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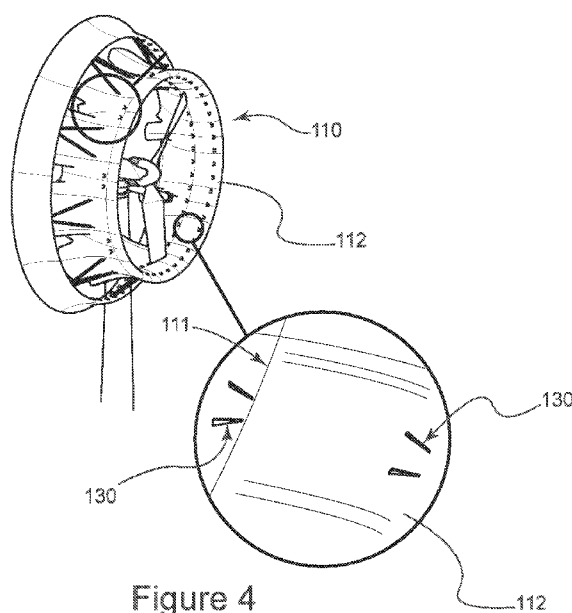
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[Continued on next page]

(54) Title: SHROUDED FLUID TURBINE WITH BOUNDARY LAYER ENERGISING ELEMENTS



(57) Abstract: The present disclosure relates to fluid turbines having a turbine shroud assembly formed with mixing elements (e.g., both inwardly and outwardly curving elements) having airfoil cross sections. These airfoils form ringed airfoil shapes that provide a means of controlling the flow of fluid over the rotor assembly or over portions of the rotor assembly. The fluid dynamic performance of the ringed airfoils directly affects the performance of the turbine rotor assembly. The mass and surface area of the shrouds result in load forces on support structures. By delaying or eliminating the separation of the boundary layer over the ringed airfoils, boundary layer energizing members (e.g., vortex generators, flow control ports) on the ringed airfoils increase the power output of the fluid turbine system and allow for relatively shorter chord-length airfoil cross sections and therefore reduced mass and surface area of the shroud assemblies.



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SHROUDED FLUID TURBINE WITH BOUNDARY LAYER ENERGISING ELEMENTS

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of U.S. Provisional Application Serial No. 61/622,294 filed April 10, 2012, the contents of which is herein incorporated by reference in its entirety.

BACKGROUND1. Technical Field

[0002] The present disclosure relates to fluid turbine systems (e.g., wind or water turbines) and, more particularly to fluid turbine systems having a rotor assembly in fluid communication with a shroud assembly (e.g., turbine shroud assembly) having boundary layer energizing members (e.g., vortex generators, flow control ports). The present disclosure further relates to fluid turbine systems having a shroud assembly with reduced surface area and or mass.

2. Background

[0003] In general, some conventional horizontal axis fluid turbines used for power generation have blades (e.g., two to five open blades) arranged like a propeller, the blades typically being mounted to a horizontal shaft attached to a gear box which drives a power generator. Attempts have been made to provide a means of delaying or preventing flow separation between the flowing fluid and the blade surfaces.

[0004] Example fluid turbines are described and disclosed in U.S. Patents Nos. 8,021,100; and 8,393,850, and U.S. Patent Pubs. Nos. 2011/0014038; 2010/0270802; 2010/0247289; 2011/0002781; 2011/0020107; 2011/0085901; 2011/0135460; 2010/0166547; 2010/0133853; and 2012/0070275, the entire contents of each being hereby incorporated by reference in their entireties.

SUMMARY

[0005] An interest exists for advantageous fluid turbine systems that provide an improved means of delaying or preventing flow separation over a flow control surface (e.g., over the turbine shroud assembly), for improving the performance of the turbine system and or rotor assembly. These and other opportunities for improvement are

addressed and or overcome by the assemblies, systems and methods of the present disclosure.

[0006] The present disclosure provides improved fluid turbine systems. More particularly, the present disclosure provides advantageous fluid turbine systems having a rotor assembly in fluid communication with a shroud assembly (e.g., a turbine shroud assembly in the shape of an airfoil or ringed airfoil), the shroud assembly having boundary layer energizing members (e.g., vortex generators, flow control ports). The present disclosure also provides for improved fluid turbine systems having a shroud assembly with reduced surface area and or mass. In example embodiments, the reduction of surface area provides a means of reducing load forces and or tower stress forces (e.g., in excessive fluid flow conditions).

[0007] In general, the present disclosure provides fluid turbine systems having boundary layer energizing members (e.g., vortex generators, flow control devices or ports). The boundary layer energizing members are advantageously configured and dimensioned to prevent separation of a fluid boundary layer over the turbine shroud assembly and or over the ejector shroud assembly to alter or improve the performance of the fluid turbine system.

[0008] In general, there are many situations in which it can be desirable to provide a means of delaying or preventing flow separation between a flowing medium and a flow control surface. For example, a fluid passing over an airfoil surface from the leading edge to the trailing edge typically flows from a region with low static pressure to a region with high static pressure. This can result in forces which tend to retard the boundary layer and cause the fluid to separate, resulting in increased separation-drag and therefore reduced lift and reduced performance of the airfoil. Boundary layer energizing members (e.g., vortex generators), associated with the flow control surface, can be used to substantially prevent and or minimize flow separation by mixing free flow with the boundary layer. As used herein, the term “boundary layer” refers to the layer of fluid flow in the immediate vicinity of a flow control surface. One skilled in the art will recognize that a boundary layer is involved or included in all embodiments of the present disclosure where a flowing fluid or medium is flowing over a flow control surface.

[0009] In general, a properly designed shroud or duct delivers greater mass flow rate to the interior of the shroud or duct than to the exterior. As such, improved performance over that of a similar open-rotor system can be achieved from a rotor in fluid

communication with a properly designed shroud or duct. In example embodiments of the present disclosure, boundary layer energizing members provide a means of delaying or preventing flow separation over a flow control surface (e.g., over the turbine shroud assembly), thereby advantageously allowing for the reduction of flow control surface area (e.g., turbine shroud assembly surface area or airfoil surface area), while maintaining or increasing performance characteristics similar to that of a relatively larger flow control surface area (e.g., an airfoil with a larger chord). Moreover, the reduction of surface area and mass also reduces loads and tower stress forces (e.g., in high velocity fluid flow conditions) of the turbine systems of the present disclosure.

[0010] In example embodiments, the present disclosure advantageously provides for turbine systems that include vortex generators or the like mounted with respect to shroud surfaces (e.g., to the suction side of shroud assembly or ringed airfoil surfaces), the vortex generators are configured and dimensioned to generate vortices (vortexes) that energize or provide energy to the boundary layer to delay or prevent flow separation before the fluid has reached the trailing edge of the shroud assembly. In example embodiments, a vortex generator is a device or member that is configured and dimensioned to generate a vortex or vortices (vortexes) or the like, thereby providing energy to or energizing (via the generated vortex) a fluid boundary layer over a surface of the turbine system (e.g., over the turbine shroud assembly), which can alter the fluid boundary layer over a surface of the turbine system (e.g., to delay or prevent flow separation before the fluid has reached the trailing edge of the shroud assembly). In certain embodiments and as discussed further below, the shroud assemblies of the present disclosure take the form of ringed airfoils (e.g., substantially circular in form), although the present disclosure is not limited thereto. Rather, the shroud assemblies of the present disclosure can take a variety of forms (e.g., assemblies or airfoils having a non-circular shape; assemblies or airfoils that include gaps of sections along their circumference, periphery or shape; etc.).

[0011] In certain embodiments, the lift-side airfoil cross-sections of a shroud assembly or ringed airfoil are on the interior surface of the shroud assembly or ring. In other embodiments, a majority or plurality of the lift-side airfoil cross-sections of the shroud assembly are on the interior surface, while portions of the interior surface of the shroud assembly can also include pressure-side airfoil cross-sections, and or portions of the outer surface of the ringed airfoil or shroud assembly may include lift-side airfoil cross-sections.

[0012] An airfoil assembly (e.g., ringed airfoil assembly) that surrounds or is disposed about a rotor assembly is typically known as a turbine shroud assembly. In general, the turbine shroud assembly is generally cylindrical and is configured to generate relatively lower pressure within the turbine shroud assembly (the interior of the shroud) and relatively higher pressure outside the turbine shroud (the exterior of the shroud). The shroud assembly or ringed airfoil can be cambered, and have cross-sections shaped like an aircraft wing airfoil. In example embodiments, the turbine shroud assembly includes inward and outwardly curving mixing elements that have airfoil cross sections.

[0013] In certain embodiments, boundary layer energizing members (e.g., vortex generators) on the pressure side of the turbine shroud assembly, proximal to the inward turning mixing elements, prevent or minimize separation of the portion of the fluid stream that provides mixing of bypass flow with flow that has passed through the rotor assembly. The turbine shroud assembly can include mixing elements such as, for example, mixing lobes or slots.

[0014] In some embodiments, a second shroud assembly may be located proximal or adjacent to the trailing edge of the turbine shroud assembly, and the second shroud assembly is typically known as an ejector shroud assembly. For example, the ejector shroud assembly can take the form or shape of a ringed airfoil that includes an annular ring having members with airfoil cross sections, although the present disclosure is not limited thereto. In example embodiments, boundary layer energizing members (e.g., vortex generators) mounted with respect to the suction side of the ejector shroud assembly prevent flow separation until the fluid stream has passed the trailing edge of the turbine system.

[0015] Load forces (e.g., originating from the shrouded system) on support structures, such as tower and foundation components, of a turbine system may be caused by drag and or side loads on aerodynamic surfaces of the turbine system. Boundary layer energizing members delay or substantially eliminate or minimize the separation of the boundary layer over flow control surfaces (e.g., airfoils), providing a means of employing airfoil cross sections with relatively shorter chord lengths than that of airfoils with similar performance characteristics. It is noted that a reduction in the chord length can provide a ringed airfoil with reduced surface area and therefore, reduced loads, drag and or reduced tower and foundation stress.

[0016] Some mixer-ejector turbines employ mixing elements such as diverging and converging airfoil segments. In general, such mixing elements provide controlled stream-wise vorticity in the area downstream of the mixer-ejector turbine. It is noted that a faceted trailing edge configuration of the turbine also provides similarly controlled stream-wise vorticity. In example embodiments, the fluid turbine systems having faceted segments with the substantially annular airfoils provides appropriate surface area for load mitigation by having a shorter turbine shroud and a longer ejector shroud.

[0017] In general, reducing lift forces over turbine aerodynamic surfaces, particularly when the turbine is in a parked configuration, reduces loads on turbine structural components. In certain embodiments, the aerodynamic augmentation provided by vortex generators may also be achieved by flow control devices or ports (e.g., active flow control devices). An advantage of flow control devices is that they can either prevent or cause separation over a flow control surface. In general, introducing fluid (e.g., air) normal to the airfoil surface can prevent flow separation. Lift forces over the shroud surfaces when the turbine is in a parked configuration can cause unintended yaw moment forces and therefore, undue stress on structural components. In example embodiments, by controlling the volume of airflow and or the angle of flow to the airfoil surface, boundary layer separation can be caused, effectively stalling the airfoil and reducing the lift force and therefore the yaw moment. A reduced yaw moment reduces the loads on turbine structural components.

[0018] The present disclosure provides for a shrouded fluid turbine system including a rotor assembly; a turbine shroud assembly disposed about the rotor assembly, the turbine shroud having a low pressure side and a high pressure side, the low pressure side in fluid communication with the rotor assembly; and at least one boundary layer energizing member associated with the turbine shroud assembly, the at least one boundary layer energizing member configured and dimensioned to alter a fluid boundary layer over a surface of the turbine shroud assembly to alter the performance of the fluid turbine system.

[0019] The present disclosure also provides for a shrouded fluid turbine system wherein the at least one boundary layer energizing member is positioned proximal to a leading edge of the turbine shroud assembly. The present disclosure provides for a shrouded fluid turbine system further including a first plurality of boundary layer energizing members and a second plurality of boundary layer energizing members;

wherein the first plurality of boundary layer energizing members are positioned proximal to a leading edge of the turbine shroud assembly; and wherein the second plurality of boundary layer energizing members are positioned between the leading edge and a trailing edge of the turbine shroud assembly.

[0020] The present disclosure provides for a shrouded fluid turbine system wherein the first and second pluralities of boundary layer energizing members are associated with the low pressure side of the turbine shroud assembly. The present disclosure provides for a shrouded fluid turbine system further including a plurality of boundary layer energizing members; wherein the turbine shroud assembly includes a plurality of curving mixing elements; and wherein each mixing element is associated with at least one boundary layer energizing member. The present disclosure provides for a shrouded fluid turbine system wherein the plurality of curving mixing elements includes a first plurality of inwardly curving mixing elements and a second plurality of outwardly curving mixing elements. The present disclosure provides for a shrouded fluid turbine system wherein at least one boundary layer energizing member is positioned on the high pressure side of the turbine shroud assembly and proximal to an inward curving mixing element of the plurality of inward curving mixing elements.

[0021] The present disclosure provides for a shrouded fluid turbine system wherein the turbine shroud assembly defines an airfoil ring having an apex; and wherein the at least one boundary layer energizing member is positioned proximal to the apex of the airfoil ring. The present disclosure provides for a shrouded fluid turbine system wherein the at least one boundary layer energizing member is a vortex generator, the vortex generator in the form of a protruding member that protrudes from a surface of the turbine shroud assembly. The present disclosure provides for a shrouded fluid turbine system wherein the vortex generator has a length and a height; and wherein the length is about four times the height of the vortex generator. The present disclosure provides for a shrouded fluid turbine system wherein the vortex generator has a length and a height; wherein the vortex generator is fabricated from a flexible material and includes a first un-flexed condition and a second flexed condition; and wherein when the vortex generator is in the second flexed condition, the length of the vortex generator is about eight times the height.

[0022] The present disclosure provides for a shrouded fluid turbine system wherein each curving mixing element includes a voluminous leading edge that transitions

to a curved planar form at a trailing edge. The present disclosure provides for a shrouded fluid turbine system further including an ejector shroud assembly positioned downstream from and coaxial with the turbine shroud assembly; wherein at least one boundary layer energizing member is associated with the ejector shroud assembly, the at least one boundary layer energizing member associated with the ejector shroud assembly configured and dimensioned to alter a fluid boundary layer over a surface of the ejector shroud assembly to alter the performance of the fluid turbine system.

[0023] The present disclosure provides for a shrouded fluid turbine system wherein the at least one boundary layer energizing member associated with the ejector shroud assembly is positioned proximal to a leading edge of the ejector shroud assembly. The present disclosure provides for a shrouded fluid turbine system further including a first plurality of boundary layer energizing members and a second plurality of boundary layer energizing members associated with the ejector shroud assembly; wherein the first plurality of boundary layer energizing members are positioned proximal to a leading edge of the ejector shroud assembly; and wherein the second plurality of boundary layer energizing members are positioned between the leading edge and a trailing edge of the ejector shroud assembly.

[0024] The present disclosure provides for a shrouded fluid turbine system wherein the first and second pluralities of boundary layer energizing members are associated with the low pressure side of the ejector shroud assembly. The present disclosure provides for a shrouded fluid turbine system wherein the ejector shroud assembly defines an airfoil ring having an apex; and wherein the at least one boundary layer energizing member associated with the ejector shroud assembly is positioned proximal to the apex of the airfoil ring. The present disclosure provides for a shrouded fluid turbine system wherein the at least one boundary layer energizing member associated with the ejector shroud assembly is a vortex generator, the vortex generator in the form of a protruding member that protrudes from a surface of the ejector shroud assembly.

[0025] The present disclosure provides for a shrouded fluid turbine system wherein the at least one boundary layer energizing member is a flow control port, the flow control port configured and dimensioned to employ high velocity flow through the flow control port for flow control purposes and to alter a fluid boundary layer over a surface of the turbine shroud assembly to alter the performance of the fluid turbine

system. The present disclosure provides for a shrouded fluid turbine system wherein the at least one flow control port is positioned proximal to a leading edge of the turbine shroud assembly. The present disclosure provides for a shrouded fluid turbine system wherein the at least one flow control port is remotely energized with the high velocity flow. The present disclosure provides for a shrouded fluid turbine system wherein the at least one flow control port is energized with the high velocity flow by harvesting fluid energy from the fluid turbine system.

[0026] The present disclosure provides for a shrouded fluid turbine system wherein the at least one boundary layer energizing member is configured and dimensioned to prevent separation of a fluid boundary layer over a surface of the turbine shroud assembly to alter the performance of the fluid turbine system. The present disclosure provides for a shrouded fluid turbine system wherein the at least one boundary layer energizing member is configured and dimensioned to alter a fluid boundary layer over a surface of the turbine shroud assembly to reduce the performance of the fluid turbine system.

[0027] The present disclosure provides for a shrouded fluid turbine system wherein the turbine shroud assembly defines an annular airfoil having a leading edge that transitions to a faceted trailing edge. The present disclosure provides for a shrouded fluid turbine system wherein the volume or angle of the high velocity flow through the flow control port is variable. The present disclosure provides for a shrouded fluid turbine system wherein the at least one boundary layer energizing member configured and dimensioned to alter a fluid boundary layer over a surface of the turbine shroud assembly alters the performance of the fluid turbine system.

[0028] The present disclosure provides for a shrouded fluid turbine system including a rotor assembly; a turbine shroud assembly disposed about the rotor assembly, the turbine shroud having a low pressure side and a high pressure side, the low pressure side in fluid communication with the rotor assembly, the turbine shroud assembly including a plurality of curving mixing elements; and a first and second plurality of boundary layer energizing members associated with the turbine shroud assembly, each boundary layer energizing member configured and dimensioned to alter a fluid boundary layer over a surface of the turbine shroud assembly, the first plurality of boundary layer energizing members positioned proximal to a leading edge of the turbine shroud assembly and the second plurality of boundary layer energizing members positioned between the

leading edge and a trailing edge of the turbine shroud assembly, at least a portion of the first and second pluralities of boundary layer energizing members associated with the low pressure side of the turbine shroud assembly, and each mixing element associated with at least one boundary layer energizing member.

