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DESCRIPTION

[0001] The present invention relates to a blade for a rotor of a wind turbine having a substantially horizontal rotor shaft, said rotor comprising a hub, from which the blade extends substantially in a radial direction when mounted to the hub, the blade having a longitudinal direction with a tip end and a root end and a transverse direction, wherein the blade further comprises: a profiled contour including a pressure side and a suction side, as well as a leading edge and a trailing edge with a chord having a chord length extending there between, the profiled contour when being impacted by an incident airflow generating a lift, wherein the profiled contour is divided into: a root region having a substantially circular or elliptical profile closest to the hub, an airfoil region having a lift-generating profile furthest away from the hub, and a transition region between the root region and the airfoil region, the transition region having a profile gradually changing in the radial direction from the circular or elliptical profile of the root region to the lift-generating profile of the airfoil region.

[0002] Ideally, a wind turbine blade of the airfoil type is shaped like a typical aeroplane wing, where the chord plane width of the 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 blade to the hub, and, moreover, this causes great loads during operation of the blade, such as storm loads, due to the large surface area of the blade.

[0003] Therefore, over the years, the construction of blades has developed towards a shape, where the blade consists of a root region closest to the hub, an airfoil 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 blade shape with respect to generating lift, whereas the root region has a substantially circular cross-section, which reduces the storm loads and makes it easier and safer to mount the blade to the hub. The root region diameter is preferably 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 blade in the transition region increases substantially linearly with increasing distance from the hub.

[0004] As for instance blades for wind turbines have become bigger and 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 blade may over the lifetime of a wind blade accumulate to a high increase in financial gains, which surpasses the additional manufacturing costs relating to such changes. The focus areas for research have in many years been directed towards improving the airfoil region of the blade, but during the recent few years, more and more focus has been directed towards improving the aerodynamic performance of the root region and the transition region of the blade also.

[0005] WO2007/065434 discloses a blade wherein the root region is provided with indentations and/or projections in order to decrease the drag from this part of the blade.

[0006] WO2007/045244 discloses a blade, wherein the root region and the transition region is designed so as to have at least two separate airfoil profiles in order to increase the lift of these regions.

[0007] WO2007/118581 discloses a blade, where the inboard part of the blade is provided with a flow guiding device on the pressure side of the blade in order to delay separation of the airflow and increasing the aerodynamic performance of the blade.

[0008] WO 02/08600 discloses a blade comprising a connection part for connection to the hub of a wind turbine, wherein the connection part is provided with a rib that projects from the connection part, thereby increasing the overall efficiency of the wind turbine.

[0009] It is an object of the invention to obtain a new blade, and which overcomes or ameliorates at least one of the disadvantages of the prior art or which provides a useful alternative.

[0010] According to the invention, the blade is provided with the features of claim 1, including amongst other features, a flow guiding device added to the profiled contour of the blade on the pressure side of the blade, the flow guiding device having an inflow surface with a start point attached to the profiled contour and an end point located in a distance from the profiled contour of the blade, the end point having a minimum distance to the profiled contour of the blade, wherein the flow guiding device extends along at least a longitudinal part of the transition region and is arranged so as to generate a separation of airflow along at least a central longitudinal portion of the flow guiding device from the pressure side of the blade at a point between the flow guiding device and the trailing edge of the blade, when the blade is impacted by the incident airflow, wherein the flow guiding device in at least the central longitudinal portion is arranged so that the end point has a relative chordal position, seen from the leading edge of the blade, lying in an interval between 40% and 92%, and the inflow surface in at least the central longitudinal portion is formed so that, for each transverse cross-section, the minimum distance from the end point to the profiled contour is at least 10% of a maximum thickness of the profiled contour in that cross-section.

[0011] Accordingly, it is seen that the relative height of the flow guiding device is at least 10% of the local maximum profile thickness for all transverse cross-section in the central longitudinal portion of the flow guiding device, which is significantly higher than conventional flow guiding devices. The flow guiding device is mounted to the inboard part of the blade, i.e. the part nearest the hub, and particularly to the transition region of the blade. The power produced from this part of the blade is very poor, but attaching a flow guiding device according to the invention increases the lift significantly on this section of the blade at the governing inflow angles for this section. The flow guiding device functions as an obstruction to the flow on the pressure side of the profile. This obstruction is resulting in a higher pressure after the flow guiding device, i.e. between the flow guiding device and the trailing edge of the wind turbine blade, due to a detachment of the flow. After the flow guiding device, i.e. between the flow guiding device and the trailing edge of the blade, a separation of the airflow occurs. Therefore, the increase in the height of the flow guiding device also increases the drag of the particular blade segment significantly. However, experiments have surprisingly shown that the flow guiding device according to the invention despite the increase in drag improves the overall lift-to-drag ratio of up to 10% or more compared to conventional flow guiding devices, where the relative height is substantially less than 10%. A realistic estimate of the potential performance improvement is 1-1.5% of annual energy yield compared to conventional wind turbine blades without such flow guiding devices. When seen over the lifetime of a wind turbine rotor this provides a substantial economical benefit compared to the additional manufacturing costs relating to the manufacturing of blades with such flow guiding devices.

[0012] The minimum distance is defined as the distance from the end point of the inflow surface to the profiled contour along a normal to the profiled contour. Thus, the minimum distance corresponds to the radius of a circle with a centre at the end point of the inflow surface and touching only a single point of the profiled contour of the blade.

[0013] The relative chordal position corresponds to the distance from the leading edge (along the chord) divided by the chord length of the particular cross-section of the contoured profile. Thus, a relative chordal position relates to a point of the flow guiding device projected on to the chord.

[0014] According to the invention, the minimum distance from the end point to the profiled contour is at least 15%, 16%, 17%, 18%, 19%, 20%, 21%, 22%, 23%, 24%, or 25% of the maximum thickness of the profiled contour. In this regard it has surprisingly been found that increasing the relative height of the flow guiding device according to these heights increases the energy yield of the blade even further.

[0015] Due to manufacturing considerations, the minimum distance from the end point to the profiled contour is advantageous less than or equal to 50%, 45%, 40%, 35%, or 30% of the maximum thickness of the profiled contour.

[0016] According to a preferred embodiment, the inflow surface in at least the central longitudinal portion of the flow guiding device is formed so that, for each transverse cross-section, an end point tangent to the inflow surface at the end point crosses the profiled contour at a crossing point, where the profiled contour has a profile tangent to the profiled contour, and wherein an angle (a) between the profile tangent and the end point tangent is at least 45 degrees. However, it is clear that the increase of the "release angle" of the airflow entails that the drag of the particular blade segment also is increased significantly. However, experiments have surprisingly shown that the flow guiding device according to this embodiment, despite the increase in drag, improves the overall lift-to-drag ratio with at least 5% within the longitudinal extent of the flow guiding device compared to conventional flow guiding devices, where said angle is substantially less than 45 degrees. Thus, the increase in lift-to-drag ratio improves the overall performance of the wind turbine rotor even further, and the increase in lift alone reduces the local inflow angle, thereby somewhat limiting the size of the separated flow region on the suction side. It should be noted that the end point tangent and the profile tangent form more than one angle. From the following detailed description, it is clear that the angle referred to is the angle between the exterior part of the end point tangent and the part of the profile tangent, which extends towards the trailing edge of the blade. In other words, the angle referred to is located in a quadrant external to the blade profile nearest the trailing edge of the blade. The two tangents form an acute angle and an obtuse angle (except for when they are mutually perpendicular). Thus, it is clear that it is the acute angle, which is at least 45 degrees.

[0017] According to an advantageous embodiment, the angle between the profile tangent and the end point tangent is at least 50 degrees, or at least 55 degrees, or at least 60 degrees. The angle may be up to 90 degrees. Preferably, the angle lies in an interval between 60 to 90 degrees, which surprisingly has found to provide the best efficiency despite the high degree of separation and increased drag. The lift-to-drag ratio has been found to be substantially constant within said interval.

