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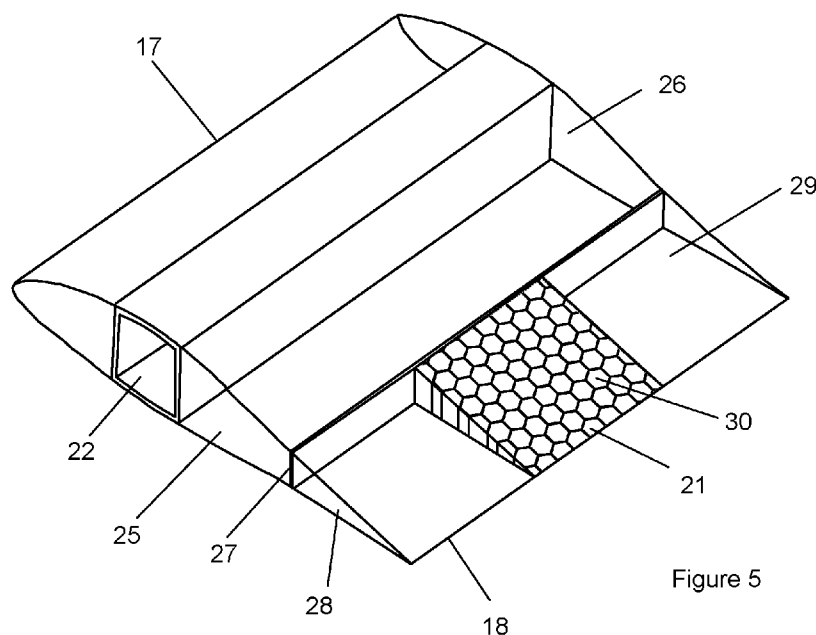


Figure 5

(57) Abstract: A wind turbine blade defining an aerodynamic airfoil cross-section between a leading edge and a trailing edge, the blade comprising a blade body; a flap moveable relative to the blade body, the flap comprising a pressure skin, a suction skin and a core disposed between the pressure skin and the suction skin; wherein the core comprises an anisotropic material.

A WIND TURBINE BLADE HAVING A FLAP

The present invention relates to a wind turbine rotor blade. In particular it relates to a wind turbine blade having a flap for modifying the aerodynamic surface and/or camber of the blade in order to alleviate loads acting on the wind turbine rotor.

Modern wind turbines are controlled during operation in order to optimise the performance of the wind turbine in different operating conditions. The different operating conditions can arise from changes in wind speed and wind gusts which are local fast variations in wind speed. It is well known to regulate the speed of rotation of the rotor of a horizontal axis wind turbine by pitching the blades of the rotor. This is typically achieved by turning the blades about their longitudinal axis to influence the aerodynamic angle of attack of the rotor blades, this is the method used in pitch controlled wind turbine and active stall controlled wind turbines.

Wind turbines are subjected to loads of a highly variable nature due to the wind conditions. In modern wind turbines, as the rotor is typically able to control its pitch angle, the pitch can be used not only for controlling the speed of the rotor, but also for reducing the variations in load on the blades. However, due to the large length of modern wind turbine blades and the associated high inertia of the masses to be rotated about a pitch axis, the blade pitch mechanisms are not ideal for reacting rapidly to variations in wind speed which occur over a short time frame. In addition the length of wind turbine blades is increasing with new technology and the blades are becoming more flexible due to their greater length. Consequently, with the length of wind turbine blades increasing, when the blades are pitched there is a longer time lag for the pitch to change at the tip where the main loads are on the blades. Furthermore, controlling the loads on the blades with the use of a pitch system can be problematic as the blade pitch bearings may become damaged with constant use.

It is possible to regulate the loads acting on the blades of a wind turbine rotor with devices which modify the aerodynamic surface or shape of the blades such as by deformable trailing edges which can include trailing edge flaps. Such aerodynamic devices are advantageous because they allow a faster response time due to their relatively low inertia as they are small compared to the size of the entire wind turbine blade. One such example of a wind turbine blade which has a deformable trailing edge is described in WO2008/132235. Such a deformable trailing edge may be described as a morphing flap.

A flap on a wind turbine blade may be moved by using one of a number of actuators, such as an electric actuator, a pneumatic actuator, a hydraulic actuator or a piezo electric actuator. The actuator used to move the flap must overcome the aerodynamic loads exerted on the flap by the wind conditions; and if the flap is of the morphing type, the stiffness of the flap itself, i.e. the resistance of the flap to deflect.

In order for a morphing flap to modify the aerodynamic surface or shape of the blades, it must be sufficiently strong to carry the aerodynamic loads. However, the greater the resistance of the morphing flaps to deformation means that the actuator will require greater power to deflect the flap. On a wind turbine blade, the actuator may be located adjacent to the flap with the blade itself and the space available for the actuator is limited by the size of the blade. Therefore, it is desirable to have as small an actuator as possible. The flaps are also in an outboard region of the blades (i.e. near to the tip end) and increased weight, through large heavy actuators, at outboard positions on a blade is undesirable. It is also desirable to have an actuator that has a low power consumption, in order to improve the efficiency of the whole wind turbine. Therefore, a problem exists between a desire to have a lightweight actuator with a low power consumption, and a flap that is structurally stiff to resist the aerodynamic loads.

