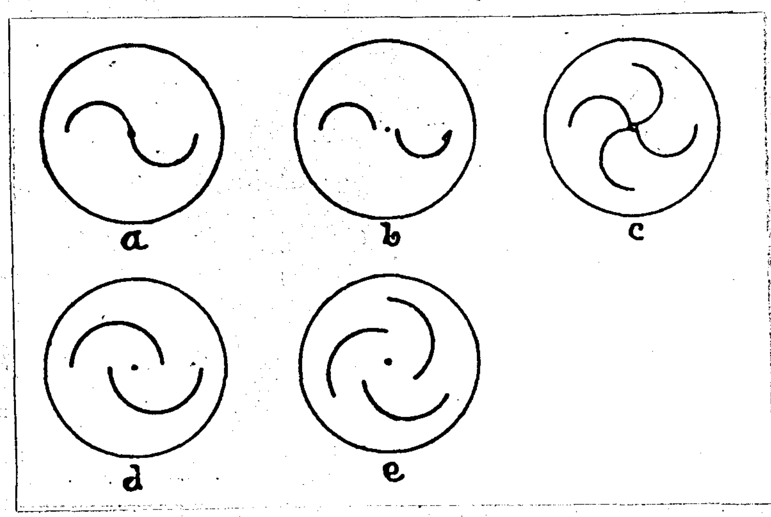


Fig 2.24-4

Different forms of wing rotors of the first type tested by Savonius. (2)

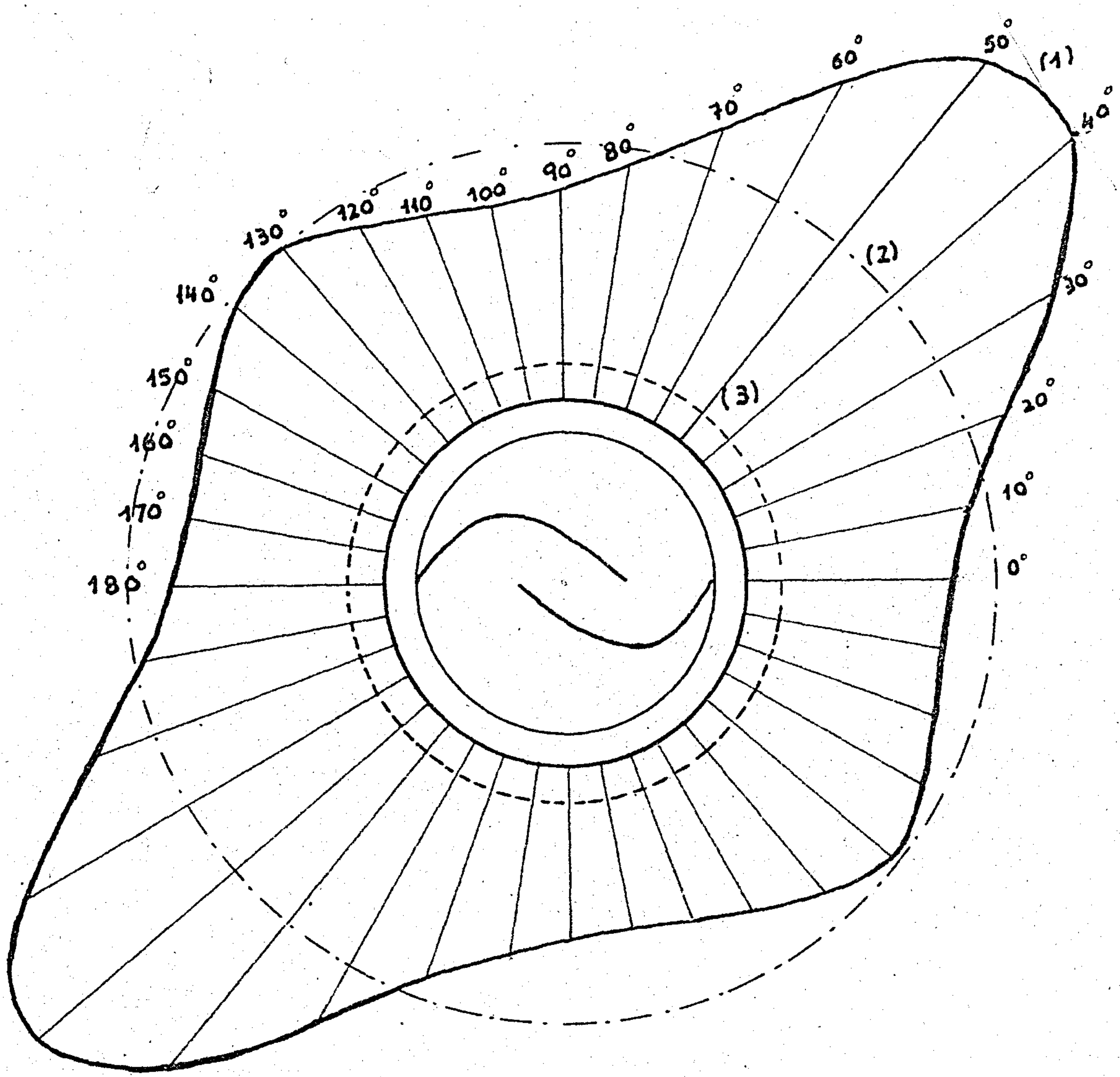


Fig 2.24-3 b

Polar torque diagram

1) S-rotor

2) 12 vaned windmill

3) 4 vaned La Cour mill

idered is: (Fig 2.24-3 b)

	Torque	
S-rotor	100	
12 vaned wheel	87	
La Cour wheel	11	(1)

ıong the many testings, Savonius experimented with different forms rotors, with openings between wings of the order of 1/4 to 1/5 of spread of the wings, with end plates. The results of the compara- e tests are given as follows (Fig 2.24-4) :

	Torque Rating
Two winged rotor with passage	100
Two winged rotor with passage closed	30.
Two winged rotor with crossed wings	20.
Three winged rotor with passage open	80
Four winged rotor with inside opening	30

his indicates the superiority of the two winged rotor with passage a windmill. He then investigated the efficiency of his rotor com- ed with a well designed modern windmill (Fig 2.24-5). This wind- l had a diameter of 70 cm with 18 vanes, the latter having curved faces with 15 angle at the outer tip and 44 at the base. Two types wing rotors were tested against the more conventional one. Wing or No.1 having a semicylindrical form with the passage 1/5 of the ead, and wing rotor No.2 having wings of 165 circumference with middle opening 1/4 of the spread. The three models had the same jected area perpendicular to the wind. The results from numerous ts in the open air, were the following (no units available in the

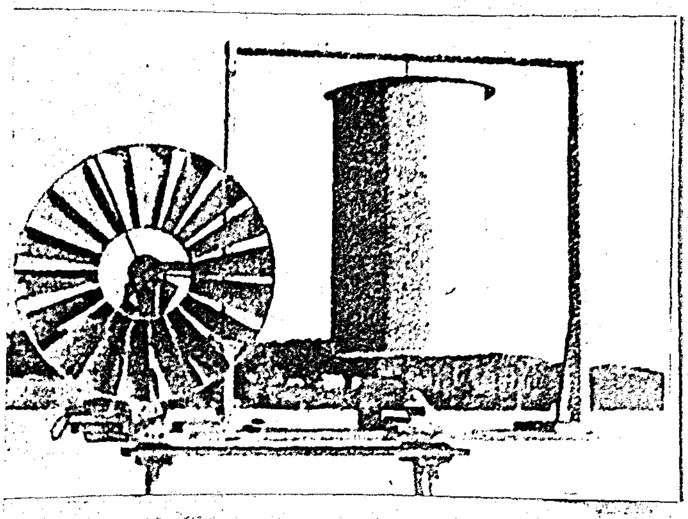
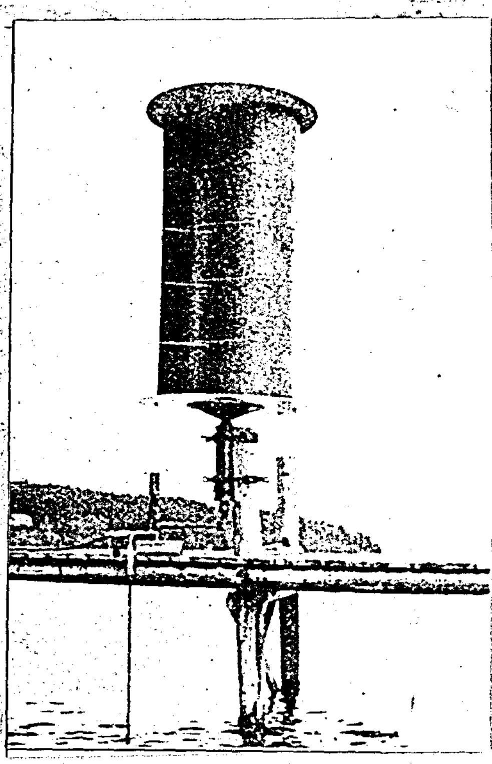
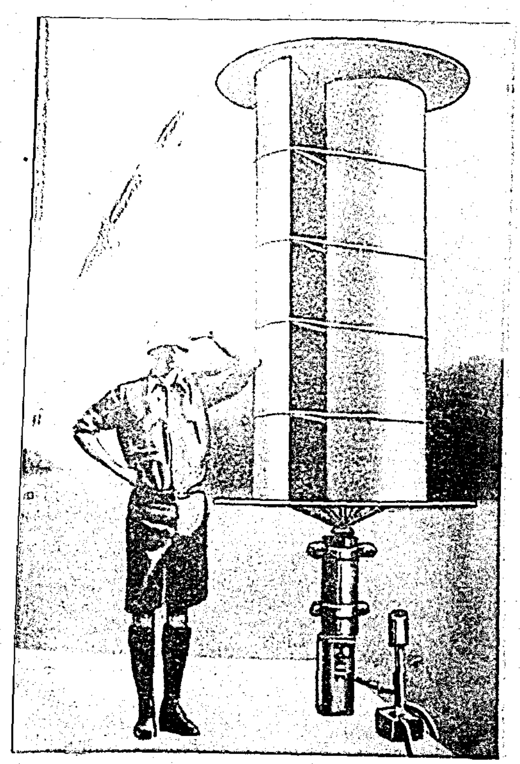


Fig 2.24-5
Modern 18 vaned windmill tested against the wing rotor. (2)



ig 2.24-6
avonius wing rotor arranged
or pumping water. (3)



ource):

Type	Load	Rpm	Work	Ratio of pow
18 vaned windmill	1.3	390	507	75
Wing rotor No. 1	1.3	520	676	100
Wing rotor No. 2	0.9	705	634	93

The wing rotors were able to start even with very feeble winds. A comparative test was made with a La Cour windmill of 4 curved vanes. The rotor windmill carried 4 radial wing rotors each provided with an end disc. The area of the vanes of the La Cour windmill was equal to the projected area of the four rotors. The comparative results were the following:

Type	Load	Rpm	Work	Ratio of power
La Cour windmill	30	110	330	72
Wing rotor	120	38	456	100

These results show that the wing rotor windmill has a starting torque 4 times as great as the more conventional windmill, the speed being much lower. (2)

After the completion of the wind tunnel tests Savonius continued his testing work in the natural wind. During these tests he confirmed that the S-rotor can run in the natural wind at a higher speed than in the wind tunnel, with an increase in the power output, which was not the case with the conventional windmills. The average power output as fixed by several tests rose to 37% on the axis. Also the starting power under load was not inferior to the conventional type, the latter loosing much power due to changes in wind direction. On the er hand the S-rotor can instantly adapt to changes in direction, matter how frequent they may occur. The only important difference the rotors is the increase in the optimum peripheral speed ratio m 0.85 in the wind tunnel to 0.92-1.0 in the wind tunnel.(1)

. Applications of the S-rotors.

he advantages of the S-rotor can be summarized as follows:

- greater power obtainable from the same projected area.
- ability to generate power from wind coming in any direction (no need for fantails).
- simplicity of construction.
- vertical drive shaft (no need for gearing).
- possibility of speed regulation with a simple device.
- possibility of changing direction of rotation.

There are many possible applications of the S-rotor, among others e following can be mentioned:

- for water pumping
- for generating electric power
- for ventilating and dust elimination
- for propelling rotorships
- as motors in rivers and in tidal flows
- for moving advertisments and signs outdoors
- as water, air or steam meters
- as a steam turbine

a) Water pumping

The S-rotor pumping plants were first tried in 1925 in Finland. In hese plants the S-rotor is fixed to a vertical shaft running on wo self-oiling ball bearings situated in a central bearing tube ri-ing half-way up the rotor (Fig 2.24-6). The upper bearing is situa-ed practically in the middle of the rotor, and the strains are thus aken up directly without any leakage. The bearing tube is fixed to he mast or tower raising the rotor to the necessary hight over the round. The power shaft is continued straight down to the ground le-el or to the pump of a special design. Larger units are equipped with laps to limit the rotor to turn over a predetermined speed, acted y the centrifugal force depending upon the speed of rotation. The peed of rotation depends upon the proportions of the rotor. A rotor f large diameter and comparatively short in length, runs at a slow peed and is suitable to use for heavy loads, while one of equal area ut long and of small diameter can have a speed several times higher. umping plants are built in sizes from 1 m^2 upwards, depending upon he application. (Fig 2.24-7). (1) A type of windmill with S-rotors ounted radially as vanes seems to be not very practical because it annot take advantage of winds coming from all directions. (2)

b) Ventilation

Another application is the rotor ventilator, equipped with a centri-ugal fan at the lower end plate, the combination mounted on a central haft on ball bearings over the suction pipe. (Fig 2.24-8). This rrangement was found to five an efficiency higher than any other ype of cowl designed before. (Fig 2.24-9). The strong suction power t develops is of special importance where air has to be drawn by entilation through ducts or pipes of considerable length, or where he air due to lower temperature or other causes - mixture of air and eavy gases, CO_2, gasoline fumes, exhaust gases - is heavier than

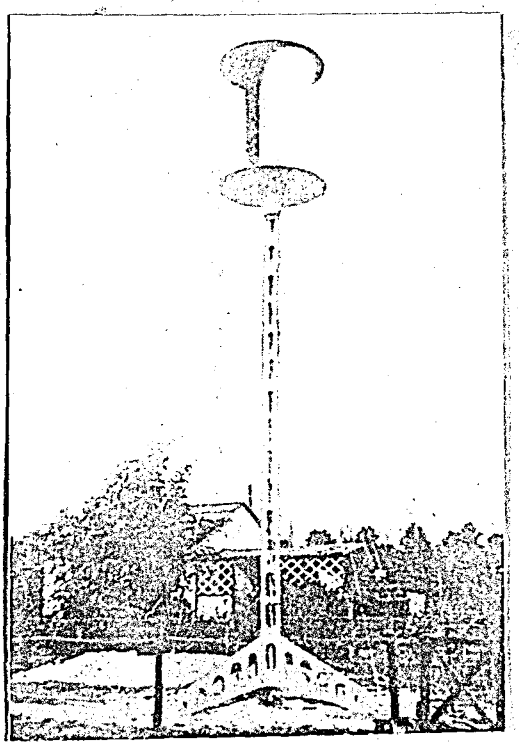


Fig 2.24-7

otor of 1 m^2 area used for water pumping

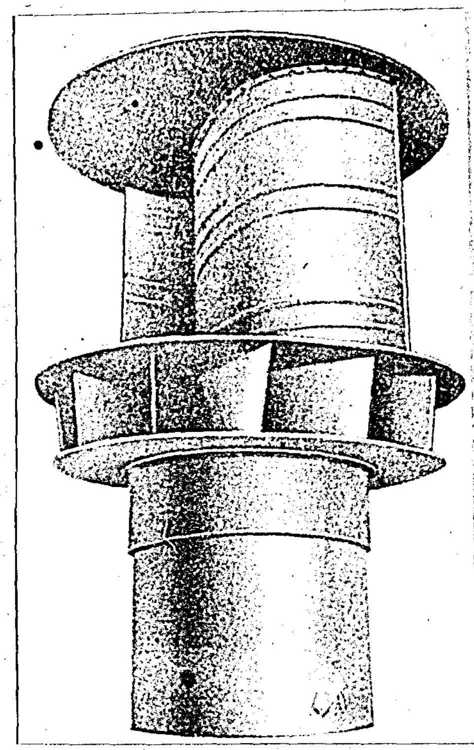
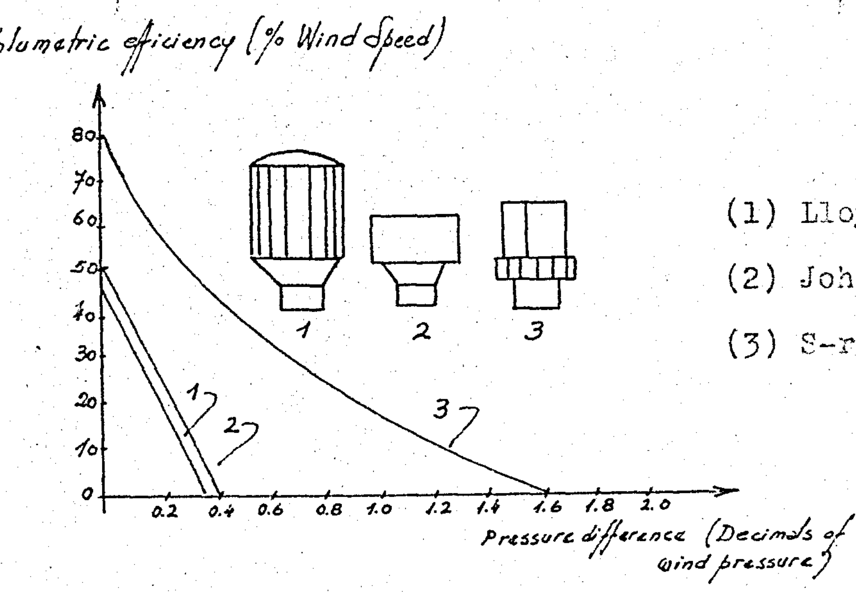


Fig 2.24-8

Rotor centrifugal ventilator consisting of a driving S-rotor and a driven centrifugal fan. (1)



(1) Lloyd ship ventilator

(2) John HNA ventilator

(3) S-rotor ventilator

Fig 2.24-9

Diagram showing air volumes and pressure differences created by various cowls. (1)

al. The rotor ventilator can be used for ventilating all kind of dings - factories, movies, theatres, schools, barracks, swimming s, fortifications, amunition stores, subterranean chambers, cable s - specially in those where electricity cannot be used or allo- They can also be used in farm buildings such as stables, henhouses ies, storage cellars, granaries, etc.. Also they can be used on s and motorboats. The rotor ventilator has the advantage of being rtight and can work on heavy storms. For removing gasoline fumes closed rooms without danger of explosion they are indispensable. orks in vehicles even when this is stopped (Fig 2.24-10). As a mney cowl the rotor is able to create a counter pressure exceeding wind pressure and draw out smoke and stop backflow.

c) Current and tidal motor

ome early trials showed that the S-rotor worked in a water stream ctly in the same way, with the same peripheral speed ratio and effi- ncy as in an air stream. Water being about 800 times heavier than , the power generated is greater ih proportion, although the flow rivers or tidal streams has lower speeds - from 2 to 3 m/sec - ept for waterfalls. Even a speed of 0.6 m/sec gives the same a- nt of power an air speed of about 5.5 m/sec, which is the wind rage. For a water speed of 2 m/sec the power per m^2 of rotor area about 1.6 hp. The rotating speed of a rotor - completely submerged the water stream - is 6 times higher than for a paddle wheel with al power - only submerged in its lower quarter. Such a rotor sub- ged in the water is well protected from waves, does not need ela- ate dams, earth works, channels and chutes, a simple frame or at bein sufficient.

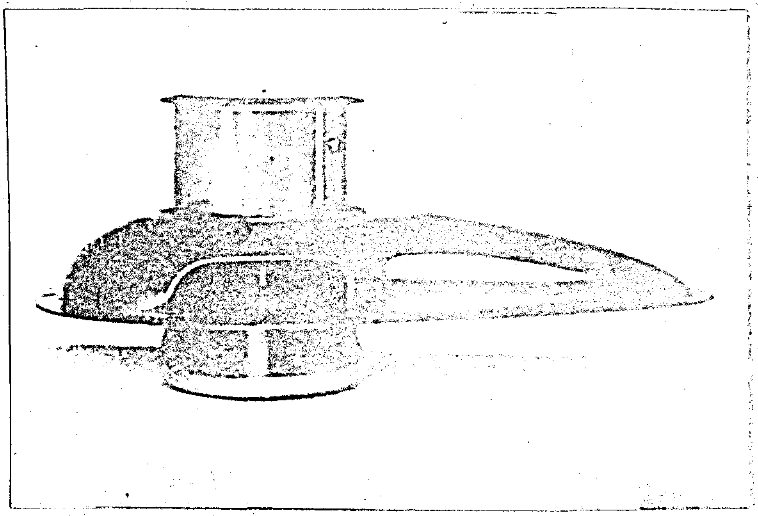


Fig 2.24-10

Combination of S-rotor with ordinary propeller fan for ventilating closed vehicles. (4)

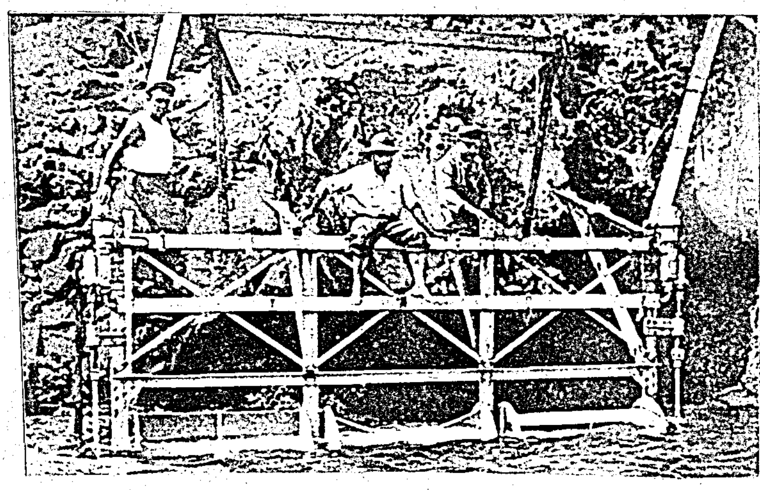


Fig 2.24-11

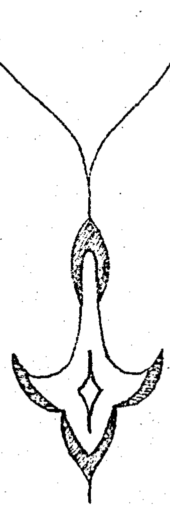
Water rotor used at Monaco. (1)

ie only application of this principle was made by Mr. Richards, lirector of the Institute Oceanographique at Monaco, with a double or of 0.4 m^2 area coupled to a pump with a stroke volume of about liter. He was able to raise water by wave motion to 6, 8, 10, 20 finally to a height of 34 m. The power obtained was at times hp/m^2. It was then decided to build a three rotor model mounted the same shaft with a total area of 3 m^2 for the purpose of raising er to the acquariums of the Musée Oceonagraphique. (Fig 2.24-11). rotor was fixed in a sort of cavity worn out of the rocks at the er line by the waves. The cavity was so shallow that a third of rotors were out of the water, and when the waves recided they e entirely out. Because of the proximity of the rocks the greater t of the power of the waves was spent in the impact and friction, interference of the wave action being considerable. In spite of s the rotor was driving two doble acting pumps lifting the water a height of 65 m . A power output of 1.8 - 2.7 hp/m^2 was obtained h wind speeds around 3 m/sec. (1)

d) Ship propelling.

s a method of propelling ships, the S-rotor is an interesting idea, ause unlike the Flettner rotorship, auxiliary machinery is not essary. It also offers more resistance to the wind than a statio-y cylihder, so that it could be used for driving a ship directly h the wind. The variation of the passage permits the regulation the speed, thus of sailing. Actual testing on a small boat was rried with satisfactory results (Fig 2.24-2). (2)

Savonius considered his wing rotor as a method of generating po- in small scale, where simplicity and low cost are important factors such as irrigation, lighting of farms, villages, etc. (1)



(1) S.J.Savonius "The S-rotor and Its Applications" Mechanical Engineering Volume 53 No. 5 May 1931 pp 333-338.

(2) Alexander Klemin "The Savenius Wing Rotor" Mechanical Engineering Volume 47 No. 11 1925 pp 911-912.

(3) Palmer C.Putnam "Power from the Wind" Van Nostrand 1948.

(4) F.O. Willhofft "Industrial Applications of the Flettner Rotor" Mechanical Engineering Volume 49 No. 3 1927 pp 249-253.

2.25 Smith - Putnam Experimental Project (U.S.A.,1941)

The Smith-Putnam project started in 1941 with a long and exhausti-
e research to find the best location of site. The location had to be
n the state of Vermont, an extensive study on the meteorological
onditions was made. Some favorable summit points were selected and
odels of these - 1/5000 scale - were prepared and tested in wind
unnels under the consultation of von Karman. Very careful measure-
ents were taken, but it was found, comparing these results with actual
ata from anemometers and pilot balloons, that experimental results
ad no valuable importance, the differences being to large. The ana-
ysis of results showed that the probable reason for this divergence
as the fact that the compressibility of air was insignificant in
he models and the actual naturq of the free-air velocity was unknown.

The failure of the experimental results forced the research group
o take actual data within a certain area of Vermont, by means of se-
eral portable anemometers located at several key locations (height
nd topography) in order to find a relationship between the geometry
f the profile of a site and the wind flow characteristics. Measure-
ents were carried in 20 selected sites to find the wind velocity
radient, estimate the free-air velocity and thus calculate the acce-
eration factor. In some cases it was necessary to use heated anemo-
eters (gas or electrically heated), because of icing of the cups;the
nstruments being frequently checked in wind tunnels. A 60 m high
hristmas tree was erected on Grandpa's Knob, and several anemometers
ounted. The structure of the tree itself caused some errors in the
easurements that had to be considered. Account of the fact that an

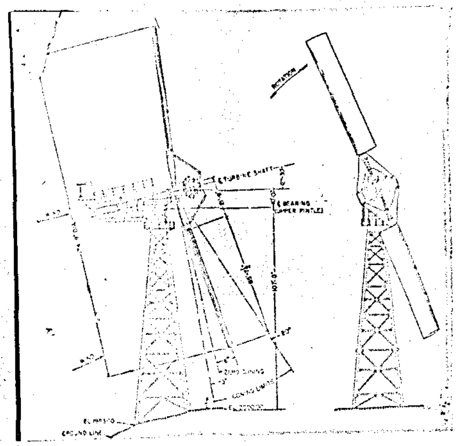


Fig 2.25-1
Grandpa's Knob 1250 kw. test unit of the Smith-Putnam wind turbine. (1)

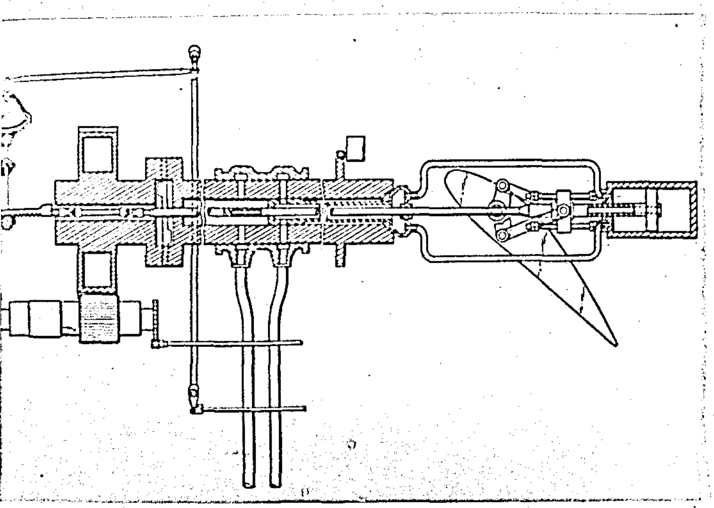
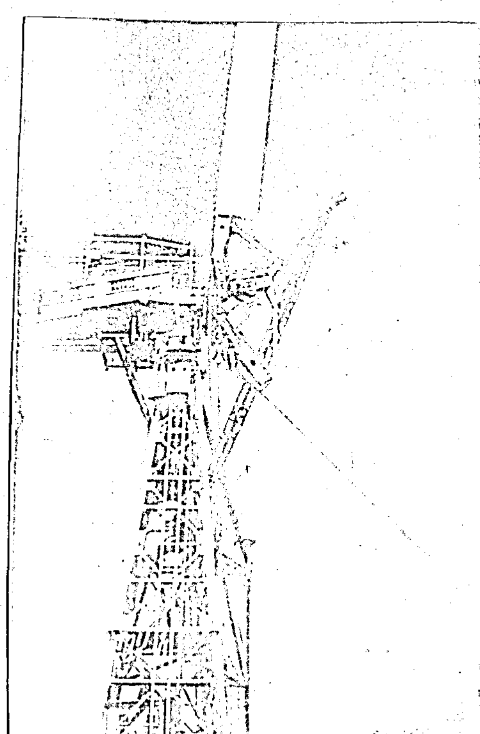
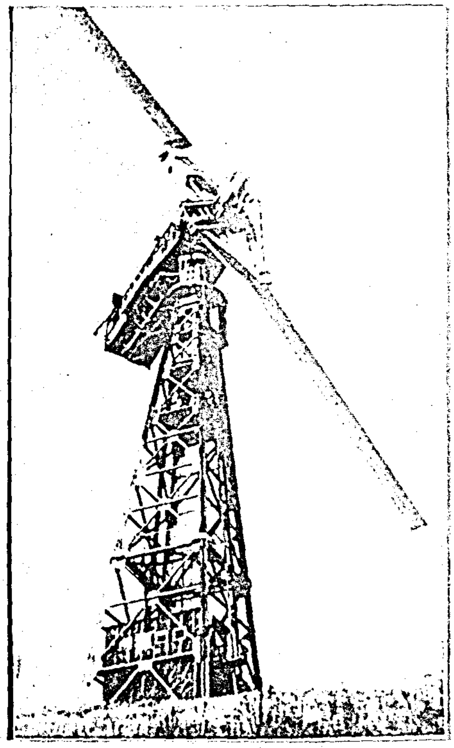


Fig. 2.25-2
Assembly of the blades of the Smith-Putnam wind turbine in August 1941.
(1)





'ig 2.25-3

Smith-Putnam wind turbine

(Ayres and Scarlott)

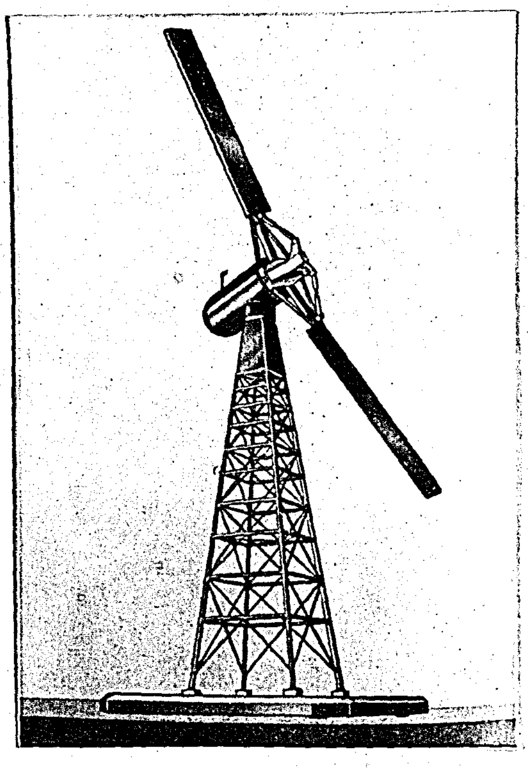


Fig 2.25-4

Scale model of the proposed prototype of a new Smith-Putnam wind turbine. 1500 kw

(1)

nemometer and a wind turbine are dynamically different had to be ma-e, the inertias being different. The anemometers recorded with a ba-tery driven stylus each time 800 m of wind had passed. Another ane-ometer which recorded the distance each 15 minutes was added. Measu-ements made on the temperature gradient, showed a strong variation of temperature with height.

After many theoretical, practical, meteorological and economical studies were made, the final design of the wind turbine was decided. The characteristics of the prototype were the following: 1250 kw. ra-ted capacity, 58 m diameter of blades, 600 rpm, 41 m hub height and 36 m tower height. Blades were NACA 4418 profile using a hydraulic pitch control system (Fig 2.25-1). The aims of testing this unit were:

a) adjust the turbine to best operating conditions.

b) measure the aerodynamic and mechanical efficiencies

c) measure the stresses developed

A large number of recording instruments were fixed to the wind tur-bine in order to measure different variables. The unit was brought into operation during October 1941, and it worked smoothly during one year, several variables having to be fixed during operation (Fig 2.25-2). On February 1943 a main bearing had to be changed and this caused an important disassembling operation; the repair being completed in March 1945. After two weeks of continuous operation, the failure of one of the blades forced the project to be discontinued. Very valua-ble information was obtained during the running periods. (Fig 2.25-3) Based on these results a new model, rated at 1.500 kw. was designed.(1)

- x -

(1) Palmer C. Putnam "Power from the Wind" Van Nostrand 1948.

2.26 SEAS Research Project (Denmark, 1947)

Although all the demand for electric power in Denmark after the orld War II, was satisfied by means of a large interconnected net-ork between Denmark, Sweeden and Zealand, the high cost of imported uels left some incentive to investigate the possibilities of using ind power in a small. This could help for a continuous utilization of the power generated by wind machines and the consequent saving of fuel or water head. The development of the power capacity in Denmark is controlled by a country wide organization.

In 1947 a research program was started by the SEAS (Sydøstsgoellands Elektricitests Aktieselskab) in the township of Haslev. The work was divided into the following items:

a) measuring wind energy,

b) wind tunnel investigations of rotor blades,

c) building an experimental mill,

d) measuring efficiency and energy production of the experimental mill,

e) determination of the effect of wind upon wind motors,

f) construction of future wind power plants,

g) economics of future wind power plants.

The project included the study of the wind structure and the measurement of the wind velocity under different conditions. (Fig 2.26-1 and Fig 2,26-2). Theoretical considerations of the output that could be obtained was also discussed. The wind tunnel experiments were considerably improved on accont of the long and thorough reseach carried on aeroplane blades. Still there were two main differences to be taken:

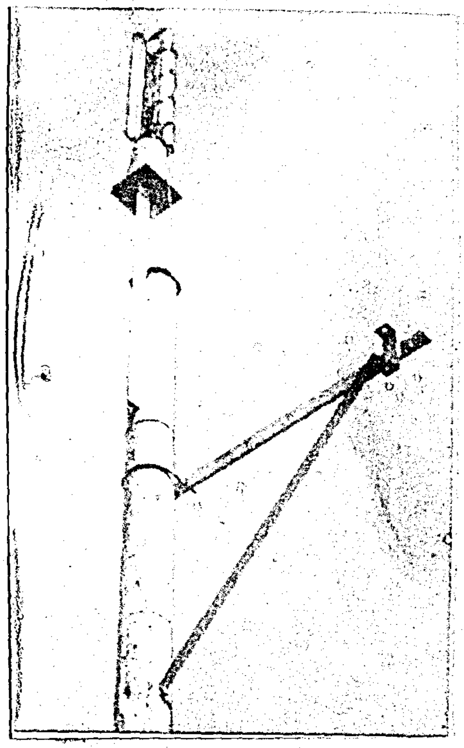


Fig 2.26-1

SEAS automatically registering anemometer. (1)

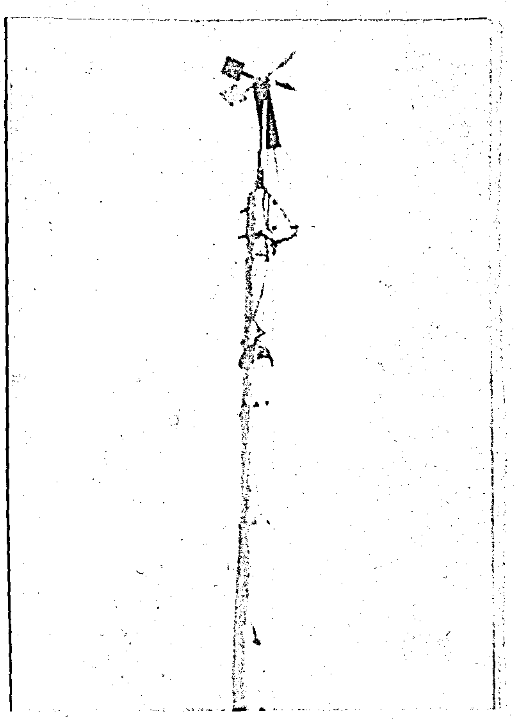


Fig 2.26-2

SEAS automatically registering anemometer. (1)

air velocities are not constant in wind rotor blades - they change with the distance from the root -, and the weight of the blades in aeroplane wings is more important than for the blades. The research on wind tunnels proved that there are differences with the results obtained in the laboratories and those in the open air. Still it was possible to determine the optimum tip-velocity and wind speed ratio from the experiments. The SEAS experimental mill at Vester Egesborg had as purpose:

1. study the operating conditions with AC generators connected to AC lines.
2. test blade performances and characteristics in the open air to compare with wind tunnel results.
3. record performance and determine annual production

The generator was mounted on the top of the tower directly coupled to the rotor (Fig 2.26-3). The blades were provided with flaps to regulate the speed, being operated by an air-pressure cylinder governed by a specially deviced control mechanism (Fig 2.26-4). The generator had to polar sets, one of 6 poles for wind velocities lower than 5 m/sec, and one of 4 poles for wind velocities higher than 8 m/sec. It was found that 35 to 40 m/sec was the optimum tip-velocity and the 4 poles set was dismantled. A circuit breaker was mounted in case dangerous vibrations were started. An anemometer was also erected at a distance of 80 m from the mill, at the same level of the rotor axis. From the experimental results it was concluded that the knowledge of the wind regimes helps to select the best tip-velocity so that the maximum annual output is obtained. The efficiency is also influenced by the blade profile and its twist.

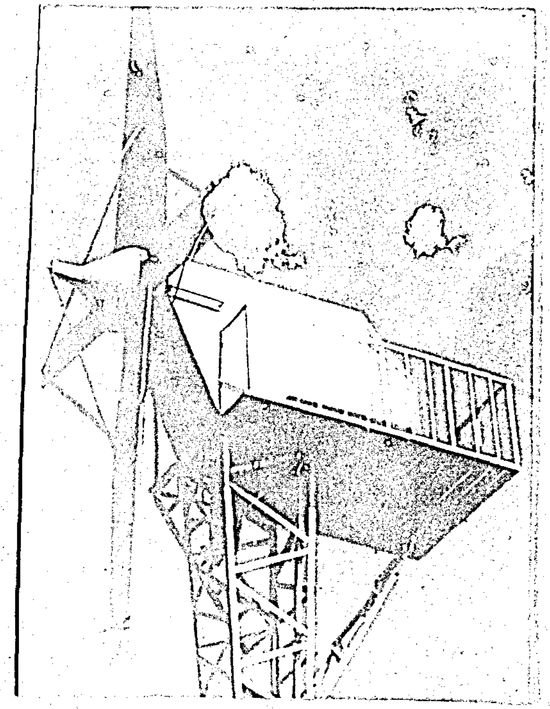
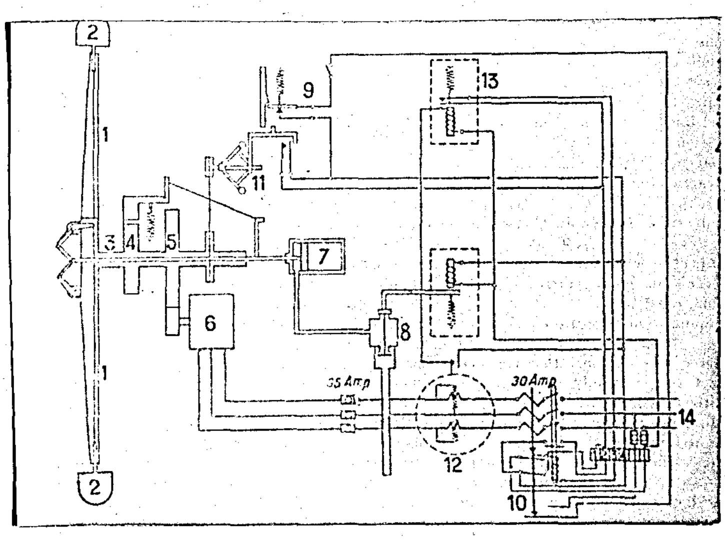
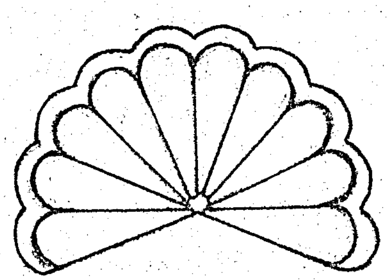


Fig 2.26-3
Experimental mill at
Vester Egesborg (Denmark)
(1)

Fig 2.26-4
Hydraulic pitch control
system of the experimental
mill at Vester Egesborg in
Denmark. (1)



The Vester Egesborg experimental mill obtained an output of around 525 kwh/m^2 of swept area, or 39% of the wind energy measured. Some teresting studies on the amount of force excerted by the wind pre- ure on the blades was made, and it was predicted that careful struc- ral analysis could help to reduce the amount of material needed, th the consequent reduction in the cost. Some investigations were de to design a 24 m diameter windmill, with 40 m/sec tip speed and maximum capacity of 200 kw. with a 8 poles, 30 rpm generator. (1)



ÇIRAĞAN S.

1) J.Juul "Wind Machines". Wind and Solar Energy Proceedings of the New Delhi Symposium. UNESCO 1958. pp 56-73

2.27 BEAIRA Research Project (England, 1949)

The British Electrical and Allied Industries Research Association with the financial support of the Ministry of Power, North of Scotland Hydro-Electric Board and the British Electricity Authority , started in 1949 a program for the economical explotation of wind power in the United Kingdom. (1)

An extensive survey was carried on the possibilities of the utilization of wind power, and it was found that if all suitable sites were used, the equivalent of 2 to 5 millon tons of coal per year - 4000 to 10.000 x 10^6 kwh per year - could be generated. The survey also estated that they were probably several hundred sites having economical usable wind speeds - 9 to 11 m/sec - on hills or ridges on which windmills with a total capacity of 1 to 2000 MW could be installed. (2) Besides the studies on the behaviour of wind - wind speeds, variations of wind with time - a research program on the effect of vibrations on the design was conducted.

The first experimental wind driven generator designed for a maximum output of 100 kw. was installed and ready for working in the winter of 1950/51, and was connected to the local electricity supply system in the Orkney Islands (Scotland). The shaft on which the blades were mounted was connected directly to a 440 volt, 3 phase induction generator having a synchronous speed of 750 rpm. The whole gearbox and generating system, together with the 3 blade propeller was mounted at the top of a 26 m tower, that could be rotated so that the blades always faced the wind. The gearbox, generator and control system were housed in a casing large enough to enable men to work inside it under over. The blades were controlled in pitch by an hydraulic mechanism operated by the power output. Safety controls were incorporated to bring the machine to rest, in the event of overspeeding or power failure and also if serious vibrations occur. The data obtained was very valuable, the whole control system prooved to be too complex for continuous and reliable operation and it was primarily the difficulty of continual maintenance and modification of the system that led to abandon the turbine alltogether. (Fig 2.27-1). (1)

The second 100 kw. pilot plant built, followed the principle developed by J.E.Andreau of Paris. By means of the depression centrifugal principle, airflow is induced up a vertical converging duct within the tower to the hub of the propeller, and by centrifugal action is exhausted through the blade tips in jets, that at the same time assist the rotation. The air enters at the base of the tower through the blades of an air turbine coupled to a generator. This system avoids the use of rigid mechanical connection between windmill and generator compensating for the lower efficiency of the transmission system. It also allowed to place the turbine and generator at the bottom of the tower, thus reducing the total weight of the rotating part at the top. The results were reported as successful, and this unit now operates on a hill a few kilometers from Algiers, operated by the Electricite et Gaz d'Algerie. It was found that the design was not economical enough to be exploited commercially. (1) (2).

Both designs prooved to be very complicated, and the fact that fuel was not a pressing problem for the British economy, made the Ministry of Power consider the possibilities of develping a new and more simplified design for underdeveloped areas overseas, with the condition

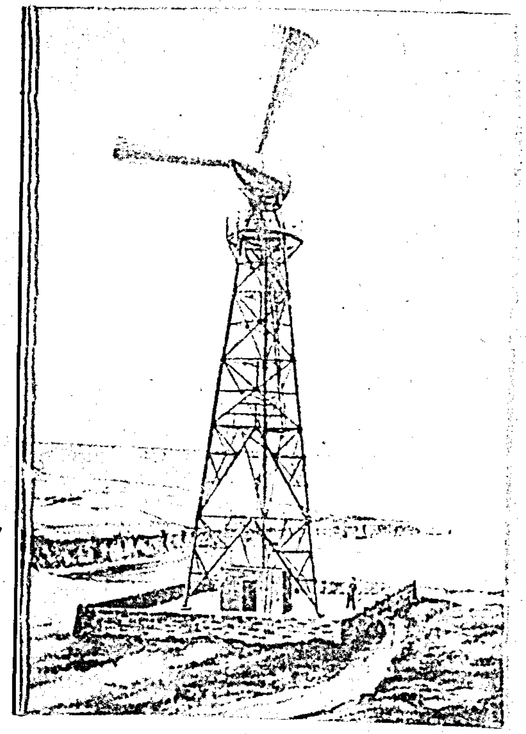


Fig 2.27-1
100 kw. windmill at Costa Hill on the coast of Orkney in the United Kingdom. (Ayres and Scarlott)

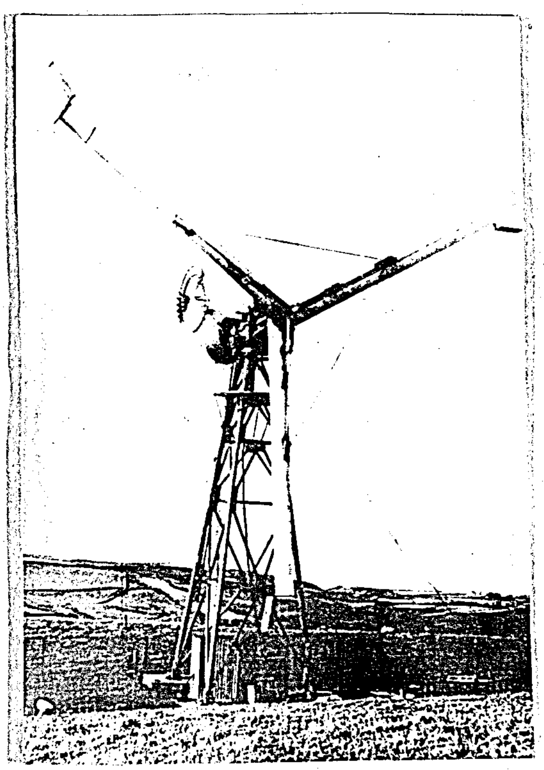


Fig 2.27-2.
100 kw. wind turbine with tip flaps. (1)

keeping costs to a minimum, so as to compete with other conventional urces of energy. For this reason a 25 kw. windmill was ordered, built d tested at Cranfield - Electric Research Association testing sta- on - and put in service in the Island of Man connected to the local ectricity network. The windmill had a tripod tower of 10 m high, on ich was mounted the blade system, gearbox and generator. The three ades had a diameter of 11 m with a small angular twist in the bla- es. In operation the blades worked in a fixed pitch, but they were rned to 45 pitch by a hydraulic mechanism, as a means of bringing e system to a safe speed when the genetator was disconnected from e main power supply. A simple friction brake allowed the system to e held stationary when required.

The output from this machine agreed with the theoretical predictions. t withstood satisfactorily wind speeds over 125 km/hr, in the Isle f Man. The hydraulic system proved to be a weakness, as it failed ecause the piston jammed. The design still was high in cost, special- y because of the control system and the fact that the blades were ade out of aluminum.