[0029] The present disclosure provides for a shrouded fluid turbine system including a rotor assembly; a turbine shroud assembly disposed about the rotor assembly, the turbine shroud having a low pressure side and a high pressure side, the low pressure side in fluid communication with the rotor assembly; at least one first boundary layer energizing member associated with the turbine shroud assembly, the at least one first boundary layer energizing member configured and dimensioned to alter a fluid boundary layer over a surface of the turbine shroud assembly to alter the performance of the fluid turbine system; an ejector shroud assembly positioned downstream from and coaxial with the turbine shroud assembly; at least one second boundary layer energizing member associated with the ejector shroud assembly, the at least one second boundary layer energizing member configured and dimensioned to alter a fluid boundary layer over a surface of the ejector shroud assembly to alter the performance of the fluid turbine system; wherein the turbine shroud assembly includes a plurality of curving mixing elements; wherein the at least one first boundary layer energizing member is positioned proximal to a leading edge of the turbine shroud assembly; and wherein the at least one second boundary layer energizing member is positioned proximal to a leading edge of the ejector shroud assembly.

[0030] These and other non-limiting features or characteristics of the present disclosure will be further described below. Any combination or permutation of embodiments is envisioned. Additional advantageous features, functions and applications of the disclosed assemblies, systems and methods of the present disclosure will be apparent from the description which follows, particularly when read in conjunction with the appended figures. All references listed in this disclosure are hereby incorporated by reference in their entireties.

BRIEF DESCRIPTION OF THE DRAWINGS

[0031] The following is a brief description of the drawings, which are presented for the purposes of illustrating the disclosure set forth herein and not for the purposes of limiting the same. Example embodiments of the present disclosure are further described

with reference to the appended figures. It is to be noted that the various features and combinations of features described below and illustrated in the figures can be arranged and organized differently to result in embodiments which are still within the spirit and scope of the present disclosure. To assist those of ordinary skill in the art in making and using the disclosed systems, assemblies and methods, reference is made to the appended figures, wherein:

[0032] Figure 1 is a front perspective view of an embodiment of a fluid turbine system;

[0033] Figure 2 is a rear perspective view of the system of Figure 1;

[0034] Figures 3-4 are front, side perspective, detail views of the system of Figure 1;

[0035] Figure 5 is a rear, side perspective, detail view of the system of Figure 1;

[0036] Figure 6 is a side cross-sectional, detail view of the system of Figure 1 depicting the proportion between the length and height of a vortex generator and the length and height of the airfoil member that it is engaged with;

[0037] Figure 7 is a side cross-sectional, detail view of the system of Figure 1 depicting the proportion between the length and height of a vortex generator and the length and height of the airfoil member that it is engaged with;

[0038] Figures 8-10 are side, cross section detail views of embodiments of the system of Figure 1;

[0039] Figures 11-12 are detailed, cross sectional views of additional embodiments of a vortex generator of a shrouded fluid turbine of the present disclosure;

[0040] Figure 13 is a front perspective view of another embodiment of a fluid turbine system of the present disclosure;

[0041] Figures 14-16 are detailed cross sectional views of the system of Figure 13;

[0042] Figure 17 is a front perspective view of another embodiment of a fluid turbine system of the present disclosure depicting boundary layer energizing members;

[0043] Figure 18 is a front, right-perspective, detailed cross section of the system of Figure 17;

[0044] Figure 19 is a side detailed cross section of the system of Figure 17;

[0045] Figure 20 is a front right, detailed cross section view of the system of Figure 17;

[0046] Figure 21 is a front perspective view of another embodiment of a fluid turbine system of the present disclosure depicting boundary layer energizing members;

[0047] Figure 22 is a front right perspective view of another embodiment of a fluid turbine system of the present disclosure;

[0048] Figure 23 is a front, right perspective, detailed cross section view of the system of Figure 22 depicting boundary layer energizing members; and

[0049] Figure 24 is a side, detailed cross section view of the system of Figure 22.

DETAILED DESCRIPTION

[0050] The example embodiments disclosed herein are illustrative of advantageous fluid turbine systems, and assemblies of the present disclosure and methods or techniques thereof. It should be understood, however, that the disclosed embodiments are merely examples of the present disclosure, which may be embodied in various forms. Therefore, details disclosed herein with reference to example fluid turbine systems or fabrication methods and associated processes or techniques of assembly and or use are not to be interpreted as limiting, but merely as the basis for teaching one skilled in the art how to make and use the advantageous fluid turbine systems of the present disclosure.

[0051] A more complete understanding of the components, processes, and apparatuses disclosed herein can be obtained by reference to the accompanying figures. These figures are intended to demonstrate the present disclosure and are not intended to show relative sizes and dimensions or to limit the scope of the example embodiments.

[0052] Although specific terms are used in the following description, these terms are intended to refer only to particular structures in the drawings and are not intended to limit the scope of the present disclosure. It is to be understood that like numeric designations refer to components of like function.

[0053] The term “about” when used with a quantity includes the stated value and also has the meaning dictated by the context. For example, it includes at least the degree of error associated with the measurement of the particular quantity. When used in the context of a range, the term “about” should also be considered as disclosing the range

defined by the absolute values of the two endpoints. For example, the range “from about 2 to about 4” also discloses the range “from 2 to 4.”

[0054] In certain embodiments, a mixer-ejector fluid turbine provides an improved means of generating power from fluid currents. A turbine shroud assembly can be disposed about a rotor assembly, with the rotor assembly extracting power from a primary fluid stream. A mixer-ejector pump can be included in some embodiments that ingests flow from the primary fluid stream and secondary flow, and promotes turbulent mixing of the two fluid streams. This enhances the power system by increasing the amount of fluid flow through the system, increasing the velocity at the rotor assembly for more power availability, and reducing back pressure on turbine blades.

[0055] The term “rotor assembly” is used herein to refer to any assembly in which blades are attached to a shaft and able to rotate, allowing for the generation of power or energy from fluid rotating the blades. Rotor assemblies can include a propeller-like rotor or a rotor or stator assembly. Any type of rotor assembly may be utilized with the fluid turbines of the present disclosure.

[0056] In certain embodiments, the leading edge of a turbine shroud assembly may be considered the front of the fluid turbine system, and the trailing edge of a turbine shroud assembly or of an ejector shroud assembly may be considered the rear of the fluid turbine system. A first component of the fluid turbine system located closer to the front of the turbine system may be considered “upstream” of a second component located closer to the rear of the turbine system. Put another way, the second component is “downstream” of the first component.

[0057] The present disclosure provides advantageous fluid turbine systems. More particularly, the present disclosure provides improved fluid turbine systems having a rotor assembly in fluid communication with a shroud assembly (e.g., turbine shroud assembly) having boundary layer energizing members (e.g., vortex generators, flow control ports). The present disclosure also provides for improved fluid turbine systems having a shroud assembly with reduced surface area and or mass. In general, the reduction of surface area provides a means of reducing load forces and tower stress forces in excessive fluid flow conditions.

[0058] In example embodiments, the present disclosure provides shrouded fluid turbines (e.g., wind or water turbines) having a shroud assembly formed with both inward and outwardly curving elements having airfoil cross sections. These airfoils form ringed

airfoil shapes that provide a means of controlling the flow of fluid over the rotor assembly and or over portions of the rotor assembly. In general, the fluid dynamic performance of the ringed airfoils directly affects the performance of the turbine rotor assembly. The mass and surface area of the shroud assemblies result in load forces on support structures. By delaying or eliminating the separation of the boundary layer over the ringed airfoils, boundary layer energizing members (e.g., vortex generators, flow control ports) on the ringed airfoils increase the power output of the fluid turbine system and allow for relatively shorter chord-length airfoil cross sections and therefore reduced mass and surface area of the shroud assemblies.

[0059] In certain embodiments, the present disclosure provides for a fluid turbine system including a turbine shroud assembly (e.g., ringed turbine shroud) that surrounds a rotor assembly, and can further include in some embodiments an ejector shroud assembly that surrounds the exit of the turbine shroud assembly. It is noted that the fluid turbine system of the present disclosure may or may not include an ejector shroud assembly, as further discussed below. In general, boundary layer energizing members (e.g., vortex generators, flow control ports) are associated with the turbine shroud assembly and or ejector shroud assembly for the purpose of preventing flow separation of the boundary layer.

[0060] The term vortex generator is used to describe a range of assemblies or devices mounted with respect to a turbine system. The term vortex generator can mean, but is in no way limited to, “device or member generating a vortex.” For example, a vortex generator can be a protruding member such as illustrated throughout the figures. However, one skilled in the art will readily recognize numerous suitable vortex generator forms or shapes may be utilized in practicing the present disclosure, and therefore the recited embodiments of the figures are not intended to be limiting in scope.

[0061] Referring now to the drawings, like parts are marked throughout the specification and drawings with the same reference numerals, respectively. Drawing figures are not necessarily to scale and in certain views, parts may have been exaggerated for purposes of clarity.

[0062] Figure 1 is a front perspective view of an example embodiment of a fluid turbine system 100 (e.g., shrouded fluid turbine system) of the present disclosure. Figure 2 is a rear perspective view of the fluid turbine system 100 of Figure 1. In general, a system having a rotor or impeller assembly 140 encircled in part or completely by one or

more shroud assemblies 110, 120 can be described as a shrouded fluid turbine system 100.

[0063] Referring to Figures 1 and 2, the shrouded fluid turbine system 100 includes a turbine shroud 110, a nacelle body or housing 150, a rotor assembly 140, and in some embodiments an ejector shroud assembly 120. It is noted that the shrouded fluid turbine system 100 may or may not include an ejector shroud assembly 120, as further discussed below. In embodiments that include the ejector shroud assembly 120, support members 106 (e.g., trusses, attachment struts) connect the turbine shroud assembly 110 to the ejector shroud assembly 120.

[0064] The turbine shroud assembly 110 includes a front end 112, also known as an inlet end or a leading edge. The turbine shroud assembly 110 also includes a rear end 116, also known as an exhaust end or trailing edge. In some embodiments, the ejector shroud 120 includes a front end, inlet end or leading edge 122, and a rear end, exhaust end, or trailing edge 124.

[0065] The rotor assembly 140 surrounds the nacelle body 150. The rotor assembly 140 includes a central hub 141 at the proximal end of the rotor blades. The central hub 141 is rotationally engaged with the nacelle body 150. The nacelle body 150 and the turbine shroud assembly 110 are supported by a tower 102. The rotor assembly 140, turbine shroud assembly 110, and ejector shroud assembly 120 can be coaxial with each other, i.e., they share a common central axis 105 (Figure 2). It is noted that the terms inward or inwardly and outward or outwardly in regards to the mixing elements 115, 117 discussed below are relative to the central axis 105.

[0066] Although turbine shroud assembly 110 is shown encompassing or encircling the rotor assembly 140, in some embodiments, the turbine shroud assembly 110 can partially encompass or encircle the rotor assembly 140 (e.g., the turbine shroud assembly 110 may have gaps, have slots, be discontinuous, segmented, and the like, or the rotor assembly 140 may extend beyond the leading edge 122 or trailing edge 124 of the turbine shroud assembly 110). See, e.g., U.S. Patent Pub. No. 2010/0247289 for example shrouds that are segmented. Moreover, the ejector shroud assembly 120, if present, may have gaps, have slots, be discontinuous, segmented, and the like. In some embodiments, the turbine shroud assembly 110 may not encircle the rotor assembly 140 (e.g., at least a portion of the rotor assembly 140 may be positioned in front of the leading edge 122 or past the trailing edge 124 of the turbine shroud assembly 110).

[0067] As noted, rotor assembly 140 refers to any assembly in which blades are attached to a shaft and able to rotate, allowing for the generation of power or energy from fluid rotating the blades. Rotor assemblies 140 can include a propeller-like rotor or a rotor or stator assembly. Any type of rotor assembly 140 may be utilized with fluid turbine system 100.

[0068] In example embodiments, the turbine shroud assembly 110 has the cross-sectional shape of an airfoil, with the suction side (i.e., low pressure side) on the interior of the shroud assembly 110. The rear end 116 of the turbine shroud assembly 110 has mixing elements or lobes, including outwardly directed mixing elements 115 and inwardly directed mixing elements 117. The mixing elements 115, 117 extend downstream beyond the rotor blades and are directed either outwardly or inwardly with respect to the central axis 105. Put another way, the trailing edge 116 of the turbine shroud assembly 110 is shaped to form two different sets of mixing elements 115, 117. Inwardly directed mixing elements 117 extend inwardly towards the central axis 105 of the mixer shroud. Outwardly directed mixing elements 115 extend outwardly away from the central axis 105. When viewed from the rear the mixing elements or lobes 115, 117 form a general circular crenellated or circumferential undulating in-and-out shape, as shown in FIG. 2. A pressure drop occurs in the wake of the rotor assembly 140 as a result of the energy taken out by the rotor assembly 140. Inwardly and outwardly directed elements 115, 117 provide turbulent mixing of high and low pressure streams, such that the fluid pressure in the wake of the turbine rapidly returns to ambient pressure.

[0069] In certain embodiments, a mixer-ejector pump is formed by the ejector shroud assembly 120 surrounding the ring of inwardly directed mixing elements 117 and outwardly directed mixing elements 115 of the turbine shroud assembly 110. In example embodiments, the airfoil defined by the ejector shroud assembly 120 can have a generally cylindrical or ring-like configuration having a circumferential body extending about the central axis 105.

[0070] The mixing elements 115, 117 can extend downstream and into the inlet end 122 of the ejector shroud assembly 120. In certain embodiments, the mixer-ejector pump provides turbulent mixing of fluid that passes through the rotor assembly 140 with fluid that bypasses the rotor assembly 140. A pressure drop occurs in the wake of the rotor assembly 140 as a result of the energy taken out by the rotor assembly 140. Inwardly and outwardly directed elements 115, 117 in combination with the ejector shroud assembly

120 provide turbulent mixing of high and low pressure streams, such that the fluid pressure in the wake of the turbine rapidly returns to ambient pressure.

[0071] In example embodiments, system 100 includes boundary layer energizing members 130. As shown in FIGS. 1-10, boundary layer energizing members 130 take the form of vortex generators 130 (e.g., protruding members, etc.) or the like. In general, boundary layer energizing members 130 are configured and dimensioned to prevent separation of a fluid boundary layer over flow control surfaces (e.g., over the turbine shroud assembly 110 and or ejector shroud assembly 120) to alter or improve the performance of the fluid turbine system 100 (or over shrouds 310, 320 of system 300, or over shrouds 410, 420 of system 400, as discussed below). Stated another way, boundary layer energizing members 130 (e.g., vortex generators), associated with flow control surface (e.g., assembly 110, 120) of system 100, can be used to substantially prevent and or minimize flow separation by mixing free flow with the boundary layer. In certain embodiments, boundary layer energizing members 130 (e.g., vortex generators) are configured and dimensioned to energize the boundary layer to delay or prevent flow separation before the fluid has reached the trailing edge of a flow control surface (e.g., shroud assembly 110 and or 120) of system 100.

[0072] In example embodiments, a vortex generator 130 is a device or member that is configured and dimensioned to generate a vortex or vortices (vortexes) or the like, thereby providing energy to or energizing (via the generated vortex) a fluid boundary layer over a surface of the turbine shroud assembly 110, which can alter the fluid boundary layer over a surface of the turbine shroud assembly 110 (e.g., to delay or prevent flow separation before the fluid has reached the trailing edge of the shroud assembly). For example, vortex generators 130 can take the form of protruding members or the like, although the present disclosure is not limited thereto. Rather, protruding members 130 can take a variety of suitable forms or shapes. In example embodiments, the protruding members 130 are designed so that they do not extend across the diameter of the shrouds 110 and or 120, and are low profile having a limited aspect ratio. The term “energizing” can mean, but is in no way limited to, providing energy or fluid flow to a system or location (e.g., to a fluid boundary layer over a surface of the turbine shroud assembly 110).

[0073] In general, at least one vortex generator 130 is mounted with respect to a surface of system 100 (e.g., to a surface of turbine shroud assembly 110, or assembly

120). In example embodiments, a plurality of vortex generators 130 are mounted with respect to a surface of turbine shroud assembly 110 (or assembly 120). In some embodiments, the vortex generators 130 are integrally formed with assembly 110 (or assembly 120), although the present disclosure is not limited thereto.

[0074] In certain embodiments and referring to Figures 3-4, vortex generators 130 can be mounted with respect to the turbine shroud assembly 110 approximately at or proximal to the leading edge 112 of the turbine shroud assembly 110. However, it is noted that vortex generators 130 can be mounted with respect to assembly 110 (or assembly 120) at any suitable location or position. For example, system 100 can include vortex generators 130 mounted with respect to the suction side (e.g., low pressure side on the interior of the shroud assembly) and or with respect to the pressure side (higher pressure side on the outside or exterior of the shroud assembly) of shroud assembly surfaces (assembly 110 and or 120). As such, the vortex generators 130 can be configured and dimensioned to energize the boundary layer to delay or prevent flow separation before the fluid has reached the trailing edge of the shroud assembly 110, 120.

[0075] As shown in FIGS. 3-4, vortex generators 130 can be mounted with respect to the turbine shroud assembly 110 proximal to the leading edge 112 of the turbine shroud assembly 110 on the suction side (e.g., low pressure side on the interior of the shroud assembly 110 – FIG. 4), and or on the pressure side (higher pressure side on the outside or exterior of the shroud assembly 110 – FIG. 3). In example embodiments, the vortex generators 130 can be positioned substantially equidistantly apart from one another around the circumference or periphery (suction or pressure side) of assembly 110 (or 120), although the present disclosure is not limited thereto.

[0076] Additional vortex generators 130 can be mounted with respect to the turbine shroud assembly 110 near or proximal to the apex 111 of the airfoil ring defined by the interior of assembly 110 (e.g., approximately at the thickest part of the cross sectional shape of the airfoil ring defined by assembly 110 – FIG. 4). In some embodiments and as shown in FIG. 4, a plurality of vortex generators 130 can be arranged or disposed in two or more circumferential rows about the surface of the shroud assembly 110. For example, the plurality of vortex generators 130 can be arranged in a first downstream row (e.g., a row downstream of the blades of the rotor assembly 140) and in a second upstream row (e.g., a row upstream of the blades of the rotor assembly 140). In example embodiments and as shown in FIG. 4, assembly 110 includes a plurality of

vortex generators 130 positioned near or proximal to the apex 111 and disposed in a circumferential row downstream of the blades of the rotor assembly 140. Assembly 110 also includes a plurality of vortex generators 130 proximal to the leading edge 112 and disposed in a circumferential row upstream of the blades of the rotor assembly 140. Again, it is noted that vortex generators 130 can be mounted with respect to system 100 at any suitable location. Moreover, vortex generators 130 can be mounted with respect to the pressure side of the assembly 110 and proximal to the leading edge 112 of the turbine shroud assembly 110, and or proximal to the inward turning mixing elements 117 (FIG. 3).