[0018] According to another advantageous embodiment, a median line to the inflow surface forms a second angle with the chord, the second angle being at least 25 degrees, or at least 30 degrees, or at least 35 degrees. The second angle may be a supplementary design parameter to the angle between the end point tangent and the profile tangent, or it may be an alternative design parameter. According to an advantageous embodiment, the inflow surface is substantially aligned along a line forming an angle to the chord being at least 25 degrees, or at least 30 degrees, or at least 35 degrees. Accordingly, the end point tangent may also form an angle to the chord being at least 25 degrees, or at least 30 degrees, or at least 35 degrees, if the inflow surface is straight. The median line corresponds to a linear fitted line to the inflow surface or an average tangent to the inflow surface. Thus, it is seen that the inflow surface on average forms a second angle of at least 25 degrees with the chord. Again, it should be noted that the second angle refers to the acute angle formed between the median line and the chord.

[0019] According to another advantageous embodiment, the relative chordal position of the end point, seen from the leading edge of the blade, lies in an interval between 75% and 92%, and wherein an angle of attack for a design point of the central longitudinal portion lies in an interval between 15 and 25 degrees, or between 15 and 20 degrees. When the end point of the flow guiding device is located at a backwards position, i.e. a position near the trailing edge of the blade, it has been found that the lift coefficient increases with increasing angle of attack up to an angle of attack of approximately 25 degrees, whereas the lift-to-drag ratio in the interval is substantially constant.

[0020] According to yet another embodiment, the relative chordal position of the end point, seen from the leading edge of the blade, lies in an interval between 40% and 80%, or between

40% and 70%, or between 40% and 60%. When the end point of the flow guiding device is located at a forward position, i.e. a position towards the cross-sectional point of maximum thickness and the trailing edge of the blade, it has surprisingly been found that the lift coefficient and lift-to-drag ratio are substantially independent on the angle of attack of the incoming airflow. Thus, the operational range for the inflow angle may be expanded and at the same time maintaining an increased operational production yield from the blade. Furthermore, the blade is less sensitive to fluctuations in the wind speed, thus lowering loads on the blade.

[0021] According to another advantageous embodiment, the flow guiding device extends along substantially the entire longitudinal length of the transition region. Thereby, the lift and the lift-to-drag ratio are improved for substantially the entire aerodynamically non-ideal transition region.

[0022] In a preferred embodiment according to the invention, the central longitudinal portion is at least 50%, 60%, 70%, 80%, or 90% of the longitudinal extent of the flow guiding device.

[0023] Experiments have surprisingly shown that the flow guiding device or spoiler advantageously may be moved towards the point of maximum thickness of the cross-sectional profile for low angles of attack, whereas the flow guiding device advantageously may be moved towards the trailing edge of the blade for high angles of attack. However, on a rotor blade, the flow angle will decrease with increasing blade radius due to the increase in the local rotational speed. Hence near the root region, the flow guiding device should be moved towards the trailing edge of the blade, and it should then approach the leading edge, when looking in the outboard direction, i.e. towards the airfoil region of the blade. Thus, according to an advantageous embodiment according to the invention, the relative chordal position of the end point, seen from the leading edge of the blade, is decreasing in the longitudinal direction of the blade. According to an advantageous embodiment, the relative chordal position of the end point at an inboard part of the flow guiding device, seen from the leading edge of the blade, lies in an interval between 75% and 92%, and the relative chordal position of the end point at an outboard part of the flow guiding device lies in an interval of between 40% and 60%. The inboard part is defined as the part of the flow guiding device nearest the root end of the blade or equivalently nearest the hub. The outboard part is defined as the part of the flow guiding device nearest the tip end of the blade or equivalently farthest from the hub.

[0024] According to the invention, the inflow surface is concave.

[0025] According to one embodiment, a starting point tangent to the inflow surface at the starting point is substantially parallel to a tangent to the profile at the starting point. Thereby, the profile has a smooth surface transition to the inflow surface of the flow guiding device.

[0026] According to one advantageous embodiment, the flow guiding device has a width, wherein the ratio between the width and the chord length decreases in the longitudinal direction towards the tip end. This can for instance be obtained by the width being substantially constant in the longitudinal direction of the blade, since the chord length is increasing in the transition region. However, the width may also decrease in the longitudinal direction of the blade.

[0027] In one embodiment according to the invention, the start point in at least the central longitudinal portion is arranged in an area between 55% and 88% of the chord length, or between 57% and 87%, or between 60% and 85%, seen from the leading edge of the blade. In another embodiment according to the invention, the end point in at least the central longitudinal portion is arranged in an area between 70% and 90% of the chord length, or between 75% and 88%, or between 80% and 87% from the leading edge of the blade.

[0028] In yet another embodiment according to the invention, the distance between the end point and the trailing edge of the blade increases in the longitudinal direction towards the tip end of the blade.

[0029] According to a preferred embodiment, the blade is manufactured partly as a shell construction made of a fibre reinforced polymer material.

[0030] In one advantageous embodiment, the flow guiding device is integrally formed with the blade. Accordingly, the flow guiding device may be manufactured together with the blade, via for instance a moulding process, such as a VARTM process. In this case, the profiled contour is to be conceived as an imaginary smooth, continuous surface extending from the start point of the inflow surface to a second point near the end point of the inflow surface. In another advantageous embodiment, the flow guiding device is fitted on the surface of the blade. Thus, the blade and the flow guiding device may be manufactured separately, and the flow guiding device be fitted to the surface of the blade afterwards. Thereby, the moulding surface of the mould for manufacturing the blade may have a much simpler form without any discontinuities. This lowers the probability of the blade surface sticking to the moulding surface and thus being damaged, when the blade is to be removed from the mould after curing. According to yet another advantageous embodiment, the flow guiding device may be actively emerged from or be retracted to the profiled contour. The flow guiding device may be actively controlled so that depending on the operational conditions, the blade may function with or without the flow guiding device protruding from the profiled contour of the blade.

[0031] As previously mentioned, the flow guiding device preferably extends along substantially the entire longitudinal extent of the transition region of the blade. However, the flow guiding device may also extend into the root region.

[0032] According to one embodiment, the flow guiding device has a rear edge with a rear edge height, and wherein the rear edge height in at least the central longitudinal portion of the flow guiding device decreases in the longitudinal direction towards the tip end. Thereby, a particular simple shape having a smooth transition from the transition region to the airfoil region of the blade is obtained, and where the ratio between the rear edge height and the profile thickness optionally may be kept substantially constant.

[0033] According to the invention, the flow guiding device has a rear edge with a rear edge height, and wherein the rear edge height is substantially constant in at least the central longitudinal portion of the flow guiding device. The rear edge height may be decreasing from the central longitudinal portion to the longitudinal ends of the flow guiding devices in order to obtain a smooth transition to the profiled contour near the longitudinal ends of the flow guiding device. The latter two described embodiments of course also relate to the minimum distance of the end point to the profiled contour.

[0034] The rear edge of the flow guiding device may be pointing backwards towards the trailing edge of the blade or forward towards the leading edge of the blade. The rear edge may be concave, straight or convex.

[0035] According to an advantageous embodiment of the blade, the blade is designed for operation with an angle of attack of 15 to 20 degrees in the central longitudinal portion of the transition region.

[0036] The flow guiding device can be designed in different ways. For instance it may be formed as a rib, a triangular shape or a slightly curved shape. Along the longitudinal direction, the flow guiding device may change its shape and chordal position. According to an advantageous embodiment, the flow guiding device is a spoiler device. According to another advantageous embodiment, the blade is further provided with vortex generators at the transition region and/or root region of the blade. When vortex generators are optimally positioned together with the flow guiding device, this provides for an even better performance of particularly the blade root area.