It was though necessary to simplify the design still more. Some esearch had been carried after the World War II in the National hysical Laboratory, and it was found that the maximum output for ixed-pitch windmills could be increased by smoothing out the blades urfaces, and a still cheaper solution could be found by using un- wisted blades. The addition of artificial roughness at the outer sec- ions of the blades could reduce the maximum output whenever required. nder the light of this research a 100 kw. wind generator was designed hich consisted of a tower on top of which a three bladed, fixed-pitched rotor made of extruded aluminium section, driving an induction generator, was mounted. The whole mechanism rotated at the top of a tower by means of a fantail, to keep the blades heading into the wind. The structure was designed for blades rotating at 75 rpm, and the generator at 750 rpm. The only auxiliary mechanism was a security device to prevent the windmill from overspeeding. This consisted of a magnetic brake, added to the generator shaft, and large flaps fixed to the blades tips with a shear pin so that it would blow out and act as wind brakes in case of emergency. (Fig 2.27-2). The tripod tower was 11 m high made of tubular steel framework, hinged at two legs to lower it for maintenance, the blades were 16.5 m in diameter. The windmill was installed at the Isle of Man, on a conveniently situated hill with a fairly good wind regime, and connected to the local network. (1)

Although the rated capacity at 72 km/hr was 100 kw., outputs of up 120 kw. were achieved in wind speeds of 80 km/hr. In 1000 hrs of operation it produced 25,000 kwh, including the calm weather and quite severe storms. (1) (2) The following recording instruments were fitted to have a record of the performance:

a) kwh meter

b) time clock

c) wind speed recorder for averages of 2 minutes

d) power output recorder

e) maximum current indicator

Besides these permanent records, some temporary data was obtained: high speed simultaneous records of power output and wind speed, rate of slowing down as brake was applied, stresses arising in the blades due to different operating conditions. Some very interesting results

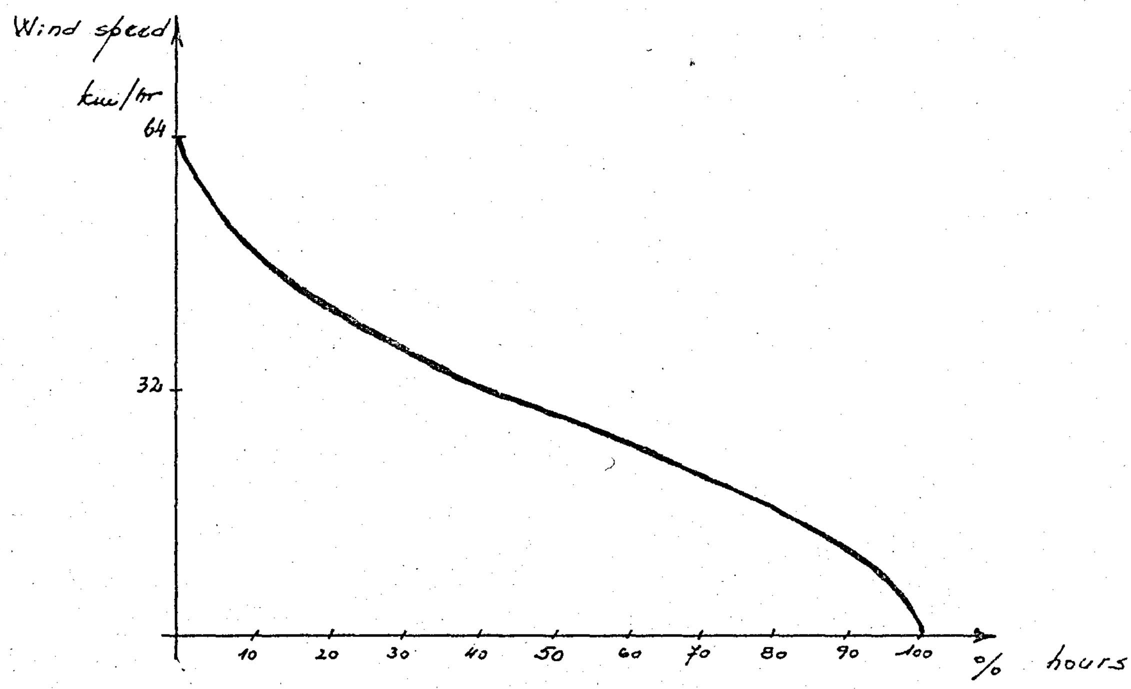


Fig 2.27-3

Wind duration curve for the 100 kw unit.(1)

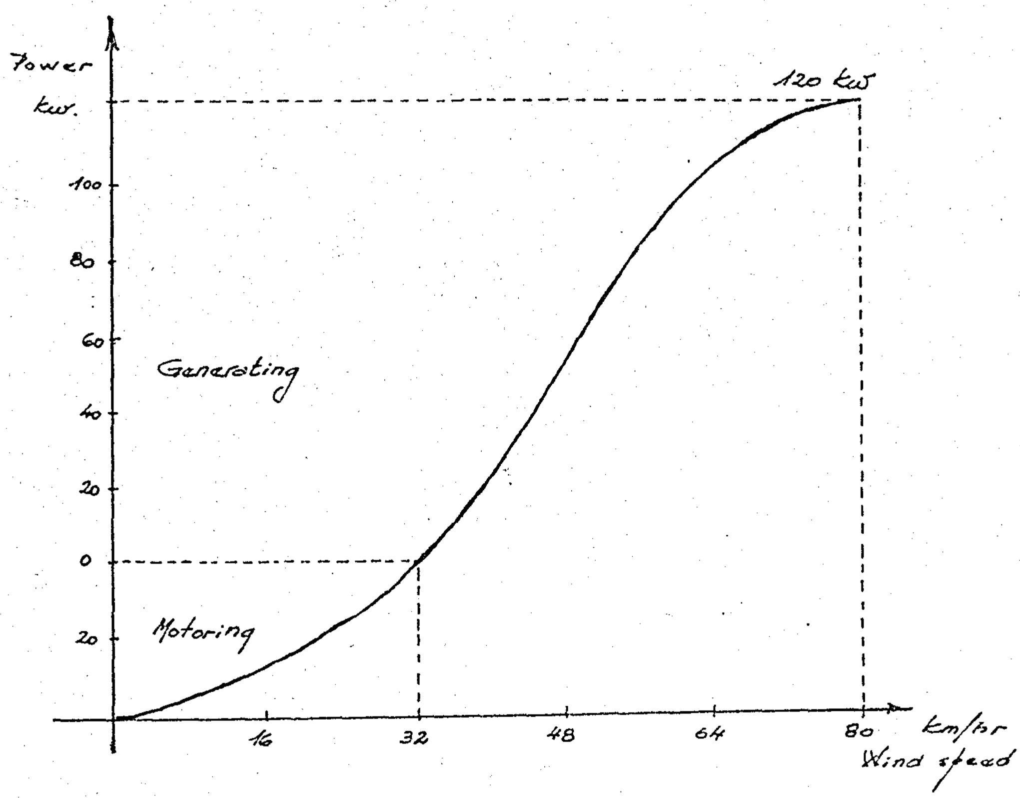


Fig 2.27-4

Output-wind speed curve for the 100 kw

unit. (1)

ith respect to maximum output were obtained. It was found that the aximum output point did not coincide with the experiments in wind unnels - actually the point is delayed - and that a larger maximum utput was obtained that what it was expected (Fig 2.27-3 and Fig 2.27-4).

From the results obtained, it was concluded that with a few minor hanges on the prototype a commercial type could be manufactured. The odifications are:

1. the stresses on the blades were larger than expected,
2. a better balancing of the blades is necessary,
3. the mechanism of shear pins to open the blade tip flaps, should be centralized so that all the three flaps open simultaneously,
4. the energy necessary to start the machine to generate power is higher than expected.

It was expected that the cost of power could be reduced by further simplifications and better balancing of the output and demand. (1)

(1) E.W. Golding and P.E. Montagnon "Development of a 100 kw. Power Plant in the United Kingdom" National Committee of Special Energies. Madrid June 1960.

(2) 5 th World Power Conference. Wien, 1956, pp 226-227.

2.28 Israel Research Project (1951)

The possibilities of the utilization of wind power in Israel, attracted attention even before the creation of the state. In 1949 the Research Council of Israel started a program for the development of Israel. Among the energy sources that were considered, wind power was of especial interest and a committee was formed in 1951 under the chairmanship of Sydney Goldstein, Professor of Aeronautics at the Haifa Institute of Technology, in order to study the question and make the necessary recommendations.

A survey made on the available wind data prooved to be unsatisfactory, but from the rough records obtained it was possible to select the most probable windy regions of the country for further investigation. The recording station already in existance in Jerusalem and Tel-aviv, showed that an average of 16 to 18 km/hr of wind velocities were available. A recording instrument was installed on Mount Canaan in the Upper Galilee, the highest inhabitated spot in the country, 1010 m from the sea level.

It was decided to ask for expert assistance from UNESCO, and the purchase of the necessary equipment to carry out a research program. E.W. Golding of the British Electrical Research Association was invited to Israel at the end of 1951 and he made the following recommendations:

a) a country wide, 2 to 3 years long wind survey,

b) preliminary trial installations of 3 kw. generators,

c) performance tests of the small units,

d) installation and testing of medium size generators at appropiate agricultural settlements.

e) investigation of the wind structure of one or two sites selected for a preliminary survey, on the basis of available wind data, in order to establish large scale windmills, connected to the main electricity net-work,

f) establishment of a large pilot plant.

The socio-economical conditions in Israel, made possible to believe that economic utilization of wind power is feasable as:

1. Small units connected to storage batteries, to be used in farms that cannot afford the cost of connection to high tension lines.

Medium size units working alone or supplementing diesel engines for rural settlement in water pumping, destillation, refrigeration, water heating, or other uses not requiring specific time.

2. Large scale units in plants favorably located in the North end center of the country connected to main network.

According to the program and recommendations made to the Concil, a wind survey was carried, installing anemometers in hill tops, whenever possible. Selection of smooth topographical areas was made in order to reduce obstacles and surface roughness. Instruments installed on peaks made it possible to use the acclerating influence of their slopes on the wind velocity. The data obtained was analyzed and correlated to long-range data of the existing stations, the results obtained were the following:

a) the best potential sites for wind power generation are situated in the north of the country,

b) at the highest sites the yearly wind velocity is around 8 m/sec,

c) wind drive machines of about 200 kw capacity giving full output at 12.3 m/sec wind velocities could be connected to main network producing 3000 kwh/year per kw. installed,

d) several other sites were charactérized by wind velocities of around 6.6 m/sec,

e) considering the high cost of electric power generated by conventional means (diesel units) at the extreme center of the country (Eilat region) installation of wind driven machines would be economically justified, at mean wind speeds of 5.3 m/sec.

In June 1953 a 3 kw. unit was put into operation in accordance with the program at Eilat, working at 110 volts DC, together with a recording instrument. Relations between calculated power (from wind data) and actual power, showed that the estimated values agree very much with actual ones. Efficiency was calculated as the ratio between electrical energy obtained and energy available in the wind, and it came out to be 31.5%. The propeller diameter was 4.6 m, meaning 0. 945 kwh per m^2. (1) (2)

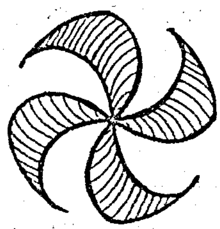
The results of the country-wide wind survey, showed that the best wind power sites belong to either of two broad topographical categories:

a) a hill forming part of a mountain ridge, with steep leeward slopes,

b) an isolated peak in a valley in the general direction of the prevailing winds.

etailed investigation of wind structure was undertaken over two es of topographical conditions, as mentioned above. It was found t the mean wind velocity vertical gradient at the hilltops influ- ed the output considerably. The optimum conditions were found on ular and smooth slopes of about 1/3.5 in the nearest few hundred ers from hilltop.

he operation of the small wind generator at Eilat during 3 years, wed that in any underdeveloped area there is definite advantage in ing wind power units in the place of diesel generators, where the n wind velocity is between 4 and 5 m/sec. (3)



) 5 th World Power Conference, Wien 1956. pp 313-314
) J.Frenkiel "Wind Power Research in Israel" Wind and Solar Energy Proceedings of the New Delhi Symposium. UNESCO 1958.pp 108-114.
) 6 th World Power Conference.Melbourne 1962. pp 450-451

2.29 Experimental Program in France (1956)

The Electricite de France, the nationalized electricity supply authority, is the responsable organ for the research program on wind power in France. It has been working for the past 10 or 15 years, with several French engineering concerns, on the development of wind power plants. Several very thorough theoretical studies on windmill design have been made and two large machines, one of 600 kw., the other of 130 kw. have been built. (1)

An important research program was carried by the French engineering company "Neypric", manufacturers of hydraulic equipment, under the direction of L.Vadot, as consulting engineer. L.Vadot has made an extensive study on the historical background of the problems, the theoretical principles involved in the design of windmills, the principles of wind survey and the application of windmills to water pumping and electricity generation. The Neypric company has erected 3 windmills for waterpumping: one of 6 m, the second of 8 m and the third one of 13 m propeller diameter. Special problems of speed regulation, pumps, blade design, structural analysis were solved in this projects (Fig 2.29-1, Fig 2.29-2 and Fig 2.29-3). (2)

Besides this waterpumping windmills, Neypric manufactured a prototype D-21 aerogenerator for energy generation, having a rotor of 21 m diameter, with variable pitch blades, 132 kw. output at 11 m/sec wind velocity, turning at 56 rpm an asynchrounous motor , Fig 2.29-4. (3)

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(1) E.W.Golding "Energy from Wind and Local Fuels" The Problems of the Arid Zone. Proceedings of the Paris Symposium 1960. UNESCO p 249- 258

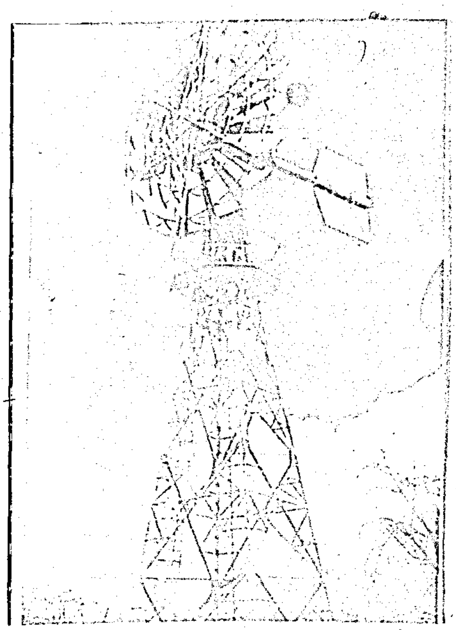


Fig 2.29-1
Slow running windmill for reciprocating pump. Propeller diameter 6.1 m, manufactured by Neypric. (2)

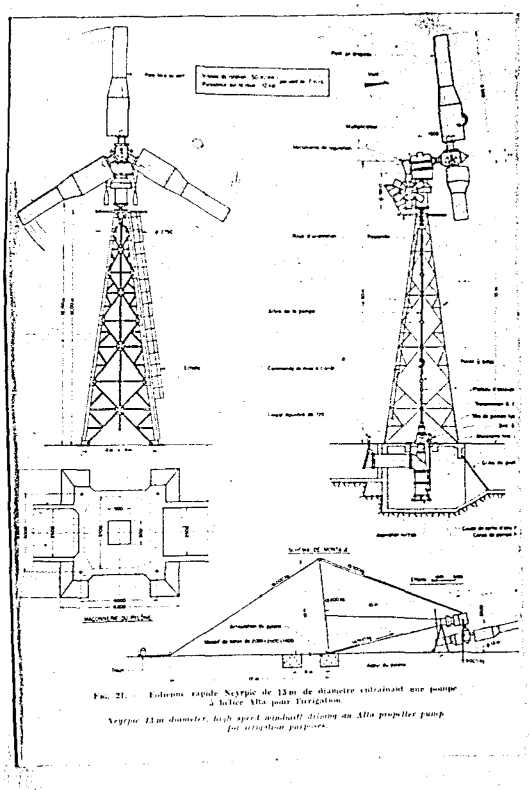
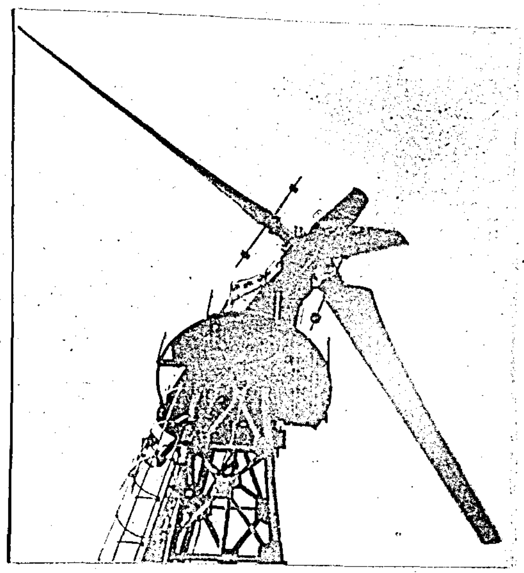
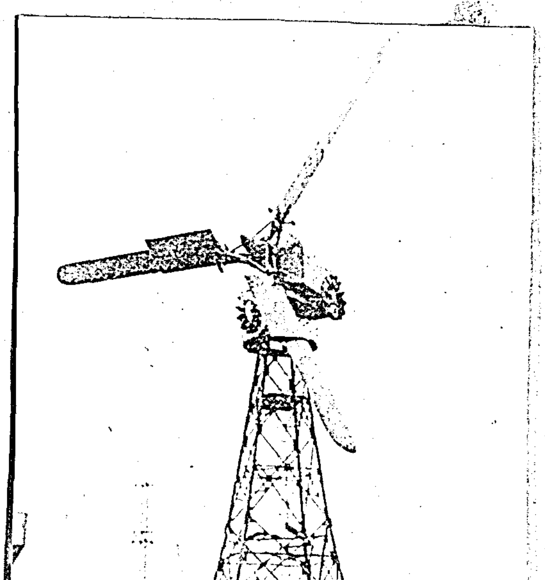


Fig 2.29-2
High speed windmill with spring linkage adjustable blades, for a centrifugal pump. Diameter 8 m. Manufactured by Neypric. (2)

Fig 2.29-3
High speed windmill
driving an Alta propeller
pump for irrigation purpo-
ses. Diameter 13 m (2)





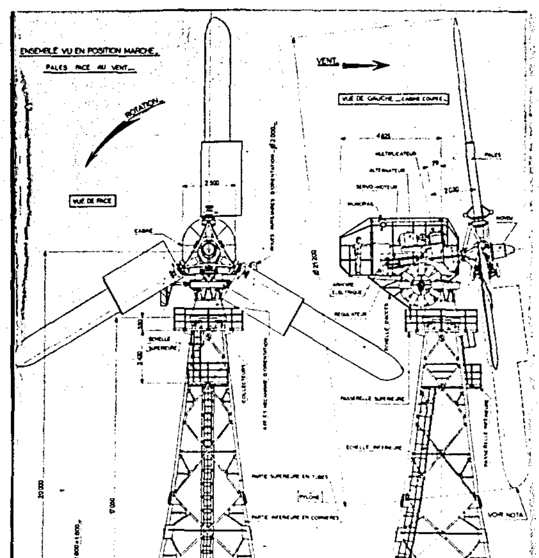


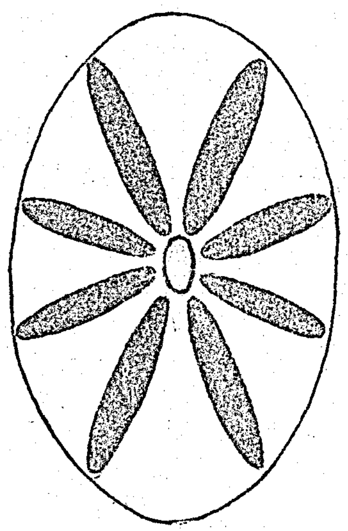
Fig 2.29-4

D-21 aerogenerator, 21 m diameter, 132 kw.

Neypric, (3)

L.Vadot "Water Pumping by Windmills". Houille Blanche Septembre 1957. pp 524-529

L.Vadot "The Production of Electrical Energy by the Wind" Houille Blanche, Octobre 1958 pp 503-525.



2.210 Wind Rotor Research Project (U.S.A., 1957)

It was reported that experiments have been made with a new type of wind-operated electric power supplier, which shows considerable promise for the future. A prototype was built, with an effective wind cross section of about 0.1 m^2, which has operated continuously for 3 years, under normal weather conditions. The average output was 1 watt, with wind velocities of about 17.5 km/hr. No maintenance was required during the period mentioned, thanks to the special design made to avoid the wearing of parts.

The turbine type of wind rotor used, consist of a set of stationary deflecting blades which capture the wind coming from any direction, and increasing its velocity due to funneling, sends it to the rotor blades causing counterclock rotation (Fig 2.210-1). The rotor is mounted on the shaft of a permant magnet generator, provided with ball bearings for long operation. The generator is mounted with a weather proof housing which protects it from climatic conditions (Fig 2.210-2). As all wind directions are equally favorable to the rotor, the system generates energy continuously. No gearing is necessary to adjust for wind direction changes. The rotor turns at low speeds with peripheral velocities of half the wind velocity (Fig 2.210-3).

Blades arrangements are the result of experiments. In this case 24 rotor blades and 20 stator blades were used. This arrangement increases wind speed 7 or 8 times. (Fig 2.210-4). The generator is a multi-pole rotating magnet wound-stator type and generates an alternating current having a frequency 30 times the rottation speed, without the use of slip rings. The alternating current is converted into DC, by

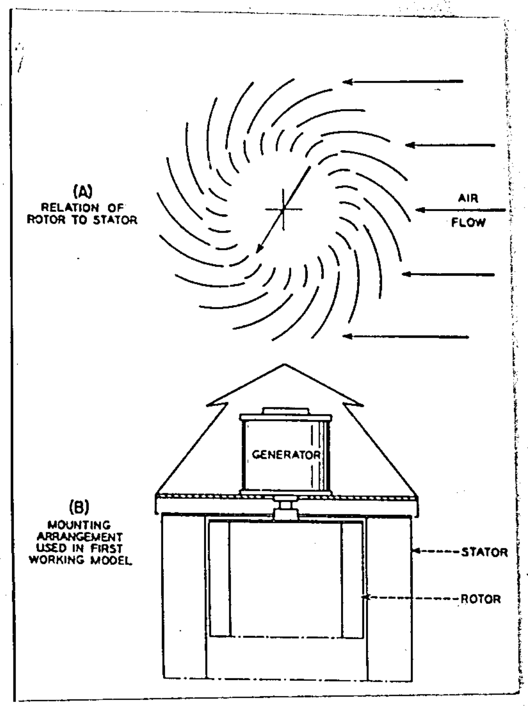


Fig 2.210-1

Sectional cross section of test model. (1)

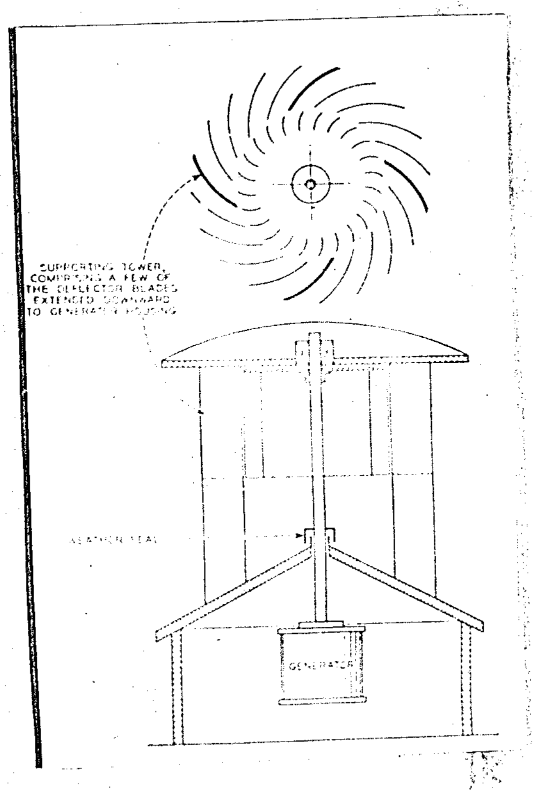


Fig 2.210-2

General layout of medium size wind power plant. (1)

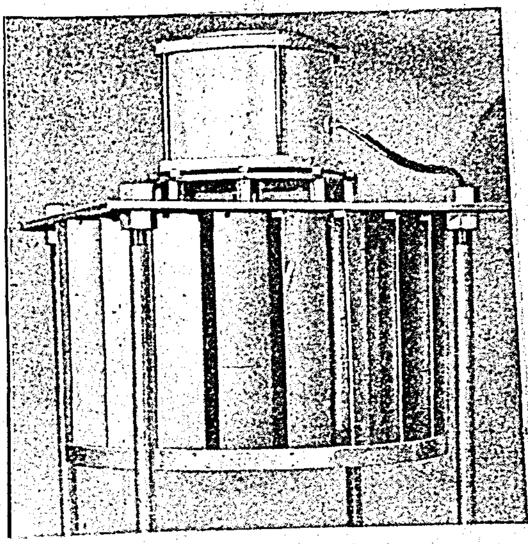


Fig 2.210-3
Assembly of stator and
electric generator. (1)

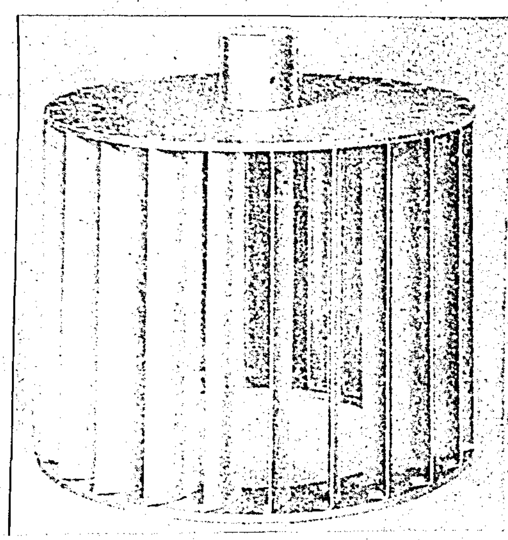


Fig 2.210-4
Rotor

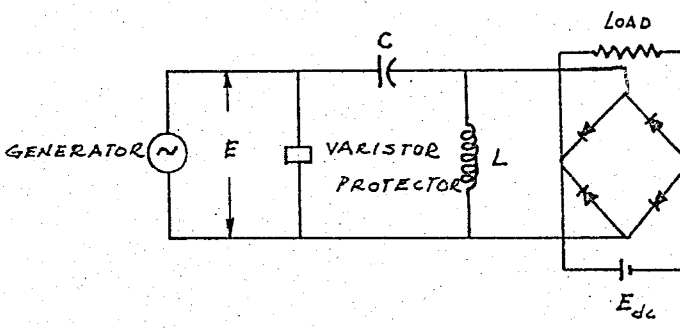


Fig 2.210-5

Load circuit used in the test of prototype (1)

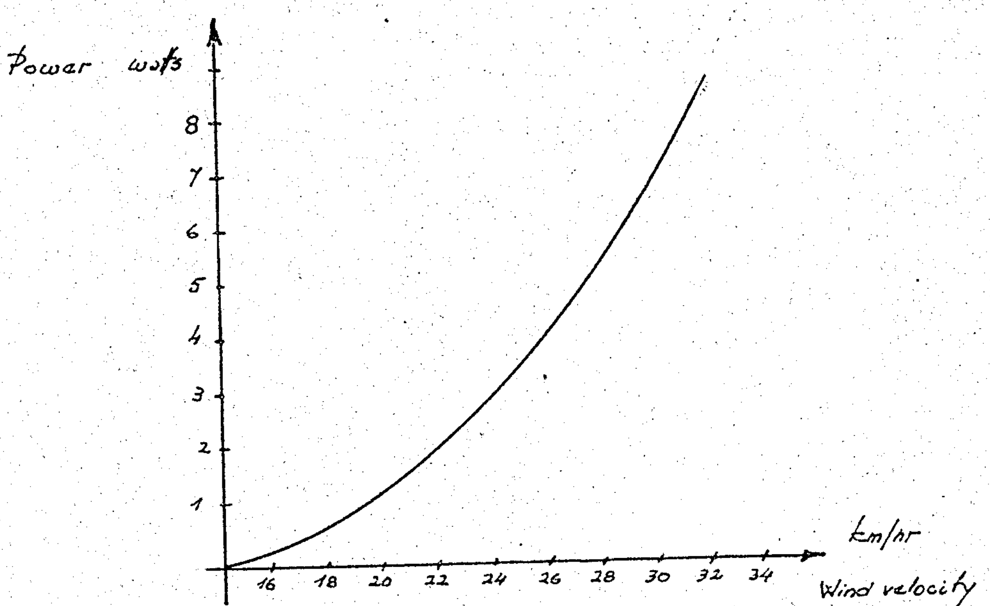


Fig 2.210-6

Power vs. wind speed for steady winds. (1)

diode rectifiers, connected to a constant load, with storage battery in parallel, to absorb excess of energy during high winds, and provide continuity during calm periods. The generator produces AC voltage with open circuit voltage and frequency about proportional to the wind speed. The capacitor and inductor resonates the generator output, and the AC is converted into DC, when the voltage exceeds the voltage of the storage battery. This help to make use of the wind over a wide range of speeds, with no auxiliary controls or regulators. The circuit resonates at the frequency corresponding to the lowest wind speed. Tpe voltage across the inductor increases with frequency, so that same DC is delivered (Fig 2.210-5).

The results obtained from the experiments are plotted in graphs, the relation between power and velocity being cubic (Fig 2.210-6). A variety of electric generator types could be used, depending upon each specific application, In larger units special compound winding - to obtain good impedance match to the load for a wider range of wind speeds - may be used. (1)

(1) W.A. Harrison " Wind-operated Electric Power Supply " Electrical Engineering Vol 76, No.5 May 1957 pp 418-420.

"Akıl akıldan üstündür"

2.3 DESIGN CONSIDERATIONS

2.31 Collection of wind data

2.32 Analysis of wind data

2.33 Power calculations

2.34 Analysis of power demand

2.35 Design of wind machines

2.36 Economic analysis

2.31 Collection of wind data

The first requirement in designing a windmill is the study of the prevailing conditions in the place where it is expected to be used.(1) The problem is a c6mplex one because wind changes with place, height, time, temperature, origin - from the sea or land - making the description of the wind structure almost unpredictable. (2) Nevertheless it is possible to study the directions, velocities, turbulence and duration of the main winds affecting a given area.

The measurement of the wind characteristics becomes then a very important factor in the design of windmills. The official or local meteorological data about wind is never sufficient for this purpose, because the local topographical and geographical conditions influence the characteristics of the surface winds - those which are of practical application - with regimes changing considerably within a few kilometers of distance. (3)

In order to record the changes on the wind characteristics with time, specially velocity and direction, several methods are used: the simpler and cheapest one being the cup anemometer. Some of this apparatus are equipped with electric impulse devices that record on a moving band or graph a sign each time a certain amount of wind has past. When several types of anemometers are used they should all be calibrated and factors accounted for any difference, readings differing with the area swept. (4) The values of the wind velocity are also varying with the height from the ground. In locating the anemometer it is of special importance to place it high enough so that the building or stucture where it is mounted will not affect the measurements, whatever the wind direction may be. In some cases it is possible to determine a correction factor to account for obstacles and thus calculate the "effective height" assuming that the shape of the obstructions do not change with time - trees growing, new buildings, etc. - . Unfortunately this is not always possible, and measurements under this conditions, should be avoided. Considering the effect of the topography on the wind structure, it seems that the best locations are the top of hills having no large obstructions in the vecinity and commanding a view of the horizon all around. From measurements taken at specific points it is possible to drive some general conclusions about the wind structure in broader areas having similar configurations. When wind power is considered for irrigation, the study of wind regimes should be made where water is available. (3)

Another important factor in the design, is the knowledge of the variation of the wind speed with the height from the ground. The utilization of anemometers fixed at various levels is very expensive, instead pilot balloons can be used up to a height of 500 m. (5) Here it must be noted that errors are introduced in the observations when the balloon rises with strong vertical motion. (6) Wind changes with height are less near the sea because there, there is no retardation friction involved. (4)

Another possible method to be used in studying the wind characteristics is the deformation of trees. Wind causes certain permanent deformations over the surface of the earth. This can be seen specially on trees, although the effect of temperature, diseases, insect injury, lighting, salt, ice, water, may mislead the observations. There are several types of possible deformations:

a) Lateral branches just below the tips of the trunk may be bent to leeward (the opposite side to the wind direction) by strong winds, while they are still young, and held there until their tissues harden.

b) A young branch generally bends into the wind rather than before it, and the lee side grows more because there is less absorption of humidity. Even when some branches may succeed to grow in the windward side during summer they are killed in winter.

c) The direction of the wind, specially the stronger ones is revealed by the fact that the small particles abrade the trunk of the windward side of the tree. Nevertheless in winter, snow may act as a cover an this incrustations may not be seen.

Although there has been some research carried on the subject, still there is no clear evidence that the conclusions arrieved at are at all valid. There are certain types of deformation that are clearly distinguished:

1. Brushing: bending of the branches in leeward direction.

2. Flagging: stretching out of branches to leeward direction so it looks like a bare trunk.

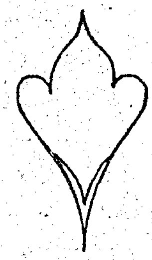
3. Throwing: bending of trunk in leeward direction.

4. Wind clipping: leveling of the tree growth, so that all branches do not grow above a certain level.

5. Tree carpets: no branch is strong enough to grow above a few cm from the ground, so the growth is to-

tally in the horizontal direction forming a carpet.

6. Winter killing and resurgence: some trees growing as a carpet manage to grow a leader during summer that is killed partly in winter, the process repeating each summer with a new leader resurging. (6)



(1) L.Vadot "Water Pumping by Windmills" Houille Blanghe. Septembre 1957. pp 524-529.

(2) L.Vadot "The Production of Electric Energy from the Wind" Houille Blanche. Octobre 1958 pp 503-525.

(3) P.Nilakantan "Some Considerations Affecting the Choice of Areas for Preliminary Wind Power Surveys in India" Wind and Solar Energy Proceedings of the New Delhi Symposium UNESCO 1958 pp 38-40.

(4) J.Juul "Wind Machines" Wind and Solar Energy Proceedings of the New Delhi Symposium UNESCO 1958 pp 56-74.

(5) L.A.Ramdas and K.P.Ramakrishnan "Wind Energy in India" Wind and Solar Energy Proceedings of the New Delhi Symposium UNESCO 1958 pp 42-54.

(6) Palmer C. Putnam "Power from the Wind" Van Nostrand 1948.

2.32 Analysis of wind data

From the records obtained from the anemometers, the following characterëstic curves can be drawn:

1) velocity-duration curve
2) wind-frequency curve
3) power-duration curve

The first çurve gives the number of hours in a given period of time, which a certain value of wind velocity blows. Nearly all velocity-duration curves have the same shape (a hyperbola). The curve is also characterized by the mean. The wind frequency curve gives the regularity of the wind, shows the number of hours during which the wind speed remains within a given range, during a given period. (1) This curve is generally bell shaped skewed to the left side. (2) The power distribution (based on the theoretical calculations of power as a function of wind velocity) gives an idea of the output. It also is very useful to draw the curves giving the energy produced for a given increment of wind velocity. (1)

If the values for the wind velocity for a period of time, obtained from the anemometer records, are ploted on a graph and the maximum and minimum wind velocities are counted, a frequency distribution on on percentage bases for maximum and minimum wind velocities can be ploted (Fig 2.32-1). The difference between the maximum and minimum wind velocity is the amplitud of the turbulence (v). If we assume that turbulence is the result of the superposition of the average wind velocity and half of the amplitud of turbulence forming an angle with the average velocity, the direction of variation can be calculated.

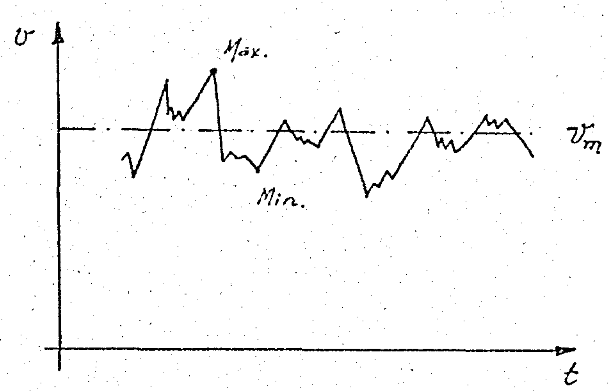


Fig 2.32-1

Wind duration curves (3)

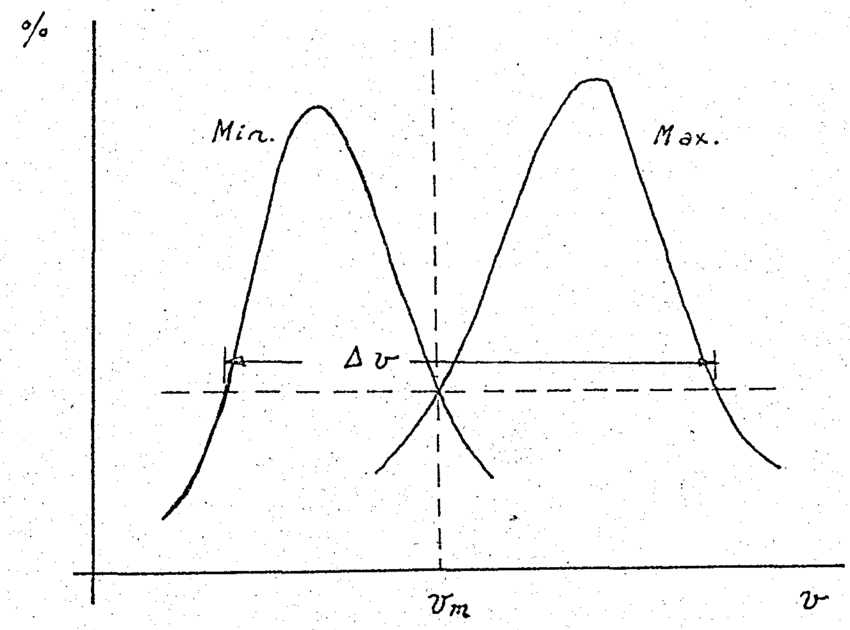


Fig 2.32-2

Amplitud of turbulence (3)

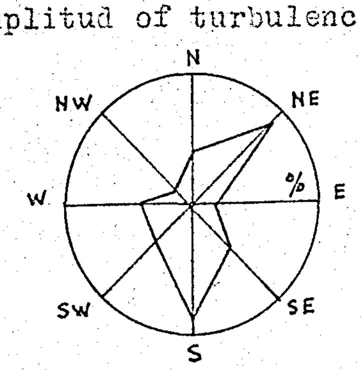


Fig 2.32-3

Graph of wind directions (2)

The half of the amplitud of turbulence is called the eddy velocity. When the eddy velocity and the average wind velocity are parallel and in the same direction we obtain the maximum speed: $v_m + v/2$, when the direction is opposite : $v_m - v/2$, is the minimum velocity (Fig 2.23-2).

The results obtained from these calculations are near the actual values. The knowledge of this angle is very important in the design of the blades because of large stresses are developed when the wind form an angle with the direction of the axis of rotation. The stress vary in sign in each rotation, causing dangerous alternating fatigues. It is interesting to note that the variation of wind direction is slower in strong winds than in low winds.

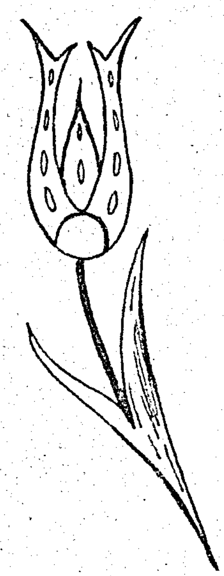
Due to friction on the surface of the earth, wind velocity varies with the distance from ground, the gradient depending partly upon the local configuration of the ground. Except for mountainous regions the variation of wind velocity (v) is a function of height (h) above the ground according to the following law :

$$v : v_o (h/ h_o) ^{1/n}$$

where v_o and h_o are the wind velocity and height at ground level respectively. The value of n varies with the roughness of the ground. For sea n is large, for land wind n is smaller. For flat ground with normal roughness, n may be taken as 5. (3)

This discussion does not hold true in mountain sides wer turbulence and accelerations occur which are almost impossible to predict. Ano ther important factor is the variation of temperature with height, because density changes with temperature, thus also the power varies. The design is also influenced by the gust, the change of wind direction, which is difficult to measure. Nevertheless a graph can be ploted and an idea obtained about the wind characteristics (Fig 2.32-2).

The analysis of annual velocity distribution curves show that they remain constant with the years within 10% for a particular region. The study of the variation of wind velocities with the year - seasonal changes - from these curves can give a good idea about the wind characteristics in the region. (3)



(1) L.Vadot "Water Pumping by Windmills" Houille Blanche Septembre 1957 pp 524-529.

(2) Palmer C.Putnam "Power from the Wind" Van Nostrand 1948.

(3) L.Vadot "The Production of Electrical Energy from the Wind" Houille Blanche Octobre 1958 pp 503-525.

2.33 Power calculations

According to Betz theory the power in kw. developed from 1 m^2 of wind cross section at a speed v in m/sec is expressed as:

$$N_t = 0.000613 \, v^3$$

Not all this energy can be captured, some pass to the other side of the rotor, and energy is necessary to evacuate the air which has done work. The maximum ratio between the wind speed entering the rotor and leaving it is 1/3. This reduces the total power by 16/27, so

$$N_B = 0.000364 \, v^3$$

There are some losses due to friction in the blades, marginal eddies, etc.

$$N = \eta \, N_B$$

The ratio N / N_t is known as the power coefficient C_N. For a rotor diameter D the power obtained is:

$$N = \frac{\pi D^2}{4} \, \eta \, \frac{16}{27} \, 0.000613 \, v^3$$

then,

$$N = 0.000482 \, C_N \, D^2 \, v^3 \qquad (1)$$

According to Juul the power developed can be calculated in the following way. The density of air at 15 C and 760 mm is 0.00122 gr/cm^3. The weight varies according to

$$W = 1.3 \, \frac{p}{760 \, . \, \left(1 + \frac{1}{273} \, t \right)}$$

where,

W : weight of air (kg/ m^3)

p : barometric pressure (mm)

t : temperature (C)

The wind energy is expressed as:

$$E = \frac{m V^3}{2}$$

where,

E : energy (kgm/ sec)

m : mass of air ($\frac{1.22}{9.81} \frac{kg}{m^3} \frac{sec^2}{cm}$)

V : velocity of air (cm/ sec)

Only part of this energy can be transferred mechanically, the formula being derived emperically as:

$$E = \frac{1.22}{9.81} \frac{V^2}{2} \cdot e \cdot A \cdot V$$

e : efficiency

A : sectional area (m^2)

For an efficiency of 0.6 and unit sectional area ,

$$E = \frac{1.22}{9.81} \frac{V^2}{2} \; 0.6 \cdot 1 \cdot V$$

$$= 0.037 \; V^3$$

Expressed in power units,

$$E \text{ (hp)} = 0.000493 \; V^3$$

or,

$$E\ (kw) = 0.37\ (V/10)^3$$

For a cylindrical wind column of diameter D,

$$E\ (kw) = 0.000\ 285\ D^2\ V^3$$

An efficiency factor has to be introduced to account for mechanical losses,

$$\varepsilon = \frac{\text{energy obtained}}{0.000285\ .\ D^2\ .\ V^3} \qquad (2)$$

According to Golding, power is expressed by the formula:

$$P = 0.0006 \cdot A \cdot V^3$$

where

P : power generated (kw.)

A : area swept (m^2)

V : wind velocity (m/sec) (3)

(1) L.Vadot "The Production of Electrical Energy from the Wind" Houille Blanche, Octobre 1958 pp 503-525.

(2) J.Juul "Wind Machines" Wind and Solar Energy Proceedings of the New Delhi Symposium. UNESCO 1958 pp 56-74.

(3) E.W.Golding "The Economic Utilization of Wind Energy in Arid Areas" Wind and Solar Energy Proceedings of the New Delhi Symposium. UNESCO 1958 pp 90-98.

2.34 Analysis of power demand

Since it is not possible to change the characteristics of the wind regimes, it seems more reasonable to study the characteristics of the power demand and try to fit it to the available output from the wind. The demand should be balanced in such a way as to reduce electrical storage in batteries to a minimum. The energy generated from the wind can be used for many different purposes, such as:

a) water pumping,
b) electricity generation,
c) grinding,
d) sawing,
e) compressing air or other gases,
f) refining metals,
g) ice production,
h) water destillation,
i) domestic appliances,
j) production of hydrogen,
k) cooking,
l) creating a water head,
m) heating and cooling, etc. (1) (2) (3).

Water pumping and electricity generation deserve special analysis. Water pumping is used mainly for irrigation, for this reason the study of the different crops need for water and the availability of rainfalls should be carefully made. The purpose of water pumping is to supplement rainfalls when the crops need water, so as to improve the harvest. The regime of rainfalls during the year, the need for water and the available wind should be studied and wind driven pumps located so as to match these factors. (4) Water tanks may be used to compensate the irregularities of wind regimes.

Another important application of wind power is the generation of electricity. This can be done in two ways:

a) as isolated units,

b) supplementing other sources of energy.

The utilization of the first seems to be reduced to smallscale application. The second one, can be used together with:

- hydraulic power plants
- steam power plants
- internal combustion power plants
- solar energy
- local fuels power plants,

connected to the main networks. The energy demand can be determined from an empirical formula, obtained from experience: e represents the ratio between the connected load (L_c) and the actual demand (D_a),

$$e = 100 \times \frac{D_a}{L_c \cdot \Delta t}$$

where,

D_a : in kwh

L_c : in kw

Δt : in hours

For farms e: 2-4 %, for cities 4-6 % and for small industries 12-

16 % . In general a well equipped farm will need 6.000 to 8.000 kwh per year, (5), while a community of approximately 100 people will require 100,000 kwh per year. Whenever possible storage of electricity should be avoided and limmited to accumulators for lighting. It is also possible to arrange the demand so that the energy generated is distributed according to a predetermined schedule of preference. Automatic devices can be used to switch off and transfer the energy from one demand to another as soon as the needs of the first one are satisfied. (3) (6)

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(1) Palmer C.Putnam "Power from the Wind" Van Nostrand 1948.
(2) L.Vadot "The Production of Electrical Energy from the Wind" Houille Blanche Octobre 1958 pp 503-525.
(3) E.W.Golding "Energy from Wind and Local Fuels" The Problems of the Arid Zones. Proceedings of the Paris Symposium. UNESCO 1960 , pp 249-258.
(4) R.V.Ramiah "Some Problems in the Utilization of Wind Power in India" Wind and Solar Energy Proceedings of the New Delhi Symposium UNESCO 1958 pp 102-106.
(5) U.Hütter "Planning and Balancing of Energy of Small-output Wind Power Plants" Wind and Solar Energy Proceedings of the New Delhi Symposium UNESCO 1958 pp 76-87.
(6) E.W.Golding "The Economic Utilization of Wind Energy in Arid Areas" Wind and Solar Energy Proceedings of the New Delhi Symposium UNESCO 1958 pp 90-98.

2.35 Design of wind machines

1. Development of windmill design.

Although windmills are more than thousand yeans old, the maximum amount of power produced by anyone unit was since half a century not more than 15 hp. In Europe windmills consisted of 4 sails turning with low r.p.m. In contrast with the German and Dutch type windmills, the Americam windmill consisted of a turbine wheel with numerous blades generally curved and made out of steel. Since the relative velocity of the wind respect to the blade varies with the distance from the center of the wheel, the blades were twisted to secure the proper angle at each point, or made in sections having diffenent entrance angles.

The first important development in windmill design was made when a smaller number of blades for the same size of wheel started to be used with the result that the flow conditions behind the blades were improved and thus the efficiency. At the same time the speed was increased, the wheel could be made lighter for the same power, but at the sacrifice of the ability to start at low wind speeds. In other words, while the old wheels started under load at a wind velocity of 8 km/hr, the high speed wheel could not start below 13 km/hr. This was a serious disadvantage for the ordinary pump wheel, while the increase of speed at average wind velocities was not much more important for electric generators. The tip velocities used to be only three times or higher the wind velocity, against only twice for the old types.

The next improvement was the use of regular airplane cross sections (airfoils), that were substituted for the turbine blades, and the number of wings reduced to six, four or even two. This resulted in greater efficiency and higher speed, but still more unfavorable starting conditions, so that these sort of windmills could only start ~~above~~ below 15 km/hr wind speeds. Here the work of Flettner and Savonius set in, and the wind rotor vertical windmill was introduced with good results. (1) Von Karman pointed out that the rotor type turbines were low in efficiency, difficult in regulation, having a higher thrust requiring a larger investment. Savonius rotor had reached an efficiency of 31 % but in order to develop 1000 kw in a wind of 50 km/hr a cylinder of about 35 m in diameter and 100 m in height would be required. The same power would be generated by a 60 m diameter turbine, using 1/30 of the material. (2) The wind rotor were soon abandoned and two or three blade wind turbines were designed and erected. The development of the airfoil profiles for airplanes was used in the design of blades, increasing the efficiency considerably.

2. Classification of windmills.

Wind machines can be classified according to several criterias, somo of the possible groups are given above:

- Axis
  - a) vertical axis
  - b) horizontal axis (3)

- Number of blades
  - a) 2 blades
  - b) 3 blades
  - c) 4 blades
  - d) multiblade

- Mounting of blades
  - a) variable pitch blade (for speed regulation)
  - b) fixed pitch blade. (4)

- Scale
  - a) small scale (from 1 to 5 kw. output)
  - b) medium " (from 5 to 50 kw. ")
  - c) large " (over 100 kw. output) (5)

- Rotor position
  - a) facing the wind
  - b) receiving the wind from behing (4)

- Speed of rotation
  - a) high speed (low number of blades)
  - b) low speed (large number of blades) (6)

- Starting torque
  - a) low starting torque (can start under load)
  - b) high starting torque (6)

3. Rated wind speed

The operation of a windmill is limited by three values of wind speed:

a) cut-in speed : is the speed at which the machine begins to supply power.

b) rated speed : is the speed at which the rated power of the machine is delivered.

c) furling speed : is the speed at and above which the machine is put out of operation for safety reasons.

The selection of these values depends upon the total energy production, the turbine diameter, the load conditions, the speed of rotation, etc. A careful selection of these values will allow to obtain the maximum annual output. (7)

4. Design principles

In the design of wind machines the following items should be considered:

- maximum power output
- speed regulation
- number of blades
- conning (angle formed by the blades and the vertical axis of the tower, to avoid the tip of the blade touch the tower)
- yawning (rotation of turbine according to changes in wind direction)
- inclination of axis of rotation (angle formed by the axis of the turbine and the horizontal line)
- location of site
- location of auxiliary equipment
- coupling system
- safety measures (for vibrations and high speeds)
- height of tower. (5) (8)

5. Blade design

The selection of blades is based upon the following calculations:

C_l : lift coefficient

C_d : drag coefficient

l : length of cord

u : tangential speed

v : wind speed

w : relative speed

R : radius

z : number of blades

L : length of blade elements

A : lift

ρ_a : density of air

I : moment of inertia of the section

σ : stress

$$Ca \cdot l \cdot z = \frac{R}{u/v} \Lambda$$

where Λ is a function of the ratio u/v. If z is choosen it is possible to determine the length of cord of the blade section. The lift is calculated as

$$A = C_a \frac{\rho_a w^2}{2 g} \cdot l \cdot L$$

From this equation, the bending moment M developed may be calculated. There are two cases in the design of blades:

a) Axis of the blades is perpendiculer to the axis of rotation

The stress on the blade rotors depends on the u/v ratio, the stress of two blade rotors being 0.45 the stress of three blade rotor. The maximum stress occur at 0.6 of the total length.

b) Axis of the blades makes an angle other than 90 with the axis of rotation

The bending stresses are replaced by tensile stresses. If F_c is the centrifugal force on the blade and F_f the bending force, the resultant force F_t will produce tension in the blade,

$$\tan^{-1}\zeta = \frac{F_f}{F_c}$$

where is the angle which the blade makes with the plane perpendicular to the axis of rotation. If V is the volume of the blade and the density, then

$$\gamma = g\,\frac{F_c\ R}{V\ .\ u^2}$$

The desired density is low, so hollow blades are used. Special considerations should be made in both cases to study the forces developed when the blades are standstill, due to high wind velocities. The maximum stress occurs at the root of the blades. Two blade designs offer vibration problems that overthrought the advantages of two blade rotors. (4)

6. Auxiliary machinery

a) Pumps

There are two types of water pumping systems to be considered:

- low power piston pump

The windmill used in this case is one of the low speed types, providing high starting torque for the piston. In this case rotors heve large number of blades and consequently large inertia, which limits its diameter to 7-8 m. The efficiency drops considerably during high winds. The rotational motion of the rotor is converted into a reciprocating motion by means of rods, slots, eccentrics. The speed of the rotor has to be reduced by means of gears to reduce inertia stresses and resonance in the rod, which causes the rod to act like a tension spring.

