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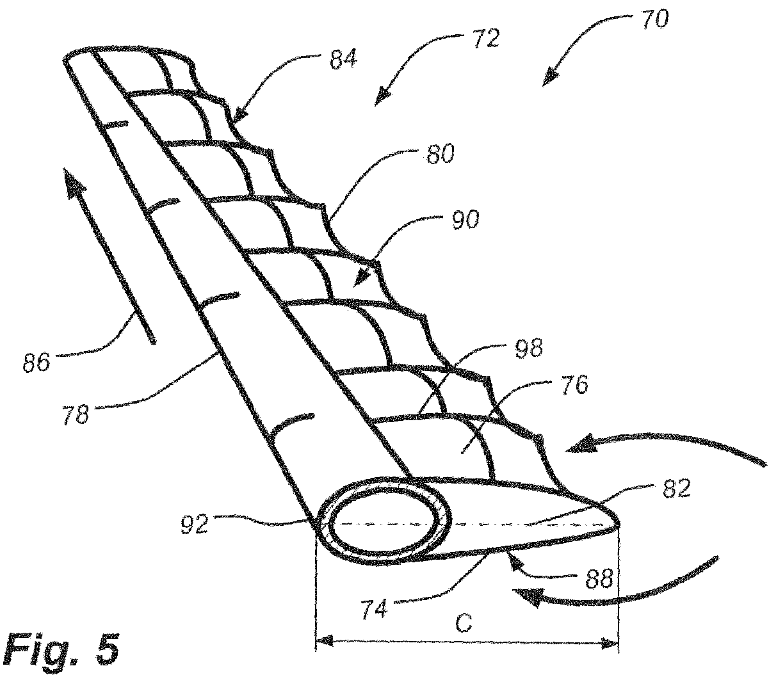

Fig. 5

(57) Abstract: The wind turbine blade (70) has an airfoil region (72) with a profiled shape comprising a pressure side (74) and a suction side (76) as well as a leading edge (78) and a trailing edge (80) between which a chord (82) extends. The blade (70) comprises at least one collapsible section (84) extending in the longitudinal direction (86) of the blade (70) and having a collapsible part (88) which is collapsible between a first, extended position, in which the airfoil has a first chord length (C) and its normal lift generating shape, and a second, collapsed position, in which the airfoil has a second, reduced chord length shorter than the first chord length (C) and a shape generating reduced lift compared to the lift generated in the first position of the collapsible part (88). Furthermore, a method of controlling a wind turbine is disclosed.

WO 2012/095478 A1

Wind turbine blade, wind turbine and method of controlling such

Technical Field

The present invention relates to a wind turbine blade for a rotor of a wind turbine having a substantially horizontal rotor shaft, the blade having a longitudinal direction and an airfoil region with a profiled shape comprising a pressure side and a suction side as well as a leading edge and a trailing edge, a chord extending between the leading edge and the trailing edge, and the profiled shape being adapted to generate a lift when being impacted by an incident airflow.

Background

Ideally, a wind turbine blade of the airfoil type is shaped similarly to the profile of an aeroplane wing, where the chord plane width of the wind turbine blade as well as the first derivative thereof increase continuously with decreasing distance from the hub. This results in the blade ideally being comparatively wide in the vicinity of the hub. This again results in problems when having to mount the wind turbine blade to the hub, and, moreover, this causes great loads during operation of the wind turbine blade, such as storm loads, due to the large surface area of the wind turbine blade.

Therefore, over the years, construction of wind turbine blades has developed towards a shape, where the wind turbine blade consists of a root region closest to the hub, an air-foil region comprising a lift-generating profile furthest away from the hub and a transition region between the root region and the airfoil region. The airfoil region has an ideal or almost ideal profiled contour shape with respect to generating lift, whereas the root region has a substantially circular cross-section, which reduces the storm loads and makes it easy and safe to mount the wind turbine blade to the hub. The root region diameter may advantageously be constant along the entire root region. Due to the circular cross-section, the root region does not contribute to the energy production of the wind turbine and, in fact, lowers this a little because of drag. As it is suggested by the name, the transition region has a shape gradually changing from the circular shape of the root region to the airfoil profile of the airfoil region. Typically, the width of the wind turbine blade in the transition region increases substantially linearly with increasing distance from the hub.

When the wind turbine blade is impacted by incident airflow, the profiled contour generates a lift. When the wind turbine blade is mounted on a wind turbine, the wind turbine hub begins to rotate due to the lift. By incident flow is meant the inflow conditions at a profiled contour section during normal use of the wind turbine blade, i.e. rotation on a wind turbine rotor. Thus, the incoming flow is the inflow formed by the resultant of the axial wind speed and the rotational component, as it is seen by the local section of the profiled contour.

As for instance wind turbine blades for wind turbines have become increasingly bigger in the course of time and may now be more than 60 meters long, the demand for optimised aerodynamic performance has increased. The wind turbine blades are designed to have an operational lifetime of at least 20 years. Therefore, even small changes to the overall performance of the wind turbine blade may accumulate over the lifetime of a wind turbine blade to a high increase in financial gains, which surpasses the additional manufacturing costs relating to such changes.

As the requirement for effectiveness of a wind turbine is increased, there is a need for increasing the effectiveness or performance of wind turbines or wind turbine blades.

The size of the chord is of importance to the performance of a wind turbine blade and in particular to the performance of the blade at different wind speeds. A blade having one chord length may for a relative profile perform optimally at one angle of attack at a given tip speed ratio, while another chord length may perform optimally at another angle of attack at yet another given tip speed ratio. This is, at least partly, attempted to be overcome by pitching and otherwise adapting the aerodynamic properties of the blades.

WO 2004/099608 A1 discloses a wind turbine blade including adjustable lift-regulating means in the form of at least one flexible flap arranged on or at the surface of the wind turbine blade, said lift-regulating means being provided with activating means by means of which they can be adjusted and thus alter the aerodynamic properties of the blade.

Disclosure of the Invention

The object of the present invention is to provide a wind turbine blade having improved capabilities in regard to adapting its aerodynamic properties to operational conditions.

In view of this object, the wind turbine blade comprises at least one collapsible section extending in the longitudinal direction of the blade and having a collapsible part which is collapsible between a first, extended position, in which the airfoil has a first chord length and its normal lift generating shape, and a second, collapsed position, in which the airfoil has a second, reduced chord length shorter than the first chord length and a shape generating reduced lift compared to the lift generated in the first position of the collapsible part.

Advantageously, the normal lift generating shape may have a substantially airfoil-shaped profile. Also advantageously, the at least one collapsible section may extend longitudinally from a position near or at a tip region of the blade to a position nearer a root region of the blade, wherein the blade optionally comprises a plurality of collapsible sections, which advantageously are juxtaposed in the longitudinal direction of the blade, and wherein the at least one collapsible section or plurality of sections extends along at least 10% of the airfoil region of the blade.

In this way, as a result of the collapsible part being collapsible between an extended position and a collapsed position, the lift generating area of the airfoil of the wind turbine blade may be altered to an extent that has not before been possible with prior art wind turbine blades. In fact, by means of the collapsible part, a basis lift at a design point of the blade may be reduced dramatically, to the point at which practically or substantially no lift is generated, whereby a practically or substantially solely load bearing part of the blade is present. Thereby, it may for instance be possible to decrease the lift of a section near the tip of the blade, whereby longer blades can be used, and/or the blade can be used at higher wind speeds compared to what was otherwise possible. Furthermore, pitch regulation of the blades may even be omitted.

Accordingly, the at least one collapsible section may extend longitudinally from a position near or at a tip end of the blade to a position nearer a root of the blade. Thus, the at least collapsible section may be arranged at an outboard section of the blade. The blade may comprise a plurality of collapsible sections, which advantageously may be juxtaposed in the longitudinal direction of the blade. In an advantageous embodiment, the at least one collapsible section (or plurality of sections) extend along at least 20% of the airfoil region of the blade, or even along at least 30%, 40%, 50%, 60%, 70%, or 75% of the airfoil region of the blade.

In another embodiment, the at least one collapsible section (or plurality of sections) extends along maximum 90%, 80%, 70%, 60%, 50%, 40% or even 30% of the airfoil region of the blade.

In an advantageous embodiment, the wind turbine blade has a length of at least 30 metres, or even at least 40, 50, or 60 metres.

In another advantageous embodiment, the at least one collapsible part at a first position has a cross-section with a first profile having a substantially pointed trailing edge, and at a second position has a cross-section with a second profile, which corresponds to a substantially truncated profile of the first profile, i.e. with a blunt trailing edge having a given thickness.

In an embodiment, the second, reduced chord length is shorter than 80%, 75%, 70%, 60%, or 1/2 (or 50%) of the first chord length, advantageously shorter than 1/3 (or 33.3%) and more advantageously shorter than 1/4 (or 25%) of the first chord length.

In one embodiment, the collapsible part is attached to a spar or a web of the wind turbine blade. Thereby, a part of the blade may be formed conventionally with a spar and a blade skin, or alternatively with a load carrying structure, such as a main laminate, integrated in a blade shell, and one or more webs connected between for instance a suction side main laminate and a pressure side main laminated.

