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(54) Title: ADAPTIVE PROFILE BLADE

FIG. 3

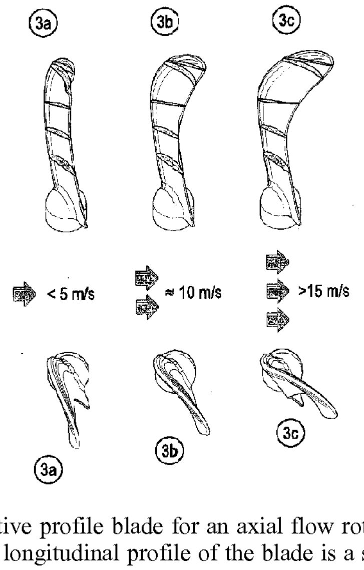
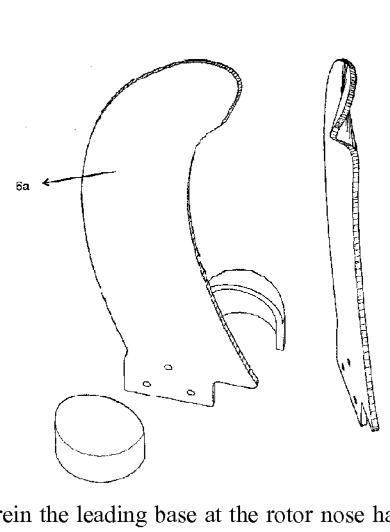


FIG. 6



(57) Abstract: An adaptive profile blade for an axial flow rotor, wherein the leading base at the rotor nose has a cylindrical-hemispherical shape, and the longitudinal profile of the blade is a semi-arched catenary and extends, on the intrados side, according to a coplanar curve to the blade itself, while on the extrados side, at 3/4 of extension of the blade towards the tip, it is characterised by the presence of a "V"-shaped undulation which exits from the blade plane towards the intrados, between 20° and 30°, with subsequent re-entry towards the extrados, and extends towards the intrados on a surface equal to 1/4-1/5 of the blade width.

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Adaptive profile blade

Field of the invention

The present invention relates to an adaptive profile blade which may be used, for example, to form a rotor for a wind turbine, with laminar axial flow, using renewable energy sources.

Prior art

Wind turbines are known which are formed essentially of a blade rotor and an electric generator, mechanically coupled by means of a motor shaft, and provided with streamlined surfaces or, more recently, surfaces boosted by electromechanical actuators, adapted to align the structure correctly to the wind. During operation, the shaft of the electric motor is dragged into rotation by the blade rotor, when the latter is hit by an axial air flow.

An essential condition of all wind turbines, whether they are of the axial laminar flow or the radial laminar flow type, is that they have to be installed in windy areas and to be provided, in general, with large-sized blades in order to be sufficiently profitable in energy terms, with inevitable problems of environmental impact, both visual and noise-related.

This occurs, in particular, since their optimal exposure requires installation in a high position or, in any case, in a position without barriers, which could reduce the air flow.

In order to overcome these problems, several solutions currently in use provide for use of particular materials and construction profiles of the blades which attempt to reduce the load on the wind turbine blade and simultaneously to reduce the noise during operation.

Various studies have been carried out on this. A first study is the one described in the document "*Load alleviation on wind turbine blades using variable airfoil geometry*" by Andersen et al., Wind Energy Dept. DK. This publication contains studies on deformation of the wind turbine blades as a function of the wind conditions and calculates possible longitudinal airfoil geometries variable as a function of the stress conditions received. This is a theoretical study, which suggests advantages in terms of both performance and noise reduction during operation, but does not identify the possible practical changes which may be made to the laminar profile, and therefore no possible application with the current materials and technologies can be found.

The publication *"Aero-elastic behavior of a flexible blade for wind turbine application: a 2D computational study"*, by Oogedorn et al., Energy, vol.35,2 - Feb.2010, like the previous one, relates to studies on deformation and flexibility properties of wind turbine blades as a function of the wind conditions. The blades are made of different materials and have different dimensional and physical characteristics. In this case, as well, the adaptive properties of these blades are shown, but no mention is made of particular advantages obtainable with the specific profiles or other construction characteristics.

The article *"Composite Rotor Blades Design of a Wind Turbine Using Flexible Multibody Modelling"* by Neto et al., Structural Dynamics conference 2008, contains information directed at the study of composite materials to be used on wind turbine blades and, in particular, the object of the authors is to identify the ideal material or materials which offer maximum blade elasticity and flexibility. Various calculations of these parameters are made based on the blade profile to be obtained, but there is no specific information on a particular profile and/or material which could offer all the advantages and achieve all the improvements indicated as necessary by the authors.

Various patent applications are known in the literature which contain several technological characteristics aimed at compensating the deformations, the reductions in performance and the high noise level as a function of wind turbine blades of different dimensions.

Application US 2006/0067828 "Wind turbine rotor blade with in-plane sweep and devices using same, and method for making same" describes a rotor and wind turbine blades with the characteristic of being bendable along the longitudinal axis as a function of the wind, causing an adaptive deformation. The object is eliminating undesired vibrations and torsions of the blade which compromise its integrity and which oppose the effect of the wind flow rate.

In EP2258943 „Profil eines Rotorsblatts einer Windenergieanlage" the invention lies in the particular profile of the blade, while document US 2013/0064663 "morphing segmented wind turbine and related method" is directed at wind turbine blades which show a particular deforming capacity adaptive to the wind conditions and, therefore, in addition to the particular construction material, have a multi-segmented structure and a specific streamlined profile.

Finally, application US 2004/0013512 „Blade of a wind turbine“ describes the possibility of using deformable plastic material (even if not along the entire length of the blade) and the streamlined profile used is also adaptive to the wind conditions and aimed at reducing the noise level during rotation.

However, all these devices are affected by the problem of having a complex construction, characterised by a multitude of parts in the assembly of the blades, which considerably increases their fragility and limits their bearing capacity, directly affecting the efficiency and performance of the entire system. Furthermore, the various construction materials are subject to a different process of deterioration by contact with atmospheric agents and the incidence of light radiation at different frequencies, causing inherent imbalances between the components and therefore requiring difficult and constant maintenance. Other major inconveniences of all the aforesaid systems, in addition to the environmental impact already mentioned and attributable, in any case, to their large dimensions, are therefore the considerable manufacturing, installation and subsequent maintenance costs, and also disturbances of electromagnetic waves, particularly radio, television and telephone waves, due to the presence of rotating metal blades. Furthermore, all the currently known systems function with specific minimum induction speeds of motion which require, in many cases, complex systems of amplification of kinetic intensity to ensure that the blade system can start the rotary movement.

In addition to the large, medium and small sized wind turbines, there are also so-called mini- and micro- wind turbines. These operate according to the same principle, but have considerably smaller dimensions and therefore show to a considerably reduced extent or not at all the aforesaid problems indicated for large wind turbines, since they do not necessarily even require installation on a mast, with all the further problems relating to this. However, in view of the particular streamlined shape and profile of the blades, and also the plastic or metal materials used in their construction, the overall performance of these systems is highly limited and the noise level is still not completely under control.

Object of the invention

In view of the aforesaid problems, the object of the present invention is the manufacture of a wind turbine blade for an axial laminar flow wind turbine able to improve energy performance, extending use of the currently known wind energy sources to other categories of users at limited costs.

A further object of the present invention is identifying a streamlined profile which allows the noise level of the blade in operation to be reduced.

A further object of the invention is providing a blade, which may be used in all wind conditions, at variable or constant flow, where the rotary motion is induced also in a breeze, which hits an individual blade of the system.

Lastly, a further object of the invention is developing a blade, which may be used for all fluid types, therefore including ship propulsion fluid.

Description of the invention

The above objectives are achieved by a blade and the relative system according to the object of claim 1. The dependent claims offer other advantageous aspects of the invention.

The surprisingly innovative characteristics of the present invention derive from the complex analysis and from the study of a multitude of models, which were then subjected to practical tests, relating to the directly existing interactions between the following aerodynamic and structural parameters of the wind turbines and the blades forming them:

- the power coefficient, or performance coefficient, C_P;
- the NACA airfoil
- the peripheral dynamic profile of the blade
- the resulting "Tip Speed Ratio" λ of the blade in relation to the power coefficient
- the consequent quantification of the optimal lift and drag forces and
- the local solidity of the rotor, a direct function of the number of blades used.

The ideas with which the authors started to obtain the results of the present invention derive from theorisation of the laminar flow models for a wind power system, as briefly explained below.

Power production by means of wind turbines depends on interaction between the rotor blades and the wind, first converting the kinetic energy possessed by the wind into rotational mechanical energy and then converting the latter into power. The kinetic energy Ec possessed by a mass of air m moving at a constant speed v_1 is given by:

$$E_c = \frac{1}{2} . m . v_1^2$$

Therefore, the specific available power P_{disp} possessed by a mass flow of air q=dm/dt is

$$P_{disp} = \frac{dE_c}{dt} = \frac{1}{2} . q . v_1^2$$

which may also be expressed in the formula

$$q = \frac{dm}{dt} = \rho \ . \ A . v_1$$

called the continuity equation, wherein:

• ρ is the air density;

• A is the section of the air flow tube considered.