It is an aim of the present invention to provide a flap that has the capabilities to withstand the aerodynamic loads exerted upon the flap, yet can be actuated with a minimal power consumption.

According to a first aspect of the present invention there is provided a wind turbine blade defining an aerodynamic airfoil cross-section between a leading edge and a trailing edge, the blade comprising:

- a blade body;
- a flap moveable relative to the blade body, the flap comprising a pressure skin, a suction skin and a core disposed between the pressure skin and the suction skin;
- wherein the core comprises an anisotropic material.

The core comprises an anisotropic material, which means that it has properties which are directionally dependent. In particular, the Young's modulus of the core is different in the chordwise and the thickness directions of the blade.

In the context of the present invention, the term "chord" shall designate the distance from the leading edge to the trailing edge of the blade at any given position along the length of the blade, and the "chordwise direction" is the direction between the leading edge and

the trailing edge. The term "thickness" shall designate the distance between the pressure and the suction side of the blade and the "thickness direction" is the direction between the pressure and the suction side of the blade. The term "span" of the blade shall designate the length of the blade from the root to the tip and the "spanwise direction" is in the direction from the root to the tip of the blade.

Preferably the core is formed from a cellular material. The core may be a honeycomb core, and cells of the core may be substantially orientated in a thickness direction of the wind turbine blade.

Preferably, the core is a hexagonal honeycomb core.

The pressure skin may be formed from an elastomeric material.

The suction skin may be formed from fibre reinforced plastic material.

The wind turbine blade may further comprise an actuator for moving the flap relative to the blade body, the actuator being connected to the blade body and a trailing edge of the flap.

A Poisson's ratio of the core may be greater than -0.1 and less than 0.1, where the Poisson's ratio of the core is defined as the ratio of the proportional decrease in the strain in the spanwise direction to the proportional increase in strain in the chordwise direction of the core when the flap is moved relative to the blade body.

The Poisson's ratio of the core may be zero, where the Poisson's ratio of the core is defined as the ratio of the proportional decrease in the strain in the spanwise direction to the proportional increase in strain in the chordwise direction of the core when the flap is moved relative to the blade body.

Preferably the flap is a morphing flap.

According to the invention, a wind turbine having at least one blade as described above is provided. Such a wind turbine may be a three-bladed horizontal axis wind turbine of the type known as the "Danish Design".

An example of the invention will now be described with reference to the accompanying drawings in which:

Figure 1 is a view of a wind turbine.

Figure 2 is a plan view of a wind turbine blade according to the invention.

Figure 3 is a cross sectional view of the wind turbine blade along the line III-III in Figure 2.

5 Figure 4 is an enlarged view of the flap of the wind turbine blade according to the invention.

Figure 5 is a view of a section of the wind turbine blade according to the invention.

Figures 6a and 6b are views showing the flap in a deflected position according to the invention.

10 Figure 7 is a cross sectional view of the wind turbine blade along the line III-III in Figure 2 showing an actuator.

Figure 8 is a schematic view of a core material according to the invention.

Figure 1 shows a horizontal axis wind turbine 10 according to the invention. The turbine
15 comprises a tower 11 which supports a nacelle 12. The wind turbine 10 comprises a rotor 13 made up of three blades 14 each having a root end 15 mounted on a hub 16. Each blade 14 comprises a leading edge 17, a trailing edge 18, and a tip 19.

Figure 2 illustrates a blade 14 according to the invention. The blade 14 comprises a
20 blade body 20 and three trailing edge flaps 21a, 21b and 21c (collectively referred to as 21) connected to the blade body and spaced along the span of the blade for modifying the aerodynamic surface or shape of the rotor blade. In use, when the turbine is generating power, the flaps 21 are actuated so that they deflect in order to reduce the loads experienced by the wind turbine 10.

25 Figure 3 is a cross section of the blade 14 along the line III-III in Figure 2. As shown in Figure 3, the blade 14 comprises a first structural member 22 which is formed as a spar. The spar 22 comprises an upper and lower spar cap 22a, 22b and a leading and trailing shear web 23a, 23b to form a hollow box section which may extend from the root end 15 in the direction of the tip 19. The spar 22 is used to transfer load from the rotor blade 14 to the hub 16 of the wind turbine 10. Such loads can be tensile and compression forces or torque. The spar 18 is formed from composite materials, in this example, glass and carbon reinforcing fibres set in a thermoset resin matrix.