In an embodiment, the collapsible part is adapted to reduce the lift of the airfoil of the wind turbine blade with at least 50%, preferably at least 60%, and most preferred at least 70% of its maximum lift.

In a structurally advantageous embodiment, the leading edge of the at least one collapsible section is formed by a longitudinal structure of relatively fixed cross-sectional shape, and the trailing edge is retractable in the direction towards the leading edge by means of the collapsible part. Thereby, the collapsible part may be formed as a part extending only behind the leading edge.

In a structurally advantageous embodiment, the leading edge of the at least one collapsible section is formed by a longitudinal structure of relatively fixed cross-sectional shape provided with a number of laterally extending support arms adapted to support the collapsible part in the extended position of the collapsible part.

In an embodiment, the laterally extending support arms are hinged to the longitudinal structure of relatively fixed cross-sectional shape so that they may swing to a collapsed position when the collapsible part is collapsed. Thereby, they may support the collapsible part in its extended position without generating lift in the collapsed position of the collapsible part.

In an embodiment, the laterally extending support arms have the form of telescopic rods so that they may collapse to a short length when the collapsible part is collapsed. Thereby, they may support the collapsible part in its extended position without generating lift in the collapsed position of the collapsible part.

In an embodiment, the collapsible part is formed by means of an inflatable structure. Thereby, complicated actuating systems comprising actuators and/or actuating rods may be avoided. The inflatable structure may simply be inflated by means of compressed air fed through pipes arranged in the blades. The inflatable structure may even be inflated by means of the natural air pressure present on the pressure side of the blade in operation, for instance in the form of a partly open inflatable structure like a parachute.

In an embodiment, an air intake opening is located at the pressure side of the profiled shape of the airfoil region and communicates with the interior of the inflatable structure. The inflatable structure may thereby be inflated by means of the natural air pressure present on the pressure side of the blade in operation. This may for instance be arranged in the same way it is done in the airfoil of a paraglider, whereby the leading edge of the airfoil has openings through which air may inflate the airfoil. From the introduction, it is clear that this embodiment as well as the later described embodiments may also be provided for blades, where the collapsible part is not positioned at or near the tip, e.g. around the shoulder of the blade, where the local chord length is largest.

In an embodiment, an inlet control valve is adapted to open or close an airflow connection from the air intake opening to the interior of the inflatable structure. Thereby, the inflation of the inflatable structure may be controlled, for instance by means of a computer system.

In an embodiment, an outlet control valve is adapted to open or close an airflow connection from the interior of the inflatable structure to an air outlet opening at the suction side of the profiled shape of the airfoil region. Thereby, the deflation of the inflatable structure may be controlled, for instance by means of a computer system.

In an embodiment, the collapsible part is formed by means of a retractable cloth-like structure, such as a sailcloth material.

In an embodiment, the retractable cloth-like structure is retractable in the direction from the trailing edge towards the leading edge.

In an embodiment, the laterally extending support arms hinged to the longitudinal structure or the laterally extending support arms in the form of telescopic rods are used to extend and retract the retractable cloth-like structure between its retracted and extended positions, preferably by having their outermost ends fixed to the retractable cloth-like structure.

In an embodiment, the retractable cloth-like structure is retractable in the longitudinal direction of the blade, preferably from a position at a tip region to a position nearer or even at a root region. Thereby, it is for instance possible to decrease the lift of an outboard or outmost part of the blade in order to minimise the load and be able to use the wind turbine blade at higher wind speeds. If the wind speed increases even further, the lift may continuously be reduced further and further from a position near the tip towards a position closer to or near the root.

In an embodiment, the collapsible part has the form of a roller blind.

In an embodiment, the collapsible part has the form of a bellows-type folding blind.

In an embodiment, the blade comprises a plurality of collapsible sections distributed in the longitudinal direction of the blade, the collapsible parts of the respective collapsible sections being separately controllable. Thereby, it is for instance possible to decrease the lift of an outboard or outmost collapsible section of the blade in order to minimise loading and be able to use the wind turbine blade at higher wind speeds. If the wind speed increases even further, the lift of more and more collapsible sections may be reduced, e.g. sequentially from a collapsible section near the tip towards a collapsible section closer to or near the root.

In an embodiment, the wind turbine blade comprises a flow sensor configured to determine inflow conditions at the wind turbine blade or at an upwind direction of the wind turbine blade. Thereby, the wind turbine blade may be prepared for automatic adaption to extremely different wind conditions.

In an embodiment, the wind turbine blade comprises a control unit configured to control the operation of the collapsible part of the at least one collapsible section in response to inflow condition information from a flow sensor as described above and/or an external source providing information regarding the wind and/or flow conditions at the wind turbine blade. Thereby, the operation of a wind turbine may automatically be adapted to extremely different wind conditions.

In an embodiment, the wind turbine blade is in its longitudinal direction divided into a root region with a substantially circular or elliptical shape closest to a root end of the blade, an airfoil region with a lift generating shape nearest a tip end of the blade, and preferably a transition region between the root region and the airfoil region, the transition region having a shape gradually changing in the radial direction from the circular or elliptical shape of the root region to the lift generating shape of the airfoil region, and the at least one collapsible section having a collapsible part being located in the airfoil region.

The present invention further relates to a wind turbine comprising a hub connected to a rotor shaft and a number, preferably two or three, wind turbine blades according to the invention as described above, extending in a substantially radial direction from the hub, wherein the wind turbine blades are fastened at a fixed pitch angle on the hub. Thereby, pitch bearings may be omitted, and the lift generation of the blades may be controlled solely by means of the collapsible parts of the blades.

The present invention further relates to a wind turbine comprising a tower having a first end and an opposite second end, the second end connecting the tower to the ground or a foundation, a nacelle arranged at the first end of the tower and having a substantially horizontal rotor shaft, a hub connected to the rotor shaft, a number, preferably two or three, wind turbine blades as described above, extending in a substantially radial direction from the hub, a flow sensor configured to determine inflow conditions at the wind turbine blade or at an upwind direction of the wind turbine blade, and a control unit configured to control the operation of the collapsible part of the at least one collapsible section of each blade in response to inflow condition information from the flow sensor and/or an external source providing information regarding the wind and/or flow conditions at the wind turbine blade. Thereby, the operation of a wind turbine may automatically be adapted to extremely different wind conditions.

The present invention further relates to a method of controlling a wind turbine comprising at least two, preferably three, wind turbine blades as described above, whereby the position of the collapsible part of the at least one collapsible section of each blade is controlled in order to vary the chord length of the airfoil of the collapsible section in order to vary the lift of the collapsible section in response to operational conditions of the wind turbine, such as inflow properties or load conditions. Thereby, the above described features may be obtained.

Brief Description of the Drawings

The invention will now be explained in more detail below by means of examples of embodiments with reference to the very schematic drawing, in which

Fig. 1 is a perspective view of a conventional wind turbine,

Fig. 2 is a perspective view of a conventional wind turbine blade,

Fig. 3 is a cross-sectional view of a conventional airfoil profile,

Fig. 4 is a top view and a side view, respectively, of a conventional wind turbine blade,

Figs. 5 is a perspective view of a part of an embodiment of a wind turbine blade according to the invention, in an expanded state,

Figs. 6 is a perspective view corresponding to that shown in Fig. 5, whereby the wind turbine blade is in a collapsed state,

Figs. 7A, 7B and 7C are plan views of another embodiment of a wind turbine blade according to the invention, whereby the wind turbine blade is shown in an expanded state, a partly collapsed state and an even more collapsed state, respectively, Figs. 8A, 8B and 8C are plan views of another embodiment of a wind turbine blade according to the invention, whereby the wind turbine blade is shown in an expanded state, a partly collapsed state and an even more collapsed state, respectively,

Fig. 9 is a transversal cross-section through an embodiment of the wind turbine blade of the type shown in Figs. 5 and 6,

Fig. 10 is a transversal cross-section through a further development of the embodiment of the wind turbine blade shown in Fig. 9,

Figs. 11 and 12 show transversal cross-sections through yet other embodiments of the wind turbine blade according to the invention.

Detailed Description of the Invention

Fig. 1 illustrates a conventional modern upwind wind turbine according to the so-called "Danish concept" with a tower 4, a nacelle 6 and a rotor with a substantially horizontal rotor shaft. The rotor includes a hub 8 and three blades 10 extending radially from the hub 8, each having a blade root 16 nearest the hub and a blade tip 14 furthest from the hub 8. The rotor has a radius denoted R.

Fig. 2 shows a view of a wind turbine blade 10. The wind turbine blade 10 has the shape of a conventional wind turbine blade and comprises a root region 30 closest to the hub, a profiled or an airfoil region 34 furthest away from the hub and a transition region 32 between the root region 30 and the airfoil region 34. The blade 10 comprises a leading edge 18 facing the direction of rotation of the blade 10, when the blade is mounted on the hub, and a trailing edge 20 facing the opposite direction of the leading edge 18.

The airfoil region 34 (also called the profiled region) has an ideal or almost ideal blade shape with respect to generating lift, whereas the root region 30 due to structural considerations has a substantially circular or elliptical cross-section, which for instance makes it easier and safer to mount the blade 10 to the hub. The diameter (or the chord) of the root region 30 may be constant along the entire root area 30.