The specific available power is therefore equal to:

$$P_{disp} = \frac{1}{2} . \rho \ . A . v_1^3$$

Through reference to fig. 1 and indicating with:

• p1 and v1 the pressure and speed of the wind in section A1 entering the flow tube and sufficiently distant from the wind turbine;

• p1 and v1 the pressure and speed of the wind in section A2 exiting the flow tube and sufficiently distant from the wind turbine;

• p3 and p4 the pressures immediately before and after section A;

• v the wind speed at the rotor plane

assuming there were no changes in potential energy and there was no heat exchange and work extraction between A1 and A, the Bernoulli equation could be written as follows:

$$p_1 + \rho \cdot \frac{v_1^2}{2} = p_3 + \rho \cdot \frac{v^2}{2};$$

similarly between A and A2: $p_4 + \rho \cdot \frac{v^2}{2} = p_2 + \rho \cdot \frac{v_2^2}{2}$

The change in pressure on the disc may therefore be defined as

$$\Delta p = p_3 - p_4 = \rho \cdot \frac{v_1^2 - v_2^2}{2}$$

Considering that axial force F, in the wind direction, on the actuator disc of section A perpendicular to the flow, is given by:

$$F = \rho \cdot A \cdot v \cdot (v_1 - v_2)$$

the speed in the actuator disc section may be expressed as $v = ½ (v_1+v_2)$.

As may be noted, a slowdown of the wind occurs half in the section upstream and half in the section downstream of the actuator disc.

Defining as *interference factor* "a" the ratio (v1-v)/v1, which represents the decrease in speed in front of the disc, the power captured by the blade may be expressed as the force exerted by the wind F multiplied by its incident speed v:

$$P = F \cdot v = (\rho \cdot A \cdot v \cdot (v_1 - v_2)) \cdot v$$

where, by changing the value of the force and the speed v as defined above, the following is obtained:

$$P = (\rho \cdot A \cdot \frac{v_1 + v_2}{2}) \cdot \frac{v_1^2 - v_2^2}{2} \qquad \text{or} \qquad P = 2 \cdot \rho \cdot A \cdot v_1^3 \cdot a \cdot (1 - a)^2.$$

An optimal value of the outgoing speed v_2 exists, at which the maximum extracted power is obtained. Said value is obtained by differentiating P with respect to a and by making the derivative obtained equal to zero. This allows a value of a = 1/3 to be obtained, with which it is possible, at this point, to define the power coefficient C_P:

$$C_p(a) = \frac{P}{P_{disp}} = \frac{2\,.\,\rho\ .\,A\,.\,v_1^3\,.\,a\,.\,(1-a)^2}{\frac{1}{2}\rho\ .\,A\,.\,v_1^3} = 4\,.\,a\,.\,(1-a)^2$$

For a=1/3, the maximum value of C_P is 0.59, which basically means that the maximum power which may be extracted, theoretically, from an air current with an ideal wind turbine cannot exceed 59% of the available power of the incident wind.

Once the value of C_P has been defined, it is possible at this point to indicate the value of the “tip speed ratio” λ of a rotor blade and identify their ratio. The aerodynamic characteristics of a blade are usually assigned by means of the relationship TSR-Cp. The TSR (Tip Speed Ratio), identified with parameter λ, is defined as the ratio between the tangential speed at the end of the blades and the speed of the wind entering the flow tube:

$$\lambda = \frac{v_t}{v_1} = \frac{\Omega.\,R}{v_1}$$

where Ω is the angular velocity and R is the rotor radius. The ratio between λ and C_P is indicated by the shape of the curve of Fig.2.

Local solidity of the rotor is strictly dependent upon analysis of the value of λ, expressible with the formula

$$S = c(r).\frac{B}{2\pi r}$$

Where c(r) is the profile chord at radius r. It is clear from this that choice of the specific profile of a blade heavily influences the efficiency of the entire system.

For a given blade, the relationship λ-C_P depends on the Pitch angle. If the Pitch angle is maintained constant, the following considerations may be made:

- there is a single value of TSR at which the conversion efficiency is at its maximum (Cp_{max}), depending on the blade type;
- as wind speed v_1 varies, it is necessary deliberately to vary the rotation speed of the blades in order to maintain the TSR constant and equal to the value at which Cp_{max} is achieved,
- for low values of the TSR, there is a reduction of the lift and an increase in drag, up to the point of stalling;
- for high values of TSR, there is a reduction in both lift and drag in a condition called "runaway";
- the optimal TSR depends on the number of blades and the lower the number of blades, the higher will be the speed at which said blades must rotate in order to extract the maximum power from the wind (increased TSR);
- the shape of the curve of the relationship TSR-Cp depends on the type of turbine.

Using all these evaluations, the authors created a specific calculation and simulation system for a particular type of rotor blade profile, which is able to exploit synergistically all the previously mentioned cofactors Cp, λ and S, which influence the final performance of the rotor. The value of Cp reached by the rotor manufactured with blades having the profile described here is around 0.5 and is close, for the various experimental tests performed in different conditions of wind intensity, fluid diversity and materials used, to the theoretical limit of 0.59.

This result is obtainable by manufacturing a wind turbine with a rotor having a pronounced nose provided with blades having the profile shown in the appended figures, to which reference will now be made, without intending to limit the invention, in order better to describe the innovative technical characteristics.

Fig. 1, 1a shows a preferred embodiment of the invention, wherein 6 blades are used with a maximum diameter (Ø) not exceeding 1000 mm., each blade being characterised by an original streamlined profile, as will be described in detail below, and also by the capacity to be automatically adapted to the wind conditions at the time. Furthermore, in combination with the characteristics of the specific profile, the blade according to the present invention allows optimisation of the

tangential flow of fluid by means of the particular shape and configuration of the rotor leading base.
The base of the blade has, in fact, a cylindrical-hemispherical shape with extrusion of the airfoil profile which, acting on the axial laminar flow to the blade, separates it into two currents, of which the first is compressed and runs along the rotor nose (Fig.2, 2a), while the second presses on the albeit minimum pressure surface of the tail of the emerging profile (Fig.2, 2b). This has a considerable advantage: the air which normally hits the rotor nose forms vortices; by means of the opposing action of the tail, said vortices are flattened towards said rotor nose, thus creating a combined action with the hemisphere of the base, which allows the contribution of flows transiting in said zone to be actively used, which increases system performance. This does not occur in any other system in the prior art.

The laminar section of the blade, according to a preferred embodiment of the invention shown in figure 2A, has a "concave convex laminar" profile, which may be designated mathematically as NACA 4317 (Fig. Xa), which, in the example shown, starts with a chord of around 100 mm. at the base of the blade and, not exclusively referring to this alternative, ends with an asymmetrical rounded profile. For better understanding of the differences compared with the “standard” NACA profiles, the figure shows in grey the section of a NACA 4412 profile superimposed on the one described here.

The NACA radial laminar profile is extruded with fractal geometry, not perfectly linear, starting from the base, in which it is embedded, along a curved axis almost to the apical end, where it becomes a rounded asymmetrical rectangle (Fig. Xb). The curved axis along which the radial profile, both streamlined and flat/curved, is extruded, has a three-dimensional trajectory, which is, in any case, definable in two dimensions as a catenary arch or hyperbolic cosine (Fig. Xc).

The section profile and related chord, in extension of the blade, have a progressive scaled reduction (not uniform), from the root to the tip, along the "semi-arched catenary " curved axis of its leading edge, adapting the crossing section of the laminar flow to compensate for centrifugation of the laminar flow, caused by rotation of the propeller, to obtain maximum propulsion (Fig.2, 2c-2d-2e).

In order to obtain all the specific advantages of the present invention and as resulting from the numerous initially theoretical and then applicative tests performed on the object of the invention, at 3/4 of the extension of the blade, the chord axis and the relative radial profile curve with the fulcrum along the leading edge axis, towards the front part (intrados), with limited angular misalignment of the chord axes, then curve immediately afterwards towards the rear part (extrados) at the blade tip. in other words, a "V"-shaped undulation or curling is formed on the profile of the extrados towards the intrados, between 20° and 30°, with respect to the plane identified by the blade, with which the median axis of the profile twists towards the front. The undulation extends in the direction of the intrados on a surface equal to 1/4-1/5 of the blade width. This is highlighted in particular in the detail circled on figure 2 and may be further appreciated in the view of the extrados in figure 6. This undulation of the section profile acts as a "flow spoiler" (bilateral) which, by re-directing the current at that point (Fig.2, 2f) with respect to the rest of the blade, generates a compression on the underlying streamlined layers (Fig.2, 2c-2d-2e), of both the intrados and the extrados, and, by re-directing them towards the base of the blade, increases its performance. Said torsion of the profile also generates further depression of the outgoing flows at the end of the blade, channelling them towards the wing end along the median axis of the exit edge (Fig.2, 2g), reducing both induced drag and the noise caused by the vortices.