35 An aerodynamic shell 24 provides the aerodynamic profile and is supported by the spar 22. The shell 24 comprises a pressure skin 25, which faces towards a pressure side and a suction skin 26, which faces towards a suction side. The shell 24 may be formed from a composite material such as glass fibres embedded in a thermoset resin matrix

sandwiching a foam core. In an example not shown, the spar 22 may form part of the external aerodynamic profile. As shown in Figure 3, a second structural member 27 is provided. The second structural member is a rear or trailing edge spar formed from carbon and glass fibre embedded in a thermoset resin matrix. The rear spar 27 acts as an additional stiffening mechanism in the trailing edge region of the blade 14. The rear spar 27 extends along the length of the blade. In an example not shown, the rear spar 27 may form part of the external aerodynamic profile. The flap 21 is located between the rear spar 27 and the trailing edge 18.

The flap 21 is formed from a pressure skin 28 and a suction skin 29. The flap 21 is a morphing type flap, that is the pressure skin 25 of the blade body 20 is connected to the pressure skin 28 of the flap 21 to provide a streamlined surface. Similarly, the suction skin 26 of the blade body 20 is connected to the pressure skin 29 of the flap 21 to provide a streamlined surface. Therefore, when the flap 21 is moved relative to the blade body 20, the airfoil profile undergoes a morphing shape change which results in a continuous change in the chordwise camber which reduces the likelihood of premature flow separation over the blade. This can be contrasted to a hinged flap, such as a hinged flap found on an aircraft which pivots about a point. The morphing flap 21 is advantageous because it does not require any spanwise gaps which are needed in a hinged flap to accommodate the rotational movement of the flap as these spanwise gaps can promote drag and aeroacoustic noise. The skilled person will also appreciate that the flap 21 of the present invention does not require any sliding surfaces that accommodate movement of the flap's pressure/suction skin relative to the pressure/suction skin of the blade body, as can be found on other morphing flaps in the prior art. The removal of these sliding surfaces also reduces drag and aeroacoustic noise.

Figure 4 shows a cross sectional schematic view of the flap 21. The flap comprises a pressure skin 28 formed from an elastomeric skin such as a compliant silicone skin, which in this example is moulded silicone rubber. The suction skin 29 of the flap is formed from a composite skin, which in this example is a compliant carbon fibre reinforced plastic (CFRP) material. The suction skin 29 could also be formed from glass fibre reinforced plastic (GFRP) in order to reduce the risk of lightning strikes, by having a non-conductive surface on the blade. Disposed between the flap's pressure skin 28, the suction skin 29 and the rear spar 27 is a hexagonal honeycomb core 30. Figure 5 schematically illustrates how the cells of the core 30 are arranged so that they extend in the thickness direction of the airfoil between the pressure skin and the suction skin. It should be appreciated that the cells drawn in Figure 5 are not drawn to scale relative to the flap.

The main function of the pressure skin 28 is to seal the flap 21 from the external environment and to provide an aerodynamic surface. As it is formed from a compliant silicone skin, it is capable of taking high strains when the flap 21 deflects, and so the pressure skin 28 also has a low in-plane stiffness, i.e. the pressure skin will not crack or break when it is elongated. The stiffness of the pressure skin 28 is in the region of 0.1 MPa to 0.2 MPa and the maximum typical strain it is likely to experience in operation is up to 10 %, for a deflection of the flap 21 of +/- 10 degrees.

The suction skin 29 is formed from composite, which in this example is CFRP for strength considerations as the aerodynamic loads on the suction side are typically larger than the aerodynamic loads on the pressure side. Furthermore, using a composite skin reduces the risks of surface imperfections when the skin is deformed under load which can lead to premature flow separation over the suction surface with detrimental changes to the lift produced by the blade.

The pressure skin 28 and the suction 29 are attached to rear spar 27 with epoxy resin, or another suitable adhesive such as polyurethane. The skins 28 and 29 are each bonded to the core 30 with an epoxy resin, and at the trailing edge 18, the skins are bonded together with a suitable adhesive. A skin is also provided on each side of the spanwise and ends of the flap between the pressure skin 28 and the suction skin 29 in the thickness direction in order to seal the core 30.

In other examples, both the suction skin 29 and the pressure skin 28 may be formed from CFRP or other suitable materials which can withstand the aerodynamic loads exerted upon them as well as sealing the interior of the flap. For instance, depending on the aerodynamic loads that a particular wind turbine is likely to experience, it may be beneficial to form the pressure skin 28 from a composite material such as GFRP or CFRP and form the suction skin 29 from an elastomeric material.

As mentioned, the flap 21 is of a morphing type which is completely sealed by the pressure skin 28 and the suction skin 29. A completely sealed flap is more reliable than a hinged flap (where there is a gap between the hinged flap and the blade body) (or indeed a morphing flap which has a sliding surface to accommodate movement), as it is sealed from the weather and the possible ingress of water, moisture, dust, insects and the like.

