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PROSPECT, EVALUATION AND CHARACTERIZATION OF AEOLIAN ENERGY

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INTRODUCTION

Up to the development of the steam machine, in the second half of the 18th century, "the countries controlling the wind also dominated the world". Aeolian Energy, the sole mechanical and natural source of energy besides hydraulics, marked a long period of history with the creation of thousands of windmills. Nowadays, wind energy is considered a legitime precursor of industrial revolution, and consequently, of contemporary civilization.

Why then, is such an old technology not properly utilized at present?

Some reasons may be examined, such as the lack of continuity the wind presents and its low energy density if compared to other massive production forms of energy, among others. On the other hand, it has some advantages which should not be forgotten; this is to say, the direct access to this resource and its harmless nature with respect to the ecosystem currently such an important factor.

The energy crisis of the last decade pointed out the importance of utilizing alternative, renewable sources of energy, characterized by their low cost. The generation of energy from wind satisfies the first condition. Nevertheless, it cannot be said that it has a low production cost, since its technology has not been thoroughly researched, and the large scale production of equipment is still lacking, in order to reduce these costs, especially in Latin America.

Within the broad variety of long and medium-terms that Latin America possesses, Aeolian Energy is one of its most promising non-conventional energy sources. Its massive utilization supposes a substantial constribution of several million kilowatts to supply, particularly, domestic needs, and even the production needs of Latin American rural population of whose 150 million inhabitants, not more than 15%, are supplied with electricity.

The evaluation of the wind resource, as well as its future utilization to benefit the large marginal rural sectors of the continent, constituted the starting point of a coordination project carried out by the Latin American Energy Organization, OLADE.

The methodology proposed in this regard by the regional organization is based on the cooperation among the countries, by means of an integral utilization of the existing technical skills, and the coordinated research development carried out with respect to this renewable energy resource.

It is considered that the application of this method will permit the realization of an inventory of current Latin American Technology as necessary parameter for establishing an exchange and consulting mechanism, as well as studies regarding knowledge about the wind resource and its distribution, in order to prepare a regional atlas on levels of aeolian energy potential.

With this, the areas of interest would finally be determined, in which both the wind intensity and availability make it an interesting resource for electrical and mechanical utilization, in addition to the estimate of potential markets with a demand for the equipment this area could offer.

To a great extent, the project programmed by OLADE, is oriented towards diffusing the use of this resource, which has massively been concentrated in grain milling tasks and water pumping for agricultural and livestock activities on a small scale. It is intended, by means of a suitable technology, to emphasize decentralization, pluralism of techniques and local control, so as to be able to supply, to a certain degree the unsatisfied energy needs of the rural area.

OLADE expects that the studies presented herein will be useful to deepen the kowledge regarding Aeolian Energy, and suggests that this energy, currently so prominent may be the one blowing in the winds of Latin American's future.

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CHAPTER 1 - THE WIND AS AN ENERGY SOURCE

1.1 HISTORICAL BACKGROUND ON THE USE OF AEOLIAN ENERGY

From the historical point of view, we can state that a technological development stage exists between the old windmills and the present aerogenerators.

Although it cannot be stated with accuracy in which place of the world the first windmill was built, there are reasons to believe it was in Egypt, and that the crusades brought the idea from the near East to Europe. At the beginning of the XII Century there were windmills in the north of Germany, in the Netherlands and in Portugal.

In 1430, the knights of the Teutonic Order used windmills in drainage works and sewage into the Vistula swamp. The use of the wind was limited, for centuries, to pumping and milling.

The idea of transforming wind into electrical energy started with the research of the Danish scientist Paul Le Cour, carried out at the end of the last century. Le Cour considered mainly the aerodynamical aspects in relation with the cross of the windmill and, in a way, became a predecesor of modern aviation and of the aeolian energy use, for the results established by him led to the improvement of the helix design of all sort later, which was developed to a maximum degree of action.

The German scientist Kurt Bilau, and the American Halliday, went further. The latter can be considered as the father of the water-wheel, which is so much employed in the rural areas. Bilau, on the other hand, was the one who conceived the idea of electrical generation with helixes moved by the wind; he designed and constructed the first aerogenerator which we know of, based on the work of Le Cour. From Bilau (who accelerated his work during the First World War) a great majority of the projects for the increasing use of the wind energy started. His works constituted the base for the ones of Schulthes, Melzer, Flettner, Savonius, Leschinsk, Wiedmer, Wenk and of all the other workers whose designes brought about the general interest in the use of the wind energy between the two World Wars.

The technical difficulties encountered, and the considerable cost which would have incurred by carrying out the projects of Honneff, Bendmann, Scheller and Kleinzhenz, retarded the overall development of this technology. With the Second World War, and the extraordinary energy demand everywhere, with the scarcity of heat fuels and the need to apply these, mainly in the chemical industry, and the enormous progress in aviation, scientists began thinking on the use of the wind energy again.

The movement started this time in England, when Percy H. Thomas published his "Electric Power from the Wind", "The Wind Power Aerogenerator" and "Aerodynamics of the Wind-Turbine". These books, published in 1945, 1948 and 1949, and the one from P. C. Putnam, "Power from the Wind", which summarized the American experiences in the field, led to what be named as the rennaissance of the wind energy research.

The previous researches by the Germans constituted the starting point for the new efforts. The Allied asked H. W. Hamm the recopilation of all available material, which brought to the publishing of his book "German Wind-Turbine". The book "Projects Planned during the Hitler Era" and the one by Dane Martin Petersen "Oversig Over Vindelektricitetsproductionen fra 1940 tin 1948", constituted the new starting point of this discipline.

Since the end of the Second World War, notable for the shortage of fuel and the extraordinary demand for energy, the interest in the wind energy has boomed all over the world.

In the same way as it happened with the old hybric mills, with regards to the present hydroelectric power stations, the old windmills may well become the origin of future large scale electrical-aeolian power stations. Possible developments (given the recent metereological and aerodynamical experiences) will find a favorable scientific atmosphere, and the possibili ty of the use of wind is different scales can be envisaged.

On the American effort in wind energy, Palmer C. Putnam has already mentioned, some years ago, in his previously referred to book. Putnam designed, in close collaboration with professors Dr. Vannevar Bush and Dr. Theodor Von Karman of the Massachusetts Institute of Technology, and the metereologist Dr. Sverre Pettersen and Dr. Karl O. Lante, a large aeolian-electrical turbine, financed by an alectrical cooperative of the State of Vermont. Putnam turbine had a height of 53 meters and generated 1250 KW through a synchronic generator, propelled by hydraulic gear-box and clutch. The cross of the gigantic windmill weighter eight tonnes each, and was made of stainless steel. The system and a diameter of 36.5 meters and accepted winds of 115 m/sec. Its functioning started in October 19, 1941, and was good, reaching an output of 700 KW. This aerogenerator was later connected to the hydroelectrical network of Vermont, reaching an output of 1500 KW; it worked well until February of 1943, when it suffered a breakdown and stopped.

Putnam's work has been extraordinary important for the aeolian-energy all over the world, for it showed that aeolian energy power stations were not a technical utopia, but are possibilities within man's reach.

In England, the British Electrical and Allied Industries Research Association published a preliminary report on the large scale aerodynamic generation by E. W. Golding.

In Denmark, following Le Cour's tradition, aerogenerators of 30 to 70 KW power output have been developed.

This brief informative resume details the development up to the 50's. In present days there are publications in different countries narrating the development of the same period, among which the report "Wind Machines", prepared by the National Science Foundation, can be mentioned (see reference).

The referred effort and background can be extended to many countries, particularly in the last few years to Latin American. Hence, it is important to chanalize the efforts for an adequate planning in this area.

Among the aspects to be considered for the use of the wind for energy purposes, the reconnaissance and the preliminar study as first priority. For decision making, the metereological researches and the correct information from them represent an economical factor of fundamental interest.

In the development of this Course-Seminar, the various aspects concerning the atmospheric vehavior directed to the study and evaluation of the aeolian resources will be dealt with.

Following, the historical background on the use of the wind energy will be detailed.

TABLE 1

HISTORICAL BACKGROUND ON THE USE OF AEOLIAN ENERGY

A.C.		
2000	( )	Windmill used by Chinese and Japanese
1700	(?)	Windmill used in irrigation in Babylon
100	(?)	Windmill used in Egypt
600's		Windmill used in Persia (Vertical axis type)
900's		Horizontal wind wheel used for irrigation in the Persian Gardens
1105		French document published, enabling windmill construction
1191		First windmill reported in England
1200's		Vertical sails sustained by posts and towers used for grain milling of European land proprietors and peasants
1349		Flamingo bronze on which a windmill of the St. Margaret Church in found illustrated, Kingslynn
1390		Painting having a windmill drawn on linen in the German Museoum of Nuremberg

1500	Leonardo Da Vinci's sketch on a windmill construction
1600's	Colonizers constructing European Style windmills in the eastern coasts of America
1700's	Vapor machines began displacing the use of wheels moved by the wind
1745	Edmund Lee patents the method for the automatic directioning of windmills
1870's	Chicago became the center of the windmill industry
1891	Establishment of an experimental station in Askov, Denmark, by Prof. B. Le Cour
Mid XX Century	Development of windmills for electricity generation and water supply purposes
Post World War	Research in diverse countries towards the use of aeolian energy in large scale
1950's	Atomic Energy decreases the interest on the use of aeolian energy
1970's	Energy shortage revives the interest on the utilization of the aeolian energy

1.2 NATURE OF THE WIND

1.2.1 Qualitative Description of the Atmosphere in Planetary or Global Scale

Let us consider the simplest possible system of distribution of the atmospheric variables: the one resulting from an assumed smooth and homogeneous earth surface. Although the distribution of the continents and oceans as well as the topography, would alter the fields resulting from the present assumption, the system is adequate as a first approach, and allows obtaining the ideas on the global scale atmospheric behavior. In these cases there will be no longitudinal variation of the average fields.

As the earth-atmosphere system is mechanically isolated, it must conserve the total angular momentum. Earth and atmosphere interact mechanically by friction: if the western atmospheric wind imparts momentum to the earth (since it moves quicker for an absolute observer), and if the wind is from the east, the atmosphere will receive the momentum of the earth. In a long time interval there will be no net transport of momentum from the earth to the atmosphere, or viceverse, for if it does, the earth angular velocity will be changed considerably. As this does not occur there must exist planetary bands of wind with their eastern and western components alternating at the earth surface.

In the tropical zones the earth has a tangential velocity greater than that of the atmosphere, resulting in eastern wind bands on the surface, defining the noreastern trade winds in the north hemisphere, and of the south-eastern in the south (see Figure 1). The trade winds coverage towards the equator, where a zone of smooth winds is present, called the intertropical convergence.

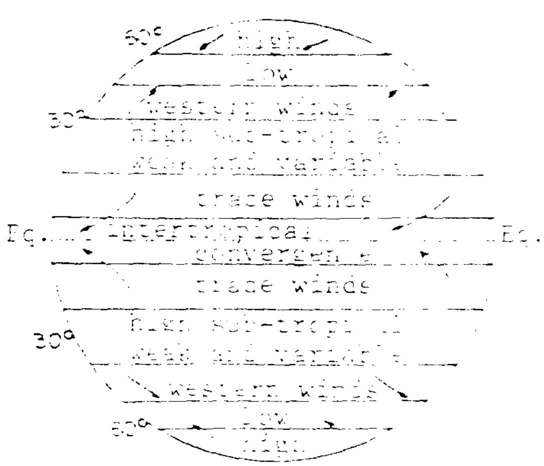

Figure 1 - Formation of Winds

At the latitude of 30° (north and south) both the earth and the atmosphere move with equal velocity, approximately, and hence bands of calmness or smoothly variable winds appear. In the intermediate latitudes (30° to 60°, approximately) there exist the western wind belts. In extreme latitudes one finds the polar eastern winds. The limiting zones between the westerns, in the intermediate latitudes, and the polar easterns one finds no calmness but tempest, with variable winds.

Regarding the pressure field, the isobars will coincide with the parallel ones in the assumed scheme (Figure 1), having: a band of relative low pressures in the equator called the Equatorial Belt, a band of high pressure at 30° latitude (north and south) called the High Subtropical Belt, a band of low pressures at a latitude of approximately 60°, called the Low Subtropical Belt.

The effect of the earth rotation makes the wind circulation in the Low Subtropical system as that of the earth rotation (in both hemisphere), called the Cyclonic Sence, and in the High Subtropical system in the opposite sence to the earth rotation, or Anti-cyclonic. The terms cyclone and anticyclone are derived from these for the low and high pressure centers, respectively, in the low and intermediate latitudes.

Regarding the thermal field, the isotherms will coincide with the parallel ones, with a high thermal contrast in the intermediate latitudes.

The above description would hold for the equinoxes; for the various seasons, the planetary bands will follow the annual movement of the sun; this is, they will move towards the poles of their respective hemisphere during summer, and towards the equator during winter time.

Let us now study in a meridional cut (see Figure 2) the zonal components of the wind at different pressure level and for different latitudes, averaged in length for the winter and summer in both hemispheres. The intensity and direction of the average zonal component of the wind are described by means of isotages (lines of constant intensity) in meters per second.

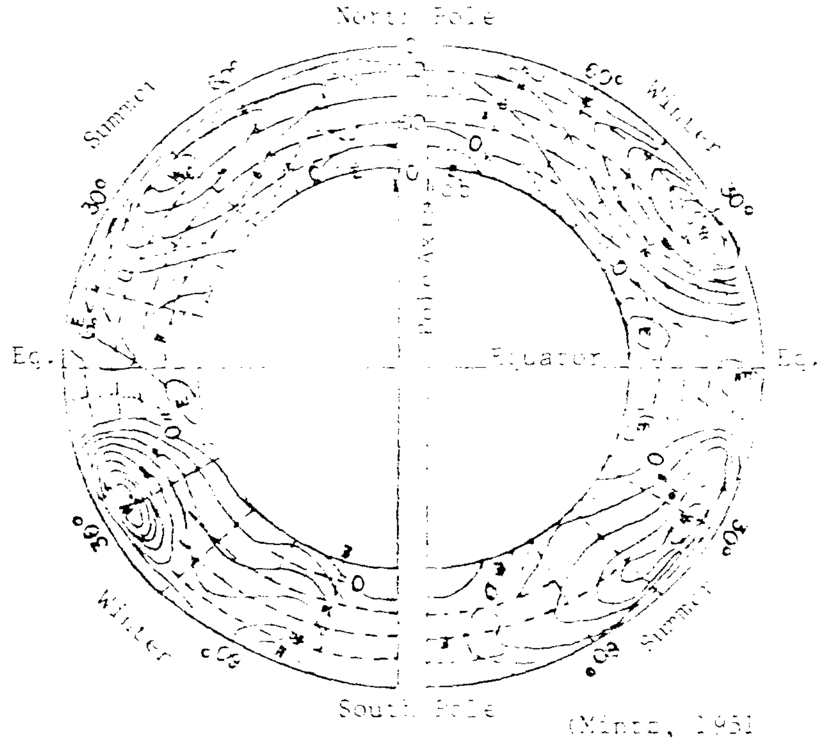

Figure 2 - Zonal Component of the Wind

Western components will be positive and the eastern ones are negative. The main characteristics are:

a) The existence of a maximum western wind, very pronounced in both hemispheres and in the seasons of the year, located approximately at the basic level of 200 mb (milibars) (corresponding to a height of 12 Km. approximately and near the 30° latitude), with average velocities up to 40 m/sec. This maximum is located directly above the High Subtropical Belts, and is called the "Jet Flow" (subtropical). This flow is more intense in the southern hemisphere, compared with the corresponding seasonal fields.

b) The existence of the eastern wind, at all levels, in the equatorial areas and in low levels in the polar areas.

c) The inclination of the axes of the subtropical anticyclones (given by the zero isotages) towards the hot zones as we go up, and the one of the low sub-polar axes towards the cold zones.

d) The seasonal movement of the wind maxima following the sun with the appearance of a secondary maximum (polar jet flow) during winter in the respective hemisphere.

Let us study the thermal structure, as annual average, for all latitudes. The troposphere is the lower layer in which the temperature decreases with height, reaching a minimum defined by the tropopause. Over the tropopause there is the stratosphere where the temperature increases (at least, it does not decrease) with height. The stratosphere extends itself from the tropopause to the stratopause which, at a height of 50-60 Km., has a temperature varying between -10° to +20° Celsius. Above this there are other layers defined also by the thermal structure called the mesosphere and thermosphere. (It is also common to define the oxonesphere as the region of maximum ozone concentration, located at 20 to 25 Km. of height). The troposphere is the zone where the metereological phenomena are produced (clouds, rain, etc.,) and the greater part of the atmospheric mass is located in it (Figure 3).

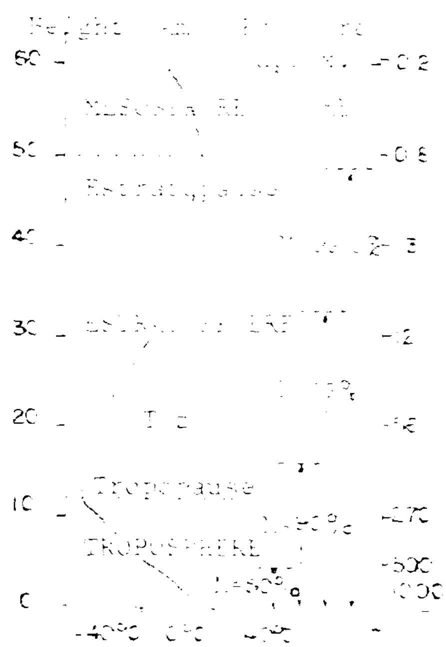

Figure 3 - Thermal Structure of Atmosphere

The seasonal variations of the average thermal field along the latitude circles are shown in Figure 4. The main characteristics are:

a) The latitudinal variation with height of the tropopause, being the equatorial tropopause much higher and colder than the polar one.

b) The horizontal thermal contrast in the intermediate latitudes is much greater during the winter than in the summer (seen through the inclination of the isotherm lines). Note that this contrast coincides in position with the corresponding jet flows.

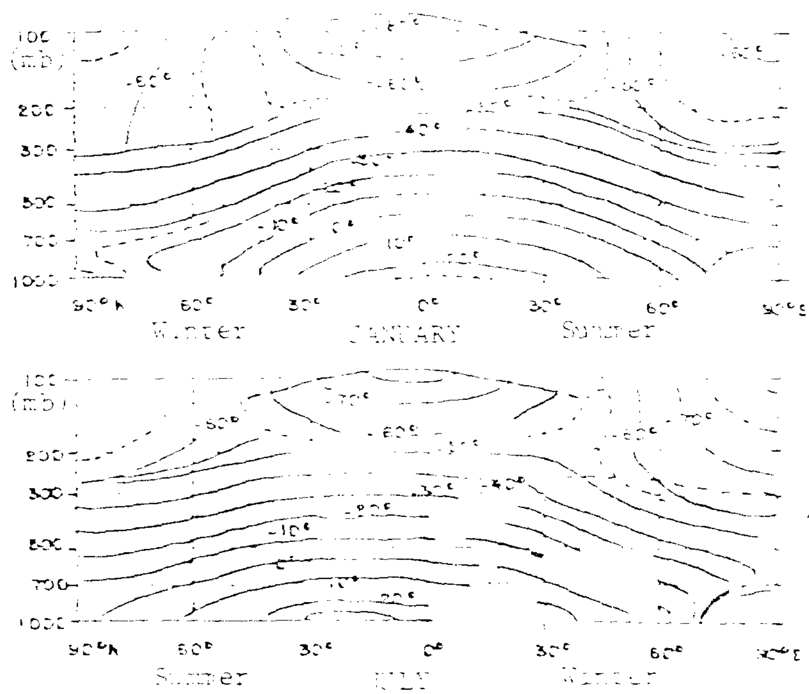

Figure 4 - Seasonal Variations of Thermal Field

In the real atmosphere the synoptic planetary systems which appear in daily maps are seldom similar to the average zonal fluxes presented above, for they are generally asymmetrical, with the high thermal contrast and the strongest winds concentrated along narrow bands, limiting zones between the cold and hot masses, known as fronts. Moreover, the planetary flux is influenced by the topography and the thermal contrast produced by the distribution of continents and oceans, particularly in the northern atmosphere. It is not, therefore, entirely accurate considering synoptic system (cyclones and anticyclones and the waves at heights associated with them) as superposed perturbations on a zonal movement, varying only with latitude and height. However, this scheme is very useful as a first approach in the theoretical analysis of the synoptic waves.

In daily synoptic charts one observes that the surface circulation (weaker in summer than in winter) consists of vortex or cyclonic whirlwinds associated with low pressure centers, and weaker anti-cyclonic vortexes clearly identified as spiral clouds in the images of the earth obtained by means of metereological satellites. The main vortexes may be seen even in level charts of 500 mb (approximately 5.5 Km.) somewhat displaced to the west and immersed in a western flux. These migratory or progressive waves are eliminated when the average values are calculated leading to the distribution as shown.

Anyway, the average distributions by zone do yield good information on the typical characteristics of the circulation in the planetary scale.

1.2.2 Atmospheric Movement

The atmospheric movements occur in an ample spectrum of spatial and time scales, starting from the molecular motion to those which dominate the general circulation.

The dynamic of the atmosphere is the study of the motion of the atmosphere directly associated with the weather phenomena at all scales.

For all movements, the atmosphere is considered as a fluid or a continuous medium.

The starting point of the dynamical metereology has its origin in the application of the hydrodynamic and thermodynamic laws of the atmosphere.

The application of these laws allows us to obtain systems of equations of high degree of complexity, which include all scales.

In order to treat the motion of interest, these systems must be duly simplified through scale analysis techniques.

It is not an objective of this course to do an exhaustive development of such a system and of the techniques of scale analysis.

The following development will be adopted in order to meet our objetives:

- 1.2.2.1 A brief description of the various scales
- 1.2.2.2 Equations of motion
  - 1.2.2.2.1 Fundamental forces
    - a. The force arising from the pressure gradient
    - b. The gravitational force
    - c. The friction force
  - 1.2.2.2.2 Apparent forces
    - d. The centrifugal force
    - e. The Coriolis force
  - 1.2.2.2.3 Expression for the equation of motions
- 1.2.2.3 Geostrophyc approximation and geostrophyc wind

1.2.2.1 A brief description of the various scales

The diverse perturbations or metereological phenomena which occur in different periods of time, or "bands", give place to a classification of spacial orders which traditionally is divided in the phenomena of:

- Microscale
- Mesoscale
- Synoptic scale
- Planetary scale

Figure 5 shows the approximate limits of these bands, the phenomena found and its space-time relation.

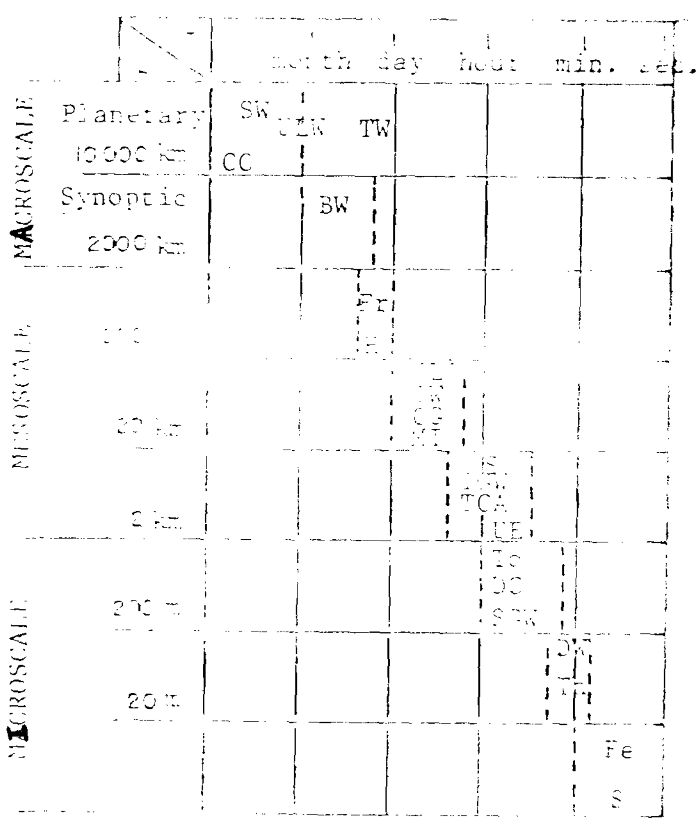

Figure 5 - Relations between Space and Temporal Scales with Associated Typical Phenomenons (after I. Orlanski, 1975).

LEGEND

SW :	Stationary waves	DW :	Dust whirlwind
ULW:	Ultra-long waves	T :	Turbulence
BW :	Baroclinic waves	CC :	Climatic change
H :	Hurricanes	TW :	Tidal waves
IW :	Inertia waves	Fr :	Fronts
MI :	Mountain interferences	IL :	Inestability lines
S :	Storms	CG :	Cloud groups
TCA:	Turbulence in clear air	IGW:	Inertia gravity waves
UE :	Urban effects	To :	Tornadoes
DC :	Deep convection	Th :	Thermal
SGW:	Short gravity waves	Te :	Feathers

1.2.2.2 Equations of motion

Newton's second law establishes that the acceleration a body suffers, referred to a fixed system of coordinates, multiplied by its mass is equal to the sum of all the forces acting on it; this is,

$$\vec{F} = \overrightarrow{ma} \qquad (1)$$

The forces acting on a mass element of gaseous fluid, which must be considered for the motions of meteorological interest are:

a. The force arising from the pressure gradient
b. The gravitational force
c. The friction force

These are known as fundamental forces. If we refer to an observer fixed on the earth and the fact that the gaseous fluid is considered rotating, other forces, called "Ap parent" forces, must also be included. These are:

d. The centrifugal force

e. The Coriolis force

Once these forces are identified we can write out the equation of motion.

1.2.2.2.1 Fundamental forces

a. The force arising from the pressure gradient

Consider an element of volume $\delta V = \delta x . \delta y . \delta z$ centered at the point Xo, Yo, Zo (see Figure 6)

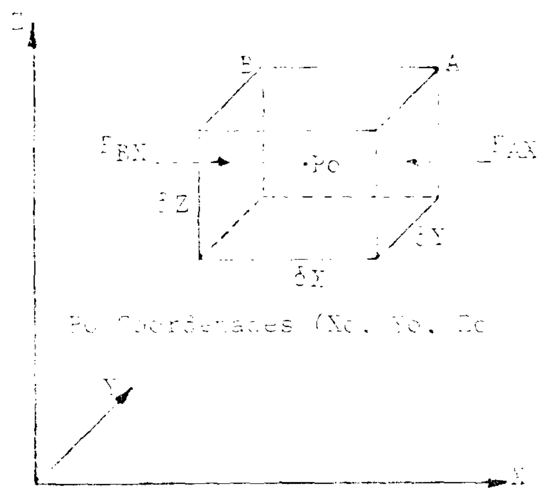

Figure 6 - The force arising from the Pressure Gradient (description)

Due to the molecular movement, momentum is continuously transferred to the walls of the volume element.

This transfered momentum per unit time and area is precisely the pressure exerted on the walls of the volume element by the surrounding air.

If the pressure at the center is Po, at the face A the pressure will be (by Taylo's expanssion).

$$Po + \frac{\partial P}{\partial x} \cdot \frac{\delta x}{2} + \text{terms of higher order (neglected)}$$

then, the pressure force on face A will be:

$$F_{AX} = - \left(Po + \frac{\partial P}{\partial x} \cdot \frac{\delta x}{2}\right) \cdot \delta y \delta z$$

and on face B:

$$F_{BX} = + \left(Po - \frac{\partial P}{\partial x} \cdot \frac{\delta x}{2}\right) \cdot \delta y \delta z$$

thus, the net component of the pressure force along x will be:

$$F_X = F_{AX} + F_{BX} = - \frac{\partial P}{\partial x} \delta x . \delta y . \delta z$$

and per unit mass:

$$\frac{F_X}{m} = \frac{- \frac{\partial P}{\partial x} . \delta x \delta y \delta z}{\rho \delta V} = - \frac{1}{\rho} \cdot \frac{\delta P}{\delta x}$$

This is the force due to a pressure gradient per unit mass along the x direction.

Equally:

$$\frac{F_Y}{m} = - \frac{1}{\rho} \frac{\partial P}{\partial y} \quad , \quad \frac{F_Z}{m} = - \frac{1}{\rho} \frac{\partial P}{\partial z}$$

It can be clearly seen that these components are directed from high to low pressures (notice the - sign).

In vectorial form it can be written as:

$$\frac{\vec{F}}{m} = -\frac{1}{\rho}\vec{\nabla}p \qquad (2)$$

where $\nabla = \frac{\partial}{\partial x}\vec{i} + \frac{\partial}{\partial y}\vec{j} + \frac{\partial}{\partial z}\vec{k}$ is the operator NABLA

b. The gravitational force

According to Newton's lay of universal gravitation, the atraction force between two elements of mass M and m, separated by a distance r, is given by:

$$|\vec{Fg}| = -\frac{GMm}{r^2}$$

in vectorial notation:

$$\vec{Fg} = -\frac{GMm}{r^2}\left(\frac{\vec{r}}{|\vec{r}|}\right)$$

If we let M= mass of the earth

m= mass of an element of atmosphere

we have:

$$\frac{|\vec{Fg}|}{m} = -\frac{GM}{r^2}$$

and: $$\frac{\vec{Fg}}{m} = -\frac{GM}{r^2}\left(\frac{\vec{r}}{|\vec{r}|}\right) \qquad (3)$$

Figure 7 shows the direction of $\vec{F}g$:

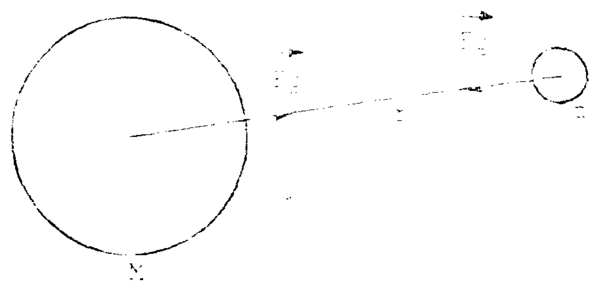

Figure 7 - The Gravitational Force (description)

c. The friction force

As it has been mentioned previously, this analysis intends only fixing some general features on the matter, particularly when a complete discussion of the friction force, or force due to viscosity, is rather complex. The physical concept will be discussed, illustrated in a simple form.

Consider a layer of incompressible fluid between two horizontal plates separated by a distance ℓ as shown in Figure 8.

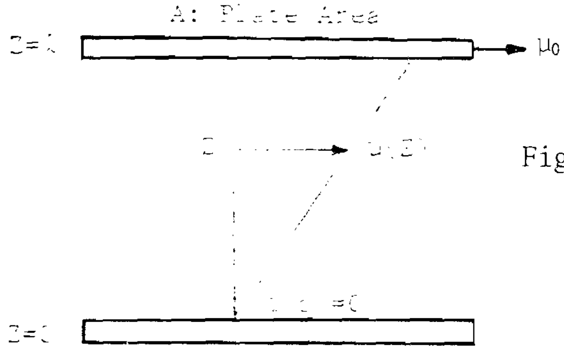

Figure 8 - The Friction Force (description)

Let the lower plate be fixed and the upper one moving with a velocity μo.

For this to occur, the applied tangential force is:

$$F = \mu \frac{A\mu o}{\ell}$$

where μ is a proportionality constant known as the dynamic viscosity coefficient.

In the limit, we can define the force per unit area, or cutting tension, as:

$$\frac{F}{A} = \mu \frac{\partial \mu}{\partial Z}$$

It can be shown that the net viscous force per unit mass on an element of volume in the X direction is:

$$\frac{F \text{ viscous } X}{m} = \frac{1}{\rho} \frac{\partial}{\partial Z} \left[\mu \left(\frac{\partial \mu}{\partial Z}\right)\right] \qquad (4)$$

If μ is a constant and letting $\nu = \frac{\mu}{\rho}$ as the kinematic viscosity coefficient, we have

$$\frac{F \text{ viscous } X}{m} = \nu \frac{\partial^2 \mu}{\partial Z^2} \qquad (5)$$

For the lower 100 Km. of the atmosphere ν is small and the friction force can be neglected in relation to the rest.

However, in the so-called limiting layer of the atmosphere (first kilometer of the atmosphere in contact with the ground) it must be considered, and with this, the expressions for calculating V (wind velocity) have different forms to those derived in free atmosphere (above first kilometer). We will refer to this consideration later.

1.2.2.2.2 Apparent forces

In considering the atmospheric motion, it is natural to consider a reference system fixed to the rotating earth.

Newton's second law establishes that an element of mass in uniform motion with respect to a reference system fixed in space will stay in uniform motion in the absence of Fs. It is said that such a motion is referred to an INERTIAL SYSTEM, and the reference system is known as INERTIAL or NEWTONIAN.

It is clear that a body at rest with respect to the rotating earth will neither be at rest nor in uniform motion with respect to a reference system fixed in space.

Hence, the motion which appears as inertial to an observer in a reference system fixed to the rotating earth is actually an accelerated motion to the observer whose system of reference is fixed in space.