- high power rotary pump

In case of high winds centrifugal or propeller type of pumps are preferred. This type provide small lifts at low winds, a regulation system is needed. (7)

b) Generators

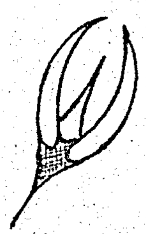
The electric equipment in a windmill is subjected to the following conditions:

- need for minimum possible maintenance
- automatic operation and regulation
- variation of power
- frequent connection to the network
- torque undergoing cycles
- vibrations
- severe atmospheric conditions
- need for a braking system

Solutions for power generation under this conditions are:

1. asynchronous generator
2. synchronous generator
   - with intermediate set
   - directly driven (4)
3. induction generator (with condenser)

The generator can be connected directly to the turbine shaft at the top of the tower or down on ground level. (8) In the larger machines for use with a network, alternating current operatión through induction generator is prefered. When the plant is to run independantly, a specially designed AC generator is needed for varying speed of the rotor. Direct current for battery charging can be used, when produced by a rectifier, (5)



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(1) F.O.Willhofft "Industrial Applications of the Flettner Rotor" Mechanical Engineering. Vol 49 No. 3 1927 pp 249-253.
(2) Palmer C.Putnam "Power from the Wind". Van Nostrand 1948
(3) E.W.Golding "The Economic Utilization of Wind Energy in Arid Areas" Wind and Solar Energy Proceedings of the New Delhi Symposium. UNESCO 1958 pp 90-98.
(4) L.Vadot "The Production of Electrical Energy from the Wind"Houille Blanche. Octobre 1958 pp 503-525.
(5) E.W.Golding "Energy from Wind&Local Fuels" The Problems of the Arid Zones Proceedings of the Paris Symposium UNESCO 1960 pp 249-58.
(6) U.Hütter "Planning and Balancing of Energy of Small-output Wind Power Plants" Wind and Solar Energy Proceedings of the New Delhi Symposium. UNESCO 1958 pp 76- 87.

7) L.Vadot "Water Pumping by Windmills" Houille Blanche Septembre 1957 pp 524-529.

8) Palmer C. Putnam "Power from the Wind" Van Nostrand 1948 pp 109-115

2.36 Economic analysis

When making an economic analysis of wind power, it is wise to make the studies on comparative basis with the conventional sources of energy available. The procedure is as follows:

1. Calculation of the annual specific output T_s (kwhr per year/kw) from recordings of wind velocities. This value varies within 10 % from year to year, measurements for one year being sufficient.

2. Calculation of the capital cost C . The ranges are the following without battery (1956) :

smaller than 10 kw	420 - 560	$ /kw
between 10 - 100 kw	280 - 420	"
larger than 100 kw	140 - 280	"

3. Calculation of the annual operating cost p (interest, depreciation and maintenance) which can be taken as 12 % of the capital cost.

The cost of power is then given by the expression:

$$P_c = \frac{p \cdot C}{T_s}$$

The cost thus obtained should be compared with alternative sources, considering the fact that wind power is random and provisions for its efficient utilization has to be made. It is up to the designer to change the rated speed of the wind machine and find the optimum ratio of:

$$\frac{C}{T_s} \qquad (1)$$

In order to find the optimum size of wind turbine, analysis of different alternatives should be made to find the least cost. The items that should be considered in an economic analysis are:

1. Installed costs

a) Engineering costs

- Personnel
- Overhead (30 %)
- Travels
- Consulting
- Furnishings

b) Manufacturing costs

- Generator
- Gears
- Electric coupling
- Governor
- Bearings
- Switchgear
- Flexible coupling
- Hoists, lifts.
- Electrical equipment
- Tower
- Paint
- Transformers
- Distribution line
- Blades
- Assembly
- Tools, jigs and fixtures

- Measurement instruments

c) Installation costs

- Freight
- Land
- Road
- Erection
- Connections

2. Operation costs

a) Interests

b) Dividends

c) Taxes

d) Depreciation

e) Maintenance costs

f) Operation costs

3. Energy cost

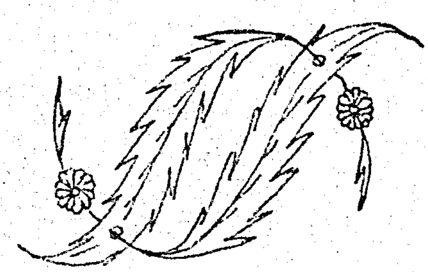
a) Operation costs

b) Annual output (2)

The future of wind power depends upon the improvements that can be made on the cost of the energy generated, and this is possible if some of the following items are considered:

1. Better selection of materials (steel, aluminium, etc.).
2. Better selection of supplies (ball bearings, shafts, etc.).
3. Better selection of site.
4. Analysis of alternatives between one and several wind machine units.
5. Analysis of cost of other power systems.
6. Better fitting of the demand to the available power.

7. Simplification of design (avoid use of variable pitch blades, speed governors, etc.).
8. Elimination of gears.
9. Standardization of design for mass production.
10. Elimination of vibrations.
11. Reduction of weight of parts
12. Better and stronger designs to reduce maintenance and increase the life of the units.
13. Careful selection of rated speed to increase the annual output.
14. Research for better efficiency.
15. Research of potentialities of wind power in wide areas.
16. Improvement of power storage system
17. Reduction of stresses in the members.
18. Improvement of the predictability of wind regime within the next 12 hours, so to fit the demand. (1) (2)



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(1) E.W.Golding "The Economic Utilization of Wind Energy in Arid Areas" Wind and Solar Energy Proceedings of the New Delhi Symposium UNESCO 1958. pp 90-98
(2) Palmer C.Putnam "Power from the Wind" Van Nostrand 1948.

"Bugünkü bilgin, yarının cahili".

2.4 CONCLUSION

Out of the information obtained from the survey on the available data, it is possible to estate the following points as a conclusion:

1. The history of the windmill starts most probably in the Mesopotamia towards 1500 B.C.

2. The first signs of the utilization of windmills in Europe date from 1000 A.C.

3. During the 18 th century the sudden development in engineering and technology made it possible to develop new and original windmill designs.

4. At the end of the 19 th century a scientific research started on windmills, and experiments were carried on new and more efficient types.

5. In 1925 Flettner and Savonius started they work on vertical type windmills using the principles of the wind rotor.

6. The wind rotor idea was soon abandoned, because it was considered of low efficiency and it required more material per unit power than other conventional windmill types.

7. In 1940 new wind turbines with 3 blades - made with airfoil profiles - and high output started to be designed and tested.

8. After the year 1950 large output windmills proved to be too complicated for practical operation, and simpler designs with lower output were started.

9. India and Israel started a country wide research program nd experimentation on windmills, following a basic outline of work:

- Study of the wind regimes within the country.
- Data collection on wind characteristics all over the country.
- Data collection on power generating systems and available resources.
- Erection of small windmills in favorable locations
- Design of larger units to be installed in sites where best conditions existed.

10. Research is still being carried today in Israel, India and England, for windmills to be used in underdeveloped areas.

For the time being, the future of windmills seems to depend upon the following points:

1) The unpredictability of the wind characteristics, makes it necessary to carry on more complete surveys on wind regimes.

2) The fact that the power generated from a windmill is directly proportional to the cube of the wind velocity, makes it necessary to improve the designs still more for better overall efficiencies

3) Storage of power has been found uneconomical, so a more careful analysis of power demands - water pumping, electricity generation, cooking, heating, etc. - seems to be a better way to improve the efficiency of windmills.

4) Economy being the ultimate test for the utilization of wind power, it is necessary to make the following analysis:

a. find the optimum size.

b. compare the efficiencies of one sole unit vs. several small units.

c. find the most favorable location for the units.

d. analyze the possibilities of using windmills connected together or to a main network.

e. compare the cost of power with other conventional power sources.

5) The future use of windmills seems to be restricted to underdeveloped areas, where the cost of generation of power by other methods is higher.

6) There is a need for simpler windmill designs, and the wind rotor seems to have the characteristics required for a feasable solution:

a. independance from changes in wind direction.

b. possibility of working at very high speeds.

c. no need for gearing system

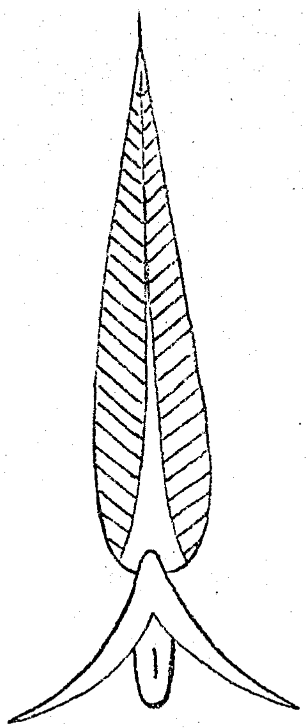
d. ease of manufacture, operation and maintenance.

We can conclude in the following way:

Wind can still be a source of power generation, such as water pumping, electricity production, ventilation, etc. in underdeveloped areas, if simple designs such as wind rotors are used.

Based on this statement the following outline will be taken as a guide in our work:

- Study of wind theory and characteristics.
- Analysis of basic aerodynamic principles involved in the application of wind rotors.
- Experimentation on different types of wind rotors and study of their performance characteristics.
- Design based on the most efficient solution.
- Economic analysis of the design.
- Analysis of the possible applications, and manufacturing methods.
- Recommendations for future work.



" Hayâl-i şem'-i ruhsârın ko yansın hâne-i dilde
Yakıp ol şem'e perrin şevk ile pervâneler dönsün. "

(Bâki)

3. THEORETICAL BACKGROUND

3.1 Wind Theory

3.2 Aerodynamic Principles

" Dehân-i gonceden ümmîd-i nîmhande ile
Nesîm-i subh-demin cüst ü cuların bilürüz " (Nâbî)

3.1 WIND THEORY

3.11 Wind motion

3.12 Forces affecting wind motion

3.11 Wind motion

Wind motion is a continuous and cyclicay tendency of the atmosphere to stabilize itself and to reach an equilibrium. Temperature differences in the atmosphere causes pressure gradients, which create forces trying to reach a state of balance. Warmer air rises, leaving a reletive deficiency of air at the surface, while cold air flows to compensate this deficiency creating a motion called wind. Cold air descends under the influence of its higher weight and this cause an increase in the air pressure, while the raising of air causes a decrease in pressure. Thus all winds are the result of horizontal differences in pressure, and all winds tend to blow from high to low pressures. The velocity of air flow will depend upon the magnitud of this pressure gradient. (Fig 3.11-1) (1)

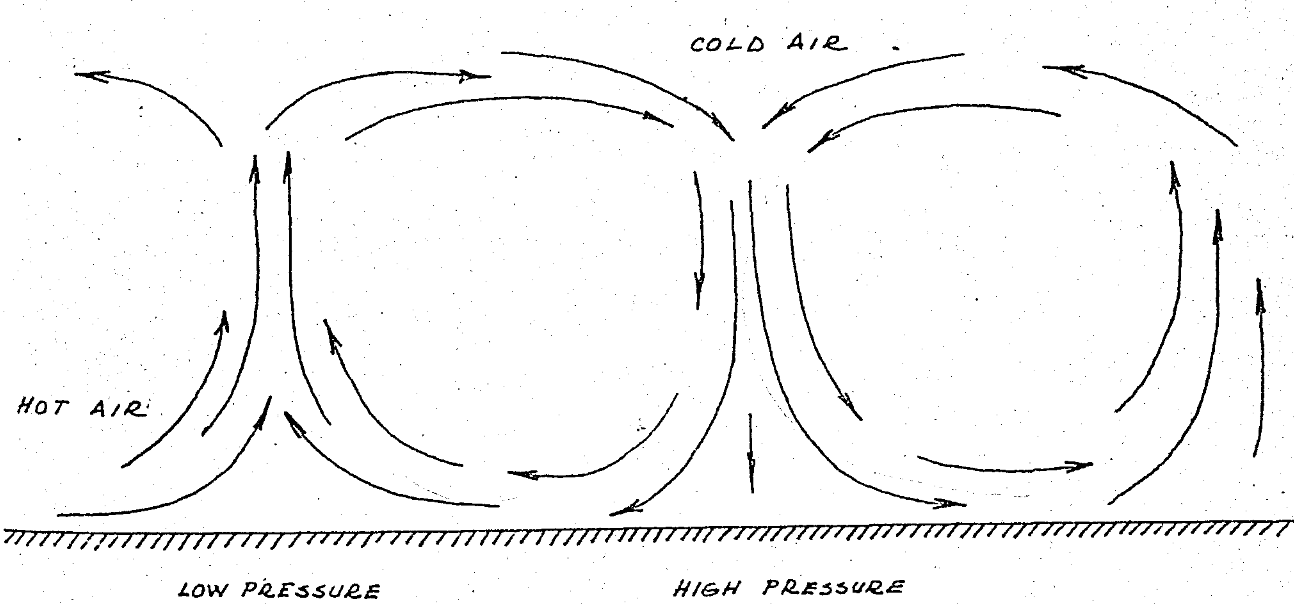


Fig 3.11-1
Pressure gradients

The best example of wind motion can be found in the thermal circulation that occur locally. The basic cause of air flow is the temperature contrast. A sea breeze is caused in the shore where the cool air fills the empty space left by the air heated by the land, raising due to drop in density. (Fig 3.11-2)

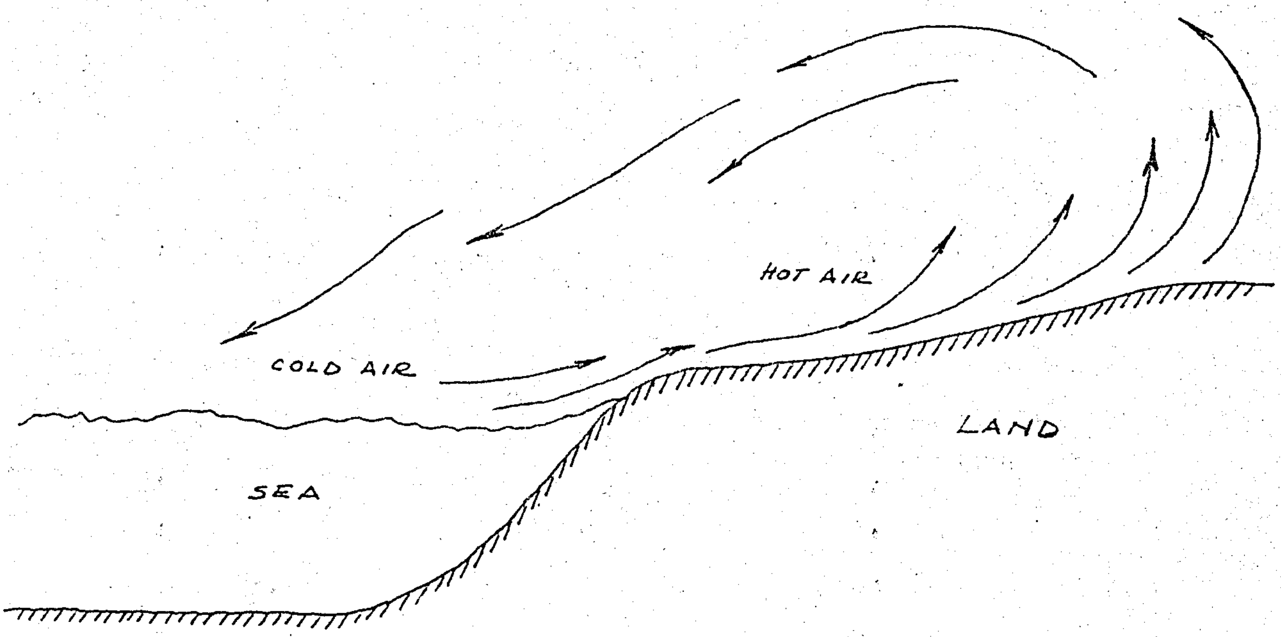


Fig 3.11-2

Sea breeze

The process is often reversed during the night, when the land cools faster than the water and an air motion in the reverse direction is generated. (2)

(1) William L.Donn "Meteorology" Mc.Graw Hill 1951 pp 140-147.
(2) George F.Taylor "Elementary Meteorology"Prentice Hall Inc. New York 1954 pp 121-140

3.12 Forces affecting wind motion

The speed and direction of the wind motion will depend upon the interaction of the following forces:

- Pressure gradient force
- Coriolis force
- Centrifugal force
- Friction force

The analysis of the forces affecting wind motion can be done mathematically and for this purpose the following nomenclature will be used:

ω :	angular velocity of rotation of earth	rad/sec
t :	time	sec
v :	velocity of air	m/sec
a :	acceleration of air	m/sec^2
m :	mass of air	gr
ρ :	density of air	gr/cm^3
n :	axis in the horizontal direction	m
ϕ :	latitud angle	degree
g :	acceleration of gravity	m/sec^2
c :	wind speed	m/sec
z :	axis in the vertical direction	m
ψ :	geopotential	m^2/sec^2
F_c :	Coriolis force	dynes
r :	radius	m
f :	friction force	dynes

1. Pressure gradient force

Wind flow is caused by a pressure difference in the atmosphere. This ressure difference can be denoted by means of pressure gradient ector, which indicates the direction of flow at right angles to the ressure lines (isobars). Pressure lines form a pressure field, and he pressure gradient is expressed symbolically as dp/dn , or the ate of change of pressure with distance. (Fig:3.12-1)

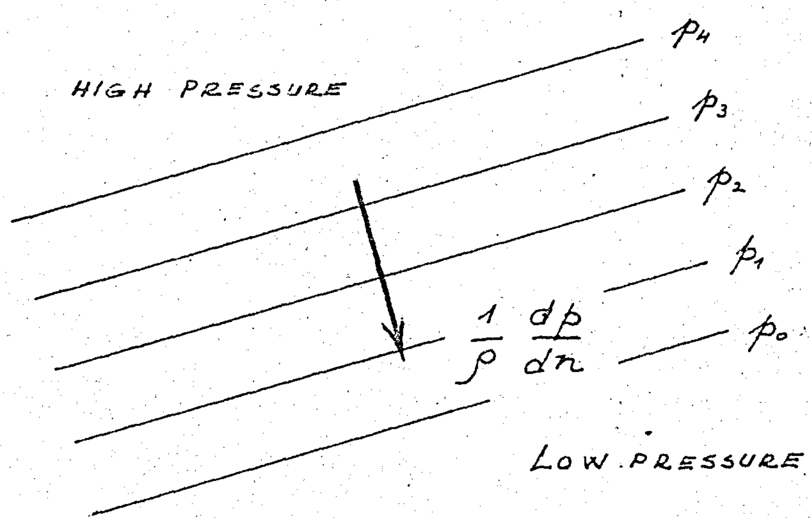


Fig 3.12-1

Pressure gradient

The expression $1/\rho$ dp/dn is called the pressure gradient force, here ρ is the density of air. Actually it is not a force, but an acceleration, so we can consider it, the force that acts upon the unit mass of air.

2. Coriolis force

Due to the rotation of the earth around its own axis, the wind is affected by the Coriolis forces. The motion of the earth continuously deflects any freely moving object, and this deflection acts so as to ause the object to move toward the right in the northern hemisphere nd towards the left in the southern hemisphere. (Fig 3.12-2)

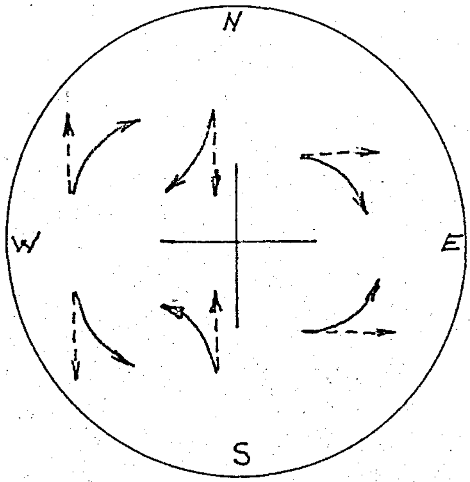


Fig 3.12-2

Deflection of wind

The force that causes this deflection is proportional to:

a. the speed of the moving object

b. the mass of the moving object

c. the sine of the latitude

This forces act at right angles to the direction of the moving object so that it can be affecting only its direction, and not its speed. This force is called Coriolis force, and can be simply derived as follows:

Assume a particle at the North Pole moving freely towards the South with a velocity v in the direction PA. By the time it has arrived at the point in space represented by A, the earth will have revolved a distance BA, and the particle will actually reach B, having followed the curve path PB. (Fig 3.12-3)

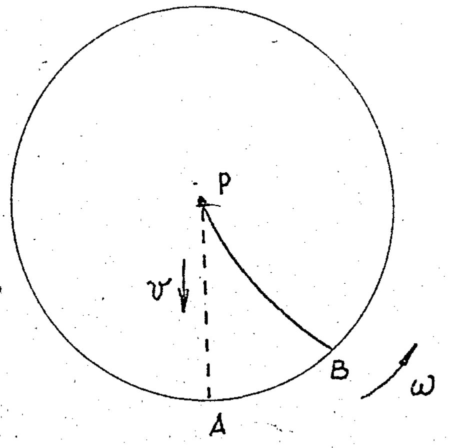


Fig 3.12-3

Coriolis force

hus it is deflected to the right. If the earth is revolving about ts axis with an angular velocity ω , the angle BPA will be $\omega \cdot dt$ fter a small interval of time dt , and the distance PA will be v dt .(Fig 3.12-4)

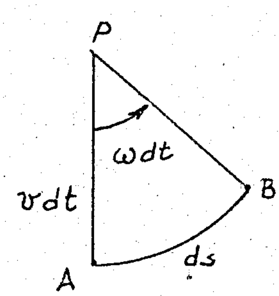


Fig 3.12-4

Deflection angle

The angle $\omega \cdot dt$ is equal to the arc ds divided by the radius v dt , or

$$\omega \cdot dt = \frac{ds}{v\ dt}$$

$$ds = v\,\omega\,(dt)^2 \qquad (E\,1)$$

In general the distance travelled by a particle depends on the initial velocity and its acceleration

$$s = v_o\,t + 1/2\,a\,t^2 \qquad (E\,2)$$

For an initial velocity equal to zero and a small interval of distance and of time:

$$ds = 1/2\,a\,(dt)^2 \qquad (E\,3)$$

Equating equations (E 1) and (E 3)

$$v\,\omega\,(dt)^2 = 1/2\,a\,(dt)^2$$

Therefore

$$a = 2\,v\,\omega \qquad (E\,4)$$

From Newton's law

$$F = m\,a \qquad (E\,5)$$

Substituting equation (E 4) in (E 5),

$$F = 2\,m\,v \qquad (E\,6)$$

Taking the component of ω at any latitude ϕ, $\omega \sin \phi$, we have

$$F = 2\,m\,v\,\omega\,\sin\phi \qquad (E\,7)$$

This is the Coriolis force. In vector notation the same equation can be expressed as:

$$\vec{F} \quad 2 \, m \, \vec{\omega} \times \vec{v}$$

A particle moving from the equater northward will be deflected to he right, while a particle moving towards the equator will also be eflected to the right. (Fig 3.12-5)

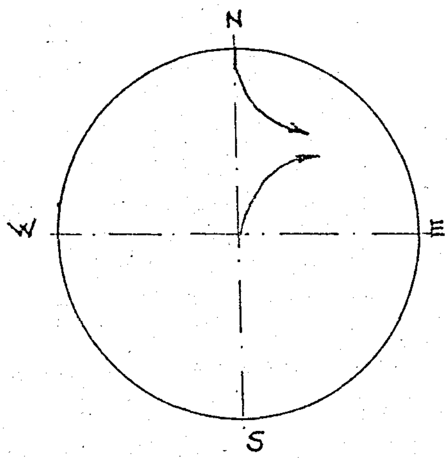


Fig 3.12-5

Deflection of a moving particle

When the only forces acting upon the air are the pressure gradient and the Coriolis force, the blowing wind is called geostrophic wind . The equation for the geostrophic wind states that the Coriolis force equals the pressure gradient force. Taking both forces per unit mass, from equation (E 7),

$$2 \omega \sin \phi = 1/\rho \quad dp/dn$$

$$c = \frac{1}{2 \omega \sin \phi \rho} dp/dn \qquad (E 8)$$

where c is the wind speed. The wind speed can be represented in the pressure field as in Fig 3.12-6

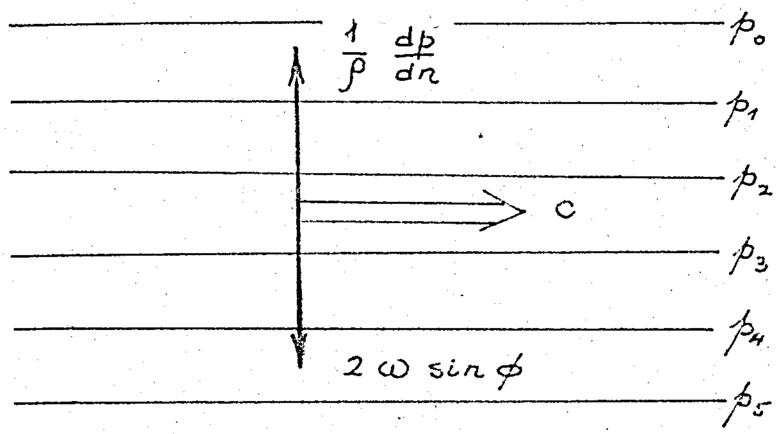


Fig 3,12-6

Geostrophic wind

Equation (E 8) shows that the wind speed is

- directly proportional to the pressure gradient
- inversely proportional to the sine of the latitud
- inversely proportional to the air density

This equation should not be used for latitudes below 10° . When goes to 0° then c goes to infinity in the limit.

In the northern hemisphere a person standing with his back against the wind will feel the low pressure side on his left, which is in accordance with this discussion.

As the wind speed is inversely proportional to the air density, and air density decreases with height, the wind speed increases with height from the surface of the earth. In order to see this behaviour we can substitute ρ by its equivalent from the hydrostatic equation:

$$dp = - \rho g \; dz \qquad (E\,9)$$

where z is the vertical distance and g the acceleration of gravity, therefore

$$\rho = - dp/g \; dz \qquad (E\ 10)$$

From equations (E 8) and (E 10)

$$c = \frac{g}{2\,\omega \sin \phi} \; \frac{dp/dn}{dp/dz}$$

or

$$c = \frac{g}{2\,\omega \sin \phi} \; dz/dn \qquad (E\ 11)$$

In this way the pressure term is eliminated and wind speed is dependant upon the vertical distance dz and the horizontal interval dn . It is possible to plot constant pressure charts, where the wind speed changes with the height from the ground. Equation (E 11) has the acceleration of gravity in, but this varies practically none with height for all practical purposes. For more precise work, g dz can be replaced by $d\psi$

$$\psi = \frac{g_o \; z}{10} \; (1 - z/E) \qquad (E\ 12)$$

where

ψ : geopotential
g_o : 9.8062 m/sec^2
E : radius of the earth in meters

3. Centrifugal force

In general it is assumed that the wind flows in a straight line, at actually wind travels large distances so that the curvature of he earth enters into picture, does the air is affected by the centrifugal force due to its curved path, proportional to mc^2/r, where m is the mass of air, c the velocity and r the radius of the curvature of its path.

Winds that blow in response to Coriolis, pressure gradient and centrifugal forces are called <u>gradient winds</u>. There can be several alternatives as shown in Fig 3.12-7.

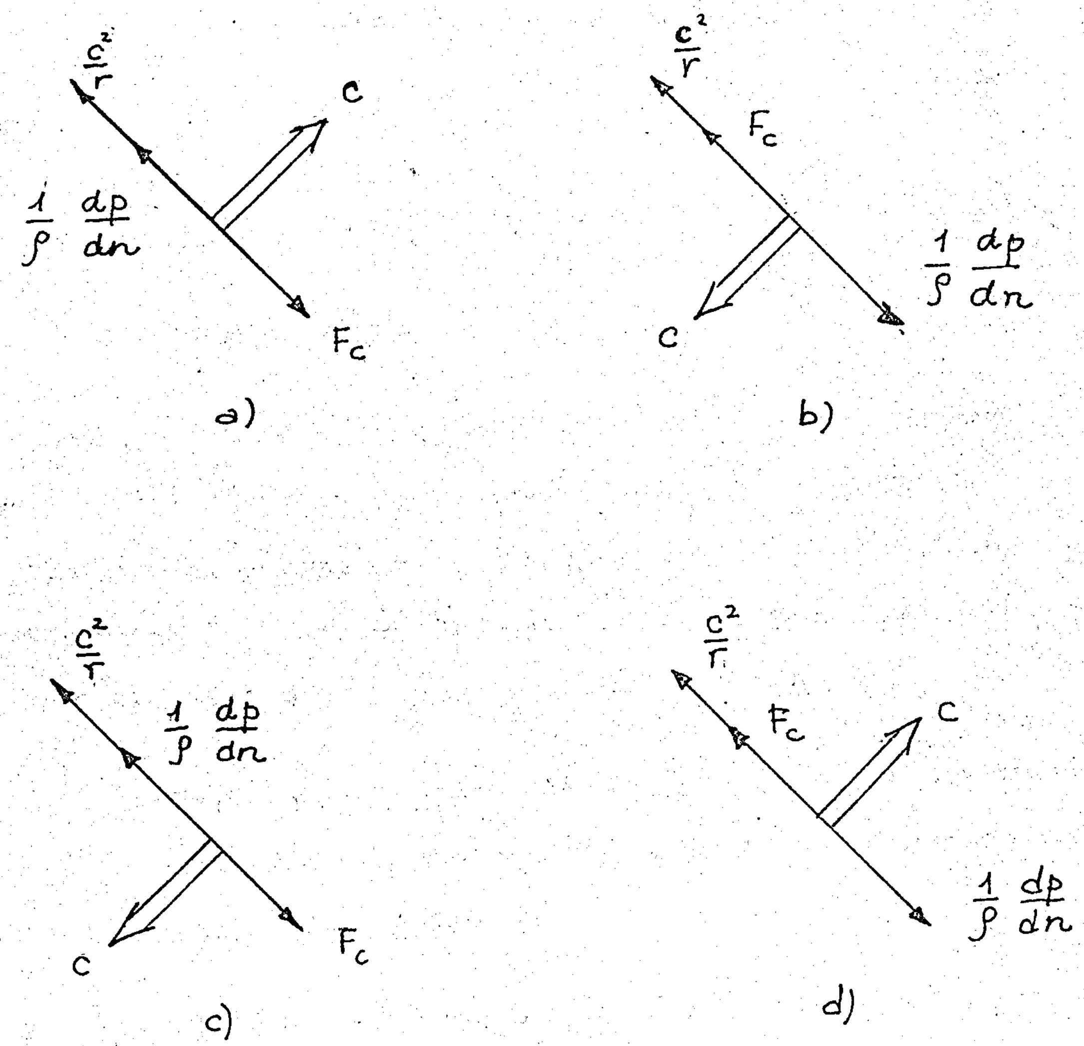


Fig 3.12-7

Gradient winds

In Fig 3.12-7,

F_c : Coriolis force

c^2/r : centrifugal force

$1/\rho \, dp/dn$: pressure gradient force

As an example take from the same figure case b)

$$1/\rho \; dp/dn = 2 \omega c \sin \phi - c^2/r$$

$$c^2 + 2 r \omega \sin \phi \, c - r/\rho \; dp/dn \quad 0$$

then

$$c = \sqrt{r/\rho \; dp/dn + (r \omega \sin \phi)^2} - r \omega \sin \phi$$

4. Friction force

In nature the effect of friction caused by the surface of the earth should also be considered. Friction deflects the wind so that it always has a component from high to low pressure. This provides a mechanism for the interchange of air between high and low pressure systems that would hardly be possible otherwise.

When friction enters into picture, the speed is decreased and the Coriolis force at once becomes too weak to balance the pressure gradient force. (Fig 3.12-8)

In order to restore a balance of forces the wind shifts so that the friction force f can assist the Coriolis force in maintaining a balance. This situation is seen in Fig 3.12-8 where f and F_c' still just balance the force $1/\rho$ dp/dn. The pressure gradient force

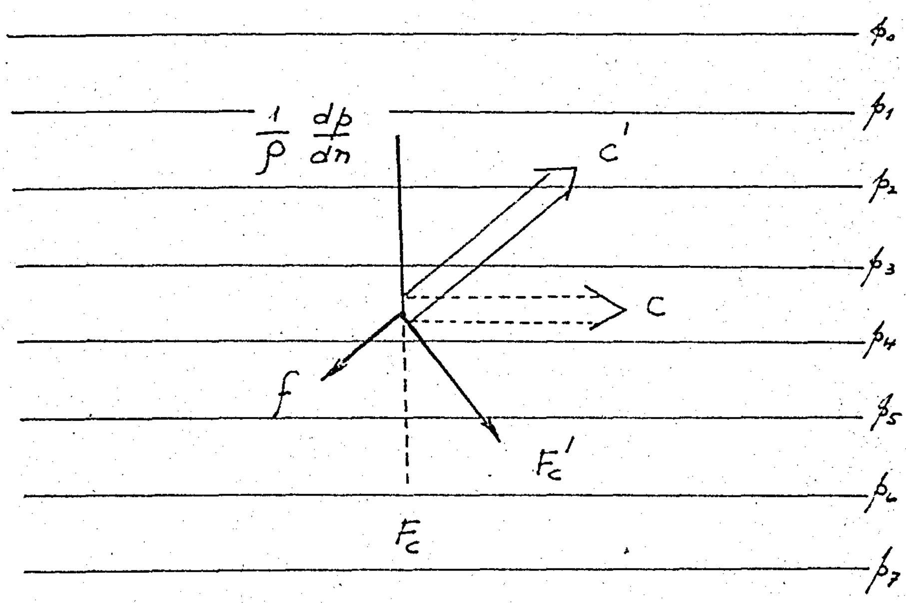
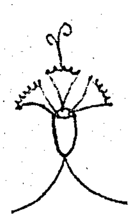


Fig 3.12-8

Effect of friction on wind

does not change, the Coriolis force is always normal to the wind direction and the friction force is always directly opposed to the wind. It must be remembered in all discussions that the wind vector itself is not a force, since the wind is assumed to be blowing with a steady velocity.

In the equator and for local winds the Coriolis force is zero, so that the wind speed is dependant only on the pressure difference and friction. (1)



(1) George F.Taylor "Elementary Meteorology" Prentice Hall Inc. New York 1954 pp 121-140.

" Dest-būsı̂ ārzūsuyle ölürsem dōstlar
Kûze eylen toprağım sunun anınla yāre su. "

(Fuzuli)

3.2 AERODYNAMIC PRINCIPLES

Nomenclature :

V	:	velocity of parallel flow	m/sec
A	:	cross section area	m^2
Q	:	flow rate or rate of discharge	m^3/sec
S_o	:	source	
E	:	source strength	m^3/sec or m^2/sec
Γ	:	circulation	m^3/sec
r	:	radius	m
D	:	diameter	m
a	:	distance from stagnation to source	m
M	:	moment of the dipole	m^4/ sec
l	:	distance between source and sink	m
v	:	velocity at the surface of a body	m/sec
v_c	:	velocity due to circulation	m/sec
r_o	:	radius of the cylinder	m
α	:	angle made by the radius with the x - axis at a point on the periphery	degrees
p	:	total pressure	kg/sec m^2
p_o	:	static pressure at a point on the parallel flow	kg/sec m^2
ρ	:	density of the fluid	kg/m^3
F_L	:	lift force	kg
F_D	:	drag force	kg
A_L	:	lift projected area	m^2
A_D	:	drag projected area	m^2
C_D	:	coefficient of drag	-
C_L	:	coefficient of lift	-

P	:	power	kg m/sec
P_o	:	power output	kg m/sec
P_a	:	power available	kg m/sec
η	:	maximum theoretical efficiency	–
V_s	:	velocity of source	m/sec
S	:	closed curve	m
β	:	angle made by the circulation velocity with the tangent	degrees
v_t	:	total velocity	m/sec
γ	:	angle of attack of airfoils	degrees
m	:	mass flow rate	kg/sec

3.21 <u>Parellel flow</u>

The ideal flow is defined as being non-viscous, in other words here is no friction. Therefore <u>ideal flow</u> is frictionless and steady low: the velocities throughout a cross section in a pipe are equal. ig 3.21-1)

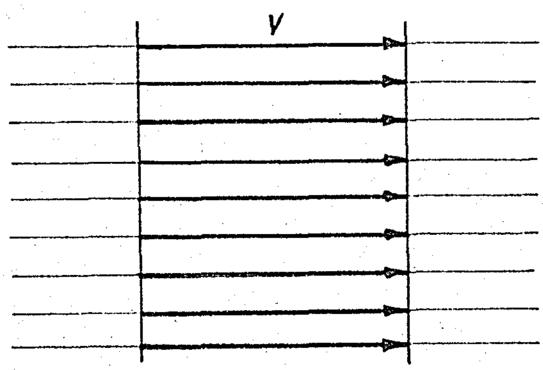


Fig 3.21-1

Ideal Flow

In the ideal flow, the flow rate or rate of discharge is :

$$Q = V \cdot A \qquad (E\ 1)$$

where

Q : flow rate in m^3/sec

V : velocity in m/sec

A : cross section area in m^2.

The continuity equation for an incompressible fluid (density cons-ant throughout the flow) is according to Fig 3.21-2 :

$$V_1 \cdot A_1 = V_2 \cdot A_2 \qquad (E\ 2)$$

where

V_1 : velocity at point 1 in m/sec

V_2 : velocity at point 2 in m/sec

A_1 : cross section area at point 1 in m^2

A_2 : cross section area at point 2 in m^2

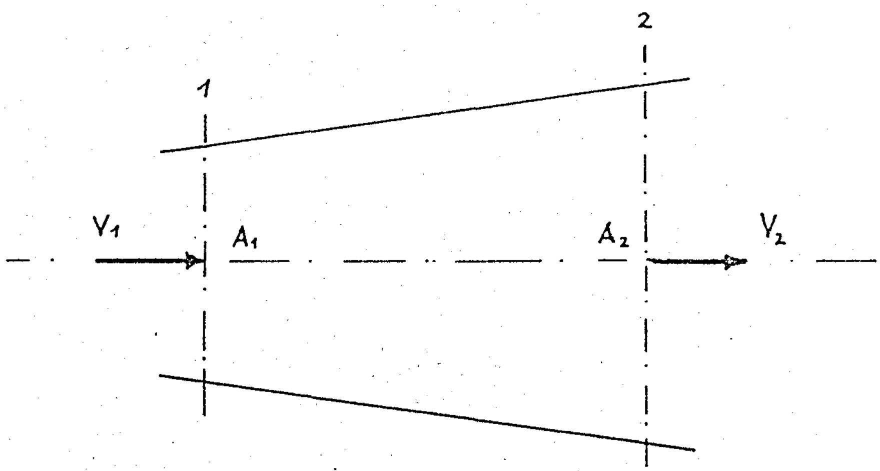


Fig 3.21-2

Continuity equation

A <u>streamline</u> is defined as the tangent line to the instantaneous locities at successive points in a flowing liquid. (Fig 3.21-3)

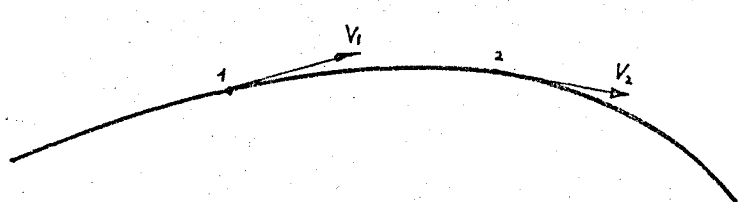


Fig 3.21-3

Streamlines

According to this definition of a streamline, the ideal flow is classified as :

1. Parallel flow
2. Source flow
3. Circulation flow
4. Combined flow

Parallel flow:

Streamlines are parallel to each other. (Fig 3.21-4) (1)

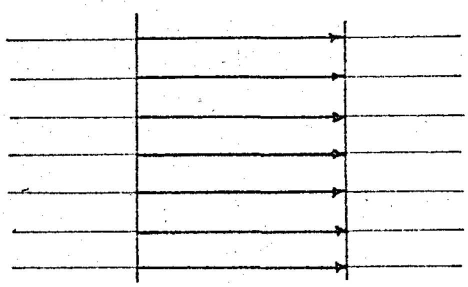
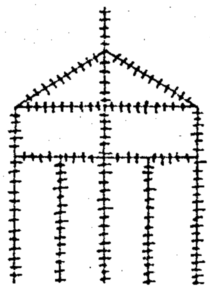


Fig 3.21-4
Parallel flow



(1) Adnan H.Taşpınar "Fluid Mechanics Notes" (not published)

3.22 Source flow

A source is a point from which fluid is generated at an uniform rate. The strength of the source is the rate of flow passing through any surface enclosing the source. (Fig 3.22-1) (1)

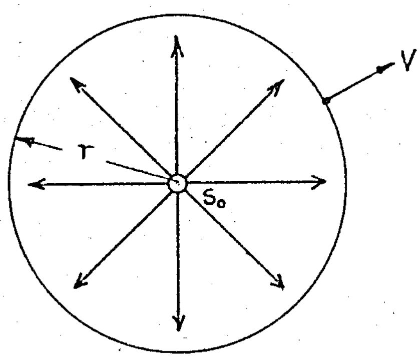


Fig 3.22-1
Source flow

For a 3- dimensional flow, the strength of the source is:

$$E = V_s \cdot 4\pi r^2 \qquad (E\,3)$$

where

E : strength of the source in m^3/sec

V_s : velocity of the source in m/sec

$4\pi r^2$: area of a sphere in m^2

For a 2- dimensional flow:

$$E = V_s \cdot 2\pi r \qquad (E\,4)$$

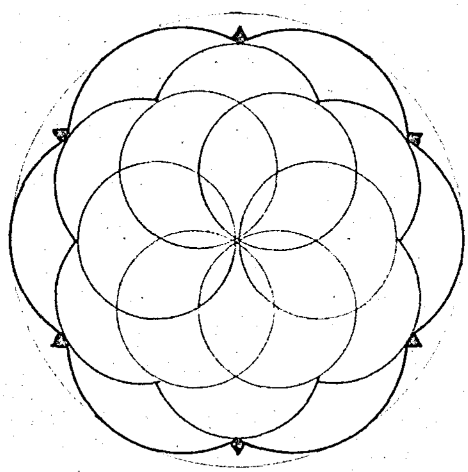
where

E : strength of source in m^2/sec

V_s : source velocity in m/sec

$2\pi r$: perimeter of a circle in m

Equations (E 3) and (E 4) are similar to equation (E 1), since the strength of the source is actually the flow rate of the source. When the velocity V_s is negative, the flow is inwards and in this case we have a sink. (2)



(1) V. Streeter "Fluid Dynamics" Mc. Graw Hill Book Co. 1948 p 43.

(2) Adnan H. Taşpınar "Fluid Mechanics Notes" (not published)

3.23 Circulation flow

When fluid circulates around an axis, streamlines are concentric circles, and there is circulation flow. (1)

Circulation is expressed mathematically as follows:

If a closed curve S is drawn on a two- dimensional steady flow streamline, where the components of the velocity v_c at all points along a curve are $v_c . \cos \beta$, the circulation Γ is defined as, from Fig 3.23-1 :

$$\Gamma = \oint_S v_c \cdot \cos \beta \cdot ds \qquad (E\ 5)$$

where

$\oint_S$: line integral along the closed curve S

$v_c . \cos\beta$: component of the velocity v_c on the curve S

v_c : circulation velocity in m/sec

ds : infinitesimal element of the curve S

Γ : circulation in m^2/sec

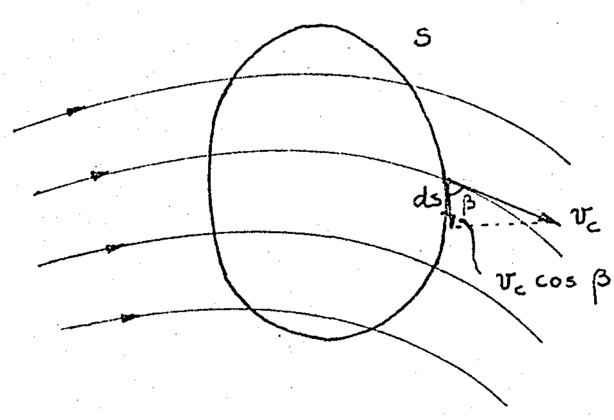


Fig 3.23-1

Circulation

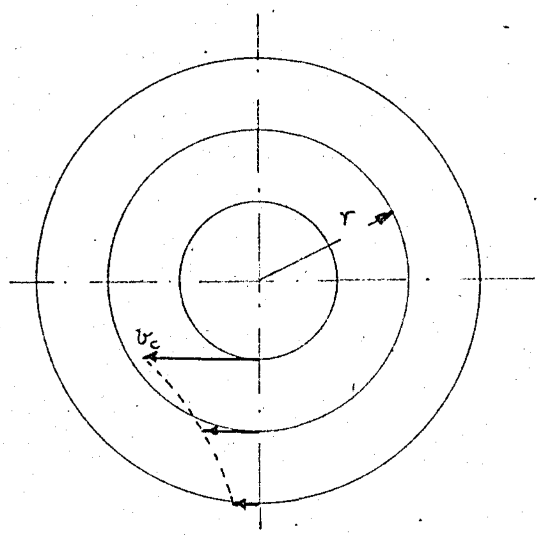


Fig 3.23-2

Free vortex

In the case of a free vortex, the velocity is given by the expression; Fig 3.23-2

$$r \cdot v_c = \text{constant} = C \qquad (E\ 6)$$

If we apply the equation (E 5), then

$$\Gamma = \oint_s v_c \cdot \cos\beta \cdot ds$$

and $\cos\beta = 1$

$$\Gamma = \oint_s v_c \, ds$$

$$\Gamma = v_c \oint_s ds$$

$$= v_c \, 2\pi r \quad (\text{for a circle})$$

From equation (E 6)

$$v_c = C / r$$

Therefore

$$\Gamma = 2\pi C$$

or

$$\Gamma = 2\pi v_c \cdot r \qquad (E\ 7) \qquad ((2)$$

1) Adnan H. Taşpınar "Fluid Mechanics Notes " (not published)
2) Richard H.F. Pao "Fluid Mechanics" John Wiley and Sons 1961 pp 422-424.

3.24 Combined flow

The superposition of more than one kind of flow is called a mbined flow. The method of solving such a flow problem is shown by ans of examples:

a) Parallel flow and source flow

A body with a source S_o has a strength E. The fluid coming out om the source remains within the boundaries of the volume of the dy. In addition of this, there is a parallel flow around the body width D. The distance of the source from the stagnation point of e body - where the velocity is zero - is expressed by a .

In order that the parallel flow of the surroundings remain undis-rbed, the quantity of fluid displaced by the body must flow out of e source. (Fig 3.24-1)

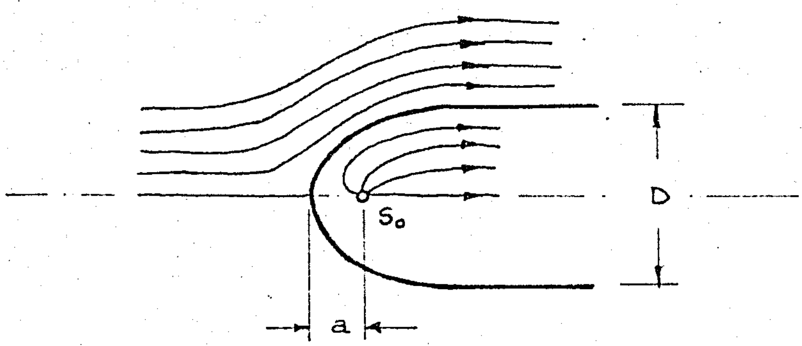


Fig 3.24-1

Parallel flow with source flow

If we assume the body to have a cylindrical cross section, then:

$$E = V_s \cdot \pi r^2 \qquad (E\,8)$$

where

E : strength of the source in m^2/sec

V_s : velocity of the source in m/sec

πr^2 : cross section area of the cylinder in m^2.