Figure 6a illustrates the position of the flap 21 when it has been deflected towards the pressure side by an angle of 10 degrees and Figure 6b illustrates the position of the flap 21 when it has been deflected towards the suction side by an angle of 10 degrees. Figure 4 shows the neutral position of zero degrees. In Figures 6a and 6b the honeycomb core has not been shown for clarity.

Figure 7 shows how the flap is caused to deflect by a linear motor 40. The linear motor 40 is anchored at a first end 41 to the spar 22, and a second end 42 of the linear motor 40 is connected via a push-pull actuator rod 43 to a mounting point 44 adjacent to the trailing edge 18. The actuator rod 43 is formed from CFRP and extends through a slot in the rear spar 27 as well as the honeycomb core 30 (not shown for clarity). The linear motor 40 is operated so as to move the actuator rod 43 in a chordwise direction between the leading edge 17 and the trailing edge 18. As the actuator rod moves towards the leading edge 17, the flap 21 will deflect to the position shown in Figure 6a. As the actuator rod moves towards the trailing edge 18, the flap 21 will deflect to the position shown in Figure 6b. Carbon fibre restraints (not shown) may be bonded to the core 30 in order to allow the actuator rod 43 to move freely and prevent it from exerting any loads on the pressure skin 28. The actuator rod 43 and the restraints may be formed from other materials such as GFRP which is non-conductive in order to avoid any potential risks of lightning strikes.

The skilled person will appreciate that there are other ways to operate the flap 21 to cause it to deflect, such as piezoelectric actuators, hydraulic actuators or pneumatic actuators, such as a pneumatic muscle as described in our co-pending patent application PCT/DK2011/050322. There may also be multiple actuators per flap. The actuators may be located at the blade root or in the wind turbine hub and a pull rod can connect this inboard actuator to the flap which is located outboard on the blade.

Referring back to Figures 4 and 5, it will now be explained how the flap structure requires a relatively low actuator power to deflect the flap against the aerodynamic loads and the stiffness of the flap itself. In this example, the core 30 is an aramid hexagonal honeycomb core. This core 30 is highly anisotropic, and the stiffness of the core is greater in the thickness direction than in the chordwise direction or the spanwise direction. This results in the flap having a low flexural stiffness in the chordwise plane and so a small actuation force is needed to deflect the flap. However, in the thickness direction, the stiffness is greater and can thus the flap can withstand the aerodynamic loads that are exerted upon it during use. The Young's modulus of the core in the chordwise

direction is typically in the range of 0.1 MPa to 0.2 MPa. The Young's modulus of the core in the thickness direction is typically in the range of 10 MPa to 1000 MPa.

5 The flap 21 is also constructed so that the core 30 approximates a zero Poisson's ratio cellular structure. This means that as the flap 21 is deflected towards the pressure side or the suction side, there is no spanwise contraction or expansion of the flap 21. If the core 30 was to have a non-zero Poisson's ratio, when the flap is deflected there would be some change in the spanwise length and this can result in spanwise curvature of the flap. However, by constructing the core 30 so that it has a zero Poisson's ratio (or substantially zero) suppresses any spanwise curvature generated when the core 30 deforms.

10 The term "substantially zero Poisson's ratio" means that when the flap is deflected, there is limited spanwise curvature of the flap so that the movement of the flap undergoes motion without any unwanted spanwise variation in geometry. Such a range of Poisson's ratio may be between -0.1 and 0.1.

Figure 8 illustrates how the honeycomb core 30 is constructed in this example so that it has a substantially zero Poisson's ratio in the spanwise direction. The hexagonal honeycomb core 30 is provided with discontinuities 50 illustrated by the dashed lines.

20 The discontinuities 50 are in the form of slits through the core 30 which extend in a thickness between the pressure surface 28 to the suction surface 29, and in a chordwise direction between the rear spar 27 and the trailing edge 18. The slits 50 result in the core being split up into separate core elements identified as 30a to 30d in Figure 8. The discontinuities 50 enable sufficient spanwise contraction and expansion of the core elements 30a to 30d such that the global response of the core approximates a zero Poisson's ratio cellular structure.

This example illustrates how a zero Poisson's ratio is achieved with discontinuities in a hexagonal cell honeycomb core material. However, the skilled person will appreciate that

30 the zero Poisson's ratio of the core may be achieved by using other cellular materials, such as a cellular material with an accordion shape.

In this example, the span of the blade is 50 meters and the chordwise length of the blade 10 through the line III-III in Figure 2 is 1.5 meters. The flap 21a has a chordwise length of

35 20% of the blade's chord length, i.e. 0.3 meters and the spanwise length of the flap is 0.25 meters. In other examples, the chordwise dimensions of the flaps are between 5% to 50% of the chordwise length of the blade. In other examples, the spanwise length of the flap is much greater, such as 1 meter, or even up to 10 meters. As described above,

the flap 21 is constructed so that spanwise curvature is avoided so long lengths of flaps are possible. The choice of a long flap length is advantageous because it avoids gaps between multiple shorter flaps, and the avoidance of gaps results in less aeroacoustic noise and less drag. The honeycomb core has a regular hexagonal shape and the length
5 of each side of each hexagonal cell is between 1 mm and 10 mm.