[0077] As noted, vortex generators 130 can be mounted with respect to ejector shroud assembly 120 at any suitable location. As shown in FIG. 5, vortex generators 130 can be mounted with respect to ejector shroud assembly 120 (e.g., on the suction or interior side) near or proximal to the leading edge 122 of the ejector 120, and additional vortex generators 130 can be mounted with respect to the ejector shroud assembly 120 between the leading edge 122 and the trailing edge 124 (e.g., approximately located or positioned at the thickest part of the cross sectional shape of the airfoil ring defined by assembly 120).

[0078] FIGS. 6-7 illustrate the relative proportion of an embodiment of a vortex generator 130 mounted with respect to the ejector shroud assembly 120. As shown in FIG. 7, the height 144 of the vortex generator 130 is approximately equal to about 1% of the chord length 140 of the airfoil cross-section defined by the ejector shroud assembly 120. Moreover, the height 144 of the vortex generator 130 is approximately 1/4th or 25% of the length 146 of the vortex generator 130. Put another way, the length 146 of this particular vortex generator 130 is about four times the height 144 of the vortex generator 130. It is important to note that the size of the vortex generators are scaled to the physical properties of the location on the surface relative to the thickness of the boundary layer and the desired effect. As such, it is noted that there are many possible combinations of height 144 and/or length 146 of vortex generators 130 to generate different effects. For example and as shown in FIG. 7, in some embodiments the height 144 of the vortex generator 130 may be configured and dimensioned to extend proximal to, above and/or past the boundary layer to displace energy or flow from the free stream flow above the boundary layer in order to prevent separation of the boundary layer over the surface of ejector shroud assembly 120. In some embodiments, the energy displaced from the free

stream flow is transferred or distributed to the boundary layer. In other embodiments, the height 144 of the vortex generator 130 does not extend above or past the boundary layer of a flow control surface of system 100. Again, there are multiple permutations of height 144 and/or length 146 of vortex generators 130 to generate different effects.

[0079] FIG. 8 illustrates the relative difference in chord length between an airfoil cross section 160 without vortex generators, and an airfoil cross-section defined by the ejector shroud assembly 120 having vortex generators 130. The airfoil cross section 160 with chord length 152 is greater than the chord length 142 of the airfoil cross-section defined by the ejector shroud assembly 120 having vortex generators 130. It has been found that a shorter chord length 142, such as that of assembly 120 having vortex generators 130 maintains and or improves upon the performance of an airfoil cross section 160 that does not have vortex generators.

[0080] FIGS. 9-10 illustrate an example embodiment displaying the relative difference in chord length between mixing element airfoil cross sections 165, 167 without vortex generators, and with airfoil cross-sections defined by mixing elements 115, 117 of assembly 110 having vortex generators 130. In certain embodiments, inward turning mixing elements 117 introduce bypass flow (arrow 172) into the fluid stream that is down-stream of the rotor assembly 140. The bypass flow 172 progresses along the pressure side, or outer surface of the airfoil cross-section defined by mixing element 117. Thus, vortex generators 130 positioned on the outer surface of the mixing element 117 (FIG. 9) prevent separation of the fluid stream along the upper surface of the airfoil cross-section defined by mixing element 117. The airfoil cross section 167 with chord length 168 is relatively greater than the chord length 119 of the airfoil cross-section defined by mixing element 117. A shorter chord length 119, such as that of airfoil cross-section 117 having vortex generators 130 maintains and or improves upon the performance of an airfoil cross section 167 that does not have vortex generators.

[0081] In example embodiments and as shown in FIG. 10, outwardly turning mixing elements 115 mix the flow (arrow 174) that has passed through the rotor assembly 140, with bypass flow in the fluid stream that is down-stream of the rotor assembly 140. The flow 174 progresses along the lift-side, or inner surface of the airfoil cross-section defined by mixing element 115. Thus, vortex generators 130 positioned on the inner surface of the mixing element 115 (FIG. 10) prevent separation of the fluid stream along the inner surface of the airfoil cross-section defined by mixing element 115. The airfoil cross

section 165 with chord length 166 is relatively greater than the chord length 186 of the airfoil cross-section defined by mixing element 115. A shorter chord length 186, such as that of airfoil cross-section 115 having vortex generators 130 maintains and or improves upon the performance of an airfoil cross section 165 that does not have vortex generators.

[0082] Figure 11 is a detail, cross section view of an additional embodiment of a vortex generator 130' of the present disclosure. Figure 12 is a another detail cross sectional view of the vortex generator 130' of Figure 11.

[0083] FIGS. 11-12 illustrate a vortex generator 130' that is fabricated at least in part from a flexible material designed to change shape under set flow velocity conditions. For example, at times it can be beneficial to reduce the performance of a ringed airfoil (e.g., ringed airfoil defined by shroud assembly 110 or 120) proximal to a rotor assembly 140 in high fluid velocity conditions. In one embodiment, the flexible vortex generator 130' may be utilized in shedding load on the shrouded turbine system 100 during periods of high fluid velocity. For example, the vortex generator 130' can be mounted with respect to the lift or interior side 223 of the ringed airfoil defined by shroud assembly 120 (or at any other suitable location). The height 244 of the un-flexed vortex generator 130' is approximately equal to 1% of the chord length 242 of the airfoil cross section defined by shroud assembly 120. The length 246 of the vortex generator 130' is, in this un-flexed configuration, approximately four times the height 244.

[0084] FIG. 12 illustrates vortex generator 130' that is in a collapsed or flexed configuration as it would be in a fluid stream of a set velocity. The reduction of performance of the vortex generator 130' causes separation along the interior side 223 of the ringed airfoil defined by shroud assembly 120, and therefore provides a reduced performance of the airfoil with the intent to reduce the speed of the rotor assembly 140 in high velocity flow. In example embodiments and in this collapsed or flexed configuration as shown in FIG. 12, the length 247 of the vortex generator 130' is approximately eight times the height 245.

[0085] Figure 13 is a front perspective view of an additional embodiment of a shrouded fluid turbine system 300 of the present disclosure. FIGS. 14-15 are detailed cross section views of the system 300 of Figure 13.

[0086] Referring to FIGS. 13-15, the shrouded fluid turbine system 300 is a mixer ejector turbine with airfoils that include single surface portions. The turbine system 300 includes a turbine shroud assembly 310, a nacelle body 350, a rotor assembly 340, and in

some embodiments an ejector shroud assembly 320. The turbine shroud assembly 310 includes a front end 312, also known as an inlet end or a leading edge. The turbine shroud assembly 310 also includes a rear end 316, also known as an exhaust end or trailing edge. The ejector shroud assembly 320 includes a front end, inlet end or leading edge 322, and a rear end, exhaust end, or trailing edge 324.

[0087] In example embodiments, the airfoil cross section defined by the turbine shroud assembly 310 includes a voluminous leading edge 312 that transitions to a curved planar portion at the trailing edge 316. The ejector shroud assembly 320 includes a voluminous leading edge 322 that transitions to a curved planar portion at the trailing edge 324.

[0088] The rotor assembly 340 surrounds the nacelle body 350. The rotor assembly 340 includes a central hub 341 at the proximal end of the rotor blades. The central hub 341 is rotationally engaged with the nacelle body 350. The nacelle body 350 and the turbine shroud assembly 310 are supported by a tower 302. The rotor assembly 340, turbine shroud assembly 310, and ejector shroud assembly 320 can be coaxial with each other, i.e. they share a common central axis 305. Support members 306 connect the turbine shroud assembly 310 to the nacelle body 350.

[0089] In certain embodiments, the turbine shroud assembly 310 has the cross-sectional shape of an airfoil, with the suction side (i.e. low pressure side) on the interior of the shroud assembly 310. The rear end 316 of the turbine shroud assembly 310 has mixing elements, including outwardly directed mixing elements 315 and inwardly directed mixing elements 317. The mixing elements 315, 317 extend downstream beyond the rotor blades and are directed either outwardly or inwardly with respect to the central axis 305. Put another way, the trailing edge 316 of the turbine shroud assembly 310 is shaped to form two different sets of mixing elements 315, 317. Inwardly directed mixing elements 317 extend inwardly towards the central axis 305 of the mixer shroud. Outwardly directed mixing elements 315 extend outwardly away from the central axis 305.

[0090] A mixer-ejector pump is formed by the ejector shroud assembly 320 surrounding the ring of inwardly directed mixing elements 317 and outwardly directed mixing elements 315 of the turbine shroud assembly 310. The mixing elements 315, 317 extend downstream and are proximate to the inlet end 322 of the ejector shroud assembly 320. This mixer-ejector pump provides turbulent mixing of fluid that passes through the

rotor assembly 340 with fluid that bypasses the rotor assembly 340. A pressure drop occurs in the wake of the rotor assembly 340 as a result of the energy taken out by the rotor assembly 340. Inward and outwardly directed elements 315, 317, in combination with the ejector shroud assembly 320 provide turbulent mixing of high and low pressure streams, such that the fluid pressure in the wake of the turbine rapidly returns to ambient pressure.

[0091] In example embodiments, system 300 includes boundary layer energizing members 330. Similar to members 130 discussed above, boundary layer energizing members 330 take the form of vortex generators 330 (e.g., protruding members, etc.) or the like, although the present disclosure is not limited thereto. In general, boundary layer energizing members 330 are configured and dimensioned to prevent separation of a fluid boundary layer over flow control surfaces (e.g., over the turbine shroud assembly 310 and or ejector shroud assembly 320) to alter or improve the performance of the fluid turbine system 300 (or over shrouds 110, 120 of system 100, or shrouds 410, 420 of system 400, as discussed above and below). Stated another way, boundary layer energizing members 330 associated with flow control surface (e.g., assembly 310, 320) of system 300, can be used to substantially prevent and or minimize flow separation by mixing free flow with the boundary layer. In certain embodiments, boundary layer energizing members 330 (e.g., vortex generators) are configured and dimensioned to energize the boundary layer to delay or prevent flow separation before the fluid has reached the trailing edge of a flow control surface (e.g., shroud assembly 310 and or 320) of system 300.

[0092] FIGS. 14-15 illustrate vortex generators 330 mounted with respect to the outwardly turning mixing elements 315, and with respect to the airfoil defined by the ejector shroud assembly 320. It is noted that an airfoil with a voluminous leading edge that transitions to a curved planar trailing edge provides a reduction in the mass of the airfoil while maintaining performance. The introduction of vortex generators 330 on such an airfoil (e.g., mixing elements 315 and or airfoil defined by the ejector shroud assembly 320) further reduces the material and therefore surface area and mass of the airfoil while maintaining performance characteristics.

[0093] Vortex generators 330 energize the boundary layer over the inner surface of the outwardly turning mixing elements 315, to prevent separation over the boundary layer. Outwardly turning mixing elements 315 mix the flow that has passed through the rotor assembly 340, with bypass flow in the fluid stream down-stream of the rotor

assembly 340. The flow 374 progresses along the lift side, or inner surface of the airfoil, hence, vortex generators 330 prevent separation of the fluid stream along the inner surface of the airfoil defined by mixing elements 315.

[0094] FIG. 16 illustrates vortex generators 330 mounted with respect to the inward turning mixing element 317. Inward turning mixing elements 317 introduce bypass flow (arrow 372) into the fluid stream down-stream of the rotor assembly 340. The bypass flow 372 progresses along the pressure side, or outer surface of the airfoil defined by the mixing elements 317, hence, vortex generators 330 prevent separation of the fluid stream along the upper surface of the airfoil defined by the mixing elements 317.

[0095] In example embodiments, the airfoil defined by the mixing elements 317 includes a voluminous leading edge 312 that transitions to a curved planar form at the trailing edge 316. The airfoil design coupled with vortex generators 330 provides an airfoil with the performance characteristics of a substantially larger and more massive airfoil.

[0096] Turning now to FIGS. 17-20, another example embodiment of a shrouded fluid turbine system is depicted in accordance with embodiments of the present disclosure. The fluid turbine system 400 includes a turbine shroud assembly 310, a nacelle body 350, a rotor assembly 340, and in some embodiments an ejector shroud assembly 320. The turbine shroud assembly 310 includes a front end 312 and a rear end 316, and the ejector shroud assembly 320 includes a leading edge 322, and trailing edge 324.

[0097] The rotor assembly 340 includes a central hub 341, and the nacelle body 350 and the turbine shroud assembly 310 are supported by a tower 302. The rotor assembly 340, turbine shroud assembly 310, and ejector shroud assembly 320 can be coaxial with each other, i.e. they share a common central axis 305. Support members 306 connect the turbine shroud assembly 310 to the nacelle body 350. The rear end 316 of the turbine shroud assembly 310 has mixing elements, including outwardly directed mixing elements 315 and inwardly directed mixing elements 317. It is noted that like reference numbers refer to like components.

[0098] In certain embodiments and as shown in FIGS. 17-20, system 400 includes boundary layer energizing members 430. Certain boundary layer energizing members 430 take the form of flow control devices (e.g., active flow control devices) or ports or apertures 430 or the like. In example embodiments, boundary layer energizing members

430 are configured and dimensioned to alter (e.g., cause or prevent separation of) a fluid boundary layer over a flow control surface (e.g., over the turbine shroud assembly 310 and or ejector shroud assembly 320) to alter the performance of the fluid turbine system 400 (or shrouds 110, 120 of system 100, or shrouds 310, 320 of system 300, etc.). In example embodiments, the flow control ports or devices 430 employ high velocity flow through or via the ports 430 on aerodynamic surfaces of the system 400 for flow control purposes (e.g., for the purpose of preventing or causing separation of the boundary layer). In example embodiments, fluid delivered to the flow control ports 430 can be provided by a suitable external pumping or actuation means or assembly or the like, and or can be provided by harvesting fluid energy from within the shrouded fluid turbine system 400.

[0099] In general, at least one flow control port 430 is associated with and or is mounted with respect to a surface of system 400 (e.g., with a surface of turbine shroud assembly 310, or assembly 320). In example embodiments, a plurality of flow control ports 430 are associated with a surface of turbine shroud assembly 310 (or assembly 320). In some embodiments, the flow control ports 430 are integrally formed with assembly 310 (or assembly 320), although the present disclosure is not limited thereto.

[00100] In certain embodiments, flow control ports 430 can be associated with and or positioned on the turbine shroud assembly 310 approximately at or proximal to the leading edge 312 of the turbine shroud assembly 310. However, it is noted that flow control ports 430 can be associated with or positioned on assembly 310 (or assembly 320) at any suitable location. For example, system 400 can include flow control ports 430 on the suction side (e.g., low pressure side on the interior of the shroud assembly) and or on the pressure side (higher pressure side on the outside or exterior of the shroud assembly) of shroud assembly surfaces (assembly 310 and or 320). As such, the flow control ports 430 can be configured and dimensioned to energize or provide fluid flow to the boundary layer to alter fluid flow (e.g., delay, cause or prevent flow separation before the fluid has reached the trailing edge of the shroud assembly 310, 320).

[00101] It is noted that the flow control ports 430 can be utilized in lieu of or in addition to the vortex generators 330 (or 130, etc.) in the fluid turbine systems of the present disclosure.

[00102] In example embodiments, the flow control ports or devices 430 employ high velocity flow through or via the ports 430 on aerodynamic surfaces of the system 400 for preventing or causing separation of the boundary layer. FIGS. 17-20 illustrate

embodiments of the system 400 having flow control ports 430 associated with the ringed airfoil surfaces (e.g., assemblies 310, 320). It is noted that in excessive fluid velocity conditions, the flow devices or ports 430 can be disengaged so as to reduce the performance of the airfoils and therefore reduce the overall performance of the turbine system 400. The flow devices or ports 430 may be disengaged using a variety of means including active pneumatic or electromechanical actuation, passive actuation due to velocity or pressure profile, or some combination thereof. One skilled in the art will readily recognize that the above noted actuation means are merely illustrative of sample embodiments and are not intended to be limiting in scope.

[00103] In example embodiments and as shown in FIG. 18, the flow control ports 430 are associated with the inner surface of the turbine shroud 310 proximal to the outwardly turning mixing elements 315. Again, it is noted that ports 430 can be associated with or positioned on assembly 310 (or assembly 320) at any suitable location. For example and as shown in FIGS. 19 and 20, flow control ports 430 can be associated with the outer surface of the turbine shroud 310 proximal to the inward turning mixing elements 317. Moreover and as shown in FIG. 19, flow control ports 430 can be associated with the inner surface of the ejector shroud assembly 320. As noted, fluid delivered to the flow control ports 430 can be provided by a suitable external pumping or actuation means or assembly, and or can be provided by harvesting fluid energy from within the shrouded fluid turbine system 400.

[00104] Figure 21 depicts another example embodiment of a shrouded fluid turbine system 500. The system 500 is a single shroud system free of an ejector shroud. As such, an example embodiment of the fluid turbine system 500 in accordance with the present disclosure is shown in FIG. 21. The fluid turbine system 500 includes a turbine shroud assembly 510, a nacelle body 550 and a rotor assembly 540. The turbine shroud assembly 510 includes a front end 512 and a rear end 516. Support members 506 connect the turbine shroud assembly 510 to the nacelle body 550.

[00105] The rotor assembly 540 includes a central hub 541, and the nacelle body 550 and the turbine shroud assembly 510 are supported by a tower 502. The rotor assembly 540 and turbine shroud assembly 510 can be coaxial with each other, i.e. they share a common central axis 505. The rear end 516 of the turbine shroud assembly 510 has mixing elements, including outwardly directed mixing elements 515 and inwardly directed mixing elements 517.

[00106] In example embodiments and as shown in FIG. 21, system 500 includes boundary layer energizing members 530. Boundary layer energizing members 530 can take the form of vortex generators and or flow control devices or ports 530 or the like, as similarly discussed and described above in conjunction with FIGS. 1-20.

[00107] As noted above, boundary layer energizing members 530 are configured and dimensioned to alter a fluid boundary layer (e.g., prevent separation of a fluid boundary layer) over a flow control surface (e.g., over the turbine shroud assembly 510) to alter the performance of the fluid turbine system 500. In general, at least one boundary layer energizing member 530 is associated with and or is mounted with respect to a surface of system 500 (e.g., with a surface of turbine shroud assembly 510). In example embodiments, a plurality of boundary layer energizing members 530 are associated with a surface of turbine shroud assembly 510.

