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(54) **Title:** MULTI-ROW PROPELLER (MRP) WITH CO-ROTATING BLADES

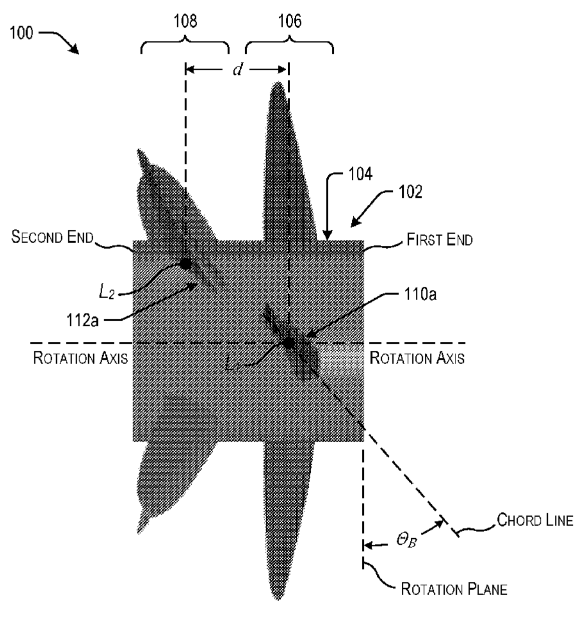

FIG. 1A

(57) **Abstract:** Propulsion devices that provide increased propeller efficiency when operating outside of an optimal advance ratio are described. In one example, a propulsion device includes a hub having a curved surface extending around and along a rotation axis of the hub. The propulsion device can further include two or more rows of blades extending radially outward from the curved surface and including a first row of blades having a first blade and a second row of blades having a second blade that is angularly and axially offset from the first blade on the curved surface. A first centerline of the first blade and a second centerline of the second blade each intersect with a helical line that extends along the rotation axis of the hub. The first blade and the second blade collectively form a helical pattern of blades that projects radially outward from the curved surface along the helical line.

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MULTI-ROW PROPELLER (MRP) WITH CO-ROTATING BLADES

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of and priority to U.S. Provisional Patent Application No. 63/370,314, titled "MULTI-ROW PROPELLER (MRP) WITH CO-ROTATING BLADES," filed August 3, 2022, the entire contents of which is hereby incorporated by reference herein.

BACKGROUND

[0002] Propellers are typically used as devices to generate axial thrust or fluid flow from rotational motion of the blades. Propellers are commonly applied as propulsion devices on aircraft and watercraft but are also used to generate rotational motion from axial thrust in turbine applications. In propulsion applications, the geometry of propeller blades is intentionally designed to generate a pressure difference between fluids interacting with the upstream and downstream surface of the blade. The difference in pressure acting on the surfaces of each blade generates axial force as the propeller blades rotate, which is used to propel a vehicle (e.g., aircraft, watercraft) on which it is installed. Propellers achieve their maximum efficiency for a narrow range of advance ratio, and the efficiency decreases rapidly if the ratio is not ideal.

SUMMARY

[0003] The present disclosure is directed to a device to produce thrust using blades mounted to a common hub such as propellers. In particular, described herein is a propulsion device having a propeller blade arrangement and geometry which increases propeller efficiency away from an optimal advance ratio. More specifically, the present disclosure describes a propeller having two or more rows of blades extending radially from and positioned in a helical fashion around a curved surface of a common hub. The arrangement and geometry of the propeller blades on the propulsion device provides for improved propeller efficiency when the propulsion device is operating outside of a narrow optimal advance ratio range.

[0004] Aspects and advantages of embodiments of the present disclosure will be set forth in part in the following description or can be learned from the description or through practice of the embodiments. Other aspects and advantages of embodiments of the present disclosure will become better understood with reference to the appended claims and the accompanying drawings, all of which are incorporated in and constitute a part of this specification. The drawings illustrate example embodiments of the present disclosure and, together with the description, serve to explain the related concepts of the present disclosure.

[0005] According to one example embodiment, a propulsion device includes a hub having a curved surface extending around and along a rotation axis of the hub. The propulsion device further includes two or more rows of blades extending radially outward from the curved surface. The two or more rows of blades include a first row of blades having a first blade and a second row of blades having a second blade that is angularly and axially offset from the first blade on the curved surface. A first centerline of the first blade and a second centerline of the second blade each intersect with a helical line that extends along the rotation axis of the hub. The first blade and the second blade collectively form a helical pattern of blades that projects radially outward from the curved surface along the helical line.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] Many aspects of the present disclosure can be better understood with reference to the following figures. The components in the figures are not necessarily to scale, with emphasis instead being placed upon clearly illustrating the concepts of the disclosure. Moreover, repeated use of reference characters or numerals in the figures is intended to represent the same or analogous features, elements, or operations across different figures. Repeated description of such repeated reference characters or numerals is omitted for brevity.

[0007] FIGS. 1A, 1B, and 1C respectively illustrate a side, front, and perspective view of an example propulsion device according to at least one embodiment described herein.

[0008] FIG. 2 illustrates another perspective view of the propulsion device of FIG. 1 according to at least one embodiment described herein.

[0009] FIGS. 3A and 3B respectively illustrate a cross-sectional view of corresponding blades on an example propulsion device of the present disclosure according to at least one embodiment described herein.

[0010] FIGS. 4A and 4B respectively illustrate a side and front view of another example propulsion device according to at least one embodiment described herein.

[0011] FIG. 5 illustrates a plot of example performance data obtained from implementation of an example propulsion device of the present disclosure according to at least one embodiment described herein.

[0012] FIG. 6 illustrates a flow diagram of an example method of improving propulsion efficiency according to at least one embodiment described herein.

DETAILED DESCRIPTION

[0013] Propellers achieve their maximum efficiency for a narrow range of advance ratio, and the efficiency decreases rapidly if the ratio is not ideal. As such, propellers used on vehicles (e.g., aircraft, watercraft) or systems (e.g., turbine-based systems) that function across a range of different operating conditions often operate in an inefficient manner, because such ranging operating conditions cause the propellers to operate outside of a narrow optimal advance ratio range. An example of such vehicles that function across a range of different operating conditions are planing hulls operating in the pre-planing, low-speed planing, and high-speed planing regimes.

[0014] Several existing propellers, including propellers with multiple rows of blades, have been designed to improve propeller efficiency when operating outside of an optimal advance ratio range. Examples of such propellers include coaxial contra-rotating propellers, which have multi-hubs of blades that rotate in opposite rotational directions and/or at different rotational rates about a rotation axis of the propeller. However, the design, fabrication, assembly, implementation, and maintenance of such propellers is complex and costly.

[0015] The present disclosure provides solutions to address the above-described current state of propulsion devices. Various examples of the present disclosure describe a propulsion device having a propeller blade arrangement and geometry which increases propeller efficiency away from an optimal advance ratio. The propulsion device can be embodied as a propeller having two or more co-rotating rows of blades extending radially from and positioned in a helical fashion around a curved surface of a common hub. The propeller blade arrangement and geometry of the propulsion device described herein provides for improved propeller efficiency when the device is operating outside of a narrow optimal advance ratio range. In this way, the propulsion device can improve the propulsion efficiency of vehicles or systems that operate in multiple operating conditions (e.g., planing hulls operating in the pre-planing, low-speed planing, and high-speed planing regimes).

[0016] The propulsion device described herein departs from the conventional propeller geometry by locating two or more rows of co-rotating blades along a propeller hub. Each blade in each row of blades is a discrete blade that is individually coupled (e.g., permanently or removable) to a propeller hub. In one example, two or more rows of co-rotating blades are arranged on a common hub (i.e., a shared hub) such that a certain blade(s) of one row corresponds in a particular manner with a certain other blade(s) of another row. In another example, at least one row of blades is arranged on each of at least two hubs that can each be designed for installation on a common shaft in a particular angular and axial configuration with respect to a rotation axis of the shaft. In this example, the blades can be respectively arranged on each separate hub such that when the hubs are installed on the shaft in a particular angular and axial configuration, certain blades of one row of blades on one hub correspond in a particular manner with certain other blades of another row of blades on another hub. In these examples, all blades rotate at the same rate and in the same direction about a shared axis of rotation.

[0017] The propulsion device of the present disclosure can be embodied to include as few as two total blades (e.g., one blade in each row), an equal or unequal number of blades on each row, and geometrically identical or unique blades on each row. The angular distribution of the blades about a shared axis of rotation, as viewed from the front or back of the propulsion device described herein, may be uniform or nonuniform. The angular distribution (also referred to as "angular offset" or "phase") between an upstream row and a downstream row of blades is a design parameter that can be altered for a particular application or desired propulsion efficiency. Additionally, the design of blades described herein, including the selection of blade geometry and type (e.g., sub-cavitating, trans-cavitating, super-cavitating) can be based on and informed by a target application.

[0018] In operation, as a propulsion device of the present disclosure rotates about its rotation axis, the furthest upstream row of blades on the device interacts with an incoming fluid, changing the direction of the fluid velocity as it interacts with the next row of corresponding blades downstream. As the advance ratio changes (i.e., as the propulsion device rotates at a higher or lower rotational rate while maintaining the same forward speed), the direction of the fluid flow at a leading edge of an upstream blade changes more than the direction of the fluid flow at a trailing edge of the upstream blade. Therefore, the direction of fluid velocity over a corresponding downstream blade is altered less than the direction of fluid velocity over the upstream blade as the advance ratio changes when rotating the propulsion device during operation. In this way, the effective advance ratio of the downstream blade remains closer to an optimal advance ratio as the effective advance ratio of the upstream blade changes. As a result, the overall efficiency of such a propulsion device described herein is improved compared to a conventional propeller at advance ratios above or below an optimal advance ratio range.