[0037] The invention is explained in detail below with reference to an embodiment shown in the drawings, in which

Fig. 1 shows a wind turbine,

Fig. 2 shows a schematic view of a first embodiment of a wind turbine blade provided with a flow guiding device not according to the invention,

Fig. 3 shows a schematic view of an airfoil profile,

Fig. 4 shows a cross section of a wind turbine blade according to the invention,

Fig. 5 shows a schematic view of a second embodiment of a wind turbine blade provided with a flow guiding device according to the invention,

Fig. 6 shows a rear edge height of a first flow guiding device according to the invention as a function of the radial distance from the hub,

Fig. 7 shows the rear edge height of a second flow guiding device not according to the invention as a function of the radial distance from the hub,

Fig. 8 shows a first rear edge shape for a flow guiding device according to the invention,

Fig. 9 shows a second rear edge shape for a flow guiding device according to the invention,

Fig. 10 shows a third rear edge shape for a flow guiding device according to the invention,

Fig. 11 shows graphs of the lift coefficient as a function of the angle of attack for an incident airflow,

Fig. 12 shows graphs of the lift-to-drag ratio as a function of the angle of attack for an incident airflow,

Fig. 13 shows further parameters for designing a wind turbine blade according to the invention,

Fig. 14 shows a cross section of a blade with a flow guiding device according to the invention,

Fig. 15 shows graphs of the lift coefficient as a function of the height of a flow guiding device, and

Fig. 16 shows graphs of the lift-to-drag ratio as a function of the height of a flow guiding device,

Fig. 17 shows graphs of the lift coefficient as a function of the angle of attack for an incident airflow, and

Fig. 18 shows graphs of the lift-to-drag ratio as a function of the angle of attack for an incident airflow.

[0038] 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.

[0039] Fig. 3 shows a schematic 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 side and the leeward 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 and lower camber, which are defined as the distances from the chord 60 and the suction side 54 and pressure side 52, respectively.

[0040] Fig. 2 shows a schematic view of a first embodiment of a wind turbine blade 10 according to the invention. 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.

[0041] 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 is typically constant along the entire root area 30. The transition region 32 has a transitional profile 42 gradually changing from the circular or elliptical shape 40 of the root region 30 to the airfoil profile 50 of the airfoil region 34. The width of the transition region 32 typically increases substantially linearly with increasing distance *r* from the hub.

[0042] The airfoil region 34 has an airfoil profile 50 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.

[0043] 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.

[0044] The wind turbine blade 10 according to the invention is provided with a flow guiding device 70, which protrudes from the pressure side of the blade in the transition region 32 of the blade.

[0045] Fig. 4 shows a cross section of the wind turbine blade 10 in the transition region 32. The wind turbine in this region comprises a profiled contour with a transitional profile 42, which gradually changes from the circular profile 40 of the root region 32 to the airfoil profile 50 of the airfoil region. The transitional profile is from an aerodynamic point of view non-ideal. It can be seen that the profile has a smooth shape, from which the flow guiding device 70 protrudes on the pressure side of the blade. The flow guiding device 70 comprises an inflow surface 72 with a start point 74, where the inflow surface 72 continues over to the profiled contour 42 of the blade, and an end point 76, where the flow detaches from the profile. The start point 74 can also be conceived as a point of attachment for the flow guiding device 70, if the flow guiding device is retrofitted to the surface of the blade 10. The flow guiding device 70 further comprises a rear edge 84, which extends from the end point 76 to the profiled contour 42 of the blade 10. The distance between the inflow surface 72 of the flow guiding device 70 and the profiled contour 42 increases towards the trailing edge of the blade, so that the flow guiding device has a wedge-like shape. The inflow surface 72 may be substantially straight or it may be slightly curved as shown in Fig. 4.

[0046] The inflow surface 72 is formed so that, for each transverse cross-section in at least a central longitudinal portion 71 of the transition region 32, an end point tangent 80 to the inflow surface 72 at the end point 76 crosses the profiled contour 42 at a crossing point 82, where the profiled contour 42 has a profile tangent 78 to the profiled contour. The end point tangent 80 and the profile tangent 78 form a mutual crossing angle a. It should be noted that the end point tangent and the profile tangent form more than one angle. From the following detailed description, it is clear that the angle *a* is the angle between the exterior part of the end point tangent and the part of the profile tangent, which extends towards the trailing edge of the blade. In other words, the angle *a* is located in a quadrant external to the blade profile nearest the trailing edge of the blade. The two tangents 78, 80 form an acute angle and an obtuse angle (except for when they are mutually perpendicular). Thus, it is clear from the description that it is the acute angle, which is at least 45 degrees.

[0047] Further, another design parameter may be used for the design of the flow guiding device 70, and in particular the shape of the inflow surface 72, viz. a second angle θ, which is the angle between a median line 86 to the inflow surface 72 of the flow guiding device 70 and a chord 44 to the profiled contour 42.

[0048] The flow guiding device 70 functions as an obstruction to the flow on the pressure side of the profile. This obstruction results in a higher pressure after the flow guiding device 70, i.e. between the flow guiding device 70 and the trailing edge of the wind turbine blade, due to detachment of the flow from the surface. After the flow guiding device 70, i.e. between the flow guiding device and the trailing edge of the blade 70, a separation of the airflow occurs.

[0049] When the angle *a* is at least 45 degrees, experiments have shown that the lift-to-drag ratio of a cross section of the transition region 32 can be increased significantly compared to prior art blades with similar flow guiding devices. This is unexpected, since the degree of separation and thus the induced drag on the profile increase significantly due to the larger "release angle" of airflow from the flow guiding device. Experiments have shown that even greater angles from 60 degrees and up to 90 degrees provide even further improvements to the lift-to-drag ratio.

[0050] In an embodiment not part of the invention, the height *h* of the rear edge 84 of the flow guiding device is in Fig. 2 and Fig. 7 seen to be decreasing in the longitudinal direction (or radial distance from the hub) towards the tip end *r* of the blade. The height of the rear edge 84 is shown as a function of the radial distance *r* from the hub in Fig. 7. At the longitudinal end of the flow guiding device 70 nearest the hub, the flow guiding device 70 is rounded or tapered in order to obtain a smooth transition to the profiled contour of the blade. The rear edge height *h* corresponds to the distance between the end point of the flow guiding device and the profiled contour in a direction perpendicular to the chord.

[0051] Fig. 5 shows an embodiment of a blade 110 according to the invention, in which like numerals refer to like parts of the first embodiment shown in Fig. 2. Therefore, only the differences between the two embodiments are described. The embodiment of figure 5 differs in that the height of the rear edge 184 of the flow guiding device 170 is substantially constant in the longitudinal direction of the blade, at least within the central portion 171. This is also shown in Fig. 6. As shown in Fig. 6, the flow guiding device 170 can be rounded or tapered near the longitudinal ends of the flow guiding device 170 in order to obtain a smooth transition to the profiled contour of the blade.

[0052] The shape of the rear edge 84, 184 of the flow guiding device 70, 170 may have various shapes. The rear edge may for instance be pointing backwards towards the trailing edge of the blade as shown in Fig. 8, be oriented substantially transverse to the chord as shown in Fig. 4, or be pointing forwards towards the leading edge of the blade (not shown). The rear edge may be either straight as shown in Fig. 8, concave as shown in Fig. 9, or convex as shown in Fig. 10.

[0053] The flow guiding device 70, 170 according to the two embodiments must be designed so that the angle a is at least 45 degrees for each transverse cross-section within the central portion 71, 171 of the flow guiding device 70, 170. Furthermore, the flow guiding device 70, 170 is arranged at a position so as to generate a separation of airflow along at least a central longitudinal portion 71, 171 of the flow guiding device 70, 170 from the pressure side of the blade at a point between the flow guiding device 70, 170 and the trailing edge 20, 120 of the blade 10, 110, when the blade 10, 110 is impacted by the incident airflow. Near the longitudinal ends of the flow guiding device 70, 170 design variances may fall outside these design parameters. Preferably, the central portion 71, 171 of the flow guiding device extends along at least 80% of the longitudinal extent of the flow guiding device 70, 170.

[0054] Fig. 11 and Fig. 12 show graphs of the lift coefficients c_l and the lift-to-drag ratio c_l / c_d, respectively, as a function of the angle of attack AOA for various angles a and for a constant rear edge height of the flow guiding device. The particular profile, which has been examined in these measurements, is designed for operation with an angle of attack AOA falling within approximately 15 to 20 to degrees. Furthermore, the inflow surface is substantially straight.