[00108] As discussed above in conjunction with FIGS. 1-20, it is noted that boundary layer energizing member 530 can be associated with or positioned on assembly 510 at any suitable location. For example, system 500 can include members 530 on the suction side (e.g., low pressure side on the interior of the shroud assembly) and or on the pressure side (higher pressure side on the outside or exterior of the shroud assembly) of shroud assembly surfaces (assembly 510). As such, members 530 can be configured and dimensioned to energize or provide fluid flow to the boundary layer to alter a fluid boundary layer (e.g., delay or prevent flow separation before the fluid has reached the trailing edge of the shroud assembly 510).

[00109] Turning now to FIGS. 22-24, another example embodiment of a fluid turbine system 1500 in accordance with the present disclosure is shown. As discussed further below, FIGS. 22-24 illustrate a fluid turbine system 1500 having boundary layer energizing members 1530 (e.g., flow control ports 1530) engaged with substantially faceted annular airfoil surfaces. Boundary layer energizing members 1530 can take the form of flow control devices (e.g., active flow control devices) or ports 1530 or the like, although the present disclosure is not limited thereto. Rather, it is noted that the boundary layer energizing members 1530 can take other forms, e.g., vortex generators.

[00110] In example embodiments and as shown in FIG. 22, the turbine shroud assembly 1510 takes the form of an annular airfoil that includes a leading edge portion 1512 (also known as the inlet end). In certain embodiments, the leading edge 1512 is substantially annular, thus providing a relatively narrow gap between the rotor blade tips

of rotor assembly 1540 and the interior surface of the leading edge 1512. The leading edge 1512 is engaged with a series of substantially linear segments with constant cross sections 1515, also known as turbine shroud facets, that transition from the annular leading edge 1512. Turbine shroud facets 1515 enjoin at nodes 1517, and further include rear ends 1516, also known as the exit or trailing edge of the turbine shroud assembly 1510.

[00111] In some embodiments, a secondary shroud assembly 1520 (e.g., a shroud assembly in the shape of an annular airfoil) includes substantially linear segments with constant cross sections 1535, otherwise referred to as ejector shroud facets, and include leading edges 1522 and trailing edges 1524 that are in fluid communication with the trailing edge 1516 of the turbine shroud assembly 1510. Facets 1535 enjoin at nodes 1537. Facets 1535 also enjoin at struts 1513 that support the nodes 1517, 1537 of both shroud assemblies 1510, 1520. The shroud assemblies 1510, 1520 are co-axial with the rotor assembly 1540, rotor hub 1541 and nacelle body 1550 about the central axis 1505. The rotor assembly 1540 and shroud assemblies 1510, 1520 are supported by a tower structure 1502.

[00112] In certain embodiments and as shown in FIGS. 22-24, system 1500 includes boundary layer energizing members 1530. Boundary layer energizing members 1530 take the form of flow control devices or ports or apertures 1530 or the like. In general, boundary layer energizing members 1530 are configured and dimensioned to alter a fluid boundary layer (e.g., prevent separation of a fluid boundary layer) over a flow control surface (e.g., over the turbine shroud assembly 1510 and or ejector shroud assembly 1520) to alter the performance of the fluid turbine system 1500. In general, the flow control ports or devices 1530 employ high velocity flow through or via the ports 1530 on aerodynamic surfaces of the system 1500 for flow control purposes. In example embodiments, fluid delivered to the flow control ports 1530 can be provided by a suitable external pumping or actuation means or assembly, and or can be provided by harvesting fluid energy from within the shrouded fluid turbine system 1500.

[00113] In general, at least one flow control port 1530 is associated with and or is mounted with respect to a surface of system 1500 (e.g., with a surface of turbine shroud assembly 1510, or assembly 1520). A plurality of flow control ports 1530 can be associated with a surface of turbine shroud assembly 1510 (or assembly 1520).

[00114] Flow control ports 1530 can be associated with and or positioned on the turbine shroud assembly 1510 approximately at or proximal to the leading edge 1512 of the turbine shroud assembly 1510. However, it is noted that flow control ports 1530 can be associated with or positioned on assembly 1510 (or assembly 1520) at any suitable location (e.g., on the suction side of a shroud assembly, on the pressure side 1538 of a shroud assembly, etc.). As such, the flow control ports 1530 can be configured and dimensioned for flow control purposes (e.g., to energize or provide fluid flow to the boundary layer to delay or prevent flow separation before the fluid has reached the trailing edge of the shroud assembly 1510, 1520).

[00115] As shown in FIGS. 23-24, flow control ports 1530 are associated with the inner surface of the turbine shroud assembly 1510 proximal to the outward leading edge 1512. Flow control ports 1530 are also associated with the inner surface of the ejector shroud assembly 1520. By providing fluid flow through the ports 1530, boundary layer attachment over the aerodynamic surfaces may be maintained or disrupted by varying volume and or angle of flow through ports 1530, and in so doing providing a means of increasing or decreasing performance of turbine system 1500 (e.g., airfoil performance). As noted, fluid delivered to the flow control ports 1530 can be provided by a suitable external pumping or actuation means or assembly, and or can be provided by harvesting fluid energy from within the shrouded fluid turbine system 1500.

[00116] Although the systems and methods of the present disclosure have been described with reference to example embodiments thereof, the present disclosure is not limited to such example embodiments and or implementations. Rather, the systems and methods of the present disclosure are susceptible to many implementations and applications, as will be readily apparent to persons skilled in the art from the disclosure hereof. The present disclosure expressly encompasses such modifications, enhancements and or variations of the disclosed embodiments. Since many changes could be made in the above construction and many widely different embodiments of this disclosure could be made without departing from the scope thereof, it is intended that all matter contained in the drawings and specification shall be interpreted as illustrative and not in a limiting sense. Additional modifications, changes, and substitutions are intended in the foregoing disclosure. Accordingly, it is appropriate that the appended claims be construed broadly and in a manner consistent with the scope of the disclosure.

What is claimed is:

CLAIMS:

1. A shrouded fluid turbine system comprising:
a rotor assembly;
a turbine shroud assembly disposed about the rotor assembly, the turbine shroud having a low pressure side and a high pressure side, the low pressure side in fluid communication with the rotor assembly; and
at least one boundary layer energizing member associated with the turbine shroud assembly, the at least one boundary layer energizing member configured and dimensioned to alter a fluid boundary layer over a surface of the turbine shroud assembly to alter the performance of the fluid turbine system.
2. The system of claim 1, wherein the at least one boundary layer energizing member is positioned proximal to a leading edge of the turbine shroud assembly.
3. The system of claim 1 further comprising a first plurality of boundary layer energizing members and a second plurality of boundary layer energizing members;
wherein the first plurality of boundary layer energizing members are positioned proximal to a leading edge of the turbine shroud assembly; and
wherein the second plurality of boundary layer energizing members are positioned between the leading edge and a trailing edge of the turbine shroud assembly.
4. The system of claim 3, wherein the first and second pluralities of boundary layer energizing members are associated with the low pressure side of the turbine shroud assembly.
5. The system of claim 1 further comprising a plurality of boundary layer energizing members;
wherein the turbine shroud assembly includes a plurality of curving mixing elements; and
wherein each mixing element is associated with at least one boundary layer energizing member.
6. The system of claim 5, wherein the plurality of curving mixing elements includes a first plurality of inwardly curving mixing elements and a second plurality of outwardly curving mixing elements.

7. The system of claim 6, wherein at least one boundary layer energizing member is positioned on the high pressure side of the turbine shroud assembly and proximal to an inward curving mixing element of the plurality of inward curving mixing elements.

8. The system of claim 1, wherein the turbine shroud assembly defines an airfoil ring having an apex; and
wherein the at least one boundary layer energizing member is positioned proximal to the apex of the airfoil ring.

9. The system of claim 1, wherein the at least one boundary layer energizing member is a vortex generator, the vortex generator in the form of a protruding member that protrudes from a surface of the turbine shroud assembly.

10. The system of claim 9, wherein the vortex generator has a length and a height; and
wherein the length is about four times the height of the vortex generator.

11. The system of claim 9, wherein the vortex generator has a length and a height;
wherein the vortex generator is fabricated from a flexible material and includes a first un-flexed condition and a second flexed condition; and
wherein when the vortex generator is in the second flexed condition, the length of the vortex generator is about eight times the height.

12. The system of claim 5, wherein each curving mixing element includes a voluminous leading edge that transitions to a curved planar form at a trailing edge.

13. The system of claim 1 further comprising an ejector shroud assembly positioned downstream from and coaxial with the turbine shroud assembly;
wherein at least one boundary layer energizing member is associated with the ejector shroud assembly, the at least one boundary layer energizing member associated with the ejector shroud assembly configured and dimensioned to alter a fluid boundary layer over a surface of the ejector shroud assembly to alter the performance of the fluid turbine system.

14. The system of claim 13, wherein the at least one boundary layer energizing member associated with the ejector shroud assembly is positioned proximal to a leading edge of the ejector shroud assembly.

15. The system of claim 13 further comprising a first plurality of boundary layer energizing members and a second plurality of boundary layer energizing members associated with the ejector shroud assembly;

wherein the first plurality of boundary layer energizing members are positioned proximal to a leading edge of the ejector shroud assembly; and

wherein the second plurality of boundary layer energizing members are positioned between the leading edge and a trailing edge of the ejector shroud assembly.

16. The system of claim 15, wherein the first and second pluralities of boundary layer energizing members are associated with the low pressure side of the ejector shroud assembly.

17. The system of claim 13, wherein the ejector shroud assembly defines an airfoil ring having an apex; and

wherein the at least one boundary layer energizing member associated with the ejector shroud assembly is positioned proximal to the apex of the airfoil ring.

18. The system of claim 13, wherein the at least one boundary layer energizing member associated with the ejector shroud assembly is a vortex generator, the vortex generator in the form of a protruding member that protrudes from a surface of the ejector shroud assembly.

19. The system of claim 1, wherein the at least one boundary layer energizing member is a flow control port, the flow control port configured and dimensioned to employ high velocity flow through the flow control port for flow control purposes and to alter a fluid boundary layer over a surface of the turbine shroud assembly to alter the performance of the fluid turbine system.

20. The system of claim 19, wherein the at least one flow control port is positioned proximal to a leading edge of the turbine shroud assembly.

21. The system of claim 19, wherein the at least one flow control port is remotely energized with the high velocity flow.

22. The system of claim 19, wherein the at least one flow control port is energized with the high velocity flow by harvesting fluid energy from the fluid turbine system.

23. The system of claim 1, wherein the at least one boundary layer energizing member is configured and dimensioned to prevent separation of a fluid boundary layer over a surface of the turbine shroud assembly to alter the performance of the fluid turbine system.

24. The system of claim 1, wherein the at least one boundary layer energizing member is configured and dimensioned to alter a fluid boundary layer over a surface of the turbine shroud assembly to reduce the performance of the fluid turbine system.

25. The system of claim 1, wherein the turbine shroud assembly defines an annular airfoil having a leading edge that transitions to a faceted trailing edge.

26. The system of claim 19, wherein the volume or angle of the high velocity flow through the flow control port is variable.

27. The system of claim 1, wherein the at least one boundary layer energizing member configured and dimensioned to alter a fluid boundary layer over a surface of the turbine shroud assembly alters the performance of the fluid turbine system.

28. A shrouded fluid turbine system comprising:
a rotor assembly;
a turbine shroud assembly disposed about the rotor assembly, the turbine shroud having a low pressure side and a high pressure side, the low pressure side in fluid communication with the rotor assembly, the turbine shroud assembly including a plurality of curving mixing elements; and

a first and second plurality of boundary layer energizing members associated with the turbine shroud assembly, each boundary layer energizing member configured and dimensioned to alter a fluid boundary layer over a surface of the turbine shroud assembly, the first plurality of boundary layer energizing members positioned proximal to a leading edge of the turbine shroud assembly and the second plurality of boundary layer energizing members positioned between the leading edge and a trailing edge of the turbine shroud assembly, at least a portion of the first and second pluralities of

boundary layer energizing members associated with the low pressure side of the turbine shroud assembly, and each mixing element associated with at least one boundary layer energizing member.

29. A shrouded fluid turbine system comprising:

a rotor assembly;

a turbine shroud assembly disposed about the rotor assembly, the turbine shroud having a low pressure side and a high pressure side, the low pressure side in fluid communication with the rotor assembly;

at least one first boundary layer energizing member associated with the turbine shroud assembly, the at least one first boundary layer energizing member configured and dimensioned to alter a fluid boundary layer over a surface of the turbine shroud assembly to alter the performance of the fluid turbine system;

an ejector shroud assembly positioned downstream from and coaxial with the turbine shroud assembly;

at least one second boundary layer energizing member associated with the ejector shroud assembly, the at least one second boundary layer energizing member configured and dimensioned to alter a fluid boundary layer over a surface of the ejector shroud assembly to alter the performance of the fluid turbine system;

wherein the turbine shroud assembly includes a plurality of curving mixing elements;

wherein the at least one first boundary layer energizing member is positioned proximal to a leading edge of the turbine shroud assembly; and

wherein the at least one second boundary layer energizing member is positioned proximal to a leading edge of the ejector shroud assembly.