From equation (E 8) :

$$r^2 = \frac{E}{V_s \pi}$$

d r = D/2, so:

$$\frac{D^2}{4} = \frac{E}{V_s \pi}$$

erefore:

$$D = 2 \sqrt{\frac{E}{V_s \pi}} \qquad (E\,9)$$

If the distance a equals r , then from equation (E 9):

$$a = \sqrt{\frac{E}{4 V_s \pi}} \qquad (E\,10)$$

b) Parallel flow with a sorce and sink of equal strength

When the distance between a source and a sink is reduced so that

$$E \cdot l = \text{constant}$$

where

E : strength of source (Fig 3.24-2)

l : distance between source and sink, in m

obtain a <u>Dipol</u> , or doublet. (Fig 3.24-3)

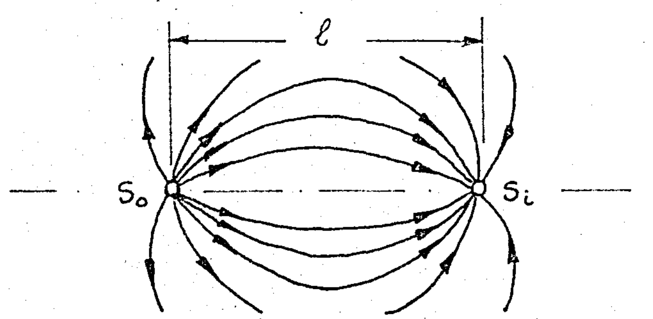


Fig 3.24-2

Source and sink

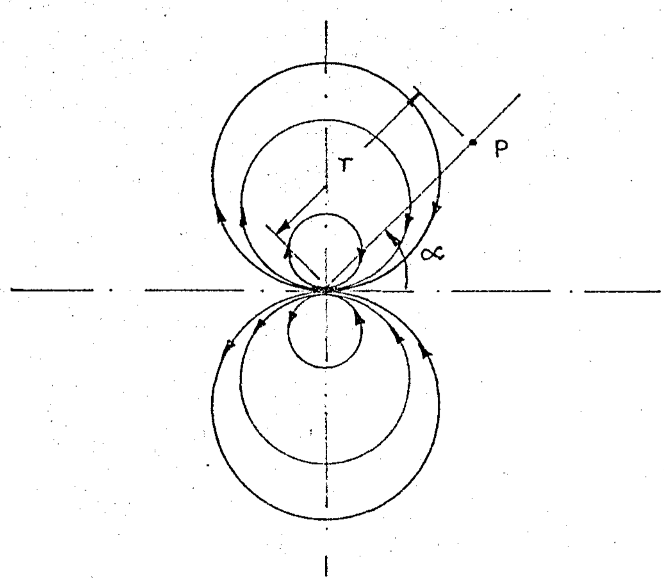


Fig 3.24-3

Dipol

The moment of the dipol is defined as:

$$M = E \cdot l \qquad (E\ 11)$$

In the case of a parallel flow with a dipole we have:

$$E = V_s \cdot \pi r^2$$

$$M = E \cdot r$$

so combining both equations:

$$r = \sqrt[3]{\frac{M}{V_s \pi}}$$

The velocity at the surface is given for a two dimensional flow by:

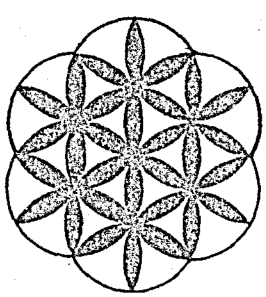
$$v = 2\, V \cdot \sin \alpha$$

where

v : velocity at the surface of the body

V : velocity of the parallel flow

α : angle with the x-axis (1)



1) Adnan H. Taşpınar "Fluid Mechanics Notes" (not published)

3.25 Magnus Effect

When a rotating circular cylinder is placed in a flowing fluid we obtain the combination of a :

a) Parallel flow (Fig 3.25-1)

b) Doublet (Fig 3.25-2)

c) Circulation (Fig 3.25-3)

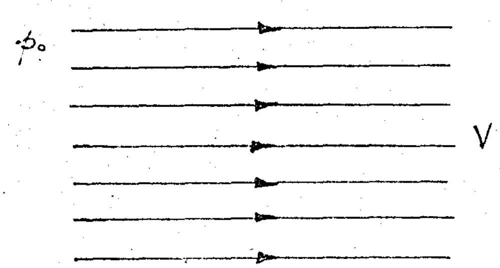


Fig 3.25-1

Parallel flow

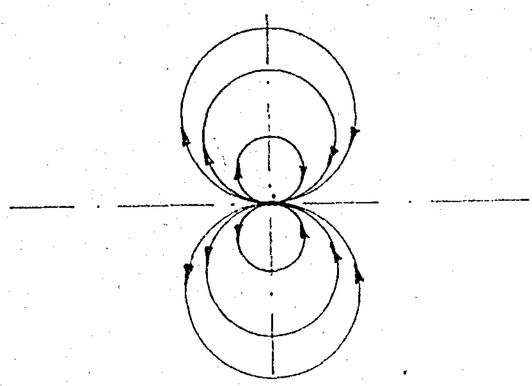


Fig 3.25-2

Doublet

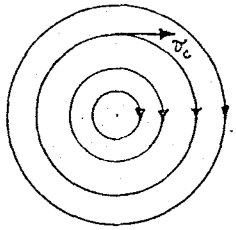


Fig 3.25-3

Circulation

The combination of the parallel flow and the doublet, represents the flow pattern of a stationary cylinder placed in a parallel flow.

The velocity at any point on the surface of the cylinder is given by the expression in equation (E 12) :

$$v = 2 V \sin \alpha \qquad (E\ 12)$$

where

- v : velocity at a point of the surface of a stationary cylinder in a parallel flow
- V : velocity of the parallel flow.
- α : angle made by the radius at a point of the surface of the cylinder with the main axis of the parallel flow. (Fig 3.25-4)

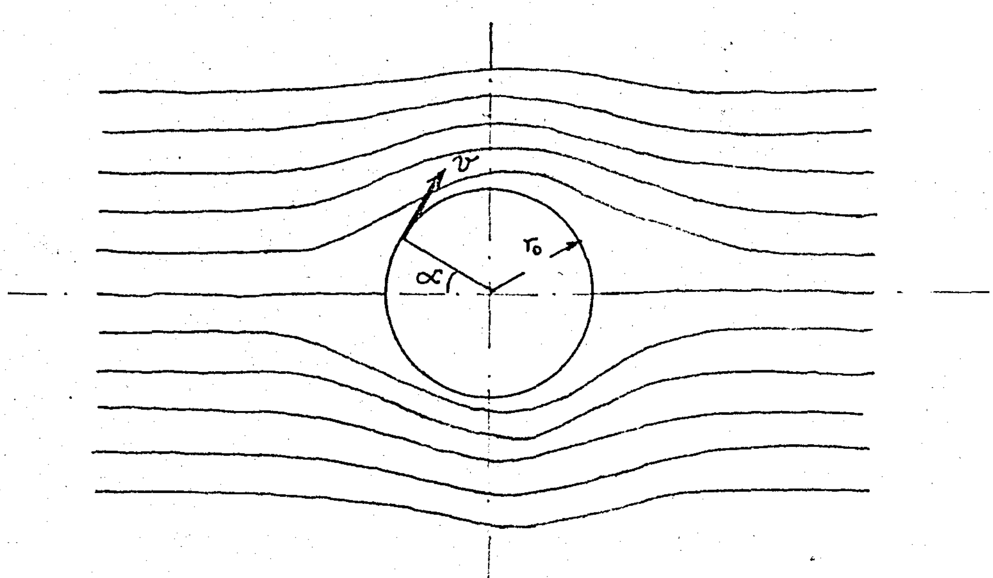


Fig 3.25-4

Parallel flow with a doublet

The velocity on the surface of the cylinder due to circulation is given by the expression in equation (E 7) :

$$v_c = \frac{\Gamma}{2 \pi r_o} \qquad (E\ 7)$$

where

v_c : velocity due to circulation at a point in the cylinder.

Γ : circulation

r_o : radius of the cylinder

The superposition of the two flow patterns, namely the stationary linder in a parallel flow and the circulation is expressed by the perposition (algebraic sum) of the velocities. From equations E 7) and (E 12):

$$v_t = 2\ V \sin \alpha + \frac{\Gamma}{2 \pi r_o} \qquad (E\ 13)$$

where

v_t : is the total velocity.

As Γ was taken clockwise, the velocity around the upper portion the cylinder is higher (velocities add) than in the lower portion elocities substract), this means that the pressure at the lower poron is higher than at the lower portion. This pressure difference roduces a lateral force called <u>lift</u>. The magnitud of this lift may e calculated applying the Bernoulli's equation:

$$p = p_o + 1/2 \cdot \rho\ V^2 - 1/2 \cdot \rho\ v_t^2 \qquad (E\ 14)$$

where

p : total pressure

p_o : static pressure of the parallel flow

V : velocity of the parallel flow

v_t : total velocity from equation (E 13)

If we substitute in equation (E 14) the value of v_t from the uation (E 13) then we have:

$$p = p_o + 1/2 \cdot \rho V^2 - 1/2 \cdot \rho \left(2 V \sin \alpha - \frac{\Gamma}{2 \pi r_o} \right)^2$$

The lateral force dF acting on an elementary area <u>per unit length</u> the cylinder portion $r_o \cdot d\alpha$, is:

$$dF = - p \, (r_o \cdot d\alpha) \sin \alpha \qquad \text{(Fig 3.25-5)}$$

where

dF : lateral force element per unit length

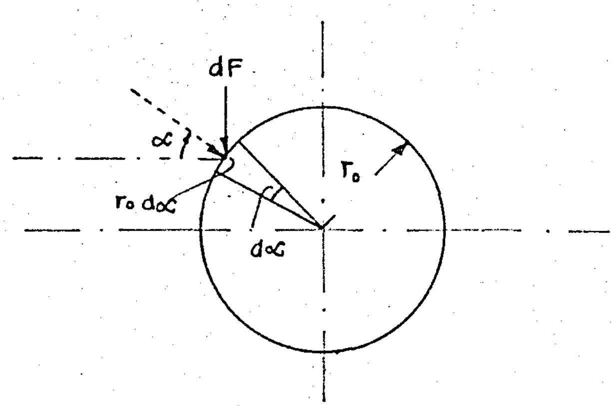


Fig 3.25-5

Lateral force

The negative sign indicates that the pressure force is always directed towards the surface and contributes a negative increment of force when $\sin \alpha$ is positive.

The total lateral force F_L acting on the cylinder per unit length is obtained by integration:

$$F_L = - \int_0^{2\pi} \left[p_0 + 1/2 \cdot \rho V^2 - 1/2 \cdot \rho \left(2 V \sin\alpha - \frac{\Gamma}{2\pi r_0} \right)^2 \right] \cdot r_0 \, d\alpha \sin\alpha$$

All the integral terms except:

$$- \int_0^{2\pi} - 1/2 \cdot \rho \left(2 \cdot 2 V \sin\alpha \cdot \frac{\Gamma}{2 \quad r_0} \right) r_0 \, d\alpha \sin\alpha$$

are equal to zero because they are sin and $\sin^3$ terms integrated from 0 to 2 .

Computing this integral:

$$F_L = \int_0^{2\pi} \frac{V \sin\alpha \cdot \Gamma}{\pi} d\alpha$$

$$= \frac{\rho V \Gamma}{\pi} \cdot \left. \frac{\alpha}{2} - \frac{\sin 2\alpha}{4} \right]_0^{2\pi}$$

$$\frac{\rho V \Gamma}{\pi} \cdot \left(\frac{2\pi}{2} - 0 \right)$$

$$F_L = \rho V \Gamma \qquad (E\ 15)$$

This is the total lateral force acting per unit length. This

quation is known as the Kutta - Joukowski theorem, and the phenome-
on was first observed by Magnus, German scientist in 1852. (1)

Experiments made to study the steamline formation around a rotating
ylinder show very clearly the lifting effect. (fig 3.25-6) (2)

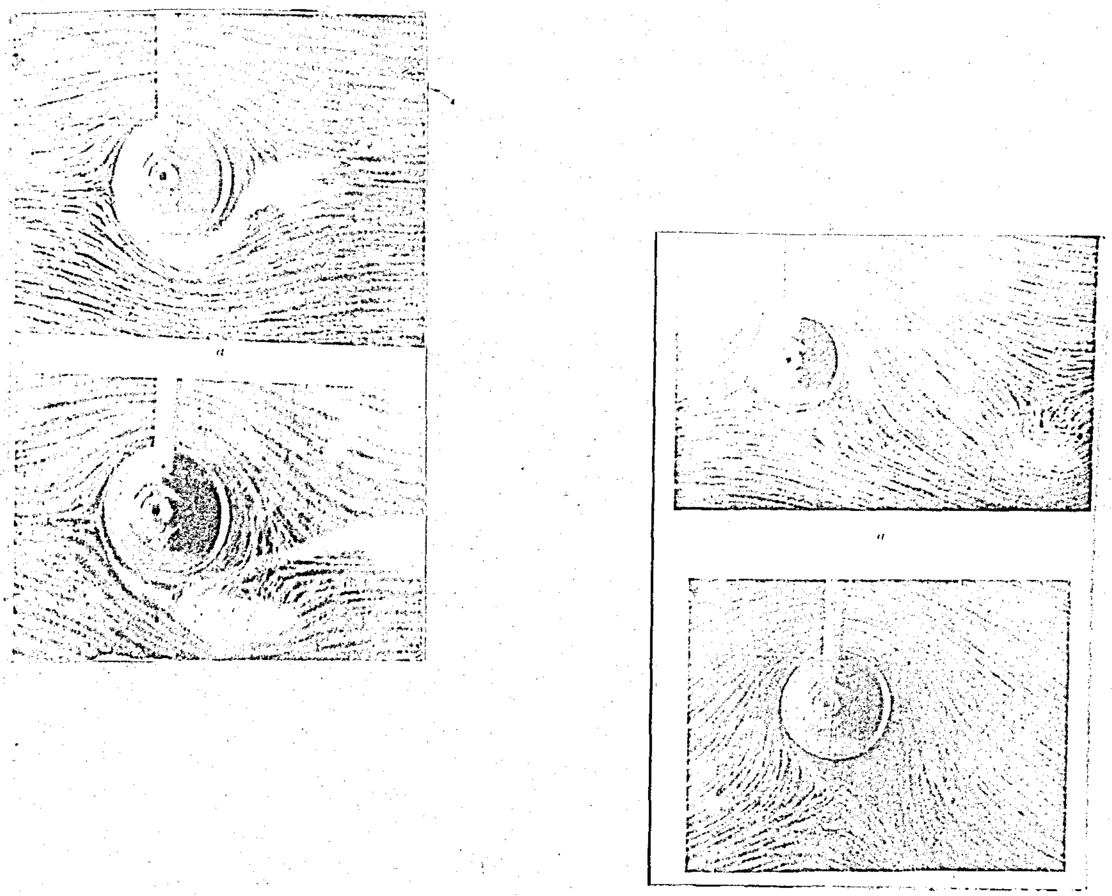


Fig 3.25-6

Magnus effect

1) Richard Pao "Fluid Mechanics" John Wiley and Sons 1961 pp 424-427.
2) S.Goldstein, editor "Modern Developments in Fluid Dynamics" V I Oxford 1943 pp 83-84.

3.26 Drag and lift in airfoils

Any stationary solid object inmersed in a fluid stream experiences a resistance called drag. The total drag can be considered the summation of the frictional drag and the pressure drag.

The resultant force on a submerged object can be discomposed into two forces:

Drag force : parallel force to the ~~fluid~~ air flow

Lift force : perpendicular force to the ~~fluid~~ air flow

The most important application of the lift and drag concepts is found in a particular profile known as the airfoil. (Fig 3.26-1)

The streamline of a parallel flow is spaced equally. The spacings between streamlines is decreased at the tip of the airfoil with an increase in the air velocity, and increased at the bottom with a decrease in the air velocity. This causes a pressure difference that causes a lift in the vertical direction.

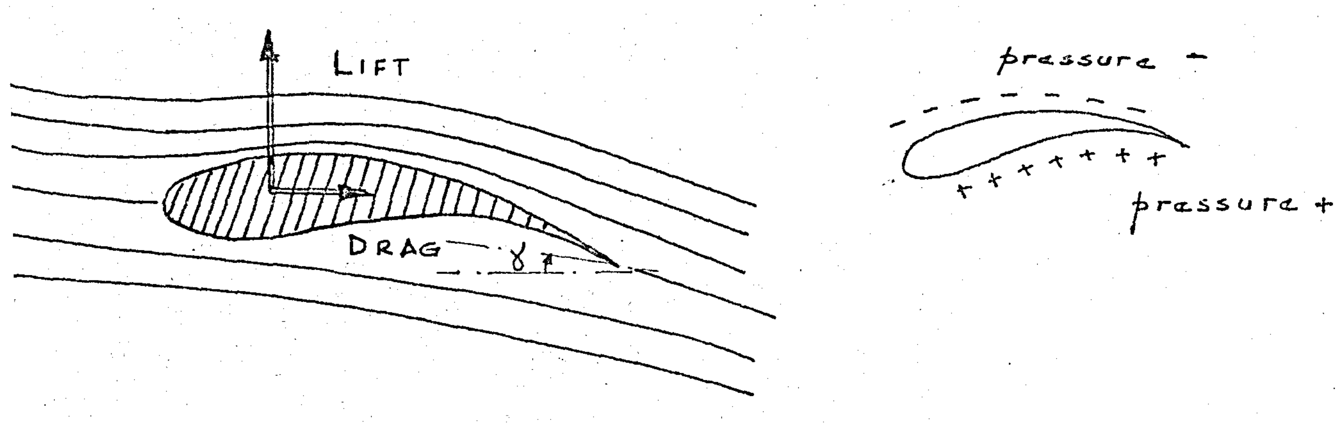


Fig 3.26-1

The mathematical expressions for the lift and the drag on an airfoil are:

$$F_L = C_L \cdot A_L \frac{\rho V^2}{2} \qquad (E\ 16)$$

$$F_D = C_D \cdot A_D \frac{\rho V^2}{2} \qquad (E\ 17)$$

where

F_L : lift force

C_L : coefficient of lift

A_L : projected area, c x b (Fig 3.26-2)

ρ : density of fluid

V : velocity of fluid

F_D : drag force

C_D : coefficient of drag

A_D : projected area, d x b (Fig 3.26-2)

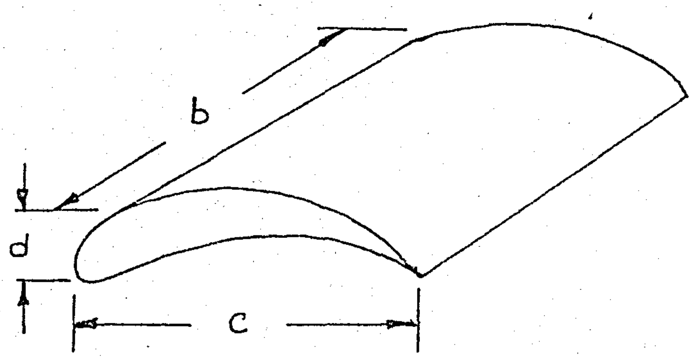


Fig 3.26-2

Airfoil dimensions

The values of the coefficients of lift and drag depend on the angle f attack γ, which are given in special graphs. (1)

The shapes of airfoils are given by tables, which plot the lower nd upper chamber as a function of x. (fig 3.26-3)

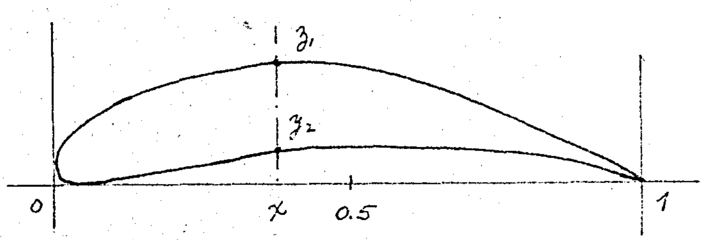
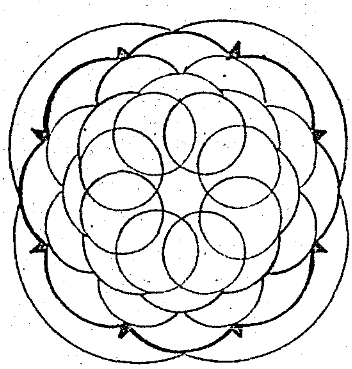


Fig 3.26-3

Airfoil profiles



1) Richard Pao "Fluid Mechanics" John Wiley and Sons 1961 pp 420-422.

3.27 Power of wind machines

The power of a wind machine has been found empirically to be proportional to the cube of the wind velocity:

$$P \propto v^3$$

This can be shown mathematically to be so, as follows:

$$P = F \times v$$

where

P : power

F : force

v : velocity

Newton's law states that

$$F = \dot{m} \cdot a = m \cdot \frac{dv}{dt}$$

where

m : mass flow rate

a : acceleration

and

$$\dot{m} = \rho \cdot v \cdot A$$

where

ρ : density of the fluid

A : cross section area

Therefore

$$P = (\rho \cdot v \cdot A) \cdot dv/dt \cdot v$$

Therefore,

$$P_o = 1/2 \cdot \rho \cdot V \cdot A \ (V_1^2 - V_2^2)$$

It can be proved applying the Bernoulli's equation that:

$$V = \frac{V_1 + V_2}{2}$$

so,

$$P_o = 1/4 \cdot \rho \cdot (V_1 + V_2) \cdot A \cdot (V_1^2 - V_2^2)$$

The available power from the wind is given by the expression:

$$P_a = 1/2 \cdot \rho \cdot V_1 \cdot A \cdot V_1^2$$

$$= 1/2 \cdot \rho \cdot A \cdot V_1^3$$

where

P_a : power available from the wind

The maximum theoretical efficiency is then :

$$\eta = \frac{P_o}{P_a} = \frac{1/4 \overbrace{\rho \ (V_1 + V_2) \cdot A}^{m'} \cdot (V_1^2 - V_2^2)}{1/2 \cdot \rho \cdot A \cdot V_1^3}$$

$$\eta = \frac{(V_1 + V_2) \cdot (V_1^2 - V_2^2)}{2 \cdot V_1^3} \qquad (E\ 18)$$

o :

$$P \propto v^3$$

The maximum theoretical efficiency can be calculated from the kine-
ic energy principles; the output of a wind machine is given by the
elation (Fig 3.27-1) :

$$P_o = 1/2 \cdot m (V_1^2 - V_2^2)$$

where

P_o : power output

m : mass flow rate

V_1 : velocity input

V_2 : velocity output

ince

$$m = \rho \cdot V \cdot A$$

where

A : cross section area of wind machine

ρ : density of the fluid

V : velocity of fluid through the machine

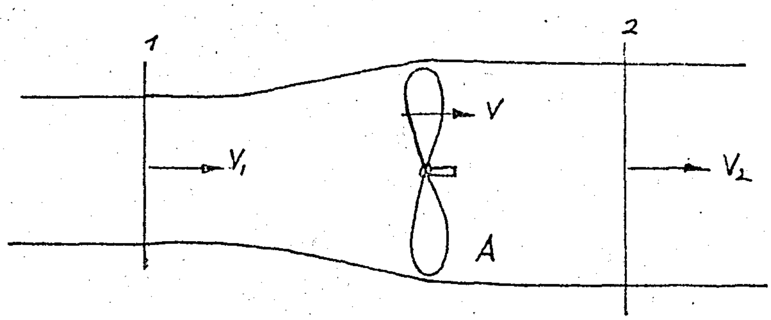


Fig 3.27-1
Power output

where

η : maximum theoretical efficiency

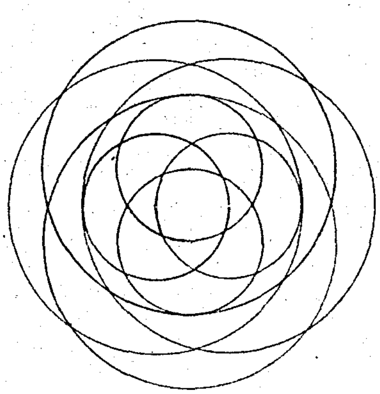
Differentiating η with respect to V_2/V_1 and setting the result equal to zero, gives

$$V_2/V_1 = 1/3$$

and

$$\eta = 16/27 = 59.3\ \%$$

which is the maximum theoretical efficiency. (1)



1) John Vennard "Elementary Fluid Mechanics " John Wiley and Sons Inc. 1940. pp 105-108.

3.28 Graphical solutions

I. Magnus effect

In the combination of a parallel flow with a rotating cylinder we have:

a) parallel flow

b) doublet flow

c) circulation flow

1. Draw the streamlines of a parallel flow with a spacing m .
2. Draw the cylinder of a diameter D with center O .
3. Draw circles tangent to the point O and passing through the intersections of the steamlines with the periphery of the cylinder. (Find the center of this circles knowing three of its points) Fig 3.28-1
4. Plot the streamlines at the intersection of the tangent circles with the parallel streamlines. The result is the combination of a parallel flow with a doublet.
5. Draw concentric circles with center at O .
6. Plot streamlines at the intersection of the concentric circles with the previous streamlines. (Fig 3.28-2). The result is the combination of a parallel flow, a doublet and circulation

II. Joukowsky profile

The Joukowsky profile of an airfoil is obtained by the method of conformal mapping. It can be constructed practically as follows:

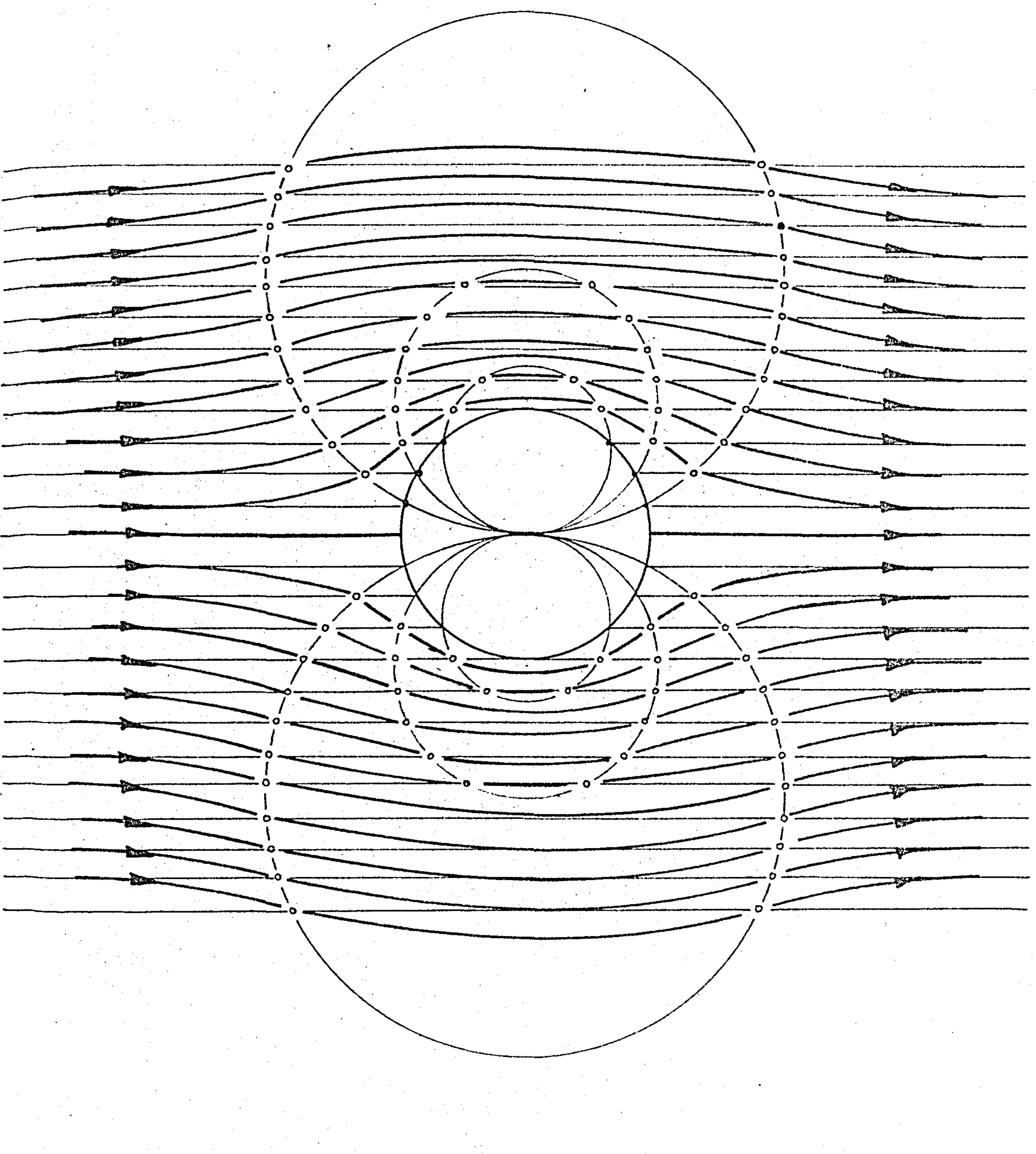


Fig 3.28-1

Parallel flow and doublet

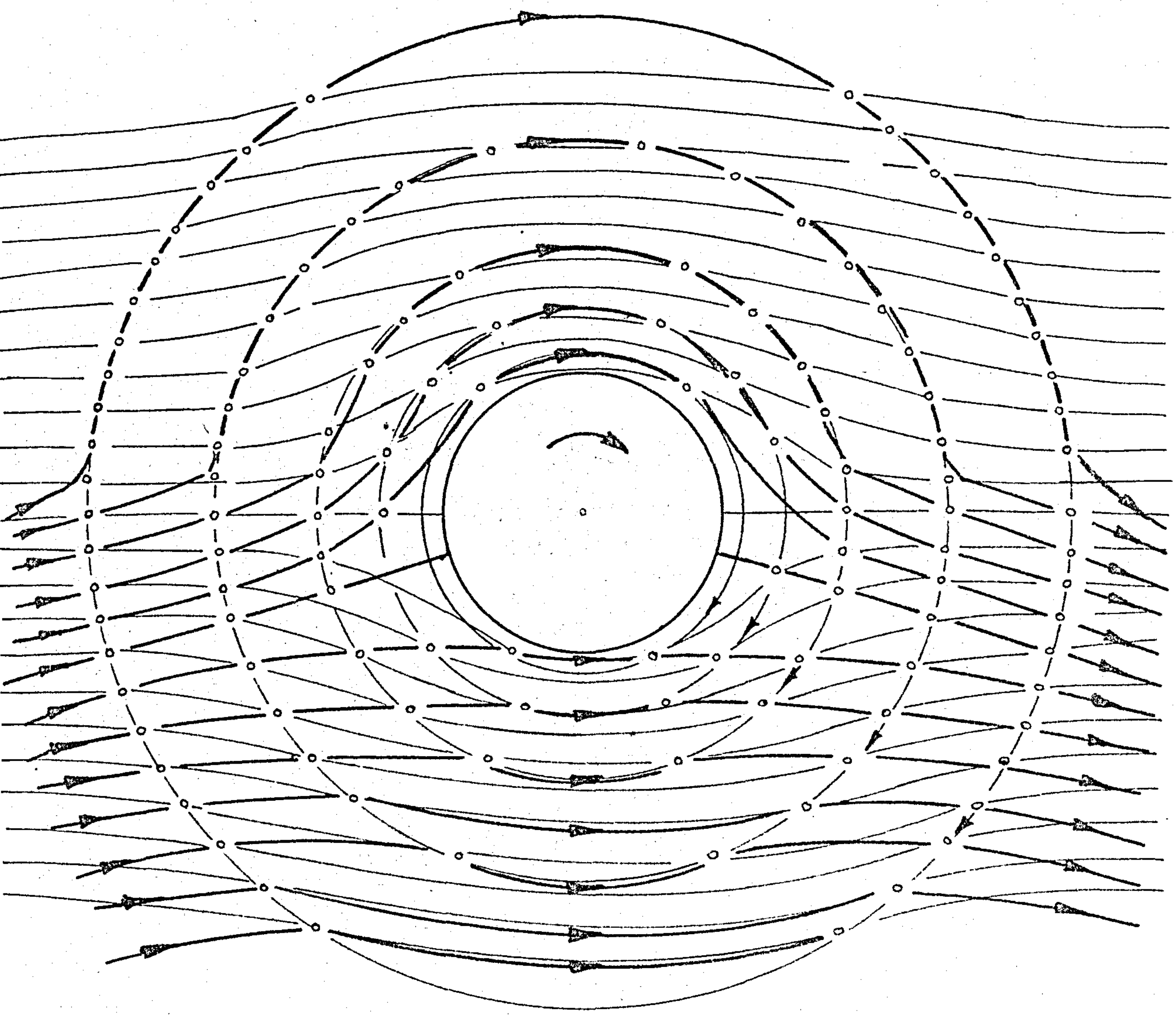


Fig 3.28-2

Parallel flow, doublet and circulation

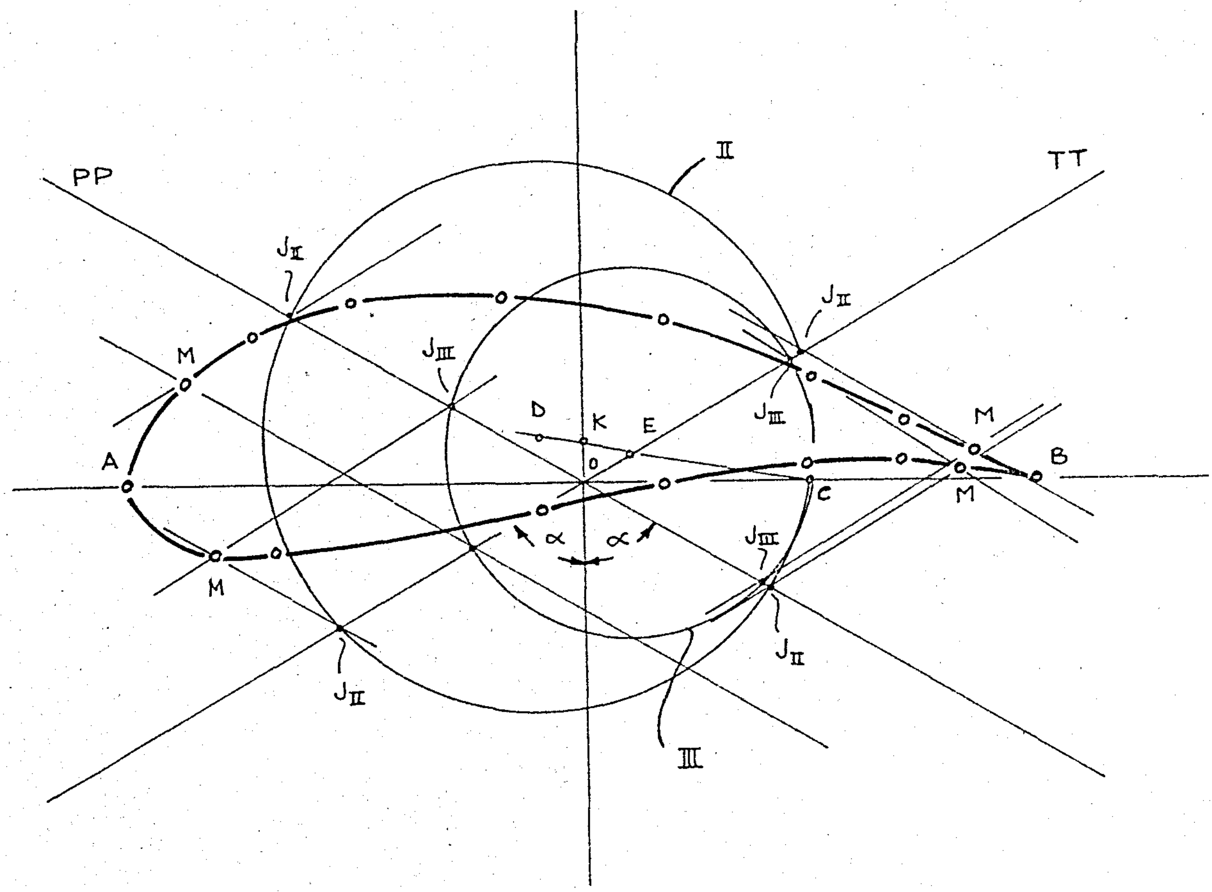
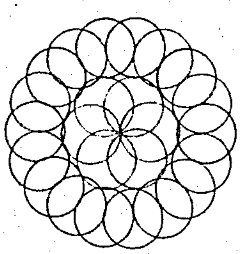


Fig 3.28-3

Joukowsky profile

1. Draw circle I of radius r and center O .
2. Lay off OB = OA = 2 r on the x-axis
3. Take a displacement p = OK.
4. Draw CD through point K .
5. Lay off KE = KD = R .
6. Draw circle II through point C with center at D .
7. Draw circle III through point C with center at E ,
8. Take $\alpha_1 = \alpha_1$
9. Draw PP and TT lines through O .
10. At the intersections J_{II} and J_{III} of PP and TT lines with circles II and III, draw parallel lines. The intersections of this parallel lines give points M of the airfoil profile.
11. Repeat items 9. and 10. taking different values of α . Fig 3.28-3. (1)



(1) Adnan Halet Taşpınar "Fluid Mechanics Notes" (not published)

Püf noktası : yordam ... "

Ölçü ... denklilik."

4. PRACTICAL CONSIDERATIONS

4.1 Wind Measurement

4.2 Visualization of Fluid Motion

4.3 Selection of Bearings

4.4 Rotor Balancing

4.5 Shaft Design

4.6 Soldering

4.7 Speed governors

4.1 Wind Measurement

In order to get an idea about the characteristics of wind, it is of primary importance to study the wind speed and the variations of direction.

There are too many factors that influence the characteristics of wind besides the temperature and the pressure differences. For example the surface roughness, type of surface - ice, water, land, etc. - presences of buildings or other obsacles such as towers, trees, etc. The wind characteristics change with height from the ground so measurements of wind are necessary starting from 2 or 3 m to heights as much as 500 m.

The method of measuring wind speed and direction should be carefully standardized. An open space should be utilized, far from trees, buildings or hills. The wind instruments should never bo mounted on the roof of a building because this will almost certainly cause the readings to be too high due to crowding of the steamlines as air moves over the building.

1. Wind direction

In meteorology, the wind direction is always given as the direction from which it is blowing. The surface wind direction is usually measured by same sort of wind vane. (Fig 4.1-1) The position of the vane may be determined by simply observing it by eye, but usually some way is provided to transmit the direction to a distant point where it may be indicated or recorded or both.

The simplest type of direction transmitter uses cam contacts as

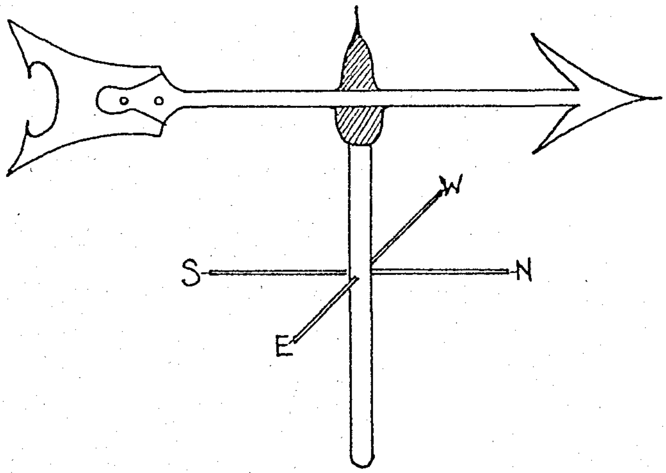


Fig 4.1-1

Wind vane

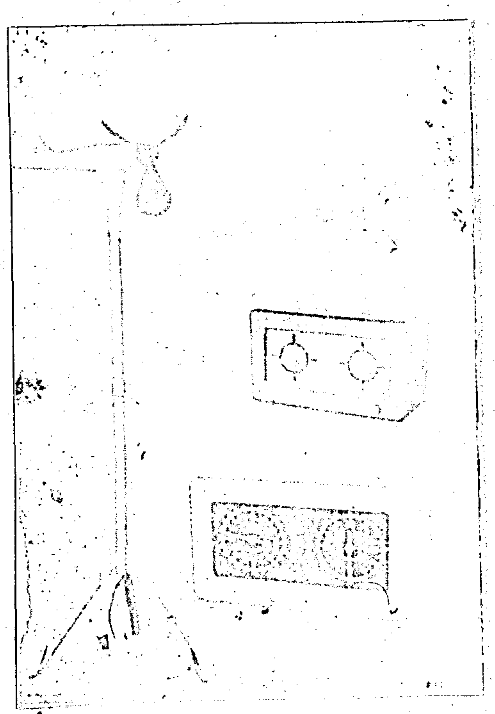


Fig 4.1-2

Potentiometer type wind direction transmitter with propeller driven, magneto type anemometer. (1)

the vane rotates, and closes a circuit to a lamp, that is lighted when the vane reaches the contact. There are generally 8 lamps, which indicate the wind direction to the 16 points of the compass, since the instrument is so disigned that two adjacent lights are lighted for intermediate directions. In some cases a wind speed measuring propeller is coupled to the vane, so that the wind speed is transmitted through an additional connection.

Another type of direction transmitter uses a continuous rotating potentiometer at the wind vane, and a milliammeter, calibrated in direction, for an indicator. This system is thus simple, and requires only two wires between the wind vane and indicator. (Fig 4.1-2)

The most reliable and satisfactory system of transmitting the wind direction uses small self-synchronous motors at both the wind vane and the indicator. In this system there are no rubbing contacts, hence friction and wear are reduced to a minimum. Five wires are needed to connect the wind vane and indicator, and a supply of alternating current is required. No special attention need be paid to either voltage or frequency stability. Continuous indication of all directions is achieved with an accuracy of 2 or better.

The wind direction may be observed and recorded either by points of the compass or by degrees on a $0^\circ - 360^\circ$ scale. When points of the compass are used, the compass circle may be divided into 4, 8 or 32 points. In the $0^\circ - 360^\circ$ scale, 0° is North, 90° is East, 180° is South, 270° is West and 360° is North again.

2. Wind speed

- Beaufort scale

Table I : Beaufort Scale

Beaufort No.	Definition	km/hr	Definition of effects
0	Calm	1.5	Smoke rises vertically, no perceptible movement of anything.
1	Light air	1.5-5	Smoke shows wind direction and barely moves tree leaves.
2	Light breeze	6-11	Wind felt on face; leaves rustle, small twigs move.
3	Gentle breeze	12-20	Leaves and small twigs in constant motion; blows up dry leaves from ground.
4	Moderate breeze	21-30	Moves small branches; dust and paper raised and driven along.
5	Fresh breeze	31-40	Large branches and small trees in leaf sway; crested wavelets form in water
6	Strong breeze	41-50	Large branches in continuous motion; clouds of dust raised;whistling of wires.
7	Moderate gale	51-64	Whole trees in motion; inconvenience in walking
8	Fresh gale	65-75	Breaks twigs and small branches;walking difficult
9	Strong gale	76-88	Loosens bricks on chimneys blows roofing slates off; broken branches.
10	Whole gale	89-105	Trees uprooted; considerable damage in structure.,
11	Storm	106-125	Widespead damage.
12	Hurricane	125	Severe damage.

The surface wind speed can be measured in a large variety of ways. he simplest is the direct obseroation of the effect of the force f the wind on the surface of the earth, without using instruments. he famous Beaufort scale of wind force was thus developed by Admiral ir Francis Beaufort in 1805 for use at sea. It was later adapted for se over land. This method cannot be used were accuracy is required nd has been substituted by modern measurement techniques. The Beaufort cale is given in Table I.

- Anemometers

The most widely used wind speed device is the three- or four-cup nemometer as shown in Fig 4.1-3. This is used both to measure speed t any moment and total wind flow per unit time. In one type a contact s made each time a certain amount of wind passes the instrument. An bserver can measure the speed with this type, by counting the numer of contacts - usually indicated by a buzzer or a light - that ccur in a minute. This gives the speed directly in km per hour. Since he instrument also records the total air flow on a dial, the observer an easily compute the average wind speed, between the readings of he dial.

Another modification of this instrument is one in which the turning f the cups rotates a small magneto. The alternating current produced n this way is nearly proportional to the wind speed. It is rectified nd then indicated on a small milliammeter whose scale is calibrated irectly in wind speed.

A modification of the cup anemometer is one in which the cups do ot revolve. In this instrument, called a bridled anemometer the pre-

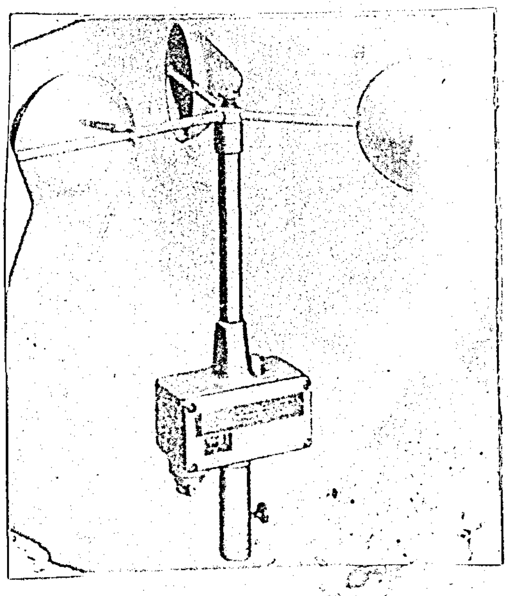


Fig 4.1-3

Three cup anemometer

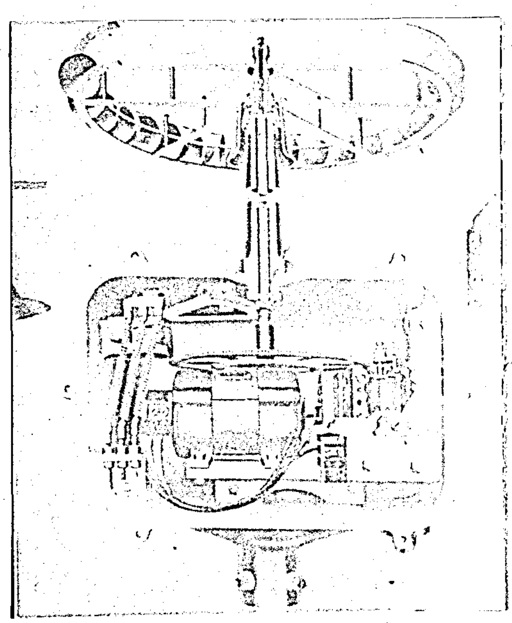


Fig 4.1-4

Bridled anemometer (1)

ssure of the wind rotates the cup assembly slightly against restraining springs. The displacement is transmitted by a selsyn motor system to indicators or recorders calibrated directly in wind speed. (Fig 4.1-4)

Other anemometers depend on the pressure of the wind acting on a tube that faces directly into the wind. Still others depend on the cooling effect of the air on a hot wire. This changes the resistance of the wire, hence the current which passes through it. Such hot-wire anemometers are specially useful at low wind speeds, they also have small lag and thus very useful in meteorological measurements. (1)

3. Wind representation

Winds may be described by the compass direction and velocity in km/hr or in Beaufort scale, or they may be shown diagramatically as on weather maps. In this maps wind is indicated by an arrow which flies with the wind, thereby indicating the direction. The number and length of the tails on the arrows indicate the Beaufort number of the wind. Each half tail stands for 1 Beaufort force, as shown in Fig 4.1-5.

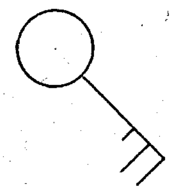


Fig 4.1-5

Wind representation

To show the average wind conditions in a given locality the ind rose is used. The lengths of the radiating lines are proportional o the frequency with which the wind blows from the different comass directions, as shown in Fig 4.1-6.

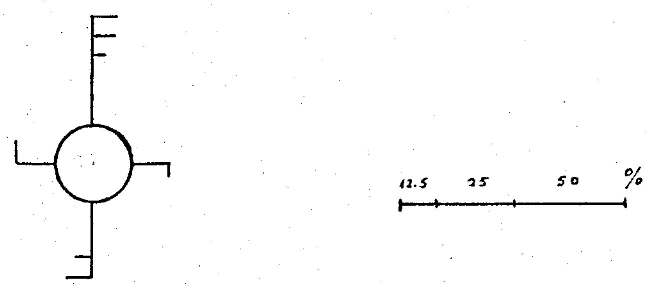


Fig 4.1-6

Wind rose

The percentage of observations with calms can be represented by a umber that is indicated by a number that is indicated inside the ind rose circle, as shown in Fig 4.1-7. (2)

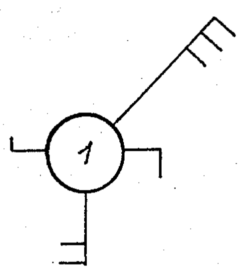


Fig 4.1-7

Calms percentage

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(1) George F.Taylor "Elementary Meteorology" Prentice Hall Inc. New York 1954. pp 40-47.

(2) William L.Donn "Meteorology with Marine Applications" Mc Graw Hill Book Co. Inc. 1951 pp 135-137

4. Practical values

- The average wind velocity can be taken as 5 m/sec, for land being as low as 3 m/sec and for sea 8 m/sec.

- The wind velocity increases in the middle of the day or early in the afternoon and decreases during the night, specially just before the sunrise.

- The duration of wind velocities during the year is :

V (m/sec)	Duration (hours/year)
0 - 3	3.200
3.5 - 5	3.000
5.5 - 8	1.500
8.5 - 10	600
11 - more	400

- In winter, the average wind velocity is higher than during summer.

- The velocity decreases next to the earth surface due to friction and turbulences. The increase in velocity according to the height H is :

H (m)	Increase (m/sec per m)
0 - 3	1
6 - 12	0.4
20 - 300	0.1 (3)

(3) Adnan halet Taşpınar "Wind Power Notes" 1946. (not published)

4.2 Visualization of Fluid Motion

There are several methods used in the analysis of fluid motion in rder to visualize what is happening when fluid flow around an object. hese methods can be listed as follows:

1. Smoke technique
2. Hot wire technique
3. Spark technique
4. Chine-clay method
5. Liquid-film method
6. Tufts method
7. Photo-viscous method
8. Schlieren method
9. Shadow-graph method
10. Interferometer method
11. hele-shaw analogy
12. Electrical analogy
13. Hydrogen bubble method

In order to decide which method is the most practical, lets make short description of each technique.

1. Smoke technique

Smoke consists of suspensions of small solid or liquid particles n a transparent gas. In this method smoke is introduced in a wind unnel, and the scattering and reflection of light passing through hese particles is used to study the flow pattern.