[0055] In Fig. 11, the first graph 210 depicts the lift coefficient c_l as a function of the angle of attack AOA for a = 25 degrees, the second graph 220 depicts the lift coefficient c_l, as a function of the angle of attack AOA for a = 65 degrees, and the third graph 230 depicts the lift coefficient c_l as a function of the angle of attack AOA for a = 85 degrees. It can be seen that the lift coefficient is increased significantly within the design AOA. The lift coefficient for a = 85 degrees is for instance 10-12% higher than for a = 25 degrees.

[0056] In Fig. 12, the first graph 240 depicts the lift-to-drag ratio c_l / c_d as a function of the angle of attack AOA for a = 25 degrees, the second graph 250 depicts the lift-to-drag ratio c_l / c_d as a function of the angle of attack AOA for a = 65 degrees, and the third graph 260 depicts the lift-to-drag ratio c_l / c_d as a function of the angle of attack AOA for a = 85 degrees. It can be seen that the lift-to-drag ratio is increased significantly within the design AOA. The lift coefficient for a = 85 degrees is for instance approximately 5% higher than for a = 25 degrees.

[0057] It should be noted that the second angle θ may be used as a supplemental or an alternative parameter for designing the flow guiding device. In this case, the second angle θ should be at least 25 degrees according to the invention. The graphs depicted in Figs. 11 and 12 correspond to second angles θ of 0, 45 and 60 degrees, respectively. Since the inflow surface is straight, the second angle θ also corresponds to the angle between the end point tangent and the chord.

[0058] It has also been found that the height of the flow guiding device as well as the chordal position of the flow guiding device are relevant for the performance of the blade. Accordingly, another design parameter must be introduced when designing the flow guiding device, viz. the height of the flow guiding device (or equivalently a minimum distance d_{ep} of the end point to the profiled contour of the blade) and the relative chordal position c_{ep} of the end point. These parameters are shown in Fig. 13. Thus, it is seen that the design parameter d_{ep} is given as the distance from the end point of the inflow surface to the profiled contour along a normal to the profiled contour. Thus, the minimum distance corresponds to the radius of a circle with a centre at the end point of the inflow surface and touching only a single point of the profiled contour of the blade. The height of the flow guiding device is in the following described as the relative height, which for a given cross-section is given as the ratio d_{ep}/t_{max} between the minimum distance of the end point to the profiled contour and a maximum thickness t_{max} of the profiled contour in that cross section.

[0059] The increase in the height of the flow guiding device also increases the drag of the particular blade segment significantly. However, experiments have surprisingly shown that the flow guiding device according to the invention, despite the increase in drag, improves the overall lift and/or the overall lift-to-drag ratio significantly compared to conventional flow guiding devices, where the relative height is substantially less than 10%.

[0060] As seen from the experiments plotted in Figs. 11 and 12, the lift-to-drag ratio is substantially constant in the range of a release angle of 60 to 90 degrees. Therefore, the experiments have shown that it as such is sufficient to use a flow guiding device protruding substantially normally from the profiled contour of the blade. Such an embodiment is shown in Fig. 14, in which like numerals correspond to like parts of the embodiment shown in Fig. 4, and where it is seen that a substantially rib-shaped flow guiding device 270 protrudes from the surface on the suction side of the blade. The inflow surface 272 is in this embodiment seen to face towards the incoming flow or towards the leading edge of the blade. The flow guiding device 270 can be mounted to the surface of the blade by use of a first attachment means 294 and a second attachment means 296, which may be connected to the blade in any conventional manner, such as by gluing or by using nut and bolt means. Alternatively, it may be sufficient to use an angle bar with only a single attachment means.

[0061] Figs. 15-18 show graphs of the lift coefficients c_l and the lift-to-drag ratio c_l / c_d, respectively, and where the effects of varying the height of the flow guiding device can be seen. The experiments were carried out on a transition profile having a chordal length of 450 mm and a maximum thickness of 280 mm. The flow guiding devices used were ribs mounted to the pressure side of the profile. The flow guiding devices were tested at two mounting points being 210 mm from the leading edge of the blade, corresponding to a relative chordal position of 47%, and 410 mm from the leading edge of the blade, corresponding to a relative chordal position of 91%. Three different ribs were used having a height of 20 mm, 30 mmm and 40 mm, respectively, corresponding to a relative height of 7.1%, 10.7%, and 14.3%, respectively.

[0062] In Fig. 15, the first graph 310 depicts the lift coefficient c_l as a function of the height of the rib for an angle of attack being 9 degrees and mounted at a relative chordal position of 47%. The second graph 315 depicts the lift coefficient c_l as a function of the height of the rib for an angle of attack being 27 degrees and mounted at a relative chordal position of 47%. The third graph 320 depicts the lift coefficient c_l as a function of the height of the rib for an angle of attack being 9 degrees and mounted at a relative chordal position of 91%. The fourth graph 325 depicts the lift coefficient c_l as a function of the height of the rib for an angle of attack being 27 degrees and mounted at a relative chordal position of 91%.

[0063] Fig. 16 shows the corresponding graphs for the lift-to-drag ratio c_l/c_d. The first graph 330 depicts the lift-to-drag ratio c_l/c_d as a function of the height of the rib for an angle of attack being 9 degrees and mounted at a relative chordal position of 47%. The second graph 335 depicts the lift-to-drag ratio c_l/c_d as a function of the height of the rib for an angle of attack being 27 degrees and mounted at a relative chordal position of 47%. The third graph 340 depicts the lift-to-drag ratio c_l/c_d as a function of the height of the rib for an angle of attack being 9 degrees and mounted at a relative chordal position of 91%. The fourth graph 345 depicts the lift-to-drag ratio c_l/c_d as a function of the height of the rib for an angle of attack being 27 degrees and mounted at a relative chordal position of 91%.

[0064] In Fig. 17, the first graph 350 depicts the lift coefficient c_l as a function of the angle of attack for a flow guiding device being mounted at a relative chordal position of 47% and having a relative height of 7.1%. The second graph 355 depicts the lift coefficient c_l as a function of the angle of attack for a flow guiding device being mounted at a relative chordal position of 47% and having a relative height of 14.3%. The third graph 360 depicts the lift coefficient c_l as a function of the angle of attack for a flow guiding device being mounted at a relative chordal position of 91% and having a relative height of 7.1 %. The fourth graph 365 depicts the lift coefficient c_l as a function of the angle of attack for a flow guiding device being mounted at a relative chordal position of 91% and having a relative height of 14.3%.

[0065] Fig. 18 shows the corresponding graphs for the lift-to-drag ratio c_l/c_d. The first graph 370 depicts the lift-to-drag ratio c_l/c_d as a function of the angle of attack for a flow guiding device being mounted at a relative chordal position of 47% and having a relative height of 7.1%. The second graph 375 depicts the lift-to-drag ratio c_l/c_d as a function of the angle of attack for a flow guiding device being mounted at a relative chordal position of 47% and having a relative height of 14.3%. The third graph 380 depicts the lift-to-drag ratio c_l/c_d as a function of the angle of attack for a flow guiding device being mounted at a relative chordal position of 91% and having a relative height of 7.1%. The fourth graph 385 depicts the lift-to-drag ratio c_l/c_d as a function of the angle of attack for a flow guiding device being mounted at a relative chordal position of 91% and having a relative height of 14.3%.

[0066] From Fig. 15 it is seen that there is an increase in the lift coefficient, when the height of the flow guiding device is increased; this being independent on the position of the flow guiding device and on the angle of attack of the incoming flow. By increasing the relative height of the flow guiding device from 7.1% to 14.3%, the lift is increased with 15%-50% depending on the position of the device and the angle of attack. For all device positions and operational angle of attacks, the tendency is that the larger the height of the flow guiding device, the higher the lift coefficient. This is also supported by Fig. 17 and additional experiments (not shown) carried out by the applicant.

[0067] It can also be seen from Fig. 15 that the flow guiding device should be moved towards the leading edge of the blade under operational conditions, where the angle of attack of the incoming flow is low. Conversely, the flow guiding device should be moved towards the trailing edge of the blade, when the angle of attack is high. On a rotor blade, the flow angle will decrease with increasing blade radius due to the increase in the local rotational speed. Hence, near the root region, the flow guiding device should be moved towards the trailing edge of the blade, e.g. near a relative chordal position of 90%, and it should then approach the leading edge, e.g. near a relative chordal position of 50%, when looking in the outboard direction towards the airfoil region.