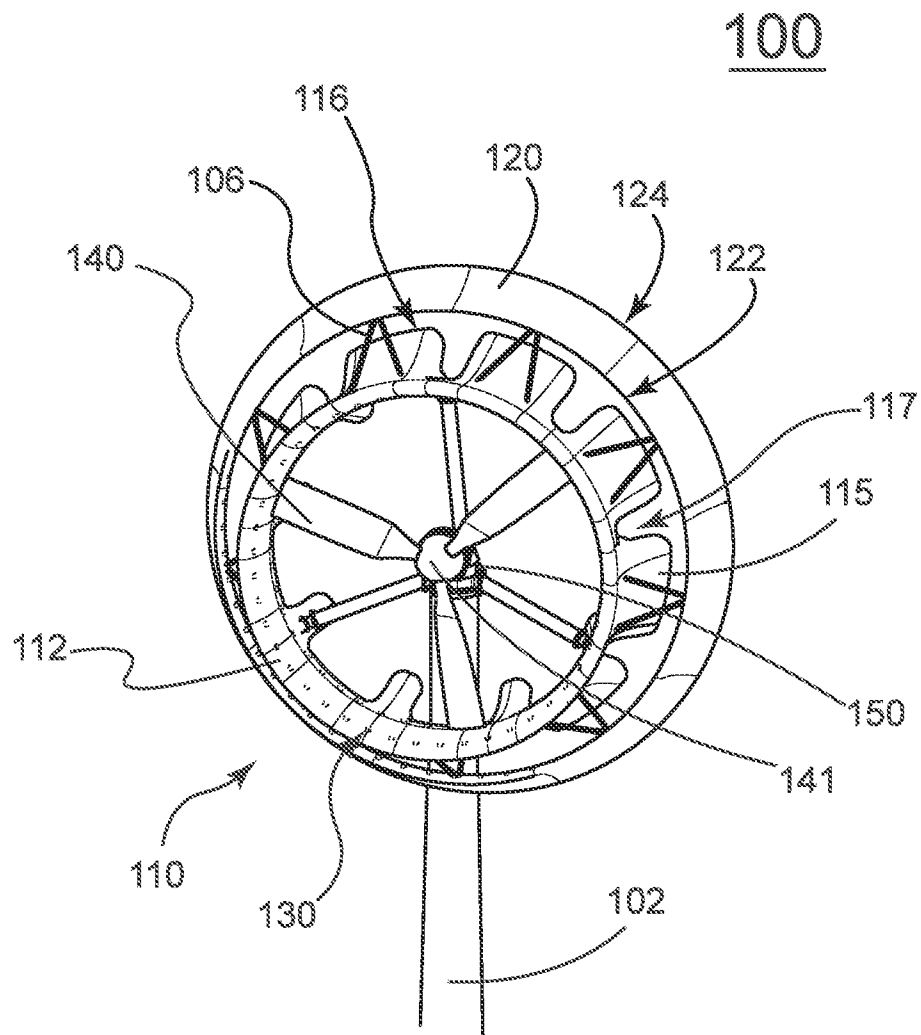


Figure 1

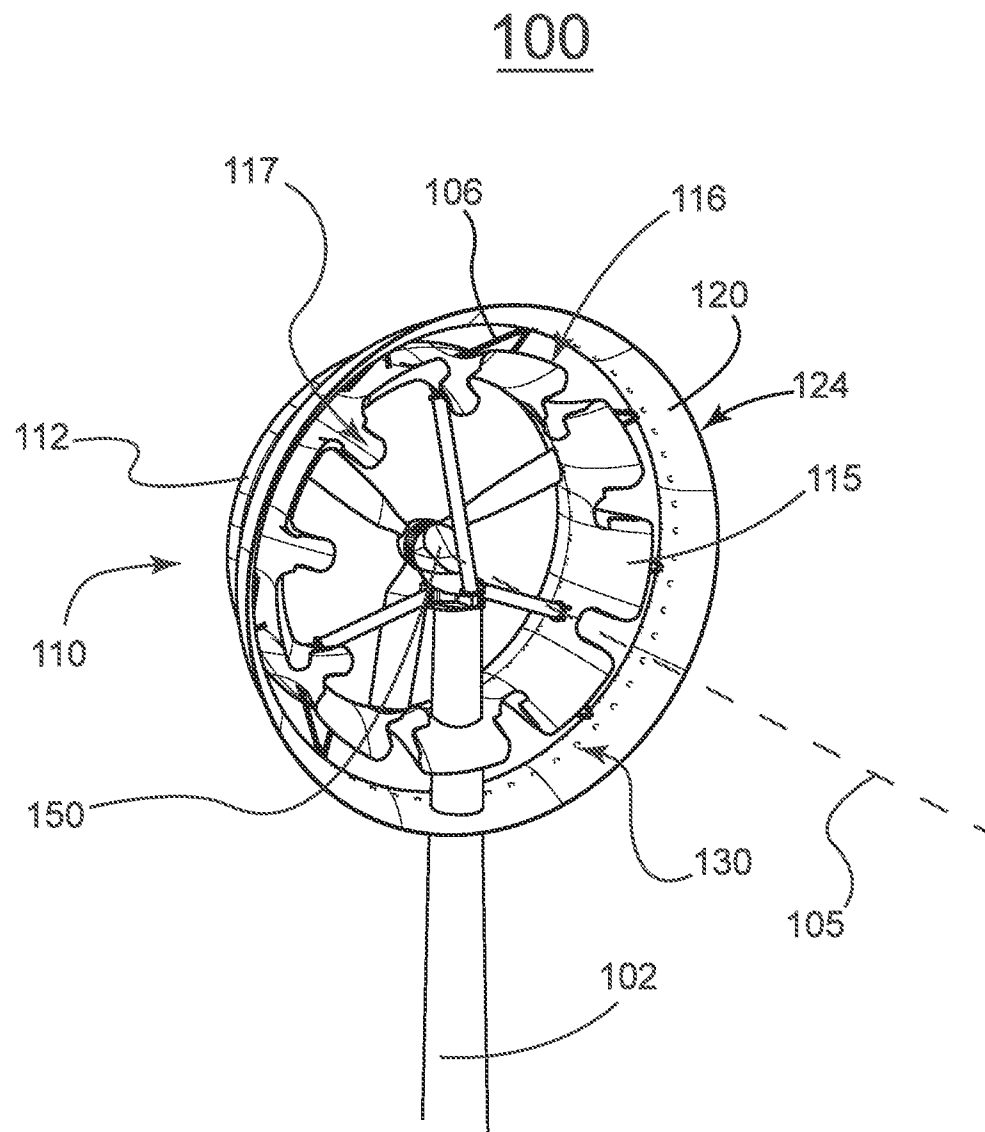
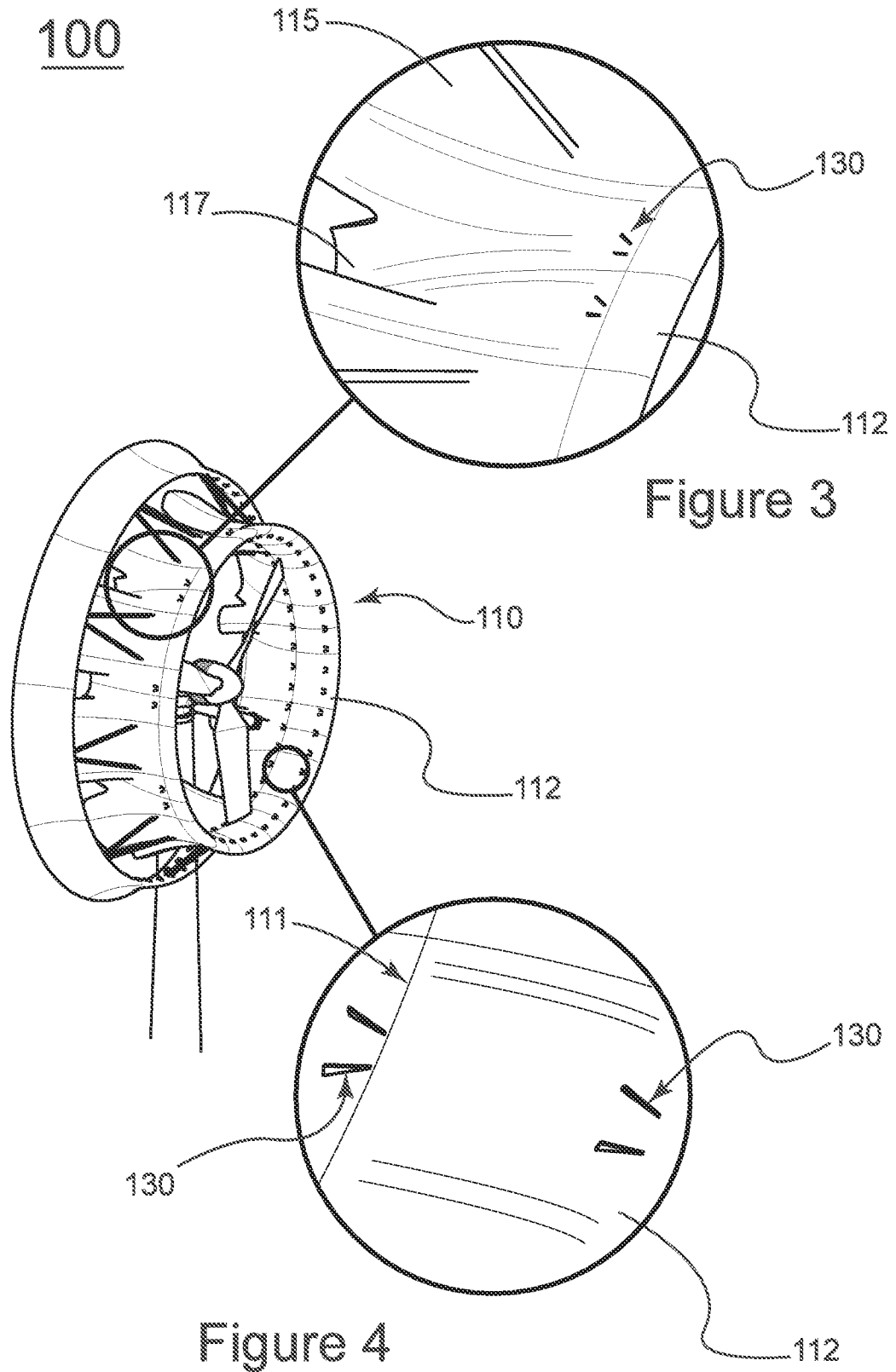