Consequently, a rotating system of reference is a NON-NEWTONIAN system. Newton's laws are applicable only if the coordinates' acceleration is considered, and this is achieved by including the apparent forces which, in our case, are: the centrifugal force and the Coriolis force.

d. The centrifugal force

Consider a mass attached to an end of a string of lenght and rotating with constant angular velocity ω (Figure 9)

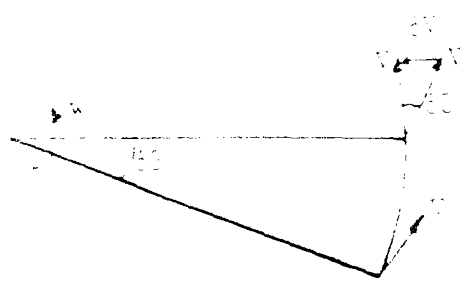

Figure 9 - The Centrifugal Force (description I)

It can be seen that $\frac{|\delta\vec{V}|}{|\vec{V}|} = \tan \delta\Theta$

when $\delta\Theta \rightarrow o$, $\tan \delta\Theta \rightarrow \delta\Theta$ and then

$$|\vec{\delta V}| = |\vec{V}| . \delta\Theta$$

dividing this by δt

$$\frac{\delta\vec{V}}{\delta t} = |\vec{V}| \frac{\delta\Theta}{\delta t} \left(- \frac{\vec{r}}{|\vec{r}|}\right)$$

This is known as the centrifugal acceleration detected by the observer from the fixed system.

If we observe the rotating element from a system fixed in it, it is clear that the particle is stationary but the force of the string is acting.

Then, to apply Newton's second law to describe the motion relative to the rotating system, an additional apparent force, known as the centrifugal force in equilibrium with the centripetal force, must be included.

Thus, a particle of mass m at rest on the earth surface, observed from a rotating system along with the earth, is subjected to a centrifugal force.

$$\vec{F}_{cfg} = \Omega^2 \vec{R} \qquad (6)$$

where $\vec{\Omega}$ is the earth angular velocity, and we can define the effective gravity:

$$\vec{g}e = \vec{g} + \Omega^2 \vec{R} \qquad (7)$$

and we have, according to Figure 10

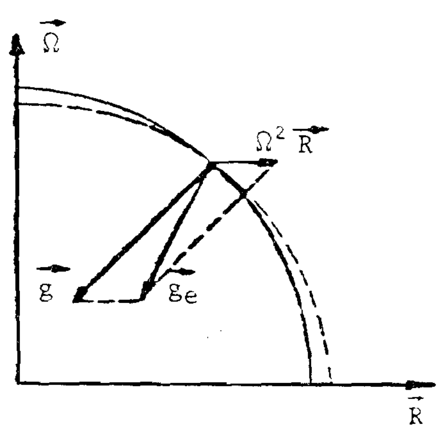

Figure 10 -
The Centrifugal Force
(description II)

e. The Coriolis force

This is a force origined from the rotation of the earth. Let us imagine an observer in the north pole (Figure 11) whose at a determined moment throw a particle to an object placed at A. The particle travel along the line OA and when reaches the point A, the object is already displaced due to the rotation of the earth, placing now the position B. An observer whose travels with the object look that the particle is deviated to your right during its trajectory and this is the effect of the Coriolis force or the force arising from the rotation of the earth.

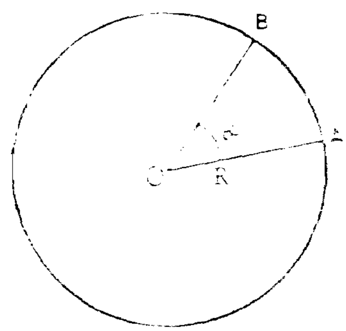

Figure 11 - The Coriolis Force (description)

As the angular speed of the earth is Ω, if t is the time in which the object travelled from A to B, we have:

$$\alpha = \Omega . t$$

Besides, if ν is the modul of speed of the particle:

$$R = \nu.t$$

where R is the ratio of the earth.

So, the longitud of arc AB is given for:

$$\widehat{AB} = \Omega.\nu.t^2$$

This shift may be explained by supposing an accel eration $\underline{\underline{a}}$ which acts at right angle to the trajectory resulting one deviation $\frac{1}{2}$ at^2

where:

$$\frac{1}{2} a.t^2 = \Omega.\nu.t$$

so:

$$a = 2\Omega.\nu$$

This is applicable to the north pole. It is possible to demonstrate that for a given latitude ϕ we have:

$$a = 2\Omega \nu \sin \phi$$

If the analysis were done for the southern hemis phere, the same expressions would be appliable and the effect of Cariolis would be to the left of the trajectory.

So the modul of the Coriolis force by unity of mass may be expressed through:

$$\left|\frac{\vec{F}c}{m}\right| = 2\Omega \ \nu \ \sin \phi$$

or in vectorial form:

$$\frac{\vec{F}c}{m} = -2 \ \vec{\Omega} \times \vec{\nu} \qquad (8)$$

1.2.2.2.3 Expression for the equation of motion

For a rotating system and according to the force described previously, the form is:

$$\frac{d\vec{v}}{dt} = - \frac{1}{p} \nabla p + \vec{g}_e - 2\vec{\Omega} \times \vec{V} + \vec{F}_{friction} \qquad (9)$$

If a system as the one shown by Figure 12 is adopted, the components of the equation can be found:

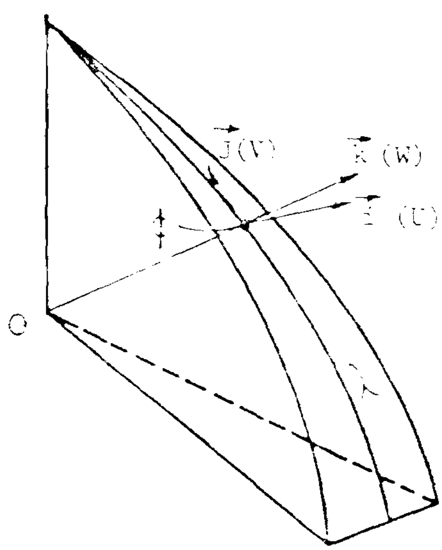

Figure 12 - Equation of Motion (description)

In particular, without considering $\vec{g}_e \times \vec{F}_{friction}$ the horizontal part is:

$$\frac{d\vec{V}h}{dt} = - \frac{1}{\rho} \nabla_H p - f \vec{k} \times \vec{V}_h \qquad (10)$$

where $\vec{V}_h$ is the horizontal component of the velocity vector.

$\nabla_H = \frac{\partial}{\partial x} \vec{i} + \frac{\partial}{\partial y} \vec{j} + \frac{\partial}{\partial z} \vec{k}$ is the horizontal operator NABLA.

1.2.2.3 Geostrophyc approximation and geostrophyc wind

This is an approximation in synoptic scale when the acceleration $d\vec{V}h/dt$ in the equation of horizontal motion is insignificant.

If the horizontal acceleration is considered negligible:

$$- f \vec{k} \times \vec{V} - \alpha \nabla_H p = 0 \qquad \vec{k} \times \vec{V} = - \frac{\alpha}{f} \nabla_H p$$

$$\vec{V}_h = - \frac{\alpha}{f} \nabla_H p \times \vec{k} \qquad (11)$$

This velocity, obtained as a result of supposing equilibrium between the Coriolis and the pressure forces, is called the geostrophyc wind. The equation shows that the wind is parallel to the isobars, in surface of constant height. Considering that $f = 2\Omega \sin \phi$ is positive in the northern hemisphere and negative in the southern one, due to the term $\sin \phi$, we deduce that the geostrophyc wind leaves the low pressures to the left of its direction of motion in the northern hemisphere and to the right in the southern hemisphere. This is shown in Figure 13.

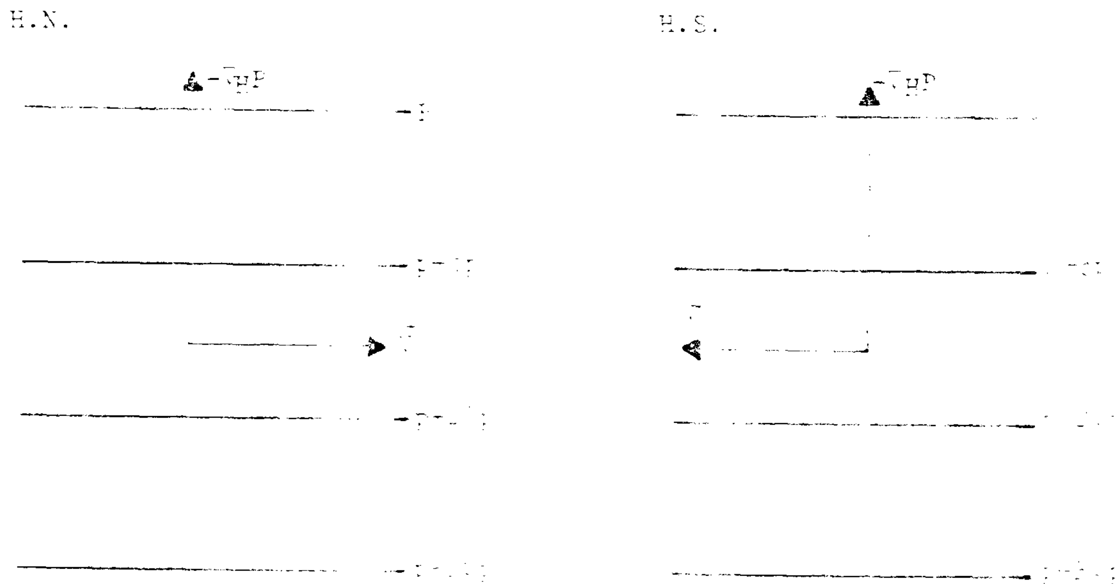

Figure 13 - Geostrophyc Wind (description)

By means of the expression of the geostrophyc wind (expression 11) it can show the deep relation between itself and the horizontal distribution of isobars in the synoptic scale.

As it was mentioned, the objective is not to do exhautives analysis of each topic. On this purpose, the lector can use the given bibliography.

The geostrophyc approximation showed is not appliable for equatorial latitudes, as in these places f is zero (ϕ=0) or tends to zero (see Necco, 1980).

1.2.3 Local Wind Systems

Although any wind is designated by its direction and velocity, some have their particular names. Some local wind systems are of general interest. Of these, some are developed from uneven heating from earth and sea; others result from heating and cooling of mountain slopes, and a third group is related to the air flow deformation when crossing the cordilleras.

1.2.3.1 Mountain and valley breezes

During the sunny hours the mountain slope, and the air in touch with it, will heat up quicker than the air at a certain height from the slope. This difference in heating will result in a circulation of the air analogous to the one of the ocean breezes. The air moves upward along the mountain slope during daytime and downward during the nights. If the land possesses a configuration such that convergent valleys exist in it, the fresh air will flow down the valley beds, accelerating downward towards the main valley; consequently, it may be that the night wind in such places are stronger than the daytime breeze.

The intensity of this type of circulations is also subjected to the synoptyc scale.

1.2.3.2 Land and ocean breezes

Frequently it is observed that in summer days the air blows crossing the coast line, in the direction of sea to land during daytime and in the opposite direction during the night. These winds affect a layer of small thickness according to the particular conditions. Their horizontal reach is dependent of the latitude and also of local factors.

Figure 14 shows the general structure of the land and ocean breezes. In the mornings, the difference of temperature between land and sea is small, devoid of a general wind, the isobar surfaces would be horizontal. Now, when the sun comes out, the earth surface heats up quicker than that of the sea due to their different thermal capacity and the mixing processes in the sea, and the thickness of the layer between isobars grows above the earth, so that the upper surface of equal pressure acquires an inclination from land to sea. Due to the pressure, a horizontal force develops which accelerates the air from land to sea; this air transference tends to increase the pressure at sea level away from the coast, and to decrease it inland. The net result is that there is a force at sea level due to the pressure which accelerates the air from sea to land. In the beginning, an ocean breeze blows crossing the isobars, which are more or less parallel to the coast; however, in due course, as the time is passing and the wind velocity increases, the Coriolis effect shows up and the wind tends to flow in the direction of the isobars, this is, parallel to the coast line.

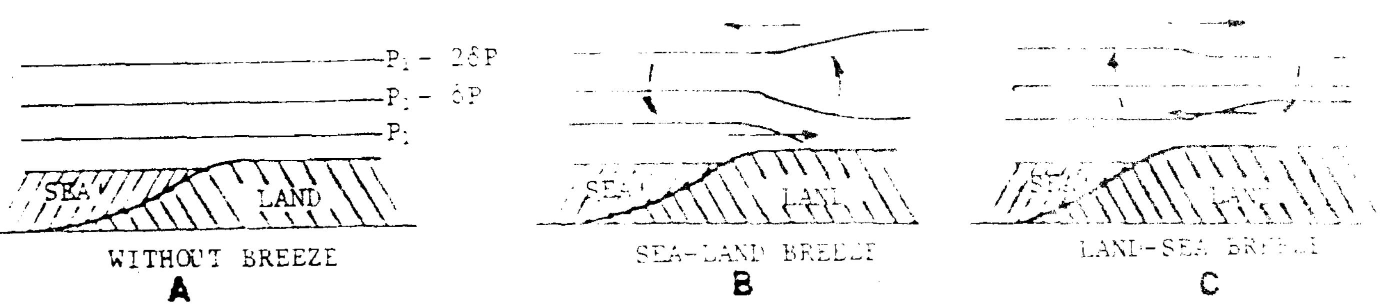

Figure 14 - Land and Ocean Breezes

During the afternoon, when the earth cools down by radiation, the temperature contrast disappears and there is no breeze. During the evenings, when the land is colder than the sea, a flux is developed from land to sea, called the land breeze.

The effect of the breeze is pronounced with conditions of calmness in the synoptic scale; if there are strong winds in this scale, the effect of the breeze is not noticeable. The intensity and penetration of a breeze also depend on latitude of the earth.

1.2.3.3 Drainage winds

During the cold season, a large quantity of cold air is accumulated in the highlands and in zones sorrounded by mountains. Part of this air will flow down the mountain slopes concentrating in the valleys and fiords, reaching the coasts as a moderate and weak breeze. However, when it reaches a movable perturbation, such as a system of low pressures, the cold wind is accelerated through mountain crevices, valleys and canyons, becoming a cascade of cold air, with strong winds. Although the air will heat up adiabatically as it descends normally, the difference of temperature between the coast and the interior will be so great that the air will reach the coast as a cold flow. The winds are particularly strong and often destructive, when a large remnant of cold air must empty itself through a small crevice or valley, or when converting from several valleys. This effect is called Catabatic. As the air is boxed between the walls of a valley, the drainage winds show little relation with the isobars. Often, the winds cut the isobars normally in going from high to low pressures.

1.2.3.4 "Föehn", "Chinook". "Zonda"

These winds are strong, dry and hot, developed ocassionally in the leeward slopes of the cordilleras. They are, above all, frequent and strong over the northern slopes of the

Alps and the Andean Cordilleras; of smaller intensity, they may develop in the leeward of any mountain. In the German-spoken countries these winds are called "Föehns", a name which is used everywhere. Similar winds may be found to the east of the Rocky Mountains, especially in Wyoming and Montana; in North America these winds are commonly called "Chinooks"; in Argentina it is known as "Zonda".

1.3 WIND POWER AND ENERGY

Having studied the wind phenomenon, what interests us now is its utilization as energy source. After determining the aeolian potential of a site, as an energy resource, it is necessary evaluating and characterizing it in order to establish the optimum operational conditions of the Aeolian Energy Converter System (AECS), destined to utilize this resource within the technical-economical restrictions, dictated by the practical limits to:

1. Area of the transversal section to the air flux obtainable to extract the wind energy, and

2. Height above ground level at which it is practical effecting the extraction of energy.

Due to technological and economical limitation only the wind flowing in the first 150 meters above ground is exploitable with the present day technology, with the swept unit area limited also to that of a circumference of 100 meters diameter.

Following, the characteristics of the wind power and energy are discussed.

1.3.1 Equations of Power and Energy

Wind is air in motion. The air has a mass, although its density is low, and when this mass has a velocity, the resulting wind has a kinetic energy proportional to half the product |mass x (velocity)^2|

If ρ = mass per unit volume of air (density)
V = wind velocity
A = area through which the wind blows

The mass of air flowing per unit time is ρAV and the kinetic energy passing through the area per unit time is:

$$P = 1/2 \, . \, \rho AV.V^2 = 1/2 \, \rho AV^3$$

This is the total power available in the wind.

The wind power density, expressed in watts/m^2 on a vertical plane and at 10 meters of height, is one way of defining the aeolian power at one point. This power per unit area is a direct function of the wind velocity to the cube:

$$P/A = K \, V^3$$

where K is a constant which depends on the air density and the units in which the power and energy are expressed. This is known as the Cube Law and it tells why it is necessary a continuous registering of velocities in order to correctly estimate its energy content, for there is a difference between the cube of the average velocity and the average of the cube of a set of velocity in a given distribution. Figure 15 shows graphically the relation between power and velocity.

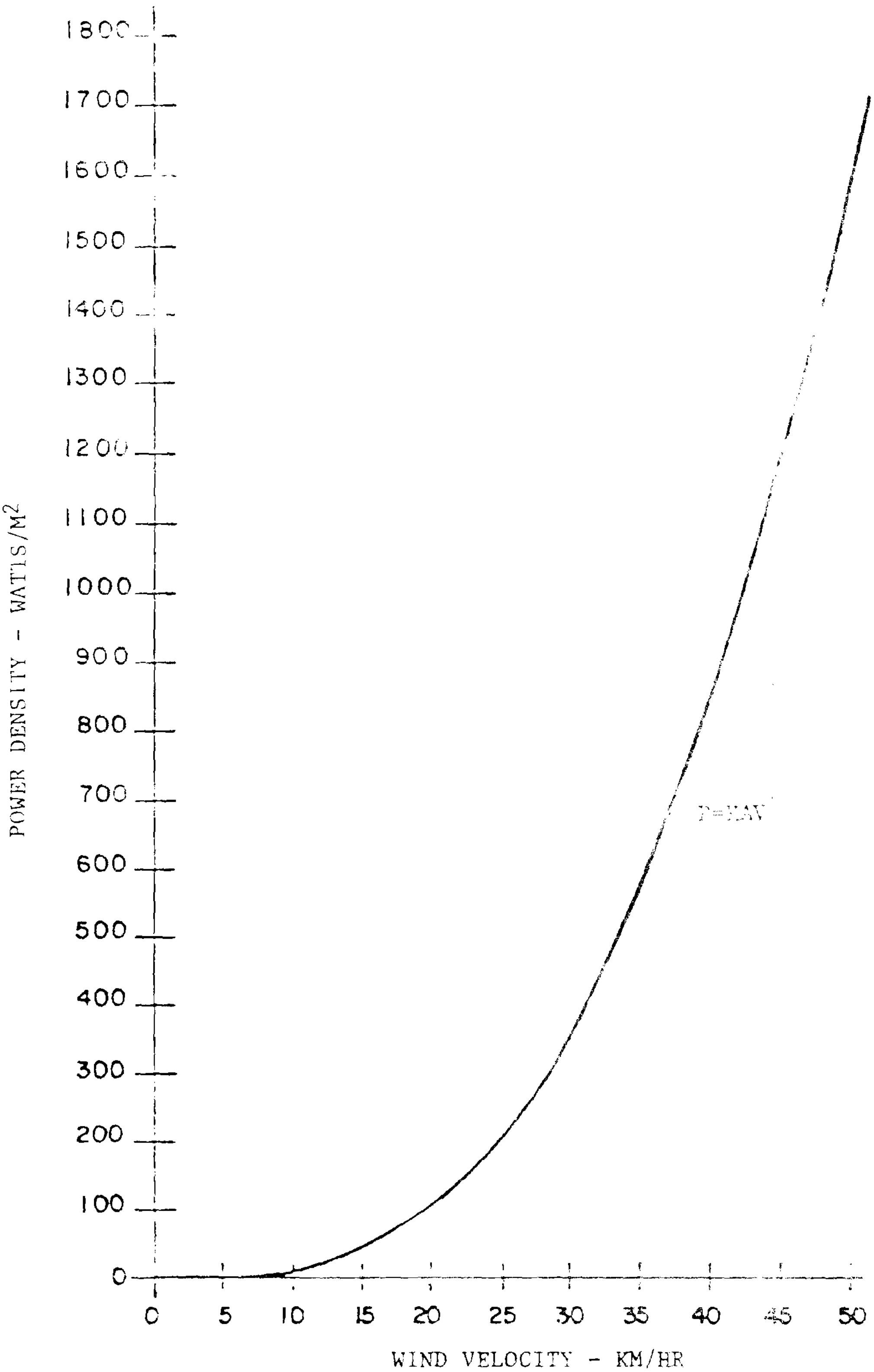

Figure 15 - Power in the Wind

Although the wind is expressed mathematically as a vector, its real behavior is one of a random way, varying its course and velocity in such a way that when we express its power per unit area, we are referring to statistical average which are obtained from continuous anemographyc measurements for at least one year.

With the wind power being proportional to the cube of the velocity, it is noticeable that a small percentage variation in the wind velocity has a strong effect in it. A wind of 20 Km/hr (5.55 m/sec) has a power of 109.6 watts/m^2, and one of 25 Km/hr (6.94 m/sec) has 213.85 watts/m^2; a wind of 50 Km/hr (13.88 m/sec) which moves the trees and hard to walk against, has a power of 1720.8 watts/m^2.

At greater heights, the aeolian energy increases at the rate of the vertical gradient of the velocities arising from the friction between the wind and the earth surface.

Of all the wind power available, it is possible to obtain only a fraction of it, the limit theoretically established by the German scientist A. Betz in 1927; an ideal aeromotor can only extract 16/27 or 59.3% of the wind power. In order to obtain 100% of the kinetic energy of the wind, it is necessary to have the converter stopping its motion, reducing its velocity to zero, which is impossible.

Thus, the equation defining the usable power of the wind under ideal conditions is:

$$P = 0.593\ KAV^3$$

Given the random characteristics of the wind, determining its power and energy for a period of time will consist of a systematic analysis of the observed velocity range and the total duration of each velocity interval. In this way, the wind energy crossing an unit area in a vertical plane always perpendicular to the wind, for a period of time is given by the expression:

$$E = \sum_{i=1}^{n} P_i . t_i$$

i = 1...n, are the intervals of wind velocity to which there is a corresponding power (P_i) and an accumulated duration t_i.

The average power for a period of time T will be:

$$\overline{P} = \frac{E}{T}$$

To carry out the analysis of wind energy and power for a given period, the following graphical representation can be used [illegible] the information obtained from the wind velocities in the site of study.

- Velocity frequency curves
- Velocity duration curves
- Power duration curves

1.3.2 Velocity Frequency Curves

The continuous registers of wind velocity translate to a curve of velocity frequency, which actually corresponds to a histogram of velocities (see Figure 16). This distribution curve is constructed [illegible] each month and for the whole year. This will allow knowing the percentage of the total time corresponding to each velocity interval. By graphing the data monthly, the seasonal variations will be determined leading to the wind behavior in the whole year. To [illegible] a good characterization of the velocity distribution for at least five years, although this may be dispensed of when there are information available which permit establishing correlations. This information is indispensable for establishing the energy the wind carries from which the potentially usable energy for a given period can be estimated.

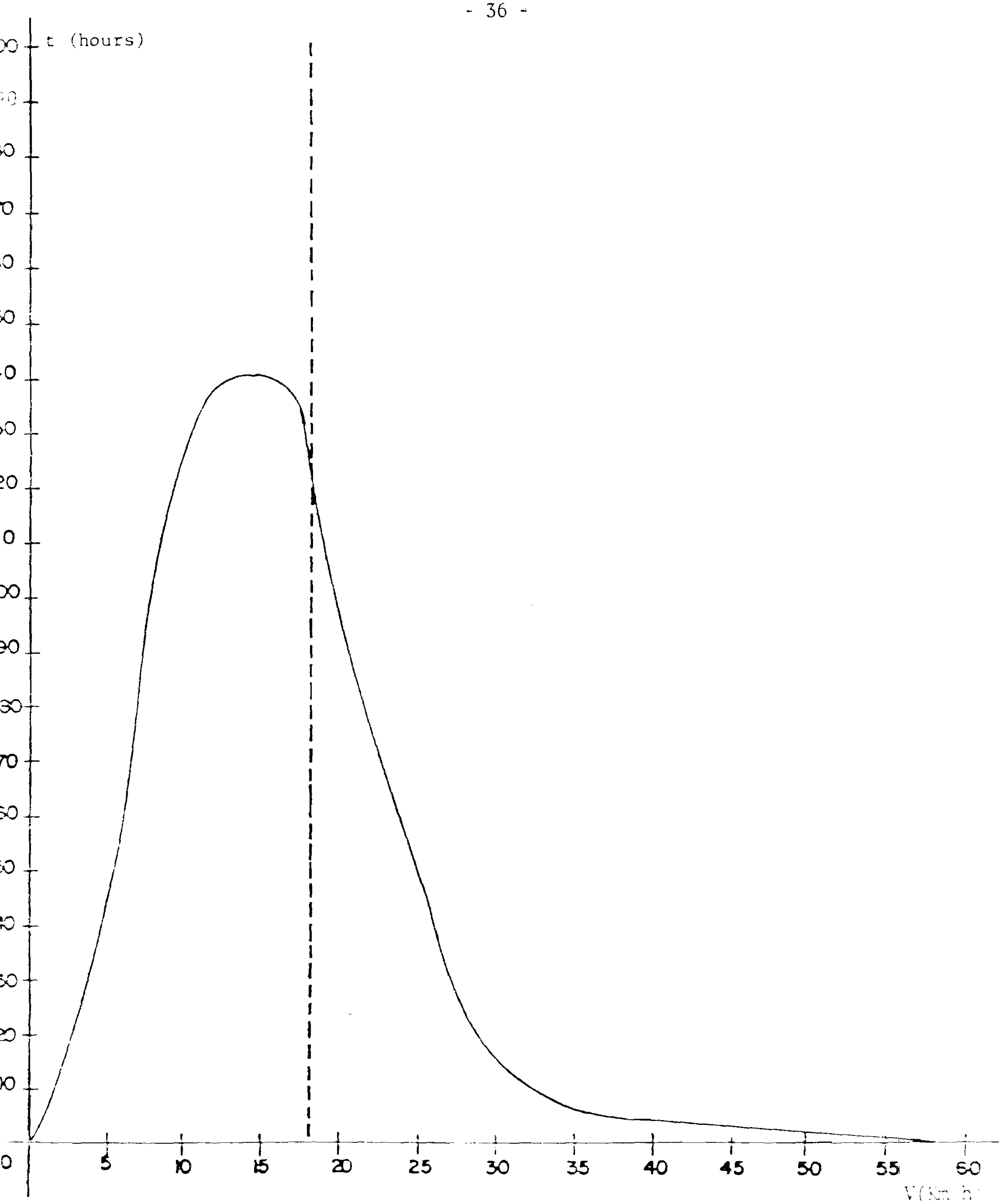

Figure 16 - Velocity Frequency Curve

1.3.3 Velocity Duration Curves

A useful form of representing the velocity frequency distribution for a given period of time is through a velocity duration curve, as shown in Figure 17, which indicates progressively the number of hours the wind had a velocity superior to the values of each ordinate.

1.3.4 Power Duration Curves

The velocity duration curve can be converted into a power duration curve by cubing the values of the ordinates and applying the coefficient of proportionality K. In this way, the energetical importance of one place relative to another can be observed by comparing the areas under the curve which are indicative of the wind energy.

The use of computer procedures to process wind informations from the continuous anemometric registers has displaced this method of energy evaluation for a given place; however, it cannot be said it is obsolete.

1.3.5 Wind Energy Conversion

The wind energy extraction is effected through a system of aerodynamic converters known as Aeolian Energy Converter System (AECS). An AECS converts the kinetic energy of the air into mechanical energy of rotation; this may, in turn, be converted into other forms of energy: thermal or electrical, or it may be used directly as mechanical energy.

In any change of one form of energy to another, certain losses are incurred. The relation between the available energy for use and the primary energy from which it comes defines the efficiency of a system of conversion.

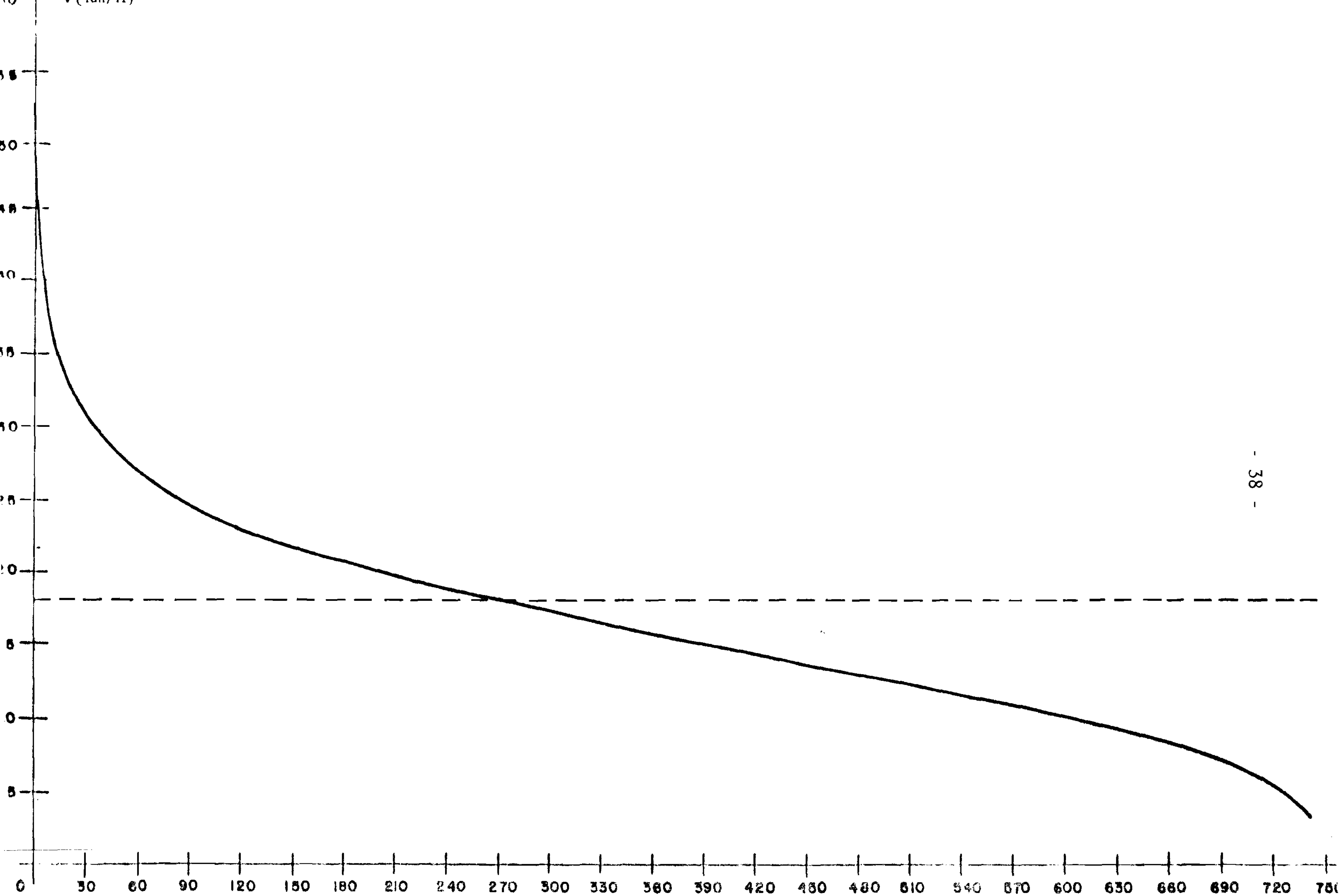

Figure 17 - Velocity Duration Curve

In the case of an aeolian turbine, the loss in the rotor may be attributed to two factors: the rotational motion communicated by the cross to the air, and the friction against the air.

1.3.5.1 Theoretical maximum power of an aeolian turbine

To determine the maximum efficiency of an aeolian turbine, the following conditions must be assumed:

1. The crosses work without drag by friction with the air.
2. A well-defined cover separates the flux passing through the disk of the rotor, from the one passing outside.
3. The inside and outside static pressures of the cover and those in front and behind of the disk are the same as the free flow static pressure ($P_2 = P_\infty$).
4. The impulse is applied uniformly over the entire disk of the rotor.
5. The disk imparts no rotation to the flux.

If we define a control volume, such as the one shown in Figure 18, and apply the momentum theorem assuming that the planes of upflow and downflow beneath the control volume are infinitely far from the plane of the turbine, we have:

T = influx momentum - outflux momentum

$$T = m\ (V_\infty - V_2) = \rho AU\ (V_\infty - V_2) \qquad (1)$$

where m is the mass flux per unit time.

Also, from the pressure conditions, the impulse may be expressed as:

$$T = A\ (P^{+} - P^{-}) \qquad (2)$$

Now, applying Bernoulli's equation to the upflow flux of the turbine, we have:

$$\frac{1}{2}\ \rho V_2^2 + P\infty = \frac{1}{2}\ \rho U^2 + P^{+} \qquad (3)$$

and for the down-flow:

$$\frac{1}{2}\ \rho V_2^2 + P\infty = \frac{1}{2}\ \rho U^2 + P^{-} \qquad (4)$$

Substracting these equations:

$$P^{+} - P^{-} = \frac{1}{2}\ \rho(V\infty^2 - V_2^2) \qquad (5)$$

substituting equation (5) into (2):

$$T = \frac{1}{2}\ A\rho(V\infty^2 - V_2^2) \qquad (6)$$

Now, setting equation (6) equal to (1), we have:

$$\frac{1}{2}\ \rho A(V\infty^2 - V_2^2) = \rho AU(V\infty - V_2)$$

or $$U = \frac{V\infty + V_2}{2} \qquad (7)$$

This result establishes that the velocity through the turbine is the average of the velocities before and after the turbine.