[0068] Fig. 16 shows that the lift-to-drag ratio increases, when the flow guiding device is moved towards the trailing edge of the blade independently on the height of the flow guiding device.

[0069] As shown in Fig. 17, the lift coefficient will increase with increasing angle of attack, when the flow guiding device is placed near the trailing edge of the blade, whereas the lift coefficient will start to decrease for forward positions of the flow guiding device. So, depending on the exact inflow angle at a given section, there is one optimum location for the flow guiding device that will yield the maximum possible lift coefficient.

[0070] Fig. 18 shows that the variation in the lift-to-drag ratio as a function of the angle of attack is insignificant compared to the effect of varying the height of the flow guiding device. It is also seen that the effect of varying the height of the flow guiding device is decreased, when the flow guiding device is moved to a forward position, i.e. towards the leading edge of the blade. Thus, the operational range for the inflow angle may be expanded.

[0071] The invention has been described with reference to a preferred embodiment. However, the scope of the invention is not limited to the illustrated embodiment, and alterations and modifications can be carried out without deviating from the scope of the invention.

List of reference numerals

[0072]

2
: wind turbine

4
: tower

6
: nacelle

8
: hub

10
: blade

14
: blade tip

16
: blade root

18
: leading edge

20
: trailing edge

30
: root region

32
: transition region

34
: airfoil region

40, 42, 50
: profiled contour / profiles

44
: chord

52
: pressure side

54
: suction side

56
: leading edge

58

trailing edge
60
chord
62
camber line / median line
70
flow guiding device / spoiler
71
central longitudinal portion
72
inflow surface
74
start point
76
end point
78
profile tangent
80
end point tangent
82
crossing point
84
rear edge of flow guiding device
86
median line to the inflow surface
210-260
graphs
294
first attachment means
296
second attachment means
310-385
graphs
a
angle between profile tangent and end point tangent
c
chord length
c_l
lift coefficient
c_l/c_d
lift-to-drag ratio
d_t
position of maximum thickness
d_f

position of maximum camber

f

camber

t

thickness

t_{max}

maximum thickness of cross-sectional profile

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- WO2007065434A **[0005]**
- WO2007045244A **[0006]**
- WO2007118581A **[0007]**
- WO0208600A **[0008]**

Krav

1. En vinge (10) til en rotor på et vindenergianlæg (2) med en i hovedsagen vandret rotorakse, idet rotoren omfatter et nav (8), ud fra hvilket vingen (10) strækker sig i en i hovedsagen radial retning, når den er monteret til navet (8), hvor vingen har en langsgående retning (r) med en tipende (14) og en rodende (16) samt en tværgående retning, hvor vingen yderligere omfatter:

- en profileret kontur (40, 42, 50) omfattende en trykside og en sugeside såvel som en forkant (18) og en bagkant (20) med en korde havende en kordelængde strækkende sig derimellem, hvor den profilerede kontur, når den rammes af en indkommende luftstrøm, genererer lidt, hvor den profilerede kontur er opdel i:

- et rodområde (30) med en i hovedsagen cirkulær eller elliptisk profil tættest på navet,

- et bæreplansområde (34) med en liftgenererende profil længst fra navet, og

- et overgangsområde (32) mellem rodområdet (30) og bæreplansområdet (32), hvor overgangsområdet (32) har en profil, der gradvist ændrer sig i den radiale retning fra rodområdets cirkulære eller elliptiske profil til bæreplansområdets liftgenererende profil, og hvor

- vingen er forsynet med en strømningsstyringsindretning (70), der er tilføjet til vingens profilerede kontur (40, 42, 50) på vingens trykside (62), hvor strømningsstyringsindretningen (70) har en indstrømningsoverflade (72) med et startpunkt (74) fastgjort til den profilerede kontur (40, 42, 50) og et endepunkt (76) lokaliseret i afstand fra vingens profilerede kontur (40, 42, 50), idet endepunktet har en minimum afstand (d_{ep}) til vingens profilerede kontur,

- strømningsstyringsindretning (70) strækker sig langs i det mindste en langsgående del af overgangsområdet (32) og er placeret til at generere en separation af luftstrøm langs i det mindste en central del (71) af strømningsstyringsindretning (70) from vingens (10) trykside (52) ved et punkt mellem strømningsstyringsindretningen (70) og vingens (10) bagkant (20), når vingen (10) rammes af en indkommende luftstrøm, hvor

- strømningsstyringsindretningen (70) i det mindste i en central langsgående del er placeret så endepunktet (76) har en relativ kordeposition, set fra vingens forkant, liggende i et interval mellem 40% og 92%, **kendetegnet ved, at**

- indstrømningsoverfladen (72) i det mindste i den centrale langsgående del (71) er udformet for hvert tværsnit så minimumafstanden (d_{ep}) fra endepunktet (76) til den profilerede kontur er i det mindste 15% af den profilerede konturs maksimale tykkelse, og hvor indstrømningsoverflade (72) er konkav, og hvor strømningsstyringsindretningen har en bagkant med en bagkantshøjde, og hvor bagkantshøjden er i hovedsagen konstant i det mindste i strømningsstyringsindretningens centrale langsgående del.

2. En vingen ifølge krav 1, hvor indstrømningsoverfladen (72) i det mindste i den centrale langsgående del (71) er udformet, så – for hvert tværsnit - en endepunktstangen (80) til indstrømningsoverfladen (72) ved endepunktet (76) krydser den profilerede kontur (40, 42, 50) ved et krydspunkt (82), hvor den profilerede kontur (40, 42, 50) har en profiltangent (78) til den profilerede kontur (40, 42, 50), og hvor en vinkel (a) mellem profiltangenten (78) og endepunktstangenten (80) er i det mindste 45 grader.

3. En vinge ifølge krav 2, hvor vinklen mellem profiltangenten (78) og endepunktstangenten (80) er i det mindste 50 grader, eller i det mindste 55 grader, eller i det mindste 60 grader.

4. En vinge ifølge de foregående krav, hvor en medianlinje til indstrømningsoverfladen (72) danner en anden vinkel (θ) med korden (44), hvor den anden vinkel er i det mindste 25 grader, eller i det mindste 30 grader, eller i det mindste 35 grader.

5. En vinge ifølge de foregående krav, hvor den relative kordeposition fra endepunktet, set fra vingens forkant, ligger i et interval mellem 75% og 92%, og hvor en angrebsvinkel for et designpunkt for den centrale langsgående del ligger i et interval på mellem 15 og 25 grader, eller mellem 15 og 20 grader.

6. En vinge ifølge ethvert af kravene 1-4, hvor den relative kordeposition fra endepunktet, set fra vingens forkant, ligger i et interval mellem 40% og 80%, eller mellem 40% og 70%, eller mellem 40% og 60%.

7. En vinge ifølge de foregående krav, hvor strømningsstyringsindretningen (70) strækker sig langs i hovedsagen i hele overgangsområdets (32) langsgående længde.

8. En vinge ifølge de foregående krav, hvor den centrale langsgående del (71) er i det mindste 50%, 60%, 70%, 80%, eller 90% af strømningsstyringsindretningen (70) langsgående udstrækning.

9. En vinge ifølge de foregående krav, hvor strømningsstyringsindretningen (70) strækker sig ind i rodområdet (30).

10. En vinge ifølge de foregående krav, hvor den relative kordeposition for endepunktet, set fra vingens forkant, mindskes i vingens langsgående retning.

11. En vinge ifølge krav 10, hvor den relative kordeposition for endepunktet ved en indenbords del af strømningsstyringsindretningen, set fra vingens forkant, ligger i et interval mellem 75% og 92%, og den relative kordeposition for endepunktet ved en udenbords del af strømningsstyringsindretningen ligger i et interval mellem 40% og 60%.

12. En vinge ifølge de foregående krav, hvor strømningsstyringsindretningen (70) er udformet som er ribbe, der rager ud fra vingens profilerede kontur, eksempelvis i hovedsagen normal til vingens profilerede kontur.