[0019] Turning to the drawings, FIGS. 1A, 1B, and 1C respectively illustrate a side, front, and perspective view of an example propulsion device 100 according to at least one embodiment described herein. The propulsion device 100 can be used to propel, drive, or otherwise implement a propulsion vehicle or a turbine-based system such as, for instance, a personal or commercial watercraft vehicle (e.g., a boat, a ship, a sub-surface vehicle, a hovercraft), a personal or commercial aircraft vehicle (e.g., an airplane, a helicopter, a drone), an energy generation system (e.g., a wind turbine, a hydroelectric system), or another vehicle or system. The propulsion device 100 provides improved propeller efficiency as compared to other types of propellers, particularly when operating outside of an optimal advance ratio range of the propulsion device 100. The propulsion device 100 can be effective in improving the propulsion efficiency of vehicles or systems with multiple operating conditions such as, for instance, planing vehicles operating in the pre-planing, low-speed planing, or high-speed planing regimes.

[0020] With reference to FIGS. 1A, 1B, and 1C, collectively, the propulsion device 100 includes a hub 102. In this example, the hub 102 has a cylindrical shape, although another shape may be relied upon in some cases. The hub 102 has a curved surface 104 that extends circumferentially around and longitudinally along a rotation axis of the hub 102, as shown in FIG. 1A. In this example, the curved surface 104 extends from a first end of the hub 102 to a second end of the hub 102. The propulsion device 100 further includes two rows of blades 106, 108 (“rows 106, 108”) extending radially outward from the curved surface 104 in the example shown. The propulsion device 100 may include more than two rows of blades in other cases. The row 106 includes four blades 110a, 110b, 110c, 110d (collectively “blades 110”) in the example shown. The row 108 includes four blades 112a, 112b, 112c, 112d (collectively “blades 112”) in the example shown. The number of blades in each of the rows 106, 108 can vary as compared to that shown. For example, at least one of the rows 106, 108 may include as few as one blade in some cases or more than four blades in other cases.

[0021] The propulsion device 100 is illustrated as a representative example in FIGS. 1A, 1B, and 1C. The example of the propulsion device 100 illustrated in these figures is not exhaustive, and the propulsion device 100 can include other components, elements, or designs in some cases. For instance, the propulsion device 100 can include mounting components such as a shaft or a shaft port and other features that allow for the propulsion device 100 to be coupled to the drive of a propulsion vehicle or a turbine-based system such as an engine or a motor of a watercraft vehicle (e.g., a boat, a ship, a sub-surface vehicle, a hovercraft), an aircraft vehicle (e.g., an airplane, a helicopter, a drone), an energy generation system (e.g., a wind turbine, a hydroelectric system), or another vehicle or system. In another example, the hub 102 of the propulsion device 100 can be formed in a different shape such as a cone shape that tapers longitudinally along the rotation axis, or another shape in some cases. In another example, at least one of the quantity, the geometry, or the arrangement on the curved surface 104 of at least one of the rows 106, 108, the blades 110a, 110b, 110c, 110d, or the blades 112a, 112b, 112c, 112d can be different from what is illustrated in FIGS. 1A, 1B, and 1C or described herein.

[0022] In the example illustrated in FIGS. 1A, 1B, and 1C, each of the rows 106, 108 includes an equal number of blades (i.e., four blades in each row), although in some cases the row of blades 106 ("row 106") may include a number of blades that is different from the number of blades included in the row of blades 108 ("row 108"). In one example where the propulsion device 100 includes more than two rows of blades 106, 108, each of such rows may include the same number of blades. In another example where the propulsion device 100 includes more than two rows of blades 106, 108, at least one of such rows may include a number of blades that is different from at least one other row.

[0023] In one example, each of the blades 110a, 110b, 110c, 110d, 112a, 112b, 112c, 112d has a same geometry (e.g., shape) and/or dimensions. However, in some cases, at least one of the blades 110a, 110b, 110c, 110d, 112a, 112b, 112c, 112d may have a geometry and/or a dimension that is different from that of at least one other blade of such blades. For instance, in some cases, at least one of the blades 110 in the row 106 may have a geometry and/or a dimension that is different from that of a corresponding one of the blades 112 in the row 108. In one example, the blade 110a can have a geometry and/or a dimension that is different from that of the blade 112a. Similarly, in another example, any or all of the blades 110b, 110c, 110d can have a geometry and/or a dimension that is different from that of their corresponding blade 112b, 112c, 112d, respectively.

[0024] In one example, each of the blades 110a, 110b, 110c, 110d, 112a, 112b, 112c, 112d is formed using the same type(s) of material. However, in some cases, at least one of the blades 110a, 110b, 110c, 110d, 112a, 112b, 112c, 112d may be formed using a type of material that is different from another material type used to form at least one other blade of such blades. For instance, in some cases, at least one blade in the row 106 may be formed using a type of material that is different from another material type used to form a corresponding blade in the row 108.

In one example, the blade 110a can be formed using a type of material that is different from another material type used to form the blade 112a. Similarly, in another example, any or all of the blades 110b, 110c, 110d can be formed using a type of material that is different from another material type used to form their corresponding blade 112b, 112c, 112d, respectively.

[0025] In some examples, one or more of the blades 110a, 110b, 110c, 110d, 112a, 112b, 112c, 112d can be formed as an integrated component of the hub 102. For instance, any or all of the blades 110a, 110b, 110c, 110d, 112a, 112b, 112c, 112d can be coupled in a permanent fashion to the curved surface 104. In other examples, one or more of the blades 110a, 110b, 110c, 110d, 112a, 112b, 112c, 112d can be formed as a removable component of the hub 102. For example, any or all of the blades 110a, 110b, 110c, 110d, 112a, 112b, 112c, 112d can be removably coupled to the curved surface 104 by way of, for instance, a fastener, an adhesive, or another coupling element. In some cases, the propulsion device 100 can be embodied or implemented as a notional multi-row propeller. In these cases, at least one of the blades 110a, 110b, 110c, 110d, 112a, 112b, 112c, 112d can be embodied as a sub-cavitating blade, a trans-cavitating blade, or a super-cavitating blade.

[0026] In the example illustrated in FIGS. 1A, 1B, and 1C, each of the blades 110a, 110b, 110c, 110d, 112a, 112b, 112c, 112d is a discrete blade that extends radially away from the curved surface 104. Additionally, the curved surface 104 is a single, continuous surface in this example. When the propulsion device 100 is rotated about the rotation axis (e.g., during operation), each of the rows 106, 108 and each of the blades 110a, 110b, 110c, 110d, 112a, 112b, 112c, 112d co-rotate at a same rotational rate (i.e., angular velocity) and in a same rotational direction about the rotation axis (e.g., rotate in a clockwise or counterclockwise rotational direction around the rotation axis). As illustrated in FIG. 1B, each of the rows 106, 108 and each of the blades 110a, 110b, 110c, 110d, 112a, 112b, 112c, 112d in this example co-rotate in a counterclockwise rotational direction around the rotation axis during operation of the propulsion device 100. However, in another example, each of the rows 106, 108 and each of the blades 110a, 110b, 110c, 110d, 112a, 112b, 112c, 112d may co-rotate in a clockwise rotational direction around the rotation axis during operation of the propulsion device 100.

[0027] Additionally, in the example illustrated in FIGS. 1A, 1B, and 1C, a leading edge (also referred to as the "upstream" edge) of each of the blades 110a, 110b, 110c, 110d, 112a, 112b, 112c, 112d is facing in a same rotational direction about the rotation axis (e.g., facing in a clockwise or counterclockwise rotational direction around the rotation axis). For purposes of clarity, only the leading edge of each of the blades 110a, 112a is denoted in the figures. As illustrated in FIG. 1B, the leading edge of each of the blades 110a, 110b, 110c, 110d, 112a, 112b, 112c, 112d in this example is facing in a counterclockwise rotational direction around the rotation axis. However, in another example, the leading edge of each of the blades 110a, 110b, 110c, 110d, 112a, 112b, 112c, 112d may face in a clockwise rotational direction around the rotation axis.

[0028] In the example illustrated in FIGS. 1A, 1B, and 1C, each of the rows 106, 108 includes a uniform angular distribution of the blades 110 and the blades 112, respectively, about the rotation axis. In this example, each of the blades 110 of the row 106 and each of the blades 112 of the row 108 are uniformly distributed around the curved surface 104 at angular locations that are equally spaced apart from each other with respect to the rotation axis. For instance, the blades 110a, 110b, 110c, 110d of the row 106 are uniformly distributed around the curved surface 104 at respective angular locations of 0 degrees (°), 90°, 180°, and 270°, and the blades 112a, 112b, 112c, 112d of the row 108 are uniformly distributed around the curved surface 104 at respective angular locations of 45°, 135°, 225°, and 315°, as illustrated in FIG. 1B.