This profile is the result of lengthy assessment of all the aerodynamic parameters discussed above, which allowed the effect of changing the lift ratio rising towards the tip and causing inversion of the streamlined profile to be obtained, thus passing, for example, from a positive NACA to a negative one. An important aspect to emphasise, which is obtained where torsion occurs, is the effective elimination of the vortices which usually form at the end of the blade (like what occurs at the wing tip of an aircraft), due to exiting of tangential flows to the bearing surface along the axis. The particular profile with curling also allows a high “tip speed ratio” (TSR) value to be obtained, indicated previously, since there is no stall point and no loss of lift occurs. This leads to an efficiency which is considerably higher than for conventional systems and therefore leads to a very high value of the power coefficient Cp initially mentioned, with noise levels during operation always reduced to a minimum, in terms of both dB and the frequencies produced.

The combination of all the profile characteristics listed above allows the blade according to the present invention to be adapted to all wind conditions, since, on the one hand, it amplifies the effects thereof due to the shape of the leading base and to the laminar profile forming it, while, on the other, it prevents propulsive dissipation and loss of thrust at the tip, avoiding, through curling of the profile, the formation of counter-productive vortices.

According to a possible embodiment of the invention, the wind turbine blade may be formed of materials with high plasticity, and therefore capable of adapting the original "idle" structure to the wind conditions at that time and in that place.
Any wind turbine blade, when subjected to fluid-dynamic pressure, flexes elastically along its longitudinal axis with a curve conditional upon both its structure and the material of which it is made, varying its energy performance.
The structure of the blade according to the invention has been designed to deform to a minimum extent at the base, to a greater extent in the middle-high section and once again to a minimum extent at the end, in order to exploit the disturbed flow typical of windiness to the maximum. When the blade is subjected to a fluid-dynamic pressure, it performs a longitudinal angular rotational flexure in the area between half and 3/4 of its longitudinal axis, adapting to the streamlined pressure of the tip and the moment (Fig. 3).
Elastic deformation of said blade, maximum if made of variously plastic materials or minimum if made of rigid monolithic materials, is affected principally by its geometrical structure and indicated by the theoretical crossing sections of the streamlined flow shown in Figs. 3a, 3b, 3c.

This means that when a propeller formed of several blades as described here is hit by aerodynamic an axial laminar flow to the turbine and higher than 1 m/s, it starts rotating, and when the flow reaches a certain intensity, it forces each single blade, independently of the others, to perform a rotational flexure towards the extrados, with localised plastic deformation in the median part of its extension, involving only minimally both the lower and the upper part. It is important to emphasise that each blade of the system is independent of the thrust of the others and the start of motion will therefore be possible as soon as one single blade is hit by a frontal flow, even if this is the only one which crosses the front of the rotor.

The propeller does, in fact, start to rotate with aerodynamic streamlined flow of 1 m/s and up to 5 m/s, but the blade does not suffer appreciable deformations (Fig.3, 3a), while from 5 to 10 m/s it flexes considerably towards a median point (Fig.3, 3b), and from 10 to 15 m/s it flexes further to reach the maximum operating deformation (Fig.3, 3c). The end of the blade rotates progressively from the minimum position to the intermediate position with an angular flexure of the intermediate part of 20°, along the chord longitudinal axis, and ends by reaching the maximum position with an angular flexure of around a further 20°.
This is demonstrated in the specific example of figure 4, where, according to a possible embodiment, it is indicated that, in the presence of fluid-dynamic currents, the longitudinal axis of the blade flexes progressively towards the rotor axis which, starting from 0° in idle conditions or at low speed (Fig. 4a), progressively reaches 11° at average speeds (Fig. 4b), then further increases its angle by another 11° at the highest speeds (Fig. 4c).

Simultaneously, the semi-apical curling of the blade, acting as a flow spoiler, forces angular rotation of the blade with respect to the rotor axis, increasing by 21° in idle conditions or at low speeds (Fig. 4a), by a further 20° at average speeds (Fig. 4b), then further increasing its angle by another 19° at the highest speeds (Fig. 4c).

The blade may be “elastic”, if made of variously plastic composite materials, or “stiff”, or less elastic, if made of minimally plastic or completely non-plastic monolithic materials. The general structure, despite maintaining the longitudinal profile dimensions and curves, both two-dimensional and three-dimensional, may have both a radial laminar profile section and a flat/curved radial profile section. The flat/curved radial profile section is more economical and the most suitable in the presence of minimally disturbed or undisturbed linear flows, preferably intubated, both in a receiving and propulsive function, despite the inevitable penalisation of development of the energy curve caused by the different stall speed.

A possible loss of efficiency is compensated, in any case, by no reduction in the area swept by the propeller which, starting with a nominal diameter of Ø mm. 1000 (Fig. 4a) in idle conditions, is reduced, with "elastic" rotational flexure, to Ø mm. 982 (Fig. 4b, -1.8%) at average speeds, and to Ø mm. 950 (Fig. 4c, -5%) at the highest speeds.
All the numbers indicated in the present figures are in millimetres.

Flexure of the upper part of the blade, adapting to the wind speed, lengthens and re-directs the crossing section of the streamlined flow and therefore increases the aerodynamic efficiency and raises the stall point, thus avoiding or limiting to a maximum detachment of the limit layer, with optimisation of energy performance and a reduction of noise levels.

In order to guarantee operation as indicated above, the blade must have a structure which may be stiff in certain areas and elastic in others, and therefore be made of a material which is plastic (Fig.5, 5a), elastic (Fig.5, 5b) and stiff (Fig.5, 5c).
With this configuration, the blade is decisively heavier than others of the same dimensions, but even if the weight of a complete propeller bears for around 1/3 on the weight of the complete turbine, it gives the propeller rotating in a disturbed environment an inertia which regulates its operation and a gyroscopic effect which amortises the fluttering of the entire turbine.

A wind turbine blade, as described above, has its optimal composition using 6 elements, anchored to a hub careened by a rotor nose, for a propeller with a disc having a maximum diameter (Ø) of mm. 1000 (Fig.1, 1a), all fitted directly onto the electric motor shaft, and in the total absence of epicycloid multipliers.
A wind turbine blade thus configured is able to obtain the energy results described in the table in figure10, where a comparison is made on the basis of the power supplied, with the system in the prior art called Air X 400, which has similar dimensions and uses. As may be seen from the value in Watt with wind conditions of 5 - 7 m/s (typical conditions), performance of the system according to the present invention is double.

From a structural viewpoint, the blade according to the present invention is innovative because:

- all the materials used for the blade, and also the rotor structure, are designed also to operate in the most hostile land environments, such as the Arctic, in tropical or desert environments, and therefore with extreme thermal excursions, and also in a marine environment;
- all the materials are designed to operate, with stable energy performance and without maintenance, for many years;
- the outer structure of the blade (Fig.5, 5a) is designed, preferably but not necessarily, in plastic material to resist light collisions and therefore to prevent, or at least reduce to a minimum, static or dynamic adhesion of any foreign body (animal, vegetable or inert) and to limit any surface abrasions, which could alter the aerodynamics and balancing of the blade, with an inevitable reduction of performance;
- the inner structure of the blade (Fig.5, 5b-5c) is designed in plastic and stiff material to resist heavy collisions, without deforming permanently, such as impacts with birds, or other objects carried by the wind, or in the presence of particularly adverse wind conditions.

From a functional viewpoint, the blade according to the present invention is innovative because:

- it allows a much greater quantity of electricity to be generated, in the same wind conditions, than other electric turbines with rotors of the same dimensions (Ø mm. 1000) or even with slightly large ones;
- the greatest amount of electricity is generated particularly at low and medium speeds, and at a lower number of revolutions (rpm) than other turbines, also due to independent flexure of each single blade with respect to the others, adapting to disturbed intensity and directions of the flow:
- the outer shape of the blade, the particular profile and the material used limit the noise levels of the rotor to the extent that it is indistinguishable from the noise produced by the streamlined flow, particularly at the highest speeds;

- the rotor diameter of mm. 1000, combined with the entire structure height of mm. 1500, allows its legal use (in many countries) for residential, general environmental and marine craft, adapting it to regulations governing radio-television structures.

The blade according to the present invention has been described, according to a preferred embodiment, as characterised by a particular NACA section which proved to be particularly advantageous. However, the blade maintains all the advantages indicated above even when the section is laminar.

The most significant example of what is indicated above is shown in figures 6 and 7, in an embodiment of the wind turbine blade which, despite maintaining both the perimeter and dimensional profile and alternated curving (or curling) of the tip (Fig. 6), has a laminar section with a flat profile obtainable by sheet processing, in metal, composite materials or plastic materials.