13. En vinge ifølge de foregående krav, hvor strømningsstyringsindretningen (70) er integreret udformet med vingen (10), alternativt hvor strømningsstyringsindretningen (70) er monteret på vingens (10) overflade.

14. Et vindenergianlæg omfattende et antal, fortrinsvist to eller tre, vinge ifølge ethvert af de foregående krav.

DRAWINGS

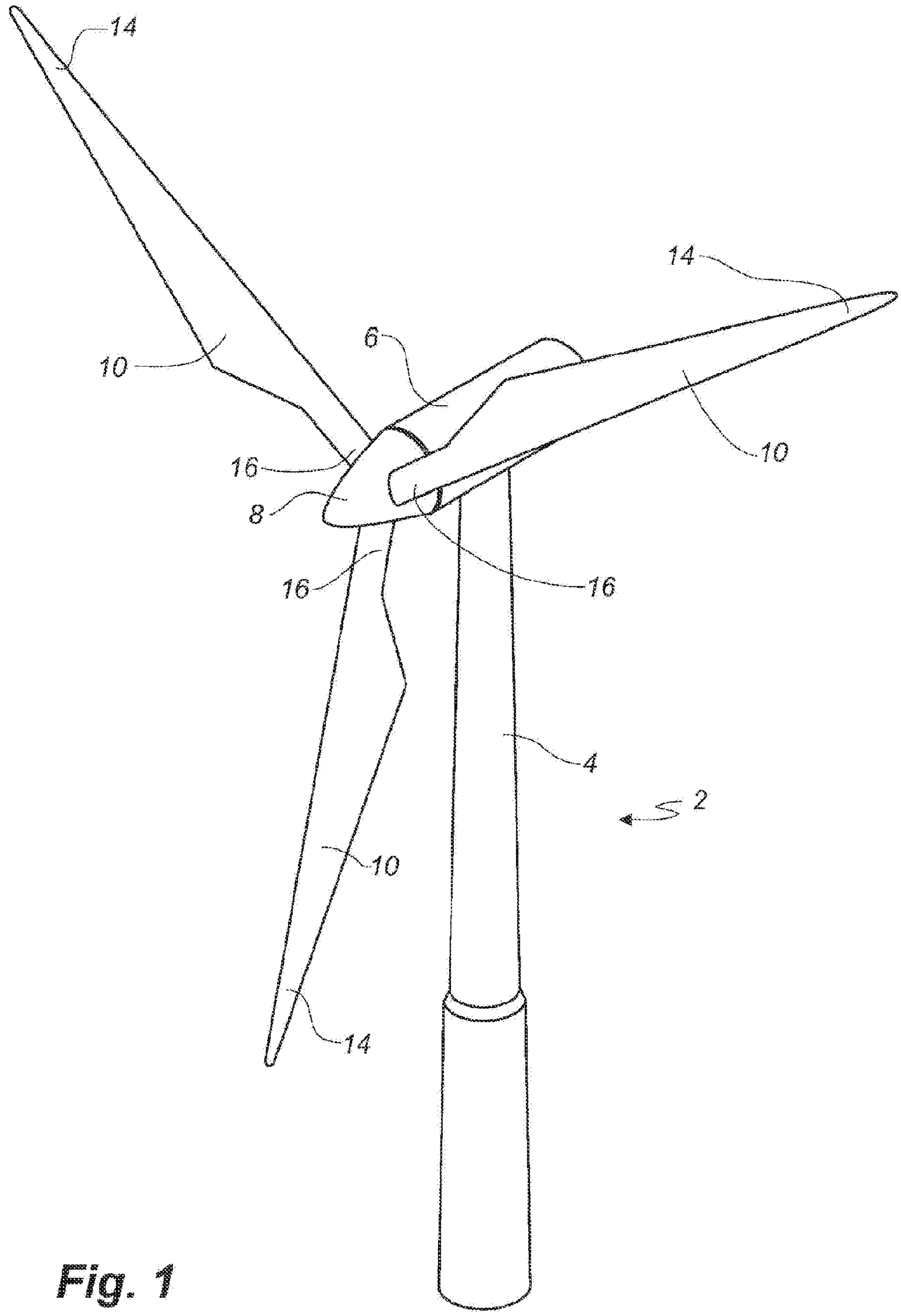

Fig. 1

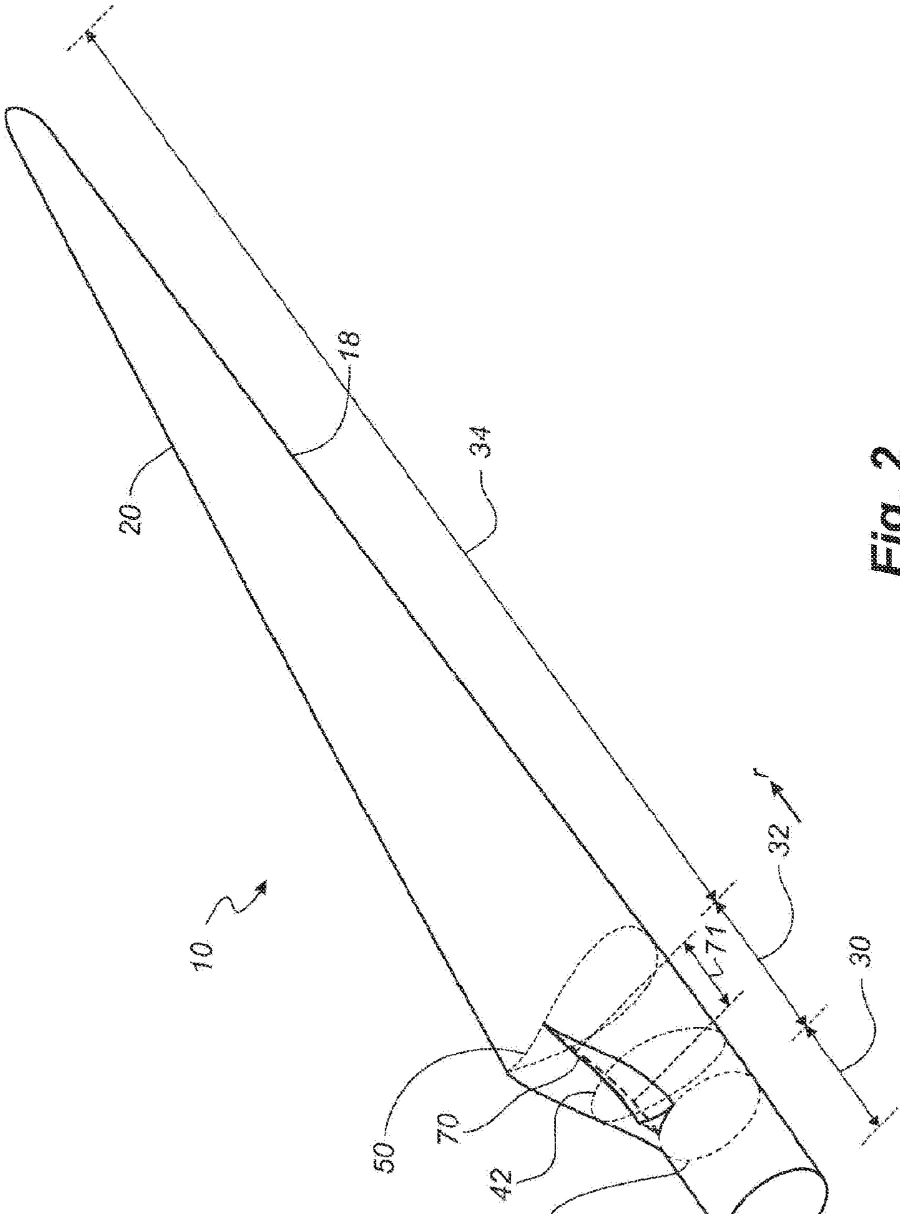