[0029] In the example illustrated, the blades 110 and 112 in each of the rows 106, 108 have the same uniform angular distribution of 90°, as measured about the rotation axis. However, the angular distribution of the blades 110 in the row 106 is offset from the angular distribution of the blades 112 in the row 108 by 45°. In other cases, at least one of the rows 106, 108 can have a uniform angular distribution of the blades 110 or the blades 112, respectively, that is different from the other row 106, 108. Additionally, in some examples, at least one of the rows 106, 108 can include a nonuniform angular distribution of the blades 110 or the blades 112, respectively, about the rotation axis. Further, the angular distribution of the blades 110 in the row 106 can be offset from the angular distribution of the blades 112 in the row 108 by an angle other than 45°.

[0030] To provide improved propeller efficiency during operation, one or more blades in the row 108 can be respectively positioned on the curved surface 104 such that it is angularly and axially offset from a corresponding blade in the row 106. For instance, in the example depicted in FIGS. 1A, 1B, and 1C, the blade 112a is angularly and axially offset from the blade 110a on the curved surface 104. In this example, the blade 112a is angularly offset from the blade 110a by a distribution angle θ_D, as illustrated in FIG. 1B. The distribution angle θ_D is measured about the rotation axis of the hub 102 between a longitudinal centerline ("CL_1") of the blade 110a and a longitudinal centerline ("CL_2") of the blade 112a, as illustrated in FIG.

1B. In this example, the blade 112a is axially offset from the blade 110a by a distance *d*, as illustrated in FIG. 1A. The distance *d* is measured along the rotation axis from a first location ("L_1") on the curved surface 104 to a second location ("L_2") on the curved surface 104, as illustrated in FIG. 1A. The locations L_1, L_2 on the curved surface 104 denote the locations where the longitudinal centerlines CL_1, CL_2 respectively intersect the curved surface 104, as illustrated in FIG. 1B. Additionally, in this example, each of the blades 112b, 112c, 112d is angularly and axially offset from their corresponding blade 110b, 110c, 110d in the same manner as described above for the corresponding blades 110a, 112a. For purposes of clarity, however, the distribution angle θ_D, the distance *d*, the longitudinal centerlines CL_1, CL_2 , and the locations L_1, L_2 are only denoted in the figures with respect to the corresponding blades 110a, 112a.

[0031] Each of the blades 110a, 112a is positioned on the curved surface 104 according to its own individual blade angle θ_B (also referred to as the "pitch" or "pitch angle"). For each blade, its blade angle θ_B is measured between a chord line of the blade and a rotation plane that is normal to the rotation axis of the hub 102, as illustrated in FIG. 1A with respect to the blade 110a. The chord line of a blade is a straight line extending from a leading (upstream) edge of the blade to a trailing (downstream) edge of the blade. In the example illustrated in FIGS. 1A, 1B, and 1C, the blade 110a has a blade angle θ_B that is different from that of the blade 112a, although in some cases the blades 110a, 112a can each have the same blade angle θ_B. Additionally, in this example, each of the blades 110b, 110c, 110d and their corresponding blade 112b, 112c, 112d, respectively, is positioned on the curved surface 104 according to its own individual blade angle θ_B. For purposes of clarity, however, only the blade angle θ_B for the blade 110a is denoted in the figures. Similar to the blades 110a, 112a, the blades of each other pair of corresponding blades in the rows 106, 108 (i.e., the blades 110b, 112b, the blades 110c, 112c, and the blades 110d, 112d) can have a blade angle θ_B that is the same as or different from that of their corresponding blade. For instance, each of the blades 110b, 110c, 110d can have a same or different blade angle θ_B as that of their corresponding blade 112b, 112c, 112d, respectively.

[0032] The first and second locations L_1, L_2 corresponding to the longitudinal centerlines CL_1, CL_2 of the blades 110a, 112a, respectively, are positioned on the curved surface 104 of the hub 102 such that the blades 110a, 112a form a helical pattern of blades that extend around and along the curved surface 104. Additionally, the locations *L* for the longitudinal centerlines *CL* of the other blades in the rows 106, 108 can also be positioned on the curved surface 104 of the hub 102 such that pairs of corresponding blades individually form a helical pattern of blades. In one example, the first and second locations L_1, L_2 corresponding to the longitudinal centerlines CL_1, CL_2 of the blades 110a, 112a, respectively, can be positioned such that the blades 110a, 112a collectively form a helical pattern of blades that projects radially outward from and wraps around the curved surface 104 as it extends along the rotation axis. For instance, the helical pattern of blades can project radially outward from the curved surface 104 along a helical line that intersects the first and second locations L_1, L_2 as it wraps around the curved surface 104 while extending along the rotation axis. In one example, the first and second locations L_1, L_2 can be defined such that the blades 110a, 112a collectively form a helical pattern of blades that projects radially outward from the curved surface 104 along a helical line 202 that intersects the first and second locations L_1, L_2, as described below and illustrated in FIG. 2.

[0033] Any propulsion device described herein such as, for instance, the propulsion device 100 (and/or the propulsion device 400 described herein and illustrated in FIGS. 4A and 4B) can be custom designed for a particular application and/or propulsion efficiency. To achieve this, any design parameter or aspect associated with any propulsion device described herein can be defined or selected based on such a desired application and/or efficiency. As such, all possible combinations of different design parameters or aspects for any propulsion device described herein are envisioned and within the scope of the present disclosure. Examples of such design parameters or aspects that can be combined in different ways across various embodiments include, but are not limited to, the number of rows of blades, the number of blades in each row, the distribution angle θ_D between corresponding blades in different rows, the distance d between corresponding blades in different rows, the locations L of the longitudinal centerlines CL of corresponding blades in different rows, the blade angle θ_B of one or more blades, the rotational direction or rate of the blades about the rotation axis during operation, or another design parameter or aspect.

[0034] FIG. 2 illustrates another perspective view of the propulsion device 100 according to at least one embodiment described herein. In particular, FIG. 2 illustrates an example of how the first and second locations L_1, L_2 can be defined such that the blades 110a, 112a collectively form a helical pattern of blades that projects radially outward from the curved surface 104 along a helical line 202 that intersects the first and second locations L_1, L_2. In FIG. 2, the blades 110, 112 are removed for purposes of clarity and root footprints 210a, 212a are used to respectively denote the area on the curved surface 104 that would otherwise be occupied by the blades 110a, 112a in this example. In some examples, at least one other pair of corresponding blades in the rows 106, 108 can individually form a respective helical pattern of blades along an independent helical line that is geometrically the same as or different from the helical line 202. However, for purposes of clarity, only the helical line 202 corresponding to the blades 110a, 112a is illustrated in FIG. 2.

[0035] With reference to FIGS. 1A, 1B, 1C, and 2, collectively, the helical line 202 (FIG. 2) wraps around and extends along both the rotation axis and the curved surface 104 of the hub 102. As illustrated in FIG. 2, the helical line 202 passes through the root footprints 210a, 212a of the blades 110a, 112a, respectively, as it wraps around and along the curved surface 104 of the hub 102. In this example, at the first and second locations L_1, L_2, the longitudinal centerlines CL_1, CL_2 of the blades 110a, 112a respectively intersect the helical line 202. Consequently, the blades 110a, 112a collectively form a helical pattern of blades that projects radially outward from the curved surface 104 along the helical line 202 in this example. Although the helical line 202 illustrated in FIG. 2 only extends partially around the rotation axis along the curved surface 104, a person having ordinary skill in the art would understand that the helical line 202 could wrap completely around the rotation axis if it were projected beyond the first end and/or the second end of the hub 102 along the rotation axis.

[0036] FIGS. 3A and 3B respectively illustrate a cross-sectional view of the corresponding blades 110a, 112a on an example propulsion device of the present disclosure such as, for instance, the propulsion device 100 according to at least one embodiment described herein. In particular, FIG. 3A illustrates a cross-sectional view of an example flow straightening that can occur before a fluid encounters the downstream blade (i.e., the blade 112a) of the corresponding blades 110a, 112a at a relatively high rotation rate. In contrast, FIG. 3B illustrates a cross-sectional view of an example flow straightening that can occur before a fluid encounters the downstream blade (i.e., the blade 112a) of the corresponding blades 110a, 112a at a relatively low rotation rate.

[0037] With reference to FIGS. 1A, 1B, 1C, 3A, and 3B, collectively, as the propulsion device 100 rotates about the rotation axis during operation, the row of blades 106 interacts with an incoming fluid (e.g., water or air), thereby changing the direction of the velocity of the fluid as it interacts with the row of blades 108 downstream. For instance, as the propulsion device 100 rotates about the rotation axis during operation, the blade 110a interacts with an incoming fluid (e.g., water or air), thereby changing the direction of the velocity of the fluid as it interacts with the blade 112a downstream. In this example, as the advance ratio changes (i.e., as the propulsion device 100 rotates at a higher or lower rotational rate while maintaining the same forward speed), the direction of the fluid flow at the leading edge of the upstream blade 110a changes more than the direction of the fluid flow at the trailing edge of the upstream blade 110a, as illustrated in FIGS. 3A and 3B. Therefore, the direction of fluid velocity over the downstream blade 112a is altered less than the direction of fluid velocity over the upstream blade 110a as the advance ratio changes when rotating the propulsion device 100 during operation. In this way, the effective advance ratio of the downstream blade 112a remains closer to an optimal advance ratio as the effective advance ratio of the upstream blade 110a changes. As a result, the overall efficiency of the propulsion device 100 is improved compared to a conventional propeller at advance ratios above or below the optimal advance ratio, for instance, as described below with reference to FIG. 5.