The transition region 32 has a transitional profile gradually changing from the circular or elliptical shape of the root region 30 to the airfoil profile of the airfoil region 34. The chord length of the transition region 32 typically increases with increasing distance r from the hub. The airfoil region 34 has an airfoil profile with a chord extending between the leading edge 18 and the trailing edge 20 of the blade 10. The width of the chord decreases with increasing distance r from the hub.

A shoulder 40 of the blade 10 is defined as the position, where the blade 10 has its largest chord length. The shoulder 40 is typically provided at the boundary between the transition region 32 and the airfoil region 34.

It should be noted that the chords of different sections of the blade normally do not lie in a common plane, since the blade may be twisted and/or curved (i.e. pre-bent), thus providing the chord plane with a correspondingly twisted and/or curved course, this being most often the case in order to compensate for the local velocity of the blade being dependent on the radius from the hub.

Figs. 3 and 4 depict parameters, which in the following are used to explain the geometry of a wind turbine blade.

Fig. 3 shows a view of an airfoil profile 50 of a typical blade of a wind turbine depicted with the various parameters, which are typically used to define the geometrical shape of an airfoil. The airfoil profile 50 has a pressure side 52 and a suction side 54, which during use – i.e. during rotation of the rotor – normally face towards the windward (or upwind) side and the leeward (or downwind) side, respectively. The airfoil 50 has a chord 60 with a chord length c extending between a leading edge 56 and a trailing edge 58 of the blade. The airfoil 50 has a thickness t, which is defined as the distance between the pressure side 52 and the suction side 54. The thickness t of the airfoil varies along the chord 60. The deviation from a symmetrical profile is given by a camber line 62, which is a median line through the airfoil profile 50. The median line can be found by drawing inscribed circles from the leading edge 56 to the trailing edge 58. The median line follows the centres of these inscribed circles and the deviation or distance from the chord 60 is called the camber f. The asymmetry can also be defined by use of parameters called the upper camber (or suction side camber) and lower camber (or pressure side camber), which are defined as the distances from the chord 60 and the suction side 54 and pressure side 52, respectively.

Airfoil profiles are often characterised by the following parameters: the chord length c, the maximum camber f, the position d_f of the maximum camber f, the maximum airfoil thickness t, which is the largest diameter of the inscribed circles along the median camber line 62, the position d_t of the maximum thickness t, and a nose radius (not shown). These parameters are typically defined as ratios to the chord length c. Thus, a local relative blade thickness t/c is given as the ratio between the local maximum thickness t and the local chord length c. Further, the position d_p of the maximum pressure side camber may be used as a design parameter, and of course also the position of the maximum suction side camber.

Fig. 4 shows other geometric parameters of the blade. The blade has a total blade length L. As shown in Fig. 3, the root end is located at position r = 0, and the tip end located at r = L. The shoulder 40 of the blade is located at a position $r = L_w$, and has a shoulder width W, which equals the chord length at the shoulder 40. The diameter of the root is defined as D. The curvature of the trailing edge of the blade in the transition region may be defined by two parameters, viz. a minimum outer curvature radius r_o and a minimum inner curvature radius r_i, which are defined as the minimum curvature radius of the trailing edge, seen from the outside (or behind the trailing edge), and the minimum curvature radius, seen from the inside (or in front of the trailing edge), respectively. Further, the blade is provided with a prebend, which is defined as Δy, which corresponds to the out of plane deflection from a pitch axis 22 of the blade.

Fig. 5 shows a perspective view of an outer part comprising an airfoil region 72 of a wind turbine blade 70 according to the invention, whereby a root region and a transition region have been cut away for illustrative purposes. The airfoil region 72 has a profiled shape comprising a pressure side 74 and a suction side 76 as well as a leading edge 78 and a trailing edge 80, and a chord 82 extends between the leading edge 78 and the trailing edge 80.

The wind turbine blade 70 comprises a collapsible section 84 extending in a longitudinal direction 86 of the blade and having a collapsible part 88 formed by means of an inflatable structure 90. The inflatable structure 90 may be formed of any material suitable to form an inflatable structure, such as sailcloth-type material or other material which is normally employed for the manufacture of inflatable structures, such as for instance a hot-air balloons, the airfoils of paragliders, parachutes or the like.

The collapsible part 88 is collapsible between a first, extended position as illustrated in Fig. 5, in which the airfoil has a first chord length C and its normal lift generating shape, and a second, collapsed position as illustrated in Fig. 6, in which the airfoil has a second, reduced chord length $C_{reduced}$ shorter than the first chord length and a shape generating reduced lift compared to the lift generated in the first position of the collapsible part. The second, reduced chord length $C_{reduced}$ may be shorter than 1/2, preferably shorter than 1/3 and most preferred shorter than 1/4 of the first chord length C. The collapsing motion is illustrated by means of arrows in Figs. 5 and 6.

In the embodiment illustrated in Figs. 5 and 6, the leading edge 78 of the collapsible section 84 is formed by a structure 92 of relatively fixed cross-sectional shape in the form of a tubular body having a certain wall thickness. The tubular body may be produced in the same way as a conventional wind turbine blade, for instance by means of one or two shell parts of a composite structure comprising a fibre reinforced matrix material. The fact that the structure 92 is of relatively fixed cross-sectional shape means that its cross-sectional shape may vary insignificantly compared to the variation that is possible of the cross-sectional shape of the collapsible part 88. On the other hand, of course, the structure 92 of relatively fixed cross-sectional shape may bend about an axis at right angles to the longitudinal direction 86 of the wind turbine blade 70, just as a conventional wind turbine blade may bend in this way. The fact that the structure 92 is of relatively fixed cross-sectional shape does, however, not exclude that the structure could be provided with movable elements, such as doors or the like for closing an opening through which the collapsible part 88 could be withdrawn into a cavity of the structure 92 when it is in its collapsed position.

As illustrated in Fig. 6, the inflatable structure 90 may be deflated, whereby the collapsible part 88 formed by the inflatable structure 90 is collapsed to its second, collapsed position, and whereby the trailing edge 80 is retracted in the direction towards the leading edge 78 by means of the collapsible part, as indicated by the arrows.

In the embodiment shown, the inflatable structure 90 is collapsed on the outside of the structure 92 of relatively fixed cross-sectional shape, whereby the inflatable structure 90 is carried in its deflated state on a backside 94 of the structure 92; said backside 94 being opposed to the leading edge 78. In this second, collapsed position, the trailing edge 80 is formed by the inflatable structure 90 in its deflated state. However, as mentioned above, the inflatable structure 90 may also be retractable into a cavity of the structure 92, whereby the trailing edge 80, in the collapsed position, may be formed for instance by a door closing said cavity. In fact, a person skilled in the art will understand that, by appropriate arrangement of the inflatable structure 90 in relation to such a cavity, the inflatable structure 90 may be retractable into the cavity by means of a vacuum formed inside the inflatable structure. The inflatable structure 90 may furthermore be formed of elastic material or may be surrounded by elastic strings or the like in order to compact the material of the inflatable structure 90 when the structure is deflated. It is also possible that the inflatable structure 90 may be compacted by means of movable elements, such as retractable rods, windable wires, swing arms or any other mechanism suitable for this purpose.

The inflatable structure 90 may especially have the form of a so-called ram-air airfoil, or blade parafoil, whereby a blade comprises two layers of fabric which are connected to internal supporting material so that a row of cells is formed. Internal walls formed by said supporting material dividing the cells from each other form valleys 98 on the outside of the airfoil in Fig. 5, as they restrict the expansion of the blade. In an embodiment, in operation of the blade, most of the cells are left open only at the leading edge, whereby incoming air (forming so-called ram-air pressure) keeps the blade inflated, thus maintaining its shape. When inflated, the cross-section of the blade has the typical aerofoil shape as shown in Fig. 9. Like in paragliders, some of the cells of the leading edge may be closed to form a cleaner aerodynamic airfoil.

Fig. 9 shows a cross-sectional view of the embodiment illustrated in Figs. 5 and 6. Fig. 10 shows a cross-sectional view of a specific variation of the embodiment shown in Fig. 9.

In the embodiment shown in Fig. 10, an air intake opening 100 is located at the pressure side 74 of the profiled shape of the airfoil region 72 and communicates with an interior 96 of the inflatable structure 90. An inlet control valve 102 is adapted to open or close an airflow connection 104 from the air intake opening 100 to the interior 96 of the inflatable structure 90. Furthermore, an outlet control valve 106 is adapted to open or close an airflow connection 108 from the interior 96 of the inflatable structure 90 to an air outlet opening 110 at the suction side 76 of the profiled shape of the airfoil region 72. By opening the inlet control valve 102 and closing the outlet control valve 106, the interior 96 of the inflatable structure 90 may be inflated automatically by means of the naturally existing air pressure on the pressure side 74 of the airfoil region 72. On the other hand, by opening the outlet control valve 106 and closing the inlet control valve 102, the interior 96 of the inflatable structure 90 may be deflated automatically by means of the naturally existing air suction pressure on the suction side 76 of the airfoil region 72.