Smoke should not disturb the flow in the wind tunnel by forming de-
osits, should be light enough not to be influenced by gravity, should
e clearly visible and non-poisonous, non-corrosive, should be easily
roduced controlled and still be not too expensive. Several smoke
ources have been used, and the most common methods are either from
ne combustion of organic material or vaporization of liquid. If wood
s used it is necessary to filter the smoke and a specially designed
lant is necessary. (Fig 4.2-1)

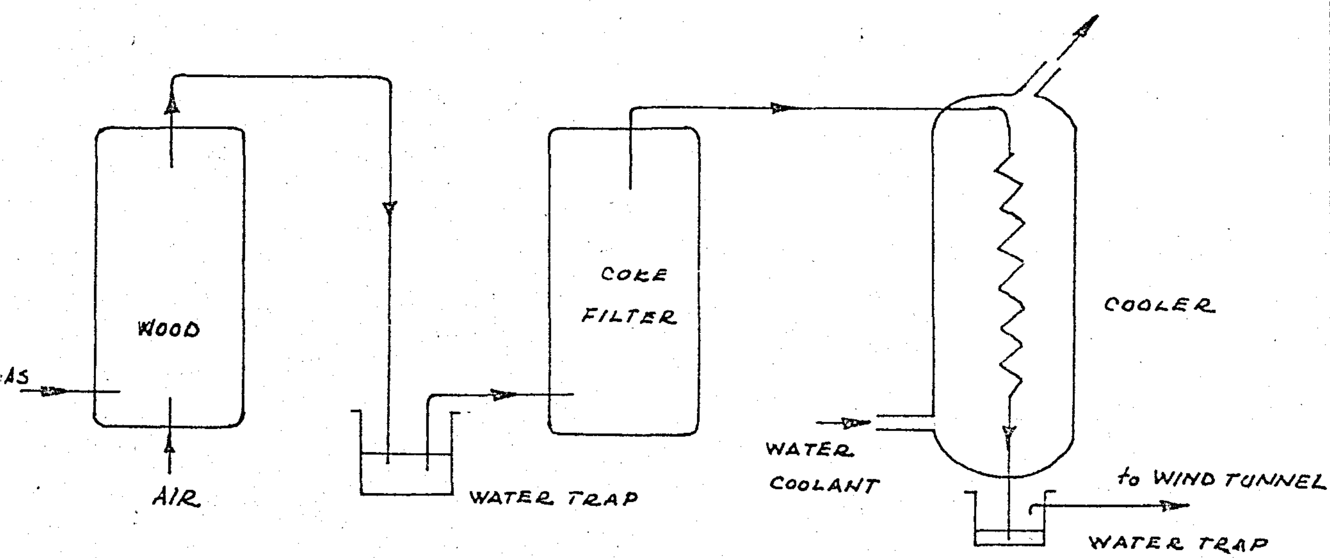

Fig 4.2-1

Smoke technique

Oils can also be used as a source of smoke. Smoke is introduced in
he wind tunnel by means of hypodermic tubes. (Fig 4.2-2)

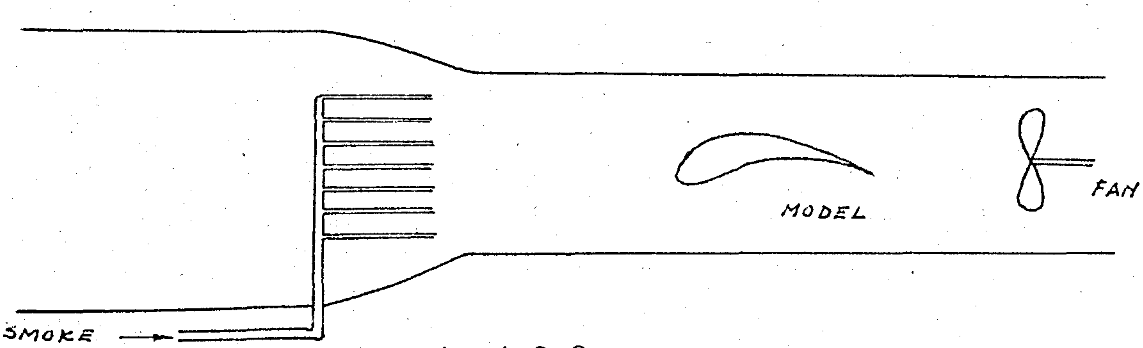

Fig 4.2-2

Smoke technique in wind tunnel

This method uses fine threads of silk or cotton to indicate the general direction and steadiness of the flow close to their points of attachment, and is useful in the visualization of the flow close to the surface of the body.

7. Photo-viscous method

In some liquids, viscous shear gives rise to optical effects which are similer to the well-known photo-elastic effects of stress analysis. In such cases, the flow may be observed by passing a beam of polarized light through the field. This method is widely used in research work. (1)

8. Schlieren method

This method depends upon the change of refractive index with changes of optical media. Light from a source (preferably a line source instead of a point source) is focused by a condenser. At the focus a staight edge is placed such that, by intercepting part of the light we get a sharply defined edge of light beam. This light then passes through the working section. (Fig 4.2-3)

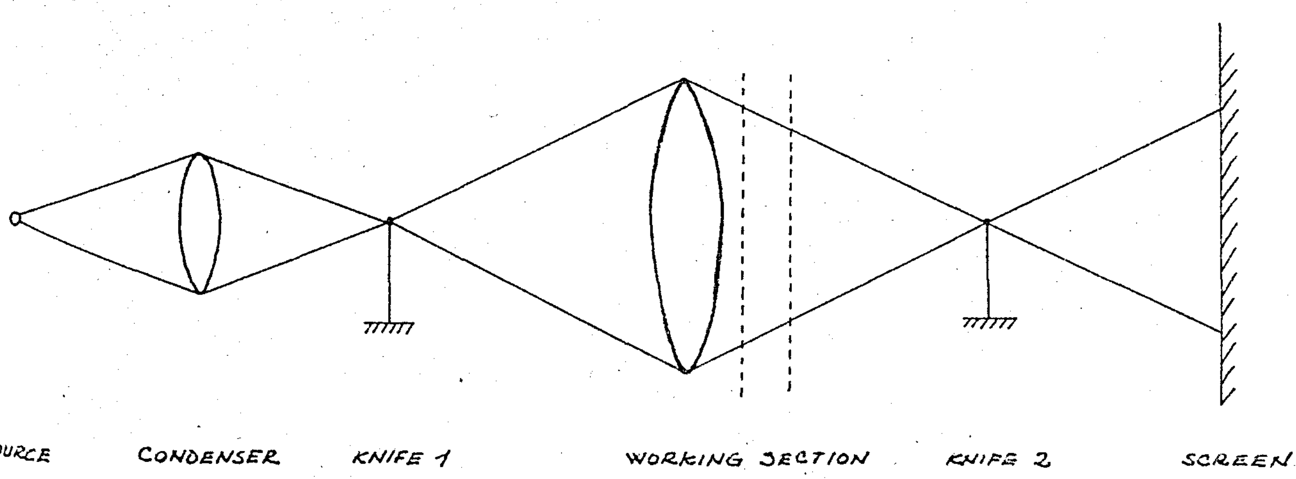

Fig 4.2-3
Schlieren apparatus

At the new focus of the light a second knife is placed, such that t intercepts a part of the luminus flux and the intensity is thus eminished. The light is then recorded by a photographing machine. If here are no gradiends of refractive index within the working section, he amount of light reaching the film or screen is fixed by the reative position of the two knife edges. If a gradiend normal to the lane of the knife edge exists however, the beam will be refracted p or down according to the gradiend - so that it either adds or subtracts from the light normally present on the screen. Thus a working ection involving a pattern of gases is reproduced in various tones n the film.

There are various methods in which the various elements of this mehod be arranged. In general, because lenses of good quality are not vailable in sizes of more than a few cm in diameter, it is found moe convenient to use concave parabolic mirrors. (Fig 4.2-4)

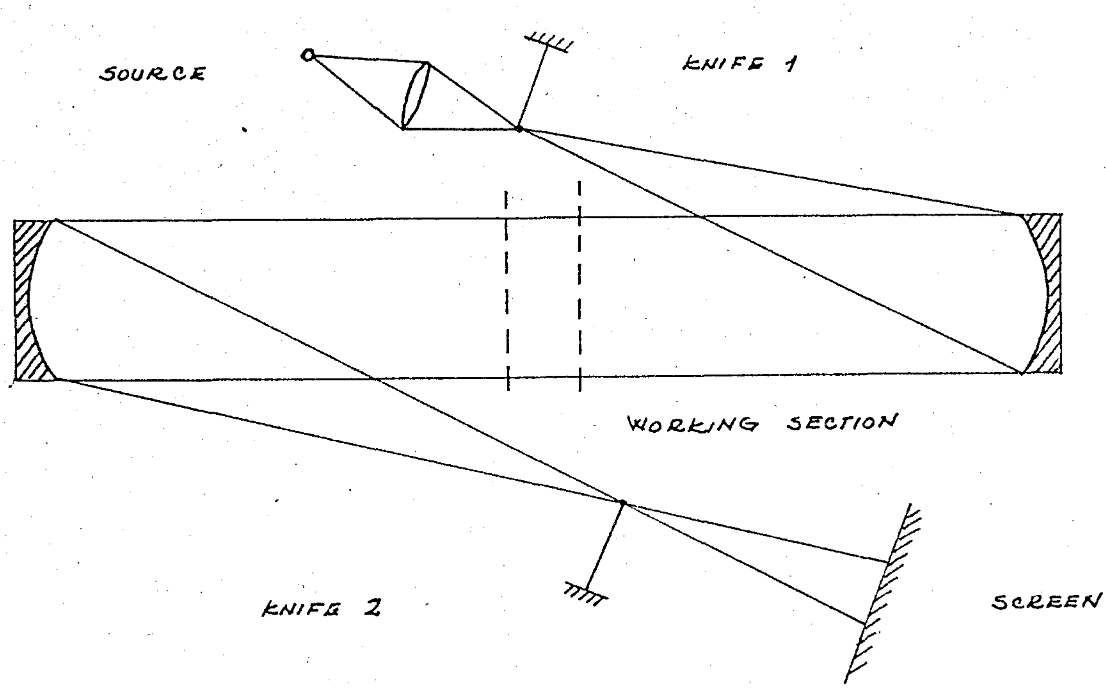

Fig 4.2-4

Schlieren apparatus

This system has the advantage that parallel light rays pass through he working section, thus producing an image of superior resolution. urther because the light source and the camera are placed on opposi- e sides of the light path between mirrors, coma is cancelled. Another dvantage is that the working section is away from the mirrors, in act since the light between the mirrors is parallel, they may be laced as far appart as desired.

The knife edges are placed in such a way that 50 % of the total llumination is cut off. However, care must be taken not to exceed he working range otherwise we shall get a black or white area where he changes are not shown and so detail is lost. (2)

9. Shadow graph method

This method is due to Dvorak, and is the simplest of all optical ethods, but it finds use in high-speed wind tunnel studies. It uses he same principle of deflection of light with density gradient. A ight source is sent to the model in the working area and the shadow rojected on a screen or a camera. (Fig 4.2-5)

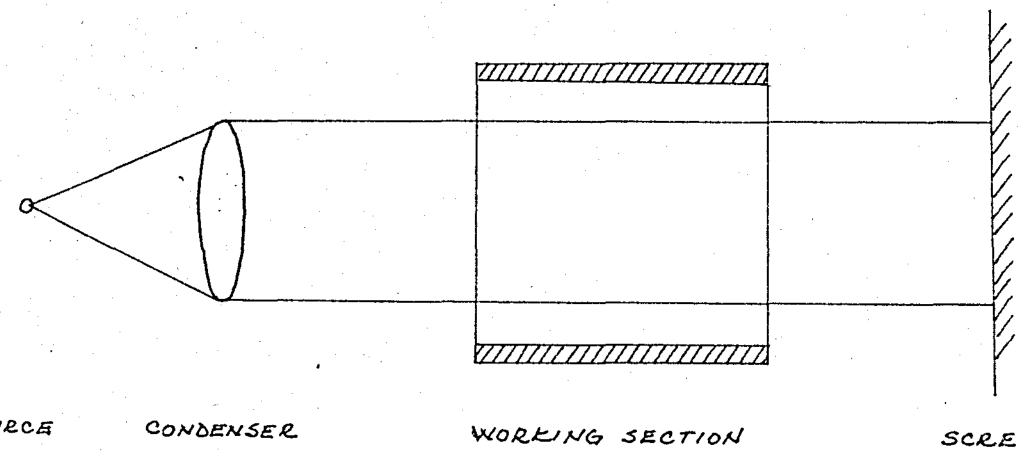

Fig 4.2-5
Shadow graph method

10. Interferometer method

This method is based on the fact that interference fringes are formed when the light from two cohorent sources - sources emitting light waves of constant phase difference - is combined. A monochromatic light is split into two and used as a source. From the fringes it is possible to measure relative densities which give an idea about the fluid flow around the object.

11. Hele-Shaw analogy

This method is due to H.S.Hele-Shaw and it produces streamlines in two-dimensional steady potential flow of an incompressible fluid around an obstacle throughout the channel.

In the original apparatus streamlines are visualized by the introduction of coloured fluid through a row of orificès, into a flow channel determined by two parallel plates where water flows. The objects to be studied are introduced in the channel and the distortion of the streamlines observed. (Fig 4.2-6)

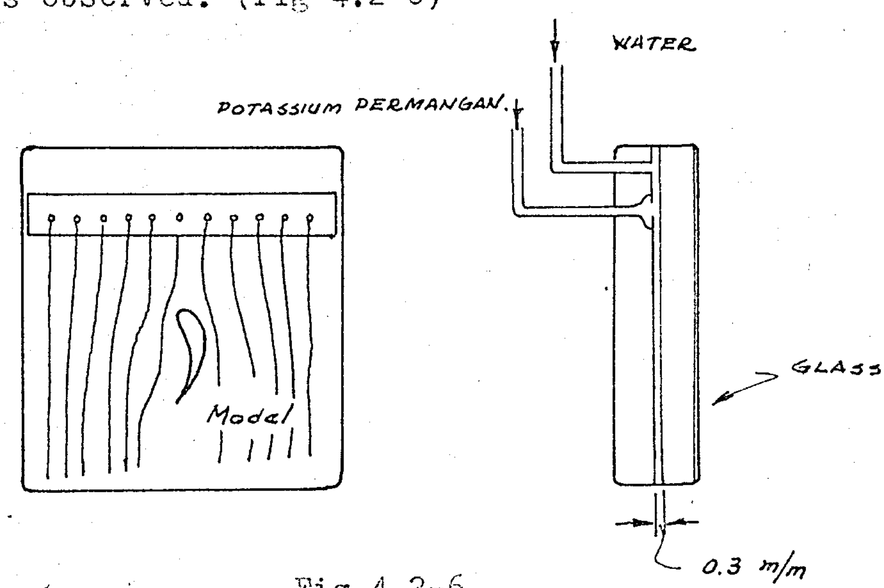

Fig 4.2-6
Hele-Shaw analogy

It must be noted here that the streamlines are not shaped at the contour of the object itself due to the influence of the boundary constraint. (1)

12. Electric analogy

The boundaries in a model are formed out of stips of nonconducting material mounted on a flat nonconducting surface, and the end of equipotential lines formed out of a conducting strip (brass or copper). An electrolyte is placed at uniform depth in the flow space and a voltage potential applied to the end of the conducting strips. By means of a probe and a voltmeter, lines with constant drop in voltage from one end are mapped out and plotted.

By reversing the process and making the flow boundaries out of conducting materials and the end equipotential lines from nonconducting material the streamlines are mapped. (3)

13. Hydrogen bubble method

In this method, hydrogen is generated by electrolysis using a DC power supply (2 ampers at 30 volts) with a small amount of salt placed in a recirculating water flow. The cathode is a fine steel wire which is crimped. The anode is a plate placed in the downstream part of the water flow. (Fig 4.2-7)

Flow velocities less than 0.3 m/sec give good results. Bubbles should be of sufficient small size that they do not rise too rapidly to the surface. (4)

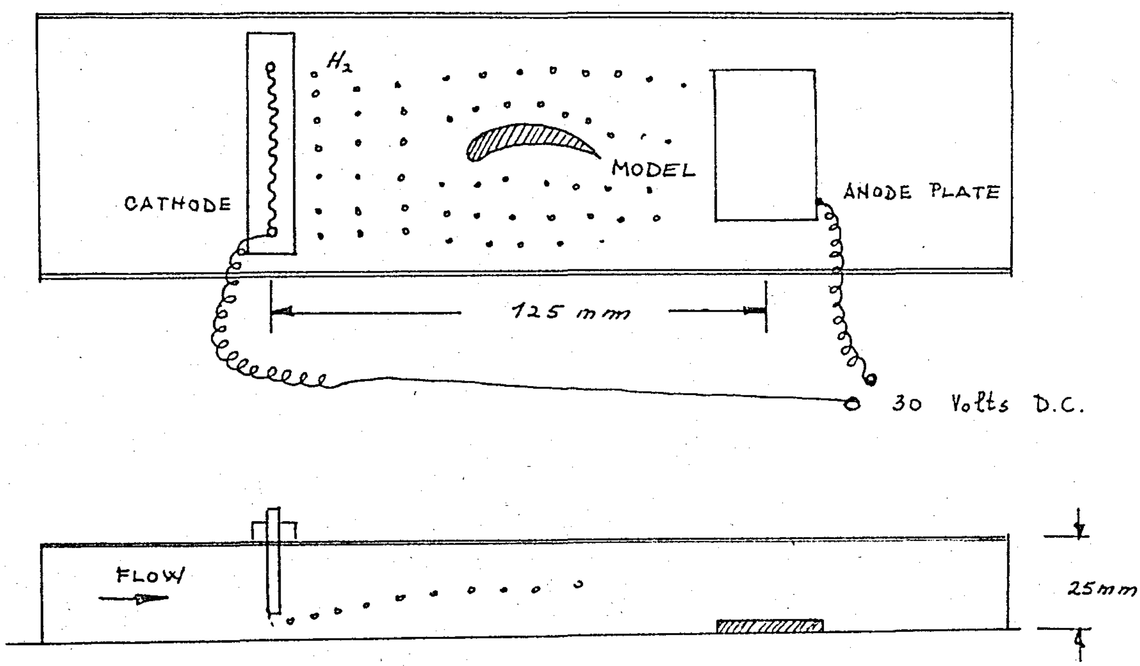

Fig 4.2-7

Hydrogen bubble method. (4)

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(1) R.C. Pankhurst and D.W. Holder "Wind Tunnel Technique" Sir Isaac Pitman and Sons Ltd. London 1952. pp 137-173 and 575-576.

(2) Orhan Kural "The Shallow Water Analogy in Gas Dynamics" Robert College School of Engineering (Thesis) May 1961.

(3) Victor Streeter "Fluid Mechanics" McGraw Hill 1958 pp 258.

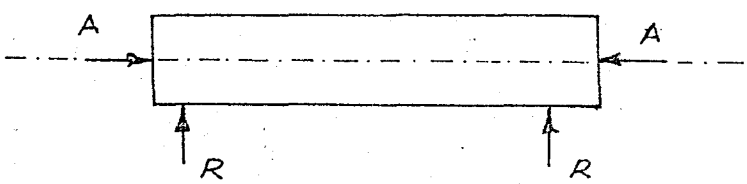
(4) Philip A. Drinker "Fluid Dynamics: Experiments and Equipment for Undergraduate Laboratory Instruction" M.I.T. 1965 pp 31-32.

4.3 Selection of bearings

According to SKF standards, in order to select a bearing, the procedure is as follows:

1. Calculation of the radial force R in kg.

2. Calculation of the axial force A in kg.



3. Calculation of speed of rotation n in r.p.m.

4. Calculation of the total force P in kg from:

   $P = X R + Y A$ for radial bearings

   $= 1.5 R + A$ for thrust bearings

   where X and Y are correction factors depending upon the type of bearing and whether the inner or the outer ring is turning as given in Table I.

5. Assumption of the life time L_h in hours.
   The value of L_h will depend upon the working conditions and is given in Table II.

6. Selection of the value of f_h
   From the value of L_h the diagram II gives the value for f_h .

7. Calculate the value for the actual bearing load C_n' in kg. from

$$C_n' = f_h \ P$$

8. Provide a safety factor for bearings working above 125 C, according to percentage value given in diagram III

$$C_n = C_n' \ (1 + p/100)$$

9. Determine the value of f_n
Knowing the value of n from diagram I select f_n .

10. Calculate the value of the dynamic bearing load C in kg. from:

$$C = C_n / f_n$$

11. Select bearing from catalogue knowing the value of C. (1)

(1) - " SKF Malzemesi " SKF Turkiye 1951 pp 3-7

4.4 Rotor balancing

In all rotating machines, the rotation axis should coincide with one of the principal axis of inertia of the body. The magnitud of any unbalance is equal to the centrifugal force : mv^2/r .

The condition of unbalance of a rotating body may be classified as static or dynamic unbalance. In the case of static unbalance, the unbalance appears in a single axis plane and on the same side of the axis of rotation, as shown in Fig 4.4-1.

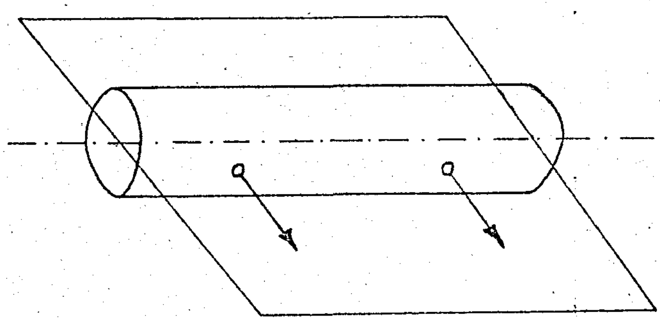


Fig 4.4-1
Static unbalance

Consequently this type of an unbalance can be detected by a static test, where the rotor is placed on a pair of parallel rails. In practice, however the effect of the unbalance is magnified by rotation. The unbalance of the disks is essentially static unbalance.

In the case of dynamic unbalance, the unbalance can be in a single axial plane and on opposite sides of the rotation axis, as in Fig 4.4-2 or in two different axial planes, as shown in Fig 4.4-3.

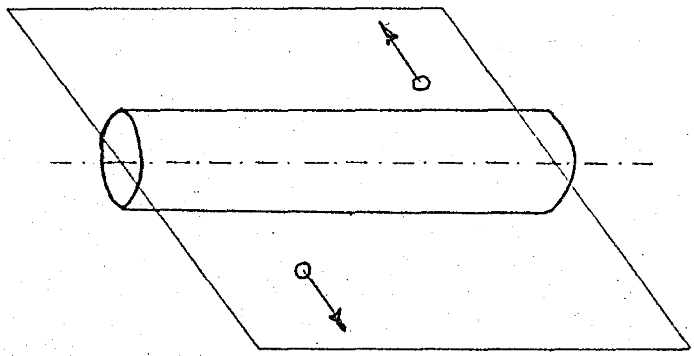


Fig 4.4-2

Single axis dynamic unbalance

In Fig 4.4-3 it is possible for the center of gravity to lie on the rotation axis, and hence the rotor may be in static unbalance. However, under rotation, the two unbalance forces form a couple which has a tendency to rock the axis of rotation. The unbalance indicated in Fig 4.4-3 is the most general case, where the rotor is in static and dynamic unbalance.

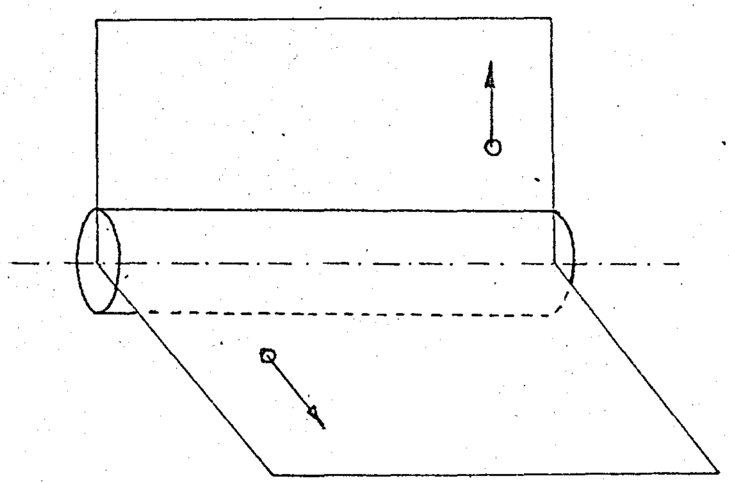


Fig 4.4-3

Two axis dynamic unbalance

In all cases, a complete balance can be obtained by adding or removing correcting weights in two arbitrary and separated transverse planes. In general the end planes of the rotor are convenient correction planes: i.e. for the rotor in Fig 4.4-4 with unbalance w_1 and w_2, the correction weights at the ends are w_1 a/L and w_1 (L-a/L) in the axial plane of w_1 and w_2 may be resolved similarly.

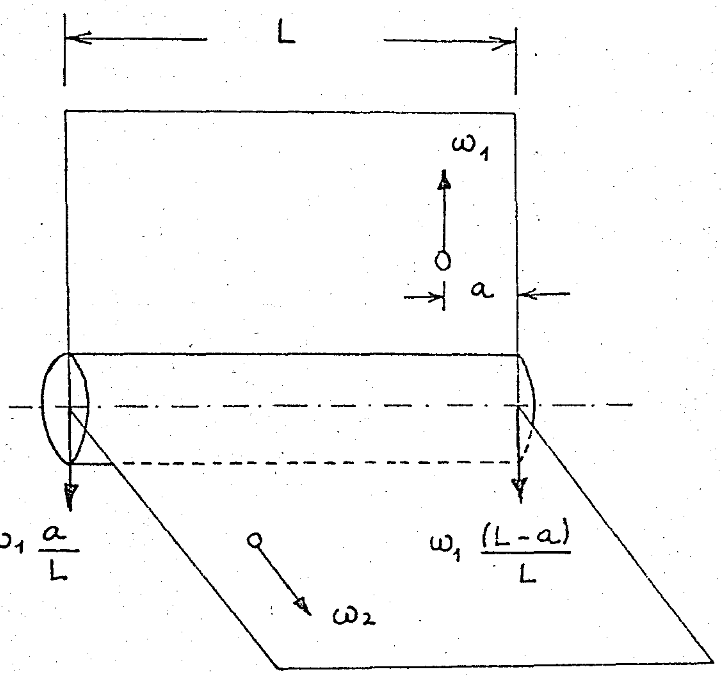


Fig 4.4-4
Balancing method

Combining the necessary corrections for each unbalance, a single weight at each end placed at a proper radial distance will completely balance the rotor.

The determination of the magnitud and angular position of the unbalance is performed by means of the balancing machine. All balancing machines are provided with elastically supported bearings in which the rotor may spin. (Fig 4.4-5)

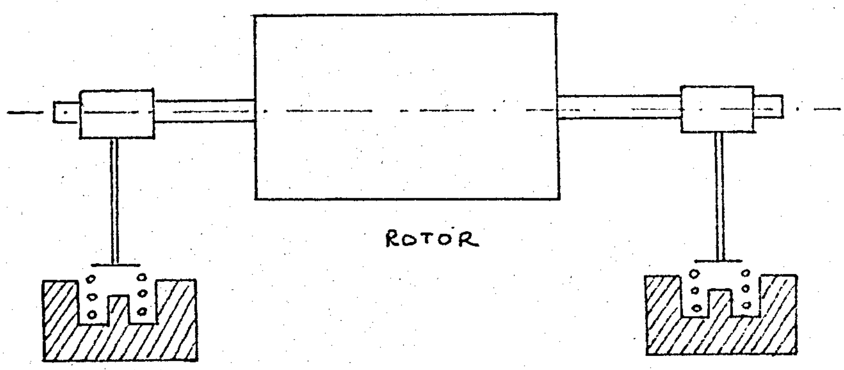


Fig 4.4-5

Balancing machine

Because of the unbalance, the bearings will oscillate laterally, and the amplitud and phase of the rotor are indicated with respect to an arbitrary rotor position by electrical pickups and a strobo-flash light.

In the case in which the rotor is very long and flexible, the position of the unbalance will depend on the elastic configuration of the rotor, which is dependant on the speed of rotation, its temperature, etc. In such cases, it is necessary to balance the rotor in its normal operating environment and speed by means of a portable balancing apparatus. (1)

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(1) Theodere Baumeister, Editor "Mechanical Engineers' Handbook" Mc Graw Hill Book Co. Inc. 1958. Sixth Edition. pp 5-102 to 5-103.

4.5 Shaft design

If a shaft has to transmit a power N in C.V. (metric horsepower) we have from Mechanics:

$$N = \frac{P \cdot v}{75} = \frac{P \cdot d \cdot \pi \cdot n}{60 \cdot 75} \quad (\text{C.V.}) \qquad (E\ 1)$$

where,

P : force in kg

v : velocity in cm/sec

d : diameter of the shaft in cm

n : speed of rotation in r.p.m.

Since the twisting moment is equal to :

$$M_d = P \cdot \frac{d}{2} \quad (\text{cm kg}) \qquad (E\ 2)$$

Substituting in equation (E 1)

$$N = \frac{2 \cdot M_d \cdot \pi \cdot n}{60 \cdot 75} \quad (\text{C.V.}) \qquad (E\ 3)$$

or,

$$M_d \quad \frac{60 \cdot 75 \cdot 100}{2 \cdot \pi} \cdot \frac{N}{n} = 71620 \cdot N/n \qquad (E\ 4)$$

expressed in cm kg.

We have from Strength of Materials:

$$Z_d = \frac{M_d}{\sigma_d} \qquad (\,cm^3\,) \qquad (\,E\ 5\,)$$

For a circular cross section:

$$Z_d \quad \frac{d^3 \cdot \pi}{16} \qquad (\,cm^3\,) \qquad (\,E\ 6\,)$$

Therefore:

$$d = \sqrt[3]{\frac{16 \cdot M_d}{\pi \cdot \sigma_d}} \qquad (\,cm\,) \qquad (\,E\ 7\,)$$

Shafts being also subjected to bending, the value for σ_d allowable is:

$$\sigma_d = 120 \ kg/cm^2 \quad \text{for Wrought Steel.}$$

Long shafts must be tested also for allowable torsion angle. It is generally required that the twisting angle should not be more than 1/4 per meter length of the shaft. We get therefore again from Strength of Materials:

$$\delta = \frac{M_d \cdot l}{G \cdot I_p} \qquad (\,E\ 8\,)$$

Taking the corresponding values:

$$G = 0.4 \ E = 0.4 \times 2{,}000{,}000 \qquad (\,kg/cm^2)$$

Where G is the modulus of rigidity.

$$I_p = \frac{d^4 \ \pi}{32} \qquad (\,cm^4\,)$$

and

$$M_d = 71620 \frac{N}{n} \quad (\text{ cm kg. })$$

so

$$\frac{2 \cdot \pi}{360} \frac{1}{4} = \frac{71620 \quad N / n}{0.4 \times 2000000} \frac{1}{\frac{d^4 \pi}{32}}$$

or

$$d = 12 \sqrt[4]{\frac{N . l}{n}} \quad (\text{ cm }) \qquad (\text{ E 9 })$$

For short shafts we use:

$$d \quad 10.5 \sqrt[3]{\frac{N}{n}} \quad (\text{ cm }) \qquad (\text{ E 10 })$$

where l is the length of the shaft.

The distance between two bearings in transmission lines should be:

$L = 100 \sqrt{d}$ cm for shafts supported by 2 bearings

$L = 125 \sqrt{d}$ cm for shafts with more than 2 bearings (1)

*

(1) Adnan Halet Taşpınar "Machine Design Notes" Robert College Bebek Istanbul 1965.

4.6 Soldering

1. Definition

Soldering is the method of uniting two or more pieces of metal by means of a fusible alloy or metal, called solder, applied in molten state (below 425 C) .

Lead and tin are the bases of most solders. Since solders are of low strength and the join depends upon adhesion of the metals, the design should be made such that the solder does not carry much load. The solder should serve primarily as a filler material to stop leaks, seal joints and carry electricity.

2. Solders

Due to the scarcity of tin, hundred of different alloys have been tried and recommended for use, among others we have:

	Tin (%)	Lead (%)	Melting (C)	Use
1.	100	-	232	High temperatures
2.	60	40	190	General purpose
3.	50	50	215	Most used
4.	40	60	237	General purpose
5.	20	80	277	For fillings
6.	95	Antimony 5	232	High strength
7.	Silver 5	95	305	High temperatures

3. Strength of soldered joints

The shear strength of soldered joints at room temperature depend on:

a) clearance in the joint,

b) soldering temperature,

c) duration of heating,

d) base material soldered,

e) flux used,

f) solder composition.

4. Design of solder joints

Proper clearance between parts should be allowed. Best strength is obtained with 0.125 mm clearance, but a range between 0.075 to 0.25 mm is permissible. The melting of the metal to be joint, may cause free alloying between metal and solder, thus changing the composition of the solder causing difficulties in the application. In such cases a larger clearance must be taken.

Parts should be allowed to remain fixed while the filler is still in the plastic state or just bellow the freezing point, otherwise the filler will be granular with cracks. The maximum shear stress is from 140 to 350 gr/cm^2.

5. Soldering fluxes

Absolute cleaniness of surface to be soldered should be assured. Oil and grease should be removed by a solvent, then the dirt and oxide should be removed by scraping the surfaces.

For large areas it is better to precoat the surfaces either with solder or pure tin. Tin coatings of approximately 0.005 mm are satisfactory if soldered within six weeks.

The clean surfaces should be covered with flux before heat is applied. The choice of flux depends upon the material being soldered. Flux is a chemical agent serving three purposes:

a) coat surfaces to protect from oxidation by the atmosphere while heating.

b) dissolve any oxides that may form in the surface.

c) lower the surface tension of the molten alloy to allow it to flow more freely into the joint.

There are two types of fluxes: non-corrosive and corrosive. For copper, brass, aluminium, bronze, zinc, carbon steel, nickel, the most commonly used fluxes are:

1. analine phosphate (paste, non-corrosive)
2. zinc chloride, amonium chloride plus water (liquid, corrosive)

6. Final cleaning

To avoid corrosion of surface any residue of the flux must be removed, the best way being by hot clean water flowing, to remove the residue and prevent any concentration of flux to build up at a point. (1)

-o-

(1) James F. Young "Materials and Processes" John Willey and Sons Inc New York 1954 pp 848-855.

4.7 Speed governors.

Governors are mechanisms designed to maintain the speed of the prime mover (r.p.m.) within reasonably constant limits, whatever the the load may be. Nearly all governors depend for their action upon centrifugal force, and consist of a pair of masses rotating about a spindle driven by the prime mover and kept from flying outward by a controlling force, generally applied by springs. (1)

Flaps can be used to govern the speed of windmills based on centrifugal action. The flaps F produce resistance by flattening. (Fig 4.7-1) (2)

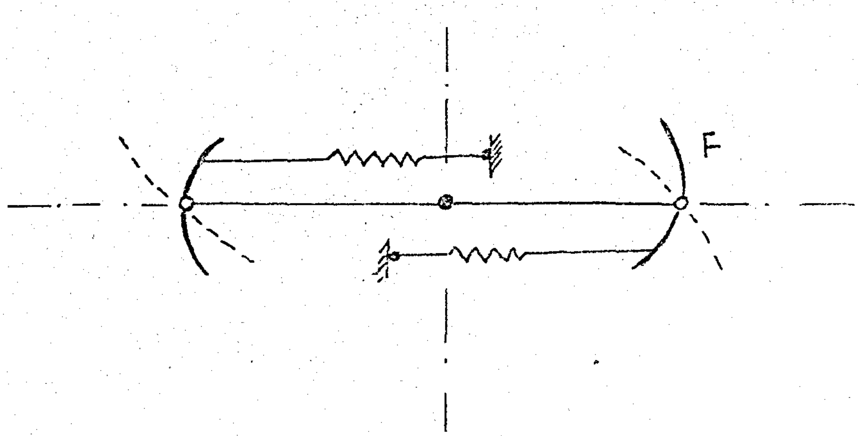


Fig 4.7-1

Speed governor

(1) Lionel S. Marks "Mechanical Engineers' Handbook" Fourth Edition

cGraw Hill Book Co. 1941 . pp 1012-1013 .
2) Andan Halet Taşpınar "Wind Power Notes" 1946 (not published)

Pilavla beraber pişmek ... "

5. E X P E R I M E N T A L S E T - U P

5.1 Development of experiments

5.2 Apparatus

5.3 Instruments

5.4 Wind rotor models

5.1 Development of the experiments

1. Preliminary work

The experimental work started immediately after tha preliminary research on the available data, in March 1964. Prof. Adnan Taşpınar advisor of this work, explained the basic principles involved in the Impala wind rotor on a paper model he had made. (Fig 2.12-4). The author then started his experiments by preparing a small rotor model made with Meccano tools, 60 mm in diameter and 40 mm in height. The model resembled a Savonius S-rotor, but it was not up to the point and it did not work satisfactorily. Prof. Taşpınar made some adjustments on the vanes, and the results were then promising. (Fig 5.1-1).

The author was adviced to make a study on airfoils, and to find an adequate profile to be used in the experiments of the Impala rotor. The profiles given by N.A.C.A. were not satisfactory for the purpose bacause they had small lower chamber. The advisor then suggested from his own experience an airfoil that resembled the vane of a steam turbine.

It was then decided to construct a model 20 cm in diameter and 20 cm in height in order to be tested. A steel shaft of 7 mm in diameter and 50 cm long was threaded to 22 cm, mounted on two 7 mm one row fixed ball bearings, mounted on a wooden chair used as a stand. The rotor blades were made of 0.2 mm tinned sheet metal and the discs of 0.6 mm galvanized sheet metal. The blades were fixed to the discs by means of 3/16" machine screws. The rotor was good enough to show the principles involved, but the shaft was very weak when tested in front of the fan at 600 m/min wind speed. (Fig 5.1-2). A bycicle dynamo was oupled by means of a fixed coupling to the shaft and mounted to the ooden stand. The rotor discs were also very thin to stand the big ir pressure.

The advisor suggested to study the performance characteristics of he Impala rotor, changing its variables:

a. Ratio of diameter to height

b. Blade position

c. Wind velocity

d. Number of stages

For this purpose the speed of rotation, power output and wind veocity had to be measured.

During the month of June 1964, a new shaft was manufactured, 12 mm n diameter out of brass, with a 1/2" thread. The ball bearings were hanged, the lower bearing changed into a 10 mm thrust bearing to upport the load of the rotor. (Fig 5.1-3). Next, several 10 cm iameter rotors of different sizes wer manufactured and tested, as een in Fig 5.1-4 to 7. Some rough attempts to test multistage rotors ere made. To the experiments made in the laboratory followed a test n the terrace of the Perkins Building at Robert College with very atisfactory results. At this stage the experiments were discontinued.

2. New developments

In November 1964 the experimental work was restarted by making a otor balancing stand using saw blades. (Fig 5.1-8). A wood pattern of the blade profile to be used for the Impala rotor was prepared,