The wind turbine blade with a flat profile section, in order to avoid possible reduction of energy performance, noise emission and resilience, is characterised by slight arching of the median axis of the profile, progressively extending along the longitudinal axis of the blade (Fig. 7, 7b), and dynamic rounding of the leading and exit edges of the blade (Fig. 7, 7c). This variant is a simpler and more economical alternative for use in laminar or minimally disturbed flow conditions, typical of small or sheltered environments, in a fixed position and preferably intubated. A typical application may be, for example, on fans for interiors or cooling fans in general (computers, electrical household appliances in general, air conditioning systems, etc.).

It is also important to emphasise that the blade according to the present invention, due to its profile and performance characteristics, may have a propulsive application, such as a ship propeller blade, and therefore underwater use.

A wide range of construction materials may be used, as they do not limit the advantages of the present invention.

Distinguishing between the two principal embodiments, i.e. a streamlined section blade (NACA) and a laminar section blade, the following materials, for example, may be used:

Basic components of a streamlined profile blade:

- Blade base spigot of connection to the hub-shaft in milled-from-solid aluminium with subsequent hard anodising;
- longitudinal metal strut in milled or laser-cut steel sheet, bent at the base and sprung by galvanic tempering
- Streamlined profile outer coating in EPDM 90 Shore.A plastic material, preferably black, in over-injection of metal inserts

Basic components of a laminar profile blade:

- Base outer semi-shells in EPDM 90 Shore.A plastic material, preferably black, injection-moulded or thermoset by a thermoplastic polymer plate (shockproof ABS, etc.)

Laminar profile blade body formed of:

- light metal alloy sheet cutting (aluminium, avional, ergal, etc.) and subsequent drawing through moulding for stiffening and programmed deformation
- normal injection (or co-injection) of plastic materials
- more sophisticated procedures, such as stratification of composite materials (fibre glass, carbon fibre, etc.), para-aramid (nomex, etc.) or aramid (kevlar, etc.) materials.

CLAIMS

1. An adaptive profile blade for an axial flow rotor,
characterised in that:
- a leading base (1) is connected to a rotor nose, said base (1) having a cylindrical-hemispherical shape from which an airfoil profile (2) is extruded, the profile (2) being shaped so as to separate a streamlined flow into two currents (2a, 2b), of which the first (2a) runs along the rotor nose and the second (2b) acts on a tail (3) of the emerging profile;
- the longitudinal profile of the blade is in the form of a semi-arched catenary extending, on the intrados side, according to a curve (4) which is coplanar to the blade itself, while on the extrados side, at 3/4 of the extension of the blade towards the tip, said profile is characterised by the presence of a "V"-shaped undulation (5) between 20° and 30° which protrudes from the blade plane towards the intrados, with subsequent re-entry towards the extrados, and extending towards the intrados on a surface equal to 1/4-1/5 of the blade width, and wherein said undulation (5) is configured so as to generate a compression on the underlying streamlined layers (2c, 2d, 2e, 2f) towards the base (1) of the blade and to lead the overlying layers (2f, 2g) towards the airfoil tip along the median axis of the exit edge.

2. The wind turbine blade according to claim 1, characterised in that the section of the blade has a concave convex laminar profile, NACA 4317 (Xa), which extends with progressive scaled reduction of the section profile, from the base (1) to the tip, along the semi-arched catenary curved axis of its leading edge.

3. The wind turbine blade according to claim 1 or 2, characterised in that the blade structure is configured to flex progressively with a longitudinal rotational flexure of the blade in the direction of the streamlined flow (3a, 3b, 3c) at wind speeds between 5 m/s and 15 m/s.

4. The wind turbine blade according to claim 3, characterised in that said flexure occurs in the median area of its extension, minimally involving both the adjacent lower and upper areas (3, 3a-3b-3c).

5. The wind turbine blade according to claims 1 to 4, characterised by the upper half being configured to rotate progressively from a minimum position (4a) to an intermediate position (4b) with angular flexure of the intermediate part of 20°, along the chord longitudinal axis, and so to reach the maximum position (4c) with angular flexure of around a further 20°.

6. The wind turbine blade according to one of the previous claims, comprising a monolithic outer structure (5c) made of plastic material.

7. The wind turbine blade according to one of the previous claims, comprising an internal ribbing (5b) made of elastic material.

8. The wind turbine blade according to one of the previous claims, comprising an anchoring spigot (5c) in stiff material.

9. The wind turbine blade according to one of the previous claims, characterised in that the profile (2) of the blade has a laminar shape (6a).