A not shown control unit may be configured to control the operation of the collapsible part 88 of the at least one collapsible section of each blade of a wind turbine in response to inflow condition information from one or more not shown flow sensors and/or an external source providing information regarding the wind and/or flow conditions at the wind turbine blade. Flow sensors may for instance be placed directly on the wind turbine blades, on the wind turbine tower or on any other suitable structure at or at a distance from the wind turbine. Said control unit may be configured to control the operation of the collapsible part 88 by controlling the opening and closing operations of the inlet control valve 102 and the outlet control valve 106 provided in the embodiment illustrated in Fig. 10. However, said control unit may alternatively be configured to control the operation of the collapsible part 88 in the form of an inflatable structure 90 by injection of compressed air from a central source of compressed air, such as a compressor located at the ground, in order to inflate the inflatable structure 90. In order to deflate the inflatable structure 90, an outlet control valve 106 as shown in Fig. 10 may be provided or a central source of suction pressure may be provided, such as a vacuum pump located at the ground.

Said control unit may just as well be configured to control the operation of the collapsible part 88 of other embodiments of the wind turbine blade according to the invention as described in the following, whereby, for instance, the operation of the collapsible part 88 may be controlled by the control of electric, hydraulic or pneumatic actuators or the like adapted to collapse or extend the collapsible part 88.

Fig. 11 shows another embodiment of the wind turbine blade illustrated in Fig. 9, whereby the structure 92 of relatively fixed cross-sectional shape is positioned at a distance from the leading edge 78 and at a distance from the trailing edge 80 so that the collapsible part 88 has the form of an inflatable structure 90 formed by a first inflatable structure 90' located in front of the structure 92 and a second inflatable structure 90'' located behind the structure 92. The structure 92 extends to the pressure side 74 and to the suction side 76 of the airfoil region 72.

Fig. 12 shows an embodiment of the wind turbine blade corresponding to the one illustrated in Fig. 11, but with the difference that the structure 92 of relatively fixed cross-sectional shape is positioned at a distance from the pressure side 74 and from the suction side 76 of the airfoil region 72, so that the collapsible part 88 has the form of a single inflatable structure 90 surrounding the structure 92. The structure 92 has supporting elements 112, such as arms, connecting the structure 92 with the inflatable structure 90.

Figs. 7 and 8 show different embodiments, wherein the collapsible part 88 is formed by means of a retractable cloth-like structure 114, such as a sailcloth material. The leading edge 78 of these embodiments is formed by a structure 92 of relatively fixed cross-sectional shape similar to the embodiments illustrated in Figs. 5, 6, 9 and 10.

In the embodiment shown in Fig. 7, the retractable cloth-like structure 114 is retractable in the longitudinal direction of the blade as indicated by the arrows, from a position at a tip region 116 to a position at a root region 118. In other embodiments, the retractable cloth-like structure 114 may extend over a shorter length of the blade than that shown in Fig. 7, and the remaining part of the airfoil region may, for instance, be made in the same way as the airfoil region of a conventional blade. Furthermore, the retractable cloth-like structure 114 may be split up in more than one section, whereby each section may comprise a retractable cloth-like structure 114 retractable in the longitudinal direction of the blade.

In the embodiment shown in Fig. 8, the retractable cloth-like structure 114 is retractable in the direction from the trailing edge 80 towards the leading edge 78, as indicated by the arrows. Furthermore, the blade comprises a plurality of collapsible sections 84 distributed in the longitudinal direction of the blade, wherein a collapsible part 88 of each respective collapsible section 84 is separately controllable. In the specific embodiment illustrated the blade comprises four collapsible parts 88', 88'', 88''', 88''''. Fig. 8A illustrates a situation, in which none of the collapsible parts is collapsed. In Fig. 8B, only the outermost collapsible part 88' is collapsed. In Fig. 8C, the three outermost collapsible parts 88', 88'', 88''' are collapsed, and the innermost collapsible part 88'''' is not collapsed. Thereby, it may be possible to decrease the lift of outmost collapsible sections of the blade in order to minimise loading and be able to use the wind turbine blade at higher wind speeds. If the wind speed increases even further, the lift of more and more collapsible sections may be reduced, e.g. sequentially from a collapsible section near the tip towards a collapsible section close to the root. This principle also applies to the embodiment illustrated in Figs. 5, 6 and 9 to 12, whereby it is possible to provide the blade with a number of collapsible sections 84 positioned in a row, each collapsible section having a separately controllable collapsible part 88 in the form of an inflatable structure 90.

In the embodiments illustrated in Figs. 7 and 8, each collapsible part 88 may have the form of a roller blind. Furthermore, each collapsible part 88 may have the form of a bellows-type folding blind.

In the embodiment illustrated in Fig. 7, laterally extending support arms 120 are fixed to the longitudinal structure 92 of relatively fixed cross-sectional shape. The laterally extending support arms 120 are placed on the suction side 76 of the airfoil, so that they may support the collapsible parts 88 in their extended position.

In the embodiment illustrated in Fig. 8, laterally extending support arms 122 are hinged to the longitudinal structure 92 of relatively fixed cross-sectional shape so that they may swing to a collapsed position when one or more of the collapsible parts 88 are collapsed, as illustrated in Figs. 8B and 8C. Thereby, they may support the collapsible parts 88 in their extended position without generating lift in the collapsed position of the collapsible parts.

In another not shown variation of the embodiments illustrated in Figs. 7 and 8, the laterally extending support arms 120, 122 have the form of telescopic rods so that they may collapse to a short length when one or more of the collapsible parts 88 are collapsed. Thereby, they may support the collapsible parts 88 in their extended position without generating lift in the collapsed position of the collapsible parts 88.

The laterally extending support arms 122 hinged to the longitudinal structure 92 as well as the laterally extending support arms 120, 122 in the form of telescopic rods may further be used to extend and retract the retractable cloth-like structure 114, for instance by having their outermost ends fixed to the retractable cloth-like structure. The retractable cloth-like structure 114 may thereby simply fold when the laterally extending support arms 120, 122 are swung in or retracted, as the case may be. The operation of the laterally extending support arms 120, 122 may be controlled by any suitable actuator, such as for instance an electric or a pneumatic actuator.

In a wind turbine comprising wind turbine blades according to the invention, the wind turbine blades may even be fastened at a fixed pitch angle on the hub of the wind turbine. Thereby, pitch bearings may be omitted, and the lift generation of the blades may be controlled solely by means of the collapsible parts 88 of the blades.

The invention has been described with reference to different embodiments. However, the scope of the invention is not limited to the illustrated embodiments, and alterations and modifications may be carried out without deviating from the scope of the invention. For instance, the embodiment illustrated in Figs. 5, 6 and 9 comprising an inflatable structure 90 may be combined with the embodiment illustrated in Fig. 8, so that a number of inflatable structures 90 would be provided in a row, possibly in combination with fixed, pivotal or telescopic laterally extending support arms 120, 122 for support of the inflatable structures. The embodiment illustrated in Figs. 5, 6 and 9 comprising an inflatable structure 90 could even be combined with the embodiment illustrated in Fig. 7, so that one or more inflatable structures in a row 90 would be expandable in the longitudinal direction of the blade.

List of reference numerals

2	wind turbine
4	tower
6	nacelle
8	hub
10	blade
14	blade tip
16	blade root
18	leading edge
20	trailing edge
22	pitch axis
30	root region
32	transition region
34	airfoil region
40	shoulder
41	first airfoil profile
42	second airfoil profile
43	third airfoil profile
44	fourth airfoil profile
45	fifth airfoil profile
46	sixth airfoil profile
50	airfoil profile
52	pressure side
54	suction side
56	leading edge
58	trailing edge
60	chord
62	camber line / median line
c	chord length
d_t	position of maximum thickness
d_f	position of maximum camber
d_p	position of maximum pressure side camber
f	camber

L	blade length
r	local radius, radial distance from blade root
t	thickness
Δ_y	prebend
70	wind turbine blade
72	airfoil region
74	pressure side
76	suction side
78	leading edge
80	trailing edge
82	chord
84	collapsible section
86	longitudinal direction
88	collapsible part
90	inflatable structure
C	first chord length
$C_{reduced}$	reduced chord length
92	longitudinal structure of relatively fixed cross-sectional shape
94	backside
96	interior of the inflatable structure
98	line
100	air intake opening
102	inlet control valve
104	airflow connection
106	outlet control valve
108	airflow connection
110	air outlet opening
112	supporting elements
114	retractable cloth-like structure
116	tip region
118	root region
120	laterally extending support arms
122	laterally extending support arms

Claims

1. A wind turbine blade (70) for a rotor of a wind turbine having a substantially horizontal rotor shaft, the blade having a longitudinal direction (86) and an airfoil region (72) with a profiled shape comprising a pressure side (74) and a suction side (76) as well as a leading edge (78) and a trailing edge (80), a chord (82) extending between the leading edge and the trailing edge, and the profiled shape being adapted to generate a lift when being impacted by an incident airflow, **characterized in that** the wind turbine blade (70) comprises at least one collapsible section (84) extending in the longitudinal direction (86) of the blade (70) and having a collapsible part (88) which is collapsible between a first, extended position, in which the airfoil has a first chord length (C) and its normal lift generating shape with an airfoil shaped profile, and a second, collapsed position, in which the airfoil has a second, reduced chord length ($C_{reduced}$) shorter than the first chord length (C) and a shape generating reduced lift compared to the lift generated in the first position of the collapsible part (88), and wherein the at least one collapsible section (84) extends longitudinally from a position near or at a tip region (116) of the blade (70) to a position nearer a root region (118) of the blade, wherein the blade (70) optionally comprises a plurality of collapsible sections (84), which advantageously are juxtaposed in the longitudinal direction of the blade, and wherein the at least one collapsible section (84) or plurality of sections extends along at least 10% of the airfoil region (72) of the blade.