[0038] FIGS. 4A and 4B respectively illustrate a side and front view of another example propulsion device 400 according to at least one embodiment described herein. The propulsion device 400 is an example of an alternative embodiment of the propulsion device 100 described above with reference to FIGS. 1A, 1B, and 1C. The difference between the propulsion device 400 and the propulsion device 100 is that the propulsion device 400 includes two hubs 402a, 402b that respectively include the rows of blades 106, 108 extending radially outward from curved surfaces 404a, 404b of the hubs 402a, 402b, respectively. The hubs 402a, 402b can be individually configured such that when they are both installed on a single, shared shaft (not illustrated), the hubs 402a, 402b together effectively form a multi-row propeller having a particular arrangement of blades extending radially about and longitudinally along a rotation axis shared by both of the hubs 402a, 402b. In the example illustrated in FIGS. 4A and 4B, the hubs 402a, 402b are individually configured such that when they are both installed on such a shared (common) shaft, the hubs 402a, 402b together effectively form the propulsion device 100 described above with reference to FIGS. 1A, 1B, and 1C.

[0039] In this example, each of the hubs 402a, 402b can be embodied and implemented as the hub 102 described above with reference to FIGS. 1A, 1B, and 1C. For instance, each of the hubs 402a, 402b can include the same structure, attributes, geometry, material, and functionality as that of the hub 102. Additionally, each of the curved surfaces 404a, 404b can be embodied and implemented as the curved surface 104 described above with reference to FIGS. 1A, 1B, and 1C. For instance, each of the curved surfaces 404a, 404b can include the same structure, attributes, geometry, material, and functionality as that of the curved surface 104.

[0040] In the example illustrated in FIGS. 4A and 4B, the hubs 402a, 402b can be individually configured such that when they are both installed on a shared shaft at the same time and in a particular configuration with respect to one another and the rotation axis of the hubs 402a, 402b, the longitudinal centerlines CL_1, CL_2 of the blades 110a, 112a respectively intersect a helical line (not illustrated) that wraps around the rotation axis along the curved surfaces 404a, 404b. In this example, such a helical line corresponding to the propulsion device 400 has the same geometry as the helical line 202 described above, and thus, it wraps around the rotation axis along the curved surfaces 404a, 404b in the same geometrical manner as the helical line 202 wraps around and along the curved surface 104. In this example, the blade 110a of the hub 402a and the blade 112a of the hub 402b together effectively form a helical pattern of blades that projects radially outward from the curved surfaces 404a, 404b along such a helical line corresponding to the propulsion device 400.

[0041] In some examples, however, the above-described helical line corresponding to the propulsion device 400 may have a geometry that is different from that of the helical line 202, and thus, it may wrap around the rotation axis along the curved surfaces 404a, 404b in a different geometrical manner compared to the helical line 202. In these examples, the blade 110a of the hub 402a and the blade 112a of the hub 402b may together effectively form a different helical pattern of blades that projects radially outward from the curved surfaces 404a, 404b along such a helical line having a different geometry than that of the helical line 202. Additionally, in some examples, at least one other pair of corresponding blades in the rows 106, 108 of the propulsion device 400 can individually form a respective helical pattern of blades along an independent helical line. In these examples, such an independent helical line(s) can be geometrically the same as or different from the above-described helical line corresponding to the propulsion device 400 and/or the helical line 202.

[0042] To install the hubs 402a, 402b on a shared shaft in a particular configuration that allows the blades 110a, 112a to form such a helical pattern of blades, the hubs 402a, 402b can include shaft ports 406a, 406b, respectively. Each of the shaft ports 406a, 406b can be configured to receive a shaft such as, for instance, a shaft that can be coupled to and driven (i.e., rotated) by an engine (e.g., a watercraft engine). In particular, the shaft ports 406a, 406b can be individually configured such that they can each receive the shaft at the same time. Additionally, the hubs 402a, 402b can further include keyways 408a, 408b, respectively, that can be configured to receive, for instance, a shaft key (not illustrated). In one example, the keyways 408a, 408b can be individually configured such that they can each receive the same shaft key at the same time. The shaft key may be configured for insertion into a corresponding key seat that may be formed in the shaft. The shaft ports 406a, 406b and the keyways 408a, 408b can be configured such that they allow for the hubs 402a, 402b to be individually installed on a shared shaft in a particular angular and axial configuration that is fixed with respect to the rotation axis. In this way, the shaft ports 406a, 406b and the keyways 408a, 408b can be configured such that when the hubs 402a, 402b are individually installed on a shared shaft in such a particular angular and axial configuration, the blades 110a, 112a are angularly and axially offset from one another as measured from the rotation axis and together effectively form the above-described helical pattern of blades.

[0043] In the example illustrated in FIGS. 4A and 4B, when the hubs 402a, 402b are installed on a shared shaft as described above and the propulsion device 400 is rotated about the rotation axis (e.g., during operation), each of the rows 106, 108 and each of the blades 110a, 110b, 110c, 110d, 112a, 112b, 112c, 112d rotate at a same rotational rate (i.e., angular velocity) and in a same rotational direction about the rotation axis (e.g., rotate in a clockwise or counterclockwise rotational direction around the rotation axis). As illustrated in FIG. 4B, each of the rows 106, 108 and each of the blades 110a, 110b, 110c, 110d, 112a, 112b, 112c, 112d in this example rotate in a counterclockwise rotational direction around the rotation axis during operation of the propulsion device 400. Additionally, a leading edge (upstream edge) of each of the blades 110a, 110b, 110c, 110d, 112a, 112b, 112c, 112d is facing in a same rotational direction about the rotation axis (e.g., facing in a clockwise or counterclockwise rotational direction around the rotation axis) in this example. For purposes of clarity, only the leading edge of each of the blades 110a, 112a is denoted in the figures. As illustrated in FIG. 4B, the leading edge of each of the blades 110a, 110b, 110c, 110d, 112a, 112b, 112c, 112d in this example is facing in a counterclockwise rotational direction around the rotation axis.

[0044] The propulsion device 400 is illustrated as a representative example in FIGS. 4A 4B. The example of the propulsion device 400 illustrated in these figures is not exhaustive, and the propulsion device 400 can include other components, elements, or designs in some cases. For instance, the propulsion device 400 can include more than two hubs 402a, 402b in one example. In another example, one or both of the hubs 402a, 402b can respectively include one or more additional rows of blades 106, 108. In another example, one or both of the hubs 402a, 402b can be formed in a different shape such as a cone shape that tapers longitudinally along the rotation axis, or another shape in some cases. In another example, at least one of the quantity, the geometry, or the arrangement of at least one of the rows 106, 108 or the blades

110a, 110b, 110c, 110d, 112a, 112b, 112c, 112d on one or both of the curved surfaces 404a, 404b can be different from what is illustrated in FIGS. 4A and 4B or described herein. In another example, at least one of the quantity, the geometry, or the arrangement of at least one of the shaft ports 406a, 406b or the keyways 408a, 408b of one or both of the hubs 402a, 402b can be different from what is illustrated in FIGS. 4A and 4B or described herein. In different examples, one or both of the hubs 402a, 402b can have various widths w (only the width w of the hub 402a is denoted in the figures for clarity). In different examples, a second end of the hub 402a can be spaced apart from a first end of the hub 402b according to different distances d_2 as illustrated in FIG. 4A.

[0045] FIG. 5 illustrates a plot 500 of example performance data obtained from implementation of an example propulsion device of the present disclosure according to at least one embodiment described herein. Specifically, the plot 500 includes curves 502, 504 that each denote example propeller efficiency data plotted as a function of advance ratio. In this example, the propeller efficiency data of the curve 502 was obtained from implementing the propulsion device 100 according to one embodiment described herein. In this example, the propeller efficiency data of the curve 504 was obtained from implementing a conventional propeller under the same conditions used to implement the propulsion device 100.

[0046] As described above with reference to FIGS. 3A and 3B, the direction of fluid velocity over the downstream blade 112a is altered less than the direction of fluid velocity over the upstream blade 110a as the advance ratio changes when rotating the propulsion device 100 during operation. In this way, the effective advance ratio of the downstream blade 112a remains closer to an optimal advance ratio as the effective advance ratio of the upstream blade 110a changes. As a result, the overall efficiency of the propulsion device 100 is improved compared to a conventional propeller at advance ratios above or below the optimal advance ratio. The curves 502, 504 of the plot 500 depicted in FIG. 5 provide an example demonstration of such efficiency gains of the propulsion device 100 when it is operated outside of a region of maximum propeller efficiency according to at least one embodiment described herein.

[0047] FIG. 6 illustrates a flow diagram of an example method of improving propulsion efficiency 600 (“method 600”) according to at least one embodiment described herein. In one example, the method 600 can be implemented to obtain the example performance data used to generate the curve 502 in the plot 500 described herein with reference to FIG. 5.