10. A rotor formed of one or more blades according to one of claims 1 to 9.

11. A wind turbine machine formed of one or more rotors according to claim 10.

12. Use of a blade according to one of claims 1 to 9 for underwater propulsion.

FIG. 1

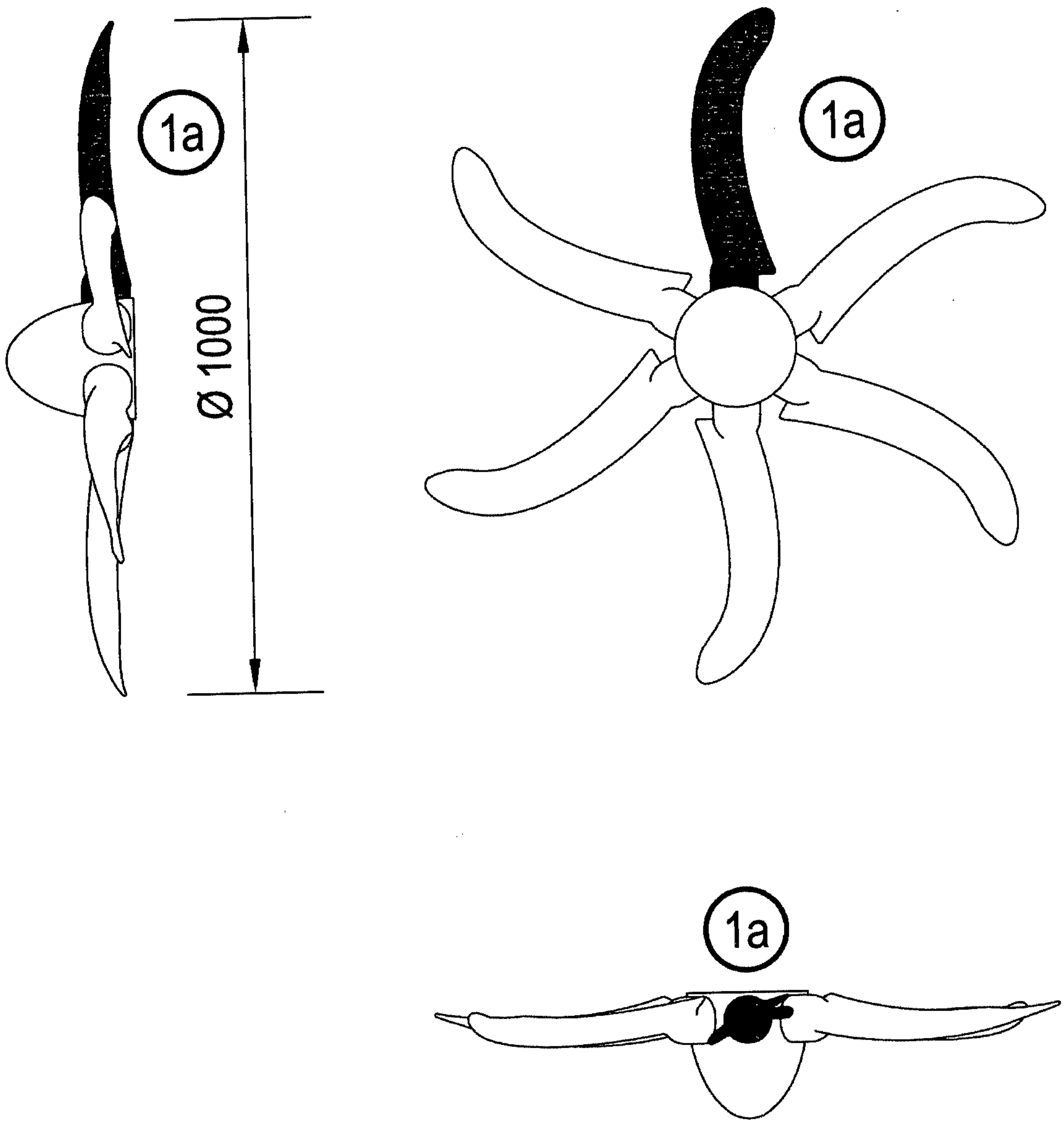


FIG. 2

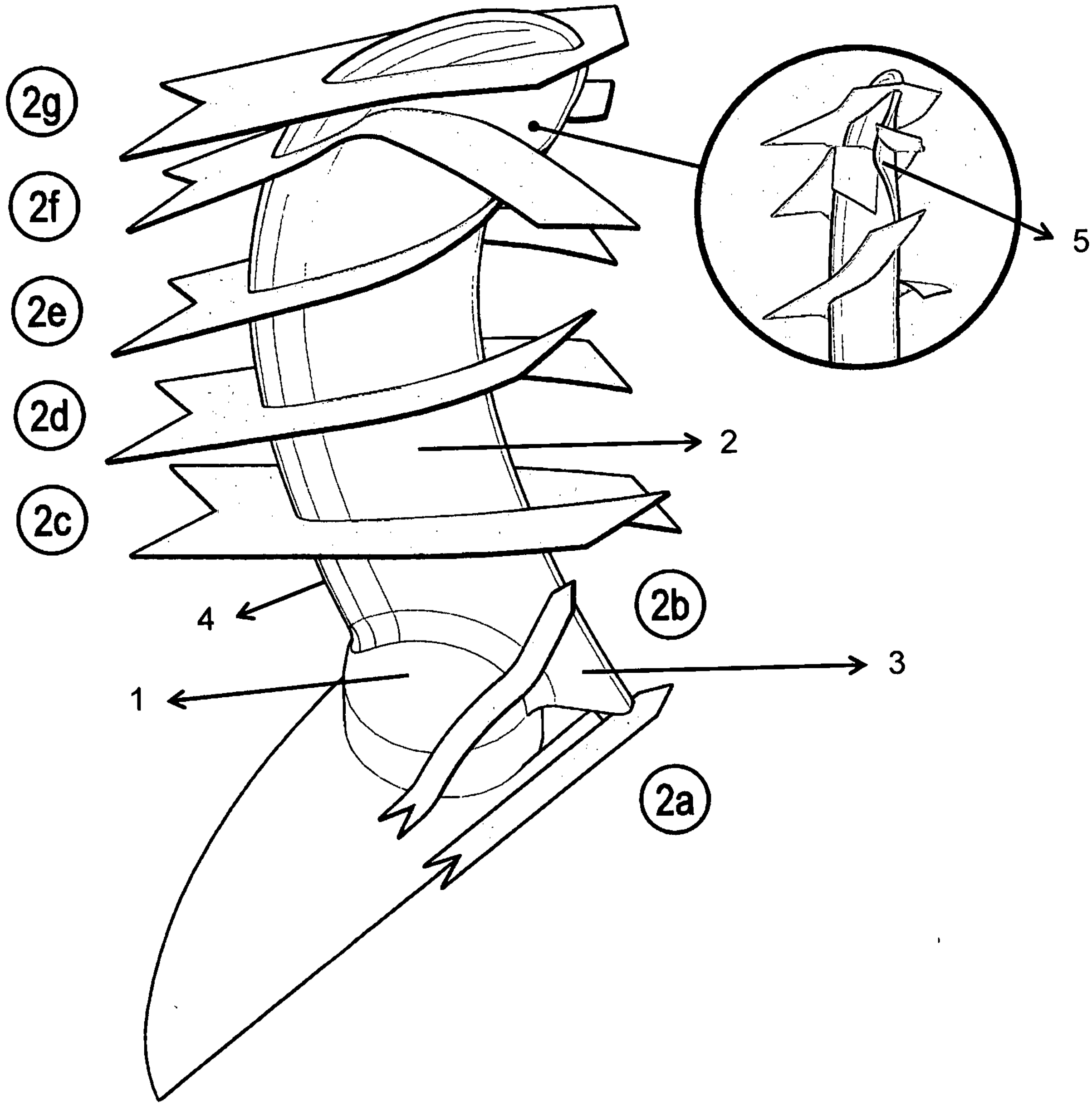


FIG. 2A

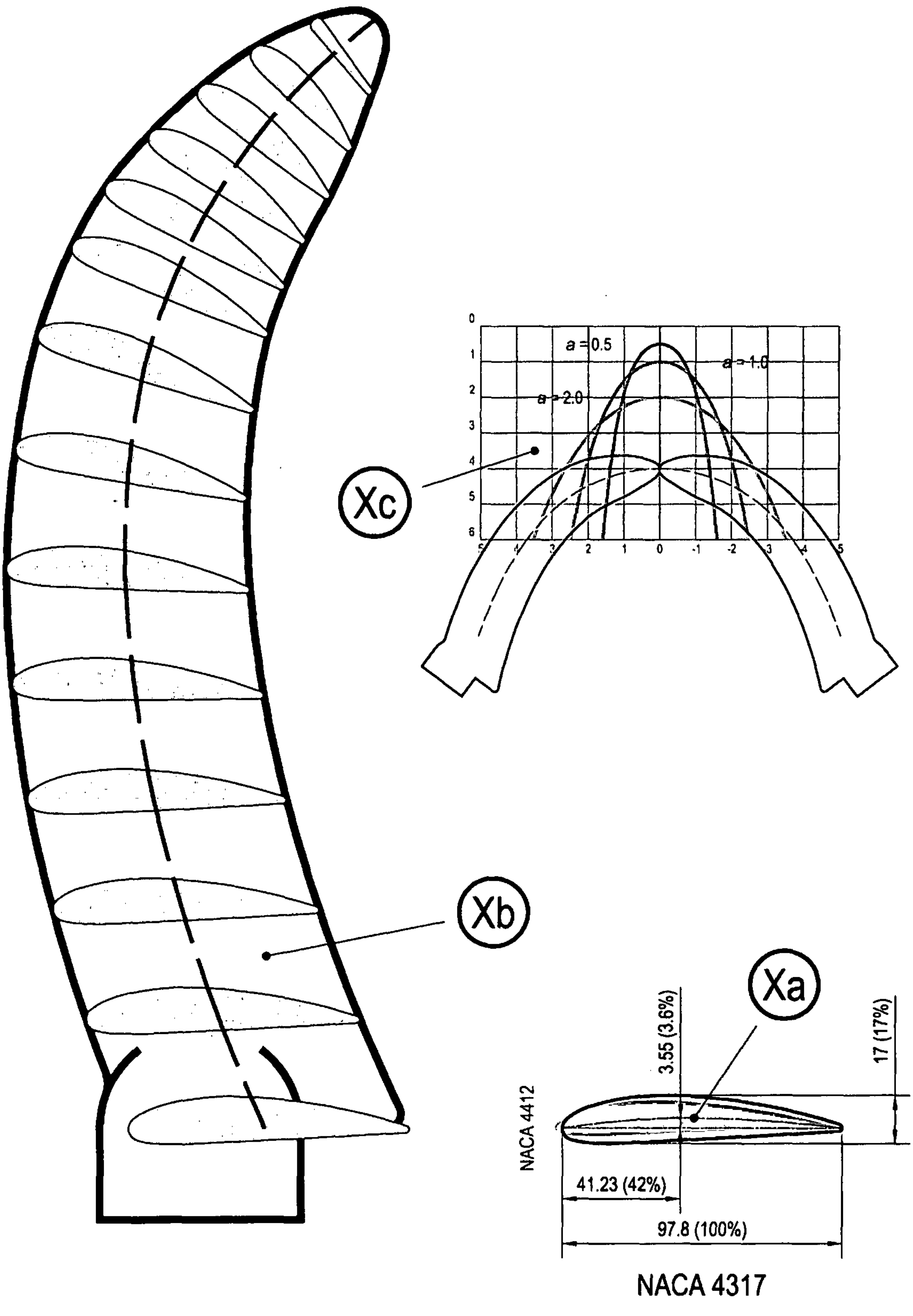

Xc
a = 0.5
a = 1.0
a = 2.0
Xb
Xa
3.55 (3.6%)
17 (17%)
NACA 4412
41.23 (42%)
97.8 (100%)
NACA 4317