If we now define the interference factor as:

$$U = V_\infty (1-a) \qquad (8)$$

Setting equation (7) equal to (8) we have:

$$V_\infty (1-a) = \frac{V_\infty + V_2}{2}$$

With this, the velocity of the turbine wake may be expressed as:

$$V_2 = V_\infty (1-2a)$$

hence,

$$a = 1 - \frac{V_\infty + V_2}{2V_\infty} \qquad (9)$$

This implies that if the rotor absorbs all of the energy, viz., $V_2 = 0$, the interference factor will have a maximum value of 1/2.

Given that power is expressed as the product of the mass flux per unit time, and the change of kinetic energy, the power P is:

$$P = m\ \Delta E.C + \rho AU \left(\frac{V_\infty^2}{2} - \frac{V_2^2}{2}\right) + \frac{1}{2}\rho AV_\infty^3\ 4a(1-a)^2$$

or $$P = 2\rho AV_\infty^3\ a(1-a)^2 \qquad (10)$$

We obtain maximum power when:

$$\frac{dP}{da} = 0$$

$$\frac{dP}{da} = 2\rho AV_{\infty}^{3} \quad (1 - 4a + 3\ a^{2}) = 0$$

or $\quad a = 1 \quad$ or $\quad a = 1/3$

We have maximum P when a = 1/3

thus,

$$P_{max} = 16/27\ (1/2\ \rho AV_{\infty}^{3})$$

This coefficient (16/27) = 0.593 is called the power coefficient, representing the rotor's efficiency of an aeolian turbine:

$$P = \frac{1}{2}\rho AV^{3}Cp \qquad (1[illegible])$$

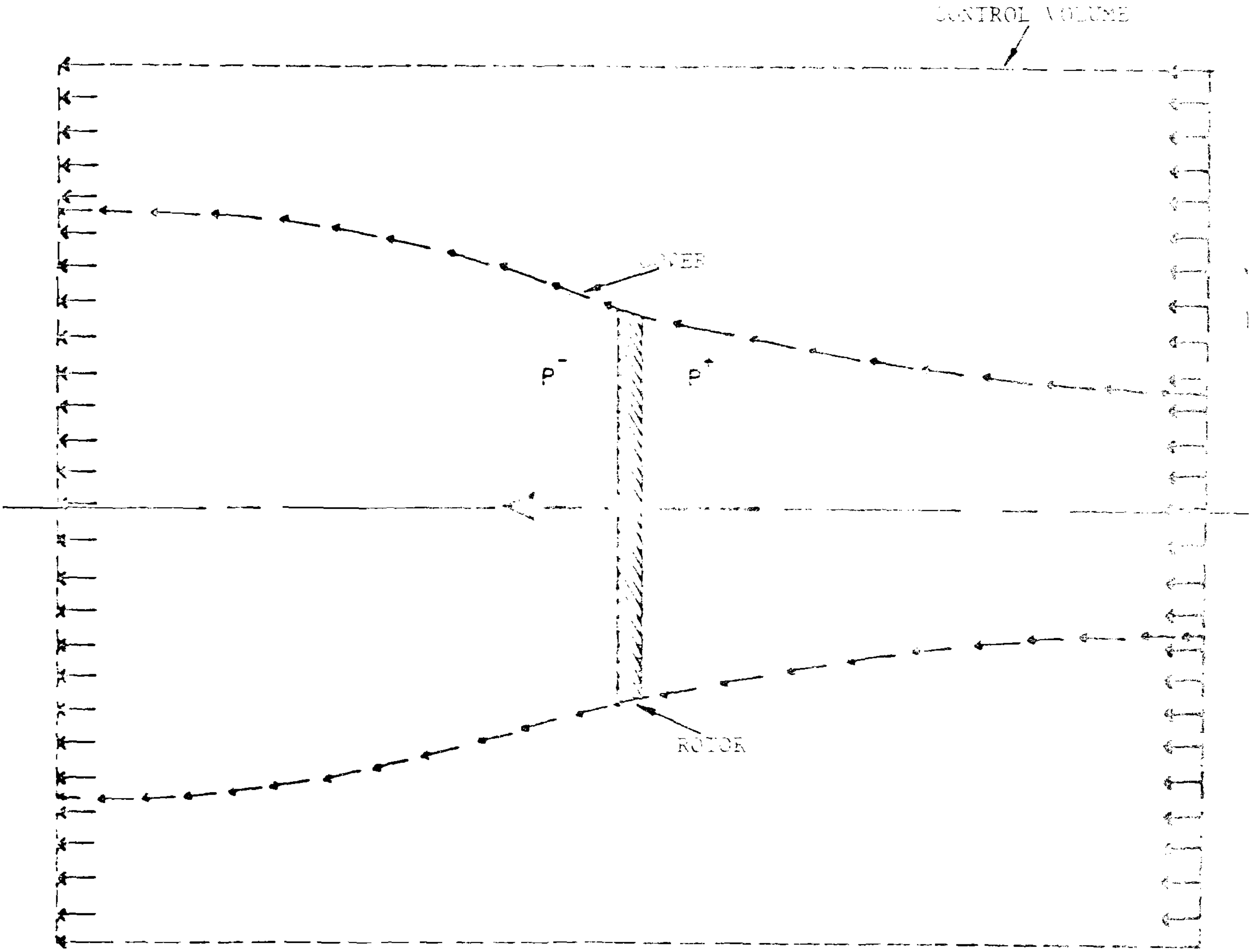

Figure 18 - Control Volume of an Aeolian Turbine

1.3.5.2 Aeolian energy converter system

There are various types of Aeolian Energy Converter Systems (AECS) which have operating in them the theoretical and practical restrictions of the recoverable wind energy.

Figure 19 shows the general scheme in block diagram of an aerogenerator, or an AECS for electricity production.

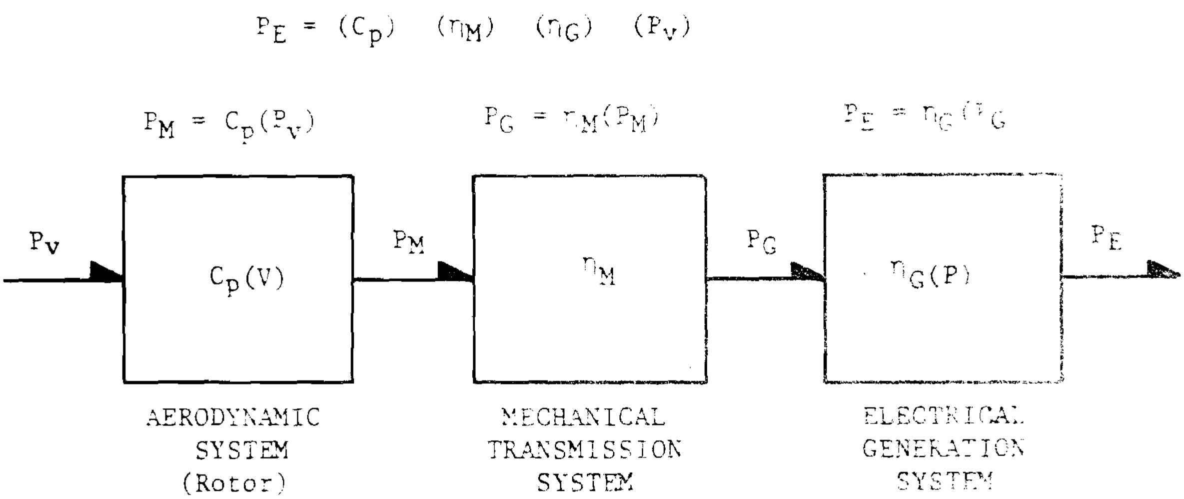

Figure 19 - Block Diagram of an AECS

Basically, the first two blocks are common to all AECS type; the last one is specific to the type of application.

The first block indicates the proper rotor which extracts part of the wind energy, which, as we have seen, of all of its power there is a theoretical maximum limit of 60%, which is what can be used under optimum conditions of energy transfer for a converter system. Actually, an aerodynamical cross aeromotor of high efficiency possesses 40% to 45% of conversion efficiency.

As in all energy conversion, the relation between the energy available for use and the primary energy from which the former comes defines the efficiency of a system. The power coefficient Cp represents the aerodynamic efficiency of the rotor, whose losses may be attributed mainly to the rotational motion imparted to the air by the crosses and to the friction against itself. This coefficient depends on the type and characteristics of the crosses of the rotor, and varies according to the tangential velocity (λ), which is defined as the instantaneous relation between the velocity of the tip of the cross and the wind velocity. The maximum value of Cp is reached for a given value of λ, characteristic of each rotor. If its value is less than 4, the rotor may be considered for low velocity and its maximum efficiency Cp will be 0.3 smaller. The firmness of the rotor, defined as the relation between the cross surface and the area swept by the rotor, tends to large values for turbines of this type. If the value of λ is of the order of 4, or higher for Cp_{max}, we are dealing with a rotor for high velocity with a maximum efficiency Cp of the order of 0.45. The firmness tends to small values for this type of rotors.

If the nominal velocity of the rotor corresponds to the maximum value of Cp, an increase or decrease in the wind velocity will result in a decrease of Cp, when the velocity of the arrow is kept constant (Figure 20). On the other hand, if the velocity of the rotor is allowed to vary with the wind velocity (ratio of tangential velocity λ constant) a maximum Cp can be achieved for all velocities of operation. This results from two basic modes of generation: constant velocity system, in which the rotor's velocity is kept constant by changing the angle of attack of the crosses and/or the characteristics of the load; and variable velocity systems, in which the velocity of the rotor is allowed to vary proportionally to the wind velocity, which allows Cp_{max} for the greater part of operation range. Figure 20 shows the power characteristics of some types of rotors.

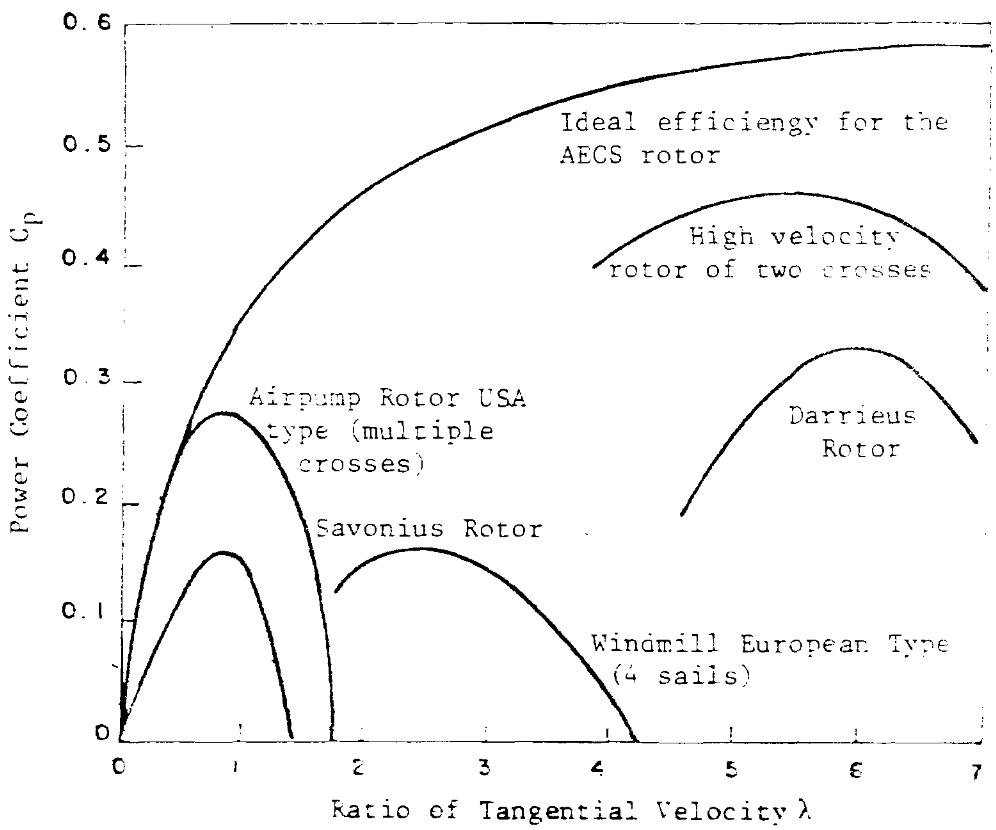

Figure 20 - Power Characteristics for different types of Rotors

There are numerous AECS configurations, each with its own advantages and designed to meet more or less specific applications. Figures 21, 22 and 23 show the main ones. Basically, all can be grouped into two types: systems of vertical axis and systems of horizontal axis. The systems of the first group do not require orienting, for they take advantage of winds of all directions. Those of the second group, although limited in their velocity response to directional changes of the wind, are characterized by higher efficiencies than those of the first group.

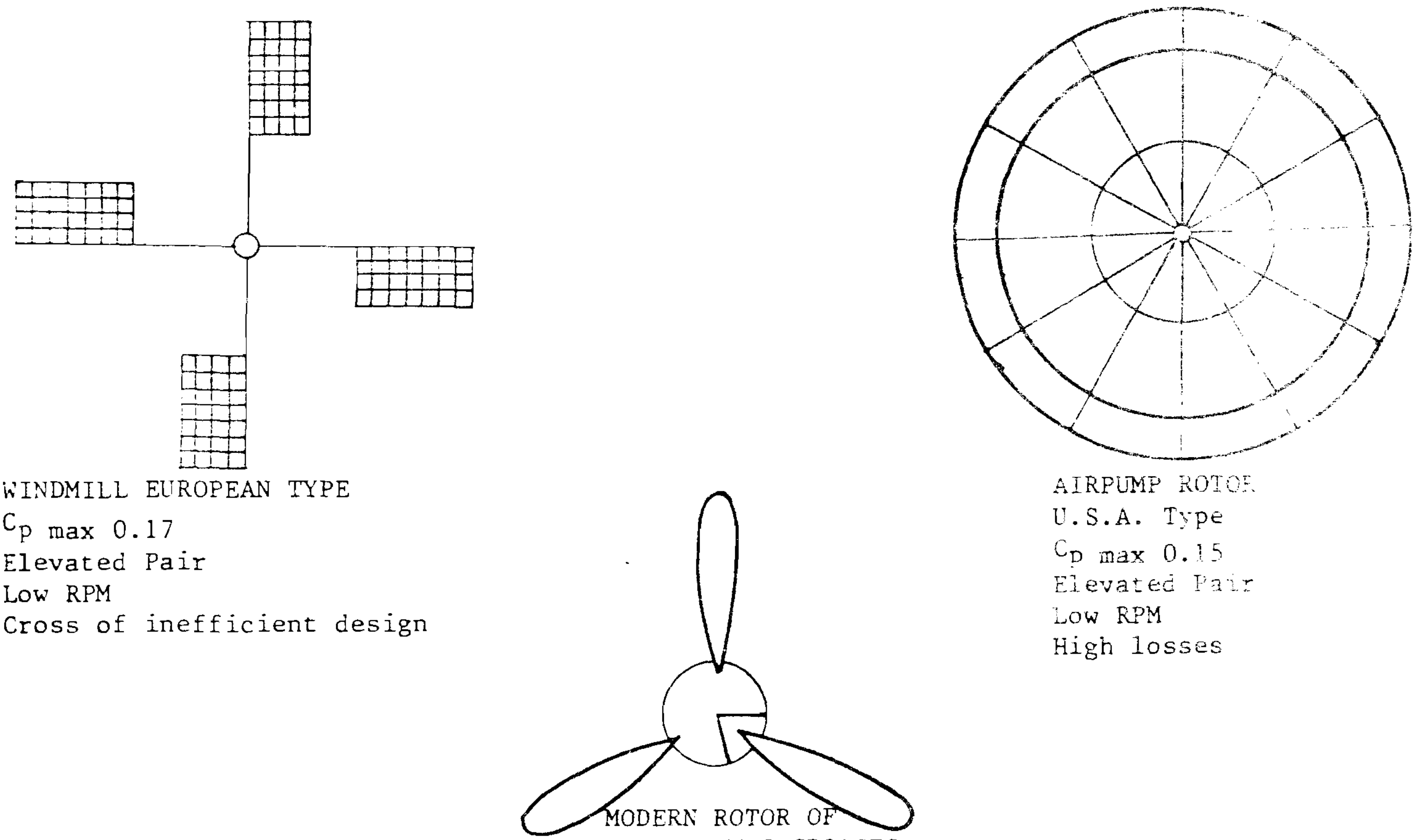

Figure 21 - Configurations and Characteristics of AECS Rotors

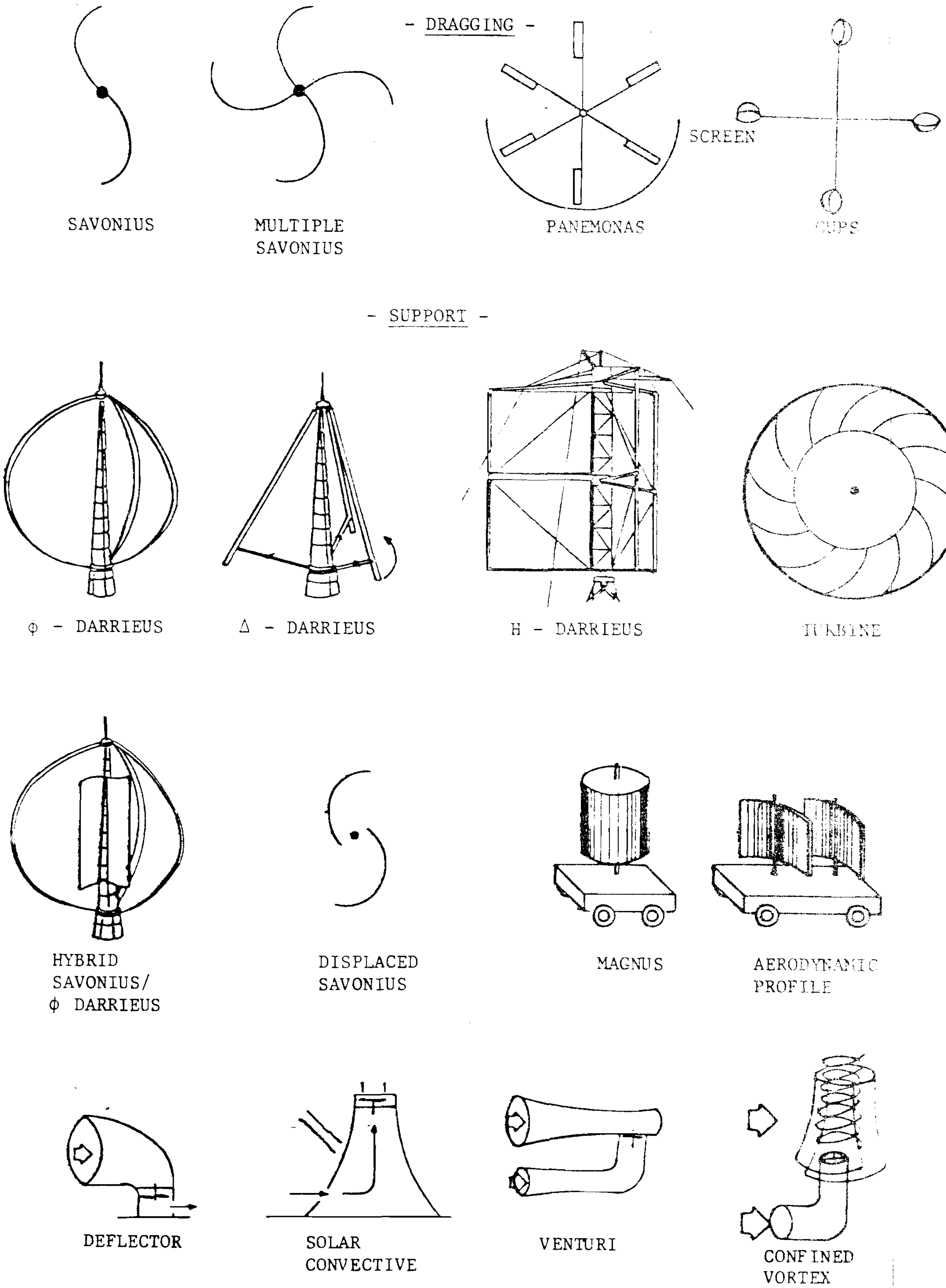

Figure 22 - Configurations of Rotors of Vertical Axis AECS

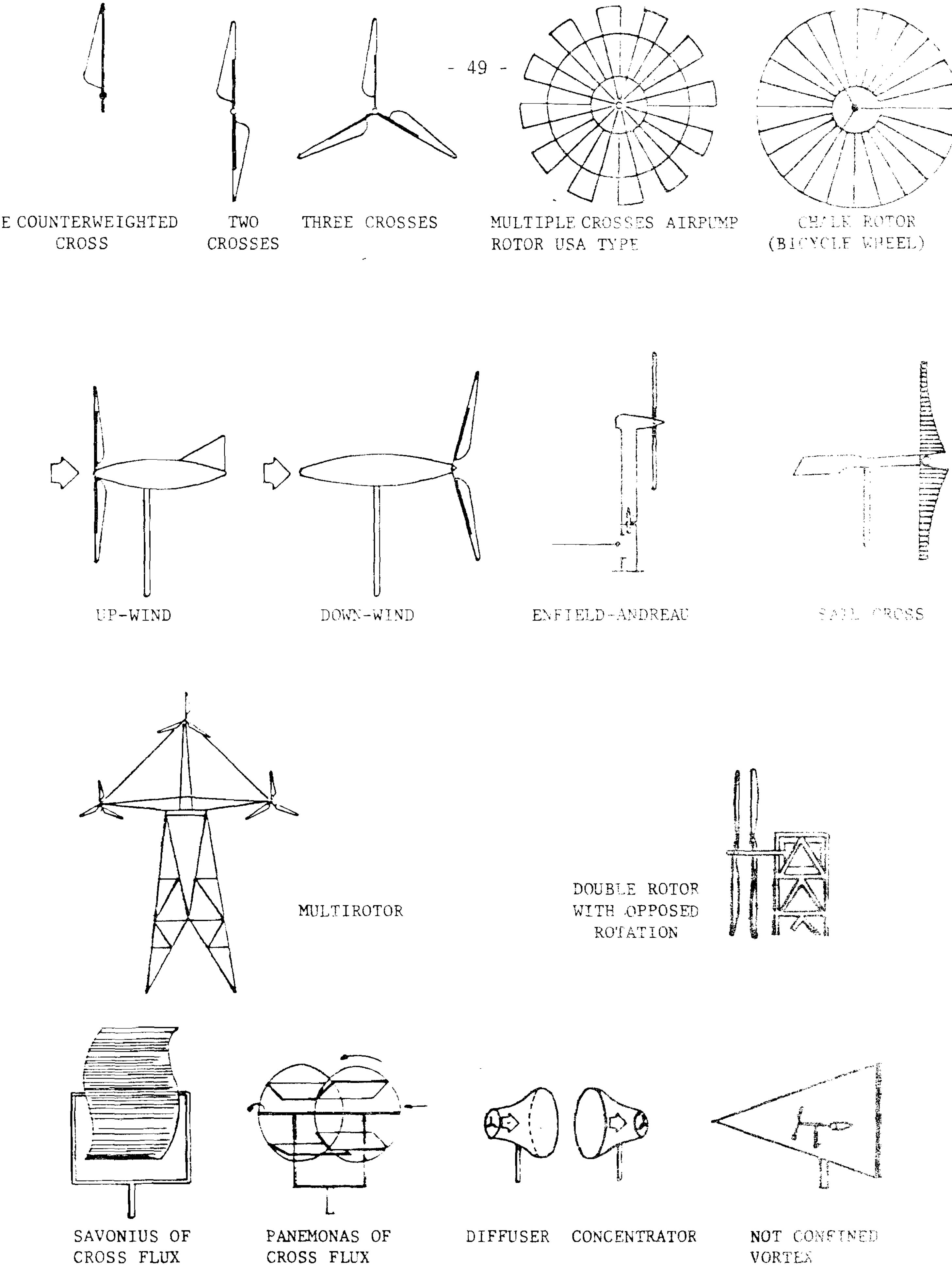

Figure 23 - Configurations of Rotors of Horizontal Axis AECS

1.3.5.3 Usable energy and preliminar economic analysis

With the measurement of a site done, having the annual velocity distribution pattern established, and having considered the seasonal variations translated into a pattern of annual energy and power, the behavior of a system of aeolian energy converter can be deter determined by considering basically three design parameters:

1. Start-up velocity
2. Upper velocity limit of operation
3. Average conversion efficiency in the range of velocity of operation

Correlating these characteristics with the energy characterization of the site, it is possible to predict the amount of useful energy from the wind. This quantity of total annual energy is, in turn, correlated with the cost of the system by considering the initial investment, interest, operational and maintainance costs during its useful life, in order to determine the annual cost of installation and to obtain the cost per unit energy from an aeolian energy converter system.

This unit cost is compared with that arising from other sources of energy to establish its economical feasibility when other alternatives are possible. The fact concerning the use of aeolian energy is that in isolated areas there are no other alternatives to compete with this energy, especially when the application for water pumping is considered.

1.3.5.4 Aeolian energy exploitation

Regarding the aeolian energy, similar to the case of the direct solar energy, the 'disadvantages' attributed to it in an industrial society with an energy greed, are its intermittency and low energy density when compared with the conventional means of massive energy production. The fact if that aeolian energy, as well as direct solar energy, possess advantages which the conventional systems do not: the access to energy. Although the aeolian energy by itself does not present the characteristics of availability and continuity of the conventional type, for which there exist the infra-structure of distribution through storage systems or the backing to achieve it. This undoubtedly increases the cost of the system and the cost of the available energy unit, even if its use may be competitive with other sources. From the economic point of view, the present technological state for the use of the aeolian energy and the level of industrial production of the equipment are susceptible to even a significant decrease in their costs by enlarging its market and with construction innovations. The actual fact is, for isolated places which are normally poor and restricted, any form of energy, either conventional or not, is too expensive.

1.3.5.4.1 The aeolian energy conversion system as fuel economizer

A set of aerogenerators, of intermediate and large capacity, producing electricity and interconnected to a sub-transmission or distribution line, synchronized with them, would feed the electric system a certain amount of energy which would represent a consequential save of water in the hydroelectric plants or fuel in thermoelectric plants. This set of aerogenerators, when representing an installed capacity of the order of 10% of an interconnected system, feed this system considerable amounts of energy without consumption of other resources and without affecting the stability of the system due to the irregular character of the wind.

1.3.5.4.2 Perspectives in the utilization of aeolian energy

To joint large hydroelectric, thermoelectric or atomic plants to the large interconnected systems, to discover and exploit new and large mineral deposits, petroleum or coal, all these benefit in no way the rural sectors, for which the infra-structure is non-existent in what refers to energy, transport and communication networks.

On the contrary, these facts propitiate the centralist pattern, sharpening the margination and migration to the cities.

The use of the aeolian energy as well as the solar energy in all its forms, the so-called non-conventional sources, constitutes the only immediate option for providing useful forms of energy, in a limited way, to rural areas which are far from the conventional energy distribution networks.

CHAPTER 2 - INSTRUMENTS FOR MEASUREMENT

2.1 BEAUFORT SCALE

This scale was established in 1905 by the English admiral whose name is precisely given to this scale (Beaufort) for estimating the wind velocity at sea.

The main object of this scale is to quantify, preliminary and in simple way, the most direct variables of the wind; that is, velocity and direction. As it is know, the wind is defined as the horizontal component of the atmospheric air motion and its velocity is measured in m/sec, km/hr, mile/hr or knots, in general, in units of distance to units of time. The course of the wind is the angular direction with respect to the four cardinal points from which the wind blows.

In aiming at using the wind energy, it is necessary to evaluate its variable at a given place. This procedure consists of several stages which go in increasing order of complexity and with the instrumentation used.

The first stage consists in using precisely Beaufort scale, for it does not require any instrument and any person with a minimum degree of education may use such a scale. This is possible due to the fact that the quantification is carried out by observing the effect of the wind on the vegetation, the water surface in lakes and oceans, the waves, the smoke, flags, etc. Following, we will explain in detail such a scale and its velocity equivalents, as well as its effects, and the name given to each type of wind.

TABLE 2

BEAUFORT SCALE FOR THE WIND FORCE

BEAUFORT FORCE	NAME	VELOCITY EQUIVALENCE TO A TYPICAL HEIGHT OF 10 METERS ABOVE PLAIN AND OPEN GROUND				CHARACTERISTICS FOR ESTIMATING THE VELOCITY ON EARTH
		KNOT	M/SEC	KM/H	M.P.H	
0	CALMNESS	0.1	0 - 0,2	1	1	CALMNESS: THE SMOKE LIFTS VERTICALLY
1	LIGHT WIND	1- 3	0,3- 1,5	1- 5	1- 3	THE DIRECTION OF THE WIND IS GIVEN BY THE MOVEMENT OF SMOKE, BUT NOT BY THE WEATHER-COCK
2	VERY WEAK BREEZE	4- 6	1,6- 3,3	6-11	4- 7	THE WIND IS PERCEIVED IN THE FACE; THE LEAVES SHAKE, THE WEATHER-COCK MOVES
3	WEAK BREEZE	7-10	3,4- 5,4	12-19	8-12	LEAVES AND SMALL BRANCHES SHAKE CONSTANTLY; THE WIND UNFLODS BANDEROLS
4	MODERATE BREEZE	11-16	5,5- 7,9	20-28	13-18	THE WIND LIFTS DUST AND PIECES OF PAPER, SMALL BRANCHES RUFFLE
5	FRESH BREEZE	17-21	8,0-10,7	29-38	19-24	SHRUBS WITH LEAVES OSCILLATE; SMALL WAVES ARE FORMED WITH CREST IN THE INTERIOR WATERS (TANKS)
6	FRESH WIND	22-27	10,8-13,8	39-49	25-31	BIG BRANCHES AGITATE; TELEGRAPHIC TREADS WHISTLE; THE USE OF UMBRELLAS IS DIFFICULT

7	STRONG WIND	28-33	13,9-17,1	50-61	32-38	ENTIRE TREES AGITATE; MARCHING AGAINST THE WIND IS PAINFUL
8	HARD WIND	34-40	17,2-20,7	62-74	39-46	WIND BREAKS BRANCHES; IMPOSSIBLE MARCHING AGAINST THE WIND
9	VERY HARD WIND	41-47	20,8-24,4	75-88	47-54	WIND CAUSES HIGH DAMAGE TO HABITAT (TORN TUBING, CHIMNEYS, ROOFS)
10	TEMPEST	48-55	24.5-28,4	89-102	55-63	RARE IN THE CONTINENTS: TORN TREES; STRONG DAMAGE IN HABITAT
11	STORM	56-63	28,5-32,6	103 - 117	64-72	RARELY OBSERVED, ACCOMPANIED BY EXTENSIVE DAMAGE
12	HURRICANE	64 or more	32,7 or more	118 or more	73 or more	GRAVE AND EXTENSIVE RAVAGE

NOTE: The instruments for measure and register the wind velocity have reduced considerably the use of Beaufort scale, particularly in land stations. However, this scale constitutes a convenient means for estimating the wind velocity when other instruments are not available.

2.2 ANEMOMETERS

We call an anemometer to a trasducer which converts the wind energy into other type of energy which is easier for measurement with regards to existing instruments; this is, electrical energy, kinetic energy, etc. The most common types of anemometers are:

- 2.2.1 Cup Type Anemometer
  - 2.2.1.1 A.C. Generator
  - 2.2.1.2 D.C. Generator
  - 2.2.1.3 Counter
  - 2.2.1.4 Contact
- 2.2.2 Windmill Type Anemometer
- 2.2.3 Pressure Tube Type Anemometer
- 2.2.4 Sonic Type Anemometer
- 2.2.5 Hot Wire Type Anemometer

2.2.1 Cup Type Anemometer

This type of anemometers was developed by T. R. Robinson in 1846. The rotor consists of a vertical axis holding four horizontal arms, placed at right angle one from another. Hemispheric cups were placed at the tips on vertical planes with a common axis of rotation, with their convex faces opposite to the direction of rotation. The principle consists in the fact that the wind pressure at their concave faces is greater than that of their convex faces; this causes rotation independent of the wind direction. Multiple theoretical studies and research on this type of anemometer have led to the conslusion that:

1. Using three cups instead of four, the resulting torque is more uniform.
2. Making the cups with conical instead of hemisferical shape, reduces the over-estimation of the wind flux fluctuations.

2.2.1.1 Cup type A.C. generator anemometer

This type of anemometer consists of a rotor which in the upper part has three cups placed as explained previously; in the lower part there is a system of permanent magnet sur_ rounding a low resistence stator, which is a small A.C. ge_ nerator producing low amplitude voltage when the wind causes the cup system to rotate and, hence, the rotor. Generally, one tries to design this type of anemometers in such a way that the voltage produced be directly proportional to the wind velocity with linear increment.

2.2.1.2 Cup type D.C. generator anemometer

This type of anemometer is manufactured similarly to the previous one, except that instead of an A.C. gene_ rator it makes use of a D.C. generator.

2.2.1.3 Counter type anemometer

This type of anemometer uses the motion generated by the rotor; it moves a mechanical counter by means of a gear-box. This is, it uses the rotation of the rotor which can be measured mechanically.

2.2.1.4 Contact type anemometer

The principle by which these anemometers operate is that through an interruptor, normally open, which is activated every fraction of the rotor round. These switches or interruptors may be of different classes, such as: pressure relay, liquid, etc., giving out a determinate number of pulses to be used according to the system for their processing.