As described with reference to Figure 7, a push-pull actuator rod 43 is used to deflect the flap 21. However, the pressure skin 29 may be formed from a pre-stressed CFRP material which is biased towards the suction side. Therefore, the actuator 40 will pull the
10 actuator 43 in order to deflect towards the pressure side, and when the flap is to be deflected towards the suction side, the actuator is released so that flap 21 will defect to its biased, at rest, position. The biased position of the flap is chosen as a fail-safe position, so that if the actuator were to fail or lose power, the flap will automatically adopt a low lift or zero position.

15 The morphing flap 21 allows a large degree of deflection. It is expected that such a design of morphing flap 21 will be able to deflect between -20 degrees and +20 degrees, with the positive flap angle defined as toward the pressure side.

20 It is also possible to tailor the deflecting shape of flap 21 through the use of core materials having different properties. For example, the stiffness of the core 30 can be varied in the chordwise direction in order to give a desired camber curvature when the flap is deflected. Similarly, the core 30 can have a varying stiffness in the spanwise direction to tailor the shape of the flap in the spanwise direction when it is deflected. The
25 chordwise and spanwise tailoring can also be achieved by varying the stiffness of the flap's suction skin in the chordwise and spanwise direction.

CLAIMS

1. A wind turbine blade defining an aerodynamic airfoil cross-section between a leading edge and a trailing edge, the blade comprising:
 - 5 a blade body;
 - a flap moveable relative to the blade body, the flap comprising a pressure skin, a suction skin and a core disposed between the pressure skin and the suction skin;
 - wherein the core comprises an anisotropic material.
- 10 2. A wind turbine blade according to claim 1, wherein the core is formed from a cellular material.
3. A wind turbine blade according to claim 2, where the core is a honeycomb core, and cells of the core are substantially orientated in a thickness direction of the wind
15 turbine blade.
4. A wind turbine blade according to claim 3, where the core is a hexagonal honeycomb core.
- 20 5. A wind turbine blade according to any one of the preceding claims, wherein the pressure skin is formed from an elastomeric material.
6. A wind turbine blade according to any one of the preceding claims, wherein the suction skin is formed from fibre reinforced plastic material.
25
7. A wind turbine blade according to any one of the preceding claims, further comprising an actuator for moving the flap relative to the blade body, the actuator being connected to the blade body and a trailing edge of the flap.
- 30 8. A wind turbine blade according to any one of the preceding claims, wherein a Poisson's ratio of the core is greater than -0.1 and less than 0.1, wherein the Poisson's ratio of the core is defined as the ratio of the proportional decrease in the strain in the spanwise direction to the proportional increase in strain in the chordwise direction of the core when the flap is moved relative to the blade body.
- 35 9. A wind turbine blade according to claim 8, wherein the Poisson's ratio of the core, is zero, wherein the Poisson's ratio of the core is defined as the ratio of the proportional

decrease in the strain in the spanwise direction to the proportional increase in strain in the chordwise direction of the core when the flap is moved relative to the blade body.