Fig. 2

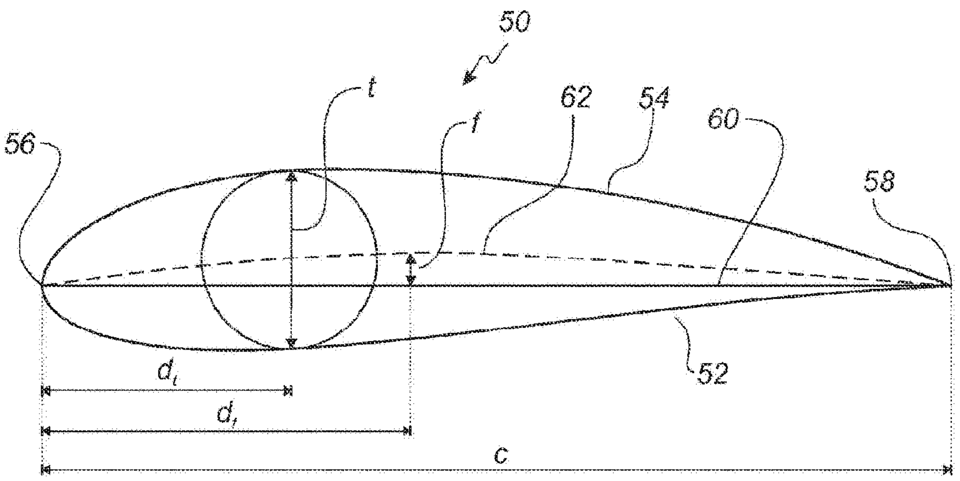

Fig. 3

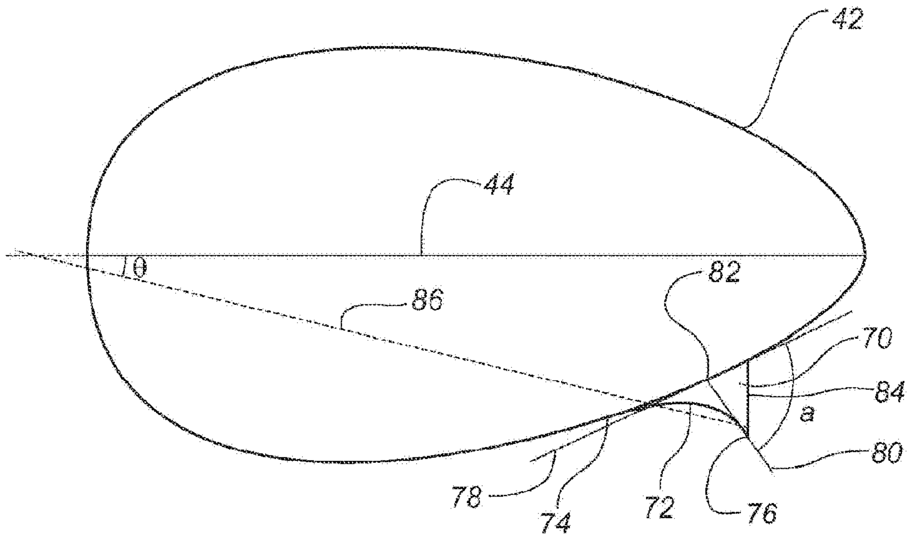

Fig. 4

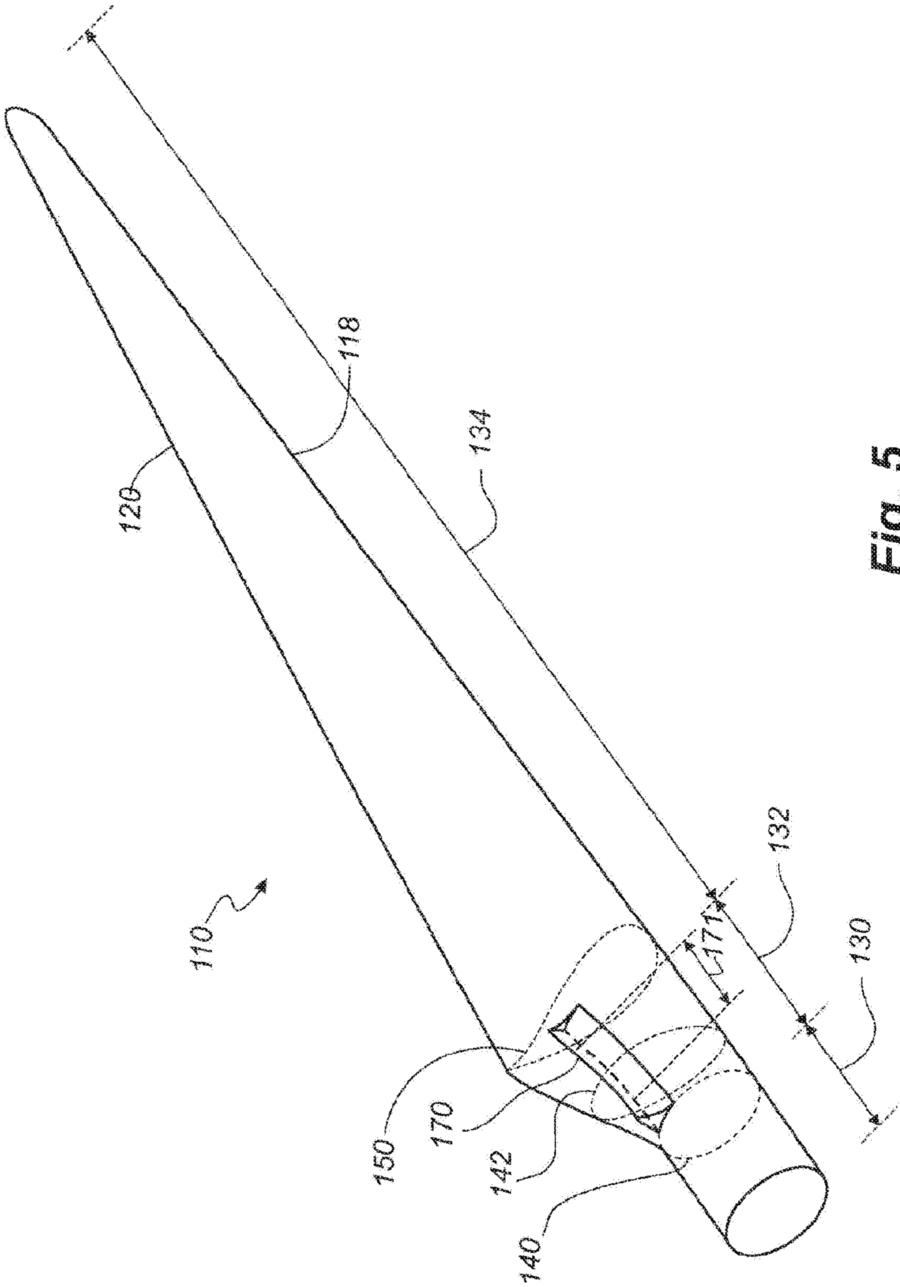

Fig. 5

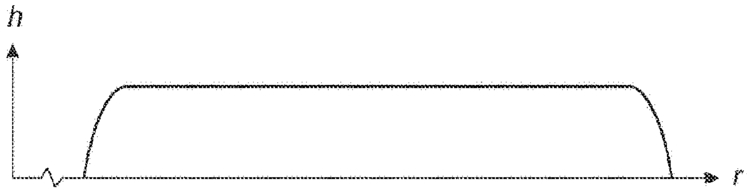

Fig. 6

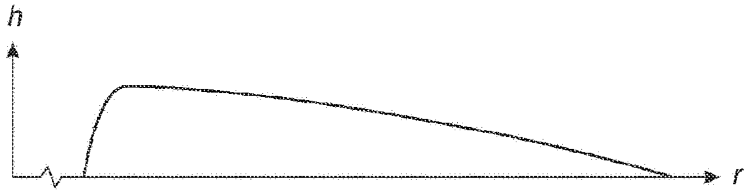

Fig. 7

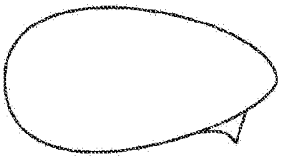

Fig. 8

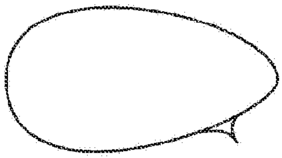

Fig. 9

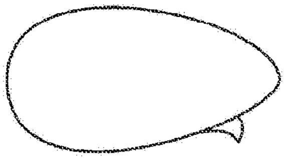