2. A wind turbine blade according to claim 1, wherein the at least one collapsible section (84) extends longitudinally from a position near or at a tip region (116) of the blade (70) to a position nearer a root region (118) of the blade, wherein the blade (70) preferably comprises a plurality of collapsible sections (84), which preferably are juxtaposed in the longitudinal direction of the blade, and wherein preferably the at least one collapsible section (84) or plurality of sections extends along at least 20% of the airfoil region (72) of the blade, or even along at least 30%, 40%, 50%, 60%, 70%, or 75% of the airfoil region of the blade.

3. A wind turbine blade according to claim 1 or 2, wherein the second, reduced chord length ($C_{reduced}$) is shorter than 1/2, preferably shorter than 1/3 and most preferred shorter than 1/4 of the first chord length (C).

4. A wind turbine blade according to any one of the preceding claims, wherein the leading edge (78) of the at least one collapsible section (84) is formed by a longitudinal structure (92) of relatively fixed cross-sectional shape, and wherein the trailing edge (80) is retractable in the direction towards the leading edge (78) by means of the collapsible part (88).

5. A wind turbine blade according to any one of the preceding claims, wherein the collapsible part (88) is formed by means of an inflatable structure (90).

6. A wind turbine blade according to claim 5, wherein an air intake opening (100) is located at the pressure side (74) of the profiled shape of the airfoil region (72) and communicates with the interior (96) of the inflatable structure (90).

7. A wind turbine blade according to claim 6, wherein an inlet control valve (102) is adapted to open or close an airflow connection (104) from the air intake opening (100) to the interior (96) of the inflatable structure (90).

8. A wind turbine blade according to any one of the preceding claims, wherein an outlet control valve (106) is adapted to open or close an airflow connection (108) from the interior (96) of the inflatable structure (90) to an air outlet opening (110) at the suction side (76) of the profiled shape of the airfoil region (72).

9. A wind turbine blade according to any one of the claims 1 to 4, wherein the collapsible part (88) is formed by means of a retractable cloth-like structure (114), such as a sailcloth material.

10. A wind turbine blade according to claim 8, wherein the retractable cloth-like structure (114) is retractable in the longitudinal direction of the blade (70), preferably from a position at a tip region (116) to a position at a root region (118).

11. A wind turbine blade according to any one of the claims 8 to 10, wherein the collapsible part (88) has the form of a roller blind.

12. A wind turbine blade according to any one of the claims 8 to 10, wherein the collapsible part (88) has the form of a bellows-type folding blind.

13. A wind turbine blade according to any one of the preceding claims, wherein the blade (70) comprises a plurality of collapsible sections (84) distributed in the longitudinal direction of the blade, the collapsible parts (88) of the respective collapsible sections being separately controllable.

14. A wind turbine comprising a tower having a first end and an opposite second end, the second end connecting the tower to the ground or a foundation, a nacelle arranged at the first end of the tower and having a substantially horizontal rotor shaft, a hub connected to the rotor shaft, a number, preferably two or three, wind turbine blades (70) according to any one of the preceding claims, extending in a substantially radial direction from the hub, a flow sensor configured to determine inflow conditions at the wind turbine blade or at an upwind direction of the wind turbine blade, and a control unit configured to control the operation of the collapsible part of the at least one collapsible section of each blade (70) in response to inflow condition information from the flow sensor and/or an external source providing information regarding the wind and/or flow conditions at the wind turbine blade.

15. A method of controlling a wind turbine comprising at least two, preferably three, wind turbine blades (70) according to any one of the claims 1 to 13, whereby the position of the collapsible part (88) of the at least one collapsible section (84) of each blade (70) is controlled in order to vary the chord length of the airfoil of the collapsible section in order to vary the lift of the collapsible section in response to operational conditions of the wind turbine, such as inflow properties or load conditions.