10. A wind turbine blade according to any one of the preceding claims, wherein the
5 flap is a morphing flap.

11. A wind turbine having at least one blade according to any one of the preceding claims.

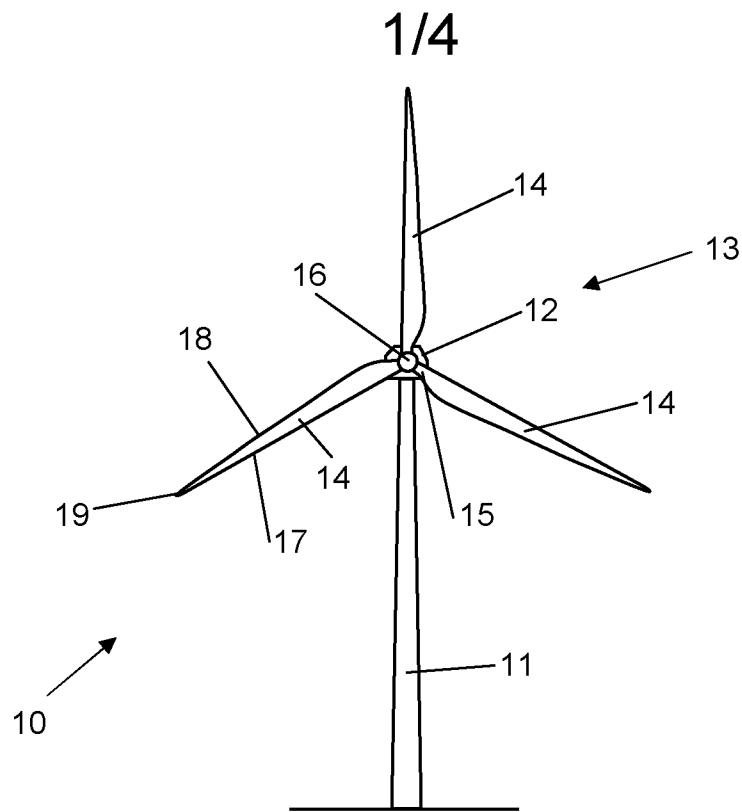


Figure 1

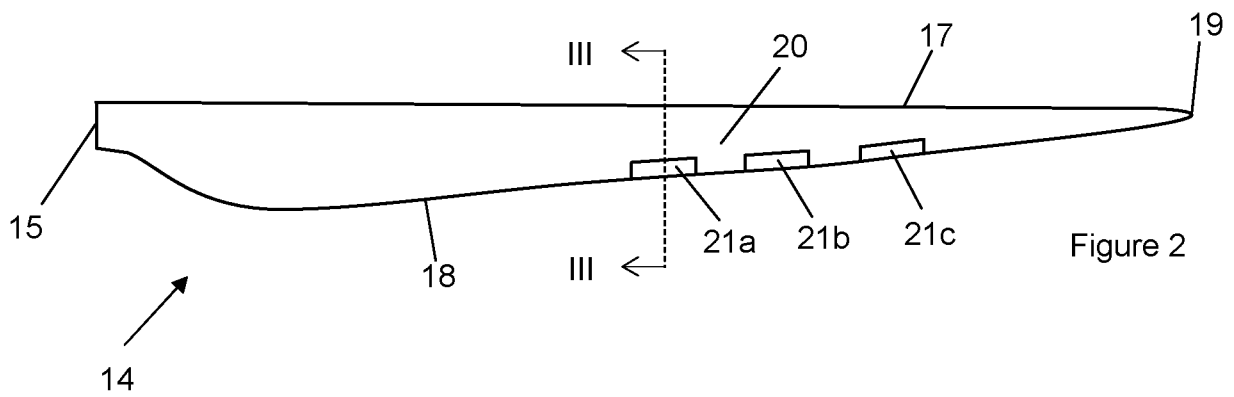


Figure 2

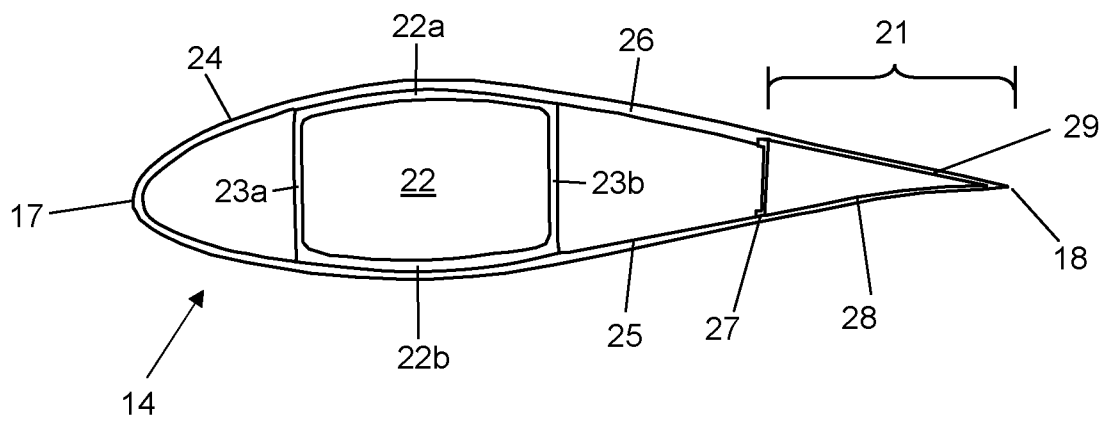


Figure 3

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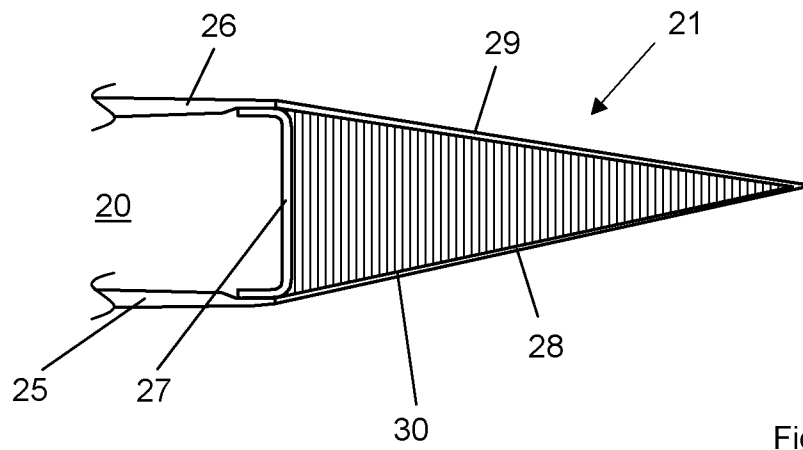