Fig. 10

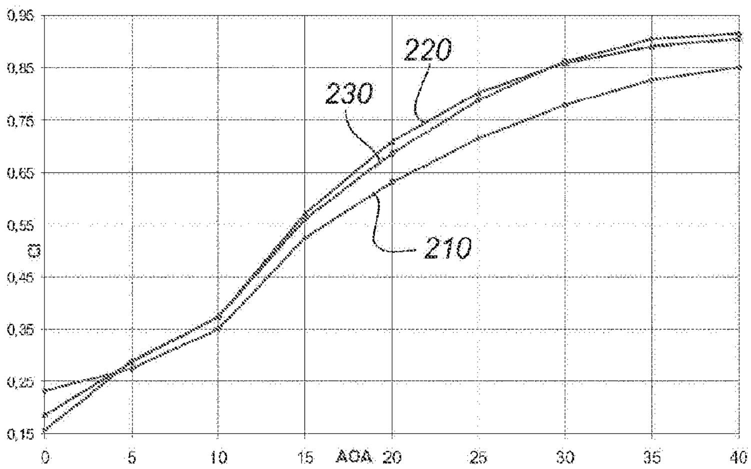

Fig. 11

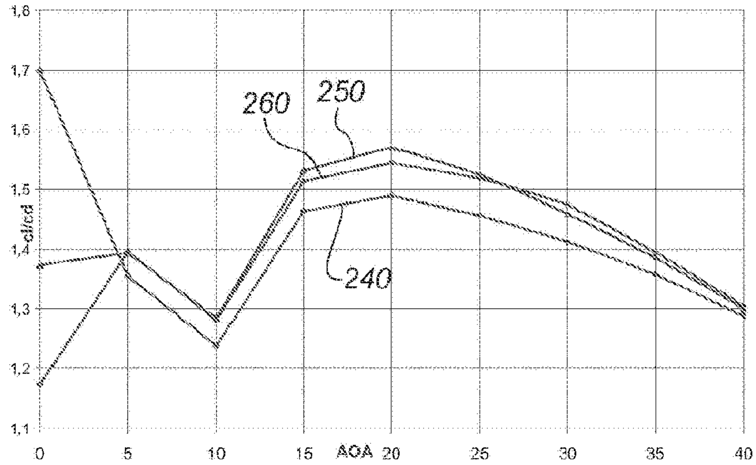

Fig. 12

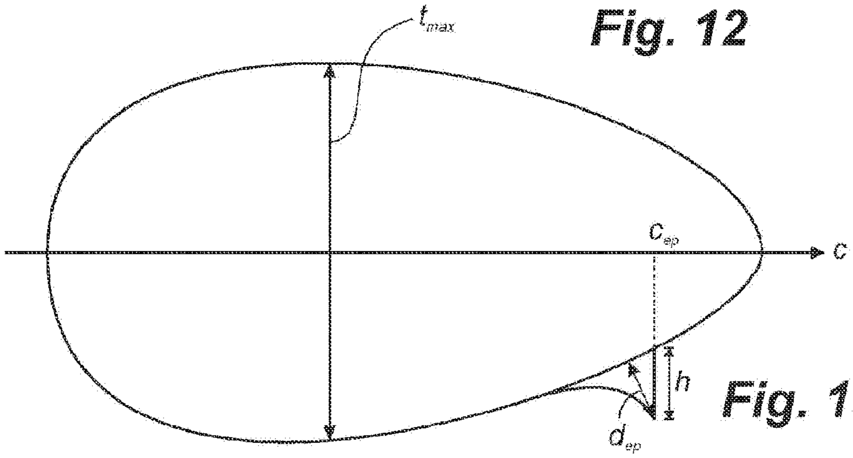

Fig. 13

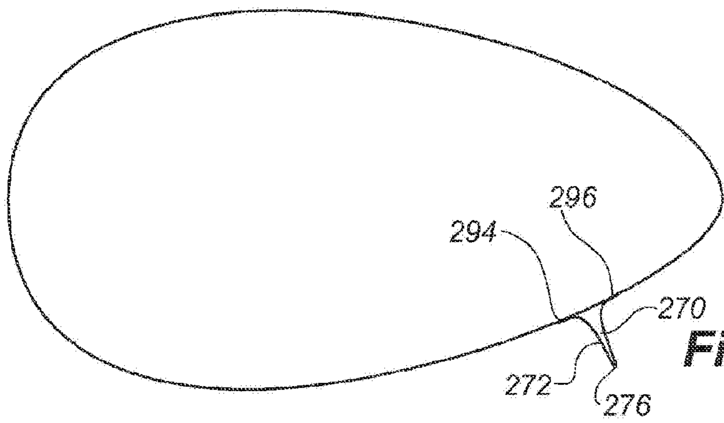

Fig. 14

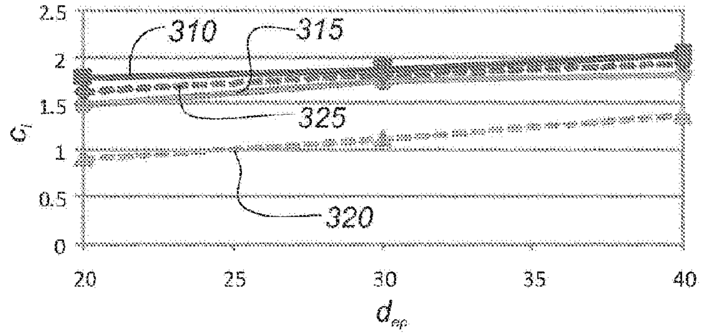

Fig. 15

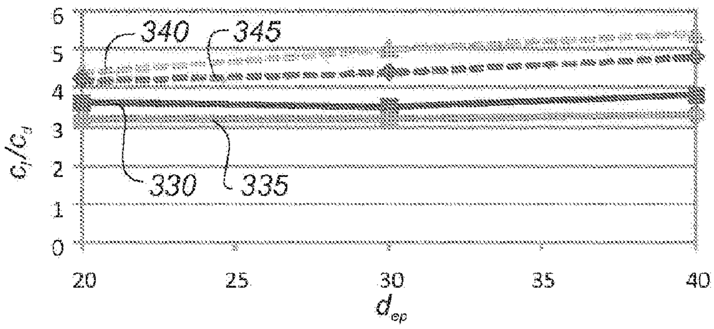

Fig. 16

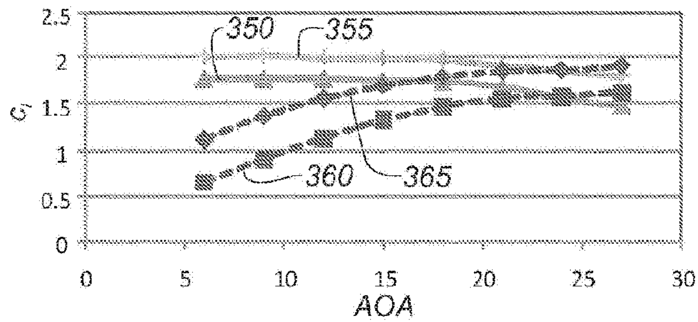

Fig. 17

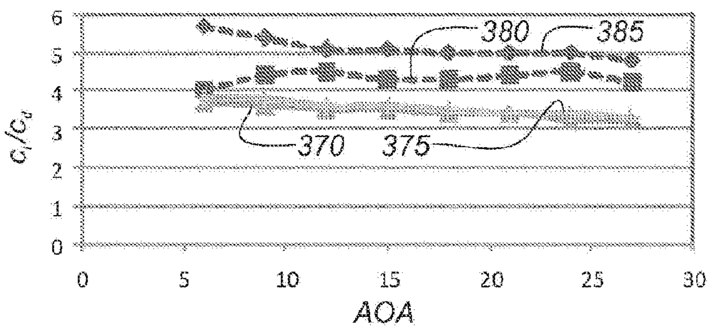

Fig. 18