Figure 2



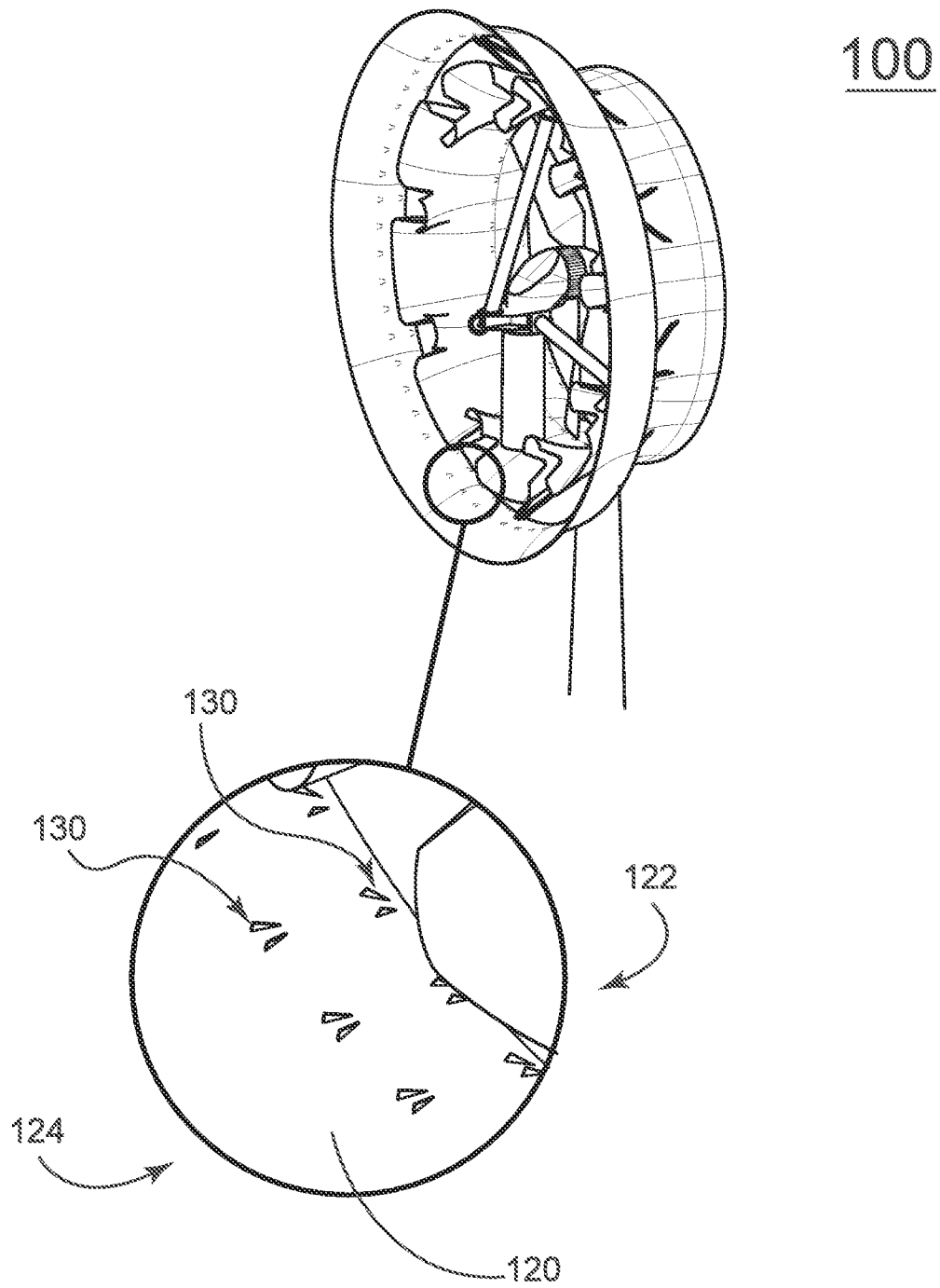


Figure 5

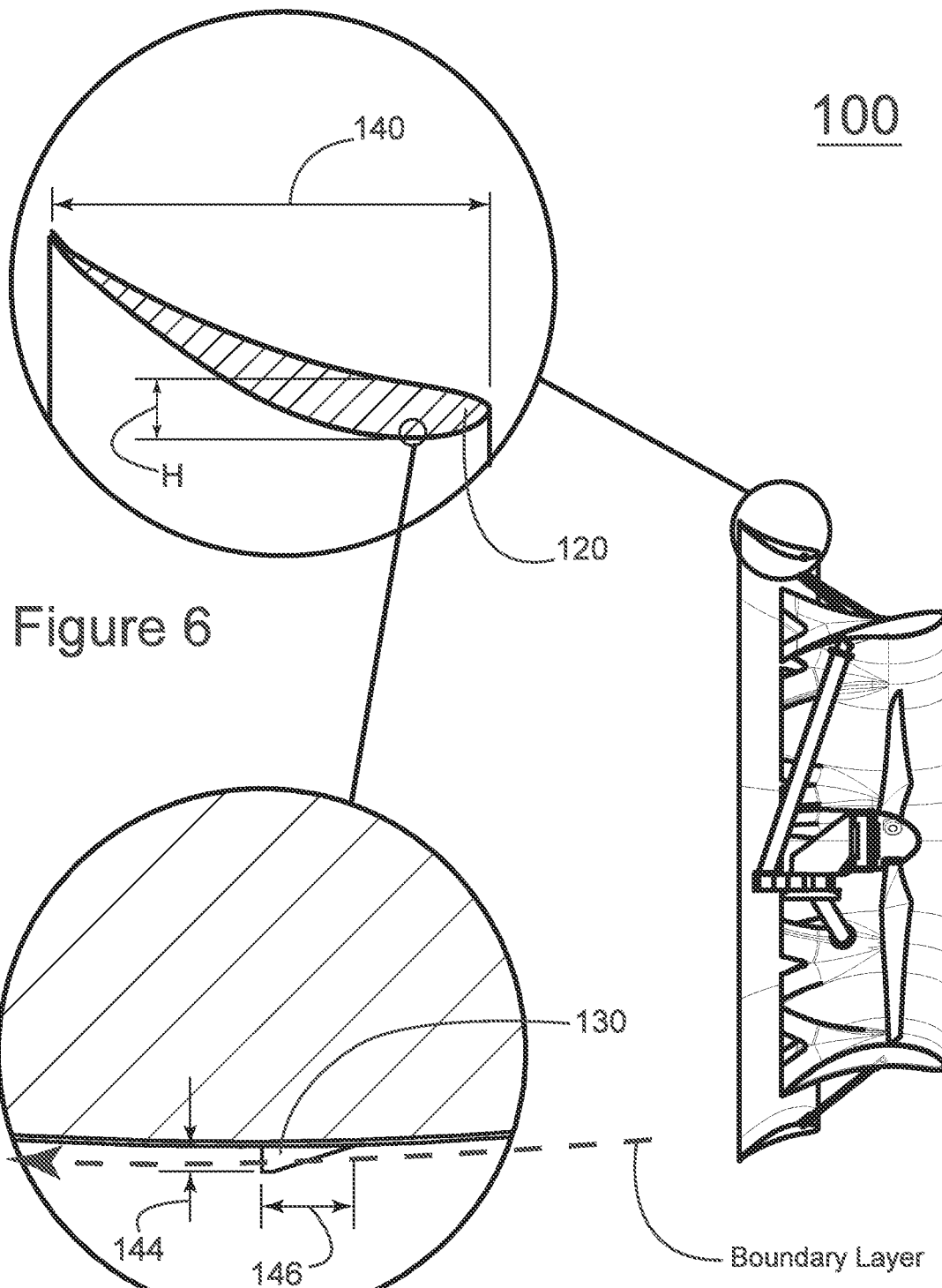


Figure 6

Figure 7

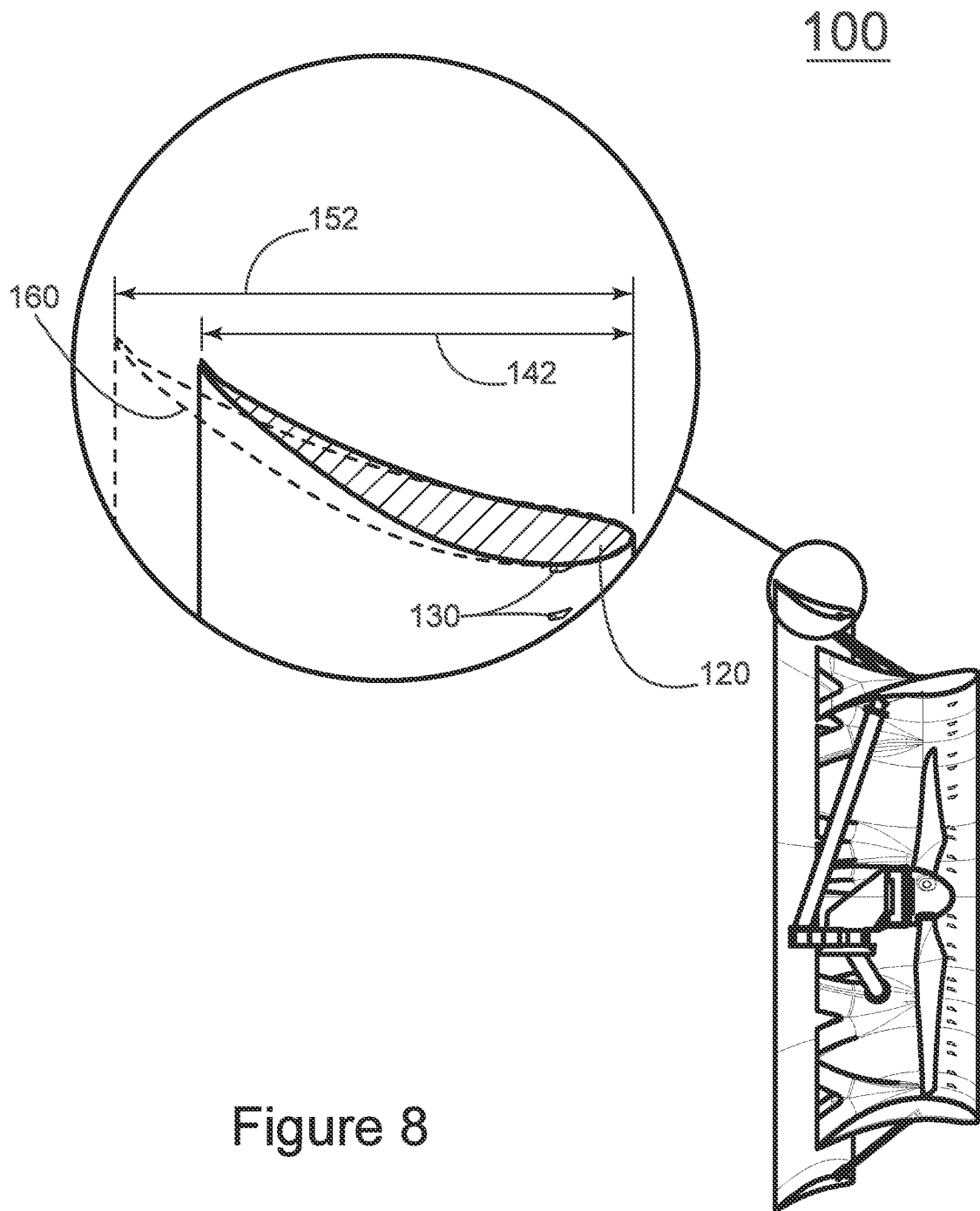


Figure 8

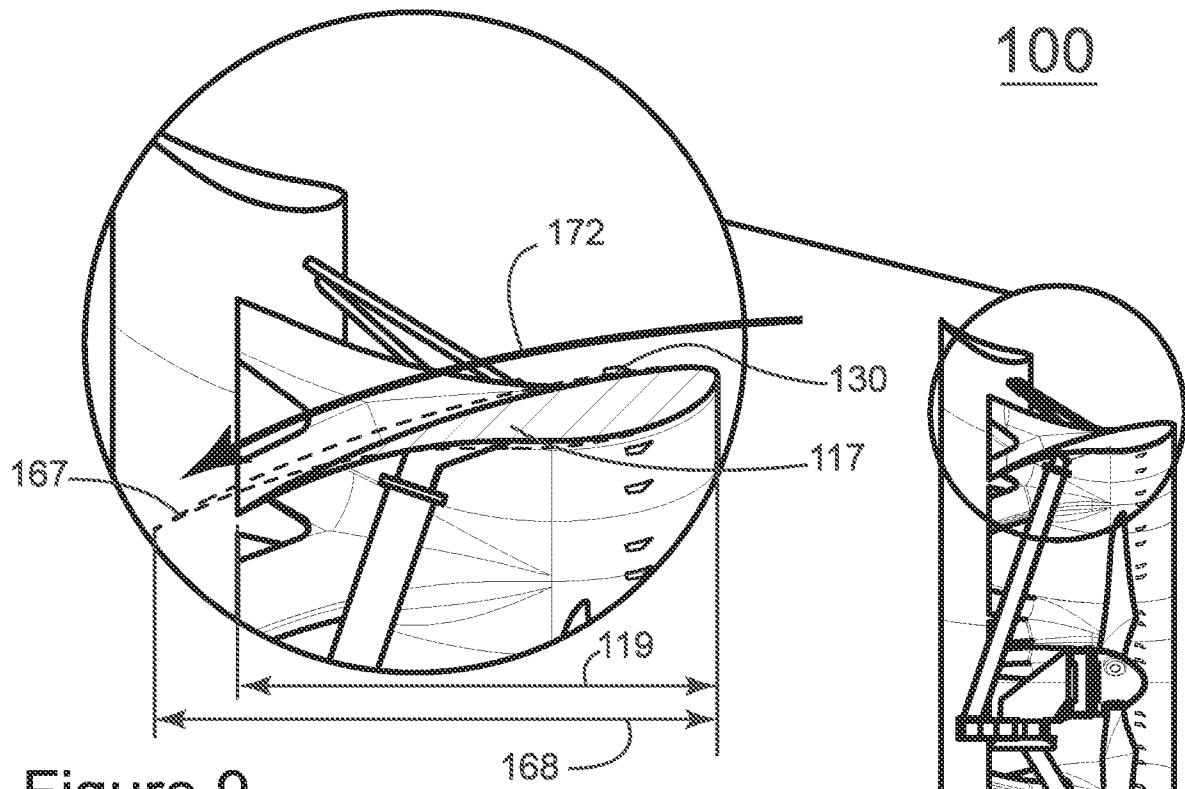


Figure 9

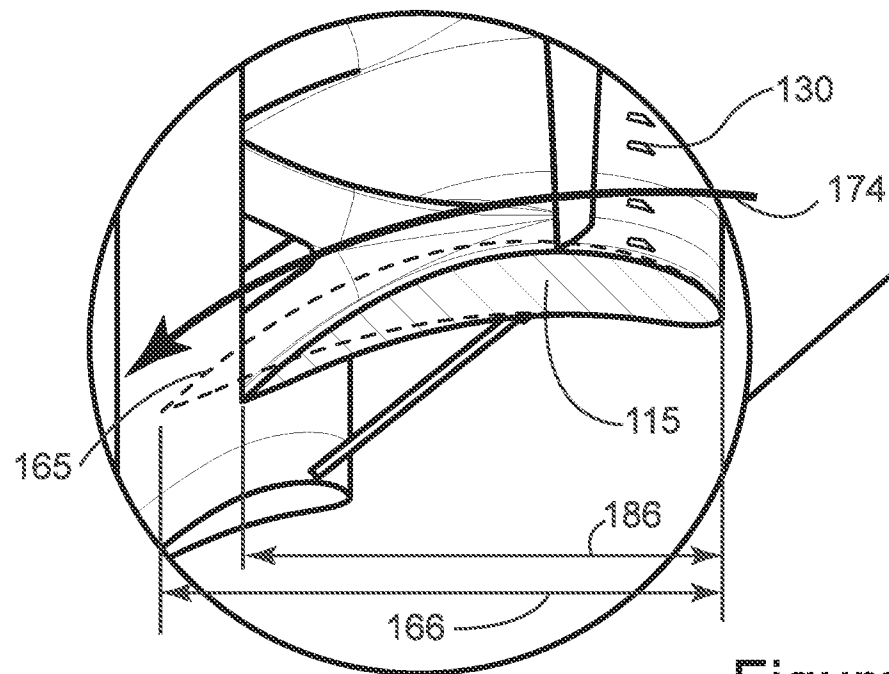


Figure 10

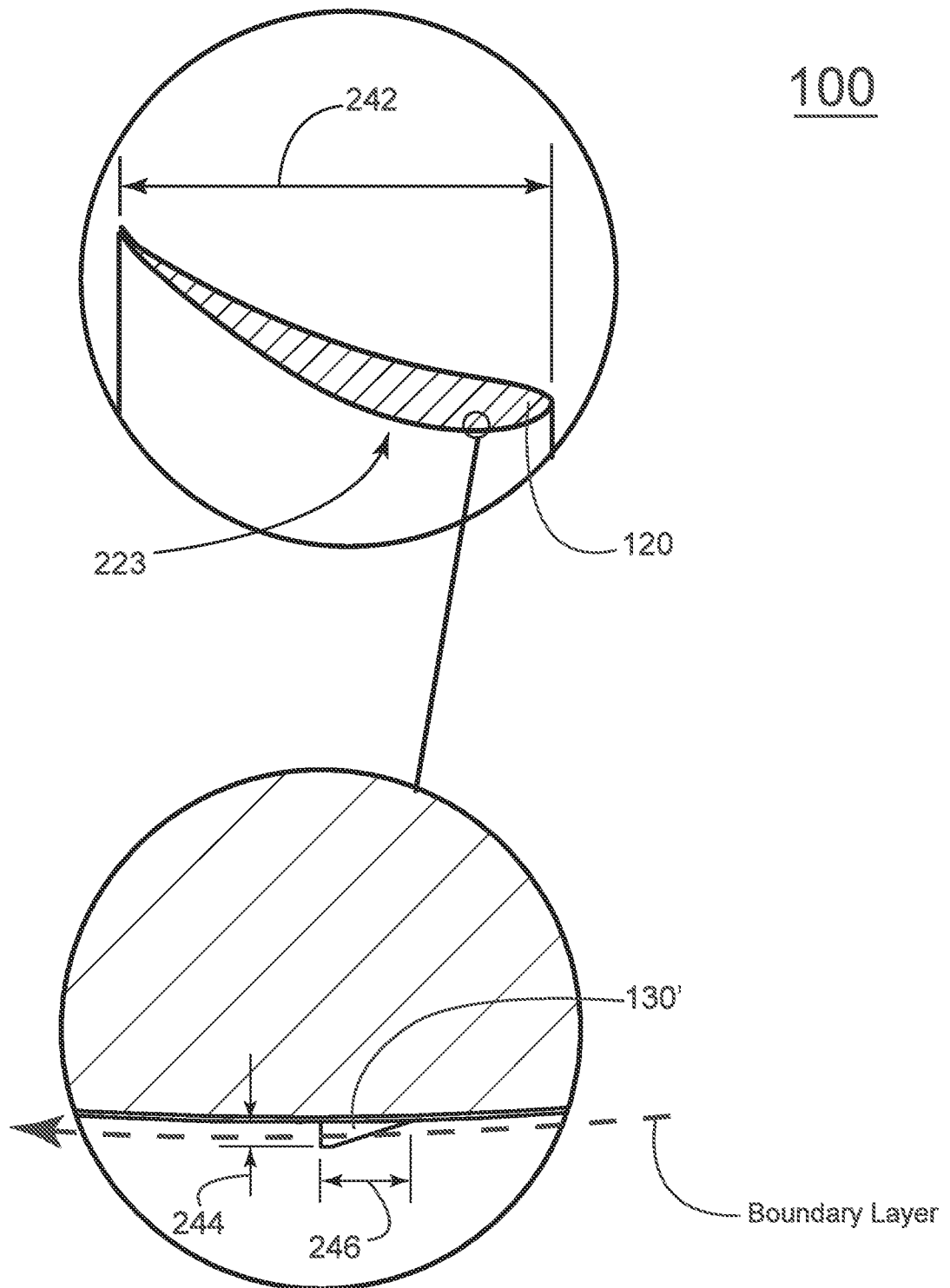


Figure 11

9/20

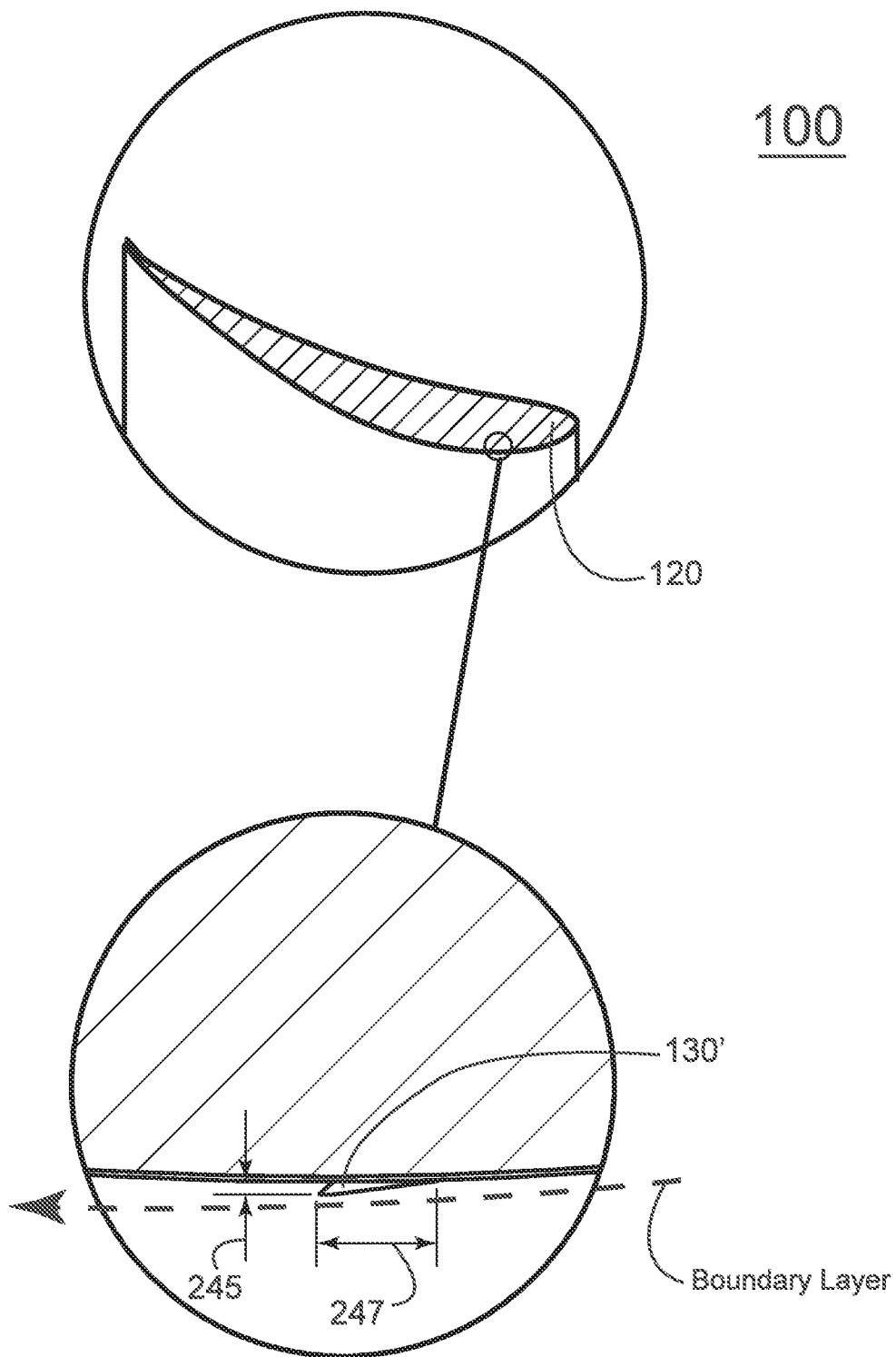


Figure 12

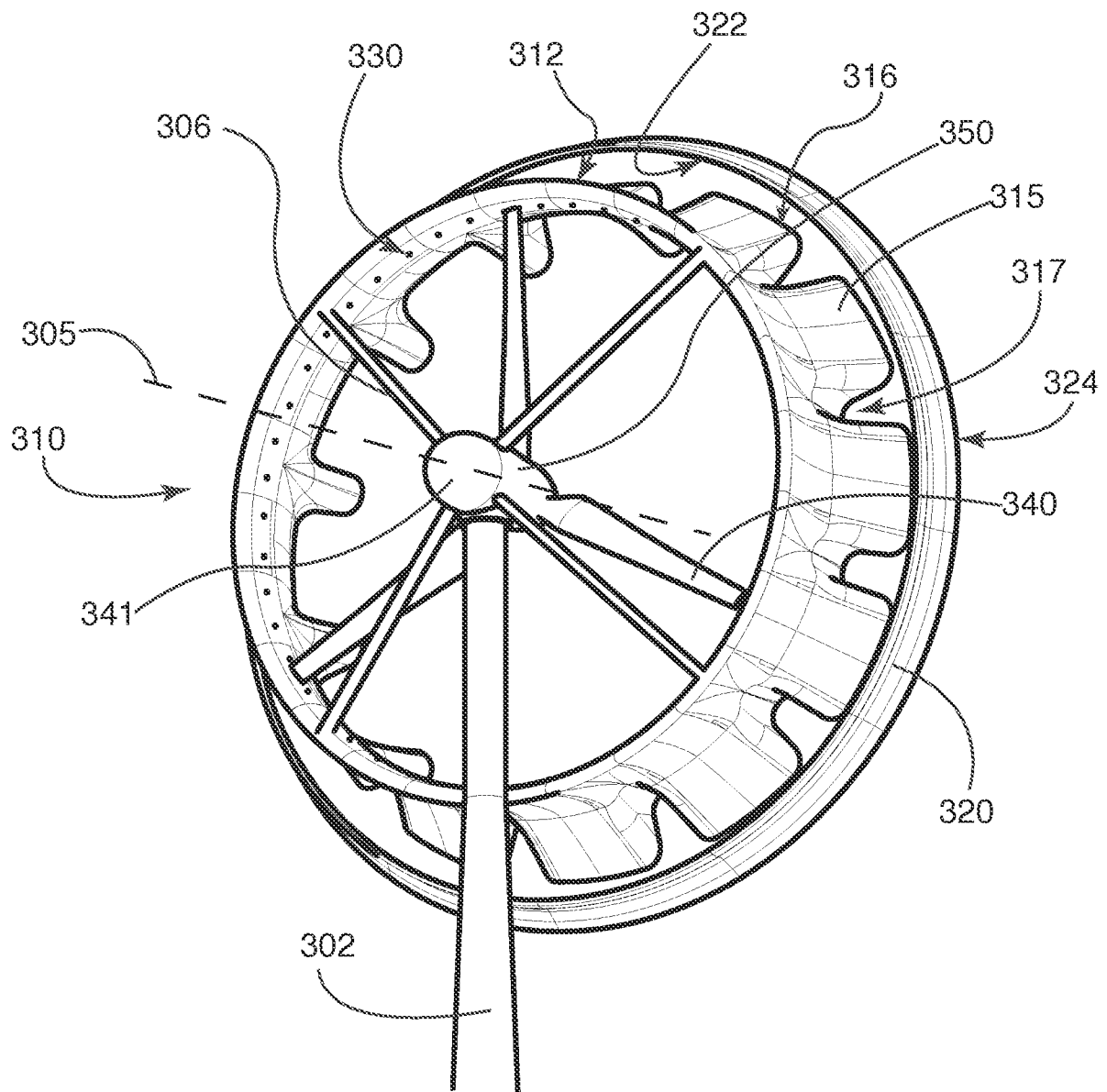
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Figure 13