[0048] At 602, the method 600 includes rotating a multi-row propeller having a first blade in a first row of blades and a corresponding second blade in a second row of blades. For example, at 602, the method 600 can include rotating a propulsion device described herein such as, for instance, the propulsion device 100 or the propulsion device 400. For instance, at 602, the method 600 can include rotating the propulsion device 100 about its rotation axis. As described herein with reference to the examples illustrated in FIGS. 1A, 1B, 1C, 2, 3A, 3B, 4A, and 4B, the propulsion device 100 can include two or more rows of blades 106, 108 that extend radially outward from the curved surface 104 of the hub 102. The row of blades 106 can include the blade 110a and the row of blades 108 can include the blade 112a that corresponds to, and is angularly and axially offset from, the blade 110a on the curved surface 104. As described herein, the blade 110a and the blade 112a collectively form a helical pattern of blades that projects radially outward from the curved surface 104 along the helical line 202 around at least a portion of the curved surface 104.

[0049] At 604, the method 600 further includes altering a direction of a fluid flow over each of the first blade and the second blade based on rotating the multi-row propeller. For instance, at 604, based on rotating the propulsion device 100 about its rotation axis, the method 600 can include altering a first direction of a fluid flow over the blade 110a by a first amount and a second direction of the fluid flow over the blade 112a by a second amount that is less than the first amount. Such respective alteration of the direction of fluid flow over each of the blades 110a, 112a is described herein and illustrated in FIGS. 3A and 3B.

[0050] At 606, the method 600 further includes increasing a propulsion efficiency of the multi-row propeller based on altering the direction of the fluid flow over the second blade by a certain amount relative to the first blade. For instance, at 606, based on rotating the propulsion device 100 about its rotation axis, the method 600 can include altering a first direction of a fluid flow over the blade 110a by a first amount and a second direction of the fluid flow over the blade 112a by a second amount that is less than the first amount, as described herein and illustrated in FIGS. 3A and 3B. In this example, the arrangement of the blades 110a, 112a on the curved surface 104 as depicted in FIGS. 1A, 1B, and 1C causes the direction of the fluid flow over the downstream blade 112a to be altered less than it was altered when it passed over the upstream blade 110a. In this example, this reduced alteration of the direction of the fluid flow over the downstream blade 112a compared to the amount of alteration of the direction of the fluid flow over the upstream blade 110a results in an overall improved propulsion efficiency of the propulsion device 100 as described herein with reference to FIGS. 3A, 3B, and 5. For instance, such a reduced alteration of the direction of the fluid flow over the downstream blade 112a compared to the amount of alteration of the direction of the fluid flow over the upstream blade 110a allows for the propulsion efficiency of the propulsion device 100 to increase when it is operated outside of an optimal advance ratio range.

[0051] The flow diagram of FIG. 6 shows an exemplary implementation of a propulsion device of the present disclosure according to an example method described herein. Although the flow diagram of FIG. 6 shows a specific order of execution, it is understood that the order of execution may differ from that which is depicted. For example, the order of execution of two or more blocks may be scrambled relative to the order shown. Also, two or more blocks shown in succession in FIG. 6 may be executed concurrently or with partial concurrence. Further, in some embodiments, one or more of the blocks shown in FIG. 6 may be skipped or omitted. In addition, any number of counters, state variables, warning semaphores, or messages might be added to the logical flow described herein, for purposes of enhanced utility, accounting, performance measurement, or providing troubleshooting aids, *etc*. It is understood that all such variations are within the scope of the present disclosure.

[0052] Disjunctive language such as the phrase "at least one of X, Y, or Z," unless specifically stated otherwise, is otherwise understood with the context as used in general to present that an item, term, etc., may be either X, Y, or Z, or any combination thereof (e.g., X, Y, and/or Z). Thus, such disjunctive language is not generally intended to, and should not, imply that certain embodiments require at least one of X, at least one of Y, or at least one of Z to each be present. As referenced herein in the context of quantity, the terms "a" or "an" are intended to mean "at least one" and are not intended to imply "one and only one."

[0053] As referred to herein, the terms "include," "includes," and "including" are intended to be inclusive in a manner similar to the term "comprising." As referenced herein, the terms "or" and "and/or" are generally intended to be inclusive, that is (i.e.), "A or B" or "A and/or B" are each intended to mean "A or B or both." As referred to herein, the terms "first," "second," "third," and so on, can be used interchangeably to distinguish one component or entity from another and are not intended to signify location, functionality, or importance of the individual components or entities. As referenced herein, the terms "couple," "couples," "coupled," and/or "coupling" refer to chemical coupling (e.g., chemical bonding), communicative coupling, electrical and/or electromagnetic coupling (e.g., capacitive coupling, inductive coupling, direct and/or connected coupling, etcetera (etc.)), mechanical coupling, operative coupling, optical coupling, and/or physical coupling.

[0054] Approximating language, as used herein throughout the specification, the appended claims, and/or the accompanying drawings is applied to modify any quantitative representation that could permissibly vary without resulting in a change in the basic function to which it is related. Accordingly, a value modified by a term or terms, such as “about,” “approximately,” and/or “substantially,” are not to be limited to the precise value specified. In some embodiments, the approximating language can correspond to the precision of an instrument for measuring the value. For example, the approximating language can refer to being within a 10 percent (%) margin. For instance, as used herein, the term or terms “about,” “approximately,” and/or “substantially” in conjunction with a numerical value can refer to within 10% of the indicated numerical value.

[0055] It should be emphasized that the above-described embodiments of the present disclosure are merely possible examples of implementations set forth for a clear understanding of the principles of the disclosure. Many variations and modifications may be made to the above-described embodiment(s) without departing substantially from the spirit and principles of the disclosure. All such modifications and variations are intended to be included herein within the scope of this disclosure and protected by the following claims.

CLAIMS

Therefore, at least the following is claimed:

1. A propulsion device, comprising:

a hub having a curved surface extending around and along a rotation axis of the hub; and

two or more rows of blades extending radially outward from the curved surface and comprising a first row of blades having a first blade and a second row of blades having a second blade, the second blade being angularly and axially offset from the first blade on the curved surface,

wherein a first centerline of the first blade and a second centerline of the second blade intersect with a helical line that extends along the rotation axis of the hub, the first blade and the second blade collectively forming a helical pattern of blades that projects radially outward from the curved surface along the helical line.

2. The propulsion device of claim 1, wherein the two or more rows of blades and each blade of the two or more rows of blades rotate at a same rotational rate and in a same rotational direction about the rotation axis during rotation of the propulsion device.

3. The propulsion device of claim 1, wherein the first blade has a first leading edge and the second blade has a second leading edge, and wherein the first leading edge and the second leading edge are facing in a same rotational direction about the rotation axis.

4. The propulsion device of claim 1, wherein a leading edge of each blade of the two or more rows of blades is facing in a same rotational direction about the rotation axis.

5. The propulsion device of claim 1, wherein the first blade and the second blade each comprise a discrete blade that is individually coupled to the curved surface, the curved surface being a single continuous surface.

6. The propulsion device of claim 1, wherein the first blade and the second blade each has a different blade angle with respect to a rotation plane that is normal to the rotation axis.

7. The propulsion device of claim 1, wherein each row of the two or more rows of blades comprises an equal number of blades.

8. The propulsion device of claim 1, wherein at least one row of the two or more rows of blades comprises a number of blades that is different from at least one other row of the two or more rows of blades.

9. The propulsion device of claim 1, wherein each blade of the two or more rows of blades has a same geometry.

10. The propulsion device of claim 1, wherein at least one blade of the two or more rows of blades has a geometry that is different from at least one other blade of the two or more rows of blades.

11. The propulsion device of claim 1, wherein each row of the two or more rows of blades comprises a uniform angular distribution of blades about the rotation axis.

12. The propulsion device of claim 1, wherein each row of the two or more rows of blades comprises a same uniform angular distribution of blades about the rotation axis.

13. The propulsion device of claim 1, wherein at least one row of the two or more rows of blades comprises a uniform angular distribution of blades about the rotation axis that is different from at least one other row of the two or more rows of blades.

14. The propulsion device of claim 1, wherein at least one row of the two or more rows of blades comprises a nonuniform angular distribution of blades about the rotation axis.

15. The propulsion device of claim 1, wherein each blade of the two or more rows of blades has a same blade angle.

16. The propulsion device of claim 1, wherein at least one blade of the two or more rows of blades has a blade angle that is different from at least one other blade of the two or more rows of blades.

17. A propulsion device, comprising:

a first hub having a first row of blades extending radially outward from a first curved surface of the first hub, the first row of blades comprising a first blade, the first curved surface extending around and along a rotation axis of the propulsion device; and

a second hub having a second row of blades extending radially outward from a second curved surface of the second hub, the second row of blades comprising a second blade that is angularly and axially offset from the first blade as measured from the rotation axis, the second curved surface extending around and along the rotation axis,

wherein a first centerline of the first blade and a second centerline of the second blade intersect with a helical line that extends along the rotation axis, the first blade and the second blade collectively forming a helical pattern of blades that projects radially outward from the first curved surface and the second curved surface along the helical line.

18. The propulsion device of claim 17, wherein each blade of each of the first row of blades and the second row of blades rotate at a same rotational rate and in a same rotational direction about the rotation axis during rotation of the propulsion device.

19. The propulsion device of claim 17, wherein a leading edge of each blade of each of the first row of blades and the second row of blades is facing in a same rotational direction about the rotation axis.