Nowadays, optoelectronic interruptors coupled to the rotor axis are used, that is, the rotor is drilled a number of times equal to the number of pulses required for each revo_ lution of the rotor, and a light-detector pair couple is placed (light-phototransistor-emitter diode) whose output produces a pulse every time the detector receives light. That is, the corresponding drilling coincides with the emitter-detector axis.

2.2.2 Windmill Type Anemometer

This anemometer has the peculiarity in that it should be oriented to the direction of the wind; for this, a weather-cock is used as a windmill. This is, the arms are on a plane perpendicular to the wind, and the crosses are inclined allowing the motion of the rotor. This motion can be used in connection with the principle of the A.C. generation, or D.C. or others. It also allows being used as an anemoscope due to the necessity of orienting to the direction of the wind.

2.2.3 Pressure Tube Type Anemometer

The construction of the anemometer of pressure is based in the following principle: a vane located at the end of a must main_ tains the orifice of a tube facing the wind. The wind flowing at this hole creates an over-pressure in the tube, which depends on the wind velocity. This over-pressure is transmitted to the indi_ cating equipments through a conduct. Another tube, located imme_ diately below the vane, with numerous small holes developes a de-pressure by the wind passing around it, which is transmitted to the equipment through another conduct. The whole constitutes a system in which the difference between the over-pressure and the de-pressure is independent of the pressure difference which may exist between the interior and the exterior of the building, where the indicating apparatus or manometer is located.

There are two types of manometers for the anemometer of pressure. In the floater manometer of Dines, the difference of pressure varies the equilibrium position of a floating cylinder on water which activates the indicating device. An aneroid manometer can also be used specially for ships, in which the floating model cannot be used. There is another type which uses an open tube directed by a vane along the direction of the wind. A pressure is produced at the tube mouth, which is proportional to the wind velocity. This pressure is transferred along the holed and flexible conductor reaching the reading apparatus, which can be differently designed. For instance: a bubble is introduced in a container with liquid (dines), a pressure applied to a liquid of a given specific density in a scaled tube.

2.2.4 Sonic Type Anemometer

It is based on the principle in which the spherical sound velocity generated is equal to the sum of the sound velocity and the wind velocity (at constant temperature); two spherical signals of equal frequency are transmitted from two transmitters to two receptors having their transmitter-receptor axis mutually perpendicular. The difference in time is a measure of the wind velocity.

2.2.5 Hot Wire Type Anemometer

The function of this anemometer is based on the varitation of the resistance of a conductor with changes in temperature.

A conductor, when heated, acquires a certain temperature and a given resistance along with it. If it is placed inside a flux of air, this will cool it, the degree of which is translated into a variation of its resistance. In a Wheatstone bridge, the cooling can be measured by a balance of the current in the circuit; the velocity of the wind can be observed by an amperimeter with a relation between the velocity and the current.

2.3 ANEMOSCOPES

As it has been said previously, one of the variables of the wind which is of interest measuring is its direction, and for this there are instruments developed called anemoscopes. An anemoscope is essentially a sensor and trasducer which converts the wind direction into another type of variable such as electricity, motion, etc.

The simplest of all anemoscopes is the one corresponding to the Beaufort scale, which consists of a ribbon tied to a post at a certain height, indicating the direction with respect to the four cardinal points.

In the development of this type of instruments one finds, in principle, a vane placed at one end of a horizontal axis with a counterweight at the other end to balance the weight of the vane. The system is placed on a vertical axis with freedom of movement on a horizontal plane, thus the vane will always point in the direction the wind blows. There are four horizontal axes, fixed, to indicate the direction of the four cardinal points as reference.

This type of sensor is highly reliable and the latest anemoscope development employs basically this principle with slight variation in the vane manufacturing. There are other types of sensors such as the sonic one.

The difference among the vane types of sensor is found in the trasducers. Basically, they are divided into two types: mechanical and electrical.

The mechanical type consists in using the movement of the vane directly. The electrical type is used more commonly and conveniently; it can be constructed based on two types of trasducers: potentiometer and of contact.

The one of contact consists of fixed poles covering a specific angle, and an additional pole activated by the vane. When the latter, with an applied current or voltage, makes contact with one of the fixed ones, it will be transferred to the other pole; thus, it can be collected by means of another trasducer to convert the electric current-position to a direction in an analog or digital scale, whatever the case may be. Of the latest designs in anemoscope, the optoelectronic contact type can be mentioned; this consists of a couple pair LED (light-emitter diode) photo-transistor, which operates in the similar way to the anemometer of this type. It is worth pointing out that this type of anemoscope output can be codified, by means of a movable plate activated by the vane, so that for a given position of the vane several holes coindice with the axis of the LED-photo-transistor pair; the output is then codified, whose code may be any of the commonly used digital circuits. In this way, the processing of information is assisted.

The anemoscope with a trasducer of the potentiometer type consists in the use of a potentiometer of 360° rotation, moved by the rotating movement of a vane; its output electrical resistance varies. If a voltage is applied between its terminals, the voltage in the mid-point will vary proportionally to the rotation produced, or to the direction of the wind. This voltage variation can be read directly from a calibrated voltmeter for course reading; else, we will obtain a variable current, which can be measured by an amperimeter. In more advanced designs, this current or voltage may be trasduced by means of a digital-analog converter, so that the digital code can be used for reading and information processing.

It is important to note clearly the difference of what can be considered as an anemocinemograph and an anemoscope or anemometer, since previously we have regarded these last two as trasducers of the wind variable; it can also be considered as a trasducer the signal going up to the final point of the trajectory to be used.

This infers that an anemometer, or an anemoscope, is one which tras_ duces the output parameter from the trasducer to an electrical, mecha_ nical or other type of displacement, that can be observed from a gra_ duated scale of corresponding units. In the course of time, the terms anemometer and anemoscope have been interpreted erroneously; they have been called to trasducers which give a signal both unrecognized and recognized by human sensors. To try changing this terminology is in_ operative, for they appear in books and handbooks, present and past. We will use them as such, keeping this reservation in mind.

2.4 ANEMOCINEMOGRAPHS

An anemocinemograph is defined as an instrument which utilizes the variables obtained from an anemoscope and an anemometer, processes such information and trasduces them into a graph with respect to time. It must be understood that the anemometer and the anemoscope which we are referring to here are of the trasducer type, producing a signal which is not directly shown in the form of monitoring.

These instruments may be divided into two categories:

- Anemocinemographs of instantaneous velocity
- Anemocinemographs of travelled distance

Before going into details, let us state that an anemocinemograph may be considered as an instrument formed by a device graphing the wind velo_ city and another one graphing the wind direction under similar principle, and depending on its differentiation within the class of anemometer and anemoscope used. This is stated in order to explain to the reader that these devices can be found individually, although a complete unit, or anemocinemograph, can be found in the market.

Let us then consider an anemocinemograph as an equipment with two channels, one for graphing the wind velocity and the other to graph the wind direction under a common time scale.

2.4.1 Anemocinemographs of Instantaneous Velocity

These devices graph the instantaneous velocity and the course of the velocity simultaneously. The anemometer and the anemoscope used may be of different type from the ones described above, the most common ones being A.C. generation, D.C. generation, and con_ tact anemometers. With regards to the anemoscopes, these can be of contact or with potentiometer.

The outcome signals from the anemometer and the anemoscope are processed and trasduced to lectrical impulses of different magnitude, proportional to the velocity and direction of the wind, respectively. These impulses are transferred to the movement of several needles, which do the graphing on papers. To this end, it is obvious that the paper should be running at a certain velocity; this is achieved by means of a motor, controlled by a clock, which triggers the motor every certain interval of time. To mention a simple and theoretical example, the graphing of the wind direction may be done in the following way (see Figure 24).

Here the potentiometer type anemoscope varies from 0° to 360° according to the wind velocity. If a constant voltage +V is applied to the terminals, in the point A we will have a variable voltage proportional to the wind direction; in passing through a resistence, a variable current is obtained which will produce a magnetic force on an electromagnet "E.M". These magnetic forces will be proportional to the current generated and will be converted into a displacement of the needle base against the force of a spring according to the magnetic force.

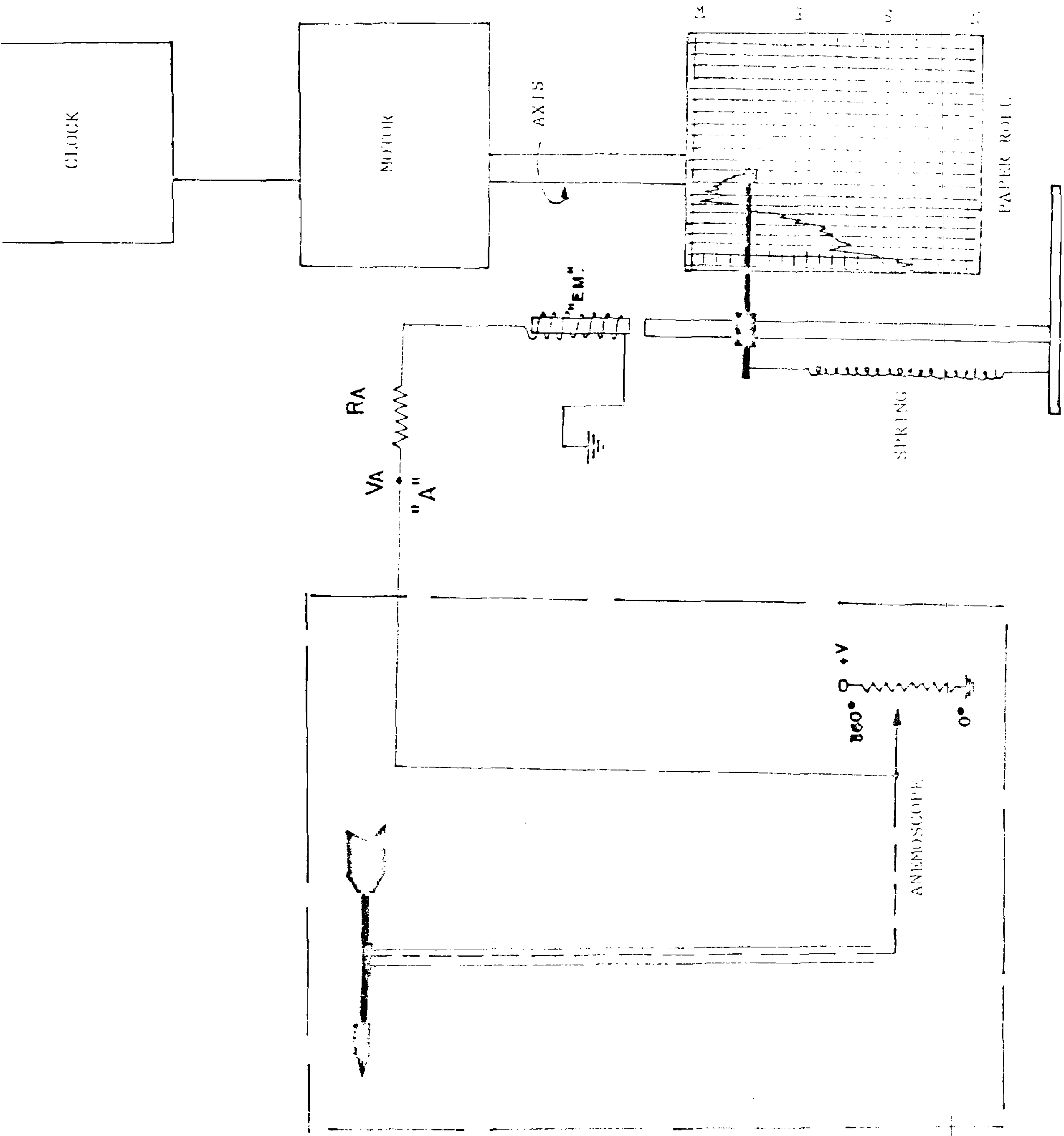

Figure 24 - Anemocinemograph of Instantaneous Velocity

If on the graphing paper the cardinal points are well marked in a scale according to the displacement of the needle, and if this is added to the displacement of the motor at certain time interval, defined by a clock, we will obtain our graph of the wind velocity with respect to time.

Although this example is a theoretical one and very simple, it does give us the idea of how to graph in an anemoscope. The complexity of a system depends on the accuracy desired from the measurements.

2.4.2 Anemocinemograph of Travelled Distance

This type of equipment, normally known as integrator, has its function based on counting the number of miles, kilometers of meters the wind travels, passing through a place at a certain time interval. A cup type anemometer, for example, will rotate a certain circular distance activated by the wind; if the distance travelled is measured by an anemo meter for a well-defined interval of time, one would obtain the distance travelled by the wind/period of time, which obviously refers to the wind average velocity.

In the same way, if a contact anemoscope is used to shot out circuits, it is possible to obtain an average of the wind direction with reference to an interval of time. Combining this and the former one we can obtain the number of miles, kilometers or meters travelled every certain time interval and in a given direction.

2.5 ELECTRONIC ANEMOCINEMOGRAPHS

The funcion of this equipment is to accumulate the time during which the wind blows with a specific velocity.

Obviously, this is done over intervals of specific velocities and not over a continuous range, which would be impossible.

Due to the large amount of data which has to be stored, its design has been done based on electronic circuits. With these, as is known, a large memory capacity and data processing can be implemented.

Let us suppose that we have an approximate idea of the maximum wind velocity, Vm, in a place. This would be represented in a graph by the point Vm (see Figure 25).

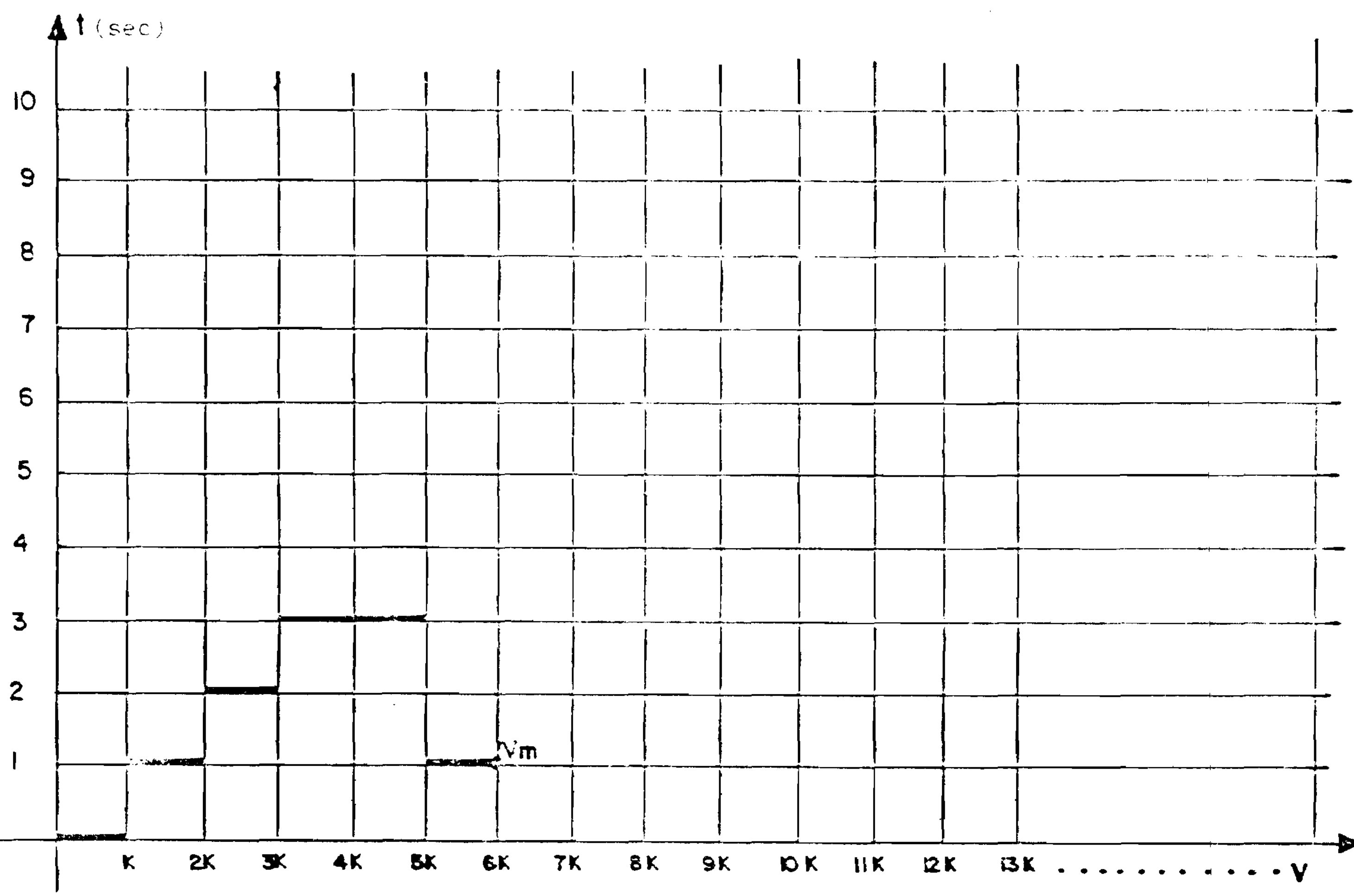

Figure 25 - Graph of the Wind Velocity

If we choose equal intervals of velocity, and calling its small value K, we will have Vm/K intervals in the velocity magnitude. Now, if each second is identified with the wind velocity, we will finish with a graph like the one shown in Figure 25. If from here we add up all the seconds the wind had each of the velocities, K, 2K, 3K,...Vmax, we will obtain the time during which the velocity had a certain value for the case:

K=0 sec., 2K=1 sec., 3K=2 sec., 4K=3 sec., 5K=3 sec., 6K=1 sec.

The sum of the times of each of the velocities will yield the total period of data recopilation.

This is exactly what an electronic register does with the observation having a memory capacity for three years/interval of velocity. To this interval, the name of Bin is given and its amplitude can be selected. The electronic procedure can be based on hardware or software; that is, based on discreet integrated circuit; or on micro-processers. Figure 26 is a scheme showing in block form one possibility of implementation of an electronic register.

Thus, in one or more locations of the memory, corresponding to 1 Bin, the number of seconds the wind velocity was in a specific Bin during a period of time x is stored. In the next topic it will be seen the way to process the data from which the great utility of these equipments can be noticed clearly.

In the Instituto de Investigaciones Eléctricas, the Equipment Division developed a device which, by the use of a micro-processer, registers these data.

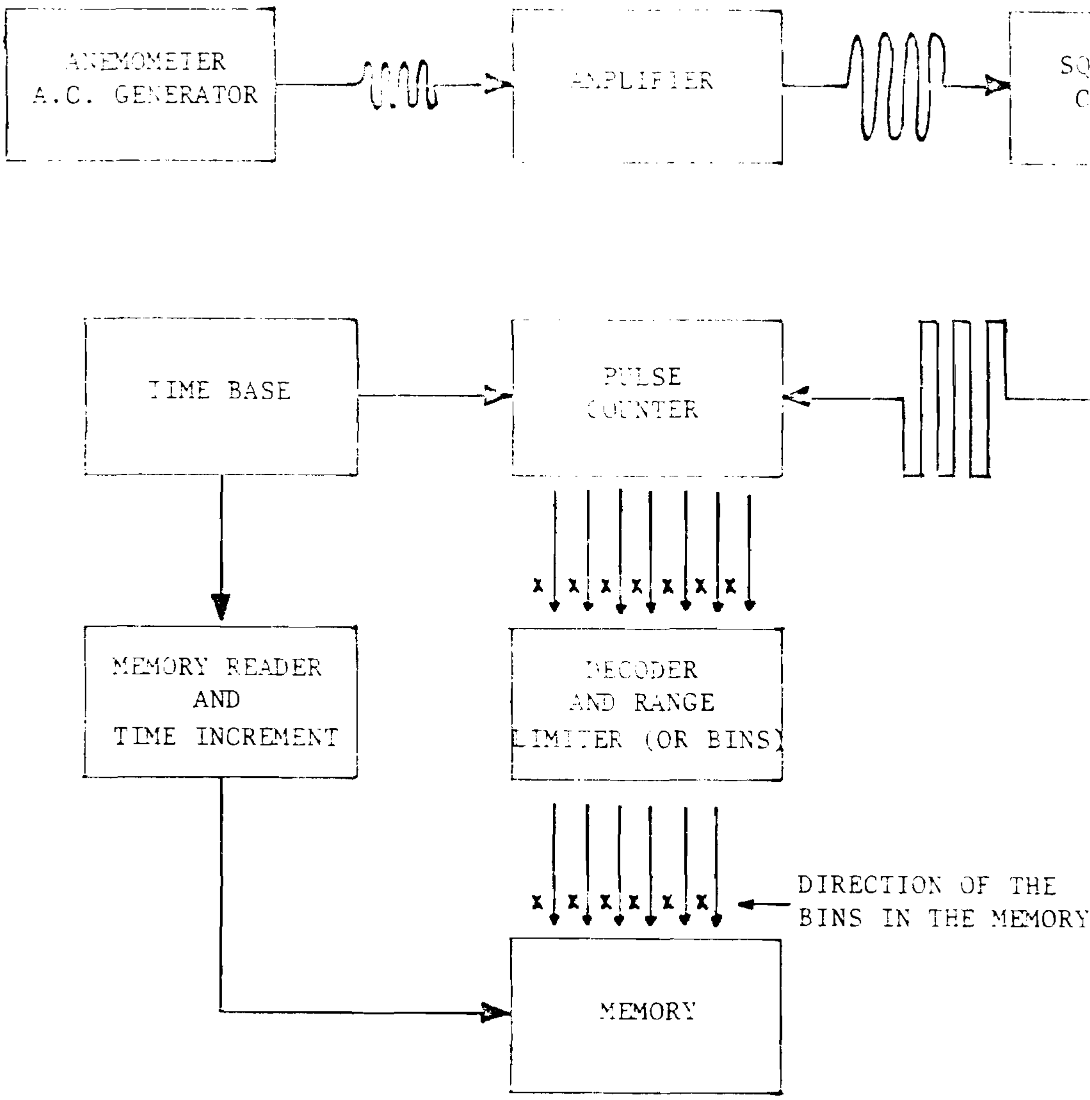

Figure 26 - Implementation of an Electronic Register

CHAPTER 3 - DATA HANDLING

3.1 BEAUFORT SCALE

To register both the wind velocity and direction using Beaufort Scale, it is proposed to employ the format shown in Figure 27.

This format allows carrying out the first evaluation and characterization of the wind, upon yielding:

a) Range of average and maximum velocities
b) Dominant winds (rose of the winds)
c) Time distribution of the winds
d) Average percentage of calmness

3.1.1 Velocity and Course Indications from the Registering Sheet

The format for "weekly register of the wind velocities" consists of seven sections, one for each day of the week; it also contains eighteen columns, one for each hour, from 5 a.m. to 10 in the evening. The eight small subdivision in each day, from zero to 7, indicate the velocity according to the Beaufort scale. Thus, to each of the day during the week there is a corresponding space to indicate the wind course and velocity.

To observe the wind direction, a ribbon of two or three centimeters of width, and 40 to 50 centimeters long can be placed in the upper end of a post; the latter will be located in a high spot (the roof, a tree, etc.). The direction the end of the ribbon tied to the post will indicate the wind direction at that moment, taken with respect to the four cardinal points; these must be perfectly identified for the site of wind observation.

WEEKLY REGISTER OF THE WIND VELOCITY ACCORDING TO BEAUFORT SCALE

Site ______________________ Formulated by ______________________

Week: From __________ to _________ of _______

Day		Hour of the day																	
		5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Sun.	7																		
	6																		
	5																		
	4																		
	3																		
	2																		
	1																		
	0																		
Mon.	7																		
	6																		
	5																		
	4																		
	3																		
	2																		
	1																		
	0																		
Tue.	7																		
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Thu.	7																		
	6																		
	5																		
	4																		
	3																		
	2																		
	1																		
	0																		
Fri.	7																		
	6																		
	5																		
	4																		
	3																		
	2																		
	1																		
	0																		
Sat.	7																		
	6																		
	5																		
	4																		
	3																		
	2																		
	1																		
	0																		

Figure 27 - Register of Wind Velocity and Direction - Beaufort Scale

The procedure to effect the registering is as follows:

a) Observe for a few seconds the visible references in order to estimate the course and velocity corresponding to that moment.
b) Letters denoting the course will be jotted in the space corresponding to the estimated velocity, in the column of the nearest hour.
c) If there is calmness, a dash line will be placed in the space "zero" at the hour observation is made.

With this format duly filled, the velocity distribution will be "drawn" for the day, and if there is a defined pattern, this will be visible. We can also detect which is the dominant wind when we verify the greater frequency of course repetition of a given wind.

From the data so obtained in the first stage, we can tell in a superficial way, if the site under study fulfills the conditions for a more accurate study of the velocity distribution, which will consists of an investigation to establish whether the wind blows with sufficient intensity for it to be economically exploitable; how the wind velocity is distributed during the day, months and year, with accuracy; which are the strong winds, of a certain periodicity, probable durations, the periods of calmness and its dominant nature.

All these data will allow us to know, probabilistically, how much energy from the wind can be utilized.

3.1.2 Analysis of the Registering Sheet

In order to carry out a valuable statistical analysis, the minimum amount of information to be processed will be that corresponding to a period of four weeks.

The three basic questions to be answered by analysing this register are:

1. Is there a daily pattern of velocity distribution?
2. Is there evidence of the presence of predominant courses?
3. Is there a more or less defined distribution and frequency with respect to the calm period?

The processing of the data should avail us of the following information:

a) Rose of the winds (polygonal)
b) Monthly average and standard deviation of the velocity, and
c) Hourly average dominant wind velocity and its standard deviation, in the case a defined daily pattern of velocity distribution exists.

The above can be effected by the following procedures:

3.1.2.1 Rose of the winds

To treat the rose of the winds, a format like the one described in Figure 28 will be used. The data of course, of at least four weeks, will be processed this way.

3.1.2.2 Velocity hourly distributions and histograms of the period

Figure 29 shows the useful format for the processing of velocity data for a given period; from this, the average velocity and its standard deviation are obtained.

To determine the velocity hourly distribution, when a defined daily pattern is observed, a format basically that of Figure 29 is used for each hour, for which the average velocity and standard deviation are to be determined.

ROSE OF THE WINDS

SITE: ______________________________

PERIOD: FROM SUNDAY ____ OF ______________ OF 19 __

TO SATURDAY ____ OF ______________ OF 19 __

FORMULATED BY ______________________________

COURSE	COUNTS	FREQUENCY	PERCENTAGE
N			
NE			
E			
SE			
S			
SW			
W			
NW			
CALM			
	TOTAL:		

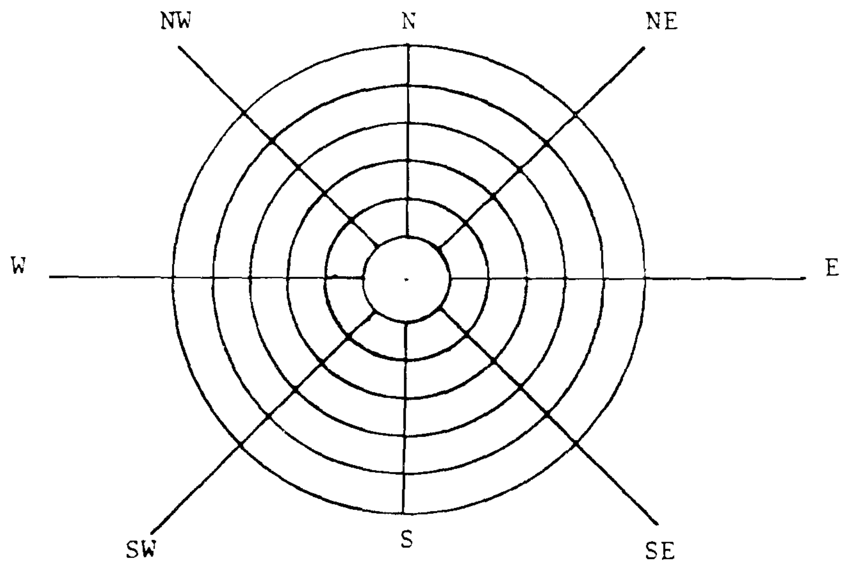


Figure 28 - Rose of the Winds

WIND VELOCITY ANALYSIS ACCORDING TO THE

BEAUFORT SCALE

SITE: ______________________ FORMULATED BY: ______________________

PERIOD: SUNDAY _____ OF _______ TO SATURDAY __________ OF __________

VELOCITY (BEAUFORT)	C O U N T S	FREQUENCY n_i	DEVIATION d_i	$n_i d_i$	$n_i d_i^2$
1			-3		
2			- 2		
3			- 1		
4			0		
5			1		
6			2		
7			3		
	TOTAL:				

a) Number of cases N= ____

b) Assumed average M.S.= 4

c) $\Sigma n_i d_i$ =

d) $\frac{\Sigma n_i d_i}{N}$ =

e) $\overline{V}$ = M.S.+ $\frac{\Sigma n_i d_i}{N}$ = 4 + ________ = ________

f) $\Sigma n_i d_i^2$ =

g) $\frac{\Sigma n_i d_i^2}{N}$ =

h) $\left(\frac{n_i d_i}{N}\right)^2$ =

i) $\sigma = \sqrt{g) - h)}$ =

SUMMARY IN: BEAUFORT

$\overline{V}$ =

σ =

Figure 29 - Analysis of the Wind Velocity According to the Beaufort Scale

With this information we will be in the position to construct a graph of daily distribution of velocities, with indication of the hourly average values and the amplitude of the standard deviation.

3.1.3 Evaluation of Results

Having processed the information and the rose of winds, percentage of calmness, average velocity of the period, standard deviation and, optionally, the graph of the hourly distribution of velocities pattern, we are in the position to carry out a preliminar evaluation of the site and decide whether or not an anemometric study should be carry out, with a anemocinemograph, so as to obtain more complete and reliable information.

It is evident that in translating the average value of the velocity from the Beaufort scale to m/s,km/hr or mile/hr, the minimum values of the range are to be used.

It is advisable to handle these values conservativelly without being too optimistic.

3.2 TRAVELLED DISTANCE REGISTERS

3.2.1 Introduction

An anemograph of travelled distance is an instrument to register the distance travelled by the wind when this passes an interval of time. Its registerings, hence, correspond to an average velocity for the intervals involved.

An anemograph of distance travelled functions as an integrator, which accumulates the number of revolutions of the cup anemometer either mechanically or electrically, until a certain number of miles or kilometers is totalled, with which the counter resets to zero.

The analogical indication of the needle of this instrument indicates the accumulated travelled distance for the specific cycle. The motion of the registering paper provides the time scale, and the combined orthogonal motion of both the registering paper and needle produces and inclined cyclic graph (saw-tooth) whose slope represents the average velocity of the wind in the interval involved.

3.2.2 Travelled distance graphing and its processing

The graph of travelled distance is illustrated in figure 30.

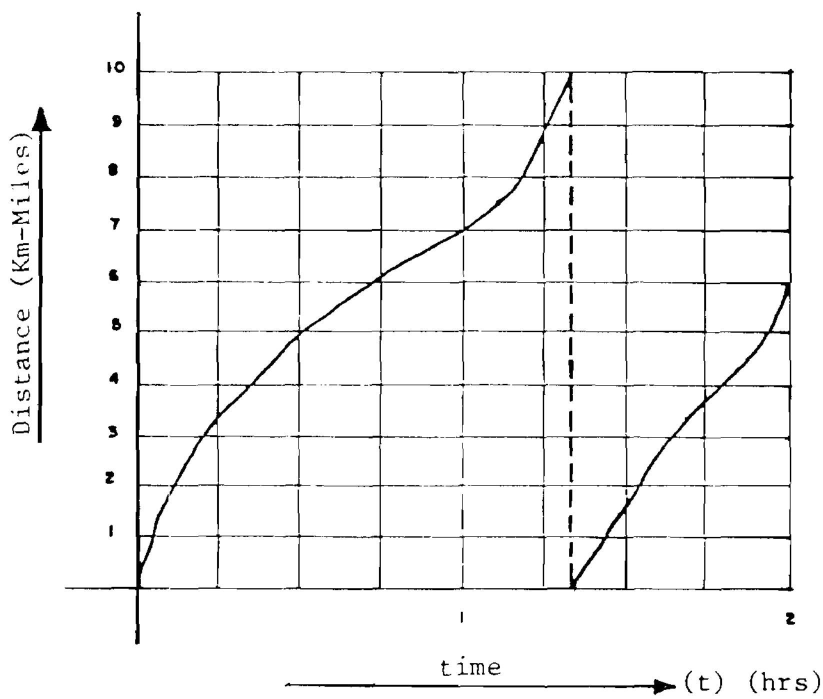


Figure 30 - Graph of Travelled Distance

The vertical axis denotes the distance, in kilometers or miles, and the horizontal axis is the time scale, according to the dragging velocity of the paper (1 inch/hr, a typical case).

The displacement of the needle on the paper results in a diagonal trace.

To obtain the wind average velocity in a given period of time, one has to simply divide the distance travelled by the time length of the corresponding interval.

Figure 31 shows the case of a graph with a distance scale of 0 to 10 miles, with the paper moving at 2 inches/hour.