FIG. 3

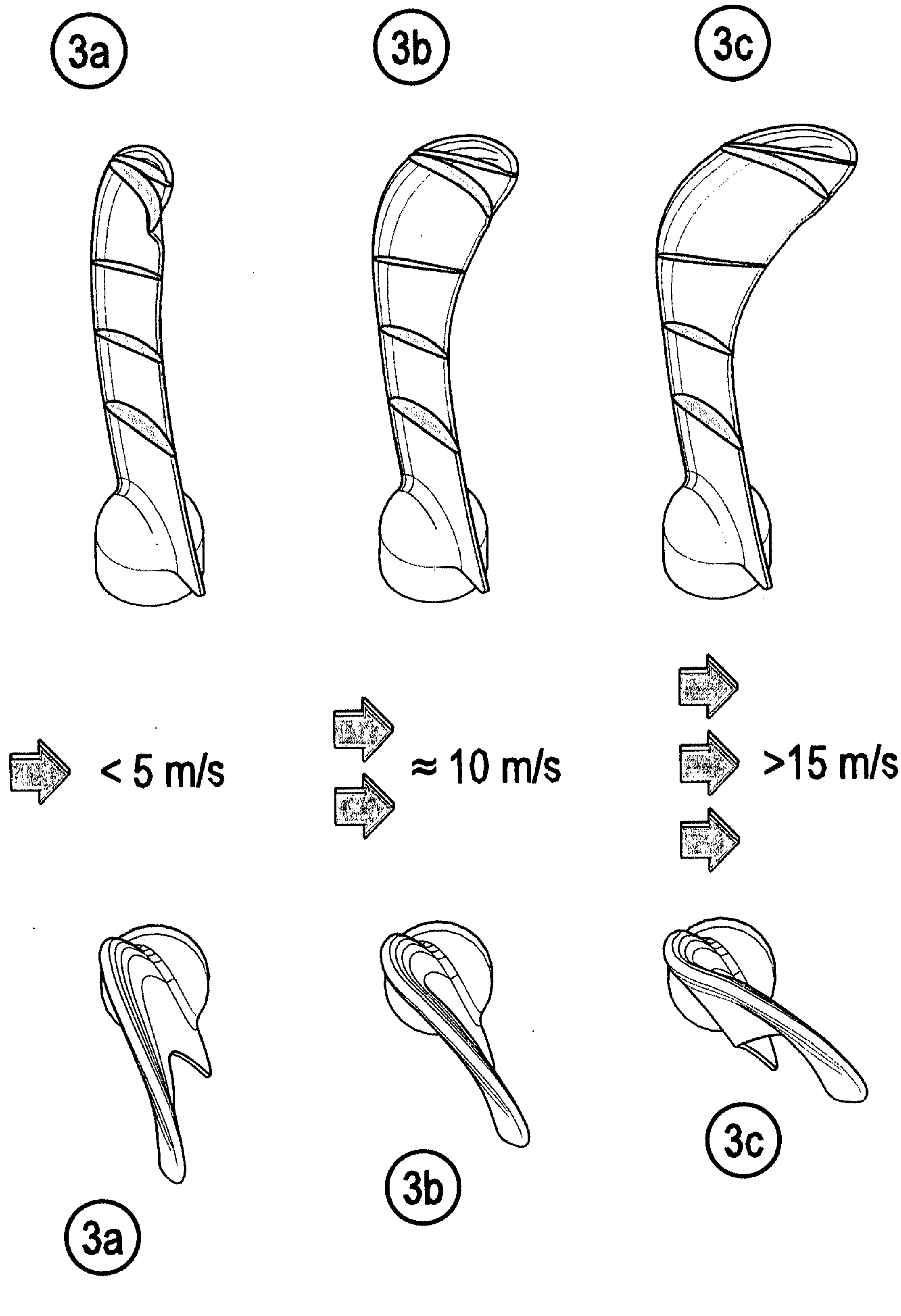


FIG. 4

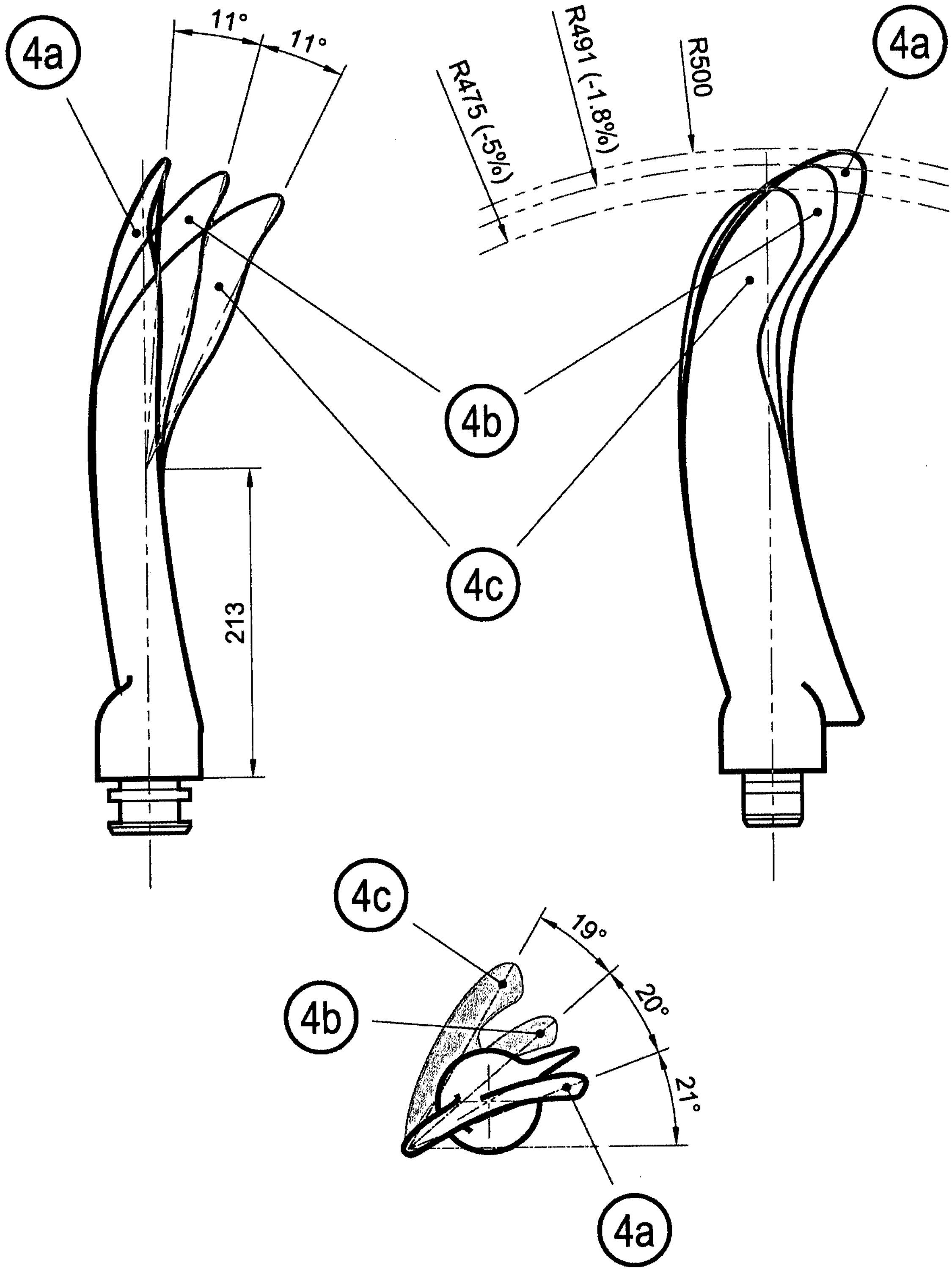


FIG. 5

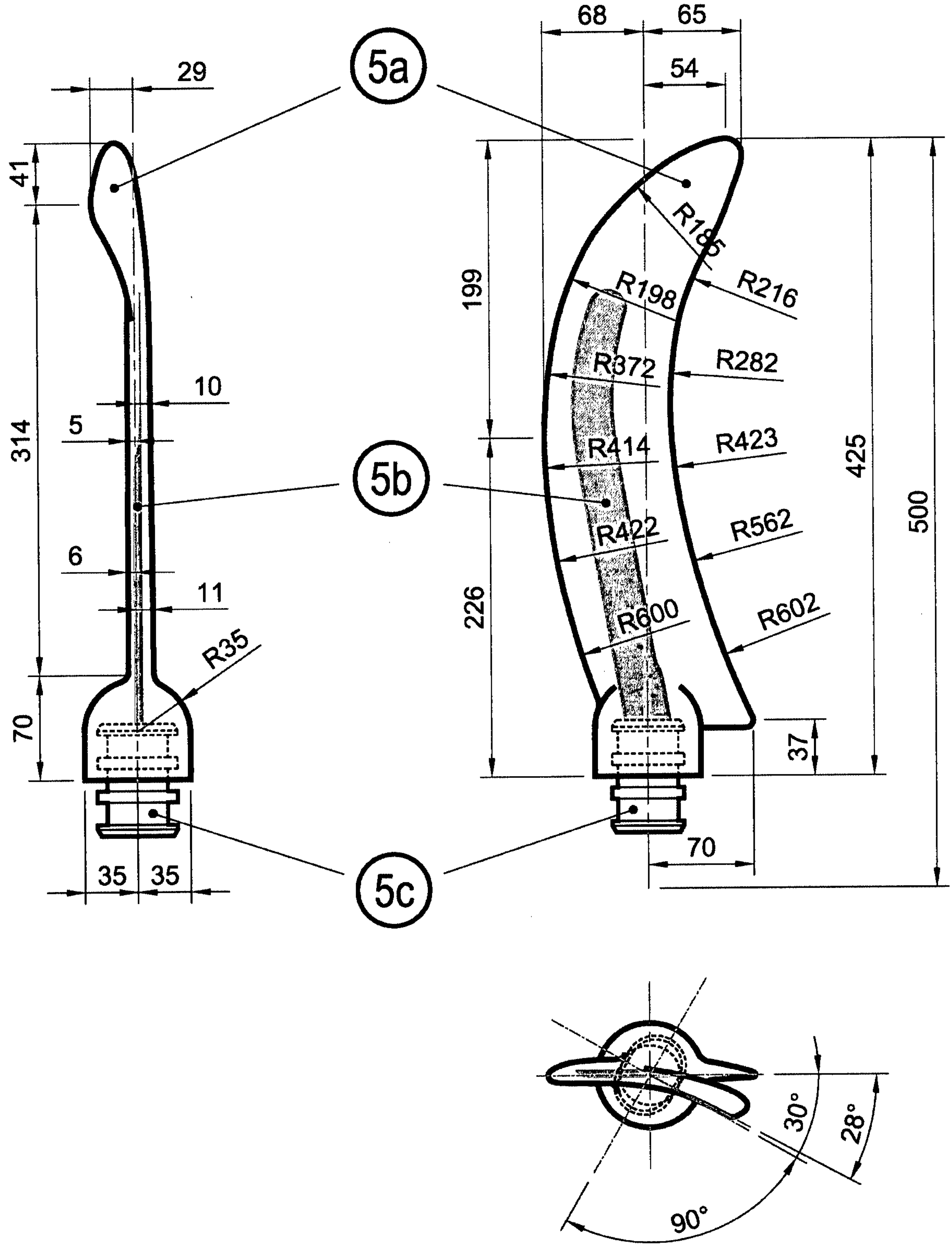

5a
5b
5c
29
41
314
70
10
5
6
11
R35
35