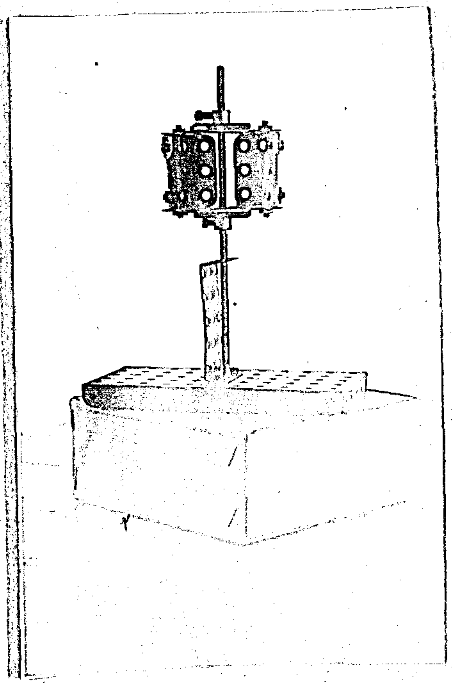


Fig 5.1-1

Meccano model

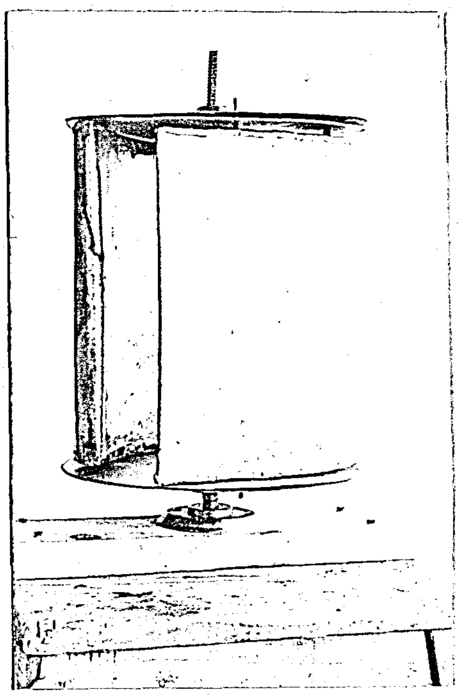


Fig 5.1-2

Impala rotor I

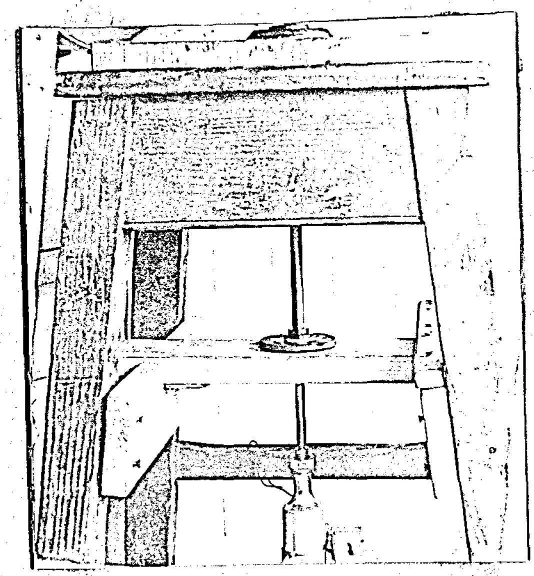


Fig 5.1-3

Wood stand

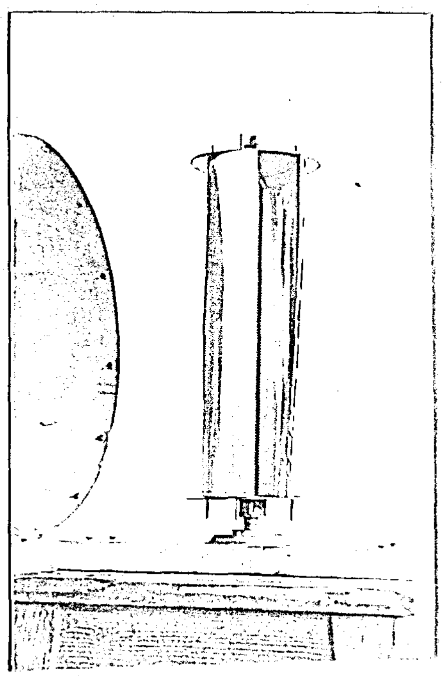


Fig 5.1-4

Express type rotor

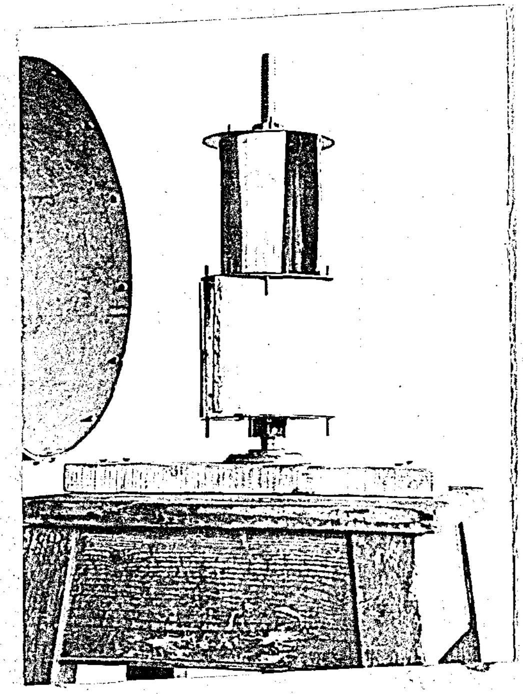


Fig 5.1-5

Two stage rotor

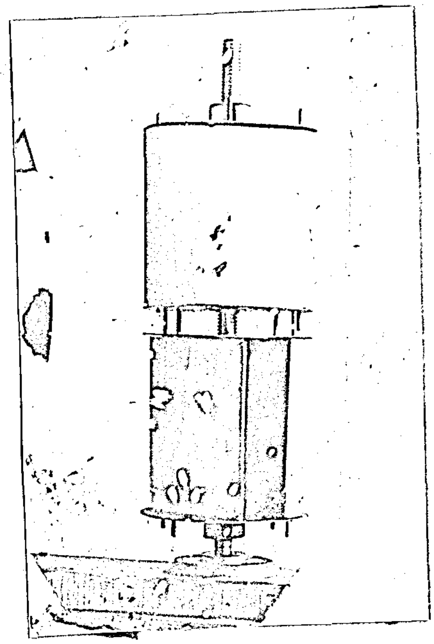


Fig 5.1-6

Two separate stage rotor

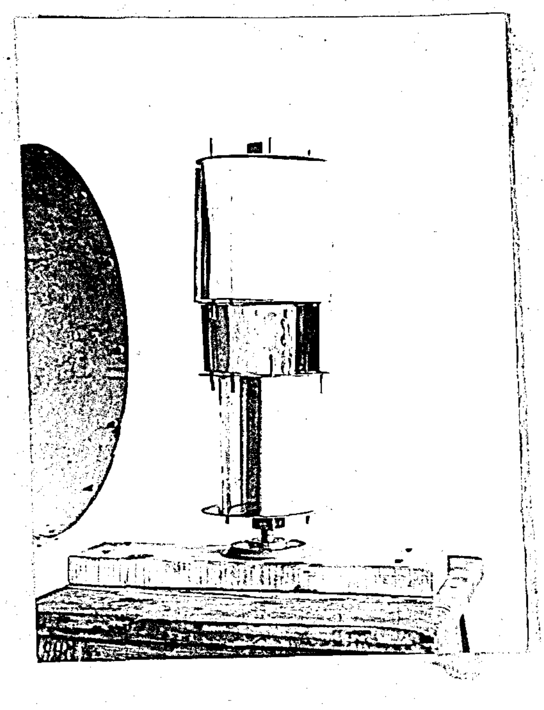


Fig 5.1-7

Three stage rotor

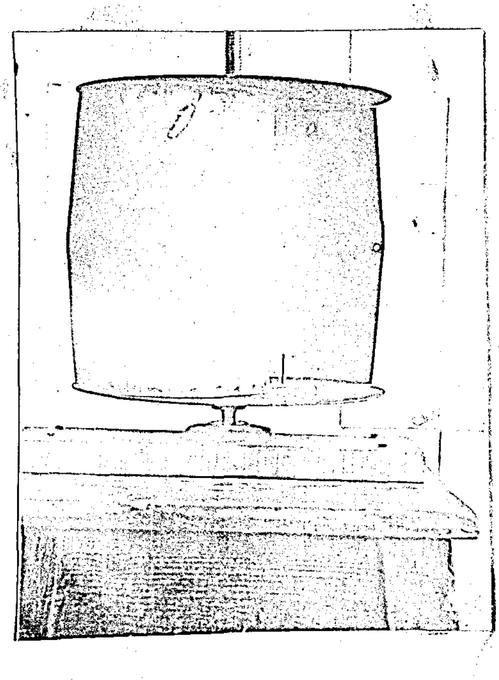


Fig 5.1-11

Savonius S-rotor

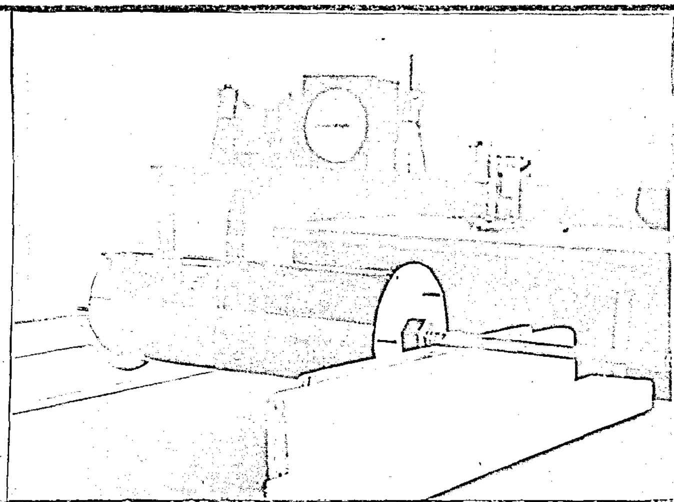


Fig 5.1-8

Rotor balancing stand

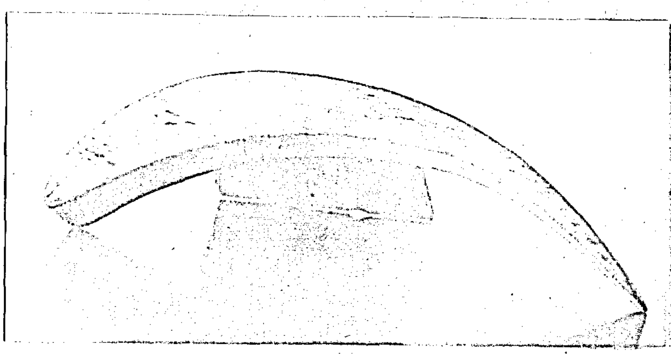


Fig 5.1-9

Wood pattern

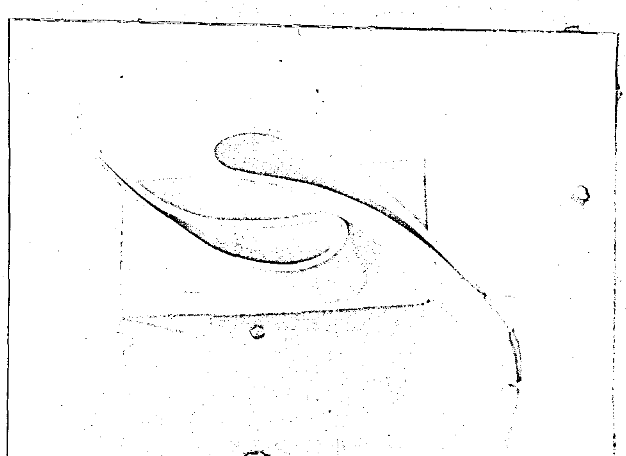


Fig 5.1-10

Plastic blades

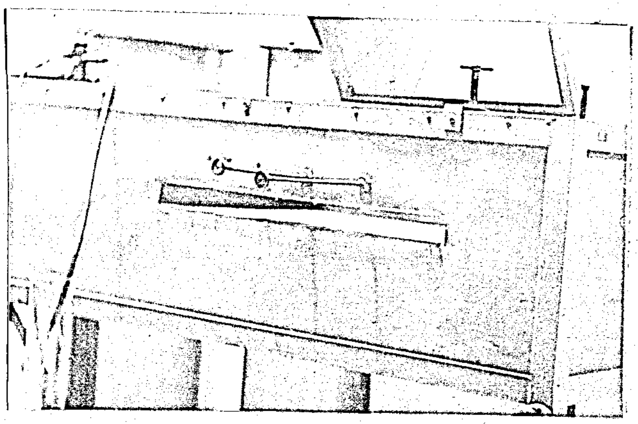


Fig 5.1-12

Water flow channel

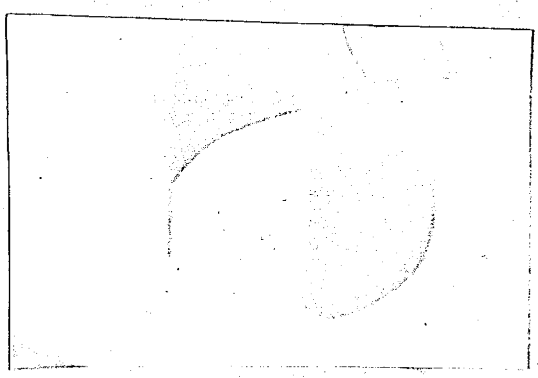


Fig 5.1-13

Flow channel

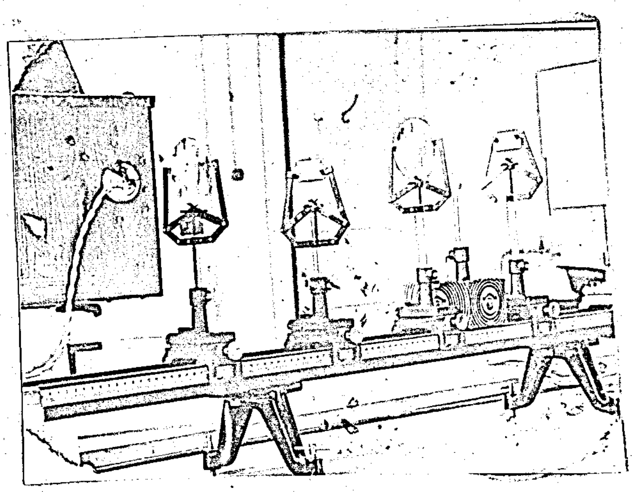


Fig 5.1-14

Schlieren apparatus

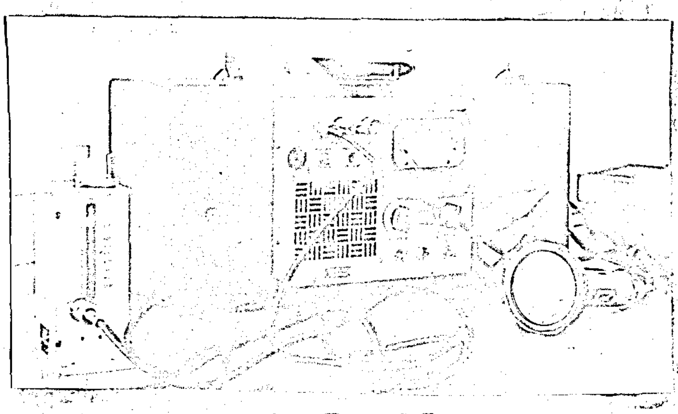


Fig 5.1-15

Vibrodyne

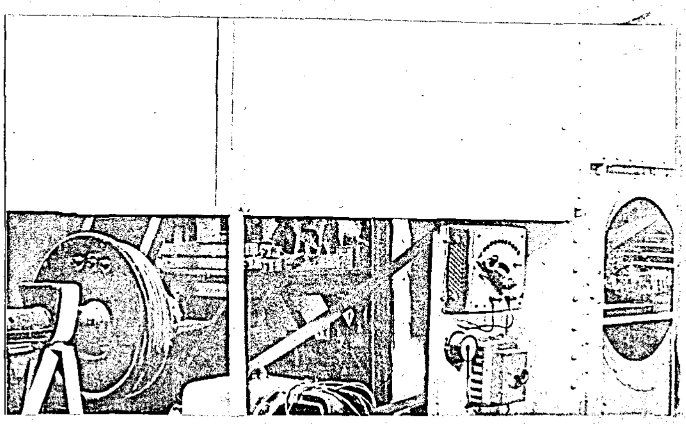


Fig 5.1-17

Wind tunnel

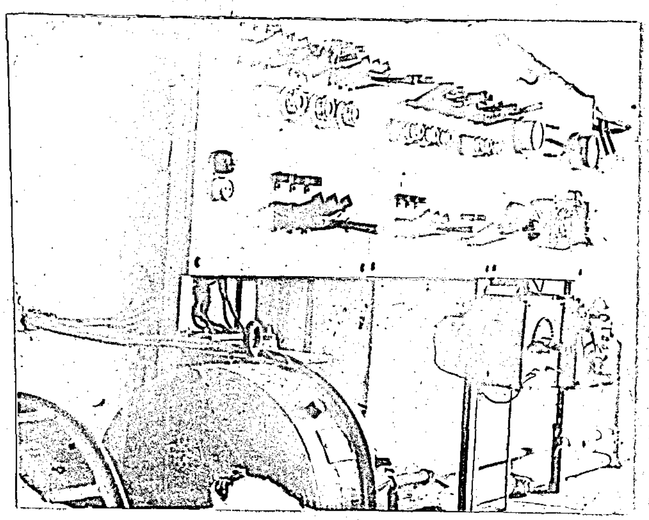


Fig 5.1-18

Wind tunnel electric system

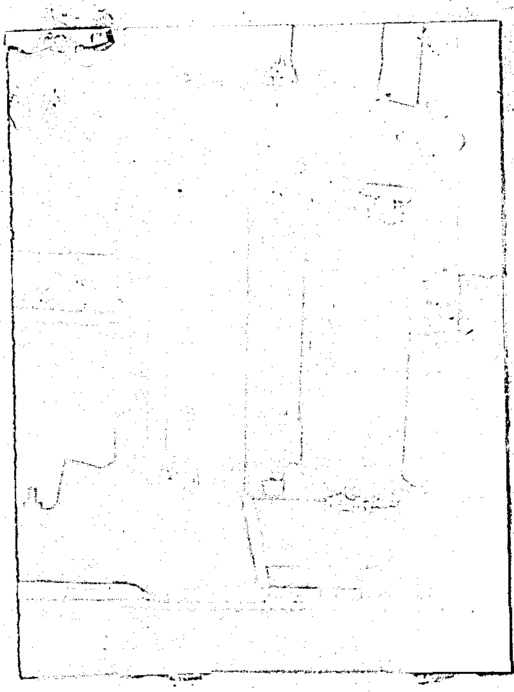


Fig 5.1-16

Metal stand

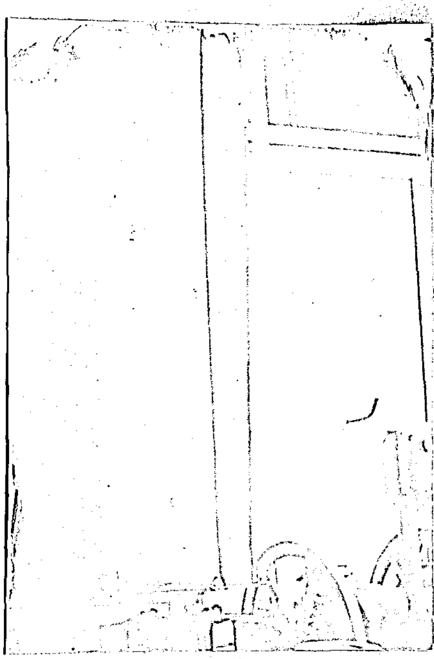


Fig 5.1-19

Express type rotor

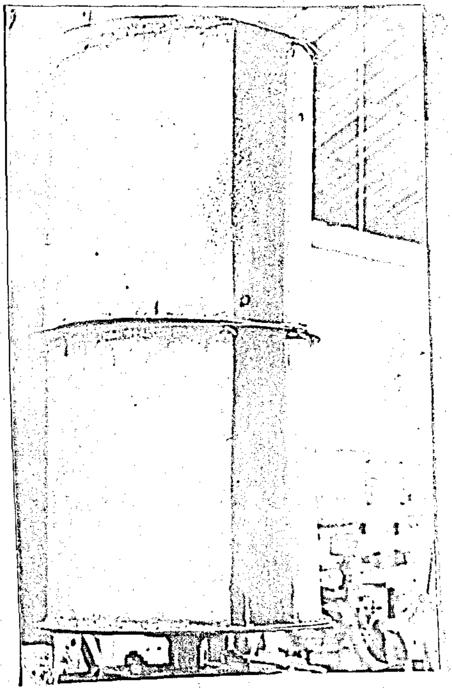


Fig 5.1-20

Two stage rotor

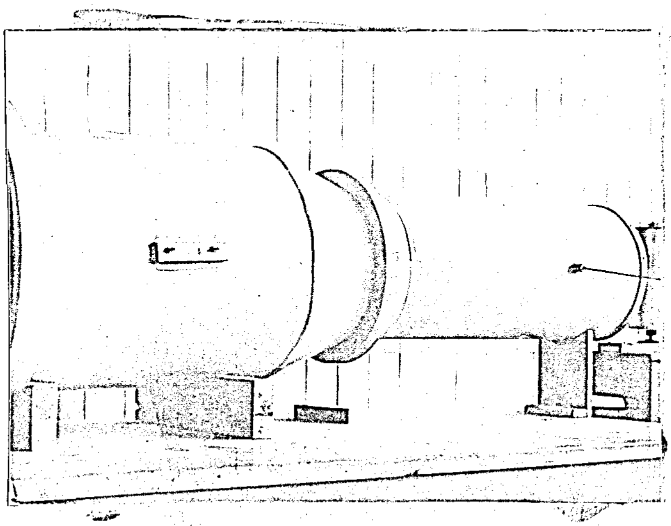


Fig 5.1-21

Fan

and the possibilities of using plastic materials to manufacture rotors was investigated. (Fig 5.1-9 and 10). It was found possible to give form to floor plastic covering material when heated. Unfortunately the sizes of plates (25 x 25) , its thickness and the difficulties of binding parts with adhesives, were important drawbacks for their immediate utilization.

A new rotor, 20 cm in diameter and 20 cm in height was manufactured and fixed to metal sheet discs by means of rods of brass in order to vary the angle of attack of the blades.

In February 1965 a Savonius S-rotor with 1/4 spread (Distance between blades equal to one forth of the diameter) Fig 5.1-11 .

The design of a new stand was started under the advice of Prof. Taşpınar. Contact with SKF İstanbul was of no use in helping in the design. With the suggestion of Yusuf Usta the use of two conical bearings was decided.

In March 1965 experiments on visualization of fluid motion were started. With the suggestion of Konstantin Kaminaris, Senior ME, glass nozzles were prepared and dipped in the water channel prepared by Orhan Kural for his thesis in 1961. The glass nozzles were filled with potassium permanganate pellets. First experiments were very promising. It was decided to use several nozzles to represent the streamlines of a parallel flow. Various methods of suspending the nozzles were tried.

The experiments were not satisfactory. It was difficult to fix glass with the available material. The flow in the channel was disturbed by the nozzles and wooden parts introduced (Fig 5.1-12 and 13)

Finally the dye pellets were placed directly in the flow channel and by proper adjustment of the water flow it was possible to obtain the desired flow pattern.

Some adjustmemts were made to the wood stand and the distance between the bearings reduced from 23 cm to mnly 15. It was necessary to fix the position of the bearing housings in three directions so as to obtain proper alignment of the shaft.

It was also decided to try setting the Schlieren apparatus, With the cooperation of the Phyiics Department Head, Prof Mac Mickle an optical bench, lenses and light source was obtained. After several trials, the light source was changed for a point source, but the experiments were discontinued becausetthe area of the image obtained was to small to allow for good results. '(Fig 5.1-14)

Some experiments were carried with the Vibrodyne apparatus to balance rotating machinery. The apparatus was set up, but the fact that rotors should be rotated on an horizontal shaft, forced the author to discontinue the experiments. (Fig 5.1-15)

In May 1965 the new stand was manufactured in the work shop by Yusuf Usta and mounted on an available stand in the Power Laboratory. (Fig 5.1-16)) The wind tunnel available at the laboratory was prepared for the experiments. (Fig 5.1-17 and 18)

An express type Impala rotor and a two-stage Impala rotor was manufactured and tested. The yawning of these rotors around their axis forced the author to finish his experimentations at this point. (Fig 5.1-19 and 20).

5.2 Apparatus

5.21 Schlieren apparatus

The apparatus is mounted on an optical bench, provided with a source light from a 6 volts lamp, two condenser lenses and two razor blades, all mounted on adjustable supports. The object is placed immediately after the second lens, the image being projected on a screen. (Fig 5.21-1 to 5)

5.22 Water flow channel

The water flow channel was designed by Orhan Kural for the "Shallow Water Analogy in Gas Dynamics" thesis, and modified to have a 30 cm width channel where water flows without turbulence. Pellets are placed at the entrance of the channel and the model at 10 cm from the pellets of potassium permanganate. (Fig. 5.22-1)

5.23 Fan

A 320 mm diameter outlet duct fan used for Pitot tube experiments. Driven by V belt with speed reduction possibilities. (Fig 5.23-1 and 2)

5.24 Wind tunnel

A 70 x 32 cm^2 outlet cross section area tunnel used for air flow experiments. Driven by a DC motor with speed regulation by means of a rehostat. (Fig 5.24-1 and 2)

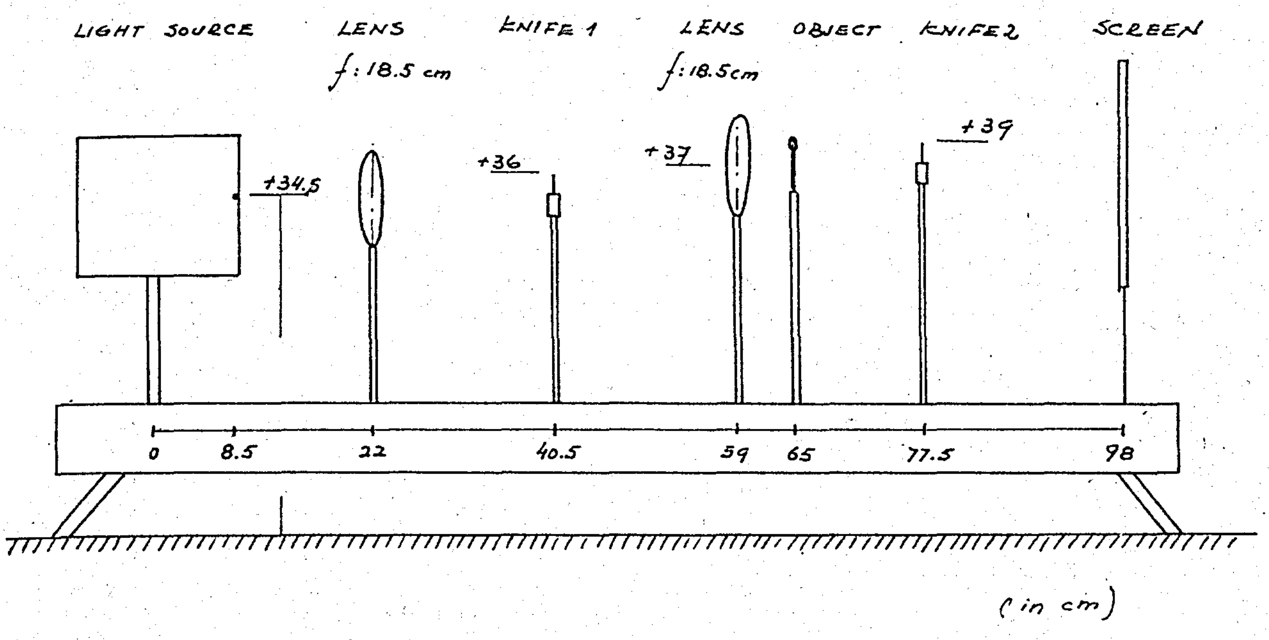


Fig 5.21-1

Schlieren apparatus (1:7.5)

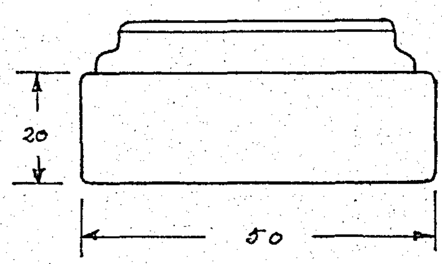


Fig 5.21-2

Knife edge (1:1))

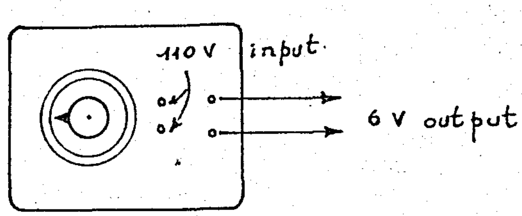


Fig 5.21-3

Variac

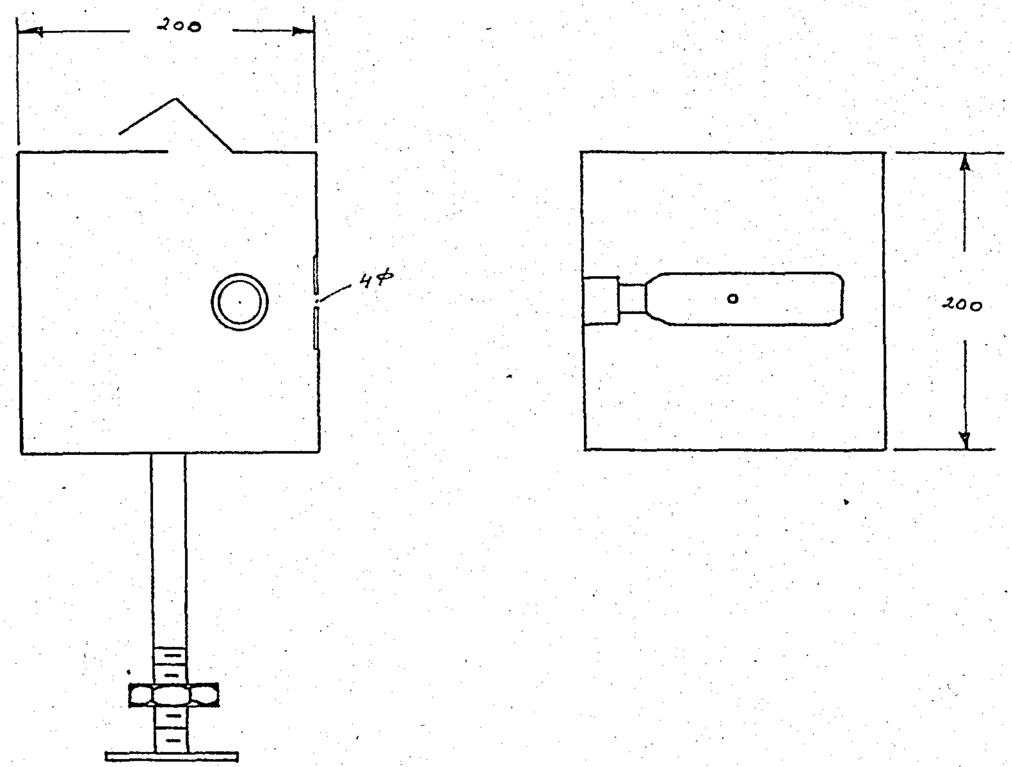


Fig 5.21-4

Light source (1:5)

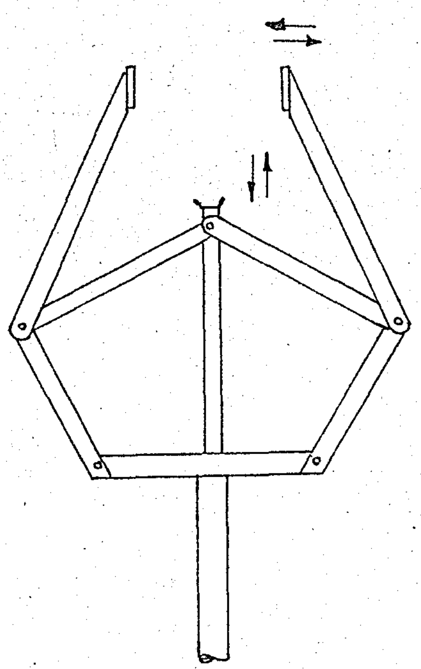


Fig 5.21-5

Support

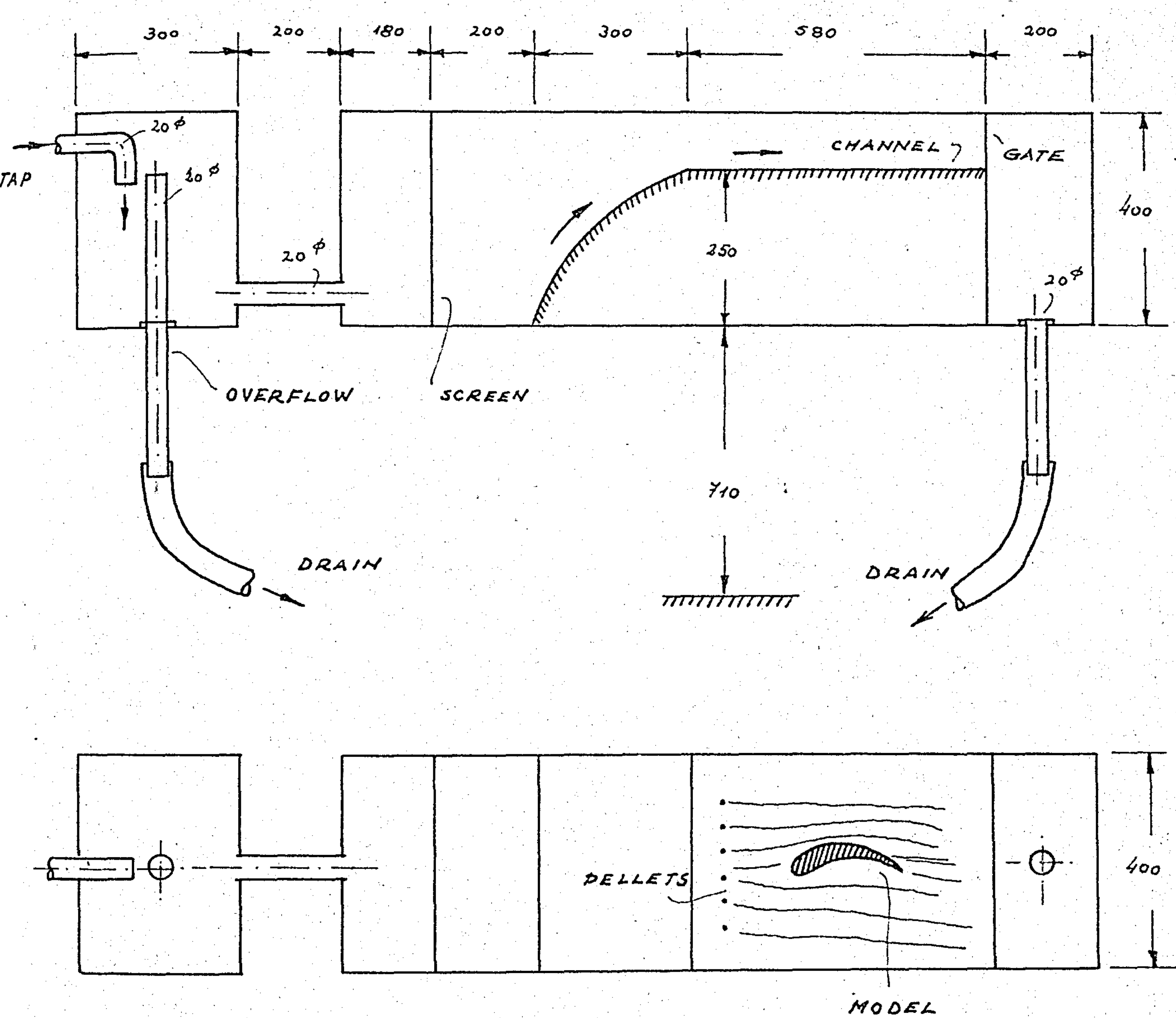


Fig 5.22-1

Water flow channel (1:12.5)

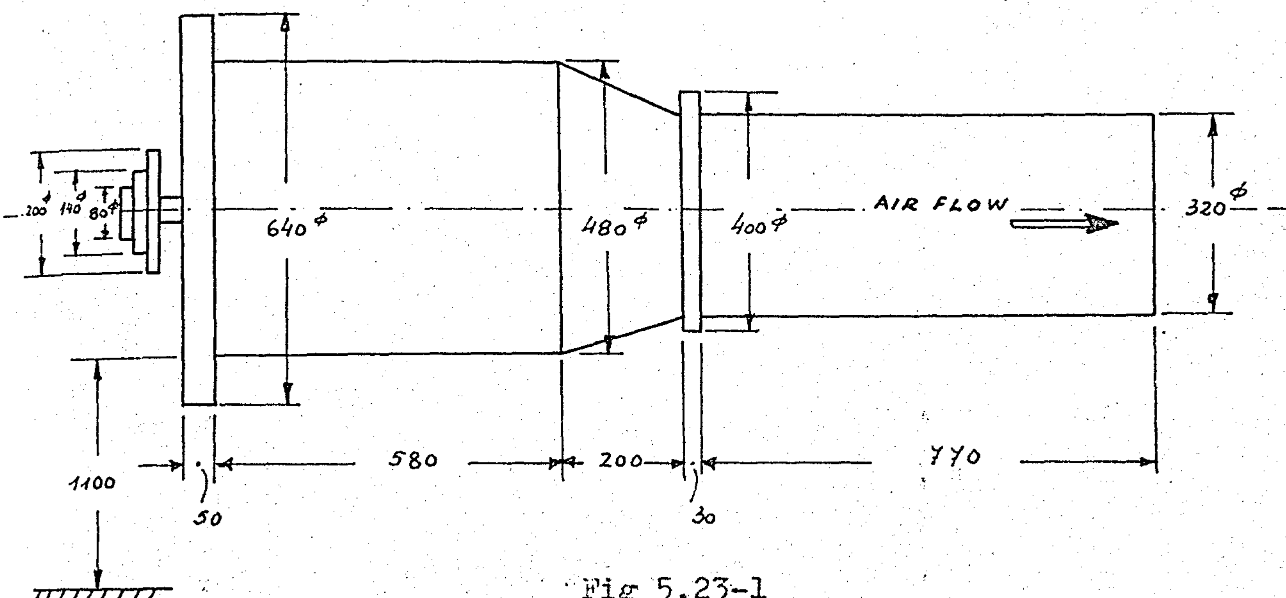


Fig 5.23-1

Fan (1:12.5)

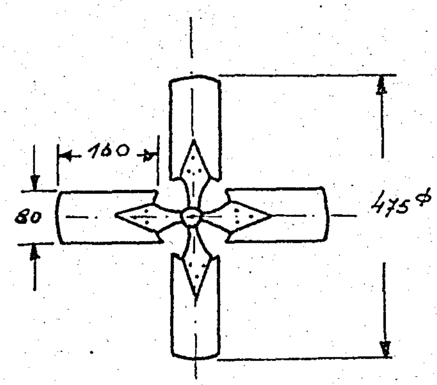


Fig 5.23-2

Fan blades (1:12.5)

Motor : 0.5 h.p. 220/380 volts 3 phase n: 1400 rpm

Fan : n_1 = 1200 rpm n_2 = 400 rpm

20 mm V belt drive

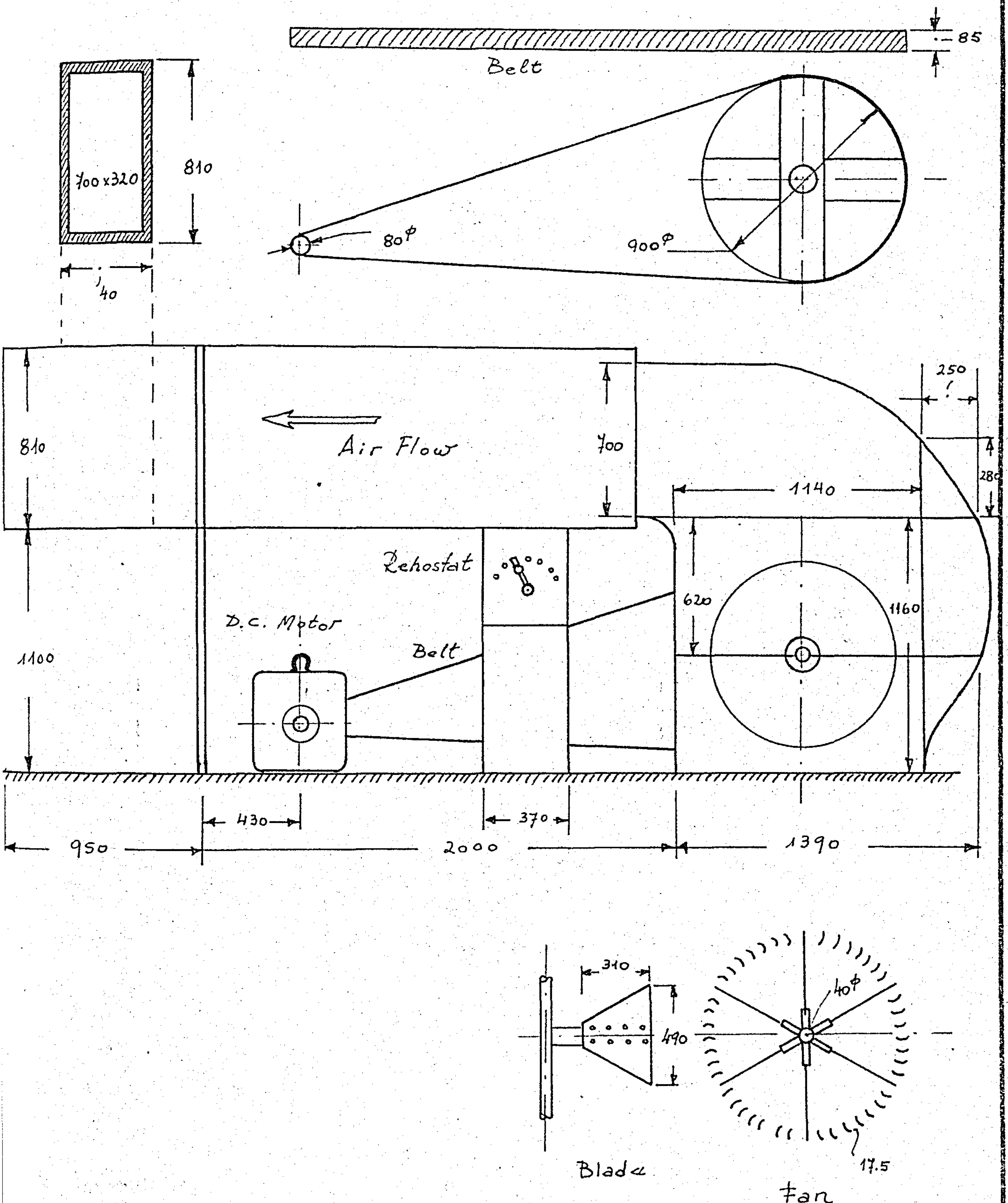


Fig 5.24-1

Wind tunnel (1:25)

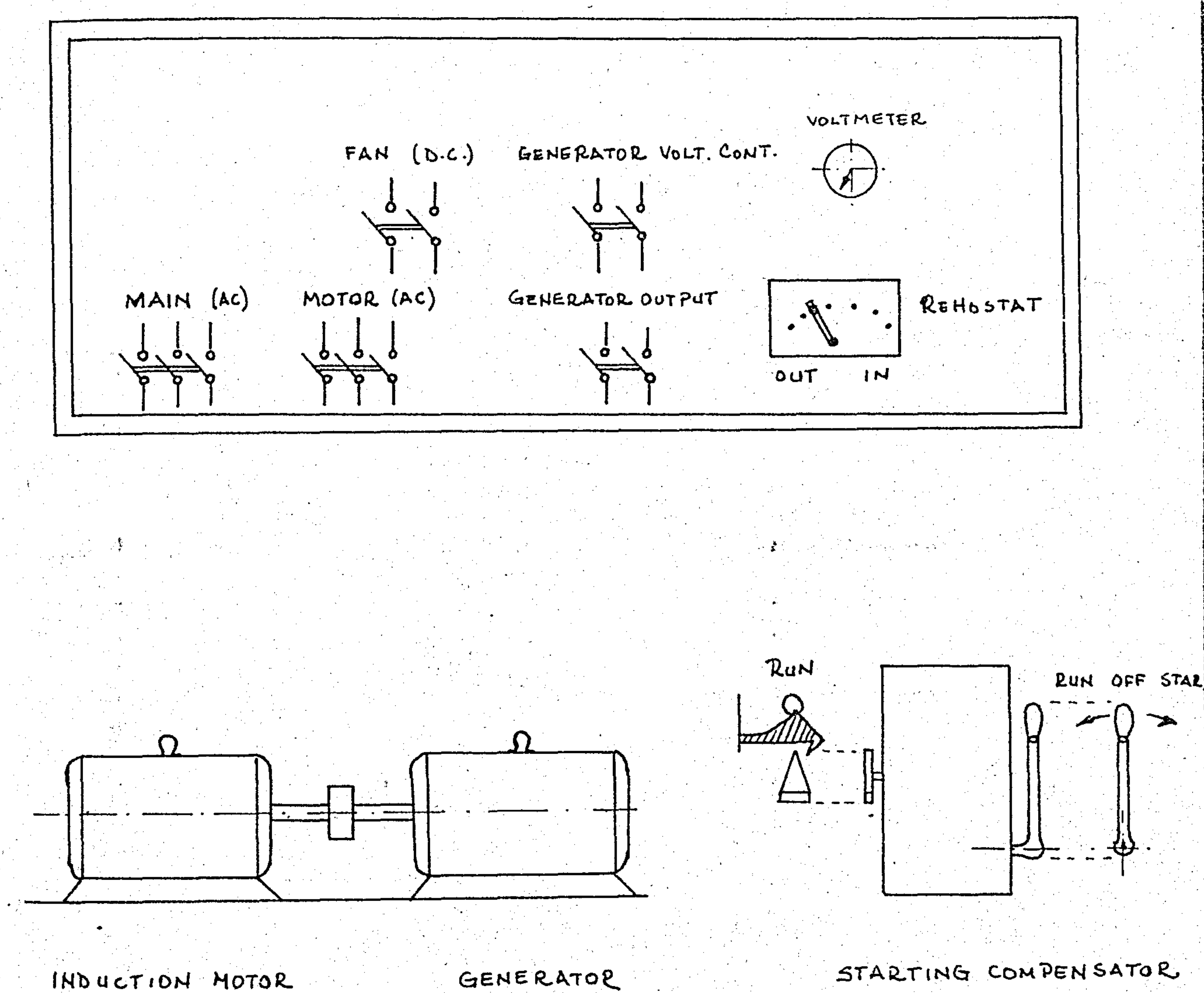


Fig 5.24-2

Wind tunnel electric system

<u>Induction Motor</u> :

3 phase , 220 volts

10 HP

26 amperes

GE

<u>Generator (Interpole)</u> :

DC , 80 volts

700 rpm

4 1/2 kw.

50 amperes

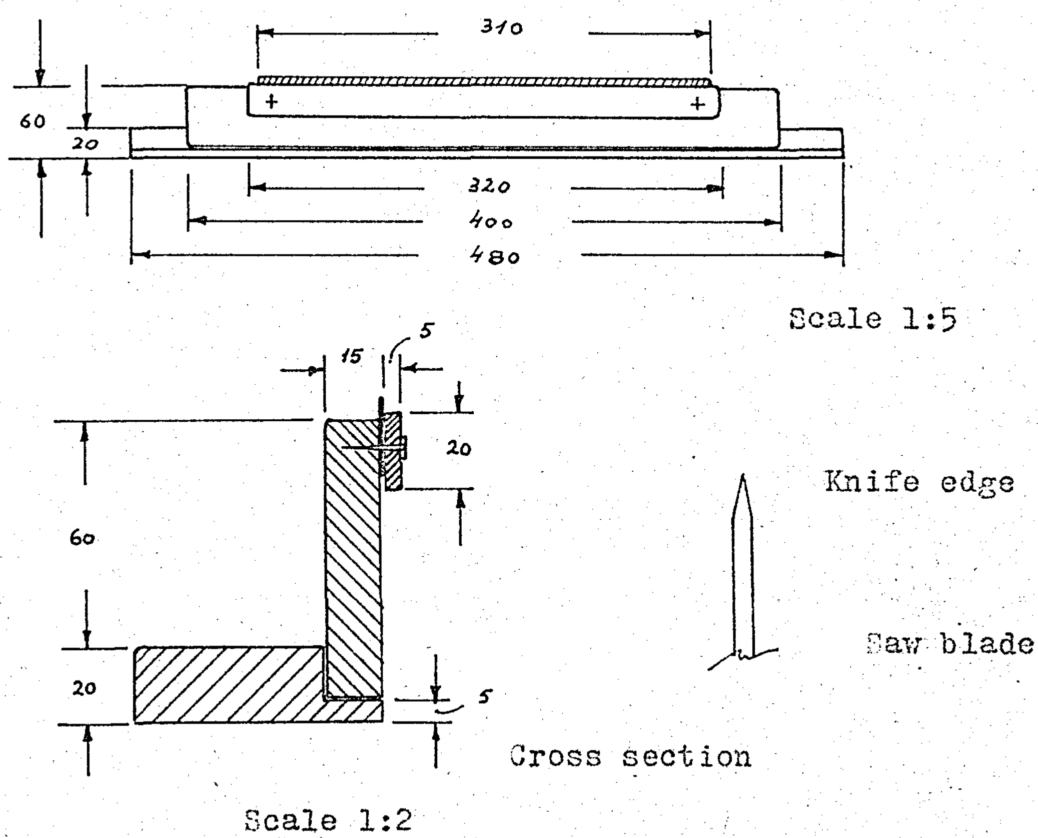


Fig 5.25-1

Rotor balancing stand

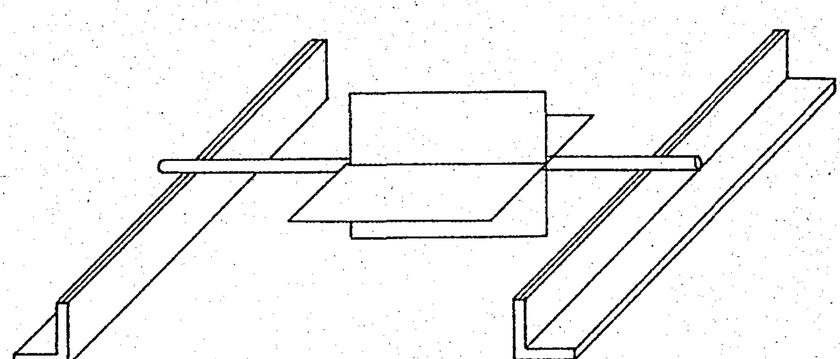


Fig 5.25-2

Balancing of rotor

5.25 Rotor balancing stand

Stand prepared with saw blades, sharped in the form of a V at one side and mounted on a wooden frame in the form of a L with the possibility of balancing statically rotors of any size by fixing the stand in an appropiate table. (Fig 5.25-1 and 2)

5.3 Instruments

5.31 Anemometer

Diameter of the anemometer is 90 mm, one revolution of the needle represents 100 m of wind. Measurements to be made with the aid of a stop watch. (Fig 5.31-1)

5.32 Dynamo

Bicycle dynamo, 6 volts and 3 watts output, to be coupled to the main shaft by means of a flexible rubber tube. (Fig 5.32-1)

5.33 Multimeter

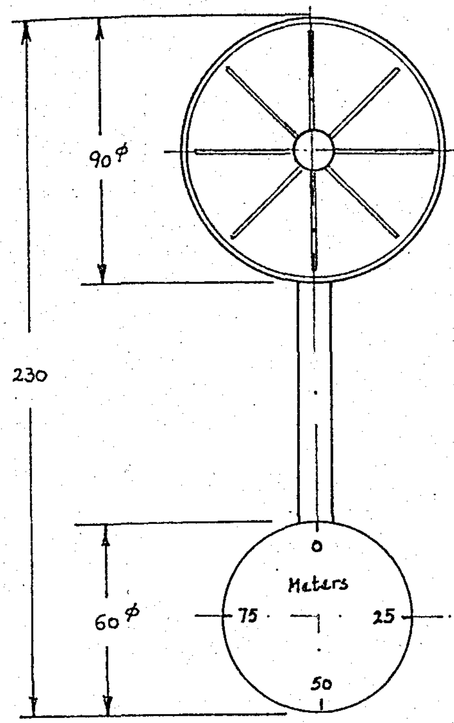
Voltmeter, ammeter and ohmmeter for AC and DC current for a wide range of values. Made in Hungary. (Fig 5.33-1)

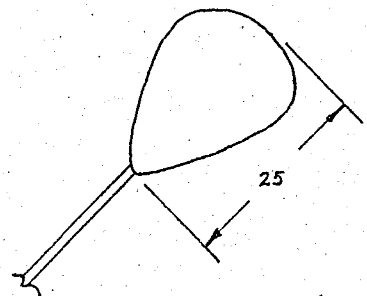
5.34 Tachometer

VEB Messgerate und Armaturen werk- Karl Marx, Magdeburg, Buckau. Ranges : 40/160, 120/480, 400/1600, 1200/4800, 4000/16000 12000/48000 r.p.m.

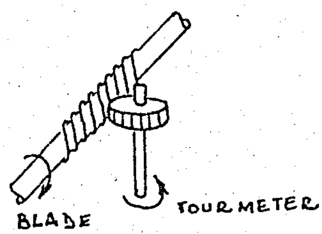
5.35 Vibrodyne

Manufactured by Tinius Olsen. Static and dynamic balancing of machinery, for speed ranges 225 - 3600 r.p.m., coupled with a strobostac light and pickups to pick vibrations through a magnetic pendulum transmitted to an electronic amplifier.





Blade (1:1)



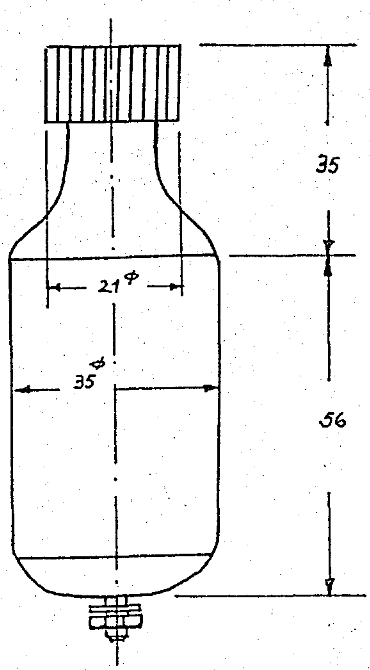
(1:1.25)

Ste Anne des Etabts.
Jules Richard, Paris

1 tour : 100 meters

Fig 5.31-1

Anemometer



Prima (Made in Japan)

6 volts 3 watts

Fig 5.32-1

Dynamo (1:1.25)

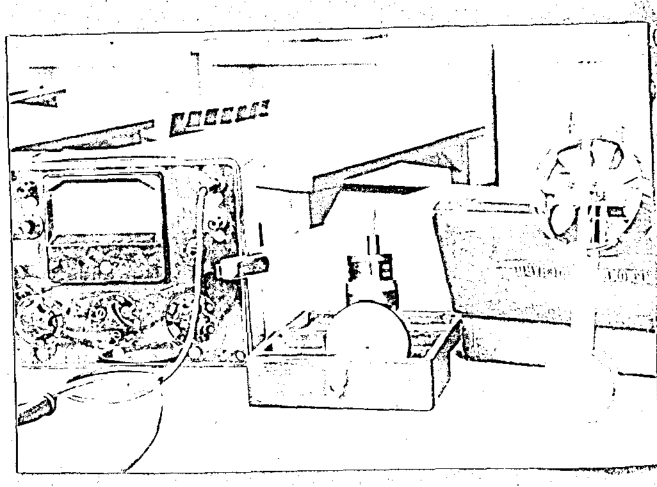


Fig 5.33-1

Multimeter, tachometer and anemometer

5.4 Wind rotor models

5.41 Meccano model

60 mmmdiameter S-rotor made of Meccano tools. (Fig 5.41-1)

5.42 Wood stand

Stand made out of a wooden chair 520 mm in height, with a brass shaft 12 mm in diameter, mounted on two ball bearings of 10 mm in diameter. (Fig 5.42-1 and 2)

5.43 Metal stand

Bearing housing pipe with two conical roller bearings of 20 mm diameter mouned on a metal stand and fixed by means of a disk. (Fig 5.43-1 to 3)

5.44 Savonius S-rotor

20 cm diameter and 20 cm height rotor with two circular blades of 135 mm in diameter placed so as to leave an air flow passage in between of 54 mm which is 1/4 of the rotor diameter (Fig 5.44-1)

5.45 Impala rotor models (Fig 5.45-1 to 3)

D : diameter H : height

a) Rotor I D: 20 cm H : 20 cm

b) Rotor II (Express type) D: 10 cm H : 25 cm

c) Rotor III (two stages) D: 10 cm H_1:H_2: 10 cm

d) Rotor IV (three stages) D: 10 cm H_1:H_2: 10 cm
H_3: 5 cm

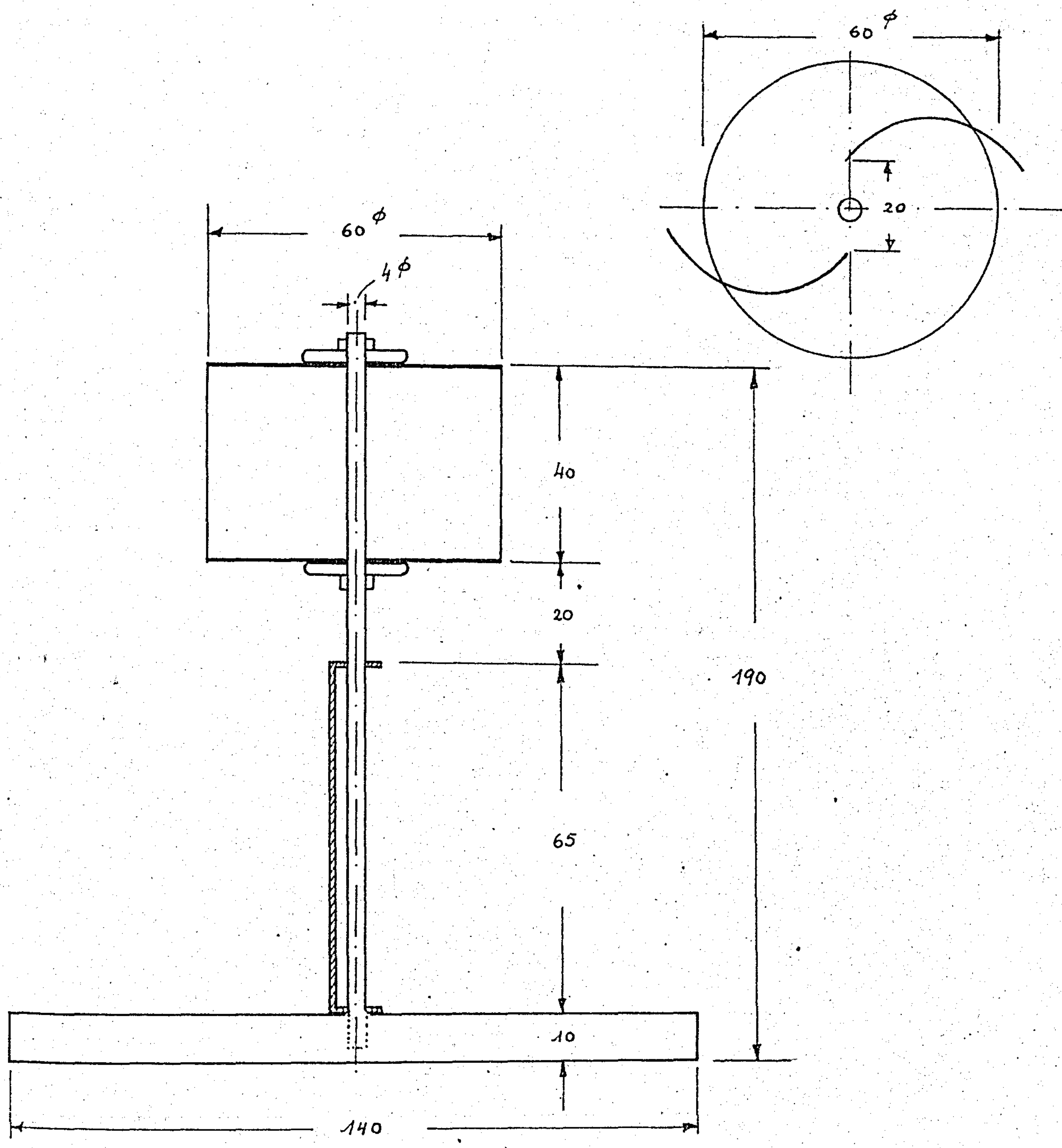


Fig 5.41-1

Meccano model (1:1.25)