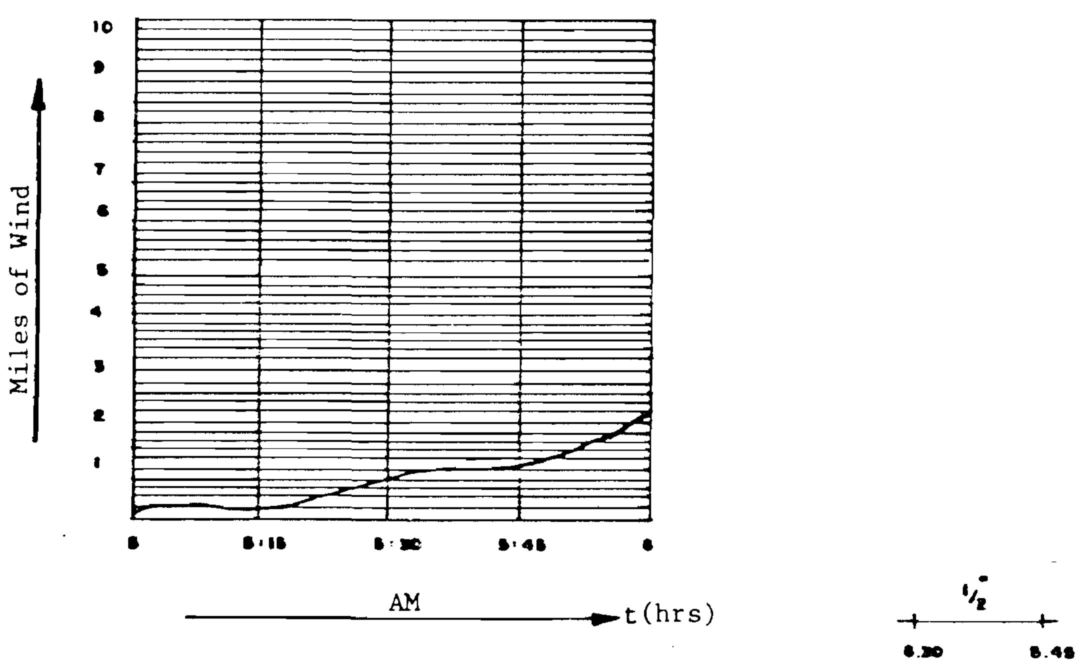


Figure 31 - Example of Graph of Travelled Distance

Considering intervals of 15 minutes, for the period of 5 to 6, we have $\overline{V}_1$= 0.178 m/sec; $\overline{V}_2$= 1.246 m/sec; $\overline{V}_3$= 1.068 m/sec and $\overline{V}_4$= 1.78 m/sec. These average velocities with 15 minute intervals, calculated for a period of 24 hours, will enable us graphing the curve of the wind velocity distribution each day.

3.2.3 Graphing Procedure for the Daily Velocity Distribution Curve

On a piece of millimetric paper, two orthogonal axes are drawn. The horizontal axis represents the time, containing 24 hours, with a scale of 1 cm: 1 hour. The vertical axis indicates the velocity in m/sec, with a scale of 1 cm: 1m/sec.

Figure 32 shows a graph of the wind velocity distribution for one day.

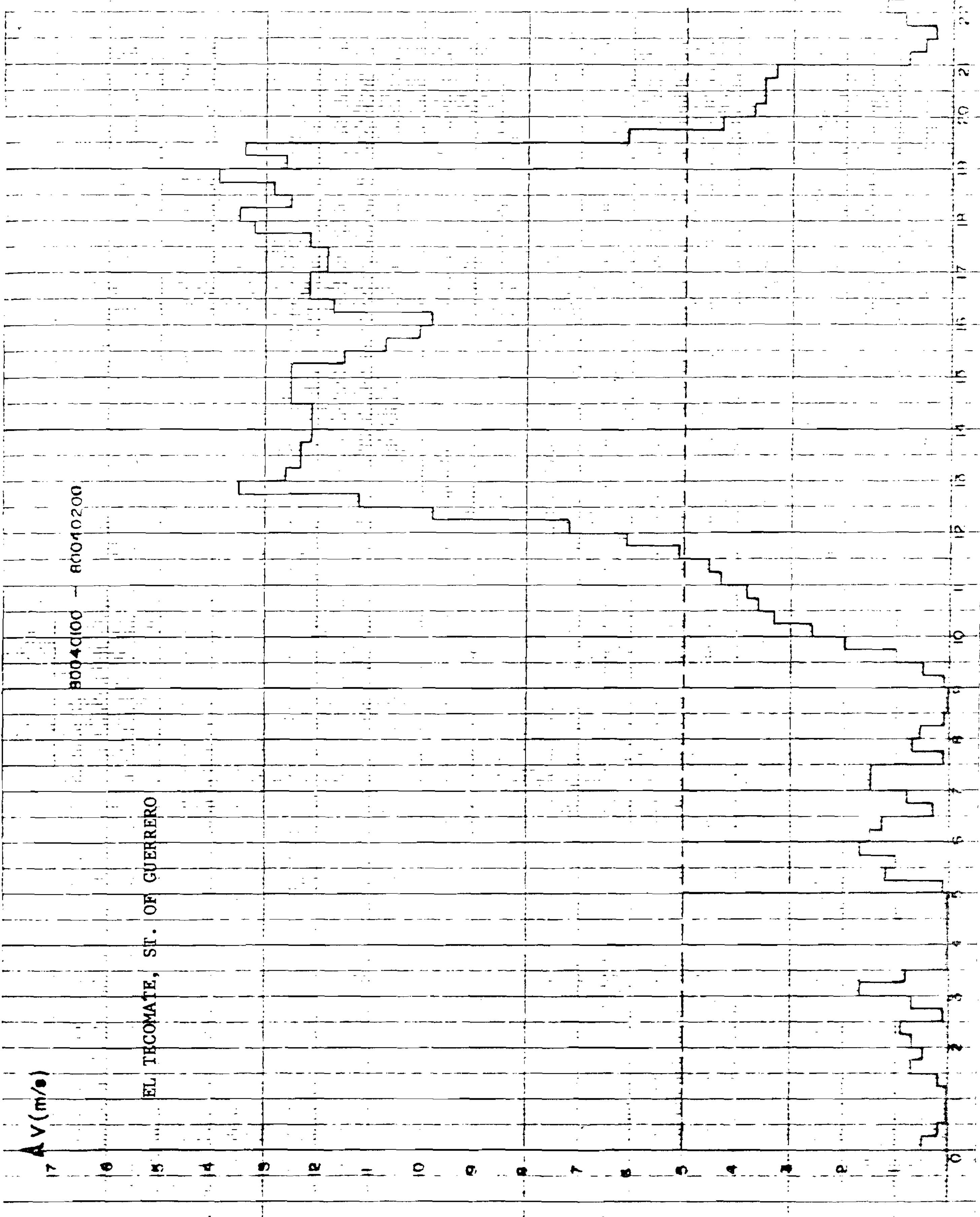
It is necessary indicating the period of registration, which can be done with a numerical code of the following type: $(AAMMDDHH)_1$ - $(AAMMDDHH)_2$

where:	AA	last two digits of the year
	MM	month, ordinally indicated
	DD	day of the month, ordinally
	HH	hour of the day, ordinally

Example: 80040100 - 80040200

From:	Year	:	1980
	Month	:	April
	Day	:	1st.
	Hour	:	zero hours
To:	Year	:	1980
	Month	:	April
	Day	:	2
	Hour	:	zero hours

Figure 32 - Graph of Wind Velocities Distribution



The last datum noted in the sheet is the full name of the site where the measurement are being taken.

3.3 ROSE OF THE WINDS

The most common representation of the distribution of the wind direction is the rose of the winds.

Its confection is done with the information obtained, for a certain period, from a register and a trasducer (vane).

It is of great importance, for it can tell the dominant wind at a glance and its occurrence percentage. It tells of the calm periods as well.

The way to carry out a rose of the winds is as follow:

1. Obtain the duration of each direction, for a given period of observation (month, season, year), and the percentage of frequency of each direction. This is done from the anemoscopic graph, Figure 33.

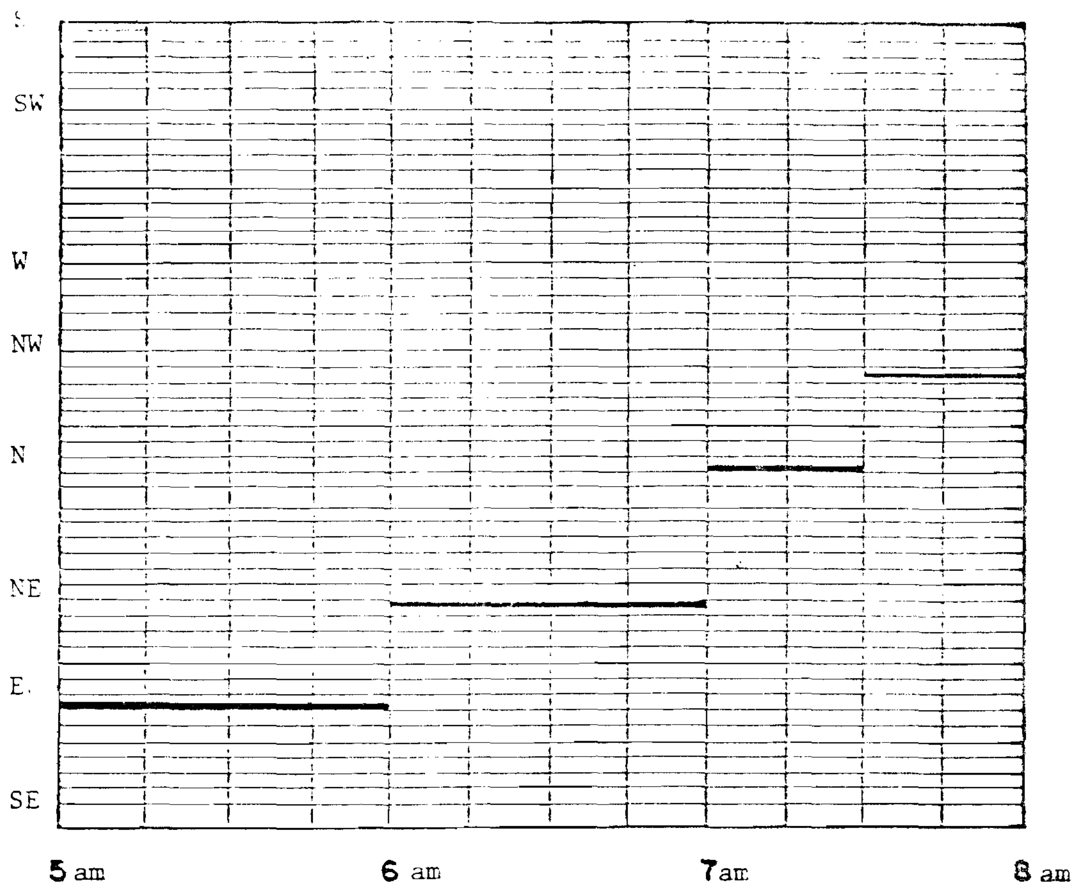


Figure 33 - Register of the wind Direction

2. Frequency percentage representation on the base of the eight cardinal points in the way of a polygon. Figure 34.

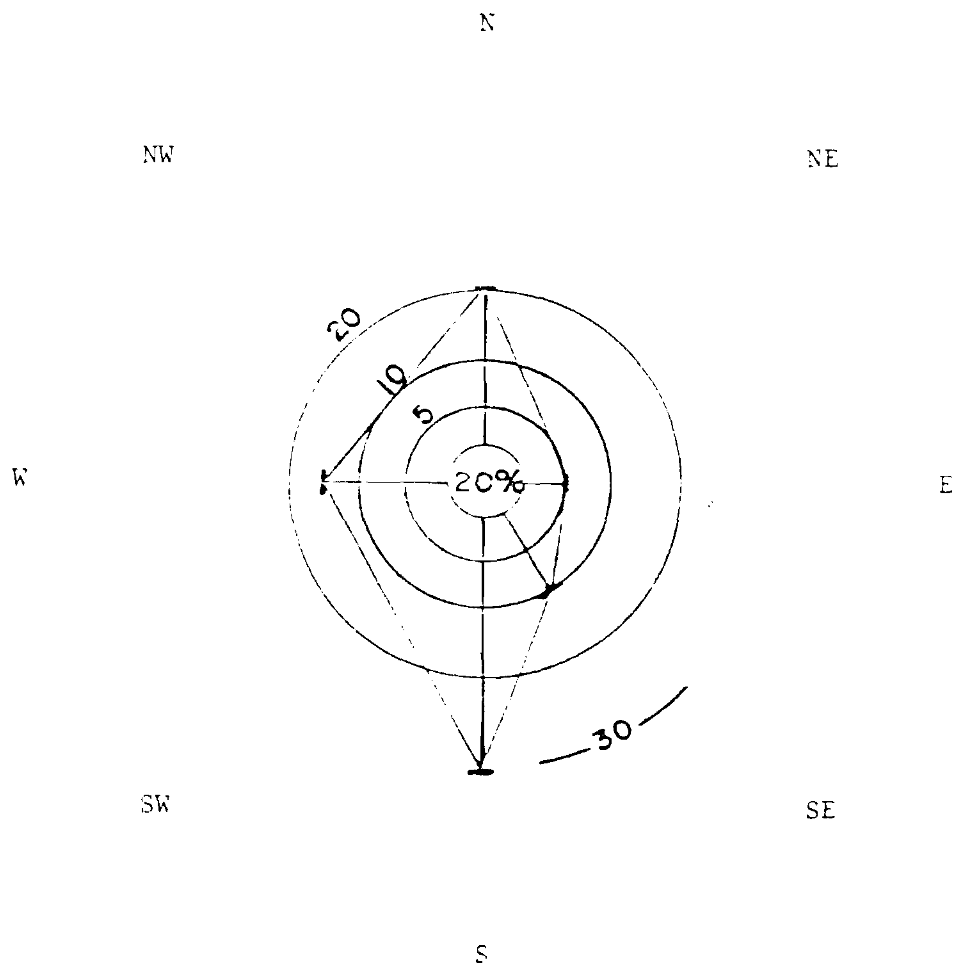


Figure 34 - Representation on the base of Eight Cardinal Points

3.3.1 Obtaining the Duration of each Direction from one Month Observation

From the register of velocity, represented in the Figure 32, we obtain the duration of each of the directions, day by day, which will be written on a data sheet (Figure 35).

course / day	N	NE	E	SE	S	SW	W	NW
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								
21								
22								
23								
24								
25								
26								
27								
28								
29								
30								
31								
TOTAL								
%								

Figure 35 - Data Sheet for Register Velocities Duration

The sheet shows each one of the directions corresponding to the days of the month of observation.

At the end of each month, the number of hours for each direction is established (by summing), thus obtaining the percentage of frequencies for each direction during one month.

NOTE: In this type of register, when there is calmness, the last position of the vane (with wind) will be graphed. Thus, it is necessary to check the velocity register to observe the directions when the wind was present.

3.3.2 Frequency Percentage Representation on the basis of the eight Cardinal Points

This is what is extrictly known as the rose of the winds; this is, along with the percentage representation of frequencies for each direction, the percentage of calmness also appears. In the percentage representation of frequencies, the percentage is summarized by a bar of a certain length, which indicates each one of the wind directions. The percentage of calmness appears in the center of this configuration (see Figure 34).

3.4 HISTOGRAMS OF ELECTRONIC COMPILERS

As was explained previously, an electronic register stores the time during which the wind, of a defines small range of velocity, blows. In order to give an example of how to handle the information registered by this type of apparatus, let us use a theoretical example of one of these apparatus.

The range of velocity for a BIN may be selected in these equipments. Let us use here a range of 0.4 m/sec, thus we consider a register with a capacity of 32 BINS. The width of the BIN would be then defined as follows:

BIN	VEL		(V_X)	in	m/s	BIN	VEL		(V_X)	in	m/s
00	0	<	V	$\leq$	0.4	17	6.8	<	V_{17}	$\leq$	7.2
01	0.4	<	V_1	$\leq$	0.8	18	7.2	<	V_{18}	$\leq$	7.6
02	0.8	<	V_2	$\leq$	1.2	19	7.6	<	V_{19}	$\leq$	8.0
03	1.2	<	V_3	$\leq$	1.6	20	8.0	<	V_{20}	$\leq$	8.4
04	1.6	<	V_4	$\leq$	2.0	21	8.4	<	V_{21}	$\leq$	8.8
05	2.0	<	V_5	$\leq$	2.4	22	8.8	<	V_{22}	$\leq$	9.2
06	2.4	<	V_6	$\leq$	2.8	23	9.2	<	V_{23}	$\leq$	9.6
07	2.8	<	V_7	$\leq$	3.2	24	9.6	<	V_{24}	$\leq$	10.0
08	3.2	<	V_8	$\leq$	3.6	25	10.0	<	V_{25}	$\leq$	10.4
09	3.6	<	V_9	$\leq$	4.0	26	10.4	<	V_{26}	$\leq$	10.6
10	4.0	<	V_{10}	$\leq$	4.4	27	10.8	<	V_{27}	$\leq$	11.2
11	4.4	<	V_{11}	$\leq$	4.8	28	11.2	<	V_{28}	$\leq$	11.6
12	4.8	<	V_{12}	$\leq$	5.2	29	11.6	<	V_{29}	$\leq$	12.0
13	5.2	<	V_{13}	$\leq$	5.6	30	12.0	<	V_{30}	$\leq$	12.4
14	5.6	<	V_{14}	$\leq$	6.0	31	12.4	<	V_{31}	$\leq$	12.8
15	6.0	<	V_{15}	$\leq$	6.4	32	12.8	<	V_{32}	$\leq$	V max of the register
16	6.4	<	V_{16}	$\leq$	6.8						

The referred equipment, and in general, all equipment of this type, has two digital type displays; one of these indicates the BIN number, and the other indicates the time (in seconds) that the wind velocity reached the range of the referred BIN. As a general rule, these displays are usually off, in order to save the maximum amount of electrical energy, specially when the equipment is fed by a battery in isolated places. When reading the compiled data is required a button of the "Push Button" type is activated, which will advance by one for every push, thus, recording the number of BIN. Hence, the information on the time display will correspondingly change when the number of BIN is changed.

If we begin our data recopilation from BIN 00, we can empty these in a table as follcws:

BIN NUMBER	TIME IN SECONDS			
00	7,000	=	1.9444	hrs.
01	8,000	=	2.2222	"
02	8,000	=	2.2222	"
03	9,000	=	2.5000	"
04	10,000	=	2.7777	"
05	12,000	=	3.3333	"
06	15,000	=	4.1666	"
07	15,000	=	4.1666	"
08	20,000	=	5.5555	"
09	35,000	=	9.7222	"
10	43,000	=	11.9444	"
11	50,000	=	13.8888	"
12	100,000	=	27.7777	"
13	110,000	=	30.5555	"
14	120,000	=	33.3333	"
15	130,000	=	36.1111	"
16	140,000	=	38.8888	"
17	150,000	=	41.6666	"
18	210,000	=	58.3333	"
19	270,000	=	75.0000	"
20	280,000	=	77.7777	"
21	300,000	=	83.3333	"
22	100,000	=	27.7777	"
23	100,000	=	27.7777	"
24	80,000	=	22.2222	"
25	70,000	=	19.4444	"

BIN NUMBER	TIME IN SECONDS			
26	60,000	=	16.6666	hrs.
27	50,000	=	13.8888	"
28	40,000	=	11.1111	"
29	30,000	=	8.3333	"
30	10,000	=	2.7777	"
31	6,000	=	1.6666	"
32	4,000	=	1.1000	"

TOTAL TIME = 2,592,000 sec. = 720h = 30 days

In order to construct a graph of distribution of the wind velocity frequency, we take the average velocity of the BIN. That is, for BIN 00, its range or class is $0 < V < 0.4$ m/sec. and the average velocity of the class is 0.2 m/sec. For BIN 01 it will be 0.6; for BIN 02, it will be 1.0, and so on. We then take such an average velocity as representative of the BIN; this, graphed against the time will result in a graph of the wind velocity vs. time, as the one shown in Figure 36.

From these data it is easy to obtain the curve of the velocity duration (figure 37). What should be done is to substract initially the time duration of BIN 00 from the total time; next, substract the time of BIN 01 to the duration BIN 00, and so on. This is,

Duration BIN 00 = Total time - Time of BIN 00
Duration BIN 01 = Duration BIN 00 - Time of BIN 01
Duration BIN XX = Duration BIN (XX-1) - Time of BIN XX

Upon emptying this information we obtain the following table:

BIN	DURATION TIME	BIN	DURATION TIME
00	718.0556 hrs.	15	527.7785 hrs.
01	715.8334 hrs.	16	488.8897 hrs.
02	713.6112 hrs.	17	447.2231 hrs.
03	711.1112 hrs.	18	388.8898 hrs.
04	708.3335 hrs.	19	313.8898 hrs.
05	705.0002 hrs.	20	236.1121 hrs.
06	700.8336 hrs.	21	152.7788 hrs.
07	696.6670 hrs.	22	125.0011 hrs.
08	691.1115 hrs.	23	97.2234 hrs.
09	681.3893 hrs.	24	75.0012 hrs.
10	669.4449 hrs.	25	55.5568 hrs.
11	655.5561 hrs.	26	38.8902 hrs.
12	627.7784 hrs.	27	25.0014 hrs.
13	597.2229 hrs.	28	13.8903 hrs.
14	563.8896 hrs.	29	5.5570 hrs.
		30	2.7793 hrs.

3.5 REGISTERS WITH WIND DIRECTION RECORDING

This type of registers separates the measurements with respect to a number of wind directions (usually eight: N, S, E, W, NW, NE, SW, and SE). Each one of these directions is associated with a certain number of BINS (32 in our example) and the data are read with a wind velocity selector. Thus, in our example we would have a selector with eight positions. Each one of them will give us the time during which the wind had a certain veloc ity range, and in a given direction. This is shown in the following table:

DIRECTION SELECTOR BIN	N	NE	E	SE	S	SW	W
00	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX
01	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX
02	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX
03	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX
04	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
XX	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX

These data can be plotted in graphs, such as the ones shown previously; from the graph we can obtain the dominant winds with determined directions.

Figure 36 - Distribution of Velocities Frequency

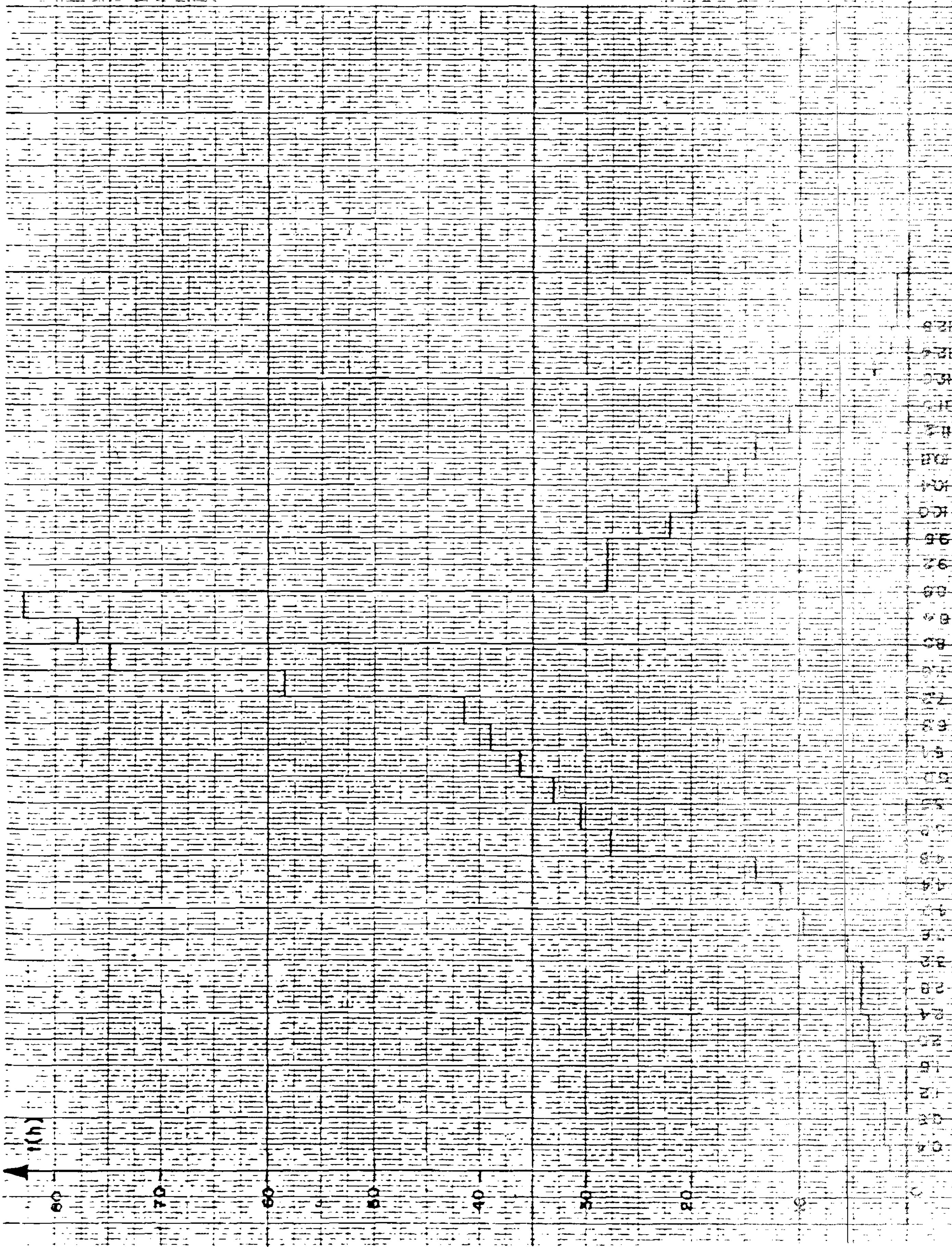


Figure – Curve of Velocities Duration

CHAPTER 4 - PROSPECT OF ZONES AND SITES OF INTEREST

The exploration of the wind may be established in three levels of resolution: wind regionalizing, the prospect of zones with high aeolian potential and the localizing of sites for optimum benefit.

For regionalizing the wind, the meteorological network of a given country and its historical information are, undoubtedly, of vital importance.

On the other hand, it is necessary developing a analytical methodology on charts which allows localizing windy zones leading to an adequate correlation between topographical and climatological factors associated to a zone of relatively constant, or of a well-defined periodicity, predominant winds.

Regarding site localization, the visual inspection of the local topography, the ecological evidence and the placing of anemometers in different places for simultaneous measurements will allow the selection of the adequate site.

The determination of the adequate site is relative to the proper application of the aeolian energy, given its magnitude and the requirements to be met. It is quite different placing a airpump for an artesian well, in which the well is the determining point of application, from the locating of a 1 MW air-generator interconnected to a subtranmision or electrical distribution line.

Here is where questions related to the feasibility of aeolian energy exploitation arise, which are:

a) Which are the locations with wind of sufficient intensity which are useful economically?
b) In a given location, what is the annually expected aeolian energy?
c) How does the wind distribute with time during the day, month or year and longer periods?
d) Which are the probable periods of high velocity winds, their calm periods and frequencies in a given time?

Locating a good place for aeolian energy exploitation is equi_ valent to locating the deposit of an ore. A geològical structure detemines the possible existence of some given ores; a detailed study locates the deposits. In this comparison, the role of geologist and a meteorologist are similar, very much the same as that of a teo_ rologist are similar, very much the same as that of a specialist in aeolian energy and the one directly directed to the study of ores. Places with high aeolian potential, as well as an ore deposit, are related to the specific characteristics of the site.

Strictly in this, which are the characteristics of the wind and, consequently, the topographical influences which are of interest in its utilization as energy?

Regarding its direction, it is the prevailing, for a relatively long time, of the dominant winds which indicates the uniformity of the pressure gradient originating them; the constant changes of direction around the dominant wind are indicative of local turbulence, what demerits it. In what concerns the velocity, it is necessary to know its daily, monthly and annually distribution. The annual average velocity is an indicative of what can be expected.

It has already been mentioned some of the topographical characteristics which can indicate a high aeolian energy potential place.

These sites may be indentified based on topographical and climatological charts, as pronounced slopes and compact isobars are indicative of strong pressure gradients, responsible for the regional nature of winds. In an specific site, the ecological evidence is important; this is manifested by the deformations of trees, which are subjected to continuous strains caused by predominant winds, and the degree of deformation is indicative of the average velocity.

On the other hand, a good site for aeolian energy utilization has to jut out on the irregularities of the ground or other obstacles: buildings, trees, rocks; or some 100 meters away if less turbulence is required.

Having located an important site and carried out the measurements, the annual velocity curves become annual potential curves by cubing the different ordenate values and multiplying by a constant.

Apart from these measurements, it is necessary to know the instantaneous velocity of an air rush; the latter, although its contribution to the extracted aeolian energy is nil, it is important to know when considering the instantaneous strain on the converters which way be located at a different height from 10 mt. above the ground. Otherwise, the measurements may be carried out at a desired height, or the vertical velocity distribution pattern at a point on the ground can be established.

For all this, a methodology for the study of this resource is necessary. Given the importance of the wind energy utilization, the study will be directly related to its length, depth and precision.

For electricity generation with AECS of medium and large capacity ($\geq$ 100 kw.), in unit or group installations, the methodology for the study and evaluation of sites covers the following six stages:

Stage 1. Obtaining and Analysis of Data

A) Existing meteorological data*

1. Temperatures
2. Pluvial precipitation
3. Wind in surface
4. Winds in free atmosphere
5. Records of wind schedule
   - Intensity
   - Persistence

* Monthly, seasonal and annual

B) Topograhic charts of the zone under study

Stage 2. Field Research

This stage is oriented to compile information on the region under study on the following aspects:

a) Potential ground use
b) Land propriety modes
c) Communication networks
d) Natural resources
e) Demographic distribution
f) Other aspects of interest

Stage 3. The Prospect of the Aeolian Resource in a given Area

A region of interest, from the aeolian potential point of view, may be limited physically to restricted areas as a result from the above analysis.

Hence, the potential areas will be studied towards determining the wind spatial distribution, which may be carried out by an anemometer network of low cost.

Stage 4. Verifying the Area

Having located the places of interest, the local wind characteristics of these will be determined. This will be done with high quality and low cost equipments. If the above three stages are oriented towards establishing the intensity, length and variation, by seasons, of the wind to detect areas of the greatest interest, the present stage will be concerned with collecting the relevant information in relation to the AECS in characterizing the wind.

Stage 5. Specific Studies of the Sites for Large AECS Installation

This meteorological analysis of the specific site, where the installation of large AECS is contemplated, requires measurement towers with velocity, temperature and pressure sensors of different scale. This will allow characterizing the behavior or the lower atmospheric layer in what concerns the vertical velocity profile, turbulence, etc., the series of parameters on the wind behavior with incidence on the fructioning, cost, useful life, etc., of a large AECS.

Stage 6. Research on the Behavior and Efficiency of the AECS

This last stage is designed to simulate the behavior of the AECS and the amount of energy produced monthly, seasonal and annually. This does not only establish the total cost of the unit of energy produced with a AECS, but also evaluates the fuel saving in thermoelectricity, or water in the case of hydroelectricity, when its integration to the electrical system is considered.

This analysis will be the one which finally determines the technical - economical feasibility for the aeolian utilization of the site.

Having grossly described the methodology for the localization of sites of interest for electricity generation to be fed to an electrical system, it is convenient to stress that the quality of the sites selection depends on the magnitude of application.

In general terms, the techniques for areas and sites locali_ zation, which are of interest due to their possible aeolian energy potential, can be devided in two groups: indirect and direct, as follow:

Indirect Prospect:

- Historical information on climatological parameters issued by the National Meteorolo_ gical Services
- Climatic charts
- Toponimes and oral reference
- Others

Direct Prospect:

- Survey
- Ecological evidence
- Measurements in situ

4.1 INDIRECT PROSPECT

4.1.1 National Meteorological Services

The historical information on the climatological parameters compil ed by the National Meteorological Services of each country is, no doubt, the starting point for the evaluation of this resource in each country of the region. However, experience shows that care must be taken in handl- ing this information, in ensuring its consistency and reliability, prior to its analysis.

4.1.2 Climatological Charts

The analysis of climatological charts is the preliminar step to direct study from which it is possible defining the zones with probabili ty of utilizing the wind.

This is based on weather transition zones with respect to topogra phy, orography, rainfall, humidity, etc., which yield the thermodynamic condition, different to the daily cycle of insolation, ant this is res- ponsible for the local convective winds similar to the sea/land breeze arising from the temperature difference in the lower atmospheric layers during the day. Figure 38 shows this.

4.1.3 Toponimes and Oral Reference

A research into the toponimes (names of places) may constitute a good reference to places with strong wind, which, for being significant, the phenomenan is associated with the name of the place. In Mexico, for instance, the most important zone for its aeolian potential is located in the surrounding of a town called "La Ventosa" ("Windy").