Figure 4

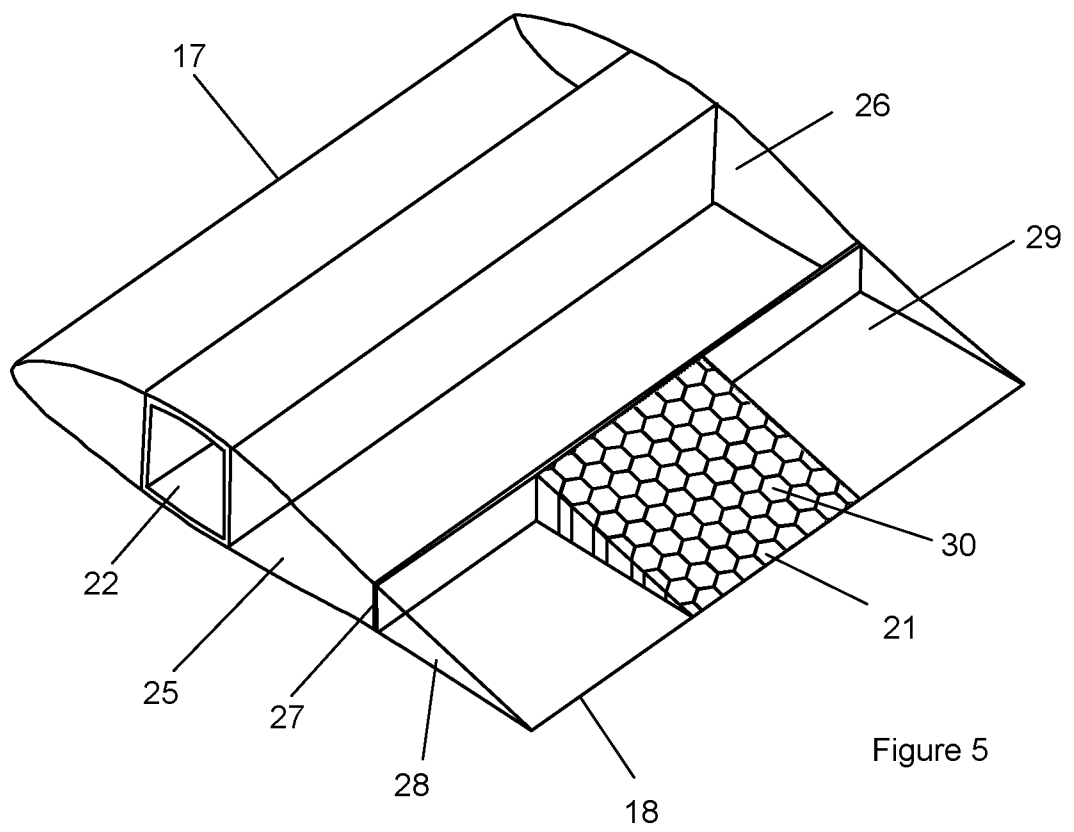


Figure 5

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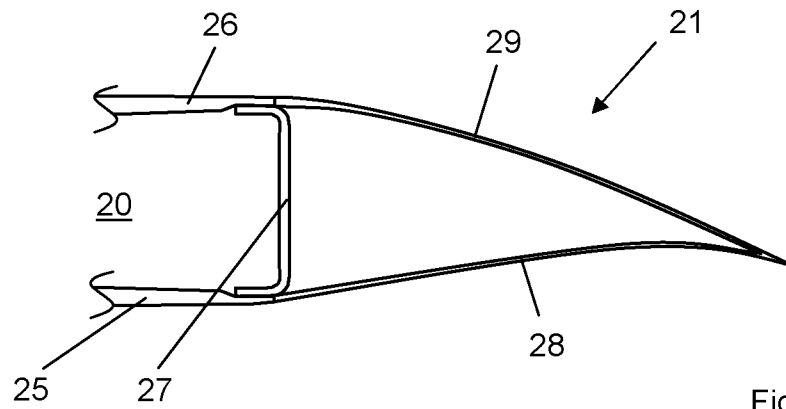