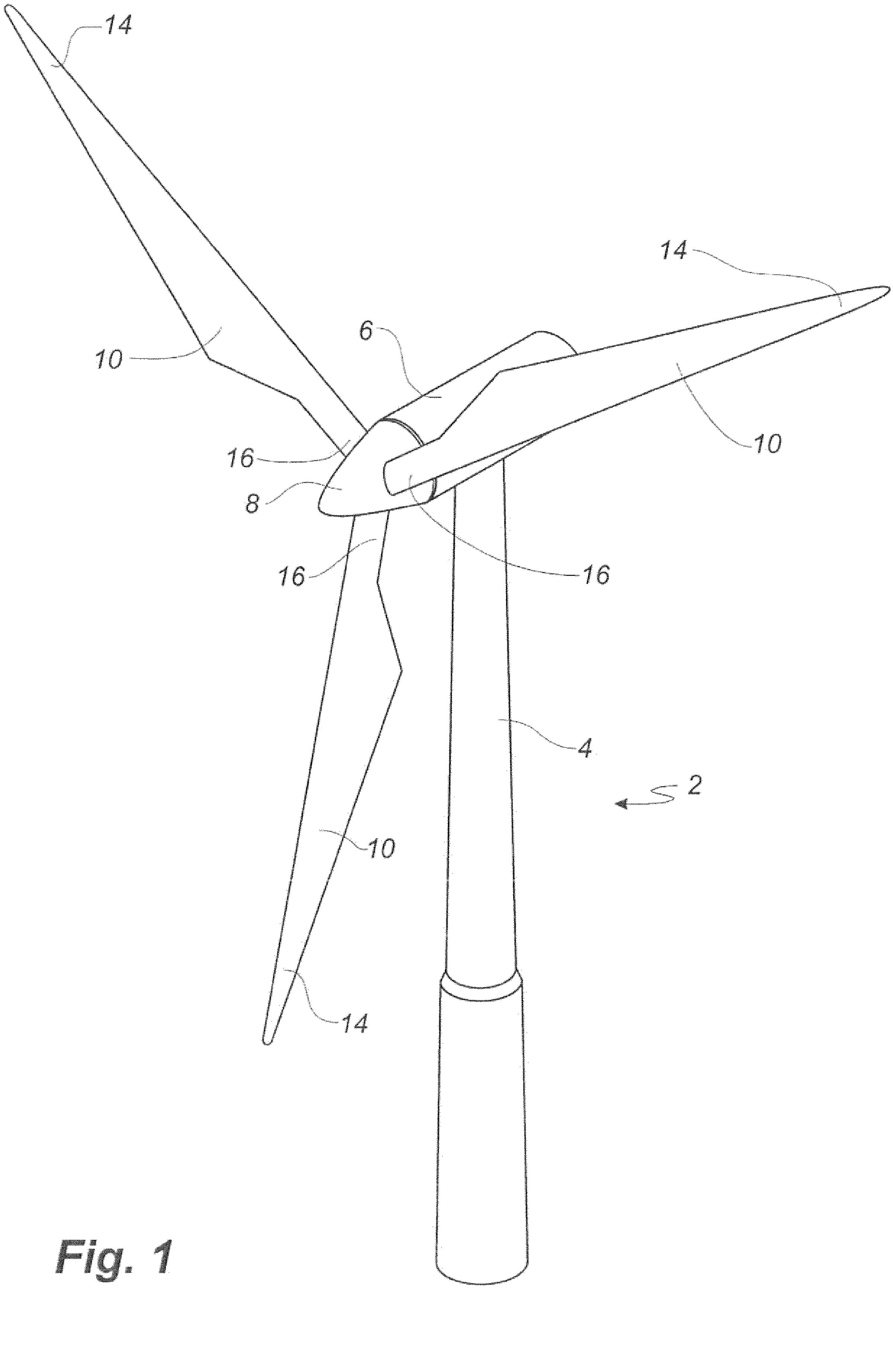

Fig. 1

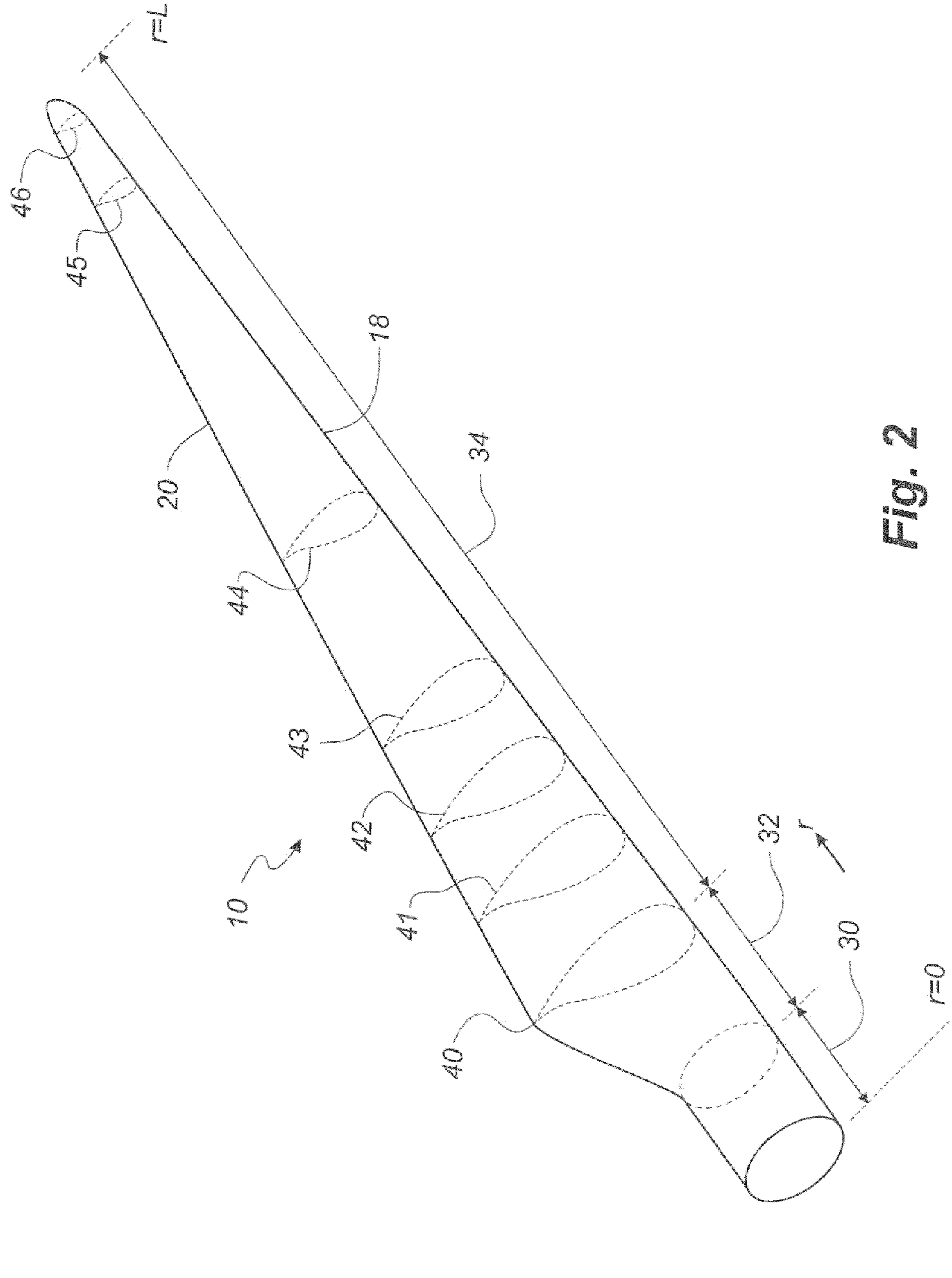

Fig. 2

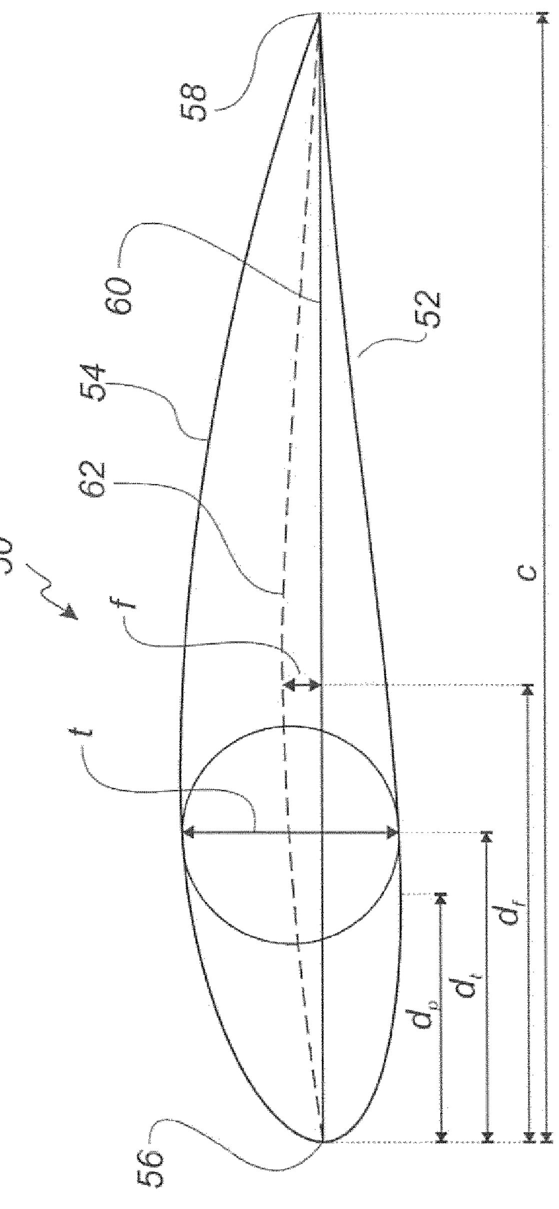

Fig. 3

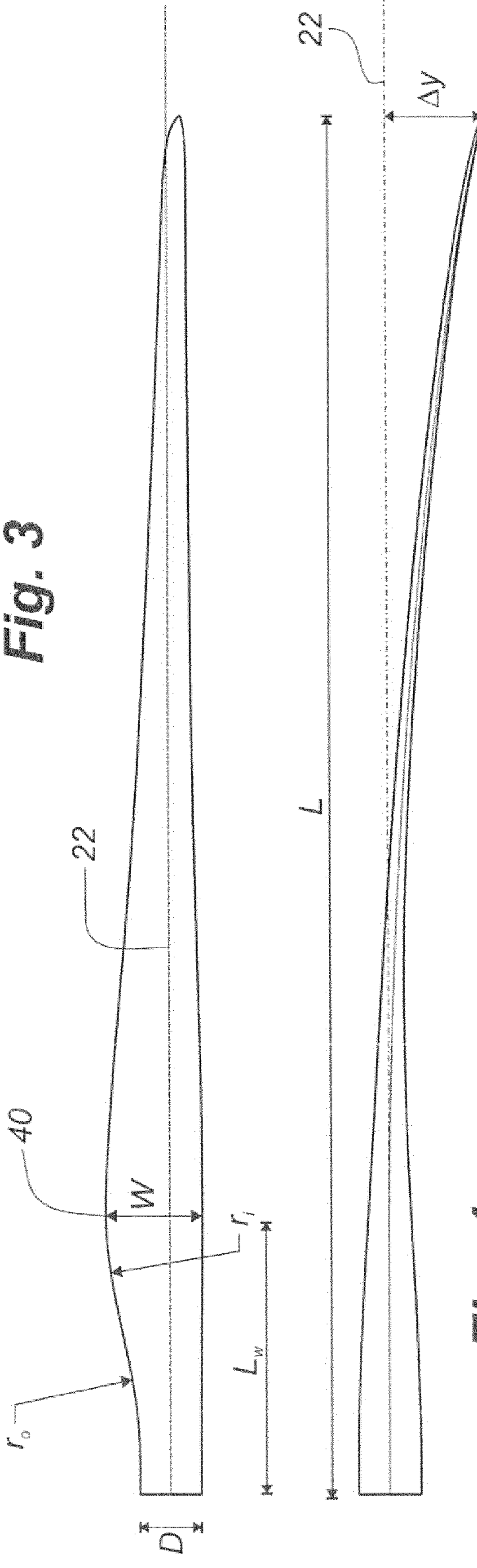

Fig. 4

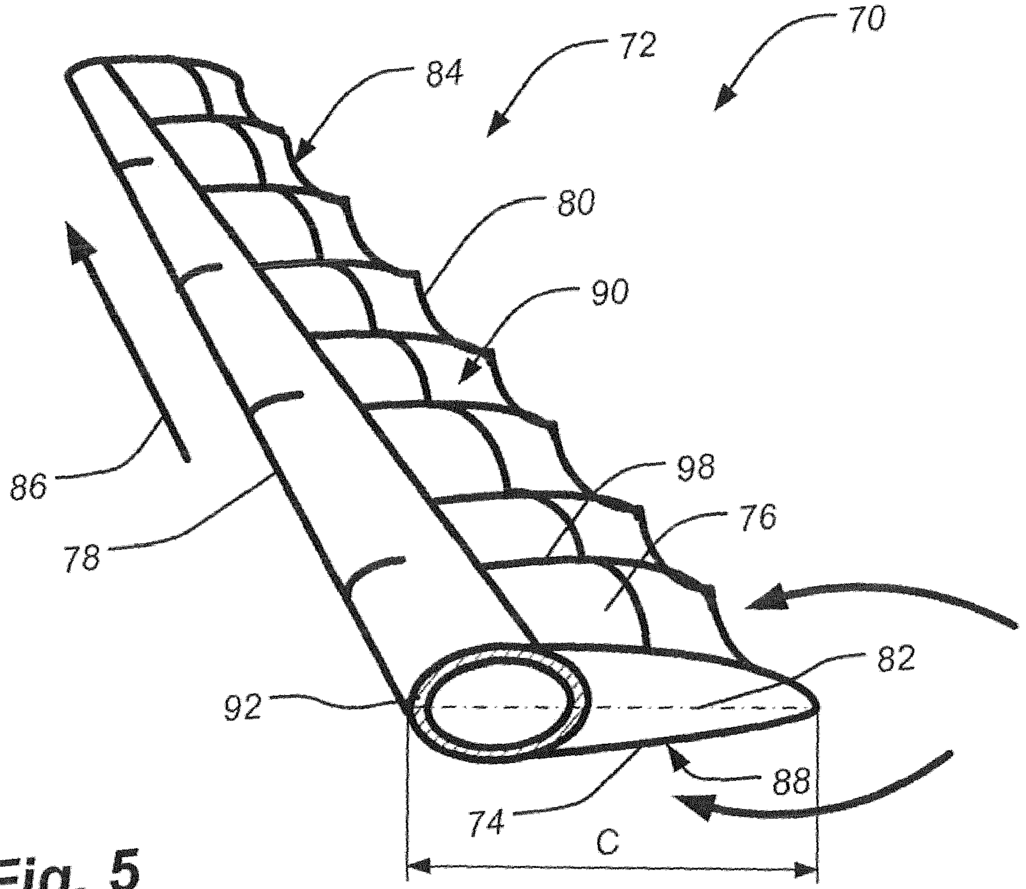

Fig. 5

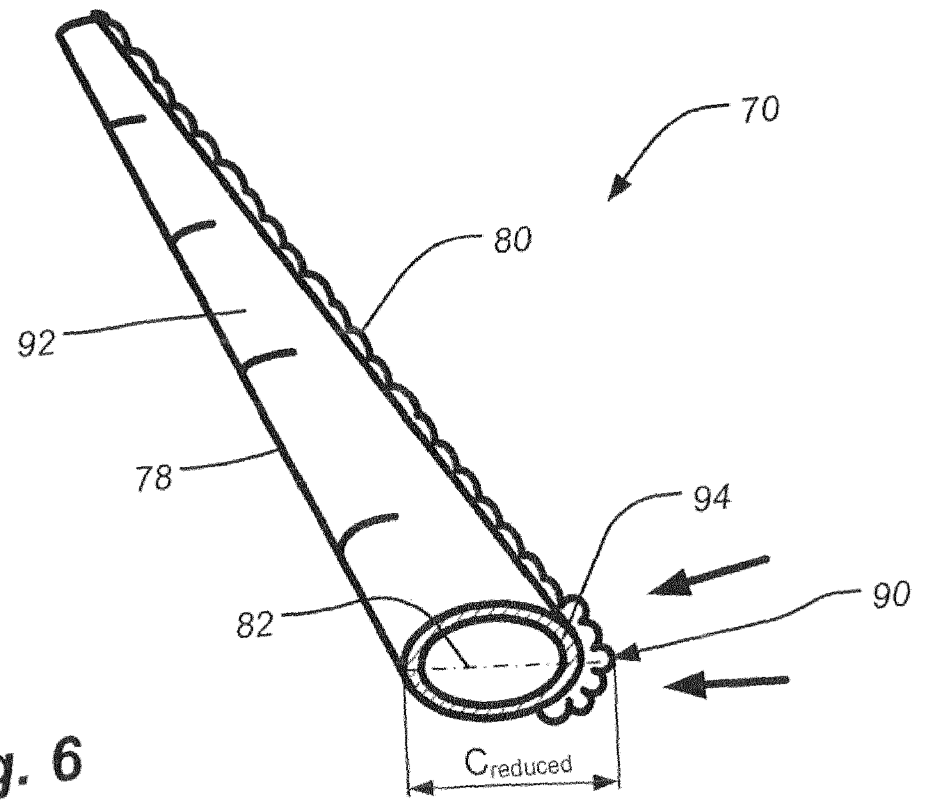

Fig. 6

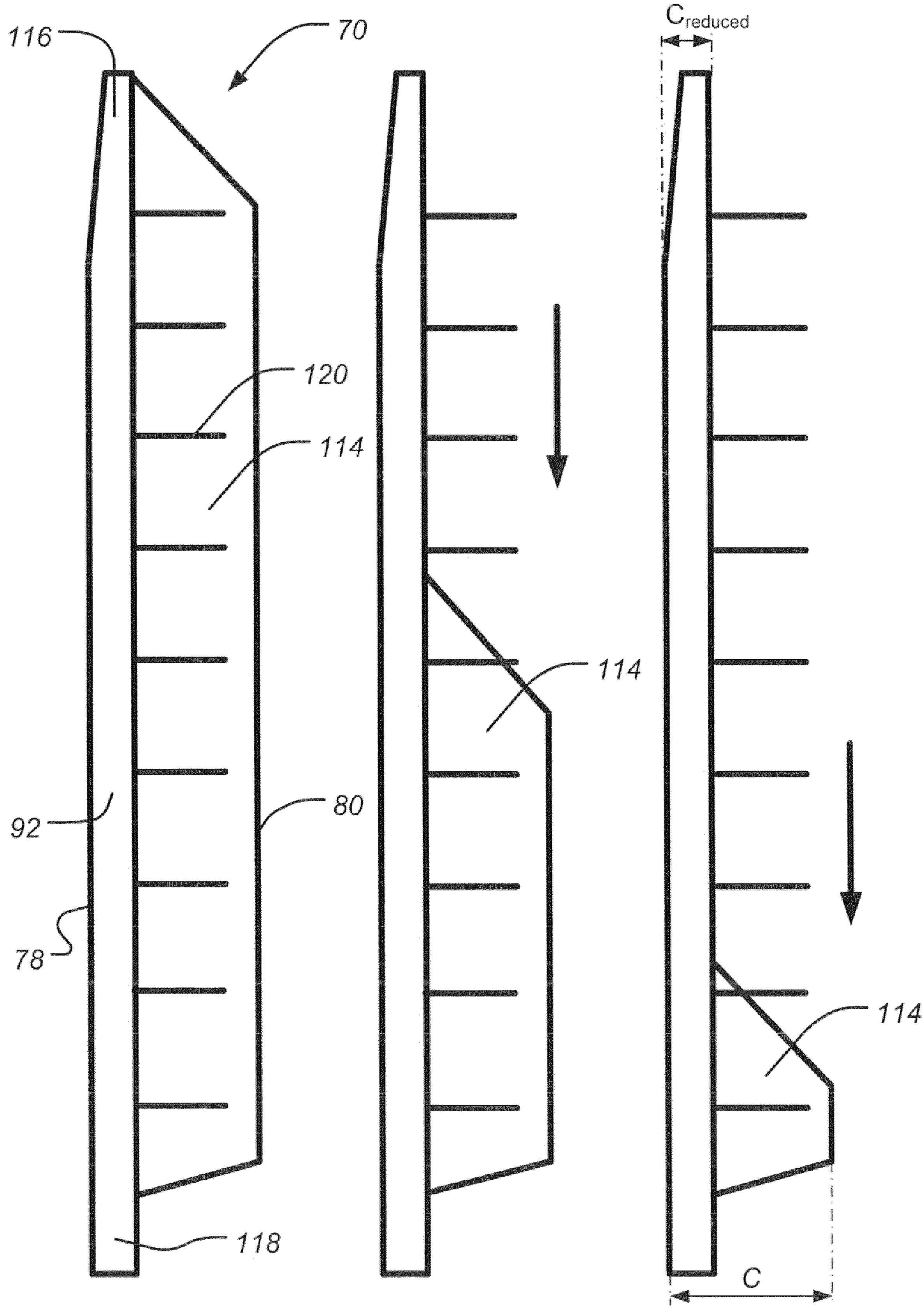

Fig. 7A Fig. 7B Fig. 7C

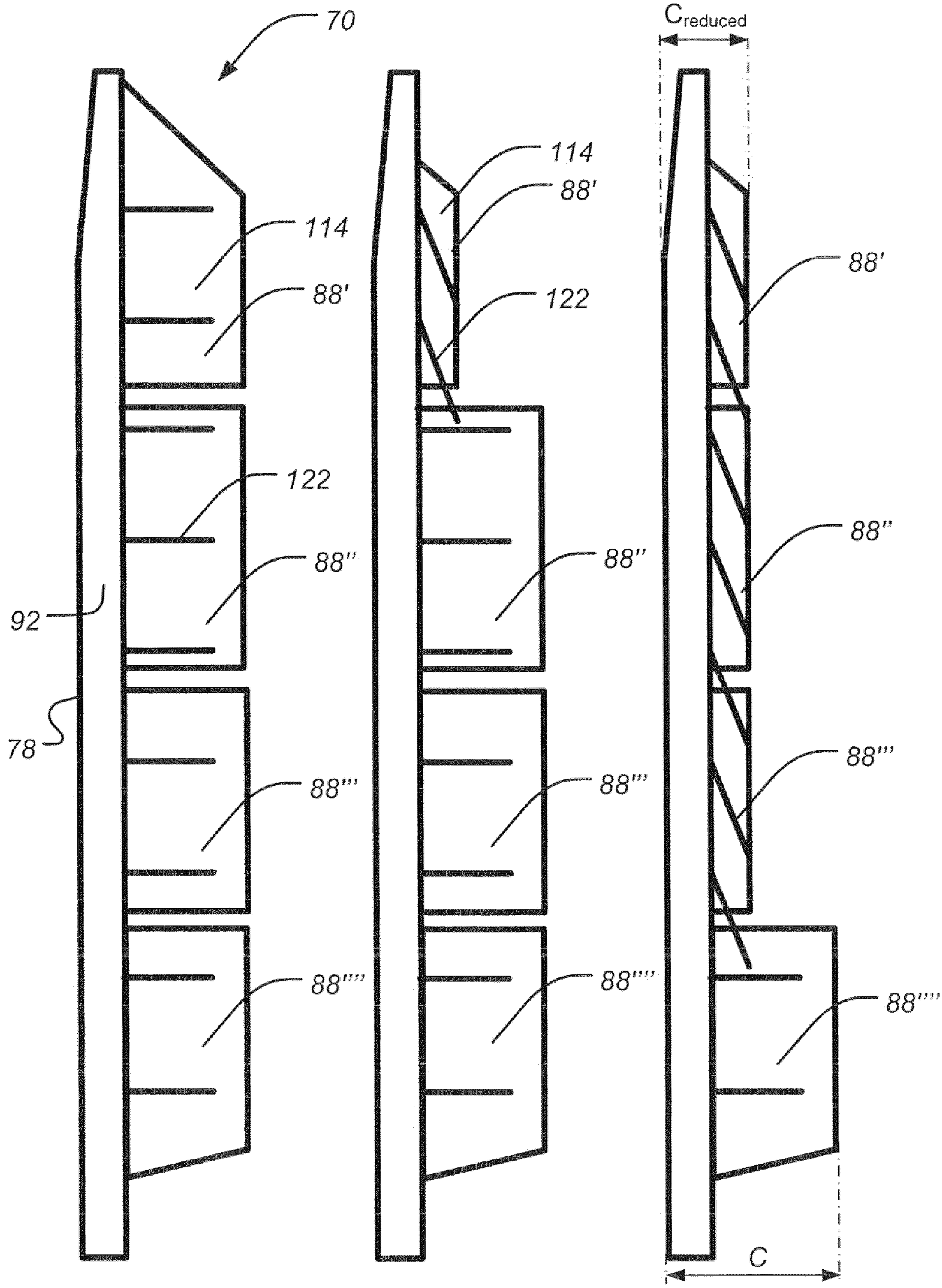

Fig. 8A Fig. 8B Fig. 8C

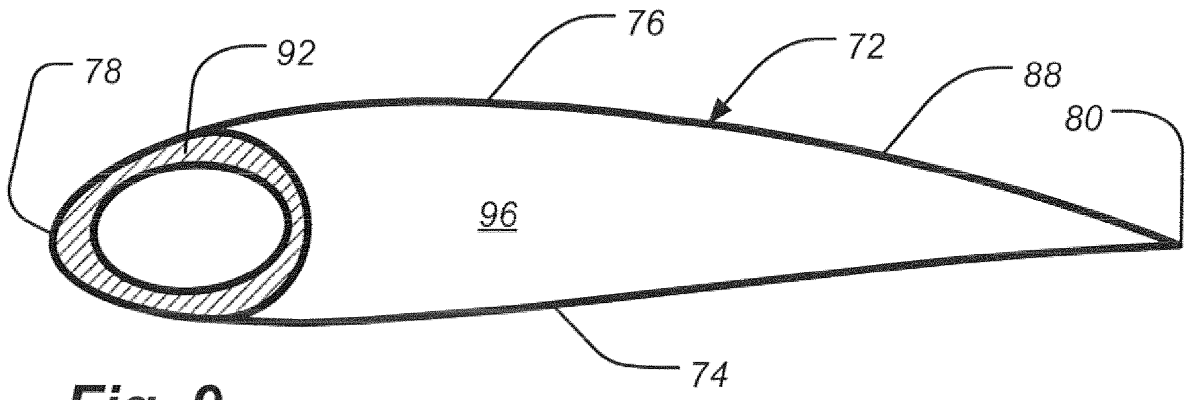