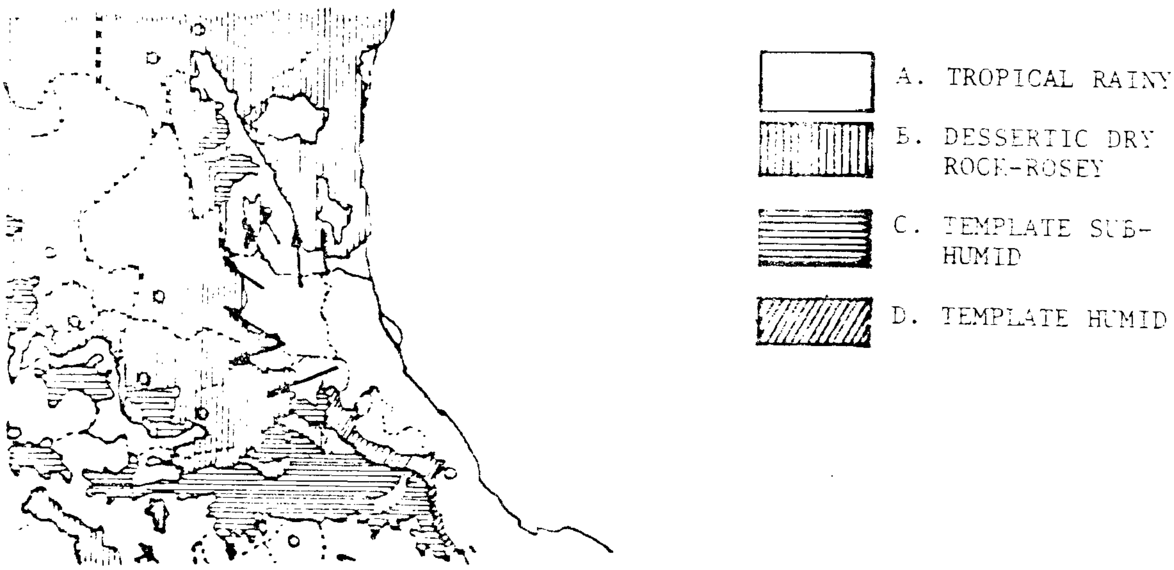


Figure 38 - Scheme of the Transition from One Climate to Another Showing the probable Direction of the Advective Wind

The oral reference is nothing else but "they say there is lots of wind in that place", for which people working in government institutions or ministries, who carry out programs in rural zones, constitute an information source of great values.

4.2 DIRECT PROSPECT

4.2.1 Survey

The survey consists of the systematic search, in the region under consideration, for the oral reference on the places and zones where the wind is of interest from the energy point of view.

4.2.2 Ecological Evidence

4.2.2.1 Introduction

The ecological evidence is basically one of the effects caused by the wind on the ground and vegetation in a given place.

Within the research for the selection of the site considered probable for aeolian energy utilization, the consideration of the ecological evidence is useful for obtaining the information on the behavior of the wind.

The main objective in the ecological inspection is to obtain the range of velocities and direction of the dominant wind, which may constitute a time saving research, since no instruments need be used. This type of analysis involves a series of observations on the ground and vegetation under the effect of the certain wind velocity range, bearing in mind that such effects may vary with location and, hence, the inspection is a preliminar step to a more detailed study on the subject.

4.2.2.2 Classification of the ecological evidence

The ecological evidence may be classified as follows:

- Effects on the ground
- Effects on the vegetation

Among the effects caused in the land by its exprosure to the wind on the ground, even though it may not be the only physical agent causing it.

Dune formation is the piling of sand in small hills in dessertic zones, caused by the wind which distribute themselves like large furrows perpendicular to the direction of the dominat wind. See Figure 39.

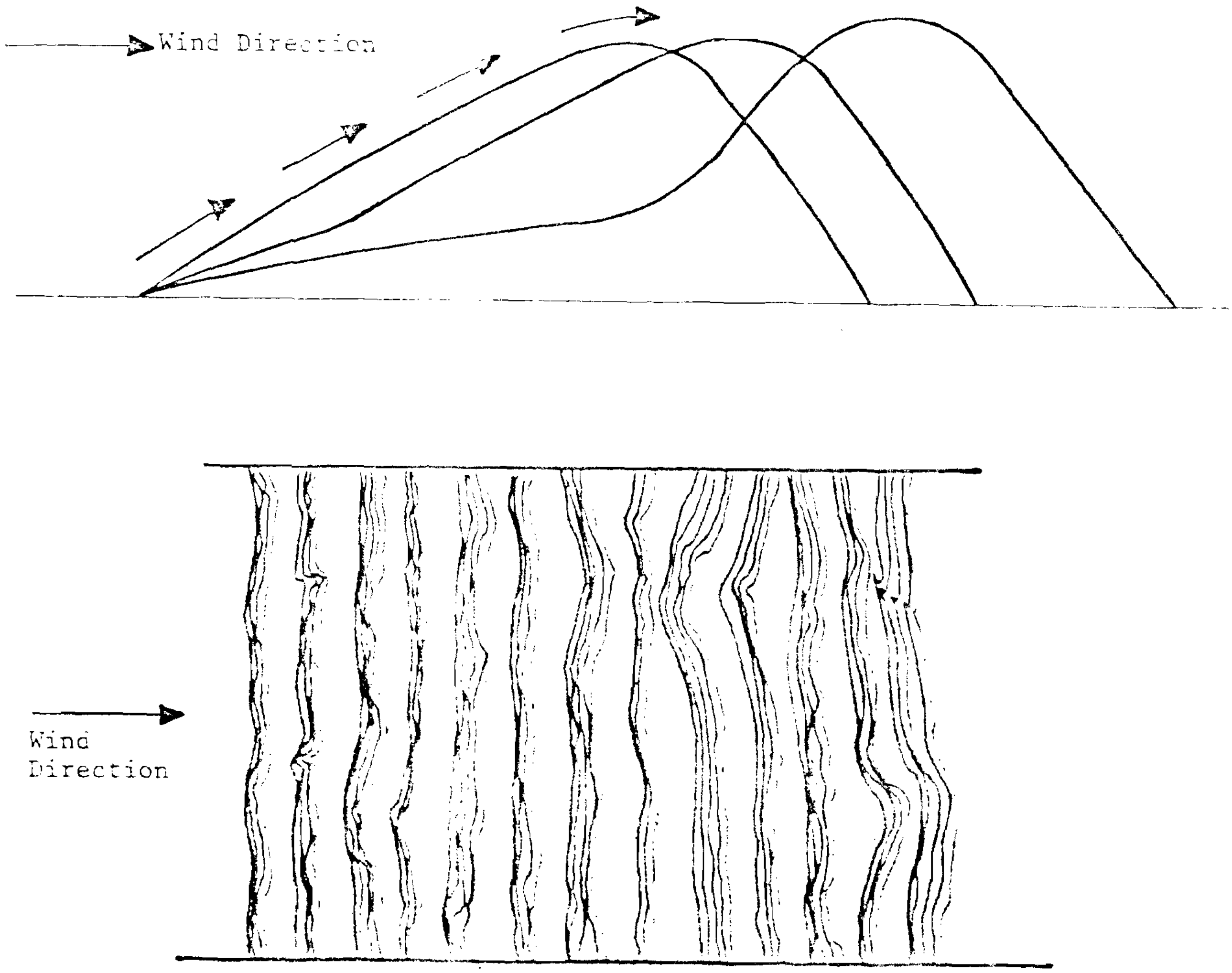


Figure 39 - Dunes Formation

The effects on the vegetation from exposure to the wind are the following:

- Combed
- Deformed
- Spread

The first effect consists of simply the friction between the wind and the vegetation, winds of annual average velocity between 2.7 and 4.5 m/s (6 and 10 mph). The second effect consists of a deformation with a direction of that of the dominant wind, which has a velocity between 3.6 and 8.5 m/s (8 and 20 mph); and finally, the spread which is basically an extreme deformation at a very short distance from the ground, with winds of 9.83 m/s (22 mph).

A case which can be taken as an example is the low growth of the vegetation in hills, where the annual average velocity is greater than 10.3 m/s (23 mph), in Great Britain.

An interesting methodology for the ecological evidence inspection consists in measuring the eccentricity proportions of the rings in a traverse cut of a tree, and its circular deformation to ellipsoidal. This methodology can be applied without having to cut the tree, by taking the external dimensions in two orthogonal axes and sample drilling in order to locate the heart and to measure the eccentricity.

Finally, it is necessary to state that these techniques possess a generalized qualitative value rather than quantitative, since their adaptation to a specific habitat may imply different mechanical properties of the wood of a same variety of trees.

4.2.2.3 Methods for velocity evaluation from the effects on the vegetation

There are methods for evaluating the velocity in a given place from the effects on the vegetation such as:

- Observing the deformation of the tree
- Calculating the deformation relation

The first method is simply observing the form of the tree and comparing it with the schemes detailed in figure 40; from this, the range of annual average velocity may be obtained from Table 3.

TABLE 3

ANNUAL AVERAGE VELOCITY ACCORDING TO THE DEFORMATION OF TREES

Scheme of Deformation	I	II	III	IV	V
Probable annual average deformation range, mph.	6-10	8-12	11-15	12-19	13-22

The other way is calculating the relation of defor_ mation from the photograph of a tree taken perpendicularly to the direction of the dominant wind, according to Figure 41; and from this, the corresponding range of annual average velocity can be obtained from Table 4.

a. Daily velocity distribution pattern
b. Daily average velocity and standard deviation
c. Daily and monthly calm percentage
d. Monthly velocity frequency pattern
e. Monthly velocity curves
f. Rose of the Winds in percentage
g. Average velocity of the dominant wind
h. Dominant direction
i. Time percentage of winds above a determined threshold
j. Average velocity in the period and standard deviation

5.3.1 Aims of the Preliminar Anemometric Measurement

Having fulfilled the above mentioned objective of the measurements, we are now in the position to achieve the following aims:

a. The energy determination, in watts-hr/m^2, at a height of 10 mt. on a monthly, seasonal and annual basis.
b. The determination of average monthly power in watts/m^2 at a height of 10 mt.
c. The determination of useful energy and power above a wind velocity threshold which constitute the usable winds (starting velocity for operating AECS).
d. The determination of the average time per day of usable wind, and its time distribution.
e. The determination of the monthly probable velocity distribution, theoretical curves.
f. To dispose of the criteria for the preliminar evaluation, technical and economical, of the potential of a site and/or the appropriateness of a given AECS to be used in the site.

5.1.4 Basic Station Configuration

Having established the requirements, objectives and aims of a basic anemometric station for the preliminar evaluation of sites, it is possible now establishing the basic configuration.

General Description

1. An anemocinemograph with travelled distance register and the following additions:

   a. Graph on recording paper
   b. Paper movement activated by a car type battery
   c. Trasducers mounted on a mast
   d. Braced mast with three sets of winds at 120° and three levels
   e. Metallic box with lock and danger indicators
   f. Optional fence for the protection of the equipment

5.1.5 Installation Procedure

5.1.5.1 Equipment and material preparation

1. Surround each of the anchors with three to four rounds of galvanized wire through the eye, ensuring both extremes of the wire with bass-string. In this way we will have a strap for holding the hook of the tensors.

2. Select an adequate site for placing the anemometer; use a piece of wood or a flag-stone to fix the support of the mast. Nail the anchors which are spaced at 120° on a circumference of 5.20 mt. of radius.

5.1.5.2 Installation

3. Place the retention rings on the corresponding sections in accordance with the diameter, and have the winds of wire secured to them as follows:

RETENTION RING	PLACING HEIGHT	LENGHT OF THE WIND
1	3 mts.	7 mts.
2	6 mts.	9 mts.
3	9 mts.	12 mts.

4. Ground the mast on the floor adjusting it to 10 meters high. Check that the screws of the mast press the internal sections perfectly. This is to avoid sliding for each of the winds.

5. Retain the aluminum tubular extension from the clamp in the upper part of the mast; insert the vane tight and the cups in each of its extremes.

6. Carry out the electrical connections between the tras_ducers and the register as well as the battery-register section. Verify this has been done correctly and that the equipment functions properly.

7. The cable of the trasducers must be attached to the mast with insulator tape in order to avoid its motion with the wind and abrasion.

8. Two persons must take the two upper winds to raise the mast while a third person pulls, ensuring the third wind in the corresponding anchor.

9. Ensure properly the nine winds so that the mast stays erected and vertical, passing a wire through the open eye of the tensor.

10. With the mast in a vertical position and the wires under tension, proceed placing the bass-string in the stap joining the tensors. Make refining adjustments to achieve erectness and verticality by using the tensors.

5.1.5.3 Operation and inspection

With the sensible paper rolling at a velocity of one inch per hour, the register is allowed to run for one month. After this period the following operations should carry out:

1. Change the battery by a newly charged one.
2. Blow the air knob, cleaning it with a small brush in order to remove the dust and residues from the paper.
3. Change the paper oil.

If periodical inspections are carried out, they should consist of the following:

1. Verify correct motion of the registering paper.
2. Check voltage and the battery is firmly connected.
3. Check connections to the register.

An important recommendation in carrying out the installation: it is advisable to mark the registering paper the daily inspection or withdrawal of the equipment, indicating the date and the time. This is convenient, for the dragging mechanism does not have a chronometric precision. This way we will have the periodical references for the correction of the time scale.

Regarding the maintainance operations of the equipment, the handbooks of maintainance and operation supplied by the manufacturers must be consulted.

5.2 DATA PROCESSING

5.2.1 Description of the Velocity Distribution Sheet

One way to visualize the wind behavior in a given place is through the curves of velocity distribution. These consist of the average velocity, recorded every 15 minutes during the day, as determined from the distance covered in the graph.

The latter constitutes also the history of the wind behavior in a given site, which will allow both the energy evaluation and the establishing of the criteria for the use of some aeolian energy conversion system. Figure 32 of Chapter 3 shows a sample of a daily velocity distribution curve.

5.2.2 Digitalizing the Daily Sheets, Method and Intermediate Data Sheet

Once the velocity distribution curve is available, one can proceed to measure the intervals of each velocity, starting from 0 m/sec up to the observed maximum average velocity. The measurement is done directly on the distribution curve, recording the concurrence time of this velocity, or the time in which it did not occur. This value is substracted from 24 hours. Either one of these two procedures will yield the time of occurrence for a given velocity. The values so obtained are recorded in a form as showned in the Figure 42. The velocities are normally analyzed at 0.2 m/sec. intervals.

ANEMOGRAPHYC STATION: "El [illegible]" MONTH: April OF 19[illegible] PAGE ___ OF ___

J \ H(J)	V(J) \ day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
J	V(J)																															
1	0	0																														
2	0.2	19.5																														
3	0.4	19.0																														
4	0.6	18.5																														
5	0.8	16.7																														
6	1.0	14.7																														
7	1.2	14.2																														
8	1.4	13.5																														
9	1.6	12.2																														
10	1.8	11.2																														
11	2.0	11.0																														
12	2.2	11.0																														
13	2.4	11.0																														
14	2.6	11.0																														
15	2.8	10.7																														
16	3.0	10.7																														
17	3.2	10.7																														
18	3.4	10.2																														
19	3.6	10.2																														
20	3.8	9.0																														
21	4.0	9.0																														
22	4.2	9.0																														
23	4.4	8.5																														
24	4.6	8.2																														
25	4.8	8.2																														
26	5.0	8.2																														
27	5.2	8.0																														

Figure 42 - Register of Duration Intervals of Wind Velocity

5.2.3 Data Sheet and Procedure

Once the data on the velocity duration are registered, one proceeds to fill the data sheet showned in Figure 43, which contains the required information for feeding into a series of computer programs, in order to evaluate the wind characteristics of the site. The way the data sheets are used is as follows:

- First of all, we observe up to what velocity its duration is of 24 hours and record the correspondent data; then, record velocity by velocity the time-lenght of occurence.

- In case there is a calm day, a zero is recorded in the beginning of the day, in both cases the day had to finish in zero.

The processing of the information from the data sheet is carried out with two programs, computing the following information:

"VIENTO"	Total energy
	Usable energy
	Total average power
	Usable average power
"WINDCA"	Total energy
	Total average power
	Average velocity
	Standard deviation

PAGE: ____ OF ____

ANEMOGRAPHYC STATION: "El [illegible]"

MONTH: Abril OF 19 80

CONSTANT K= 0.2

EA:		DATA
300	DATA	0, 12.5, 13.0, 13.5, 16.7, 14.7, 14.2, 13.5, 12.2, 11.2, 11.0, 11.0, 11.0, 11.0, 10.7, 10.7
310	DATA	10.7, 10.2, 10.2, 9.0, 9.0, 9.0, 8.5, 8.2, 8.2, [8.2], 8.0, 8.0
	DATA	
	DATA	
	DATA	
	DATA	
	DATA	
	DATA	
	DATA	
	DATA	
	DATA	
	DATA	
	DATA	
	DATA	
	DATA	
	DATA	
	DATA	
	DATA	
	DATA	
	DATA	
	DATA	
	DATA	

Figure 43 - Data Sheet of Wind Velocity Duration

5.2.4 Programs: "VIENTO" and "WINDCA"

The information concerning the programs "VIENTO" and "WINDCA" follows; these are coded in BASIC and organized in the following way:

"VIENTO"

LIST OF VARIABLES

1. Listing of variables identification
2. Flux diagram
3. Program listing
4. Result sheet

K = Velocity increment of 0.2 m/2

T1 = Accumulated total energy in Watts-hr/m^2

T2 = Accumulated useful energy in Watts-hr/m^2

T3 = Average Total Power in Watts/m^2

T4 = Useful Average Power in Watts/m^2

T5 = Monthly hours of usable winds

H4 = Daily hours of usable winds

E1 = Daily total energy in Watts-hr/m^2

E2 = Daily usable energy in Watts

P1 = Daily Average total Power in Watts/m^2

P2 = Daily Average usable power in Watts/m^2

D = Number of days

J = Datum number

H2 = Time-length of a certain velocity $\geq$ Average velocity of this in hours

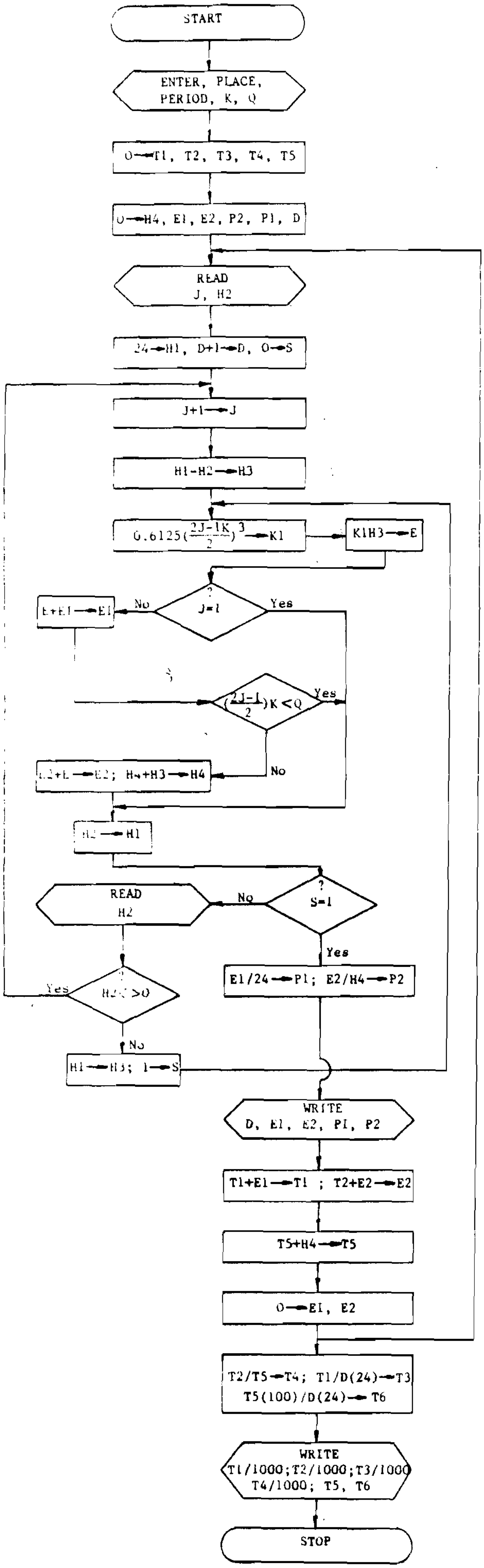
S = Alternative variable for date change

K1 = Factor for energy calculation

E = Total Energy in Watts-hr/m^2

H1 = Variable for calculating the time-lenght in hours of a given velocity

H3 = Time-length in hours of a given class average velocity



DESCRIPTION

Name of site from where the information was extracted, month, velocity increment and velocity threshold for useful winds.

Variables initialize

Data read in

Iteration for the change of the class average velocity

Calculation of energy in watts-hr/m^2

Total energy calculation in watts-hr/m^2

Criterion for the calculation of daily useful energy in watts-hr/m^2

Data read in

Calculation of total average power and daily average useful power in watts/m^2

Alternative for changing date

Print of daily results

Calculation of total accumulative energy, the useful energy watt-hr/m^2 and number of hours with wind 5 m/s

Calculation of the monthly average useful power, total average power in watts/m^2 and the percentage of total number of hours with useful winds

Print of the monthly summary in KWH/m^2 for energy, and in KW/m^2 for power

```
VIENTO  17:22              May 16, 80
5!     CALCULATION OF WIND ENERGY
10     INPUT "AEOLIAN ENERGY DISTRIBUTION IN";A$
15     INPUT "MONTH";B$
17     INPUT "K=";K
18     INPUT " THRESHOLD ";Q
20     PRINT
25     PRINT , " E N E R G Y " , " P O W E R "
30     PRINT "DAY","TOTAL","USABLE","TOTAL AVERAGE","USABLE AVERAGE"
35     PRINT,"W-H"."W-H","WATTS","WATTS":PRINT
40     T1,T2,T3,T4,T5.T6=0
45     H4,E1,E2,P1,P2,D=0
50     !BEGIN DAILY ITERATION
55     READ J,H2 : ON ERROR GO TO 200
56     H4=0.0001
60     H1=24 :D=D+1 : S=0
70     ! BEGIN HOURLY ITERATION
80     J=J+1
90     H3=H1-H2
100    K1=0.6125*(((2*J-1)/2)*K)**3
110    E=K1*H3
115    IF J=1 THEN 140
120    E1=E1+E
130    IF ((2*J-1)/2)*K < Q THEN 140
135    E2=E2+E : H4=H4+H3
140    H1=H2
145    IF S=1 THEN 170
150    READ H2
160    IF H2 <> 0 THEN 80
165    H3=H1 : S=1 : GO TO 100
170    P1=E1/24 : P2=E2/H4
180    PRINT D,E1,E2,P1,P2
185    T1=T1+E1:T2=T2+E2
187    T5=T5+H4
189    E1,E2=0
190    GO TO 55
200    PRINT:PRINT:PRINT:PRINT
205    T4=T2/T5: T3=T1/(D*24):T6=(T5*100)/(D*24)
210    PRINT "SUMMARY:";B$
220    PRINT: PRINT  "TOTAL ENERGY KWH/M2:"; T1/1000
230    PRINT:PRINT  "USABLE ENERGY" KWH/M2:";T2/1000
240    PRINT: PRINT  "TOTAL AVERAGE POWER KW/M2:";T3/1000
250    PRINT:PRINT  "USEFUL AVERAGE POWER KW/M2:";T4/1000
260    PRINT: PRINT  "NUMBER OF HOURS WITH WIND GREATER THAN 5 M/S:";T5
270    PRINT: PRINT  "% OF TOTAL TIME WITH USEFUL WINDS:";T6
280    PRINT:PRINT DATES$(0)
32767 END


Ready
```

"VIENTO" PROGRAM

AEOLIAN ENERGY DISTRIBUTION IN? ACAPULCO, GRO
MONTH? MARCH-APRIL 1980
K=? 0.2
THRESHOLD? 5

	ENERGY		POWER	
DAY	TOTAL W-H	USABLE W-H	TOTAL AVERAGE WATTS	USABLE AVERAGE WATTS
1	4433.46	4037.56	184.728	734.088
2	6927.35	6767.53	288.64	697.676
3	5685.59	5570.72	236.9	773.701
4	6341.04	6257.03	264.21	812.591
5	964.122	714.187	40.1717	476.093
6	571.398	277.144	23.8083	102.642
7	3153.04	2944.86	131.377	516.634
8	4813.88	4697.94	200.578	652.483
9	1461.34	1199.23	60.8891	444.142
10	6926.76	6760.05	288.615	965.708
11	3493.64	3277.68	145.568	595.931
12	4477.38	4346.86	186.558	668.737
13	764.011	493.067	31.8338	154.079
14	3857.84	3745.45	160.743	604.096
15	6685.67	6560.92	278.569	852.056
16	4582.89	4453.75	190.954	618.567
17	4150.23	3896.81	172.926	779.345
18	3795.13	3662.76	158.13	563.493
19	6032.53	5952.58	251.356	725.916
20	7574.81	7490.31	315.617	881.203
21	6825.56	6713	284.398	789.755
22	8326.19	8227.07	346.925	1003.29
23	7710.5	7573.15	321.271	923.543
24	6541.54	6365.88	272.564	1026.74
25	1732.83	1432.14	72.2013	340.976
26	6155.39	5971.07	256.475	728.17
27	5624.18	5408.62	234.341	676.069
28	5046.03	4914.55	210.251	534.184
29	1899.21	1699.18	79.1335	261.408
30	2573.55	2221.72	107.231	694.266

SUMMARY: MARCH-APRIL 1980

TOTAL ENERGY KWH/M2: 139.127

USEFUL ENERGY KWH/M2: 133.633

TOTAL AVERAGE POWER KW/M2: .193232

USEFUL AVERAGE POWER KW/M2: .696719

NUMBER OF HOURS WITH WIND GREATER THAN 5 M/S: 191.803

% OF TOTAL TIME WITH USEFUL WINDS: 26.6393

May 16, 1980

Ready

"WINDCA"

LIST OF VARIABLES

K = Velocity increment of 0.2 m/s

T1 = Accumulative total Energy in Watts-hr/m^2

T3 = Accumulative Average Total Power in Watts/m^2

T5 = Monthly number of hours with winds

T6 = Monthly percentage with wind in %

M1, M2, M3, M4, = Factors of standard deviation calculation

H4 = Number of hours per day with wind

E1 = Daily total energy in watts-hr/m^2

P1 = Daily average Total Power in Watts-hr/m^2

V3 = Monthly Accumulative Velocity in m/s

53 = Monthly accumulative standard deviation in m/s

J = Number of data

H2 = Time-length of certain velocity average class velocity of data

D = Number of days

S = Alternative variable for changing data

H3 = Time-length of a certain average class velocity

H1 = Variable for calculating the time-length of a certain velocity

V1 = Average class velocity in m/s

V2 = $(\text{Average class velocity})^2$

V = Daily average velocity in m/s

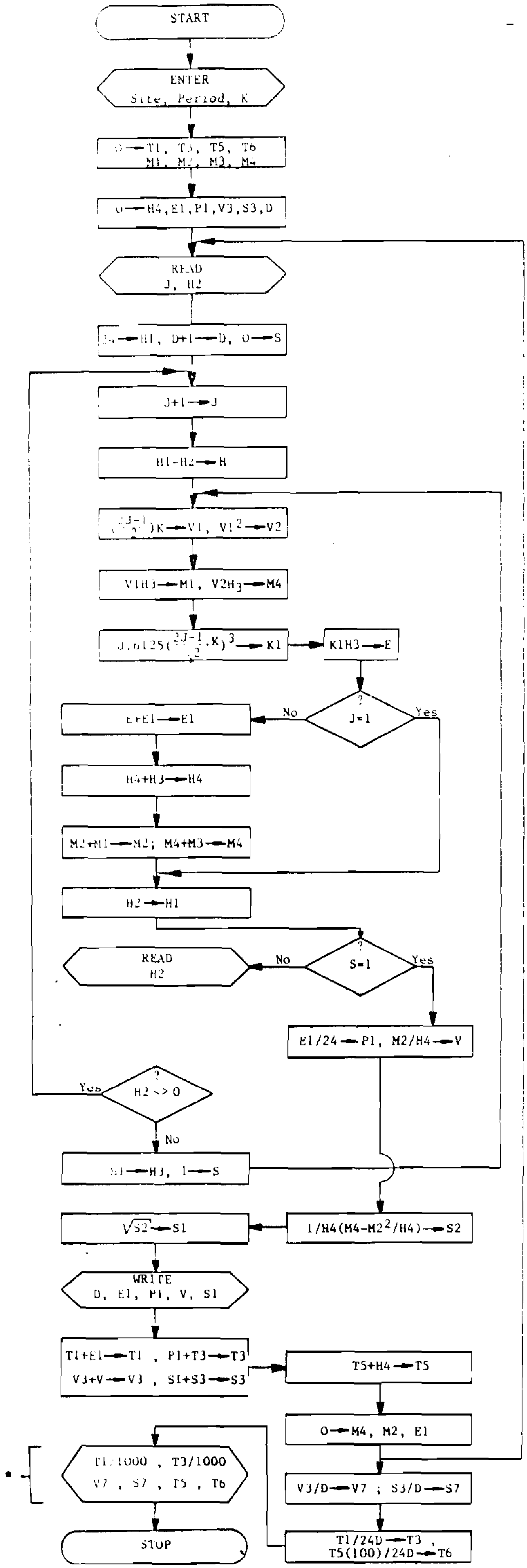
S2 = Factor for calculating the standard deviation

S1 = Daily Standard Deviation in m/s

V7 = Monthly average velocity in m/s

S7 = Monthly average standard deviation in m/s

"WINDCA" PROGRAM - FLOW-CHART



DESCRIPTION

Name of the site from where the information was extracted, month and velocity increment

Initializing variables

Read in Data

Iteration for changing class average velocity

Calculation of class average velocity

Calculation of energy in watts-hr/m²

Calculation of daily total energy and number of hours with wind

Read in data

Calculation of total average power and daily average velocity

Alternative for changing date

Calculation of standard deviation

Print of daily results

Calculation of monthly total energy in watts-hr/m², total average power in watts/m², the accumulative velocity in m/sec., the accumulative standard deviation in m/sec., and the number of hours with wind.

* Print results in KWh/m² for energy, KW/m² for power and m/sec. for both standard deviation and velocity.

Calculation of the monthly average velocity, the monthly average standard deviation, the average total power and the lenght of time with wind.

```
WINDCA  17:26           May 16, 1980
2!     CHARACTERIZATION OF WIND
5!     CALCULATION OF WIND ENERGY
10     INPUT "AEOLIAN ENERGY DISTRIBUTION IN";A$
15     INPUT "PERIOD";B$
17     INPUT "K=";K
20     PRINT
25     PRINT,"ENERGY","POWER","VELOCITY","DEVIATION"
30     PRINT "DAY","TOTAL","TOTAL AVERAGE","AVERAGE","STANDARD"
35     PRINT,"W-H","WATTS","M/S","M/S". : PRINT
40     T1,T3,T5,T6,M1,M2,M3,M4=0
45     H4,E1,P1,V3,S3,D=0
50     !BEGIN DAILY ITERATION
55     READ J,H2 : ON ERROR GO TO 200
56     H4=0.0001
60     H1=24 :D=D+1 : S=0
70     ! BEGIN HOURLY ITERATION
80     J=J+1
90     H3=H1-H2
95     V1=((2*J-1)/2)*K : V2=V1**2
96     M1=V1*H3 : M3=V2*H3
100    K1=0.6125*(((2*J-1)/2*K)**3
110    E=K1*H3
115    IF J=1 THEN 140
120    E1=E1+E
130    H4=H4+H3
135    M2=M2+M1 : M4=M4+M3
140    H1=H2
145    IF S=1 THEN 170
150    READ H2
160    IF H2 <> 0 THEN 80
165    H3=H1 :S=1 : GO TO 95
170    P1=E1/24 :V=M2/M4
172    S2 =(1/H4)*(M4-((M2)**2)/H4)
174    S1=SQR(S2)
180    PRINT D,E1,P1,V,S1
185    T1=T1+E1:T3=T3+P1: V3=V3+V:S3=S3+S1
187    T5=T5+H4
189    E1,M2,M4=0
190    GO TO 55
200    PRINT:PRINT:PRINT:PRINT
205    V7=V3/D :S7=S3/D
207    T3=T1/(D*24) :T6=(T5*100)/(D*24)
210    PRINT "SUMMARY:";B$
220    PRINT: PRINT "TOTAL ENERGY KWH/M2:"; T1/1000
240    PRINT: PRINT"AVERAGE TOTAL POWER KW/M2:";T3/1000
250    PRINT:PRINT "AVERAGE VELOCITY OF PERIOD M/S";V7
255    PRINT : PRINT "STANDARD DEVIATION M/S";S7
260    PRINT: PRINT"HOURS WITH WIND";T5
270    PRINT: PRINT "% OF TOTAL TIME WITH WIND";T6
280    PRINT:PRINT DATE$(0)
32767 END

Ready
```

"WINDCA" PROGRAM

AEOLIAN ENERGY DISTRIBUTION IN? ACAPULCO, GRO
MONTH? MARCH-APRIL 1980
K=? 0.2

DAY	TOTAL ENERGY W-H	AVERAGE TOTAL POWER WATTS	VELOCITY AVERAGE M/S	STANDARD DEVIATION M/S
1	4433.46	184.728	4.77487	3.35399
2	6927.35	288.64	5.6022	4.19859
3	5685.59	236.9	4.80529	4.37714
4	6341.04	264.21	5.26241	4.56996
5	964.122	40.1717	2.84696	1.93494
6	571.398	23.8083	2.79453	1.50387
7	3153.04	131.377	3.97487	3.21969
8	4813.88	200.578	5.13184	4.09413
9	1461.34	60.8891	3.03421	2.42277
10	6926.76	288.615	4.92931	4.53381
11	3493.64	145.568	4.2073	3.49721
12	4477.38	186.558	4.79648	4.21512
13	764.011	31.8338	3.09242	1.88461
14	3857.84	160.743	4.2817	3.85437
15	6685.67	278.569	5.32924	4.52617
16	4582.89	190.954	4.55944	3.80655
17	4150.23	172.926	4.34855	3.70572
18	3795.13	158.13	4.09653	3.54809
19	6032.53	251.356	5.45787	4.44631
20	7574.81	315.617	6.10852	4.72717
21	6825.56	284.398	5.68151	4.52074
22	8326.19	346.925	5.77382	5.10757
23	7710.5	321.271	5.32131	4.63002
24	6541.54	272.564	4.73346	4.3821
25	1732.83	72.2013	3.34694	2.5025
26	6155.39	256.475	5.39563	4.18153
27	5624.18	234.341	5.10835	3.96902
28	5046.03	210.251	5.46039	3.87586
29	1899.21	79.1335	4.33876	2.70147
30	2573.55	107.231	3.72465	2.84831

SUMMARY: MARCH-APRIL 1980

TOTAL EVERGY KWH/M2: 139.127

AVERAGE TOTAL POWER KW/M2: .193232

AVERAGE VELOCITY OF PERIOD M/S: 4.61065

STANDARD DEVIATION M/S: 3.70164

HOURS OF WIND: 623.303

% OF TOTAL TIME WITH WIND: 86.5699

16-May-80

Ready

5.3 WIND VELOCITY PROBABILITY DISTRIBUTION CURVES

5.3.1 Introduction

It has been possible to apply a mathematical function for the probability density of the wind velocity distribution, of which a typical pattern has been observed from its statistical studies. This function is the Weibull distribution model, which has the following general form:

$$P(V) = (K/C)\ (V/C)^{k-1}\ \exp\left|-(V/C)^{K}\right|$$

where C is a scale factor in units of velocity and K a non-dimensional factor. Figure 44 shows a family of curves of this type.