Figure 6a

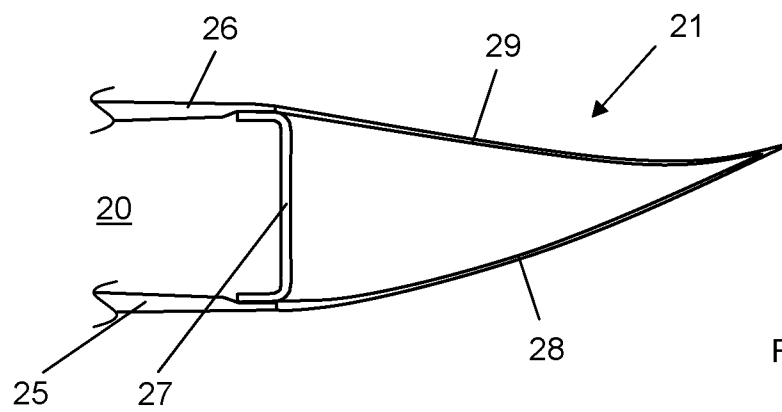


Figure 6b

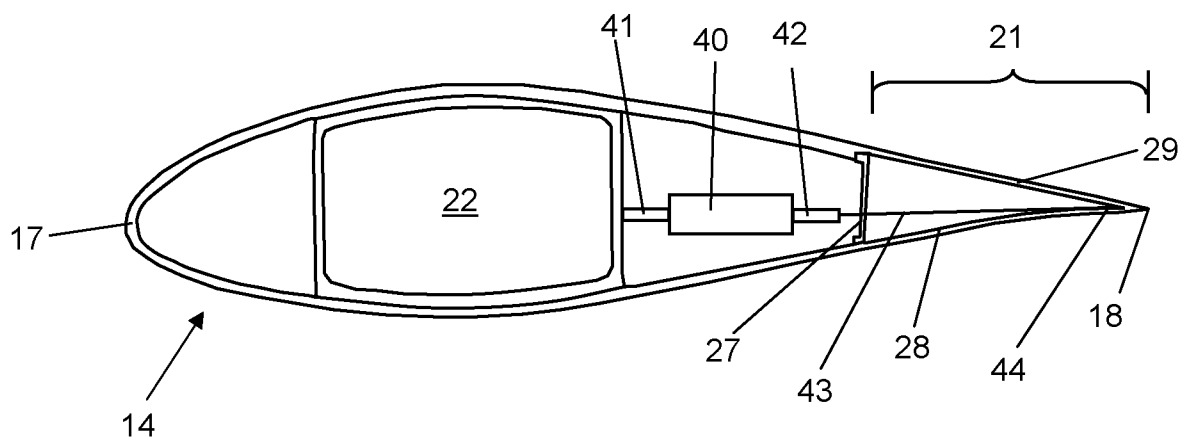


Figure 7

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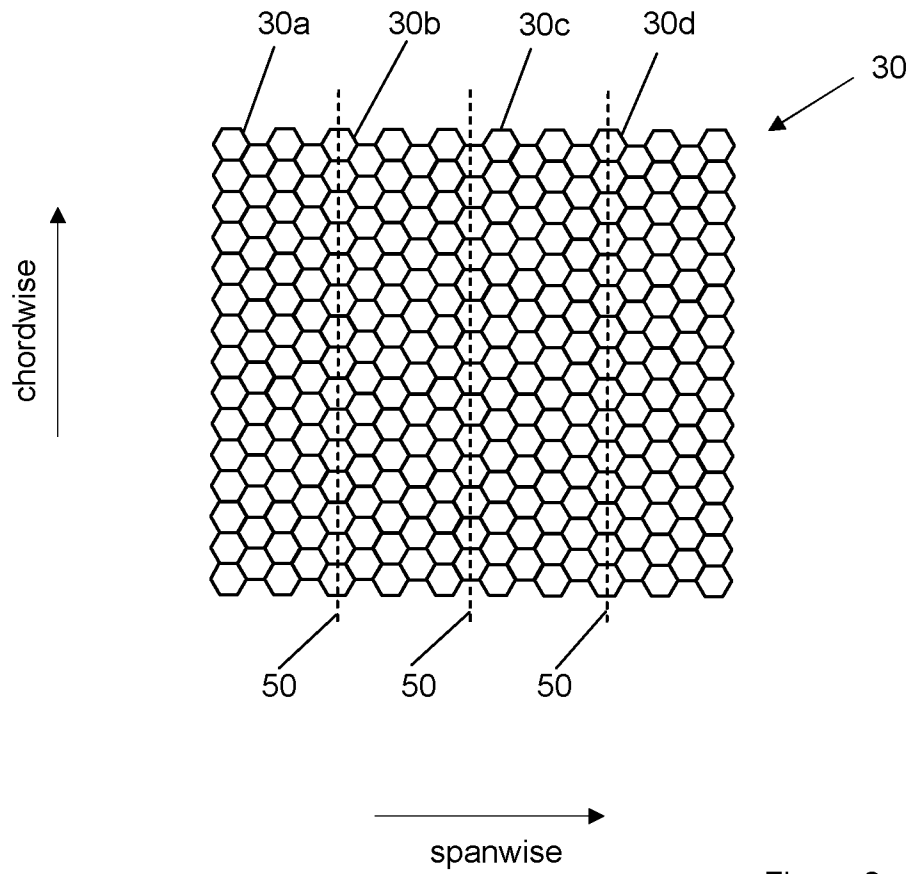


Figure 8