Fig. 9

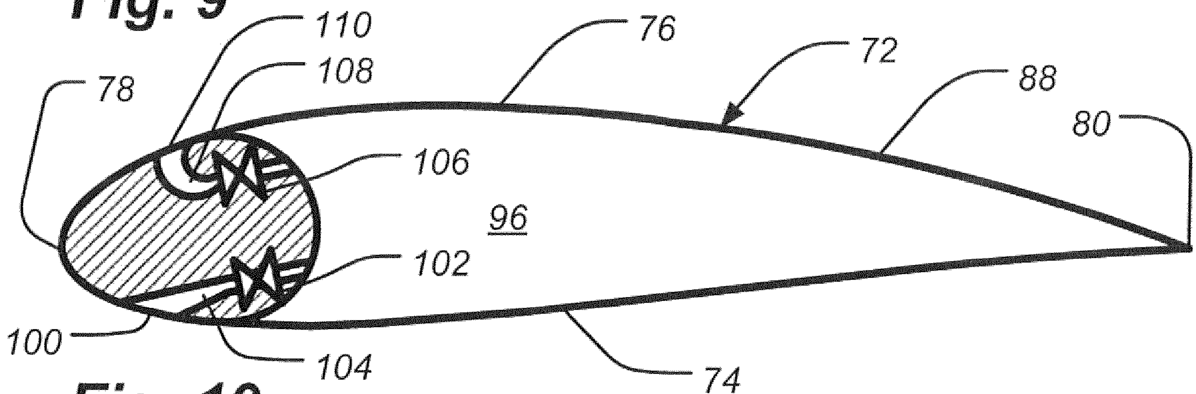

Fig. 10

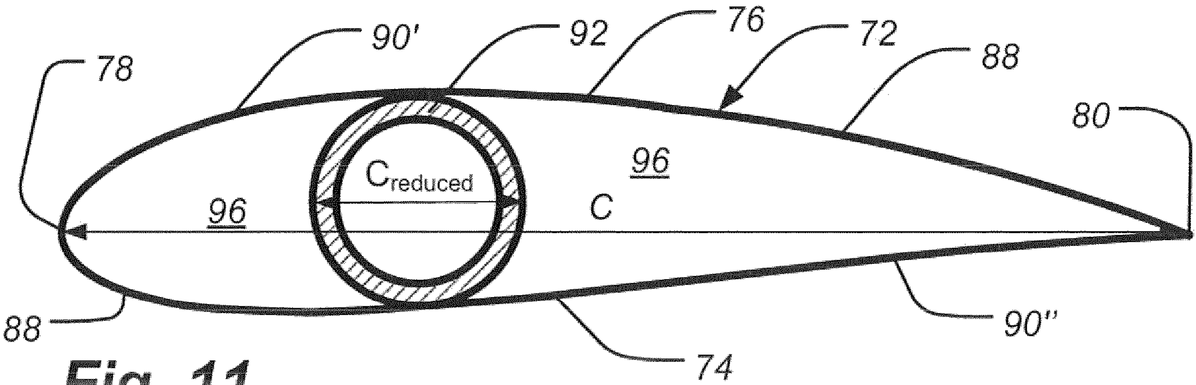

Fig. 11

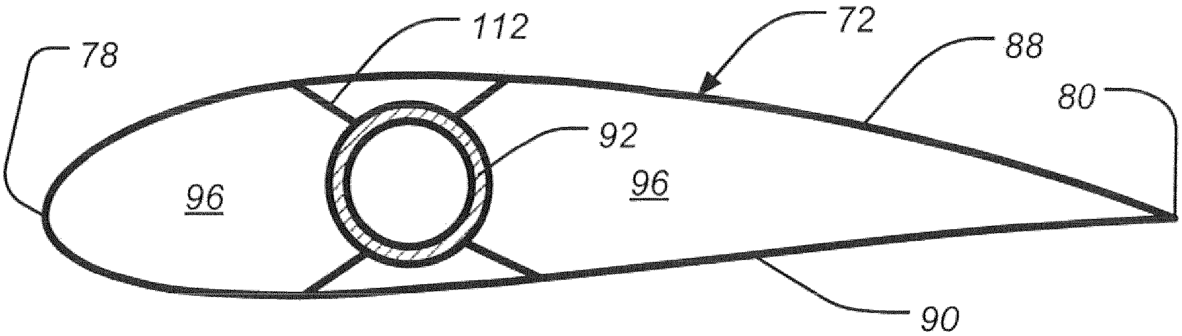

Fig. 12

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2012/050413

A. CLASSIFICATION OF SUBJECT MATTER
INV. F03D1/06 F03D7/02
ADD.

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

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 practical, search terms used)

EPO-Internal, PAJ, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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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
29 March 2012	11/04/2012

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	Jucker, Chava

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INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2012/050413

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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