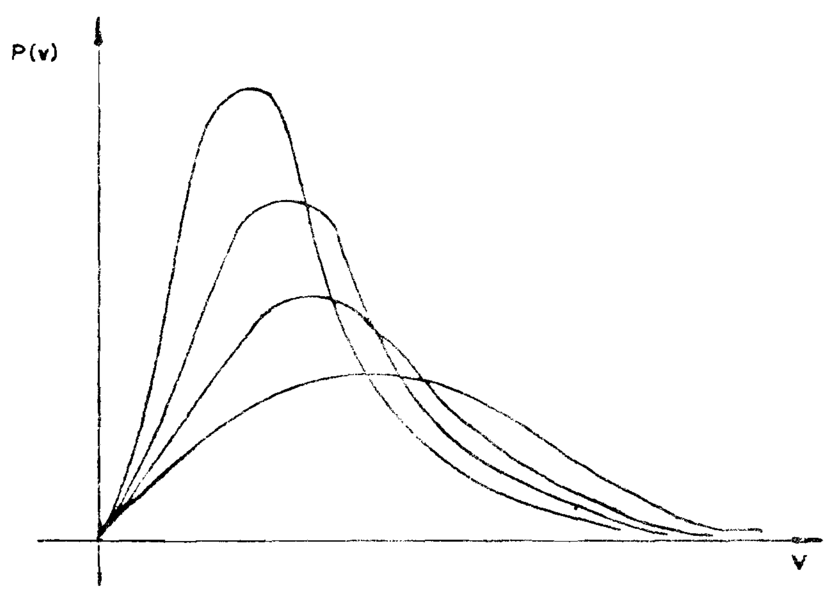


Figure 44 - Wind Velocity Probability Distribution Curves

For applying the theoretical velocity distribution analysis to a site it is only required to know the average velocity and the standard deviation of the period analyzed.

This tool is important, basically for two reasons:

1. It reduces the time required for using anemocinemographs in the sites under study, for it predicts the expected velocity histogram of a long period (annual, for example), from relatively short periods of measurement (three months) and the regional information which allow performing the seasonal corrections to the observed average.

2. This theoretical distribution allows programming computer simulations of the generated energy by a AECS (initial or ignition, of nominal power regime and of operational throughput by excesive winds). This will allow predicting the total energy produced annually and obtaining the respective total costs and per energy unit, in the economic studies, of the feasibility of using the aeolian energy in a given place.

5.3.2 The Density Probability Function

The Weibull distribution is a special case of the generalized Gamma Distribution.

Rayleigh distribution is an specific case of this, where K=2 (Chi distribution with two degrees of freedom) and which correlates well with the average time lenght distribution curves.

Having the average velocity $\overline{V}$ and the standard deviation σ for a period of analysis and the following table, it is possible determining the values of the coefficients K and C.

TABLE 5

COEFFICIENTS K AND C FOR THE WIND VELOCITIES PROBABILITY DISTRIBUTION CURVES

K	$\overline{V}/C$	$\sigma/\overline{V}$
1.2	0.941	0.837
1.4	0.911	0.734
1.6	0.897	0.640
1.8	0.889	0.575
2.0	0.886	0.523
2.2	0.886	0.480
2.4	0.886	0.444
2.6	0.888	0.413
2.8	0.890	0.387
3.0	0.893	0.363
3.2	0.896	0.343
3.5	0.500	0.316
4.0	0.906	0.281
5.0	0.918	0.229
6.0	0.928	0.194
7.0	0.935	0.168
8.0	0.942	0.148
9.0	0.947	0.133
10.0	0.951	0.120

Following this section, the list of variables, flow chart, program listing and the result sheet of the "DISWIN" program are annexed, coded in BASIC for calculating the density probability function, thus availing us with the theoretical distribution of the expected wind velocities in a site of interest, as showned in Figure 45.

"D I S W I N"

LIST OF VARIABLES

$\overline{V}$	Monthly average velocity in m/s
σ	Monthly average standard deviation in m/s
K	Form factor (non-dimensional)
C	Scale factor in m/s
J	Velocity for which the occurence probability is wished to know
K1,K2,K3, E1	Factors for calculating the occurrence probability of given velocity
P1	Occurrence probability of a given velocity

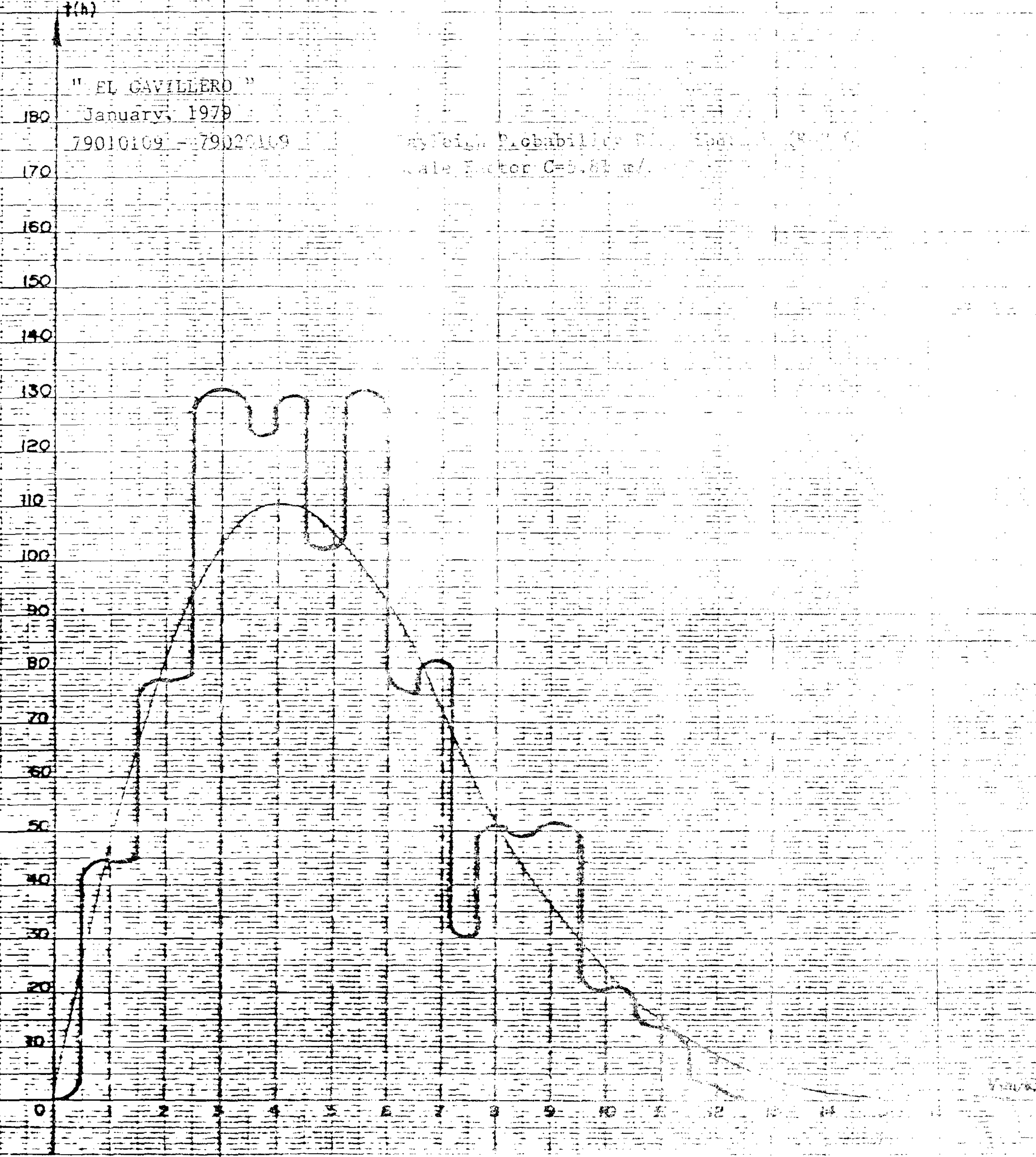
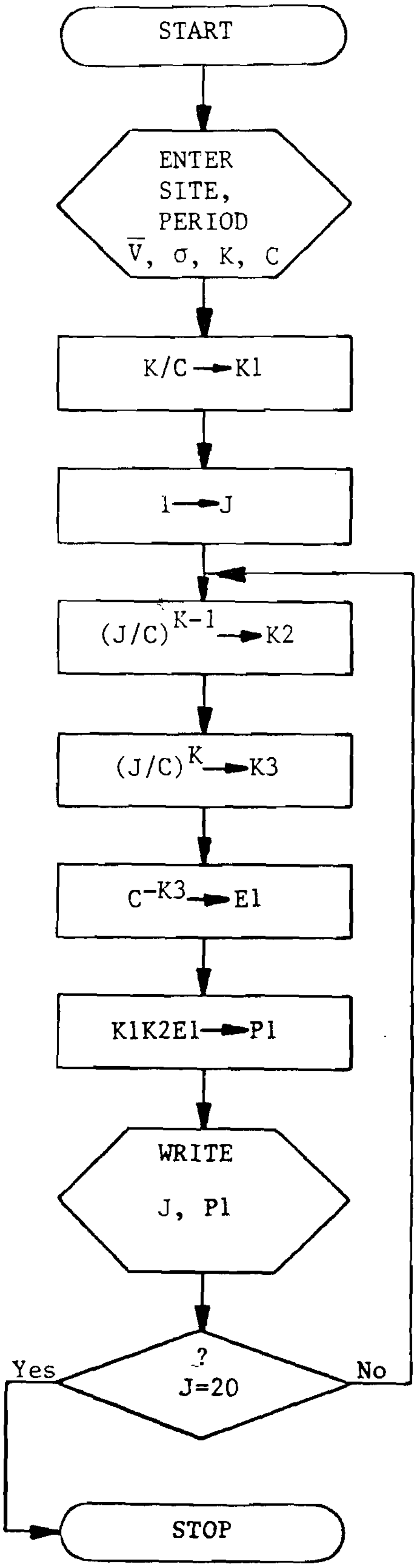


Figure - Rayleigh Probabili...
Distribution

"DISWIN" PROGRAM - FLOW-CHART



DESCRIPTION

Name of site from where the information was extracted, month, average velocity, standard deviation, form factor, scale factor.

Start iteration for the velocity change on which the occurrence probability is wished to know

Calculation of the occurrence probability (according to Weibull) of a given velocity.

Print of the velocities values and their occurrence probability

Maximum velocity value whose occurrence probability is wished to know

```
DISWIN  12:48           May 28, 1980
5!      DETERMINATION OF THEORETICAL WIND VELOCITY DISTRIBUTION
15!     WEIBULL DISTRIBUTION
20      PRINT "THEORETICAL WIND VELOCITY DISTRIBUTION"
30      INPUT "PLACE";A$,"PERIOD";B$
40      INPUT "AVERAGE VELOCITY";V1,"STANDARD DEVIATION";S1
60      INPUT "K=";K, "C=";C
70      PRINT:PRINT:PRINT, "THEORETICAL DISTRIBUTION"
100     PRINT "VELOCITY", "PROBABILITY"
110     Y$="XXXXXXXXXXXXXXXX" : K1=(K/C)
120     ! BEGIN VELOCITY ITERATION
130     FOR J=1% TO 20%
135     X$=""
140     K2=(J/C)**(K-1)
150     K3=(J/C)**K
155     ON ERROR GO TO 200
160     E1=EXP((-1)*K3)
170     P1=K1*K2*E1
172     X2=INT(P1*60)
174     X$= LEFT(Y$,X2)
180     PRINT:PRINT J, P1,,X$
190     NEXT J
200     PRINT:PRINT:PRINT DATE$(0)
300     END

Ready
```

"DISWIN" PROGRAM

THEORETICAL WIND VELOCITY DISTRIBUTION
PLACE? GAVILLERO
PERIOD? JANUARY 1979
AVERAGE VELOCITY? 5.15
STANDARD DEVIATION? 1.06
K = ? 2
C = ? 5.81

VELOCITY	THEORETICAL PROBABILITY DISTRIBUTION	
1	.575191E-1	XXX
2	.105256	XXXXXX
3	.136147	XXXXXXXX
4	.147532	XXXXXXXX
5	.141256	XXXXXXXX
6	.122367	XXXXXXX
7	.971311E-1	XXXXX
8	.711812E-1	XXXX
9	.483951E-1	XX
10	.306275E-1	X
11	.180853E-1	X
12	.998169E-2	
13	.515614E-2	
14	.249538E-2	
15	.113239E-2	
16	.482158E-3	
17	.192731E-3	
18	.723563E-4	
19	.255228E-4	
20	.846143E-5	

Oct. 10, 1979

Ready

APEE/ /EE PEND FEBE
?End of file on device

Ready

RUNNH

CHAPTER 6 - WIND CHARACTERIZATION

6.1 TURBULENCE

6.1.1 Concept of Turbulence

The Analysis of the system of hydrodynamic equations for the determination of velocity fluxes, temperature, pressure and humidity, which can be solved if the heat flux as a fruction of time and coordinates is known, gives us the general view for defining the concept of turbulence.

The general principles of the mechanic of atmosphere can be formulated according to the three conservation laws, mass, momentum and energy. These principles may be described by five scalar functions; the sixth equation completing the system is the air state equation.

However, the use of these equations to describe both the time and spatial variations of the meteorological elements are subjected to the determination of serious difficulties, arising from the turbulent characteristic of the atmospheric movements.

To clarify the importance of this difficulty let the definition and main particularities of the turbulent fluxes be analyzed first.

Turbulent motion is the one whose characteristics change with space and time in an irregular and chaotic way, even though the ambient conditions remain unchanged.

The random character of the parametric variation is the main particularity of the turbulent flows, as opposed to the laminar flows, whose properties can be exactly determined at any time, with the external conditions.

We can check the turbulent character of the atmosphere movements by registering the time and spatial variations of the meteorological elements (wind velocity), with special recorders of small inertia. For example, figure 46 shows the variation of the wind horizontal component velocity V_3 with time, obtained from known ambient conditions. The curve shows the oscillations with different periods and amplitudes, thus indicating the complex internal structure of the atmospheric movements.

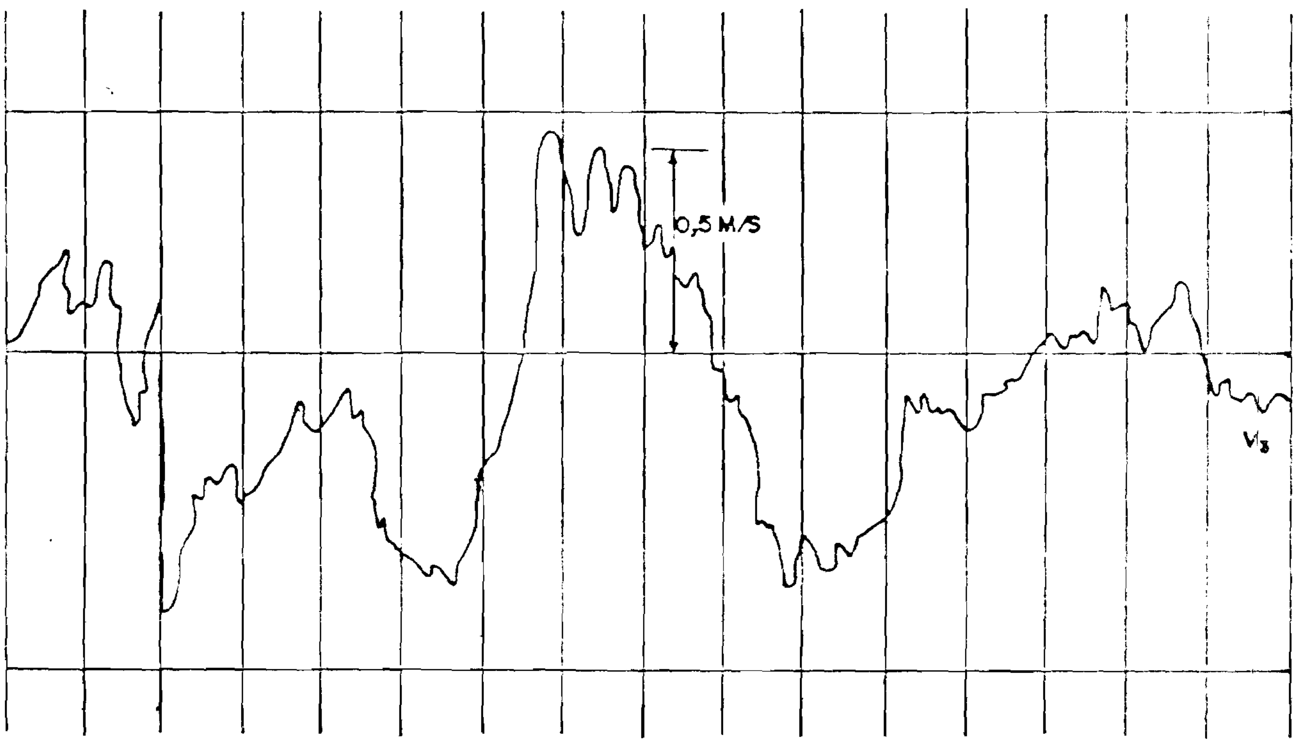


Figure 46 - Typical Register of the Temporal Variation of the Wind Velocity Horizontal Component

Atmospheric movements are not the only examples of turbulent flows. The great majority of flows which are found in nature are turbulent. Under certain circumstances, the ocean flows as well as that of the seas, rivers, sewerage, aqueducts and oleoducts are turbulent, much the same as the motion of the lower layers of air. The main differentiating causes of the atmospheric turbulence is the difference of scales and the stratification influence.

As it shall be seen, the turbulent regime arises as a result of the motion becoming unstable, under certain circumstances, with respect to small perturbations. This means that the random and uncontrollable variations of the initial or marginal conditions, lead to the principal variation of the velocity field, in such a way that the field avaluation is one of random character and the instantaneous values of the velocity vector cannot be determined before hand. Consequently, the mathematical description of turbulent and laminar flows must be different in principle. In the case of laminar flow, the system of hydrodynamic equations allows one to determine the value of every characteristic at any time, according to the initial values and the boundary conditions. With the turbulence flow, the initial conditions of the corresponding characteristics also determine their subsequent values. However, the latters depend on the uncontrollable and limiting perturbations of the initial conditions, which are impossible to be determined exactly. Hence, the interpretation of the corresponding differential equations describing the instantaneous behavior of the turbulent fields is practically impossible.

For the turbulent fields, only their probability distributions can be given, and not their exact values. For this, in the case of turbulent flows, the hydrothermodynamic equations may be used only to determine the corresponding probability distributions, or the average characteristics of the random fields established for these distributions. Thus, it is only possible to describe statistically turbulent motions, which consists of an analysis on the statistical regularities, characteristics of a set of flows under the given ambient conditions.

The situation found in the turbulent regime of motion is similar to the kinetic theory of gases, which contemplates a system of a great number of molecules moving and acting reciprocally. The motion of one molecule is impossible to describe and hence, the average statistical properties of the set must be analysed.

Despite the difference between the motion of a large number of molecules and the turbulent motion, there are certain analogies which are useful for the turbulent motion description.

6.1.2 The Origin of Turbulence

The laminar and turbulent flows are two types of motion whose properties are substantially different, and which, given the required conditions, may transform from one to the other. The differences between them appear in a series of processes of great practical interest. It is known that the effect of the turbulent motion of a gas or a liquid on nearby bodies is greater than that of the laminar motion; also, the heat diffusion and mixing processes are more intense in turbulent fluxes, an important fact. As a consequence of all this, the determination of the conditions for the transition from laminar to turbulent flow is rather important to solve a series of application problems.

At the same time, the establishing of the mechanism for the appearance of turbulence must lead to the undestanding of the nature of the turbulent motion. This is the reason why its study is also one of the atmospheric physics.

The criteria for the origin of turbulence was obtained by O. Reynolds, an English physicist in 1883. In stydying the motion of liquids in circular glass tubes, Reynold showed that laminar flow became turbulent when the non-dimensional number Re = UL/ν, known as the Reynolds Number, was greater than a critical value Rec (U and L are the scalar characteristics of velocity and lenght; ν is the kinetic viscosity coefficient). Reynolds Number characterize the relative role of the inertial force and molecular viscosity in fluid-dynamics.

The inertial force, whose role consists of a spatial change of momentum, accounts for the appearance of perturbations in the flux. Opposing to this, the viscosity force smoothes out these irregularities. When Re is small, this is, when the viscosity predominates over the perturbations in the flux, which arise as a consequence of the inertial force, the flow is laminar. When Re is large, the inertial force predominates, there are perturbations in the flux, the characteristics of the flux acquire irregular variations and the motion is turbulent. This explains why the Reynolds Number acts as a criteria for the origin of turbulence.

Critical values, Rec, have been established experimentally for various types of turbulent flows. It is established that Rec depends largely on the degree of perturbation in the laminar flow (initial turbulence of the flow), the greater the initial turbulence, the smaller the Rec.

The theoretical approach to the problem on the origin of turbulence is based on the following conception. According to the definition, stationary laminar flows are described by fixed solutions to the hydrodynamic equation in normal conditions. In principle, it may be supposed that these solutions must exist for any Reynolds Number. At the same time, experience has shown that laminar flows exist when Re<Rec. This leads one to think that the solution obtained corresponding to a given motion must satisfy the hydrodynamic equation, apart from being stable. To achieve stability of motion,

it is necessary that the perturbations disappear with time. If it is unavoidable the appearance of perturbations, however small these may be, they will increase with time, leading to fundamental changes in the initial motion. This kind of motion is called unstable motion. Since turbulence appears when Re>Rec, Rec may be thought of as characterizing the conditions for the loss of instability. Due to this, the theoretical analysis on the origin of turbulence is centered in the mathematical analysis of the matter; this is, stability of the solutions to the hydrodynamic equations.

The study of the mathematical theory of the laminar flow stability is, by itself, another important problem on which much research has been carried out. Let us analyze qualitatively this and also, examine some basic points based on the ideas expressed by Landau.

The mathematical research on motion stability related to small perturbations is carried out according to the following scheme.

A small perturbation $V_{i1}(x,t)$ is introduced into the stable main motion $V_{io}(x)$, where $V_{i1}(x,t) << V_{io}(x)$, which determines the resulting motion $V_i(x,t) = V_{io}(x) + V_{i1}(x,t)$ satisfies the equations of motion and continuity.

The perturbation to the velocity field $V_{i1}(x,t)$ satisfies a system of linear differential equations with time independent coefficients. The general solution to these may be presented in the form of a sum of partial solutions of the type:

$$V_{i1}(x,t) = A\ (t)\ f\ (x)$$

where A (t) is the amplitude which changes periodically with time.

Thus, the instability, when Re>Rec, leads to the presence of a non-stationary periodic motion. For large values of Re, near to Rec, this motion can be represented by a superposition of the stationary motion $V_{io}(x)$ and the periodical motion $V_i1(x,t)$ with a small but limited amplitude, the value of which increases proportionally to $\sqrt{Re-Rec}$ as $t\to\infty$.

It is necessary to point out the following important particularity of the unstable periodical solution $V_{i1}(x,t)$: in the equation determining the absolute value of amplitude, the phase of the undetermined periodical motion depends on the random initial conditions. Thus, the periodical motion considered is not defined only by the limiting conditions. It may be stated that this motion possesses a degree of freedom (as different from the stationary laminar motion, with which the limiting conditions are deterministic, and it does not possess any degree of freedom).

In this way, the presence of a small perturbation leads to, jointly with a large Reynolds Number Re near to the critical Rec value, the appearance of an unstable periodical motion, in which one of the components is unstable at a certain frequency. With successive increase of Re, a point will be reached at which the motion becomes unstable with respect to the small perturbation $V_{12}(x,t)$ and the stationary periodical motion $V_{10}(x) + V_i1(x,t)$* The study on the instability in this case is very much the same as done formerly. Again, for the perturbation $V_i2(x,t)$ a linear differential equation is obtained, whose coefficients will depend not only on the coordinates but also on time, since the initial flux is non-stationary.

* This shows that Reynolds Number, Re, can be introduced not only in all the fluxes but also in the given motion of frequency. Instability in the motion appears when Re>Rec. It can be seen that Re will surpass Rec quicker when the scale is greater; that is, in the first order, motion of greater scale will lose greater stability.

As a result, there appears a pseudo-periodical motion characterized by two different periods and two degrees of freedom (since we now have two free phases).

When Re is kept increasing, there appear new random oscillations with different periods and undetermined phases; this is, the motion acquires a complex and irregular character with a great number of degrees of freedom. In this case, one can think of the intervals between the corresponding Re critical values, generating new orientations, which become gradually smaller; these will be of a higher frequency and of smaller scale. Thus, for large values of Re there will appear a developed turbulent motion consisting of a superposition of motions of different periods and scales. The motion for a given period or scale is called the turbulent vortex (or turbulent field).

In this way, we have a visual appearance of the turbulent motion. All these conclusions are related to flows possessing a constant density.

There is another procedure for investigating the conditions for the existence of the turbulence regime which, in essence, consists of analysing the energy balance of the perturbation of the corresponding vorticity of scale and under certain conditions in which the energy of the given perturbation will not decrease with time (this is, it may exist for a long time).

Let us analyze the use of the method with a typical atmospheric situation. Supposing that in a homogeneous horizontal flow a perturbation of scale ℓ exists, with velocity V_1 and a temperature potential Tp, different from the surrounding temperature. The characteristic existence time of this vortex is $\tau, \sim \ell_1/V_1$. In this case, the energy $R_1 \ell$ per unit time will be substracted from the kinetic energy of the main flow (or from the vorticity of the greatest scale) for the formation of the kinetic energy of the turbulent motion.

The kinetic energy of the vorticity is spent in the work R against the viscosity force. This force is described by the last member of the equation of motion. The work done against the viscosity force per unit time is $R_2\ell$.

Besides this, in a stratified and stable flux, the vorticity does work against the Archimedes force, which, per unit time, is given by $R_3\ell$.

For this scale ℓ perturbation not to disappear with time, that is, that the kinetic energy increases with time, the following condition must exist in the stratified and stable atmosphere:

$$R_1\ell > R_2\ell + R_3\ell$$

If the effect of stratification is small ($R_3\ell \ll R_2\ell$) then, the above condition reduces to:

$$R_1\ell > R_2\ell \quad \text{This is:} \quad Re\ell > 1$$

If, on the contrary, $R_3\ell \gg R_2\ell$, then we have:

$$Re\ell < 1$$

In this case $Re\ell$ is the Reynolds Number for the scale ℓ vorticity. Thus, in order to maintain the turbulence of scale ℓ it is required that Re be sufficiently large.

In an unstable stratification, the work of the Archimedes force R_3 is a complementary force of energy, and for maintaining the scale ℓ, the following inequality must hold:

$$R_1\ell + R_3\ell > R_2\ell$$

6.1.3 Vertical Turbulence

The problem of the vertical motion of air is one of the main problems in metereology. Many metereological elements undergo time and spatial variations under the influence of the vertical motions (temperature, pressure, humidity, and others). The presence of vertical flows presents a practical interest additionally, for it influences the diffusion of atmospheric pollutants: the flying regime of airplanes, etc.

Depending on the characteristic horizontal dimensions, all observed atmospheric vertical motions can be divided into three types:

- Chaotic vertical velocities

  The characteristic horizontal dimensions in this case may vary from a few centimeters to tens of meters. The characteristic vertical velocity in these flows is of the order of a few meters per second. The influence of these vertical velocities on the transference and distribution of different physical properties (heat, humidity, momentum, and others) can be described with the concepts on turbulence.

- Convectic vertical flow

  These present themselves in volumes of air with horizontal dimensions of several kilometers (no more than 20-30 Kms.), and the characteristic vertical velocity values are of the order of some m/sec.; they are originated under the influence of irregularities of the active surface and the orographic circulation.

- Regular vertical flows

  These cover zones with horizontal dimensions of the order of thousands of kilometers with a vertical velocity of approximately 2 m/sec.

Based on the similarity theory, Prandtl formula can be written as follows:

$$\ell = \gamma(Z + Z_o) \tag{4}$$

where Z is the height above the surface, Z_o is the value which corresponds to ℓ on the earth surface (when Z = 0) known as the rugosity parameter; γ = 0.38, is the Karman constant.

Integration equation (3) from Z = 0, where the wind velocity is zero under the influence of adhesion (c = 0) to any height Z, where the wind velocity is C(Z), we obtain the expression of logarithm distribution law of the wind velocity in the lower layer:

$$c(Z) = \frac{U^*}{\gamma} \left(\ln \left[\frac{Z + Zo}{Zo}\right]\right) \tag{5}$$

If the wind velocity is measured at a height Z_3, then

$$c(Z3) = \frac{U^*}{\gamma} \left(\ln \left[\frac{Z3 + Zo}{Zo}\right]\right) \tag{6}$$

Using this formula, the value of U* can be determined. Replacing the velocity of friction between (5) and (6) results:

$$c(Z) = c(Z3) \left[\frac{\ln \left(\frac{Z + Zo}{Zo}\right)}{\ln \left(\frac{Z_3 + Zo}{Zo}\right)}\right] \tag{7}$$

Differentiating this equation and by using relations (2) and (4) we get:

$$K(Z) = \gamma^2 \frac{C(Z3)}{\ln \left(\frac{Z3 + Zo}{Zo}\right)} (Z + Zo) \tag{8}$$

The K dependence on height is expressed by Prandtl in the following form:

$$K(Z) = Ko + aZ \qquad (9)$$

From equations (8) and (9) we have:

$$a = \gamma^2 \frac{C(Z3)}{\ln\left(\frac{Z3 + Zo}{Zo}\right)}$$

$$\text{and} \quad Ko = aZo \qquad (10)$$

Thus, the linear dependence of ℓ and Z confirms the linear dependency of K and Z.

The analysis of a great number of observations in different zones on the earth has shown that the logarithmic law (5) is followed closely, if the thermal stratification of the layer is not much different from the indifferent strafication. Figure 47 shows the scheme of the wind velocity distribution with height, obtained from gradient measurements in a semi-dessertic zone. In this graph, the semi-logarithmic axes are used; one axis is the logarithm of the height (lg Z) and the other is the wind velocity at different heights (C), in linear scale. From this graph, at 08:00, when the stratification is near the indifferent one, the wind velocity distribution is logarithmic. All the experimental points satisfying formula (5) are distributed approximately along a line.

Equally, when the instability is marked (12:00) specially when stable stratification is present (02:00), the wind distribution along the axes (C, lg Z) possesses a well-defined curve, of one sign for unstable stratification, and of the other sign for stable stratification (of inversion). In comparison, when $C \sim \lg Z$, the increase of the wind velocity with height is slower when $g > ga$ (Richard Number $Ri < 0$) and faster for $g < ga$ ($Ri > 0$).

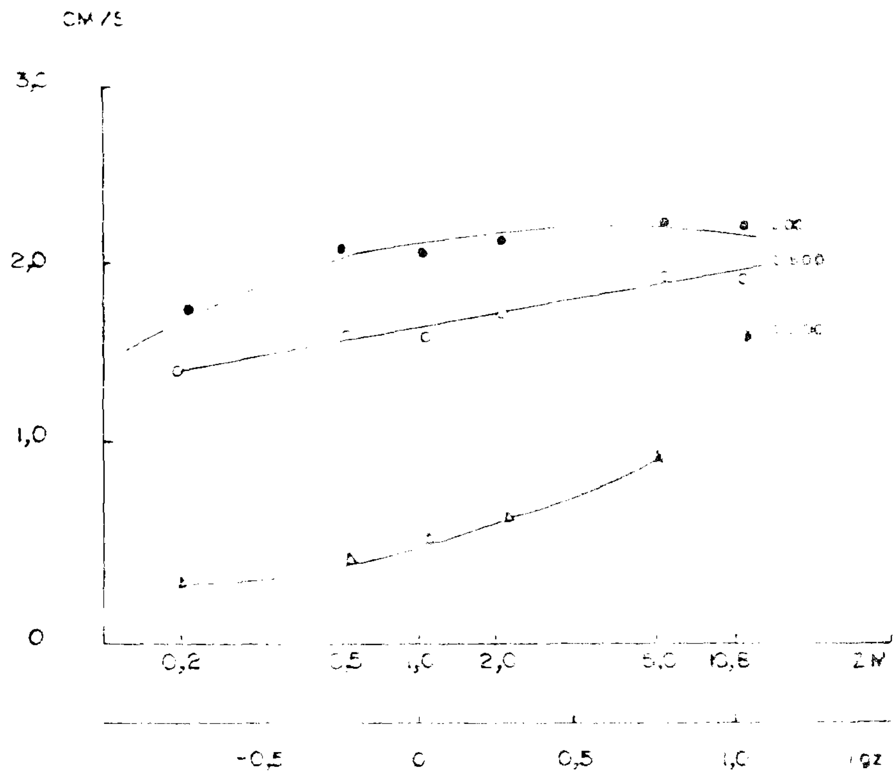


Figure 47 - Wind Velocity Distribution at Heights under Indifferent Stratification (0800), Unstable (1200) and Stable (0200) of the Lowest Atmospheric Layer.
Arys, Republic of Kazajstan, USSR - August 27, 1945

In the past few years, several research have been carried out on the wind distribution with height under non-uniform conditions (|g|>>ga). The best known have been the formulas presented by MONIN-OBUJOV, which were obtained based on the theory of similar and of dimension.