20. A method of improving propulsion efficiency, the method comprising:

rotating a propulsion device, the propulsion device comprising a hub having two or more rows of blades that extend radially outward from a curved surface of the hub and comprise a first row of blades having a first blade and a second row of blades having a second blade, the second blade being angularly and axially offset from the first blade on the curved surface, the first blade and the second blade collectively forming a helical pattern of blades that extends along at least a portion of the curved surface;

altering a first direction of a fluid flow over the first blade by a first amount and a second direction of the fluid flow over the second blade by a second amount that is less than the first amount based on rotating the propulsion device; and

increasing an efficiency of the propulsion device based on altering the second direction of the fluid flow over the second blade by the second amount.

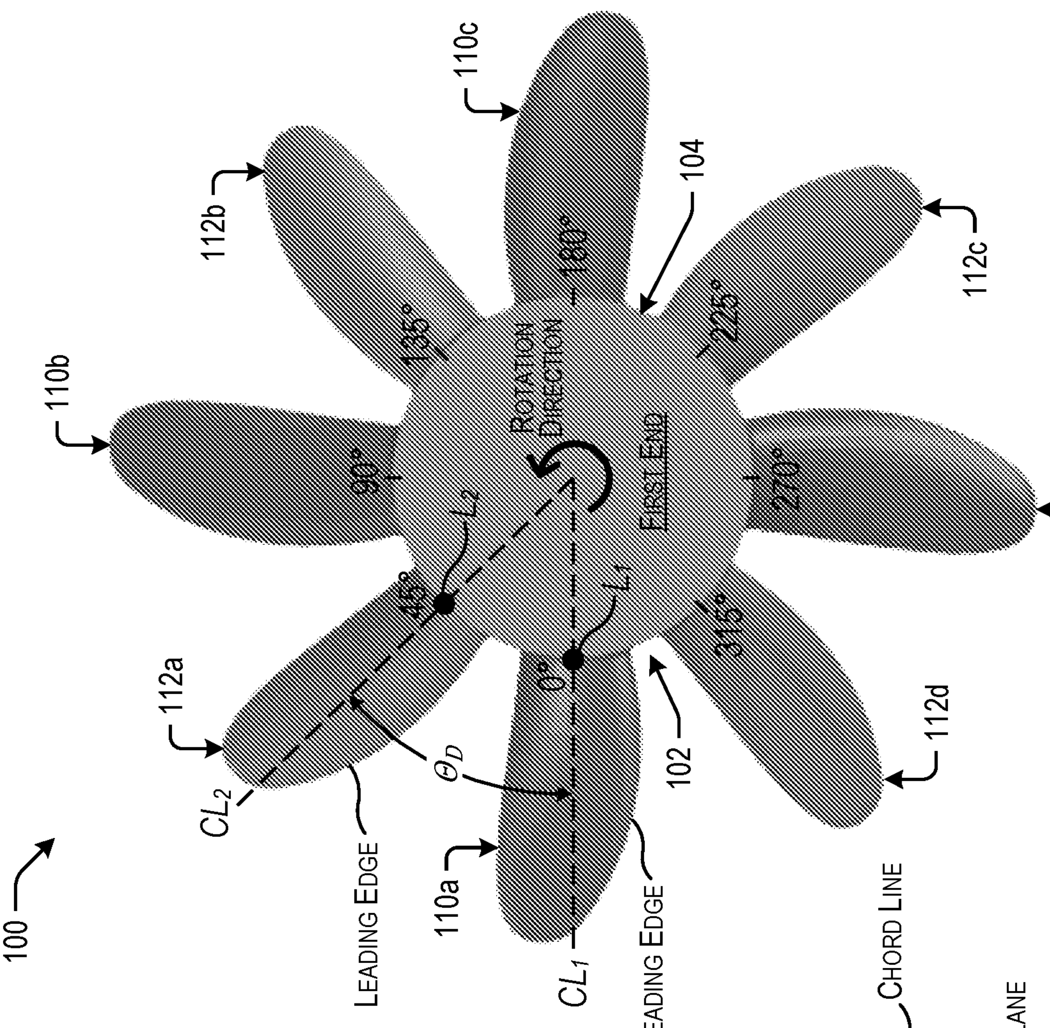
100
110c
112b
110b
104
180°
112c
135°
225°
Rotation Direction
90°
First End
270°
L2
110d
45°
L1
315°
112a
0°
112d
102
ΘD
CL2
110a
Leading Edge
Leading Edge
CL1
Chord Line
Rotation Plane

FIG. 1B

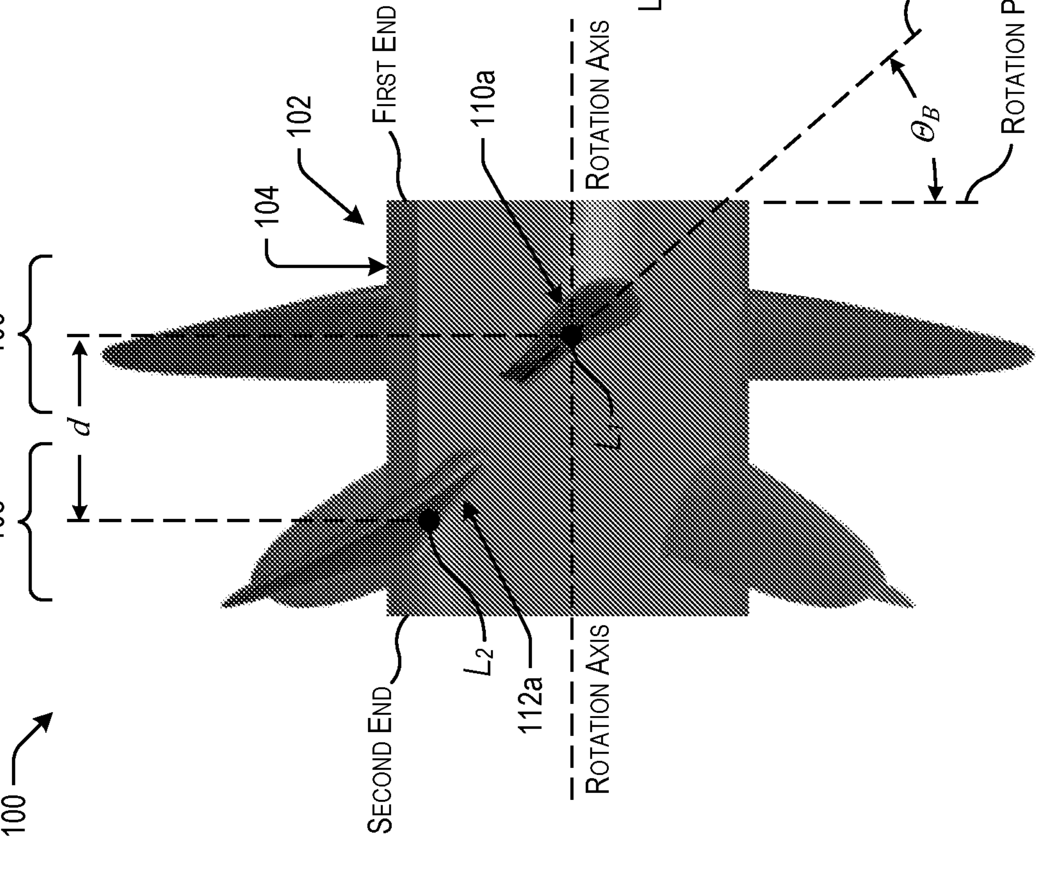
100
106
108
d
104
102
First End
110a
Rotation Axis
ΘB
L1
L2
112a
Second End
Rotation Axis