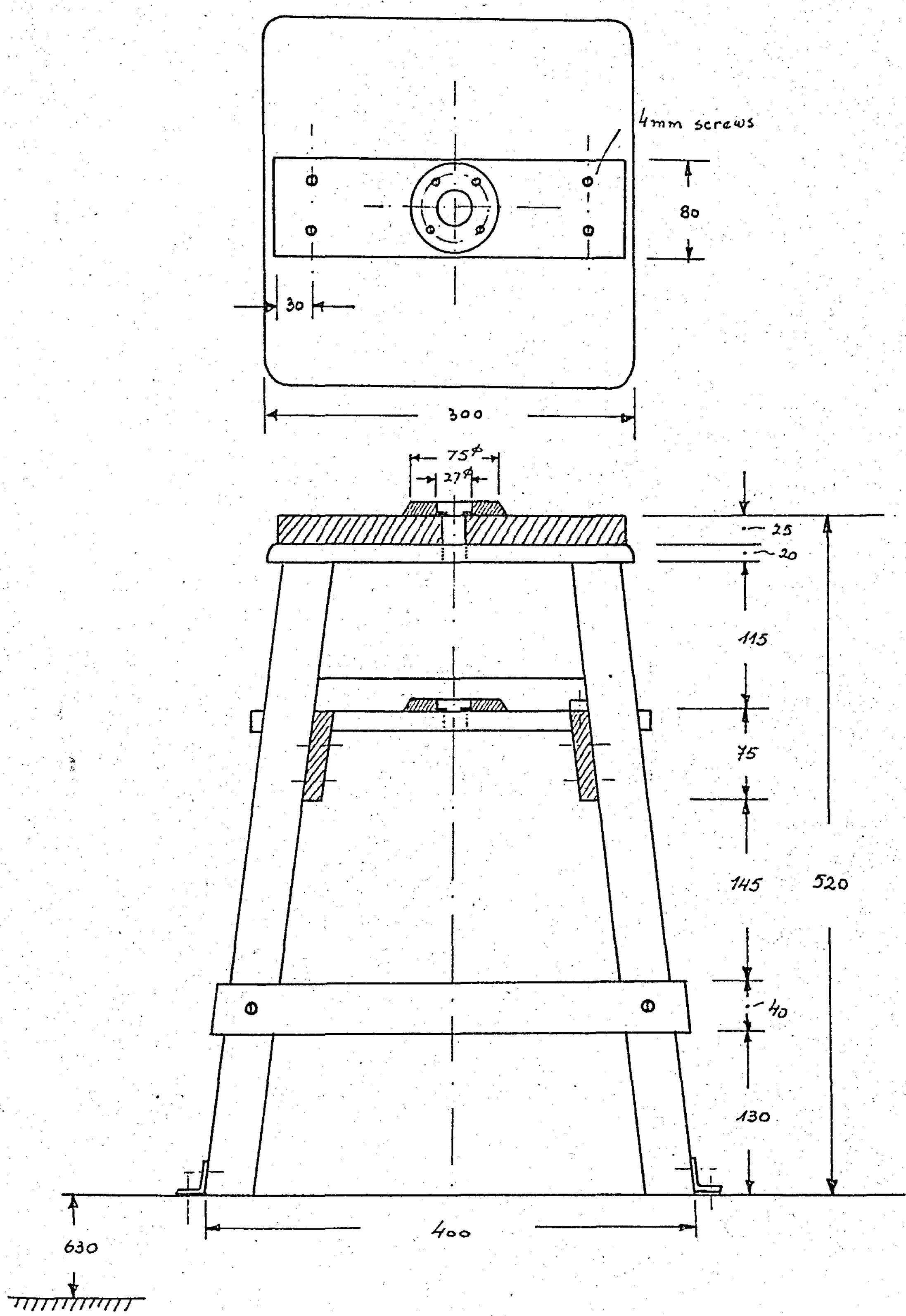


Fig 5.42-1

Wood stand (1:5)

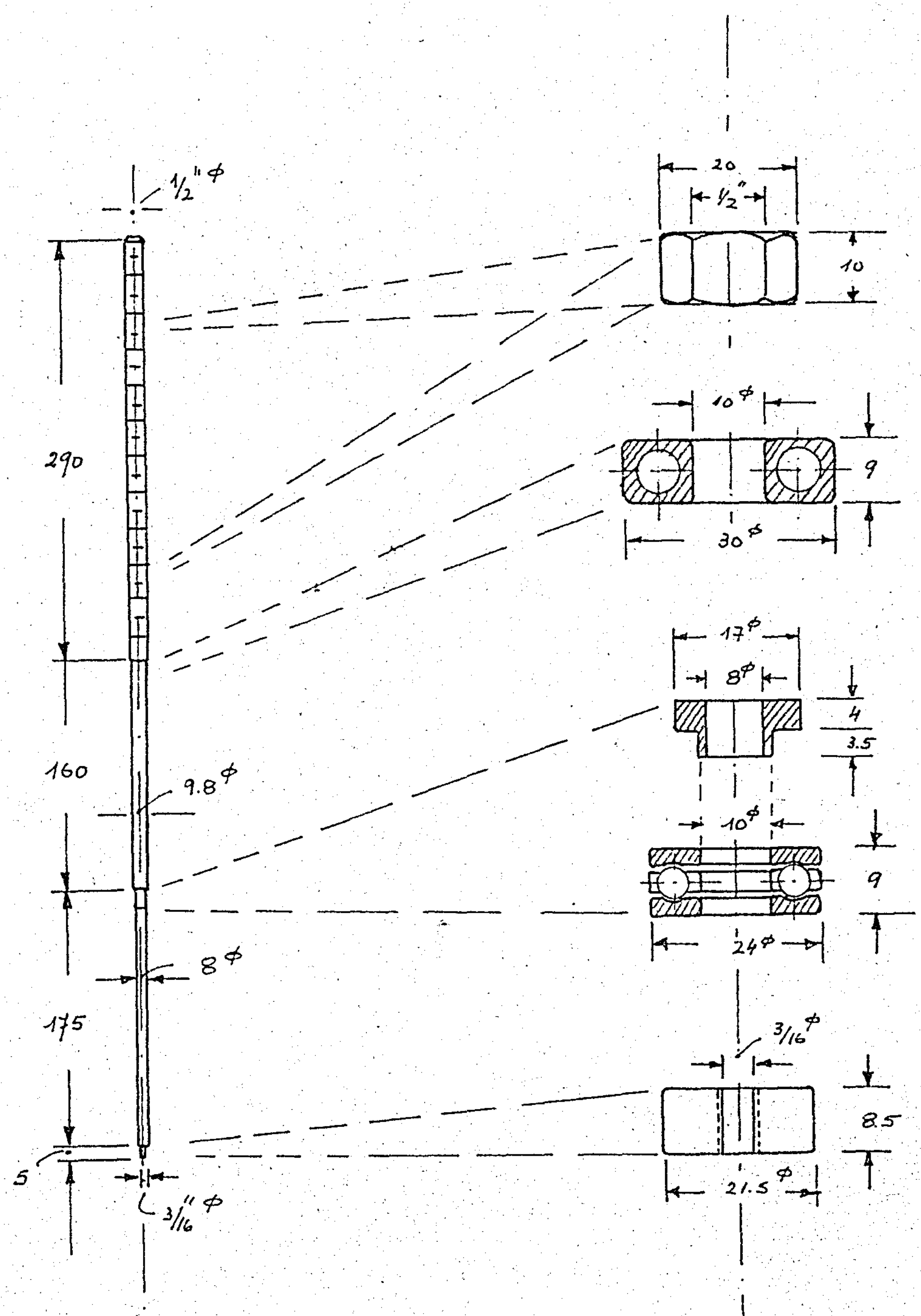


Fig 5.42-2

Wood stand shaft, brass. (1:5)

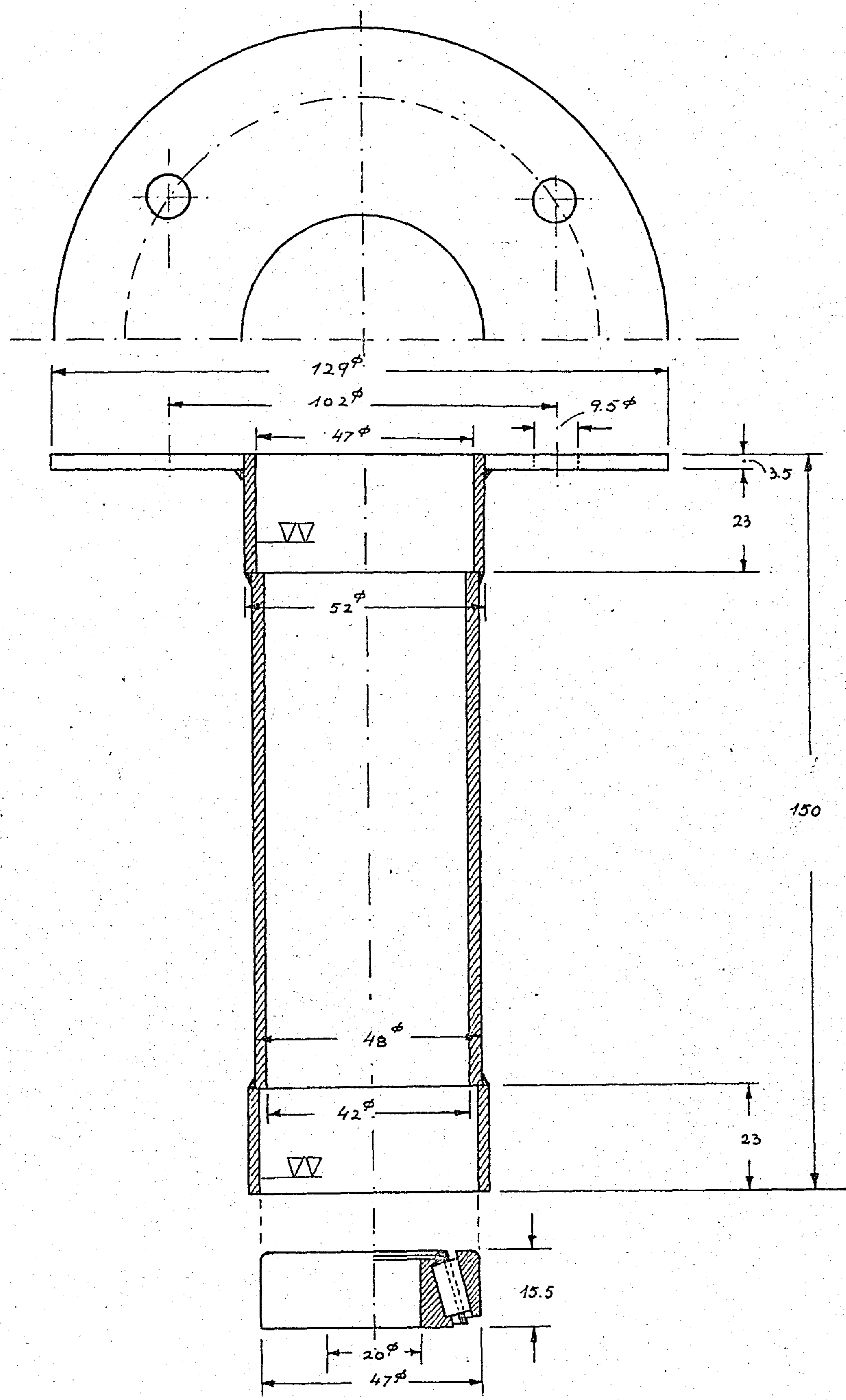


Fig 5.43-1

Metal stand bearing housing (1:1. 25)

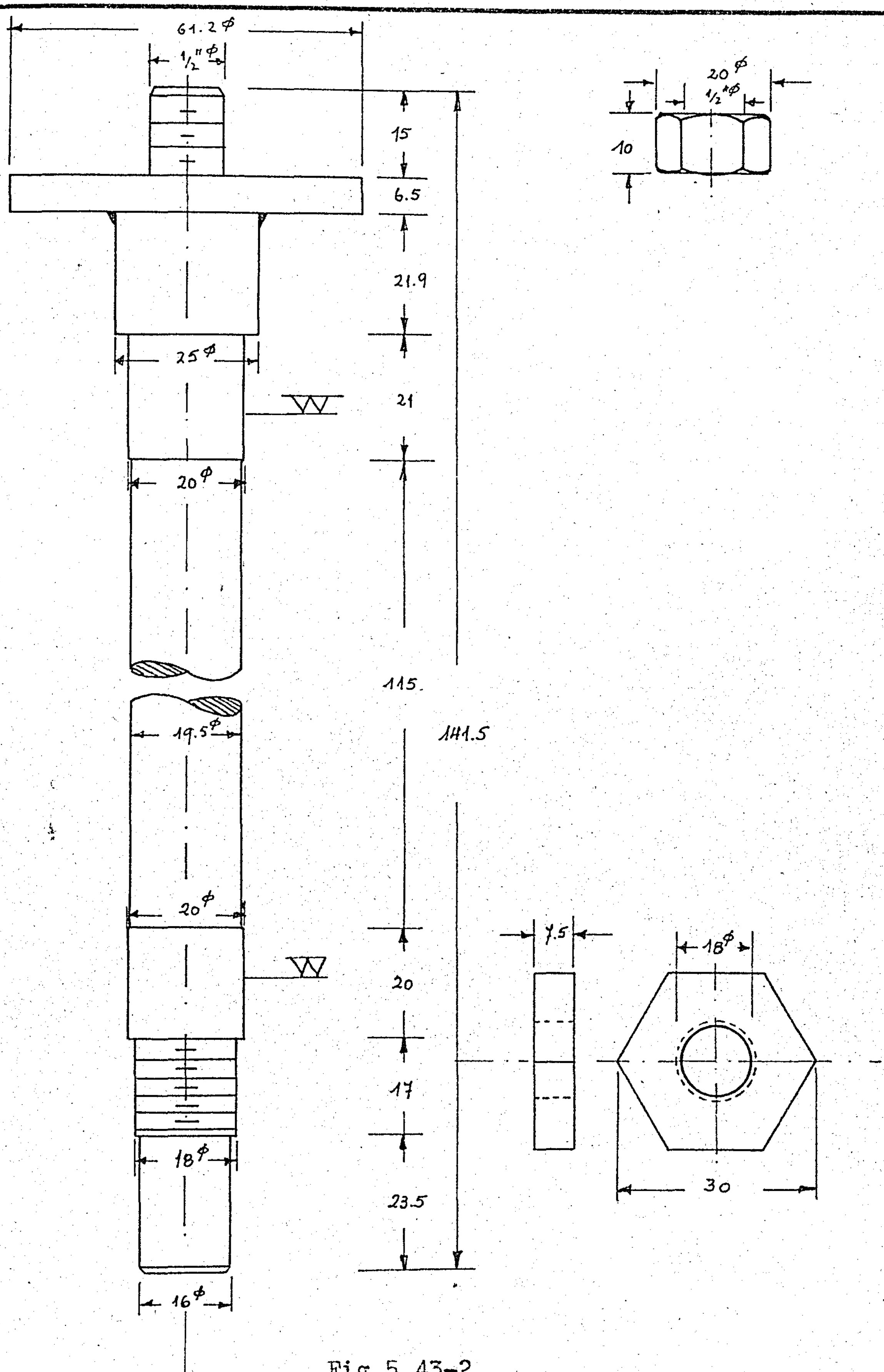


Fig 5.43-2

Metal stand shaft (1:1)

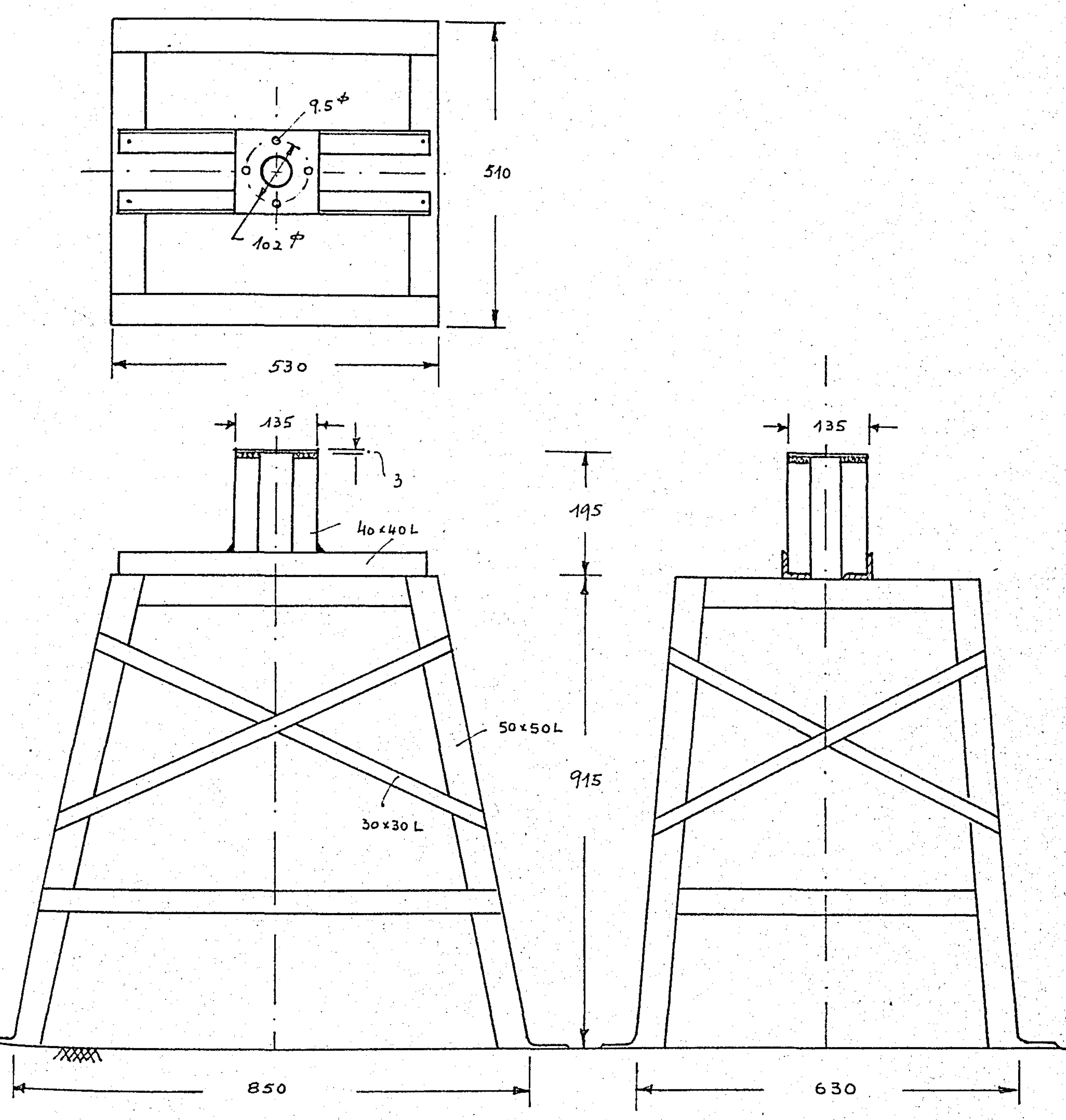
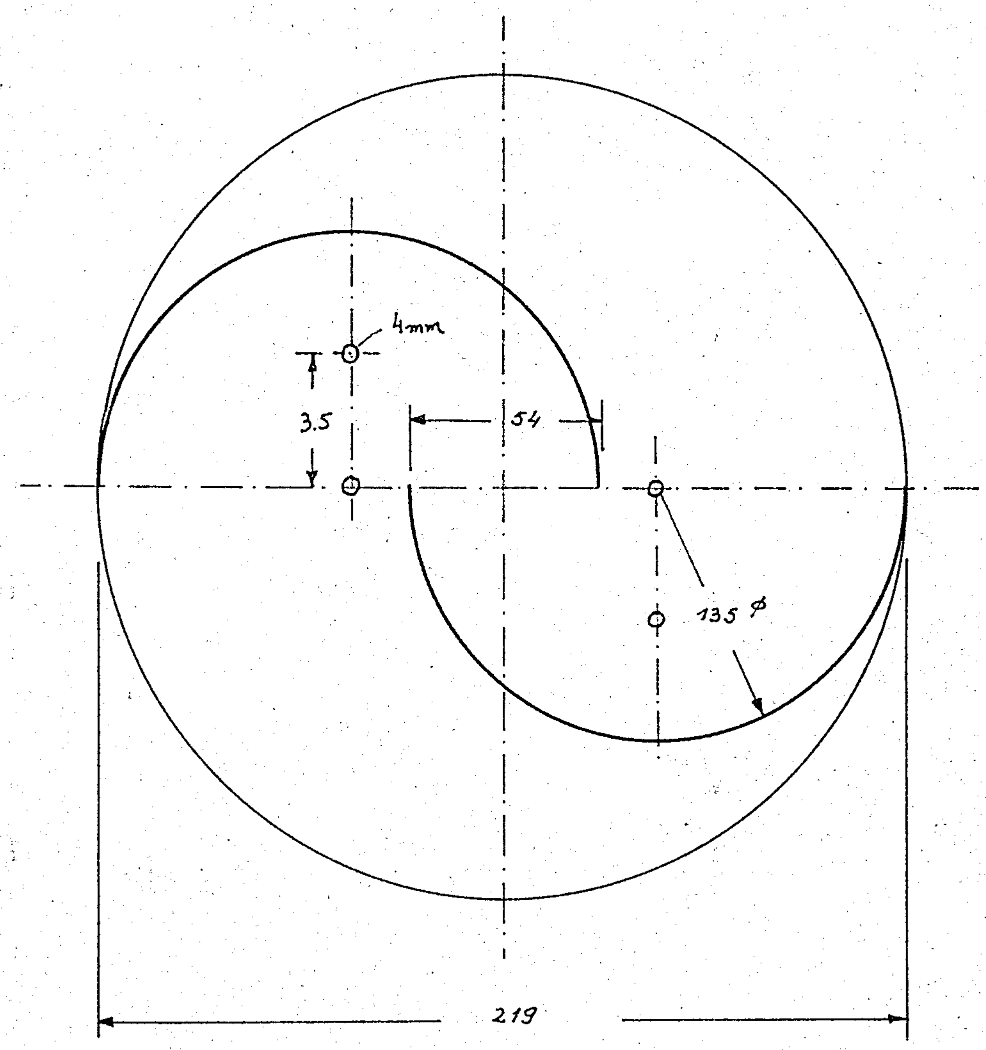
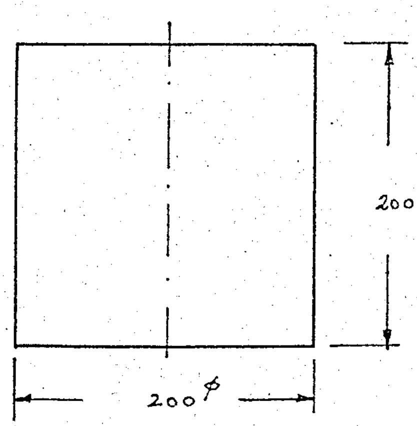


Fig 5.43-3

Metal stand (1:10)



Scale 1:2



Scale 1:5

Fig 5.44-1

Savonius S-rotor

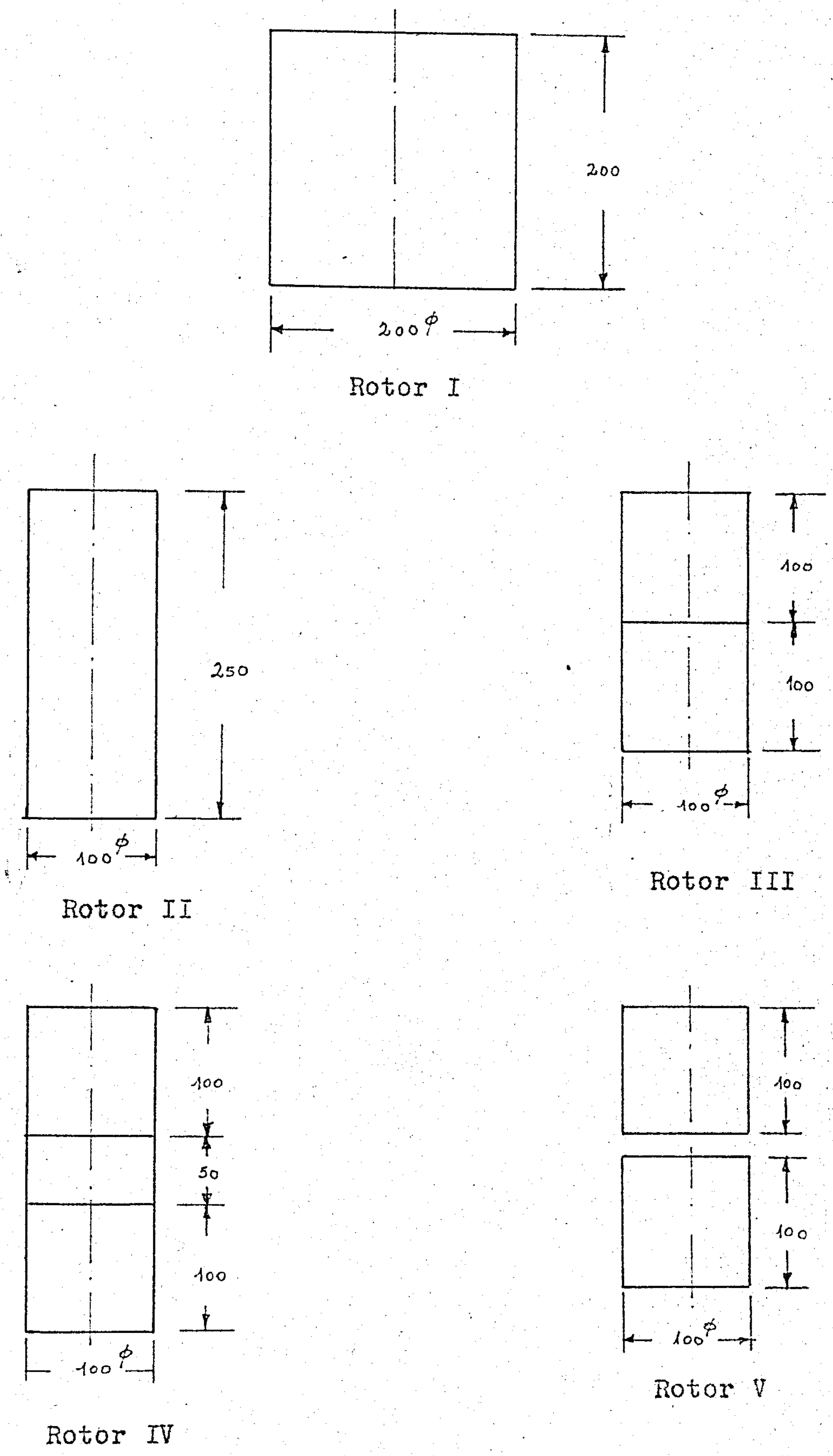
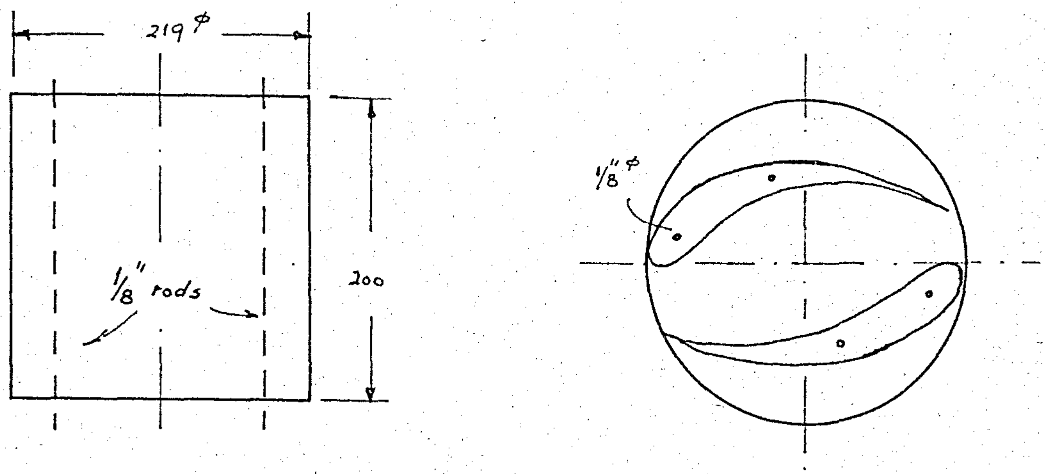
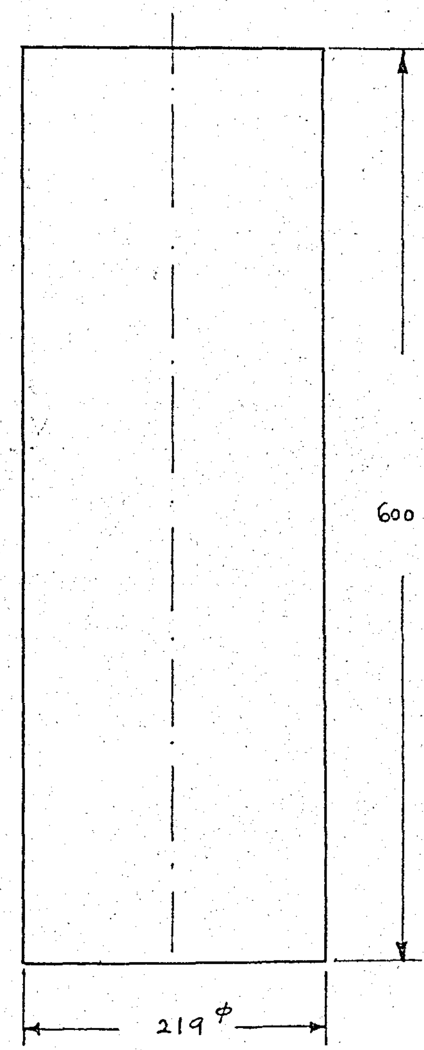


Fig 5.45-1

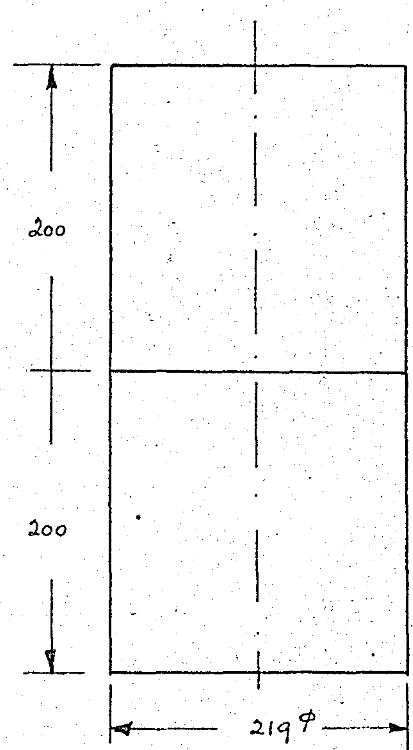
Impala rotors (1:5)



Rotor for angle of attack



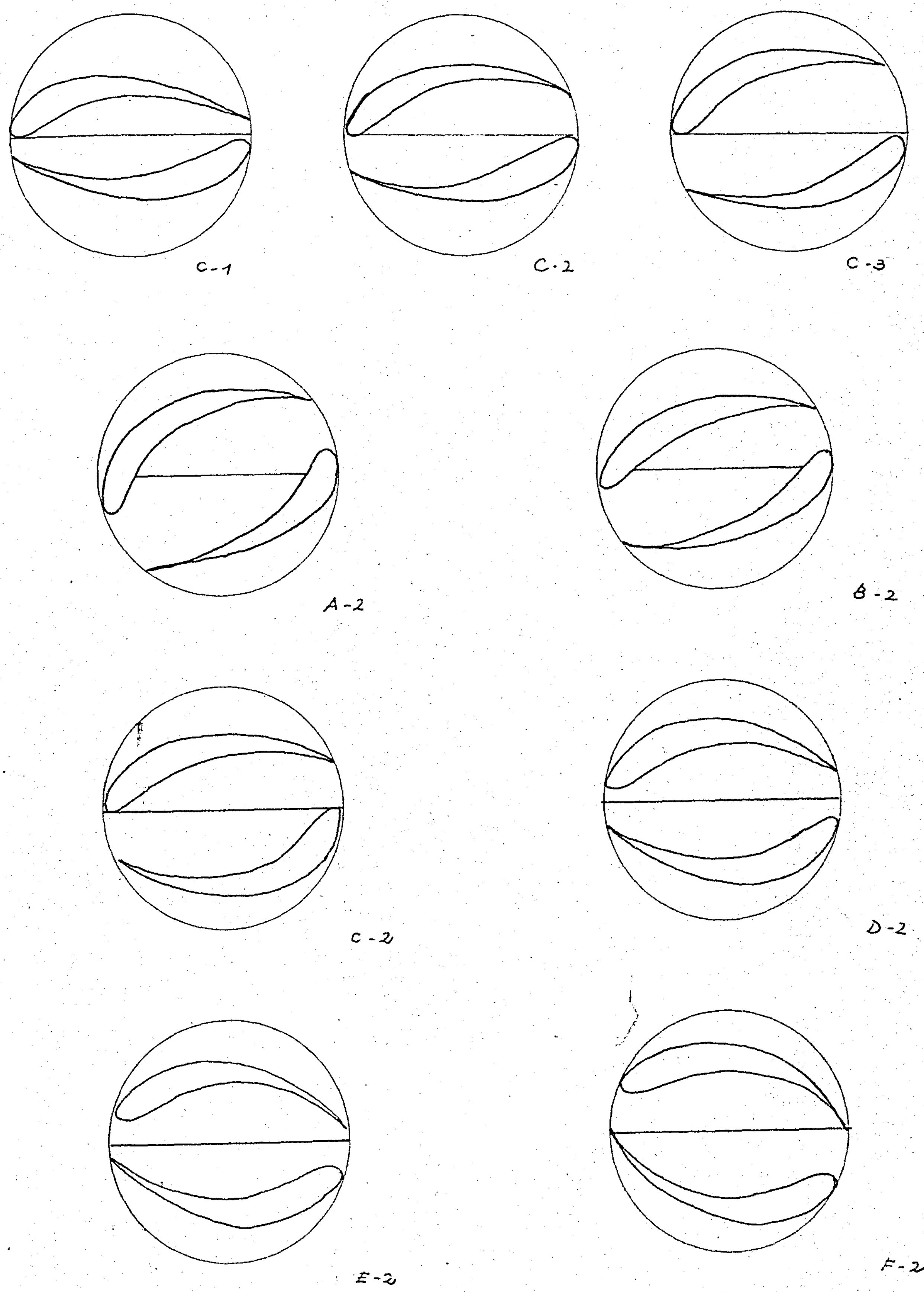
Express type



Two stage

Fig 5.45-2

Impala rotors (1:5)



(1:5)

Fig 5.45-3

Impala rotors for different angles

x	y_1	y_2
0	-	2.5
5	2.5	17.5
10	8.0	24.0
15	13.0	28.0
20	16.5	31.0
25	20.0	33.0
30	23.5	34.5
35	25.5	36.0
40	27.5	37.0
45	29.0	38.0
50	30.0	38.0
55	31.0	38.0
60	31.0	37.5
65	31.0	37.0
70	31.0	35.5
75	30.0	34.0
80	29.0	32.5
85	27.5	30.5
90	25.0	28.0
95	22.0	24.8
100	20.0	20.0

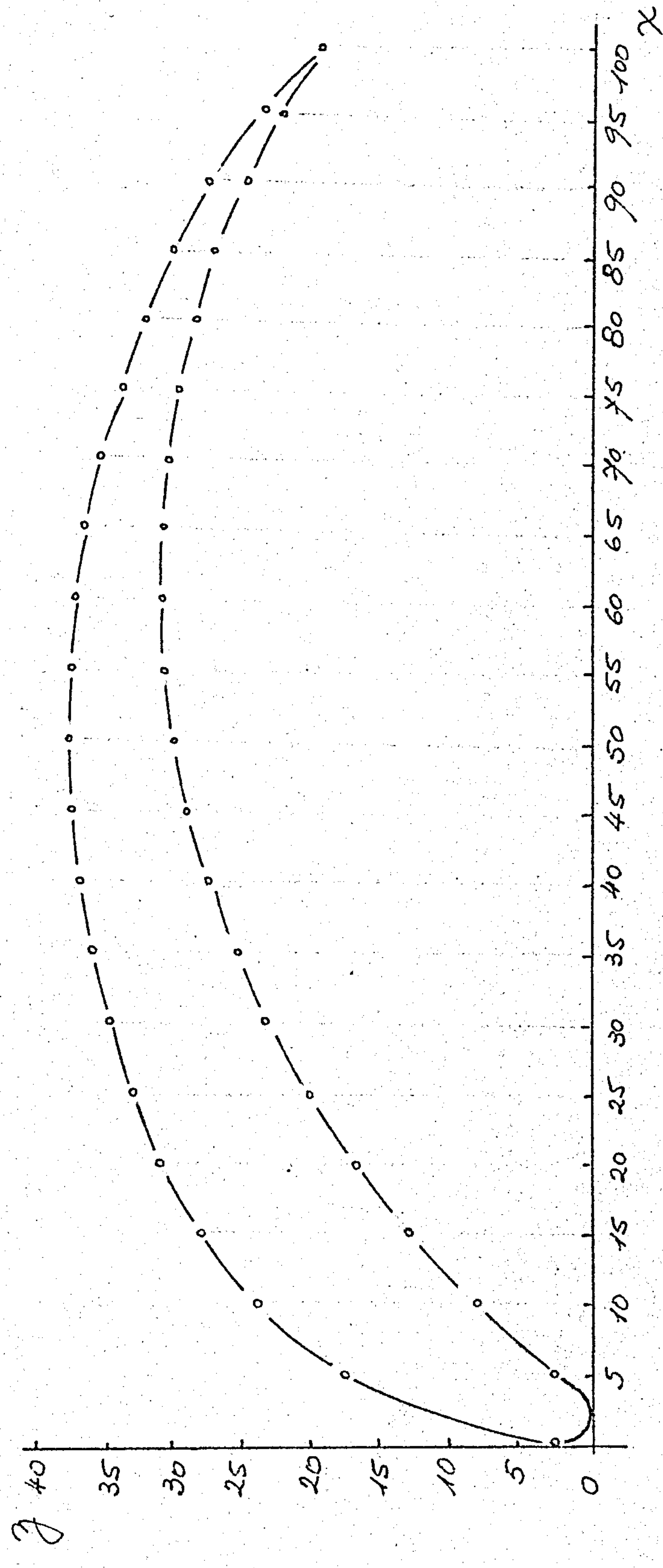


Fig 5.46-1

(1:1) Impala rotor blade profile

e) Rotor V (two separate stages) D: 10 cm $H_1:H_2$: 16 cm

f) Rotor with variable blades D : 21.9 cm H: 20 cm

g) Express type rotor D: 21.9 cm H : 60 cm

h) Two stage rotor D : 21.9 cm H_1: H_2 : 20 cm

5.46 Blade profile

The airfoil profile used for the Impala rotor can be constructed by plotting its values of (y_2) upper chamber and (y_1) lower chamber against the distance (x). Values are given in percent so any size of profile can be obtained by multplying all values by the disired factor. (Fig 5.46-1)

5.47 Manufacture of blade profiles

1. Sheet cutting
2. Filing sheet edges
3. Forming with pattern
4. Soldering
5. Cutting edges
6. Filling excess solder
7. Turning edges

Equipment: scissors, files, scriber, measure, triangle, solder soldering material and flux, wooden hammer, brush.

" Yiğit olan döne döne doğulür." (Köroğlu)

6. DATA AND RESULTS

6. 1 Visualization of fluid flow

1. Schlieren apparatus

After several trials and adjustments of the apparatus, a working area of 5 cm in diameter was obtained, the image being of the same size as the object but inverted. The working area being very small the experiments were discontinued. (Fig 6.1-1)

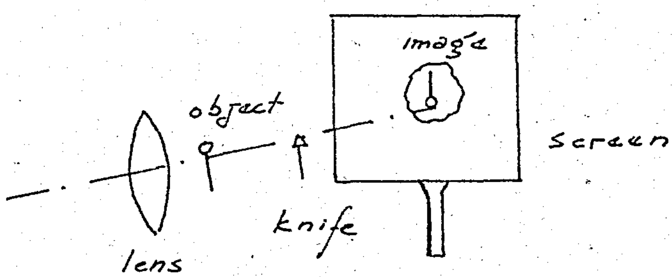


Fig 6.1-1

Schlieren apparatus

2. Water flow channel

It was possible to investigate the eddies and vortex developed in airfoil profiles. The results are sketched in Fig 6.1-2 to 4. The channel width is 320 mm and 9 to 12 pellet sources can be placed to generate the parallel streamlines.

It must be remarked here that this experiment represents only the flow pattern around stationary blades. Flow pattern change with moving airfoils. It was possible to observe the halo effect around the blades due to retardation in the flow, Also some of the point sources did not generate any streamline because they were disturbed by the objects introduced in the flow; these are shown as "backflow". The adjustment of the water flow is an important factor in the success

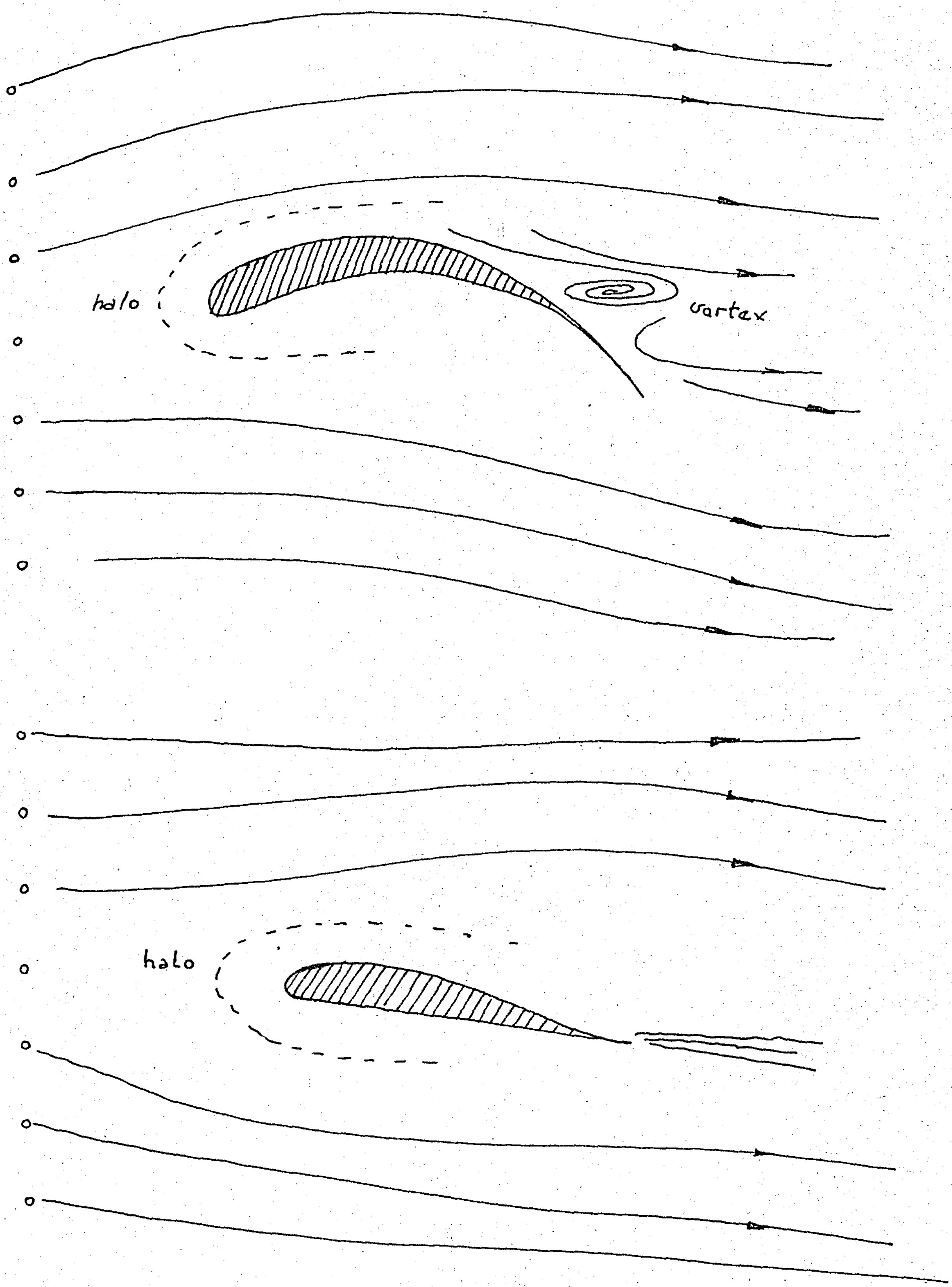


Fig 6.1-2

Water flow channel I

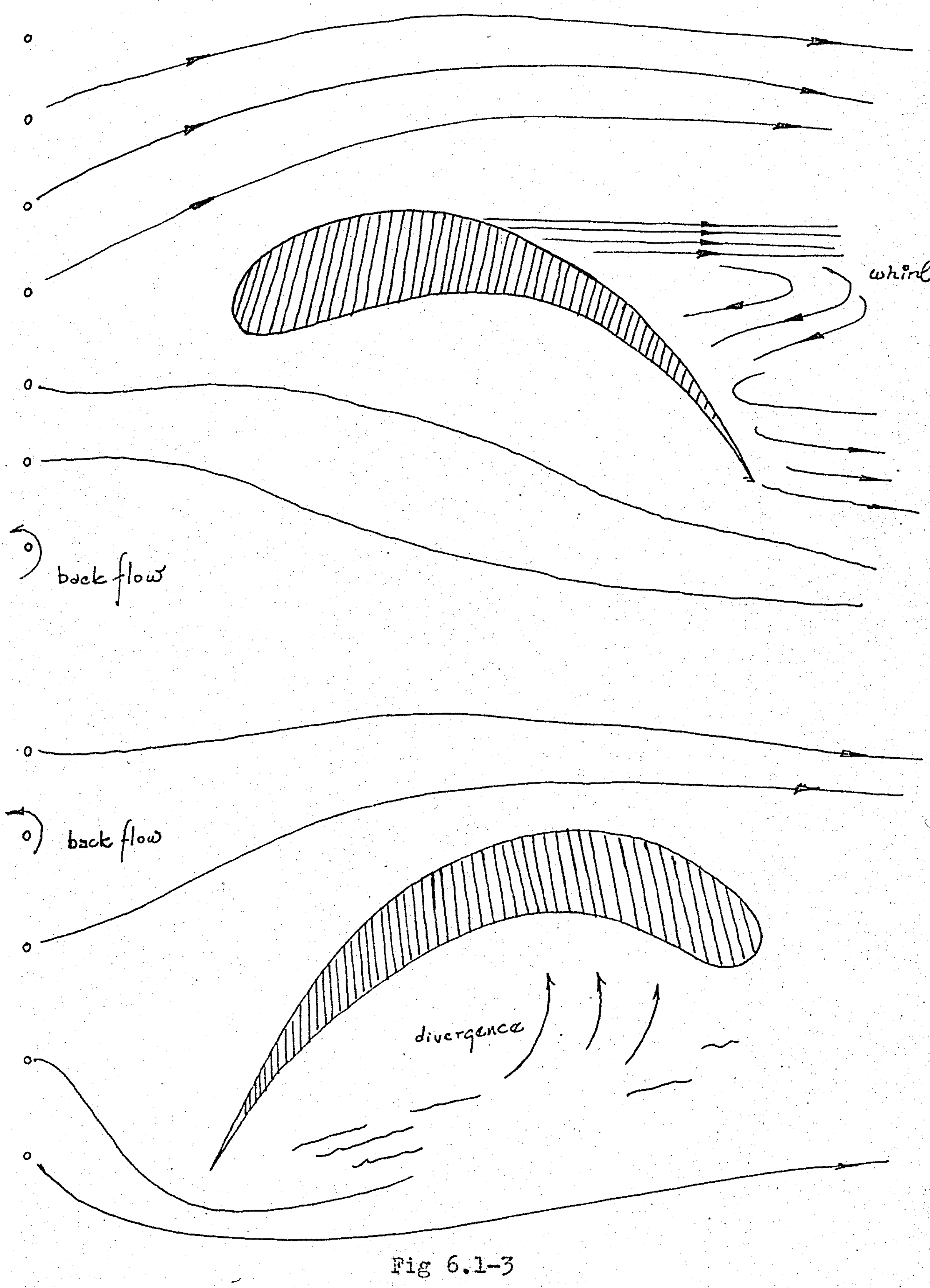


Fig 6.1-3

Water flow channel II

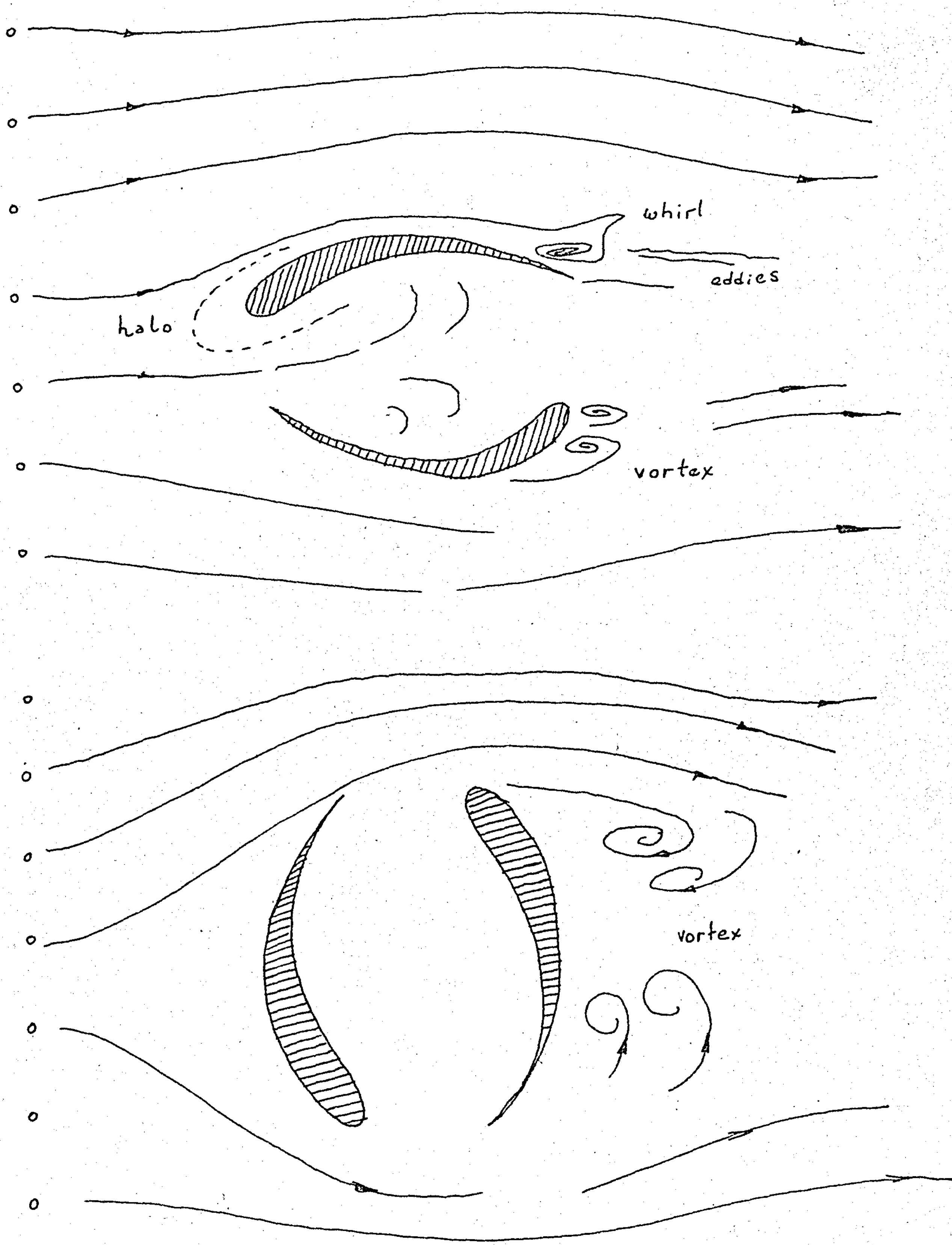


Fig 6.1-4

Water flow channel III

of these experiments. Models must be heavy enough not to float.