The analysis of the dimensional values, which form part of the determinant equations of the temperature and wind velocity variation with height in the nearby layer leads up to the following conclusions: the non-dimensional temperature (that is, relation T/T*) and the wind velocity (relation C/U*) are universal functions of non-dimensional relation of the static stability parameter:

$$B = Z/L^* \tag{11}$$

where L* is the height scale of MONIN-OBUJOV, and it is equal to:

$$L^* = \frac{U_*^2}{\gamma b T^*} \tag{12}$$

where U* is the friction of dynamic velocity (velocity scale), T* is the temperature scale given by the formula

$$T^* = -\frac{Q_o}{\gamma C_p \rho_o U^*} \tag{13}$$

b = G/T are the Archimedes parameters (G: free fall accelera tion); γ the Karman constant.

The formula for the velocity distribution of the wind velocity in the lower layer of the atmosphere, according to the similarity theory, is as follows:

$$c(Z) - c(Z1) = \frac{U^*}{\gamma} \left| f_c(B) - f_c(B_1) \right| \tag{14}$$

where $f_c(B)$ is an universal function of the variable h. This function has been determined by a series of observations carried out under vari ous conditions and in different zones of the world. These are the results obtained:

$$f_c(B) = \begin{cases} \ln B + 10B & \text{for } B>0 \\ \ln(B) & \text{for } 0.07 \leq B \leq 0 \\ 0.25 + 1.2B^{-1/3} & \text{for } B<-0.07 \end{cases} \tag{15}$$

6.2.2 Atmospheric Limiting Layer

Previously, an analysis on the atmospheric turbulence behavior has been done.

Also, when analyzing the geostrophyc approximation it has mentioned that the effect of friction has been neglected from the motion equation. This approximation is valid in the so-called free atmosphere, that is, from the first kilometer above. Under this, in the layer in contact with the earth surface, friction effects must be taken into account, and to this layer the name of limiting atmospheric layer is given.

This can be characterized as the atmospheric region near the earth surface which is directly affected by the friction effect tiself. As it has been stated, although its height is variable, the approximate value of 1 Km. may be taken for intermediate latitudes. Figure 48 shows a graph of the atmospheric layer with its subdivisions.

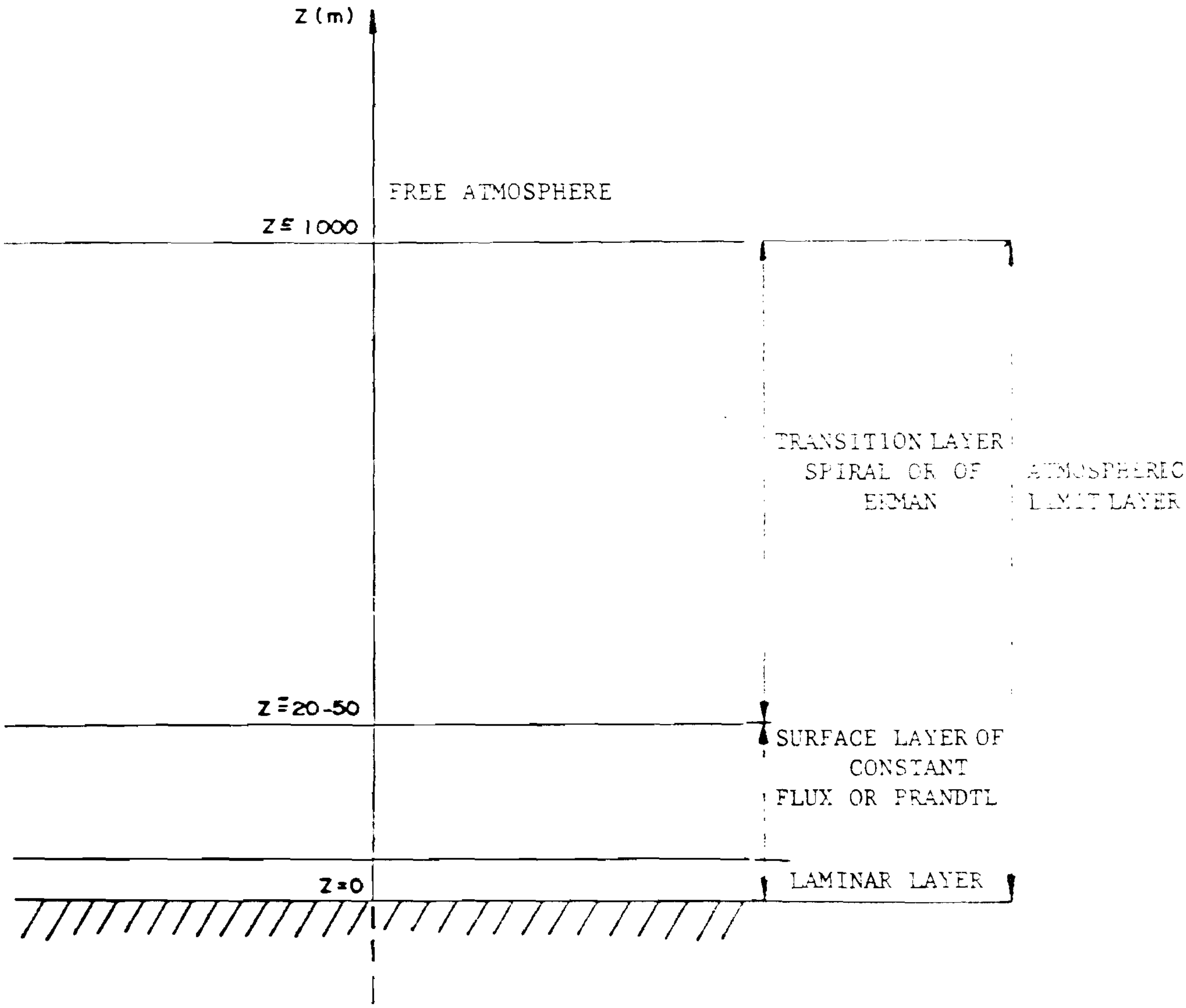


Figure 48 - Atmospheric Limiting Layer and its Subdivisions

6.2.2.1 Surface layer

This is also known as the constant flux or Prandtl layer. It is usually defined as the part of the atmospheric limiting layer in contact with the earth surface, characterized by the constancy of the turbulent fluxes with height (actually, measurements have established variations which oscillate around 10%). Its interaction with the earth surface is very strong and the adjustment of its structure to the surface conditions is relatively fast, hence it can be assumed that a state of quasi-stationary is present within. Its height is variable, and a value of 20 to 50 meters may be given as representative.

In the previous analysis of sections 6.1 and 6.2.1 the different considerations of the treatment to identify its structure have been seen. In what follows, it will be pointed out how the useful expressions to characterize the wind distribution with height behave, and certain dependency of the value is shown.

Under adiabatic conditions (when the potential temperature gradient is zero or the one of temperature is approximately 1°C/100 m) the logarithmic expresion is taken to be valid:

$$u(Z) = \frac{u_*}{K} \cdot \ln \frac{Z}{Zo} \qquad (16)$$

where u is the modulus of the wind and Z is the height, K and Zo have already been defined previously.

This expression becomes useful if u is known at a given level; for example, let u (h) (h may be the anemometric level), then

$$u(Z) = \frac{u_*}{K} \cdot \ln \frac{Z}{Zo}$$

$$u(h) = \frac{u_*}{K} \cdot \ln \frac{h}{Zo}$$

from which $$\frac{u(Z)}{u(h)} = \frac{\ln(Z/Zo)}{\ln(h/Zo)} \qquad (17)$$

The usefulness of this expresion can clearly be seen, for u does not appear, and it provides the distribution u (Z) from u (h) within the region considered.

From the expression, it can be noted that the only parameter affecting the distribution under adiabatic conditions is the rugosity Zo.

Some measurements of Zo on typical grounds are:

Ground Description	Zo(Cm)
Smooth	0.001
Sand	0.03
Surface with snow: smooth snow on short grass	0.005
Over prairies	0.1
Old snow	0.5 - 1.0
Short grass	1 - 4
Long grass	4 - 8
Pines (up to 10 meters)	50 - 100
Ocean (depending on the wind velocity)	0.001 - 0.5

Suppose h = 10 m., the relation u (40m)/u (10 m) vary from 1.12 to 1.30 for a Zo range of 0.01 to 10 cm. When the ground "up the wind" is of smaller Zo, the main wind increase occurs below 10 m. (from experience). The smoother is the earth surface, the greater is the wind in the lower levels. This suggests that, with all the factors constant, it is preferable placing an aerogenerator in a site of low rugosity, far from places with obstacles. If it is inevitable placing it in a rugose ground, it will be placed at higher heights than in the case of smoothened ground (little rugosity).

If the atmospheric condition are unstable (that is, when the temperature decrease with height is greater than 1°C/100m), as it is the case with high insolation values, the former equation u (Z) is not valid and it is necessary using the various techniques for predicting the distribution under non-adiabatic conditions. For example, MONIN-OBUJOV's treatment (already mentioned) may be referred to, which for small values of $\beta Z/L$. gives:

$$u(Z) = \frac{u*}{K} \left(\ln \frac{Z}{Zo} + \beta \frac{Z}{L}\right) \qquad (18)$$

where β is a constant with values 4 to 7, and

$$L = - \frac{U*C_p T}{KgH} \qquad (19)$$

where: H = turbulent heat flux

When the atmosphere is unstable ($\frac{\partial \Theta}{\partial Z}$ < zero or $\frac{\partial T}{\partial Z} < -1°C/100m$) then L<<o.

Under unstable conditions, u(Z) increases at a lower rate with Z than under adiabatic conditions (note that the expression $\beta Z/L<o$). This is, under these conditions, the aero generator will achieve the same yield as under adiabatic conditions but at a higher height.

If the atmosphere is under stable conditions (this is, $\frac{\partial T}{\partial Z} > - 1°C/100m$), obviously including the isothermal conditions), H<o (downward towards the earth) and the wind increases faster with height than under adiabatic conditions. In this case it is preferable using the following empirical expression.

$$u(Z) = u_*(\frac{Z}{Zo})^\alpha \quad (20)$$

or

$$\frac{u(Z)}{u(h)} = (\frac{Z/Zo}{h/Zo})^\alpha \quad (21)$$

The value of α fluctuates between 0.25 and 0.35, with higher values for conditions of higher stability.

It is interesting pointing out some recommendations:

- Under neutral or slight unstable conditions, the wind is determined by the logarithmic law up to a height of 100 m. above the ground.
- Under synoptic conditions, as detected in Holland and Texas, and on grounds of low Zo, the increase of u with height on the referred level does not bring important consequences for the installation of the aerogenerator under daily conditions.
- There is a rather marked increase under low stable conditions, in which case it is interesting to locate the aerogenerators relatively high above the ground.
- Temperature inversions are a special case of stable conditions and hence, for a given synoptic behavior, a climatology of the same is of economics interest.

6.2.2.2 Laminar sublayer

In spite of the height of the laminar sublayer, to know the u(Z) distribution in it is of no interest for aeolian purposes. A brief description for this follows.

In certain cases, when Zo is small, this is, for smooth surface, the value of the turbulent diffusivity coefficient $K_m = K\, u_* Zo$ may reach the same order of magnitude as ν. When this occurs,

$$(K_m + \nu) \frac{\partial u}{\partial Z} = u_*^2 \qquad (22)$$

What is more, when

$$K_m = K\, u_*\, Z_o << \nu$$

the structure of the surface layer is dominated by the effects of the molecular viscosity, and the turbulent transference is negligible. This condition is known as "aerodynamically smooth flux".

The theory shows that when

$$Re = \frac{ZoU_*}{\nu} > 2.5$$

it is allowable not to consider ν in equation (22).

When: $Re < 0.13$ the flux is aerodynamically smooth, and the following expression is used.

$$\nu \frac{\partial u}{\partial Z} = u_*^2$$

from which

$$u(Z) = \nu^{-1} u_*^2 . Z \qquad (23)$$

6.2.2.3 Transition layer

In this layer, the effect of the friction force will retard the wind velocity when the motion is balanced, this is,

$$o = - f\, \vec{K} \times \vec{V} - \alpha \vec{\nabla}_H P + \vec{F}_{fric}$$

The schemes present in the two hemispheres, in the case of straight isobars, is presented in Figure 49.

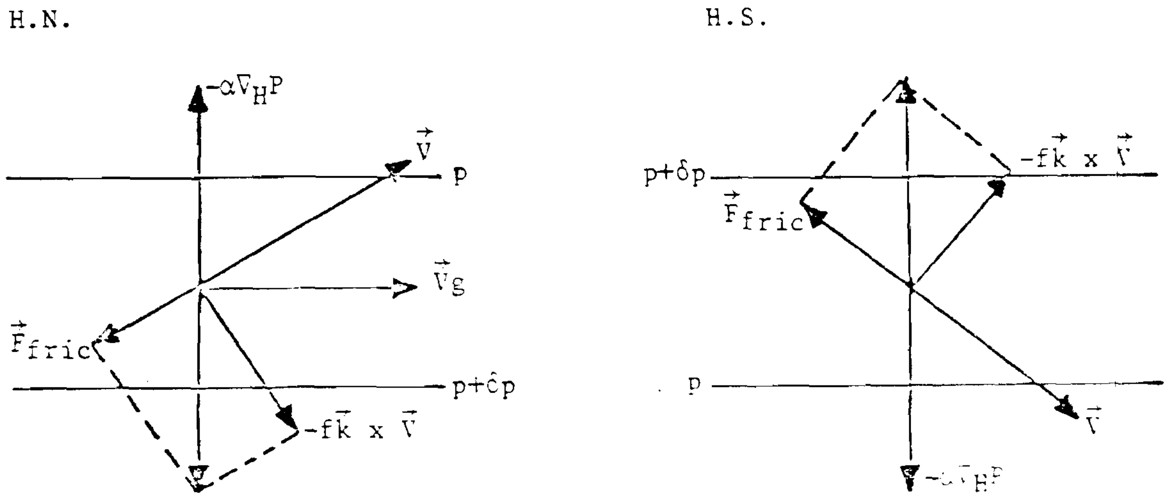


Figure 49 - Effect of the Friction Force in the Transition Layer

The following conclusions can be extracted:

a. The effect of friction is to decrease the wind.
b. The real wind has shifted to the left in the Northern Hemisphere, and to the right of the geostrophic wind in the Southern Hemisphere. This is, in both cases the shift is to lower pressure sides.

The origin of the above is found in considering the Coriolis force: $- f \vec{k} \times \vec{V}$, which acts perpendicularly to $\vec{V}$, to the right in the Northern Hemisphere and to the left in the Southern Hemisphere; the friction force must act in the direction of $\vec{V}$ and in the opposite sense.

Ekman considered the problem of the wind shift with height, reducing the equation of motion to another one of second order, in which the dependent variable is the velocity vector and as independent variable, the height.

This is possible since the force $\vec{F}_{fric}$ may be expressed by:

$$F_{fric} = \nu \frac{\partial^2 |\vec{V}|}{\partial Z^2}$$

To solve the equation for the wind variation with height in the friction layer, it has been assumed that:

a. The horizontal pressure force, and hence the geostrophic wind, have the same direction and magnitude at all levels.
b. The specific volume is independent of the height. The does not constitute a serious violation of the real condition -as it may be conceived- for the effect of friction is confined to the lowest layers.
c. The viscosity is also height independent. This assumption led to the result that the motion hodography was a spiral (figure 50). Thus, the real wind rotates with height in the northern hemisphere and in the opposite sense in the southern hemisphere, with increasing velocity with height in both cases. The highest level in which the wind tends to be parallel to the isobars is usually taken as representative of the geostrophyc wind or gradient.

For information purposes, the expressions for the wind horizontal components, u and v, are detailed according to Ekman solution (see as reference Wiin Nielsen, 1974):

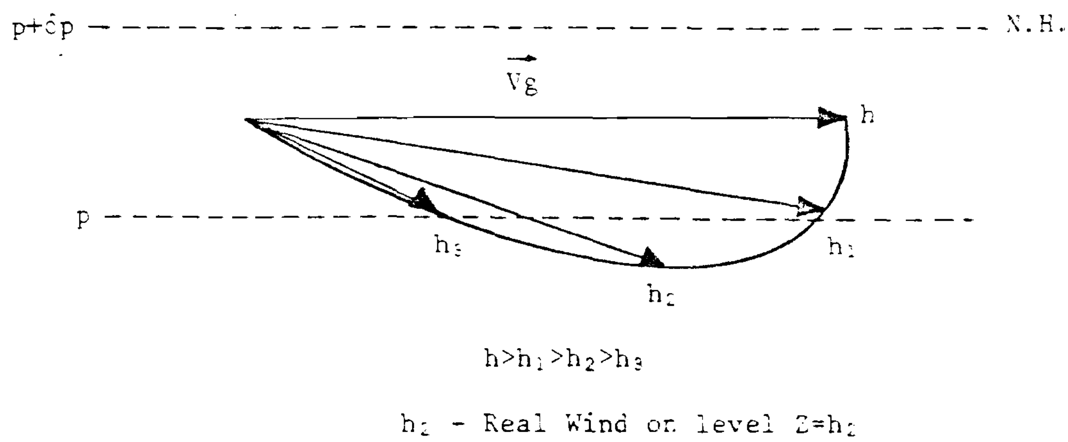


Figure 50 - Spiral of Ekman

$$u = Vg + \sqrt{2}\ Vg \sin \alpha_o\ e^{-Z/H*} \cos \left(\alpha_o + \frac{3\pi}{4} - \frac{Z}{H*}\right)$$

$$v = \quad + \sqrt{2}\ Vg \sin \alpha_o\ e^{-Z/H*} \sin \left(\alpha_o + \frac{3\pi}{4} - \frac{Z}{H*}\right) \qquad (24)$$

where:

Vg = geostrophyc wind modul
α_o = angle between the real and the geostrophyc wind at Z=0
H* = $\sqrt{2.Km/f}$

6.3 GUSTS AND STORMS

When dealing with the velocity variation of winds, it is necessary to distinguish carefully the difference between gusts and storms.

A gust is a brusque increase of the wind with respect to its average velocity within a certain interval of time. Its duration is shorter than that of a storm, followed by a weakening of the wind.

A storm is a strong wind with a brusque start; it lasts for a few minutes and calms down quickly. It is more accurately defined as a brusque increase of the wind velocity from 8 m/sec, at least, reaching 11 m/sec as a minimum, lasting for at least one minute.

Figure 51 shows an example of a storm and some gusts recording.

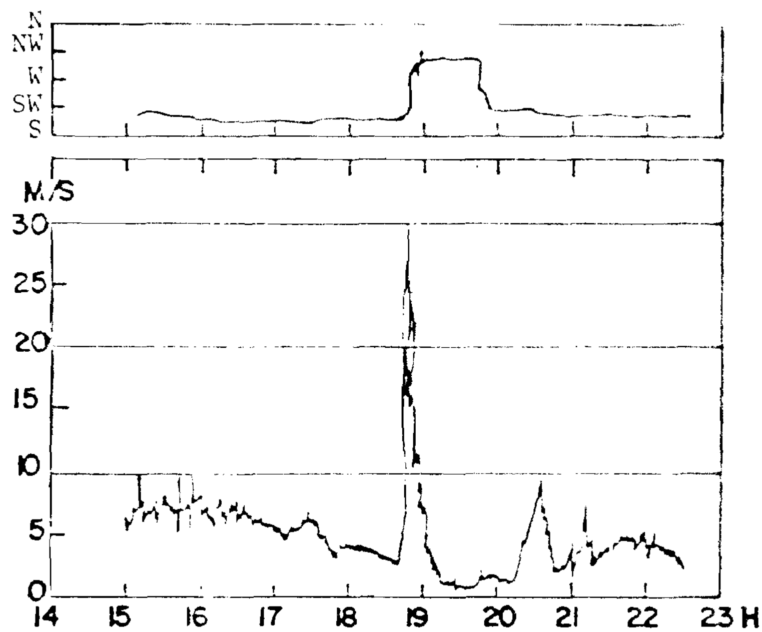


Figure 51 - Wind Direction and Velocity Variation when a Storm appears

Storms are a rather complex metereological phenomenon, which develops in the atmosphere with a highly unstable stratification. One of the characteristics of storms is the presence of strong winds (storms and gusts). Storms usually last a short time (two hours).

The strong wind in the storms has a scale ranging from 10 (25-28 m/sec) to 11 (29-32 m/sec) as measured in the Beaufort scale.

6.3.1 Spectral Characteristics of the Velocity Turbulent Field

In many practical problems, the description of the irregular features of a turbulent flow is not so important, as it has been done, as the detailed description of the turbulent fields.

In particular, for the use of the Aeolian Energy, it is important to consider the fluctuation characteristics in the wind direction.

The complex structure of the turbulent motion has been described, in which the presence of fluctuations of different periods and frequencies has been pointed out. Thus, the turbulent motion is presented as a superposition of the whirlwind motions of different scale. In order to calculate the energy distribution in these, it is necessary to decompose the motion in its components, which is based on physics, since the sum of the individual energy components must be equal to the total energy of the turbulence B.

This method consists of presenting the velocity field in the form of Fourier Integral, in wave vectors, which are inversely proportional to the whirlwind scale, which may be different in the various directions. Thus, the velocity pulse in point A, in the form of Fourier Integral, is given by:

$$u_i' \ (Xa,t) = A_i(\gamma,t)e^{i\gamma Xa} \, d\gamma \quad , \tag{1}$$

where $$A_i(\gamma,t) = \frac{1}{8\pi^3} \int u_i' \ (Xa,t)e^{-i\gamma Xa} \, dXa \tag{2}$$

is the Fourier velocity component, characterizing the contribution to the velocity pulse u_i' (Xa, t), of the component of motion with the wave vector γ.

The spatial tensor of correlation for the velocity field is:

$$Rij\ (X_a,X_b,t) = \overline{u_i'(X_a,t)u_j'(X_b,t)} =$$

$$\int \overline{Aj(\gamma,t)Aj(\gamma',t)}e^{i\gamma X_a}\ e^{i\gamma' X_b}\ dX_a dX_b \quad (3)$$

In the homogeneous turbulent field, the tensor of correlation depends only on the difference $D = X_a - X_b$ which will result if:

$$\overline{A_i(\gamma,t)Aj(\gamma',t)} = \int F_{ij}(\gamma,t)B(\gamma-\gamma')$$

Replacing this expression into equation (3) we have:

$$R_{ij}(n,t) = \int F_{ij}(\gamma,t)e^{i\gamma n}\ d\gamma \quad (4)$$

where F_{ij} $(\gamma,\ t)$ is the Fourier transformation coefficient of the spatial tensor of correlation, also called the tensor of spectral correlation.

Making n=0 and i=j in (4) we have:

$$R_{ii}(o,t) = \int F_{ii}(\gamma,t)d\gamma = 2\beta \quad (5)$$

Tensor $F_{ii}(\gamma,t)$, which describes the contribution from the whirlwinds with the wave vector of turbulence energy, is called the spectral tensor of energy.

Considering the fact that it is easier analyzing a function which depends on a scalar value, we take the spectral turbulence energy density $E\ (\gamma,\ t)$, which is equal to the integral of $F_{ii}(\gamma,\ t)$ in the surface $d\sigma$ of the sphere of radius.

$$R = \sqrt{\gamma_1^2 + \gamma_2^2 + \gamma_3^2}$$

$$E(\gamma,t) = \frac{1}{2} \oint\oint_{\gamma_i\gamma_i=\gamma^2} F_{ii}(\gamma,t)d\sigma \tag{6}$$

From equation (5) it is deduced that:

$$\beta = \frac{1}{2} \int F_{ii}(\gamma,t)d\gamma \quad =$$

$$\frac{1}{2} \int_0^\infty d\gamma(\oint\oint_{\gamma_i\gamma_i=\gamma^2} F_{ii}(\gamma,t)d\sigma) = \int_0^\infty E(\gamma,t)d\gamma \tag{7}$$

The spectral energy density, E (γ,t), characterizes the contribution of the total turbulence energy of the components of motion, whose wave number is independent of the direction of the wave vector.

The simplest case for analysis is the one concerning a turbulent isotropic field, in which all the turbulent motion characteristics are identical in every direction. All average scalar function describing the statistical structure of the field are invariable with the rotation, or when projected on a imaginary coordinate system. Thus, for example, the spectrum F_{ii} (γ, t) of the homogeneous isotropic field may be a function only of the length of vector γ, which is invariable in relation to the rotation of the element. For the isotropic field of equation (7) and in the spherical coordinate system, the relation between E (γ, t) and F_{ii} (γ, t) has the following form:

$$E(\gamma,t) = 4\pi\gamma^2 F_{ii}(\gamma,t) \tag{8}$$

Equations (5) and (7) show the condition of equality, of the sum of all the motion energy components and of the total turbulence energy, by the use of the transformation of the functions for the velocity field.

6.4 ROSE OF THE WINDS

One part of the solar radiation energy reaching the earth is eventually transformed into the kinetic energy of the gases of the atmosphere, whose molecules, consequently, are in constant motion.

The wind is the natural movement of the atmosphere air. In meteorology, this term refers to, in general, a movement of a set of air near the earth surface, or high above. The present chapter is dedicated to the horizontal motion of the air over the earth surface.

The motion of air is rarely regular. Usually, it is turbulent with whirlwinds of various forms and dimensions, which develop in the air and perturb the air flux. The effect of turbulence near the earth surface is the production of quick and irregular variations of both the velocity and the direction of the wind. These fluctuations of high frequency are mutually independent.

In this chapter, it will be seen how the measurement of the wind on surfaces are carried out, and its main characteristics are considered.

6.4.1 General Principles of the Measurement of the Wind on Surfaces

The wind can be considered as a vector, defined by its magnitude, the wind velocity, and a direction. The wind direction is the one if its origin.

Generally, the wind suffers rapid fluctuation. The degree of perturbation contributed by these fluctuations is expressed by the term of turbulence.

The velocity, direction and turbulence of the wind are preferably measured by the use of instruments; when this is impossible, however, they can be estimated. This is the case when the velocity is below two knots; with low velocities, the instruments are rather insensitive and stop being accurate. Calm refers to the absence of all perceptible movement of the air.

6.4.2 The Direction of the Wind on Surfaces - Units

The direction of the wind is defined as that in which it blows. It is expressed in degrees taken in the clockwise sense, starting from the geographic north or by using the course of the rose of the winds.

However, for coded messages, the direction of the wind must be given in the scale of 00-36. Table 6 presents the codes and their exact equivalent in degrees relating the 32 courses of the rose of the winds.

TABLE 6

WIND DIRECTION - EQUIVALENCE IN THE COURSE OF THE ROSE OF THE WINDS

Direction in the rose of the winds	Exact equivalence in degree	Code number	Direction in the rose of the winds	Exact equivalence in degree	Code number
Calm	-	00	S quarter SW	191.25	19
N quarter NE	11.25	01	SSW	202.50	20
NNE	22.50	02	SW quarter S	213.75	21
NE quarter N	33.75	03	SW	225.00	23
NE	45.00	05	SW quarter W	236.25	24
NE quarter E	56.25	06	WSW	247.50	25
ENE	67.50	07	W quarter S	258.75	26
E quarter N	78.75	08	W	270.00	27
E	90.00	09	W quarter NW	281.25	28
E quarter SE	101.25	10	WNW	292.50	29
ESE	112.50	11	NW quarter W	303.75	30
SE quarter E	123.75	12	NW	315.00	32
SE	135.00	14	NW quarter N	326.25	33
SE quarter S	146.25	15	NNW	337.50	34
SSE	157.50	16	N quarter NW	348.75	35
S quarter SE	168.75	17	N	360.00	36
S	180.00	18	Variable	-	99

6.4.3 The Measurement of the Wind Direction on Surfaces

In general, the direction of the wind is measured with the help of a vane. For this to function correctly, it must rotate with a minimum friction on its axis; also, it must be equilibrated with respect to this axis.

It is essential to keep the axis perfectly vertical and the orientation of the vane, with respect to the true north, must be accurate.

For synoptic observations it is necessary determining the average direction of the wind for an interval of 10 minutes prior to the hour observation. For this, it is convenient using a recording vane.

For aviation and other purposes, often it is preferable using a distance transmission, and the vane must respond to quick changes of direction. Often, an electrical transmission between the vane and the register is used.

Frequently, it is also necessary to estimate the wind direction when the instruments are not available, or when the wind is sufficiently weak. In fact, the great majority of the vanes are insensitive to the wind direction, when the velocity of this is below two knots.

6.4.4 Velocity of the Wind on Surface - Units

The velocity of the wind is expressed in knots. A knot is equal to a marine mile per hour or 0.51 meter per second.

The wind velocity on surfaces is rarely constant for a given period of time, however short this may be; in general, it varies quickly and continuously. The turbulence of the wind produces variations which are irregular in both period and amplitude.

It has been agreed that calm exists when the wind velocity is below one knot.

The wind velocity can be measured in different ways. The simplest consists of the direct observation of its effect on the earth surface without using instruments. The Beaufort scale, established in 1905 by admiral Sir Francis Beaufort to estimate the wind velocity at sea, has been adopted to be used on land sometimes. Later, equivalences of the wind velocity for each observed effect class have been added to it.

Measuring instruments and the wind velocity register have reduced the use of the Beaufort Scale condierably, particularly in land stations. However, the Beaufort scale constitutes a convenient a convenient means for estimating the wind velocity in the absence of other procedures.

6.4.5 Measurement and Register of the Wind Direction

The lag coefficient of an instrument to determine the wind direction must be equal, or smaller, to one second, in order to register 63% of a sharp change of direction.

The practical methods for indicating or registering the direction consist of both mechanical types (such as the double-feather model, which is frequently adapted to the tubular pressure anemometers) and electrical transmission types. The latters are more convenient for indication at a distance, generally made of auto-synchronized repeaters, ran by A.C. or D.C. current. With these systems it is possible to establish the wind direction with an accuracy of $\pm 2°$.

6.4.6 Estimation of the Wind Direction

The majority of the vanes do not respond to changes of direction, when the wind velocity is below 3 knots (1.4 m/sec); in this case, the direction must be estimated by observing, for example, the direction of the smoke of a tall chimney, the movement of the leaves, etc. in open space.

The determination of the wind persistence, which is the resultant value of the relation between the vectorial and scalar velocity, indicating the quadrant where the wind blows with greater frequency, possesses a great practical and scientific interest for climatological analysis, contamination studies and the diffussion of pollutants, planning, etc.

If the wind blows in the same quadrant all the time, both scalar and vectorial velocity coincide and the persistence will be 100%. On the other hand, if the wind blows in the opposite direction with equal frequency, the persistence of the wind will be zero.

There are various methods for calculating the wind persistence, although none has shown to be reliable for specific purposes.

When 4 and 8 courses of the rose of the winds are used, and for a specific purpose of form utilization, keeping in mind that the wind direction is a continuous variable and not discreet, it is required to establish a correction factor in order to determine, by considering the relative frequencies, the angle indicating the average point of the quadrant with greater relative frequency, in percentage, in which the wind blows.

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CONCLUSIONS AND RECOMMENDATIONS

Specialists from Argentina, Bolivia, Colombia, Ecuador, El Salvador, Guatemala, Mexico, Nicaragua, Panama, Peru, the Dominican Republic, and Venezuela attended the First Latin American Course-Seminar on the Prospect, Evaluation, and Characterization of Aeolian Energy, in order to analyze and discuss the aspects related to the problematic that presents itself in the exploitation of wind as an alternative energy source in Latin America.

Ideas were exchanged with regard to the basic guidelines required to realize the preliminary evaluation of the aeolic resource in the Region, with the following conclusions.:

1. For the proposed aims, it is necessary to unify the criteria in all of the Latin American countries with respect to the processing of all kinds of climatological information.

2. With the help of OLADE, the establishment of a mechanism for the exchange of the different technologies and meteorological experiences of all of the Latin American countries is needed.

3. With a view to the short-term realization of the zonal maps for Aeolian Energy, it is imperative to centralize the available information for wind, in a competent organism, easily accessible to all of the countries of the Region.

4. The World Meteorological Organization being the directing organism for meteorological activities, it was considered convenient to use

its structure for operations and diffusion in order to quantify and assess the available information required.

5. An inventory must be done of the existing meteorological network, at the regional level.

On the basis of the foregoing conclusions, the following is suggested:

1. To direct, through OLADE, a survey to the Governments of the Member States, in order to learn about the Institutions and Organisms that possess meteorological information and that realize activities with regard to the problem of the utilization of Aeolian Energy.

2. To solicit the remittance of the information required from the Institutions and Organisms in the previous item.

3. To recommend to the Member States of OLADE that they reinforce the internal coordination of the Institutions and Organisms that work on the exploitation of Aeolian Energy.

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