FIG. 1A

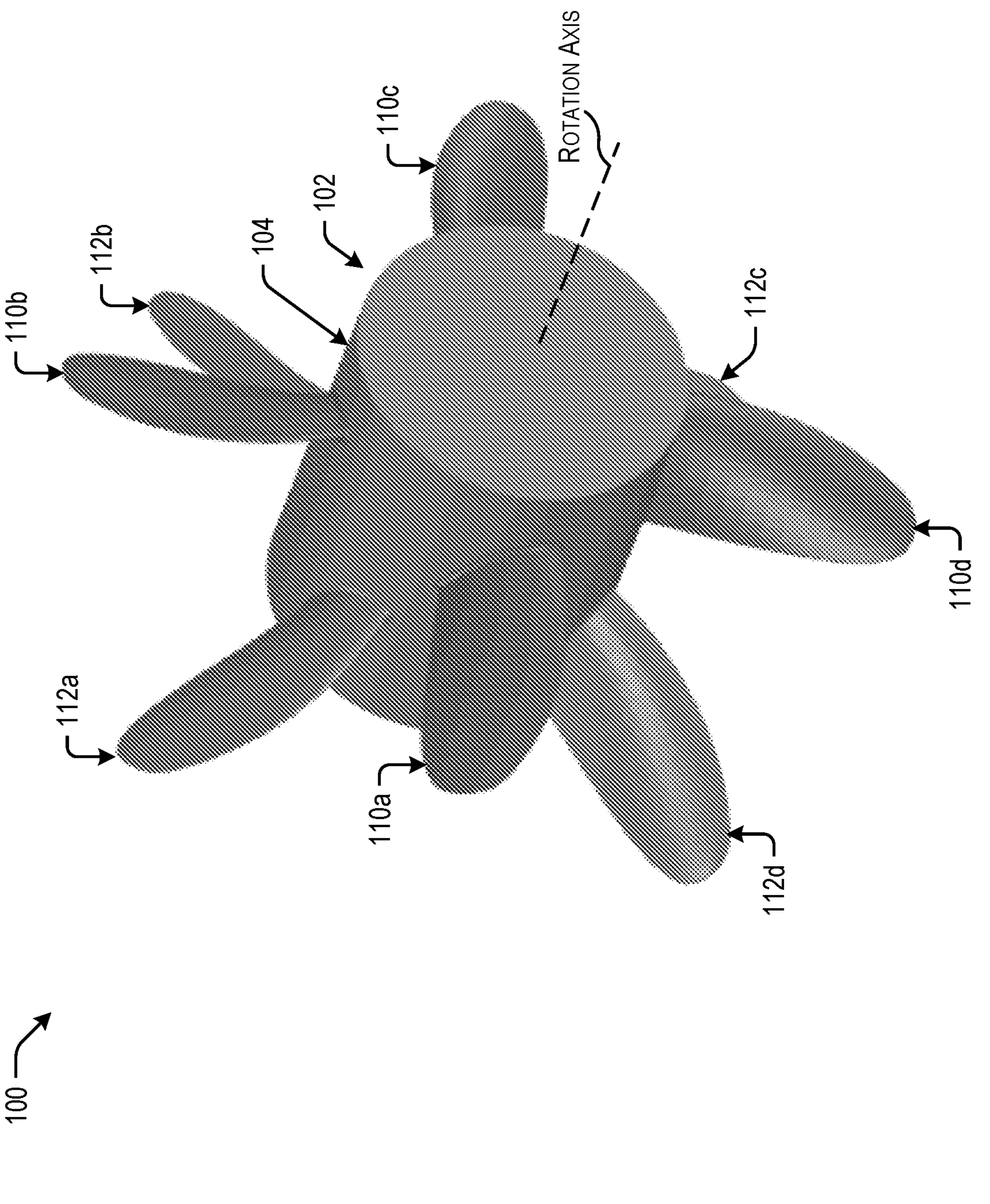
100
110a
110b
110c
110d
112a
112b
112c
112d
102
104
ROTATION AXIS

FIG. 1C

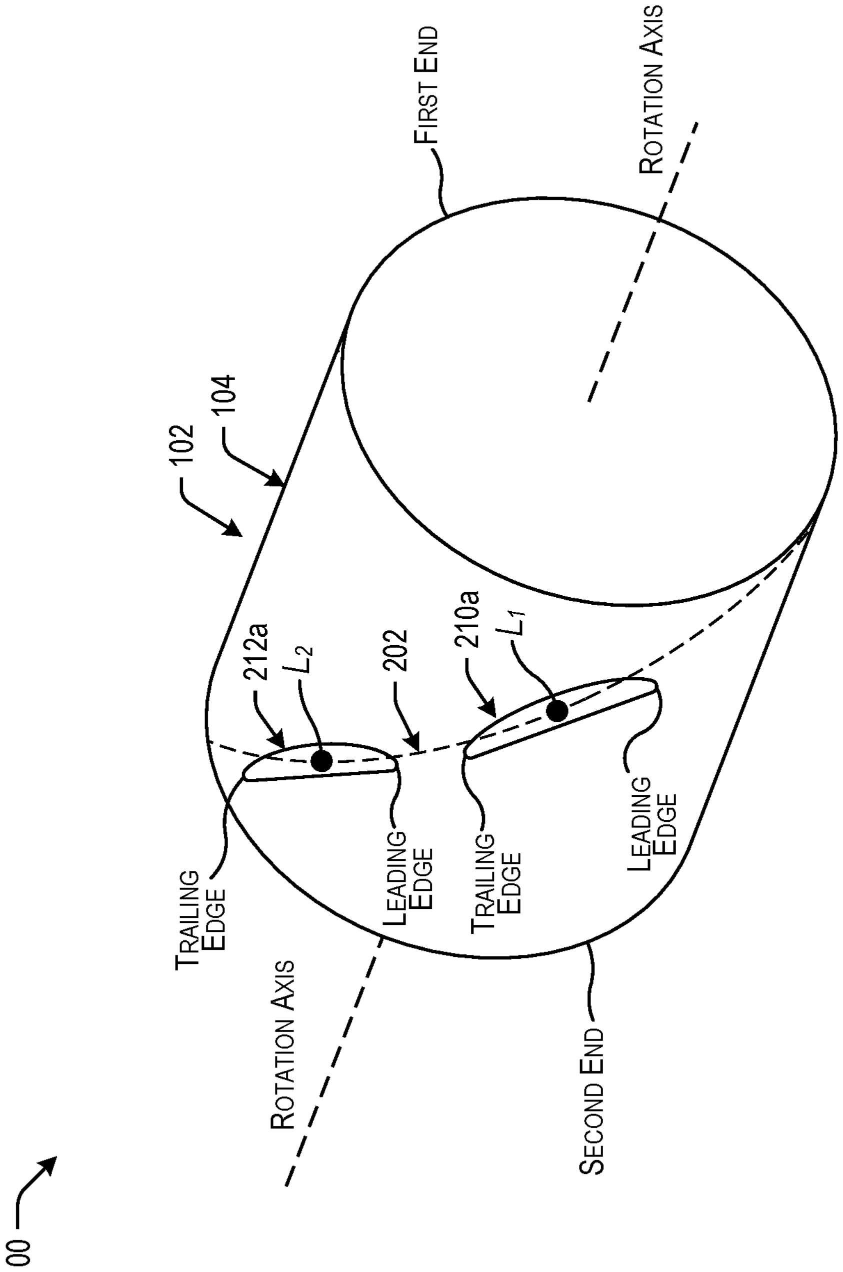
First End
Rotation Axis
102
104
212a
L_2
202
210a
L_1
Trailing Edge
Leading Edge
Trailing Edge
Leading Edge
Rotation Axis
Second End
100

FIG. 2

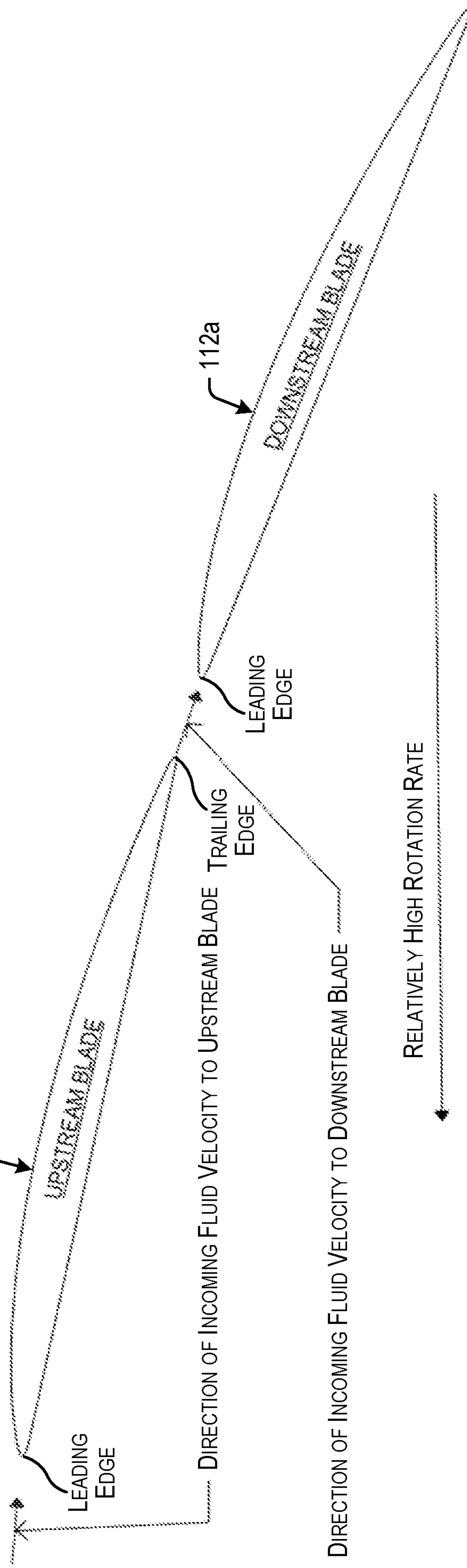
110a
Upstream Blade
Leading Edge
Trailing Edge
112a
Downstream Blade
Leading Edge
Trailing Edge
Direction of Incoming Fluid Velocity to Upstream Blade
Direction of Incoming Fluid Velocity to Downstream Blade
Relatively High Rotation Rate