6.2 Preliminary data on wind rotors

Results obtained on June 30, 1964:

Wind velocity 650 m/minute

Rotor I (one stage)	640	r.p.m.
Rotor II (express type)	650	
Rotor III (two stages)	320	
Rotor IV (three stages)	420	
Rotor V (two separated stages)	320	

6.3 Data on different angles of attack

1. .Preliminary data

Results obtained on March 20, 1965

Wind velocity 650 m/minute

a) Impala rotor

	L 1	2	3
A	355/- *	285/40	280/200
B	340/-	210/230	395/240
C	285/-	295/240	440/220
D	285/-	310/260	370/20
E	320/45	300/300	520/40
F	410/-	520/310	520/40

* r.p.m. values both in clock- and counterclockwise direct.

b) Savonius S-rotor

900 r.p.m.

2. New data

After the wood stand was fixed and the ball bearings aligned, the following results were obtained on June 3, 1965

a) Impala rotor

	2	3
A	220/520	580/540
B	490/510	500/370
C	585/580	610/440
D	550/500	600/420
E	600/550	540/40
F	–	625/40

Rotor II, Express type , 10 cm in diameter : 620 r.p.m.

b) Savonius S-rotor

940 r.p.m.

6.4 <u>Data in the wind tunnel</u>

Using the metal stand and the E - 2 position of the İmpala rotor the following results were obtained in the wind tunnel on June 4 , 1965:

Wind velocity	R.p.m.
540 m/min	200
600	250
700	290
780	360

6.5 Data on new rotors

Using the metal stand in the wind tunnel the following data was obtained in June 10, 1965 with the new Impala rotors :

Wind velocity 600 m/min

Express type, 20 cm diameter : 280 r.p.m.

Two stage 20 cm diameter : 320 r.p.m.

6.6 Discussion of results

1. From the experiments on the angle of attack of the blades of the Impala rotor, it was seen the large variety of speed of rotation available. Certain blade positions give high rotation in one direction only, others a high rotation in one direction and low rotation in the other, and finally some give the same speed in bothe directions.

2. Experiments on the Savonius S-rotor showed a very high speed of rotation: 940 r.p.m. (compared with the same size Impala rotor of 640 r.p.m.) , but with the disadvantage of one directional rotation.

3. Experiments with the Express type Impala rotor showed that it is possible to obtain very high speeds of rotation.

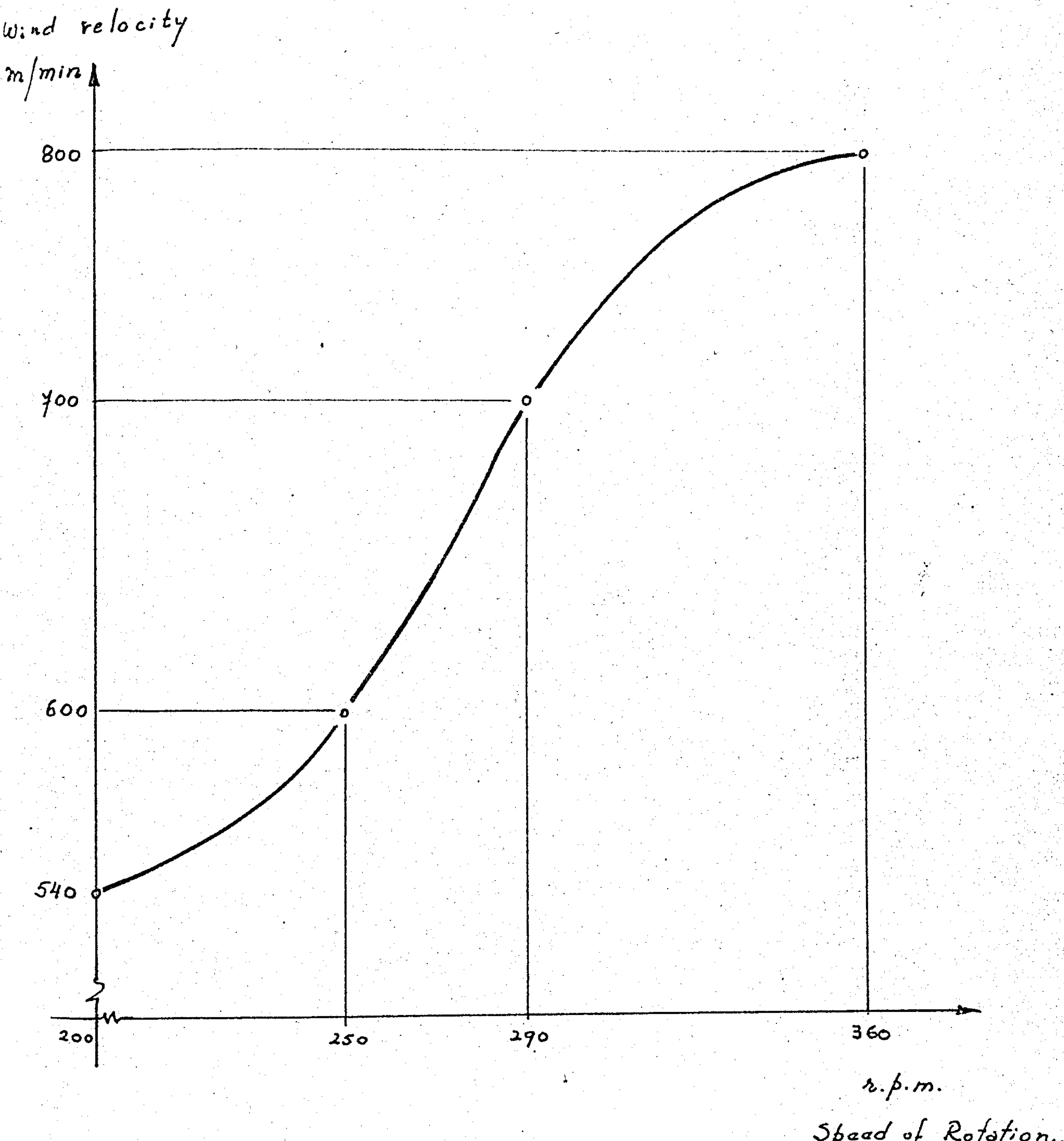


Fig 6.6-1

Wind velocity vs. speed of rotation

4. Experiments with multi-stage Impala rotors showed that there is a wide range of performance characteristics that can be obtained from this type of rotor.

5. Experiments in the wind tunnel with different wind velocities shows an approximate cubic relation when plotted in a graph, as seen in Fig 6.6-1.

6. Although it was not possible to make accurate measurements of power output, an attempt to find a mathematical relation between the power and the speed of rotation was made:

Power is expressed by the formula-

$$P : \frac{T \cdot n}{75} \quad \text{in h.p.}$$

From Fig 6.6-2

$$T : F \cdot t$$

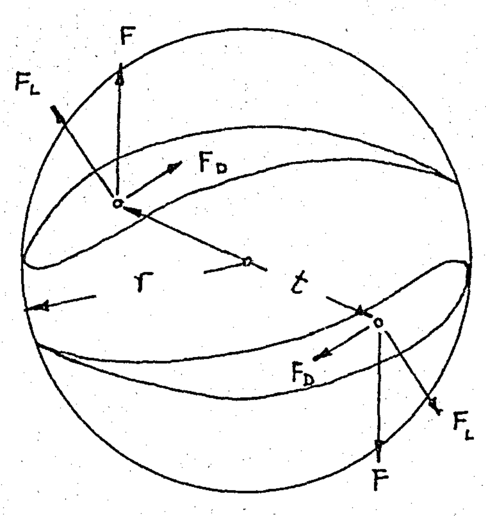


Fig 6.6-2

Power output

The force is the resultant of the lift and drag forces on the airfoil blades, (see 3.26) :

$$F : (F_L^2 + F_D^2)^{1/2}$$

where

$$F_L : C_L \cdot \rho \cdot A_L \cdot V^2/2 : k_L \cdot V^2$$

$$F_D : C_D \cdot \rho \cdot A_D \cdot V^2/2 : k_D \cdot V^2$$

The velocity at the tip V is :

$$V : \omega \cdot r : \frac{2 \pi n}{60} \cdot r \text{ , so } n : 60 V / 2 \pi r$$

Finally the power output is:

$$P : \frac{k \cdot V^2 \cdot t \cdot \frac{60 \cdot V}{2 \pi r}}{75}$$

$$: k \cdot V^3 \cdot \frac{60 \cdot t}{2 \pi r \cdot 75}$$

where

$$k : (k_L^2 + k_D^2)^{1/2}$$

This analysis shows the cubic relation between the power output and the velocity, but it is only a simplification of the actual case, since the effects of the following items are neglected:

a) Circulation lift of the whole rotor when rotating in a parallel flow.

b) Pressure drop developed in the airfoil upper chamber due to the air flow chamber occuring between the disks in the outer region

c) Streamline formation around the cylinder rotating arround his axis, wth the development of eddies near the disks.

d) Blades changing constantly their position, change the forces and their point of application.

e) Effect of the blades upon each other.

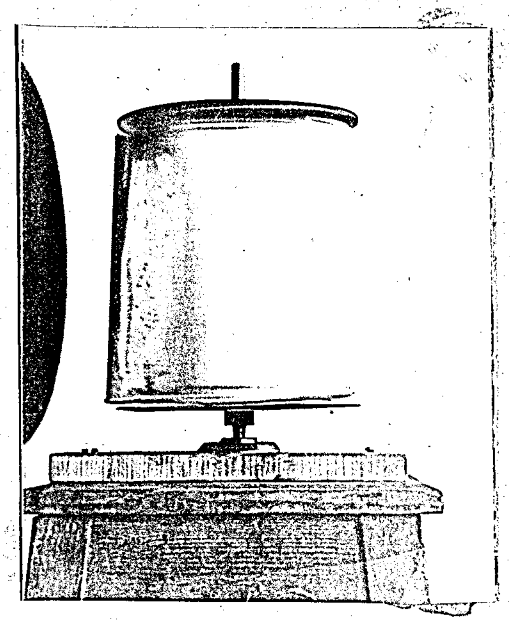


Fig 6.6-3

Running conditions

" Ayağını yorganına göre uzatmalı."

7. ECONOMIC CONSIDERATIONS

7. 1 Economic survey

"Engineering is the economic solution of human needs". For this reason it is necessary to analyze the role of wind power in the frame of the energy generated in a given community.

A suggested outline for an economic survey on wind power is as follows:

1. Power demand analysis
   - Population and population growth
   - Per capita power demand
   - Power demand forecastings
2. Power supply analysis
   - Thermal power plants
   - Hydroelectric power plants
   - Local power sources: windmills, watermills, etc.
3. Power sources available
   - Oils
   - Coal
   - Solid fuels
   - Gas
   - Water heads
   - Local fuels (waste, wood, tar, peat, etc.)
   - Solar
   - Wind
   - Nuclear
   - Other

4. Comparative cost analysis

   - Thermal

     a) Oil

     b) Coal

     c) Gas

     d) Nuclear

   - Hydroelectric
   - Solar
   - Wind
   - Geothermal
   - Local fuels

5. Planning of power generation

   - Balancing of supply and demand
   - Location of power plants (according to lowest cost)
   - Research

In this way it is possible to determine the position of each power eneration method in the whole economy. In those regions where wind ower offers economic solutions, planning and fometing the utili- ation of this power source may be possible.

7.2 Design of wind rotors

Assuming that the result of the economic survey shows possibilities f using wind power, the design of the wind machine follows. Here s a procedure for the design of wind rotors:

1. Determination of the power demand

   a) Field of application

b) Capacity

2. Determination of the wind power available
3. Design of the rotor
   a) Calculation of cross section area
   b) Calculation of speed of rotation
   c) Determination of performance characteristics
4. Design of rotor shaft
5. Selection of bearings
6. Design of bearing housing
7. Design of tower
8. Design of power transmission mechanisms (couplings, gears)
9. Selection of auxiliary equipment (pump, generator, fan, heat pump, refrigerator, etc.)
10. Design for storage (water tank, batteries, etc.)
11. Design of governor.

7.3 Cost analysis

In order to calculate the cost of a wind rotor the following items hould be considered:

1. Materials
   - Blade sheets
   - Disc sheets
   - Shaft
   - Bearings
   - Housing
   - Tower members
   - Power transmission mechanisms

- Paint
- Welding material
- Storage
- Lubricant

2. Labor
   - Cutting
   - Welding
   - Lathe
   - Foundation
   - Erection

3. Equipment
   - Lathe
   - Drill
   - Welding
   - Files
   - Saw
   - Scissors
   - Wrenches

4. Maintenance

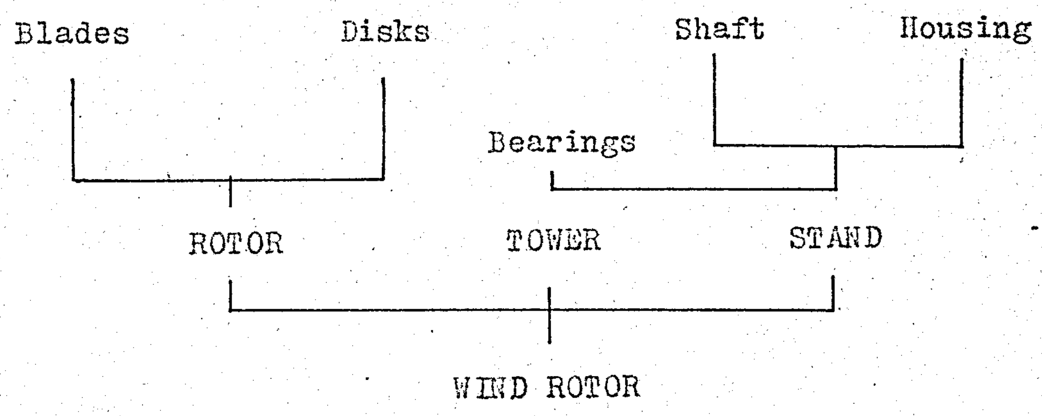
7.4 Manufacture of wind rotors

The following items should be considered in the manufacture of nd rotors; for production in lots:

1. Prepare pattern of blades
2. Measure blade overall length
3. Mark lengths on metal sheet

4. Cut blade sheets
5. File edges of sheets
6. Form blades in the pattern
7. Weld blades
8. File welded surfaces
9. Mark end disks and cut
10. Weld end disks to blades
11. Cut shaft
12. Lathe shaft to size
13. Cut bearing housing pipe
14. Lathe bearing housing to size
15. Make transmission mechanism
16. Cut and weld tower profiles
17. Paint
18. Lubricate bearings
19. Erect tower
20. Mount housing and shaft
21. Mount rotor

A routing diagram for the manufacture is as follows:



7.5 Comparative economic analysis

As in any other engineering project, it is necessary to find a criteria to analyze the different feasable alternatives. A comparative analysis of the following items in necessary:

1. Optimum size selection
2. Determination of best location
3. Selection of number of units
4. Materials alternatives analysis
5. Comparison with other power sources
6. Make or buy analysis

In order to give an example and also an idea of the order of magnitud, the comparative cost analysis between a gasoline engine and a wind rotor in pumping water is taken. Assumed power 2.5 kw and 20 m water column.

1. Calculation of the cross section area

$$P : 0.0006 \cdot A \cdot V^3 \quad \text{(see 2.33)}$$

$$A : \frac{P}{0.0006 \cdot V^3}$$

Assume a maximum wind velocity of 12 m/sec.

$$A : \frac{2.5}{0.0006 \cdot 12^3} : 2.5 \ m^2$$

Take a diameter of 0.75m and a height of 3.5 m

2. Cost estimation of shop

- Shop area 100 m^2 x 400 TL/m^2 — 40.000 TL

- Equipment

Lathe	30.000 TL
Drill	2.000
Welder	3.000
Files	10
Saw	25
Scissors	100
Other	100

35.235

- Erection (15% of equipment) — 5.000
- Power (15% of buildings) — 6.000

86.235 TL

3. Cost of materials (per unit)

- Blade plates	110 TL
- Disk plates (3 mm)	20
- Shaft (30 mm diameter	8
- Bearings (3 x 30 mm)	50
- Bearing housing pipe (2")	3
- Tower members	100
- Coupling	15
- Paint	7
- Welding material	29
- Storage tank	200
	632 TL

4. Cost of labor (per unit)

- Cutting and welding rotor

  1 worker x 2 days x 30 TL/day — 60 TL

- Cutting and welding tower

  1 worker x 2 days x 35 TL/day — 70

- Lathe and erection

  1 worker x 1 day x 35 TL/day — 35

  165 TL

5. Cost of general expenses (per unit)

   10 % of total cost — 100 TL

6. Cost of overhead charges

   Depreciation of buildings 2% per year

   $$\frac{40.000 \text{ TL} \times 2\% \text{ year}}{8.000 \text{ hrs/year}} : 0.10 \text{ TL /hr}$$

   Depreciation of machinery 10% per year

   $$\frac{46.235 \text{ TL} \times 10\% \text{ year}}{8.000 \text{ hrs/year}} : 0.57 \text{ TL/hr}$$

   Total depreciation : 0.67 TL/hr

   Working hours per unit : 25 hrs

   Overhead charges per unit : 0.67 TL/hr x 25 hrs : 16.80 TL

7. Cost of product

   Materials — 632 TL

   Labor — 165

General expenses	100
Overhead charges	16.80
	913.80 TL / unit

8. Cost of water

If we assume that the average annual wind velocity is 8 m/sec, the power output is :

$$P : 0.0006 \times A \times V^3$$

$$: 0.0006 \times 2.5 \times 8^3 : 0.7 \text{ kw.}$$

This power will pump :

$$P : \frac{Q \cdot H}{75 \cdot \eta}$$

$$Q : \frac{P \cdot \eta \cdot 75}{H} \qquad \text{take } 80\% \ \eta$$

$$: \frac{0.7 \times 0.80 \times 75}{20} : 2.1 \text{ kg/sec}$$

$2.1 \times 3600 \times 8000$ x: 60500000 l/year : 60,500 m^3/year

Depreciation 10%	91.40 TL
Maintenance 5%	45.50
	136.90 TL/year

$$\frac{136.90 \text{ TL/year}}{60{,}500 \text{ m}^3\text{/year}} : 0.00225 \text{ TL/m}^3$$

9. Cost of power with a gasoline engine

Cost of a 2.5 kw gasoline engine 1.500 TL

Erection 10% of cost		150	
		1.650 TL	
Depreciation 10%	165 TL		
Maintenance 10%	165		
			330
Fuel : 0.3 kg/hr x 8000 hr x 1 TL/kg			2.400
			2.730 TL

The amount of water pumped is:

$$Q : \frac{P \times \eta \times 75}{H}$$

$$: \frac{2.5 \times 0.80 \times 75}{20} : 7.5 \text{ kg/sec}$$

7.5 x 3600 x 8000 : 216000000 l/year : 216.000 m^3/year

$$\frac{2.730 \text{ TL/year}}{216.000 \text{ m}^3\text{/year}} : 0.0125 \text{ TL/ m}^3$$

10. Comparative analysis

Wind rotor : 0.00225 TL/m^3

Gasoline engine : 0.01250 TL/m^3

Although it is not possible to take the cost of water as the sole riteria for the selection of any of the alternatives, this figures give an idea about their reletive values. The following factores are not considered in the above analysis:

- Higher investment required by the gasoline engine
- Difficulties in the transportation of fuel
- Difficulties in the maintenance of gasoline engines
- Need for fuel storage

7.6 Conclusion

In order to obtain the most favorable design the following items should be considered:

1. Determination of the capacities and type of work in which the wind rotor is going to be used.
2. Standardization of sizes according to a certain range
3. Use of modern manufacturing techniques and materials to reduce cost and increase the efficiency.
4. Design of portable units, middle size units and large size units for power generation.

" Hiç ... "

8. SUMMARY AND CONCLUSION

1. Object

The aim of this work is to study the possibilities of the utilization of wind rotors for the generation of power in underdeveloped areas.

2. Historical background

The first evidence of the utilization of wind power in Europe dates from the year 1000 A.C. in England. Nevertheless it is assumed that the cradle of the windmill may be found in the Mesopotamia towards 1500 B.C.

The first important application of wind power is found in Holland in 1350, with the object of draining the land situated below the sea level. During the 18 century several engineering designs were put into practice with the main purpose of pumping water.

The first scientific research on wind power was carried by Prof. La Cour in Denmark towards 1890, using a small wind tunnel to test models. After the World War I, several famous engineers became involved in the design of more efficient windmills: Prandlt, Betz, Joukowsky, Eiffel among others.

In 1924 Flettner developed the first rotorship Baden Baden, which used rotating cylinders instead of sails, to create a thrust based on the lifting effect of a rotating cylinder in a parallel flow, effect first investigated by Magnus. He also studied the possibilities of using rotors to design wind machines. During the same years Savonius designed his S-rotors (two circular blades placed one in front of the other, between two end disks) and used them for pumping water, ventilation and sailing. The idea of using rotors (cylindrical shaped windmills with vertical shaft) was soon abandoned because it was considered of low efficiency.

In 1941, The Smith Putnam project was started in the United States. It consisted of research and experimentation on a 1000 kw, 2 blade wind machine. The erection and operation of such a huge machine proved to be very complicated and commercially not feasable. The whole project had to be discontinued when one of the blades failed.

In 1949, the British Electrical and Allied Industries Research Association started a research program on wind power with two 100 kw units placed in the windiest region of the world, in the north of England. This units also were very big, and a simpler type 25 kw unit was designed and tested. The research showed that complicated wind machines having variable pitch were not practical.

In 1951 Israel started a research program which went gradually from small size units to large size plants, together with a very wide meteorological survey.

In France some experimental work was carried by the Neypric Co. using aerogenerators up to 21 m in diameter with satisfactory results.

In 1957 a small vertical rotor of a cross section of 0.1 m^2, with an average output of 1 watt was tested in U.S.A. with satisfactory results.

Finally the research work started by Prof. Taşpınar on the Impala rotor has to be mentioned. This rotor consists basically of two air-foil profiles placed one in front of the other between two end disks. Study of the performance characteristics of this rotor showed the possibilities of designing Express type (height equal four or more times the diameter) and Multi-stage (rotors placed one on top of the other at different angles) rotors with good perspectives. This rotor has also application in other fields.

From the research carried up to date the following information about the design of wind machines was found to be interesting:

a) It is possible to have an idea about wind regimes in a region from the study of the deformation of trees.

b) In order to analyze the available wind it is necessary to plot the yearly wind duration curves (number of hours each wind velocity blows per year).

c) Wind power is calculated from the empirical relation,

$$P : 0.0006 , A . V^3$$

where A is the cross section area of the machine, in m^2; V the wind velocity and P the power in kw when the velocity is expressed in m/sec.

d) Wind rotors have the advantages that they can start at low wind velocities, run at very high veloctíes and run with winds coming in all directions without the need for adjustment.

3. Theoretical background

The theory of rotors deals with the study of the lift developed when a cylinder is rotated in a parallel flow. Here there is a superposition of parallel flow, source flow and circulation, which cause a pressure difference to develop between the lower and upper portion of the rotating cylinder with the consequent creation of thrust or lift.

The study of the airfoil lift and drag forces is an important tool for the mathematical analysis of rotors.

From kinetic energy considerations it is possible to calculate the maximum theoretical efficiency of a wind machine, which comes out to be 59.3%.

4. <u>Practical considerations</u>

a) Wind measurement

In the study of the characteristics of wind two instruments are used : the wind vane and the anemometer. The data obtained can be represented graphically on maps by means of the wind rose, which fixes the direction, speed and frequency of the winds. The average wind velocity can be taken as 8 m/sec.

b) Visualization of fluid flow

In order to have an idea about the flow characteristics around submerged bodies, several flow visualization techniques are available among which the Schlieren optical method and the Hele-shaw analogy are the most practical. The first one uses the principle of change in defraction due to a change in density of the fluid, this change being projected by means of difracted rays; the second one uses dyes such as potassium permanganate to visualiza streamlines

c) Selection of bearings

In order to select a bearing from a catalogue, the speed of rotation the expected life, the axial and radial forces have to be calculated. The dynamic load is determined and the bearing selected according to the required dimensions

d) Rotor balancing

In order to obtain a satisfactory performance of a rotor it is necessary to balance it statically and dynamically, special apparatus being deviced to measure the amount of unbalance from the vibrations, balancing being performed by adding or substracting weights by trial and error.

e) Shaft design

The diameter of a shaft is given by the expression:

$$d : \left(\frac{16 \cdot M_d}{\pi \cdot \sigma_d} \right)^{1/3}$$

the deflection of the shaft having also to be controlled

f) Soldering

Careful selection of solder material and flux are prerequisites for good soldering. The cleanness of the surface and the clearance between parts should also be checked.

g) Speed governors

In order to control the speed of rotation it is necessary to include in the design speed control systems; flaps being a good solution for controlling the speed in wind machines

5. Experimental set-up

a) Schlieren apparatus

The result obtained in the Schlieren apparatus were not satisfactory and the experiments were discontinued

b) Water flow channel

In troducing potassium permanganate pellets in the laminar flow channel it is possible to study the streamline formation around solid bodies.

c) Wind rotor models

Several models for wind rotors were manufactured, including a Savonius S-rotor, an Express type Impala rotor and a Multi-stage Impala rotor.

6. Data and results

The experiments on the Impala rotor showed a wide variety of performance characteristics from one directional rotation to rotation in both directions The maximum speed rotation obtained with the models was 640 r.p.m. The high torque developed caused some troubles in the stucture and reinforcement of the stand was found necessary.

The Savonius S-rotor of the same size developed a maximum of 940 r.p.m. It was also possible to see the relation between wind velocity and speed of rotation.

A theoretical analysis of the power developed by an Impala rotor was attempted, but this had to be done making too many simplifications, the actual case being too complicated.

7. Economic considerations

In order to determine the economical importance of wind power it is necessary to make an economic analysis and see the relative importance of all power generation sources. The cost analysis of 2.5 kw wind turbine was made, and the cost of one unit together with a storage tank for water was found to be around 1.000 TL , The analysis of modern manufacturing techniques and materials remains to be done.

8. Conclusion

This work should be considered only as an introduction to the problem. Through the survey on the available data it was possible to see the trend in the development of wind machines and have a glimpse to what the future may be. The examples of Holland, Denmark and Israel in developing a program for the utilization of wind power should be remarked. Many fields of application for wind power have been found:

- water pumping
- electricity generation
- grinding of corn
- sawing
- compressing air or other gases
- refining metals
- ice production
- water destillation
- domestic appliences
- production of hydrogen
- cooking
- creating a water head

- heating and cooling
- ventilating
- ship propelling

The experiments on wind rotors although are not complete, they are very promising and more investigation should be carried in order to get better idea about the performance characteristics of different types so as to apply this information in the design of desired types

It remains to make a complete economic analysis of the problem and make the planning and implementation program for the utilization of wind rotors in communities of scarce resources.

" Nasibimizi aldık ... "

" Yıktın perdeyi
Eyledin viran
Varayim sahibime
Haber vereyim heman. "

(Karagöz)

" İyiye ve güzele doğru."

9. R E C O M M E N D A T I O N S

The following items require further work :

*1. Measurement of the torque by means of a stationary rotor placed in the air flow, using calibrated springs.

*2. Study df the flywheel effect in the rotors.

3. Design of bearing housing for self-lubrication.

4. Study of the possibilities of the utilization of wind rotors for ventilation, electricity generation and water pumping.

5. Improvement of the wind tunnel design.

6. Study of the influence of the rotor weight on the performance.

7. Study of the effect of increasing the diameter of disks.

*8. Design of disks with airfoil shape. (Fig 9.1)

*9. Increase of the number of stages to 6 and 9 .

10. Study of the difference in output in the natural wind.

*11. Study of the eddy formation in the multi-stage rotor in the water flow channel.

*12. Study of the streamline formation around the blades and disks, using blades fixed to glass disks in the water flow channel.

13. Improvement of manufacturing processes

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* Suggested by Prof. Adnan H. Taşpınar.

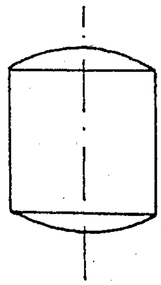

Fig 9.1

Airfoil disks

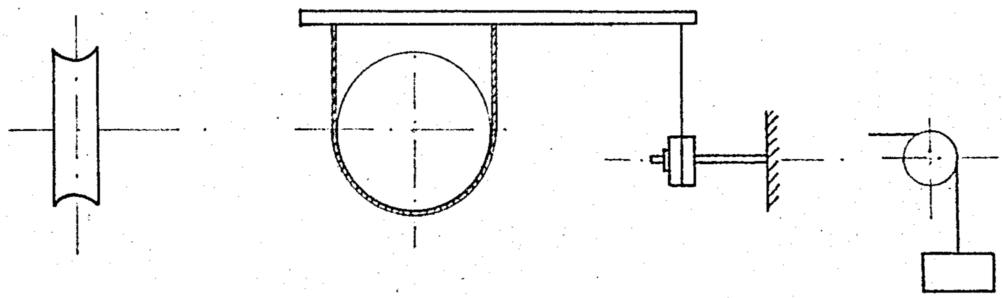

Fig 9.2

Prony brake

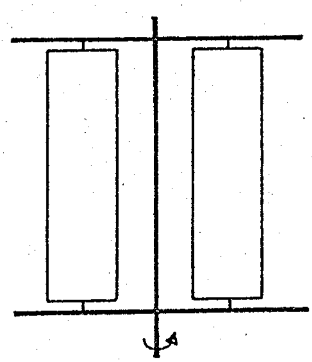

Fig 9.3

Rotor blades

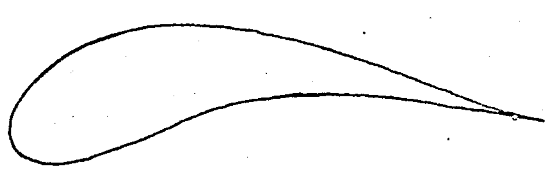

Fig 9.4

Blade profile

14. Contact Israel, India, Great Britain and Denamark to study the lattest developments in the field of wind power.

15. Use of plastic materials and aluminium for the manufacture of rotors.

16. Study the possibilities of casting plastic or aluminum blades for mass production.

* 17. MMeasurement of the output using a prony brake, to be compared with the maximum theoretical output. (Fig 9.2)

18. Study the effect of replacing the blades by two rotors. (Fig 9.3)

19. Study the influence of mass production in the reduction of cost.

20. Study the planning, financement and implementation of a wind rotor program.

21. Use of the Vibrodyne dynamic balancing apparatus for balancing the rotors.

* 22. Study of the performance of other blade profiles. (Fig 9.4)

23. Analysis of optimum wind rotor size.

* 24. Prepare circulation models:

a. cylinder placed in a troley. (Fig 9.5)

b. spinning cylinder (Fig 9.6)

* 25. Improvement of metal stand to account for the rotor yawning. (Fig 9.7)

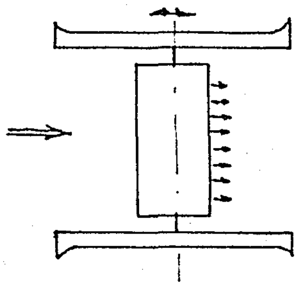

Fig 9.5

Troley model

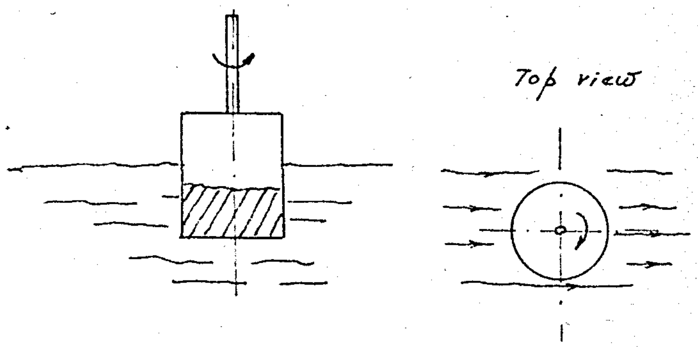

Fig 9.6

Spinning cylinder

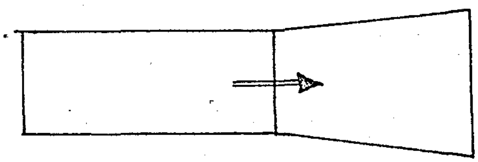

Fig 9.8 : Wind Tunnel diffuser

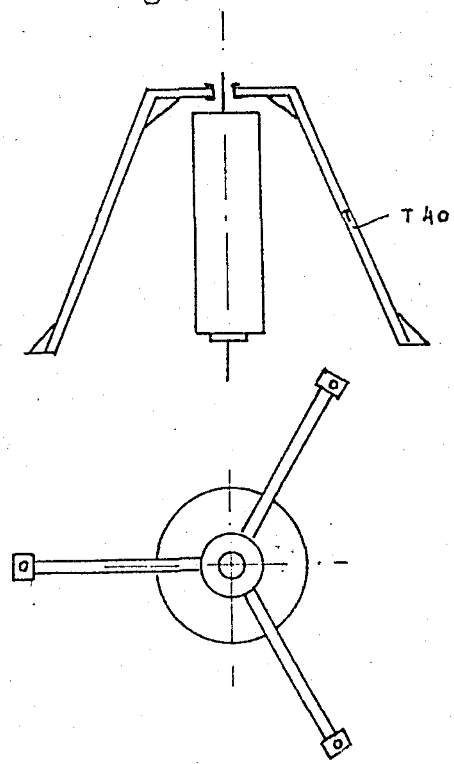

Fig 9.7

Reinforcement of stand

* 26. Improvement of the wind tunnel by adding a diffuser to reduce losses at the exit.

27. Survey of the Engineering Index for new literature.

* 28. Study of the blade flapping of very long Express rotors.

* 29. Improvement of the study of the performance characteristics of wind rotors with the purpose of obtaining data for the design of different types of rotors to serve in diffenent applications.

30. Survey on the Wind machine section of Hütte

* 31. Improvement of power transmission mechanisms for rotors.

" Anlıyana sivrisinek sazdır, anlamıyana davul zurna azdır. "

10. G L O S S A R Y

1. Fantail : special vane placed with tpe purpose of guiding a wind machine through changes in the wind direction.

2. Flapping: vibrations of the blades due to high vibrations.

3. Pitch: angle made by a blade with the axis of the rotor.

4. Governor: special device used to regulate the speed of rotation.

5. Motoring: power that is required to turn the wind machine without delivering any power.

6. N.A.C.A. : American Association dealing with the research of the Aeronautical sciences.

7. Tip velocity ratio: ratio between the speed of the tip of the rotor and the wind velocity.

" Çok okuyan değil çok gezen bilir ."

11. R E F E R E N C E S

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5. John Vennard "Elementary Fluid Mechanics" John Wiley and Sons. Inc. 1940

6. Victor Streeter "Fluid Dynamics" Mc. Graw Hill 1948.

C. Practical Considerations

1. R.C. Punhurst and D.W. Holder "Wind Tunnel Technique" Sir İsaac Pitman and Sons Ltd. London 1952.

2. Philip A. Drinker "Fluid Dynamics: Experiments andEquipment for Undergraduake Laboratory Instruction" M.I.T. 1965.

3. Lionel Marks "Mechanical Engineers' Handbook"

4. Adnan Halet Taşpinar "Machine Design Notes" Robert College Bebek Istanbul 1965.

5. Victor Streeter "Fluid Mechanics" Mc. Graw Hill 1958

6. James F. Young "Materials and Processes" John Wiley and sons Inc. 1954.

" Sabreden derviş, muradına ermiş."

12. A P P E N D I X

1. Correspomdance
2. Instructions for the operation of Wind Rotor experiments

1. Correspondance

THE ELECTRICAL RESEARCH ASSOCIATION

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Secretary: S. T. KILLICK, [illegible]

YOUR REF:
OUR REF: EWG/MTL

25th March, 1964.

Professor Adnan H. Taspinar,
Assoc. Dean of Engineering,
Robert College,
Bebek,
Istanbul,
Turkey.

Dear Professor Taspinar,

Thank you for your letter of March 23rd. I have pleasure in enclosing one or two papers which might be of interest to you in connection with your course on Energy Generation.

Although I have not got copies here, I suggest that you write to
Mr. A. D. Faunce, Chief, Agricultural Engineering Branch, Land and Water
Development Division, Food and Agriculture Organization of the United Nations,
Viale delle Terme di Caracalla, Rome, Italy, asking him to let you have, free
of charge, copies of Informal Working Bulletins No. 16: Possibilities for the
utilization of solar energy in underdeveloped rural areas, No. 17: Windmills for
water lifting and the generation of electricity on the farm, and No. 23: The
potentialities for rural electrification in Asia and the Far East.
I think these might also be useful.

Yours sincerely,

E. W. Golding,
Overseas Liaison Officer.

INSTRUCTIONS FOR THE OPERATION OF

WIND ROTOR EXPERIMENTS

1. Visualization of fluid flow
2. Savonius S-rotor
3. Angle of attack of Impala rotor
4. Express type Impala rotor
5. Multi-stage Impala rotor

1. Visualization of fluid flow.

1.1 Object

Study the flow pattern around different blade profiles in the water flow channel

1.2 Apparatus

- Water flow channel
- Potassium permanganate
- Blade profile models

1.3 Procedure

- Open the tap of the flow water channel.
- Wait until the water reaches the channel region.
- Adjust the tap and the gate until an uniform flow is obtained.
- Place pellets of potassium permanganate at the entrance of the channel at 1 cm from each other.
- Wait for an equilibrium in the flow to be reached, so as to obtain parallel flow streamline formation.
- Place blade models at 10 cm from the pellets.
- Change position of blades

1.4 Data

- Draw the flow pattern of different blade profiles with different positions.

_____ x _____

2. Savonius S-rotor

2.2 Object

Study the performance characteristics of the S-rotor

2.2 Apparatus

- Savonius S-rotor blades
- Metal sheet disks
- Fan
- Dynamo
- Tachometer
- Multimeter
- Wood stand

2.3 Procedure

- Mount blades on disks by means of its screws.
- Place the rotor on the wood stand and fasten the bolts
- Mount the dynamo
- Open the fan

2.4 Data

- Measure the output in volts and amperes
- Measure the r.p.m. at load and no load conditions

-------- x ------

3. <u>Angle of attack of Impala rotor</u>

3.1 Object

Study the performance characteristics of the Impala rotor at different angle of attack of its blades

3.2 Apparatus

- Impala rotor blades
- Metal sheet disks
- Fan
- Dynamo
- Tachometer
- Multimeter
- Wood stand

3.3 Procedure

- Fix the Impala rotor blades on the metal sheet disks
- Place the rotor on the wood stand and fasten the bolts
- Mount the dynamo
- Open fan

3.4 Data

- Measure the output in volts and amperes
- Measure the r.p.m. at load and no load conditions
- Make measurements in both directions (Clock- and counter - clock wise directions)
- Change blade positions using different holes available in the metal sheet disks and repeat the same procedure.

------ x ------

4. <u>Express type Impala rotor</u>

4.1 Object

Study the performance characteristics of the Express type mpala rotor.

4.2 Apparatus

- 10 x 25 Impala rotor
- 20 x 60 Impala rotor
- Wind tunnel
- Metal stand
- Tachometer
- Metal disks
- Anemometer

4.3 Procedure

- Mount the Express type Impala rotor on the metal stand
- Connect the AC motor to the mains. Start motor with the starting compensator. Connect the DC generator, adjust the voltage to 75 volts and connect the wind tunnel.fan.
- Start wind tunnel by means of its rehostat

4.4 Data

- Measure the r.p.m. with tachometer and wind velocity with anemometer.
- Change wind velocity and repeat measurements
- Plot r.pm. vs wind velocity.

------ x ------

5. Multi-stage Impala rotor.

5.1 Object

3.2 Apparatus

- Impala rotor blades
- Metal sheet disks
- Fan
- Dynamo
- Tachometer
- Multimeter
- Wood stand

3.3 Procedure

- Fix the Impala rotor blades on the metal sheet disks
- Place the rotor on the wood stand and fasten the bolts
- Mount the dynamo
- Open fan

3.4 Data

- Measure the output in volts and amperes
- Measure the r.p.m. at load and no load conditions
- Make measurements in both directions (Clock- and counter - clock wise directions)
- Change blade positions using different holes available in the metal sheet disks and repeat the same procedure.

------ x ------

4. <u>Express type Impala rotor</u>

4.1 Object

Study the performance characteristics of the Express type

Study the performance characteristics of the multistage Impala rotor.

5.2 Apparatus

- 20 x 20 Impala rotors
- Wind tunnel
- Metal stand
- Tachometer
- Metal disks
- Anemometer

5.3 Procedure

- Mount multistage rotor on metal stand
- Proceed same as 4.3

5.4 Data

- Measure r.p.m. and wind velocity
- Plot r.p.m. vs wind velocity.

-------- X -------

"Allah, insanlara bahşettiği nimetlerinin eserlerini görmek ister: Bilginlerde, öğretme zevki; amirlerde, adalet; zenginlerde, yoksullara yardım gibi ... "

A. <u>Criticisms by Prof. Adnan Halet Taşpınar</u>:

1. A report to be added as preface summarizing the content of the thesis with a conclusion at the end

2. Complete layout of a Pala Wind Rotor Power Station.

3. (1.1) a) Why wind power? Comparision between wind, heat power, nuclear power and water power. b) State the fact that as long as the world exist wind will exist; and if water is used for generating power why shouldn't wind be used too. c) Give reasons why wind power is not used, and state if there is any future for it.

4. (2.12) Prof. Taşpınar became interested in hydrodynamics even before teaching at Robert College. He was involved in the complete design of a water turbine, pump design, ICE scavenging and water wheel. The name given by Prof. Taşpınar to his rotor is "Pala Wind Rotor". The Pala wind rotor is suitable for the power generation with the least available head. For example it could be used in the "Akintiburnu Hydroelectric Power Station Project", using 4 or 6 rotors in series. Prof. Taşpınar followed closely the work by Prof. Forheimer, professor of Hydraulics at Robert College in the Bosphorus power project which used a head difference to generate energy. This project was not satisfactory, the Pala rotor being more efficient in this aspect. Power can be calculated taking the velocity of water as 5 nautic miles/hr.

5. (2.4) Wind power storage. Although use of batteries is uneconomical, wind power can be stored as water, compressed air, heat (i.e. heat pump). Even when part of the energy is lost in the conversion,

at least the wind energy is not lost.

6. (3.25) <u>Dipol</u> should be preferred to doublet. There is a similar effect in electricity.

7. (4) Design to be revised and rearranged. At first a design outline to be discussed. Weakness of this section is due to lack in the preparation in the undergraduate years and specially in Mechanical Drawing, Mechanisms, Machine Elements, and Machine Design courses.

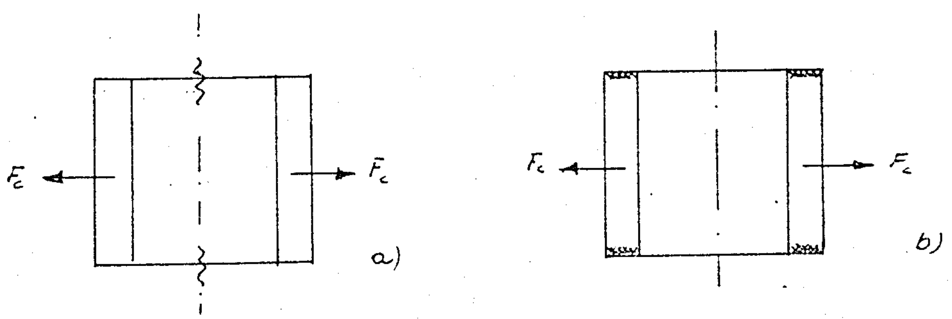
<u>Design Outline</u>:

1. Make a sketch of the design
2. List the component parts in all its details.
3. Specify materials of each part.
4. Take each component part and analyze all forces affecting from the mechanic and dynamic point of view: acceleration, inertia, stresses, stress, deformations, stress concentrations.
5. Make strength of materials calculations
6. Develop equations for the design of each part and apply them to various sizes and types. Tabulate the results.

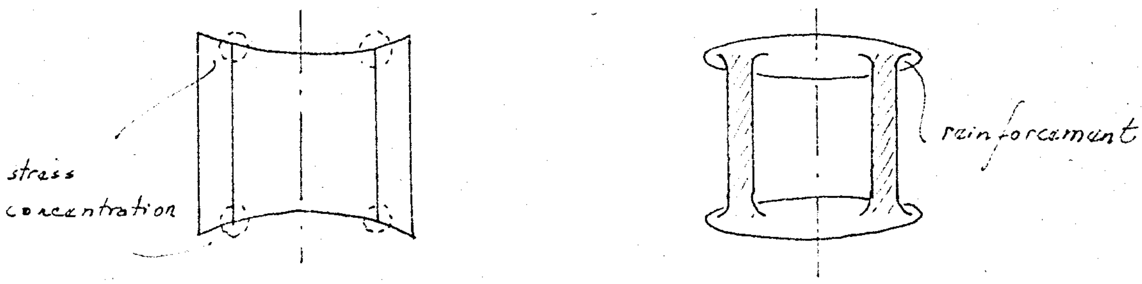
The following design analysis is required for the Pala rotor:

a) Forces on the end plates due to centrifugal force

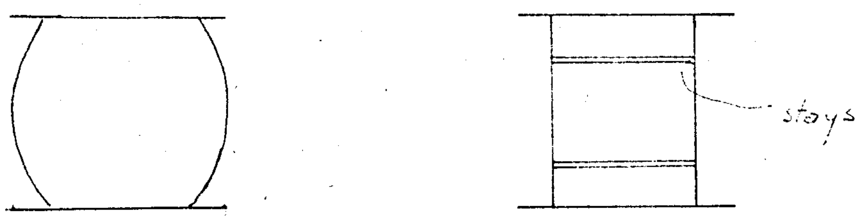
b) Forces on weldings due to centrifugal forces



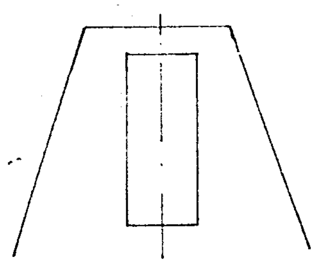
c) Stress concentrations at the blade ends due to the deformation of plates. Sresses can be reduced by reinforcement (fiber glass)



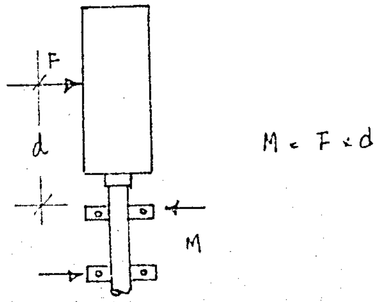
d) Deflection of the blades due to centrifugal forces. This deflec-
tions may be reduced by using stays across the blades.



f) Forces on rotor attachment to the main shaft. The attachment should be designed so to be easily dismantled.



g) Forces on bearings and main shaft: torsion and bending combined.



8.8. (4.1 and 2) Wind measurement and Visualization of fluid motion should be separate chapters.

9. (4.7) Governing of the Pala rotor should be expanded:

a) Study of the forces with position: velocity, torque and acceleration variations.

b) Study of the variations with wind velocity.

10. (7.2) To be revised adding items suggested.

11. (7.4) Plant layout for the manufacture of Pala rotors.

12. (7.5) To be expanded, proportions of the rotor to be 1/2.5.

13. (9) To be classified and rearranged in groups

14. (9.25) Yawning of the rotor is due to the suction effect. This effect should be investigated.

15. (9.26) Wind tunnel to be used for the Pala rotor testing should be of quite different design. The exit should be designed so as to reduce the turbulences. This can be cheked using the smoke techniqueb.

16. (3) Special chapter to be added on the theory of the Pala Wind Rotor

a) Aeorodynamics of the Pala Wind Rotor

b) Aerodynamics of the parallel flow between head plates

c) Efficiencies

- mechanical
- hydrodynamic
- volumetric (amount of air entering)

d) Performance characteristics of the Pala Wind Rotor.

e) Power output analysis per revolution.

B. <u>To be added</u>:

1. (1.1) e) Economic analysis in the operation

2. (1.2) d) Technical measurement

e) Engineering economics

f) Industrial Engineering

3. (2.12) Prof. Spannhake was Director of the Research Institute for Hydraulic Machinery in the Technische Hochschule.

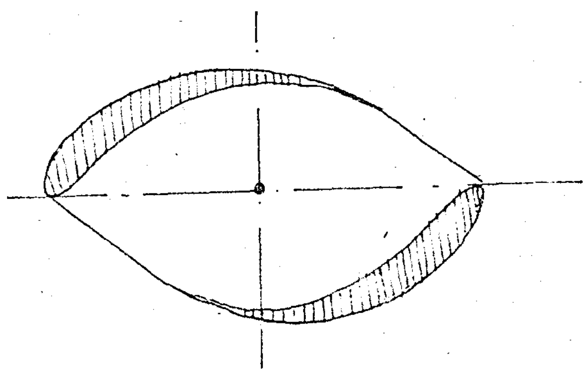
The use of rotor also in pumps, power brakes, power transmission mechanisms, fluid drive, fluid clutch, compressor, ICE etc.

4.. (2. 34) n) heat pump

5. (9.15) Glass-fiber reinforced plastics

6. (9.17) Prony brake or fluid brake.

June 17, 1965



Pala Rotor

(1941)