35
68
65
54
199
226
R186
R216
R198
R282
R372
R423
R414
R562
R422
R602
R600
425
500
37
70
30°
28°
90°

FIG. 6

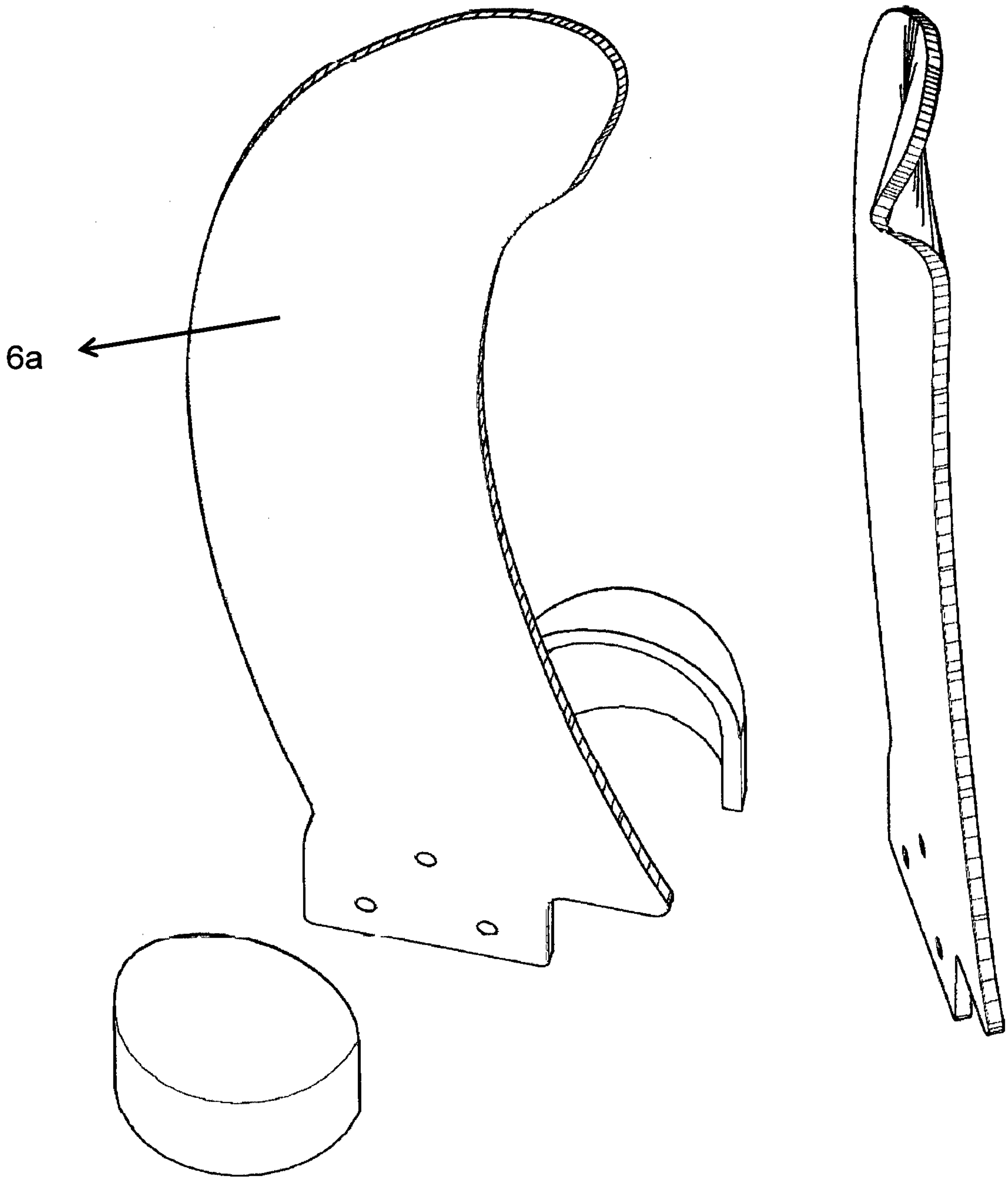
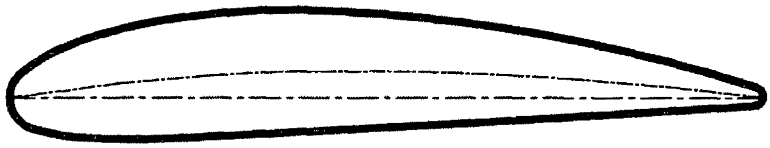