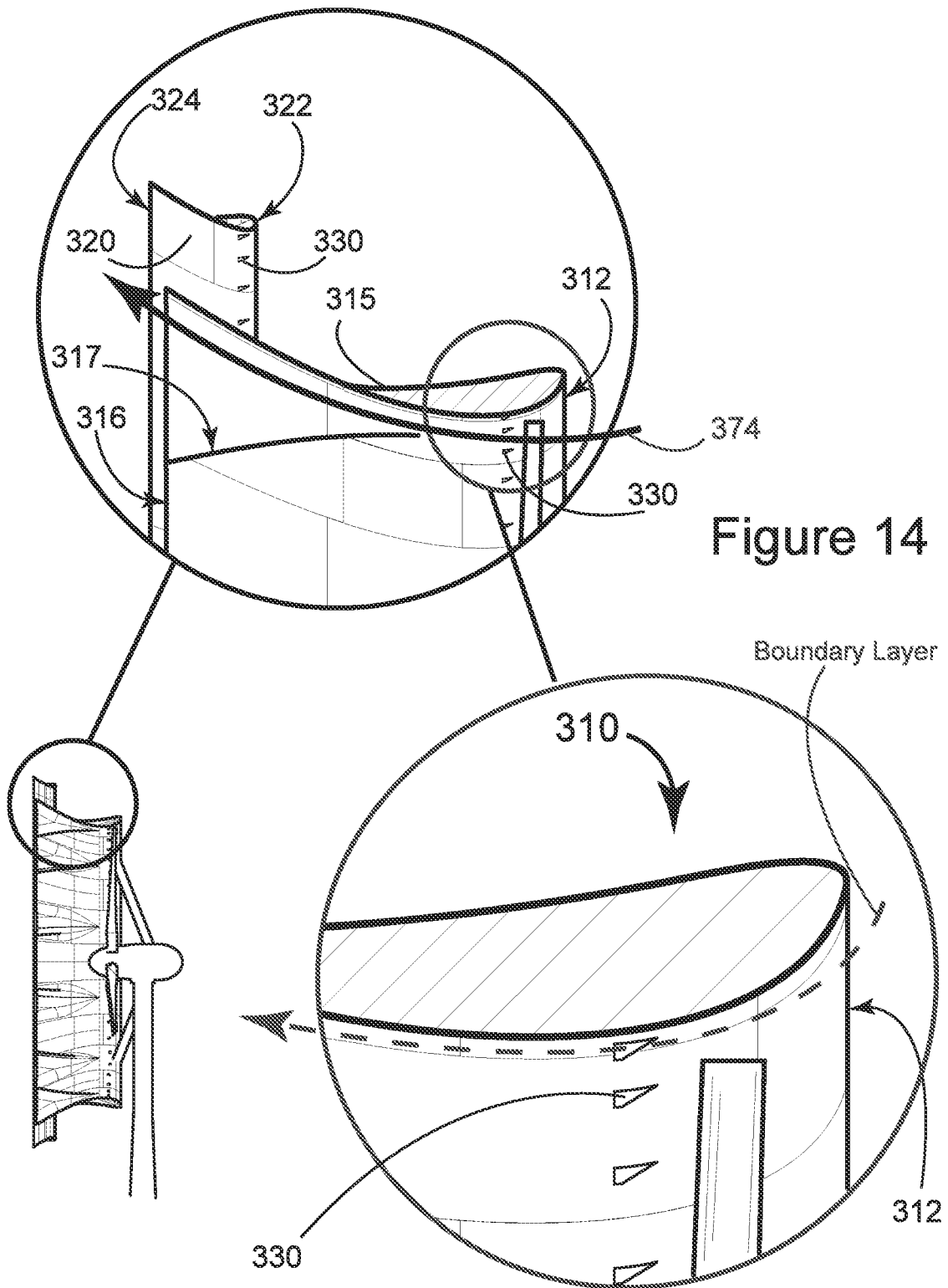


Figure 15

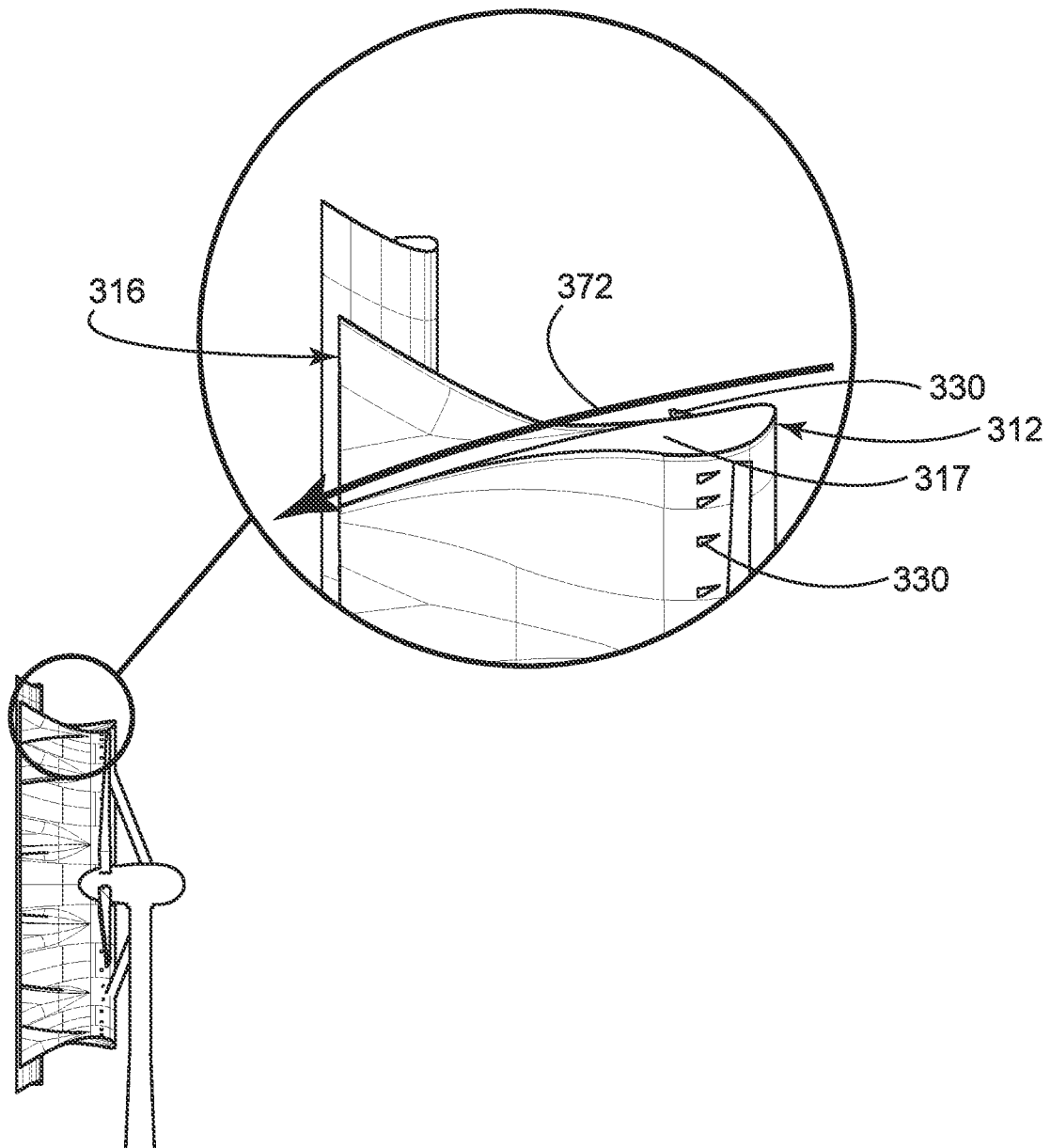


Figure 16

400

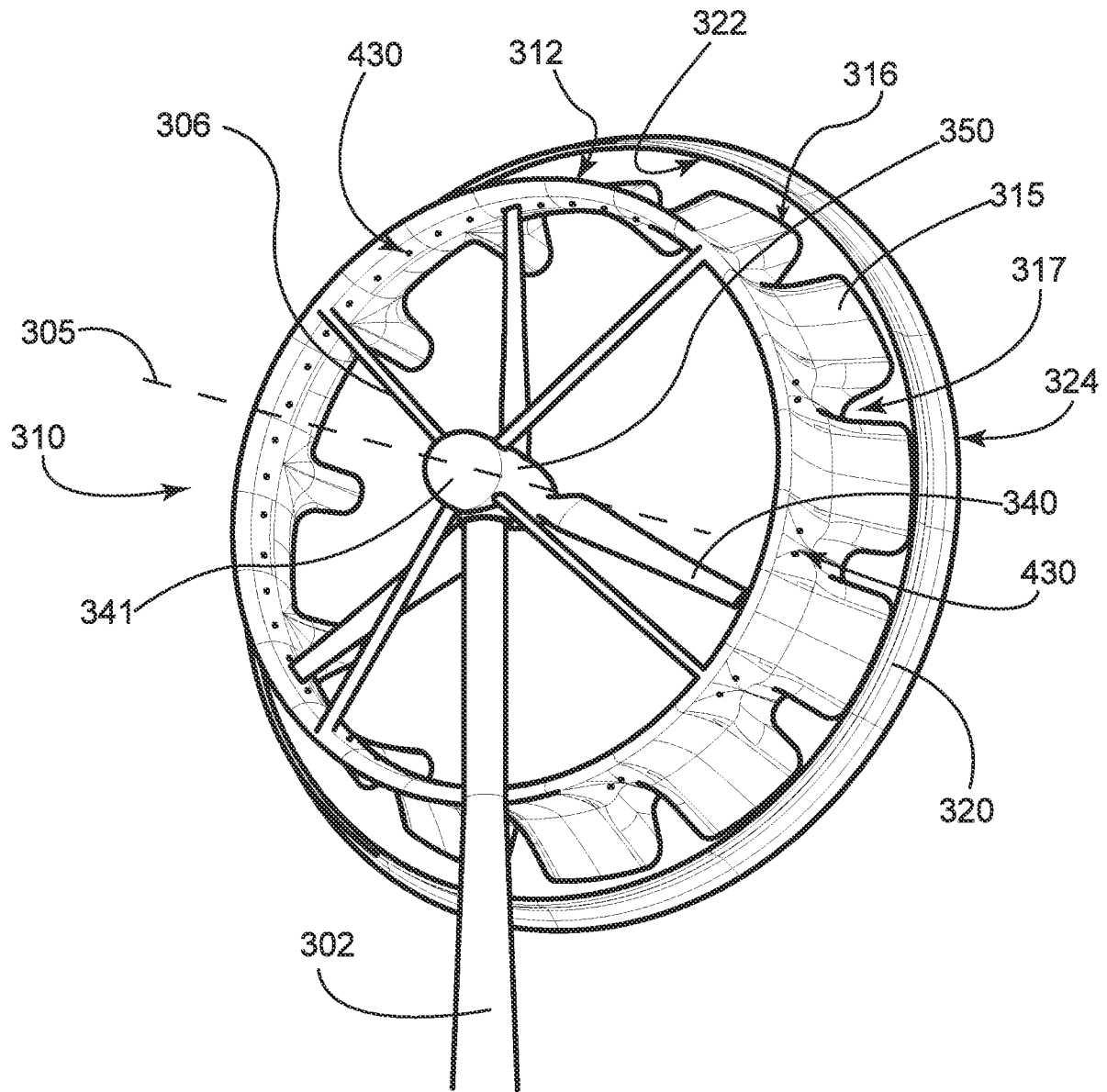


Figure 17

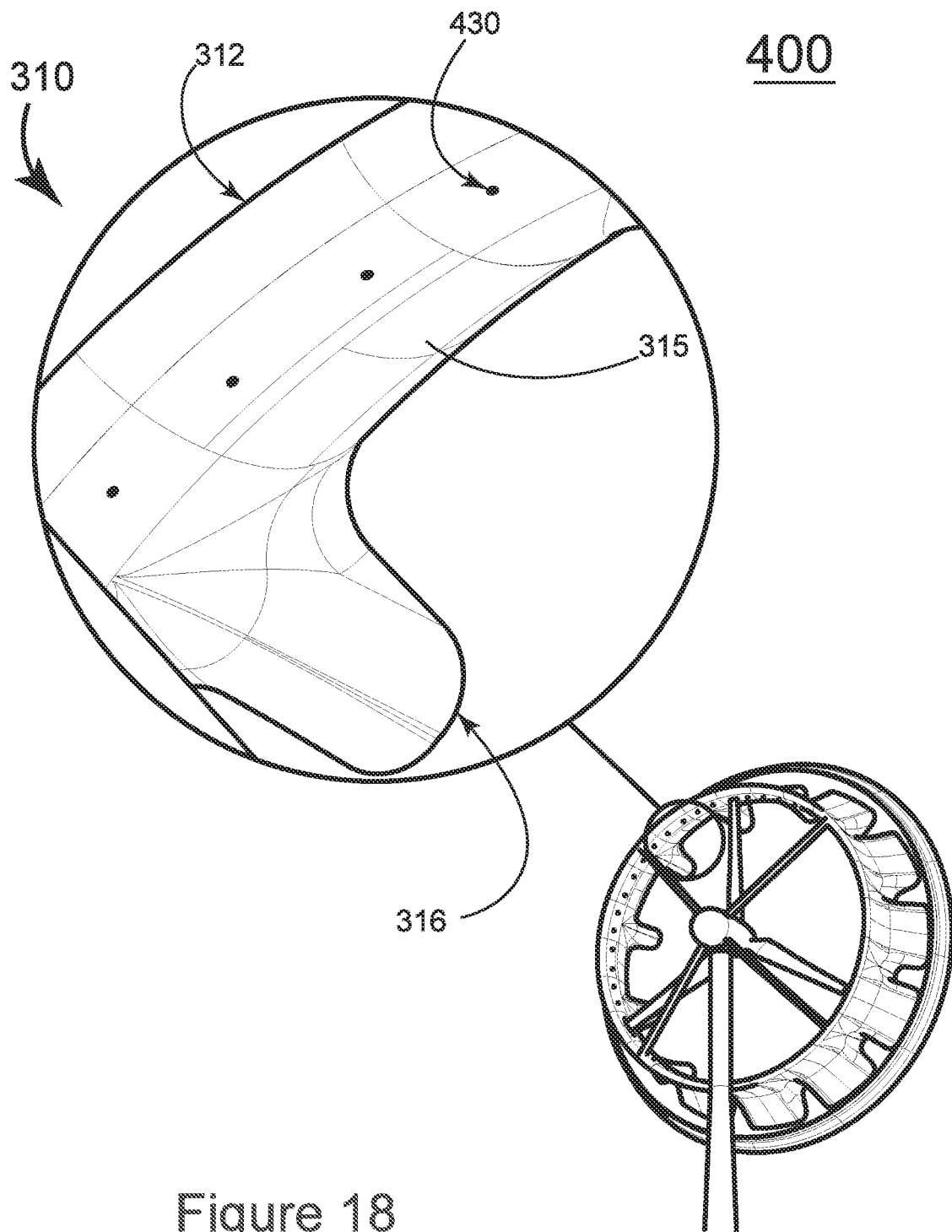


Figure 18

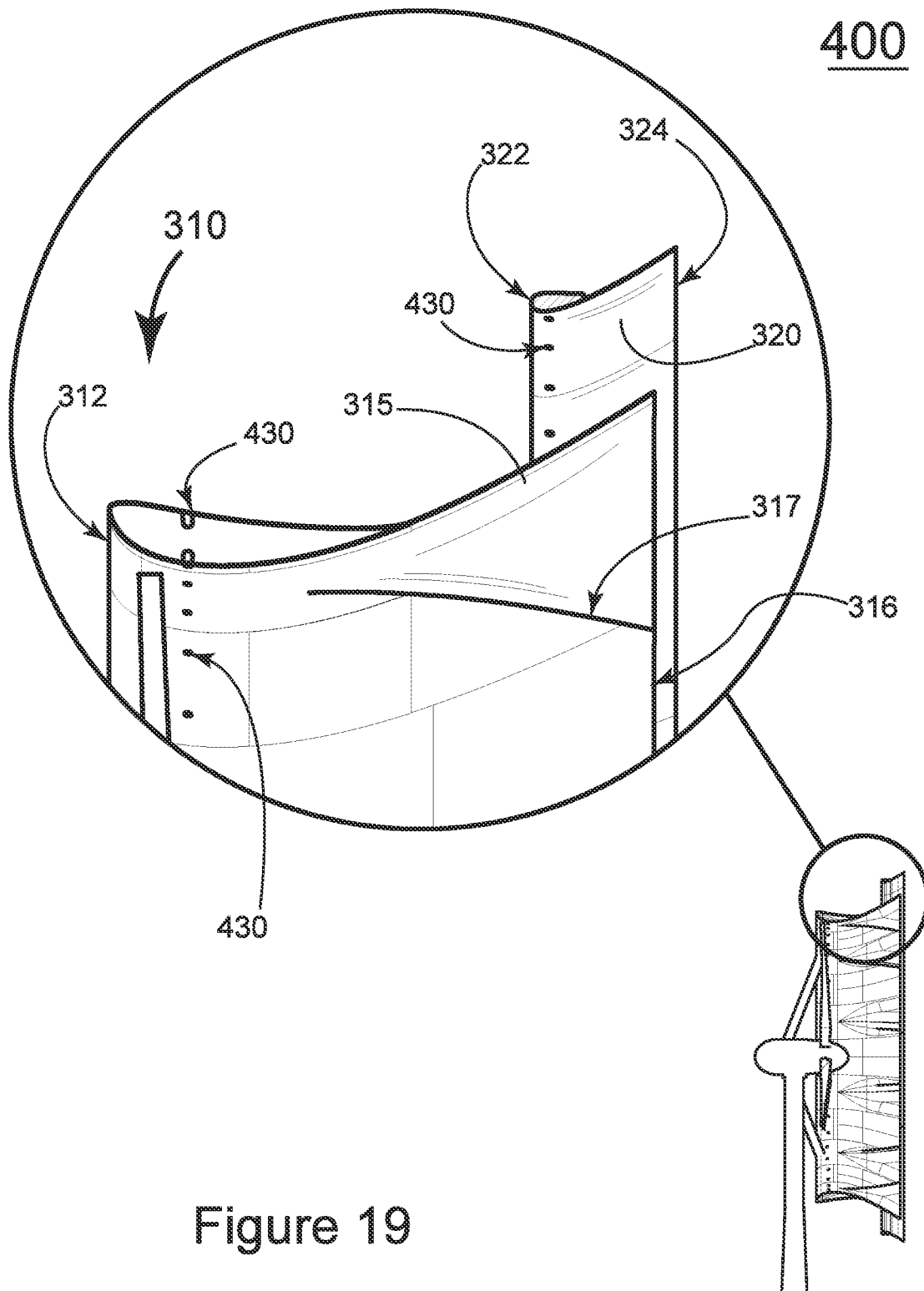


Figure 19

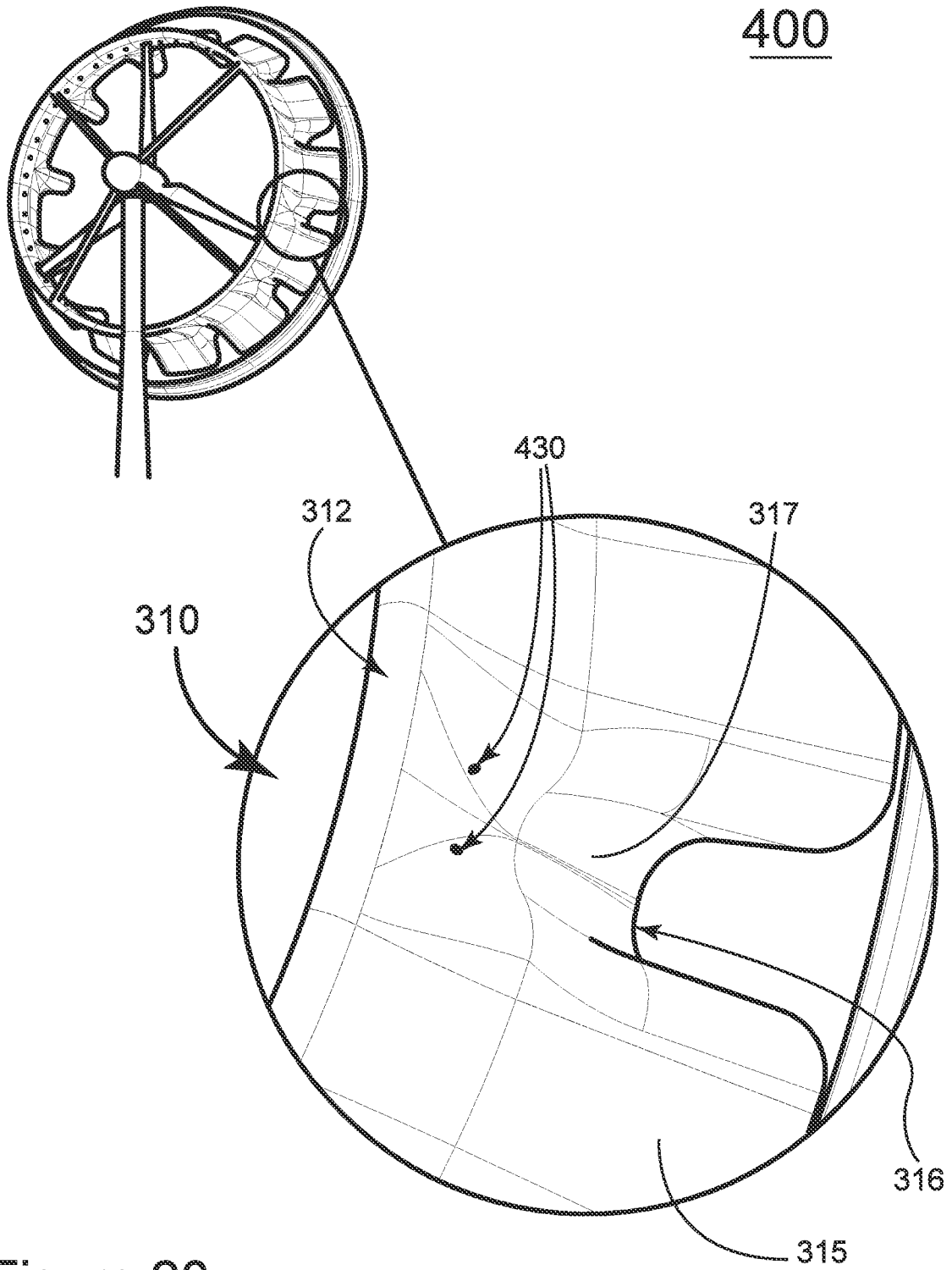


Figure 20

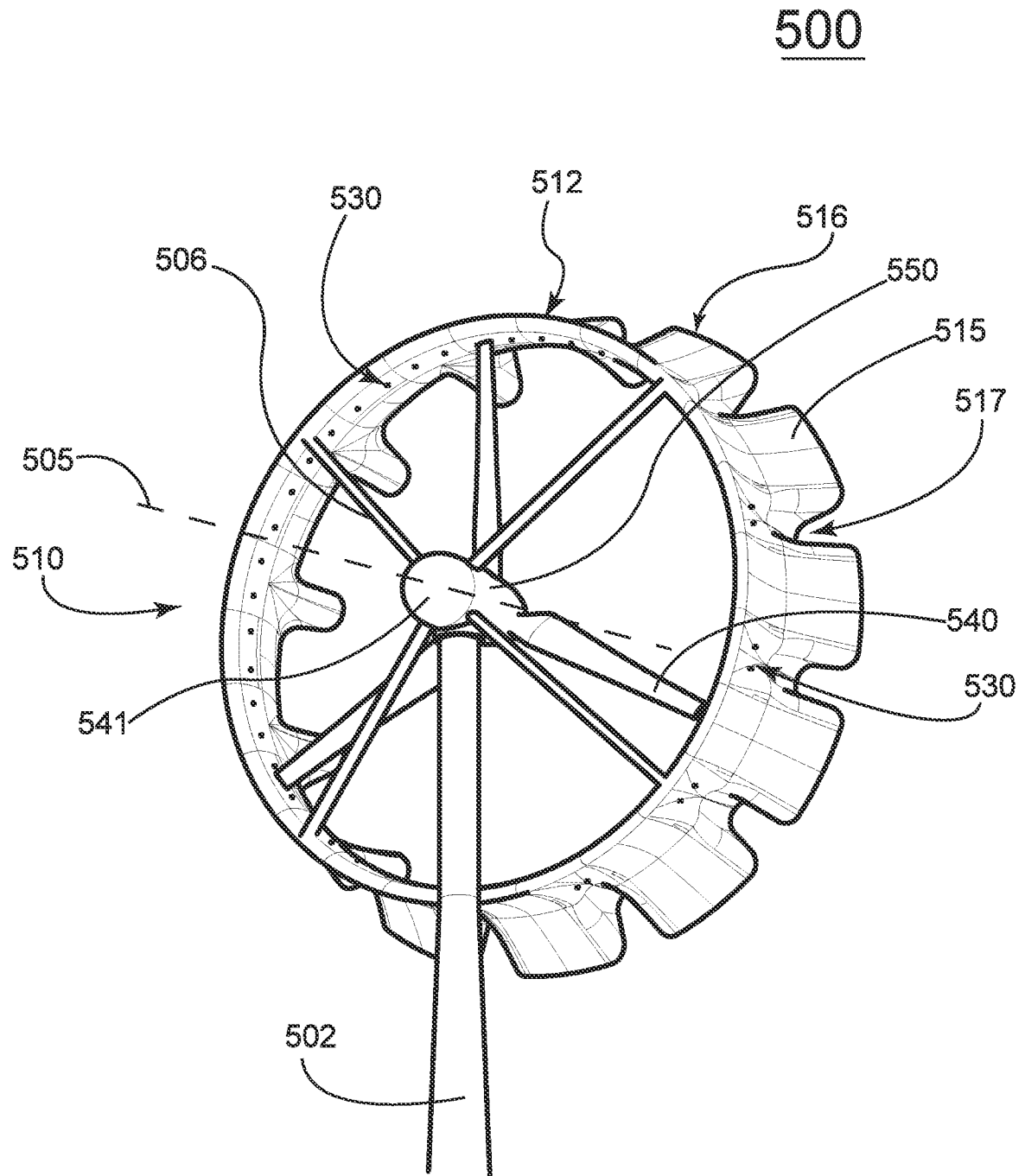


Figure 21

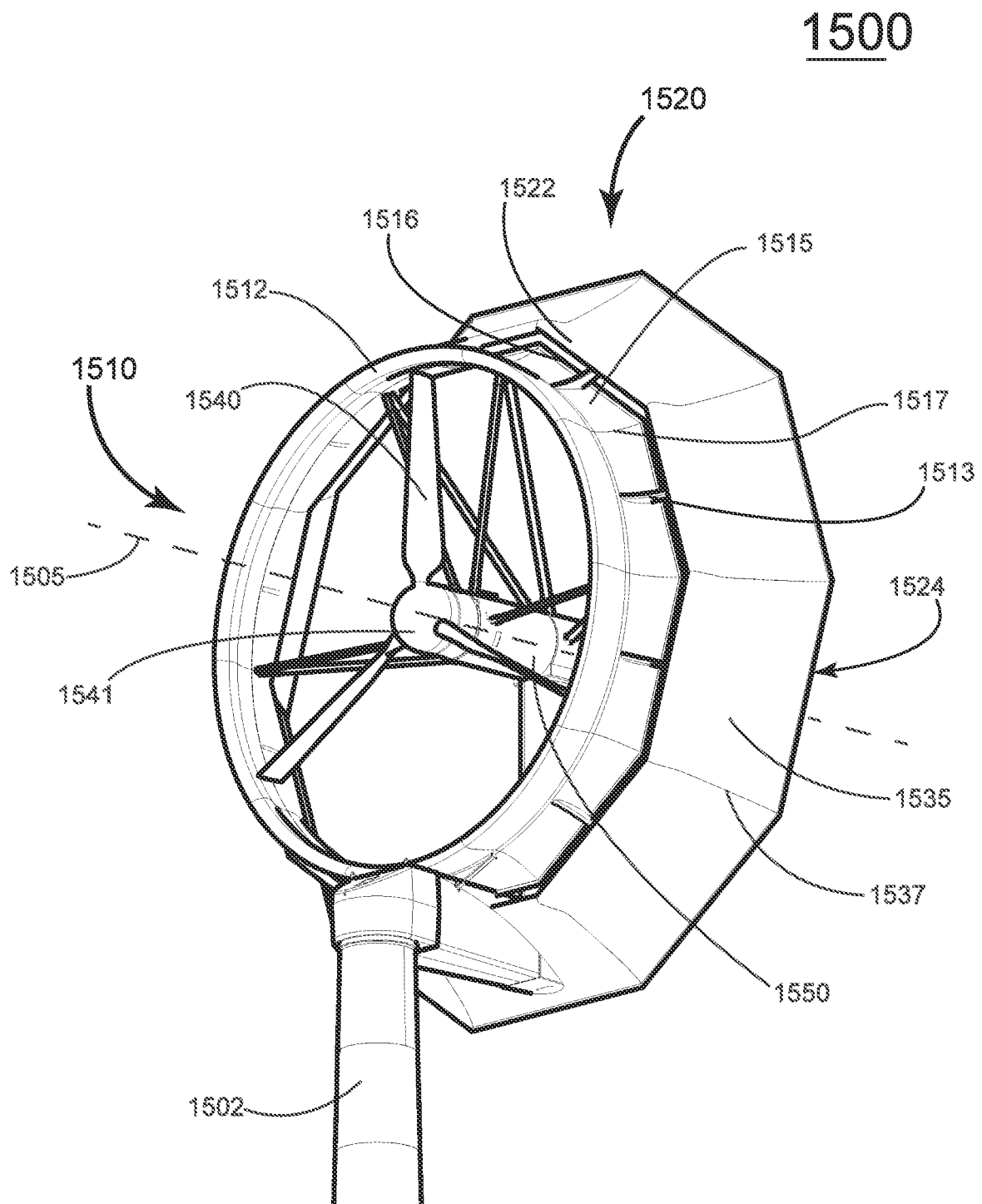


Figure 22

1500

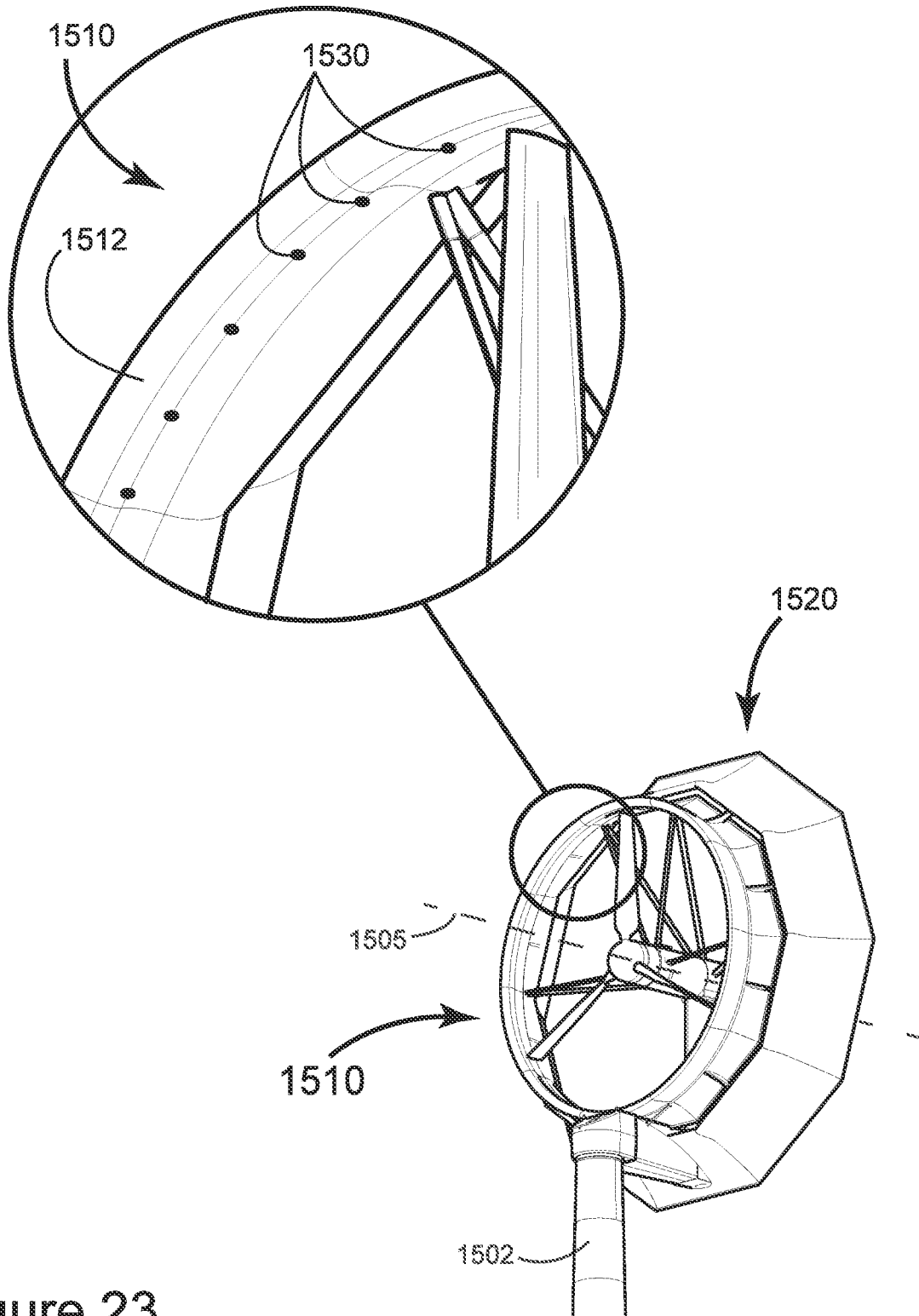


Figure 23

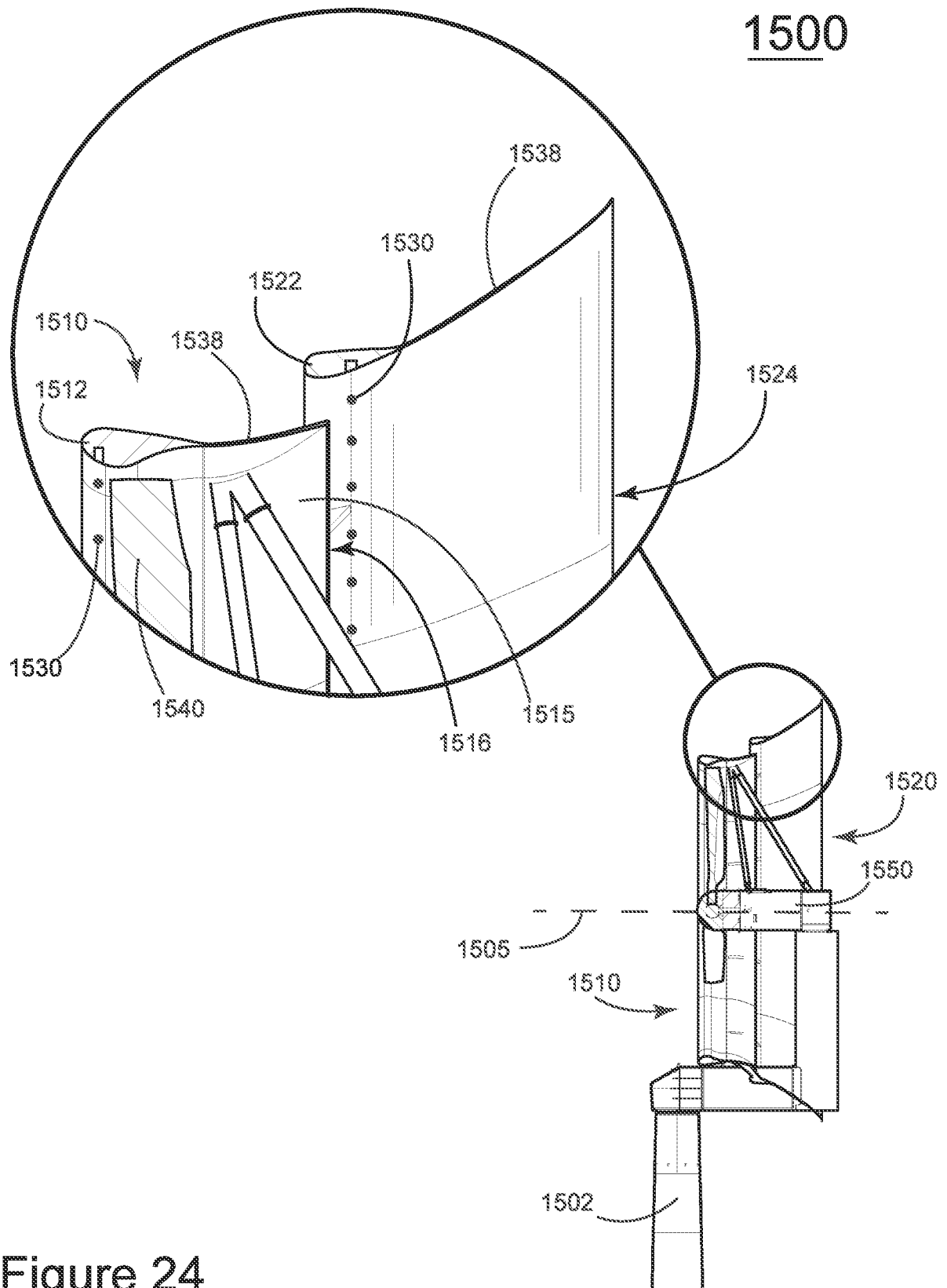


Figure 24

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2013/035980

A. CLASSIFICATION OF SUBJECT MATTER
INV. F03D1/04
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 practicable, search terms used)

EP0-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2011/037268 A1 (SAMMY JOHANN QUINCY [US]) 17 February 2011 (2011-02-17) paragraphs [0020] - [0034]; figures 1A-1D -----	1,2, 5-18,23, 24,29
X	WO 01/06122 A1 (VORTEC ENERGY LTD [NZ]; FOX MILES PETER [NZ]; PHILLIPS DEREK GRANT [NZ]) 25 January 2001 (2001-01-25)	1-6, 12-16, 19-24, 26-29
Y	page 1, line 15 - page 5, line 28; figures 1,4	25
X	GB 1 508 752 A (UNIV BEN GURION) 26 April 1978 (1978-04-26) page 1, line 53 - page 3, line 14; figures 1,3 ----- -/--	1-4, 12-16, 19-24, 28,29



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

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

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

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

8 July 2013

Date of mailing of the international search report

23/07/2013

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