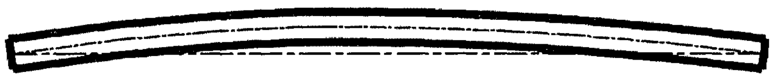
FIG. 7



NACA profile 4317

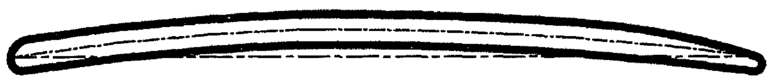
7a

Rectangular profile with
no arched axis and sharp edges



7b

Rectangular profile with
slight arched axis and sharp edges



7c

Rectangular profile with
slight progressively arched axis and
smooth edges

FIG. 8

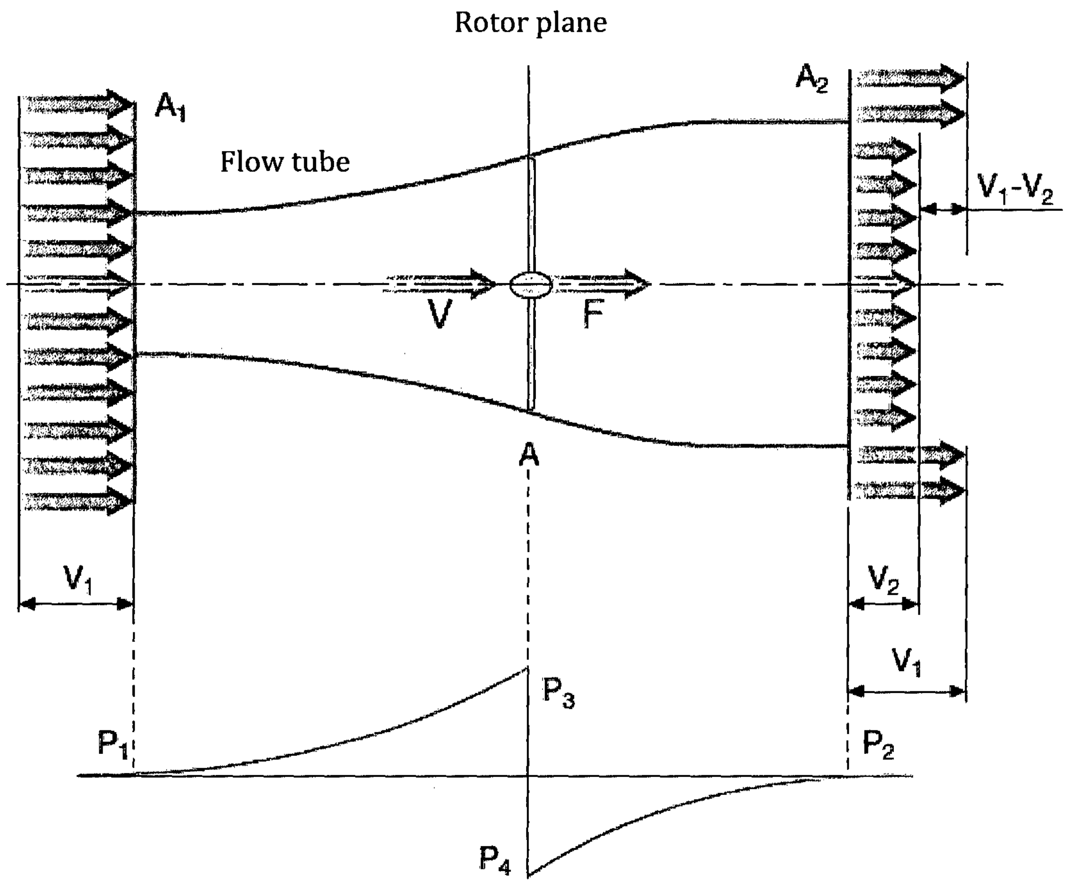

Rotor plane
A1
Flow tube
A2
V1-V2
V
F
A
V1
V2
V1
P3
P1
P2
P4

FIG. 9

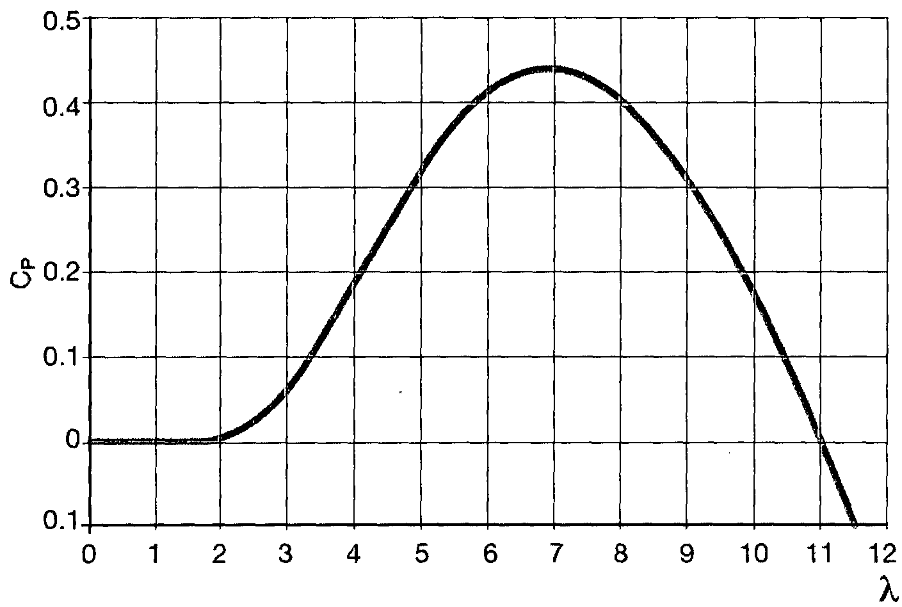
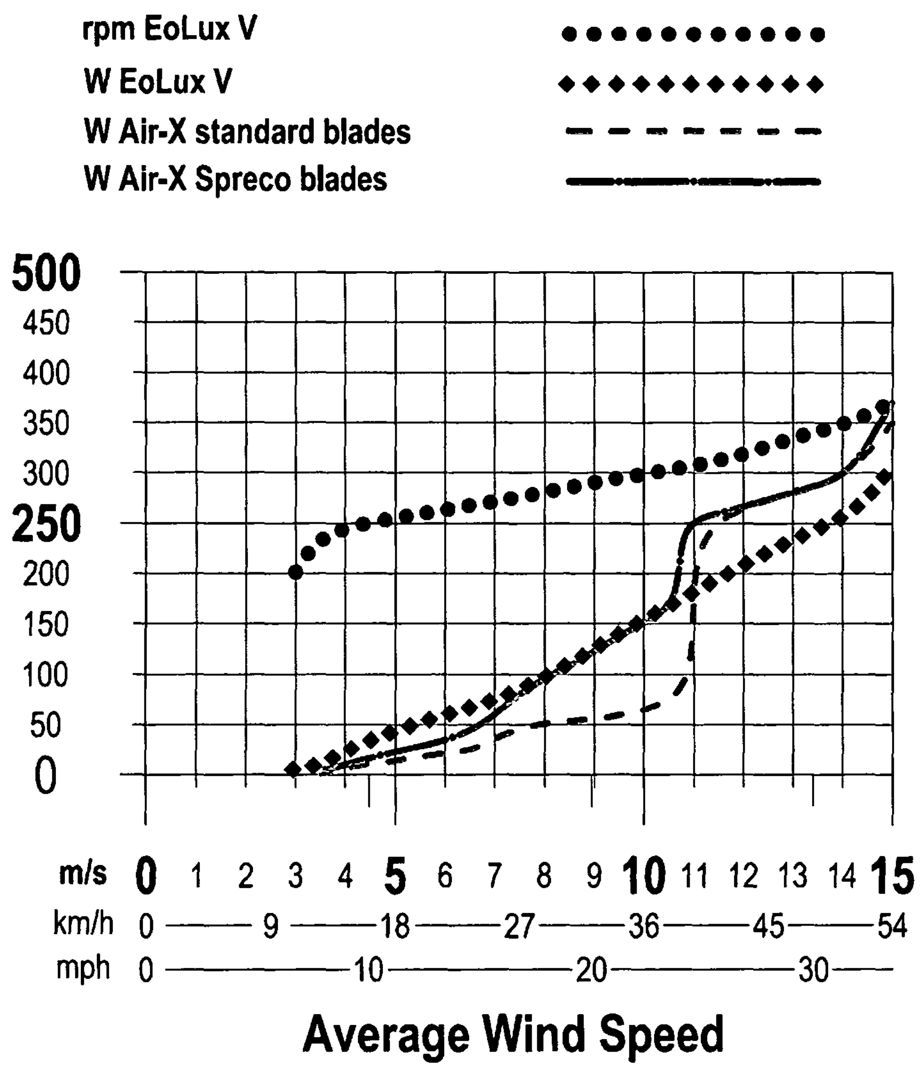
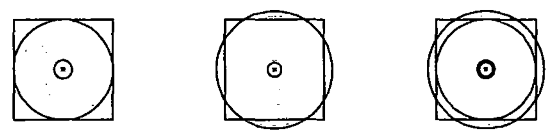

0.5
0.4
0.3
Cp 0.2
0.1
0
0.1
0 1 2 3 4 5 6 7 8 9 10 11 12
λ

FIG. 10

RPM / Power Curve - EoLux V Ø m 1.00 vs Power Curve - Air-X Ø m 1.17



m/s	rpm	W		
		EoLux V	Air-X standard blades	Air-X Spreco blades
3	204	7.60	-	-
4	247	24.16	6.71	10.00
5	258	45.15	13.83	22.74
6	266	61.06	21.21	34.42
7	275	76.51	35.54	59.74
8	284	97.88	50.64	94.97
9	293	126.14	55.39	122.96
10	302	155.45	64.70	151.42
11	310	182.70	170.00	250.00
12	322	209.36	264.22	266.59
13	337	234.80	280.22	281.13
14	352	258.21	300.00	300.00
15	374	307.61	350.00	370.00



EoLux V - Area mq. 0.754 71,15% | Air-X - Area mq. 1.0597 100% | EoLux/Air-X - Area mq. 0.3057 28,85%

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2015/051604

A. CLASSIFICATION OF SUBJECT MATTER
INV. F03D1/06
ADD. B63H1/12

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F03D F03B B64C B63H

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 2 270 312 A1 (PEM ENERGY OY [FI]) 5 January 2011 (2011-01-05) paragraphs [0002], [0005], [0008], [0012], [0013] figures 1,2,5 -----	1-5,9-12
X	DE 10 2006 043462 A1 (DEUTSCH ZENTR LUFT & RAUMFAHRT [DE]) 27 March 2008 (2008-03-27) paragraphs [0001], [0002], [0009], [0014] figure 3 -----	1-5,9-11
A	US 2010/329879 A1 (PRESZ JR WALTER M [US] ET AL) 30 December 2010 (2010-12-30) paragraphs [0008], [0009] figures 1-6B ----- -/--	1,3,4, 9-11

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
1 June 2015	09/06/2015

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Pasquet, Pierre

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Form PCT/ISA/210 (second sheet) (April 2005)

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2013/315746 A1 (HUANG ZAIMAN [CN] ET AL) 28 November 2013 (2013-11-28) paragraphs [0002], [0048] -----	1,3,4
A,P	WO 2015/016704 A1 (STICHTING ENERGIE [NL]) 5 February 2015 (2015-02-05) page 1, lines 4-8 page 6, lines 7-9 page 2, line 32 - page 3, line 7 figures 1, 2b -----	1,3,4, 9-11

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IB2015/051604

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 2270312 A1	05-01-2011	NONE	
DE 102006043462 A1	27-03-2008	NONE	
US 2010329879 A1	30-12-2010	CA 2763898 A1	09-12-2010
		EP 2438299 A2	11-04-2012
		US 2010329879 A1	30-12-2010
		WO 2010141720 A2	09-12-2010
US 2013315746 A1	28-11-2013	NONE	
WO 2015016704 A1	05-02-2015	NL 2011236 C	02-02-2015
		WO 2015016704 A1	05-02-2015