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Fax: (+31-70) 340-3016

Authorized officer

Beran, Jiri

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2013/035980

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2011/058937 A1 (PRESZ JR WALTER M [US] ET AL) 10 March 2011 (2011-03-10) paragraph [0106]; figure 7 -----	5-7,12, 28,29
A	US 2011/274533 A1 (PRESZ JR WALTER M [US] ET AL) 10 November 2011 (2011-11-10) paragraphs [0081] - [0094]; figures 1,2,7 -----	5-7,12, 28,29
X	WO 2008/043367 A1 (GORIN VADIM KONSTANTINOVICH [RU]) 17 April 2008 (2008-04-17)	1
Y	page 3, line 27 - page 4, line 11; figure 1 -----	25
X	US 4 021 135 A (PEDERSEN NICHOLAS F ET AL) 3 May 1977 (1977-05-03)	1
A	column 2, lines 22-34; figure 1 -----	25
A	US 2 650 752 A (HOADLEY HENRY H) 1 September 1953 (1953-09-01) column 3, line 6 - column 10, line 12 -----	1-29

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2013/035980

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2011037268 A1	17-02-2011	NONE	

WO 0106122 A1	25-01-2001	AU 6325000 A	05-02-2001
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		US 2011274533 A1	10-11-2011
		WO 2011140412 A1	10-11-2011

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US 2650752 A	01-09-1953	NONE	

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2013/035980

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☒ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-24, 26-29

a shrouded fluid turbine with a plurality of curving mixing elements

2. claims: 1, 25

a shrouded fluid turbine with a facettted trailing edge of the shroud