FIG. 3A

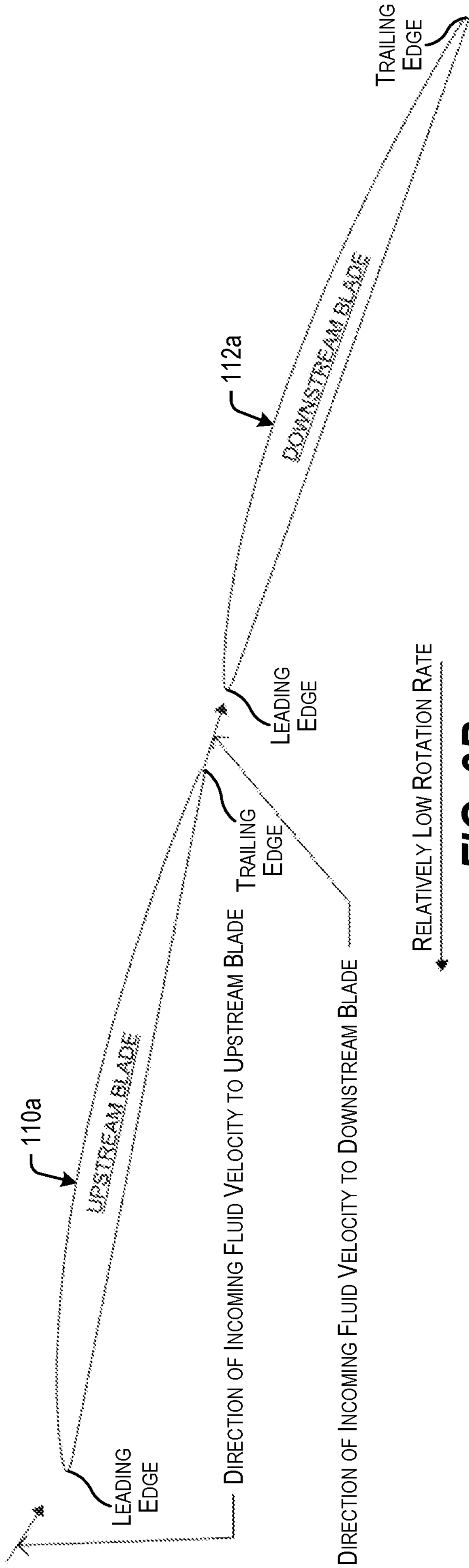
110a
Upstream Blade
Leading Edge
Trailing Edge
112a
Downstream Blade
Leading Edge
Trailing Edge
Direction of Incoming Fluid Velocity to Upstream Blade
Direction of Incoming Fluid Velocity to Downstream Blade
Relatively Low Rotation Rate

FIG. 3B

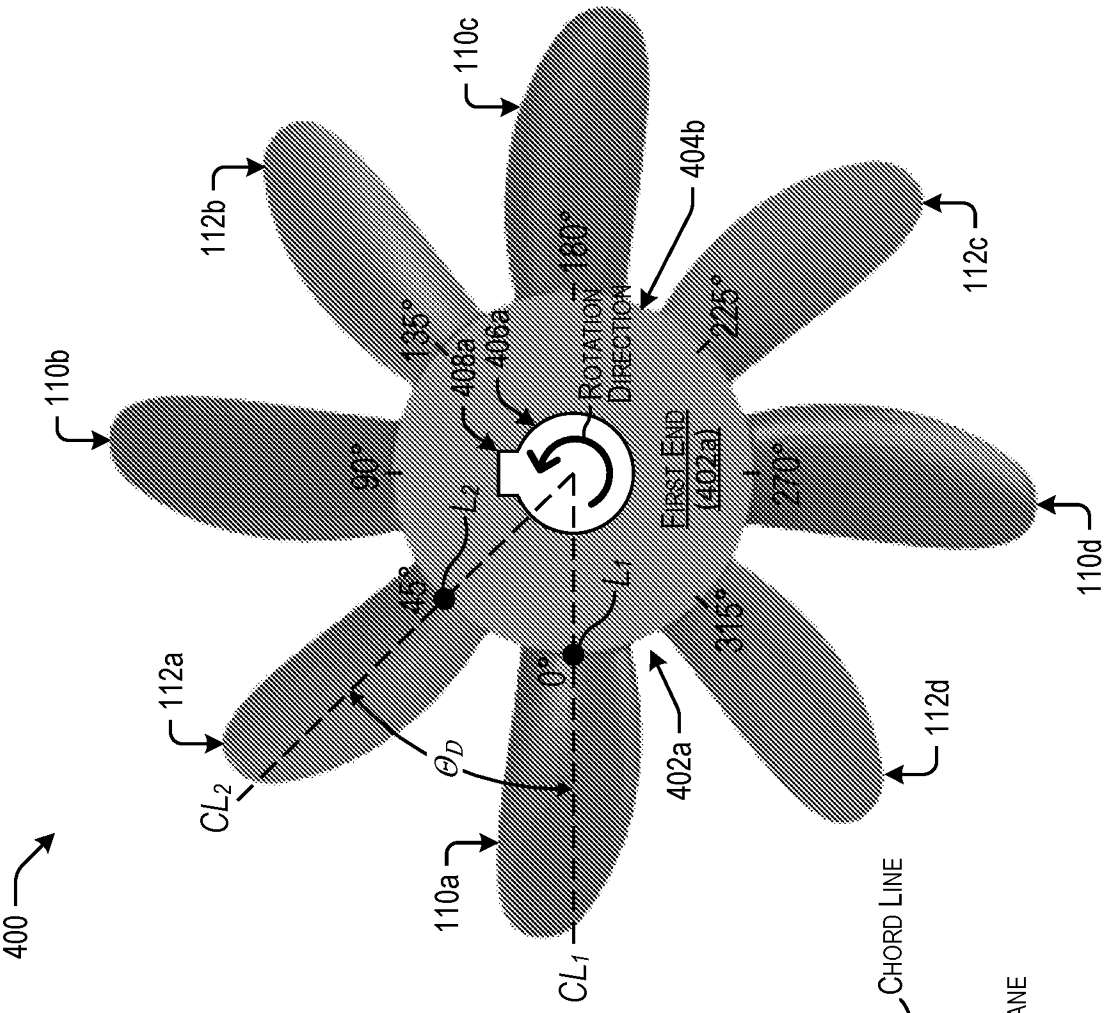
400
110a
110b
110c
110d
112a
112b
112c
112d
402a
404b
406a
408a
0°
45°
90°
135°
180°
225°
270°
315°
ROTATION DIRECTION
FIRST END (402a)
L2
L1
CL2
CL1
ΘD

FIG. 4B

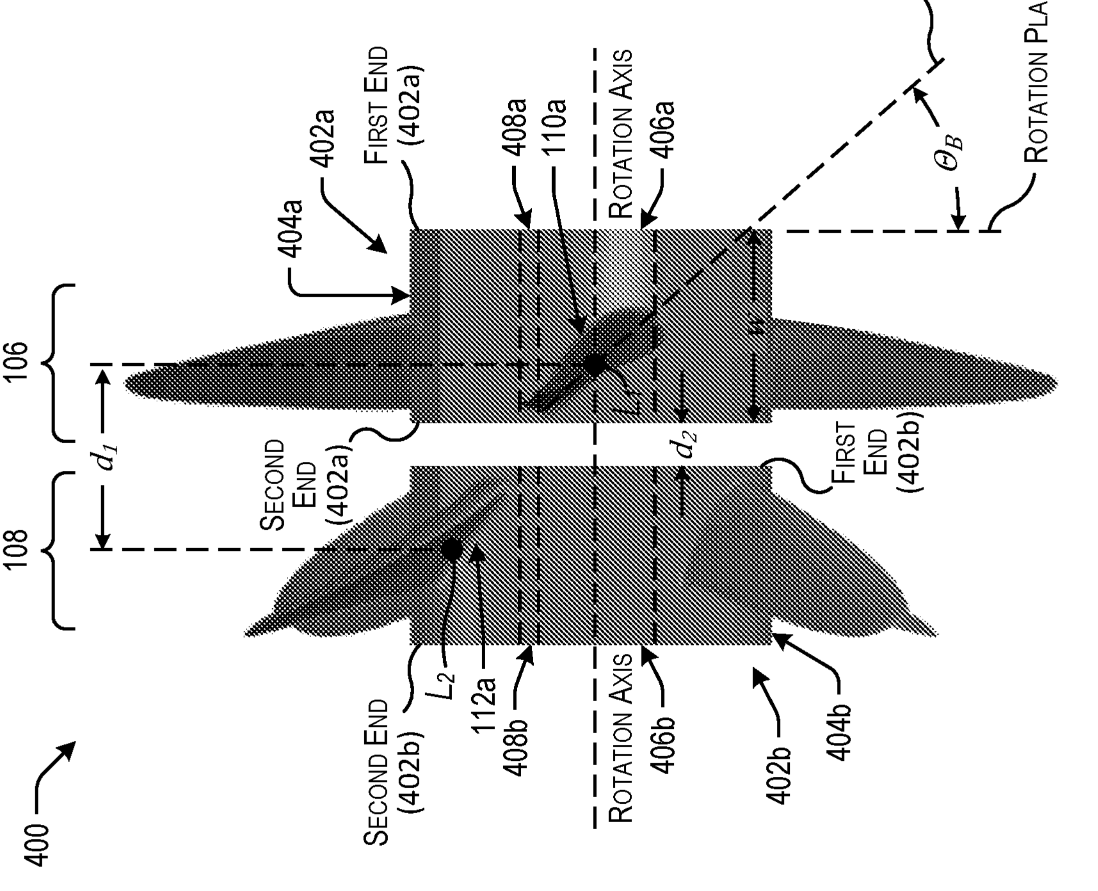
400
106
108
d1
d2
w
404a
402a
FIRST END (402a)
408a
110a
ROTATION AXIS
406a
CHORD LINE
ΘB
ROTATION PLANE
SECOND END (402a)
FIRST END (402b)
L1
L2
SECOND END (402b)
112a
408b
ROTATION AXIS
406b
402b
404b

FIG. 4A

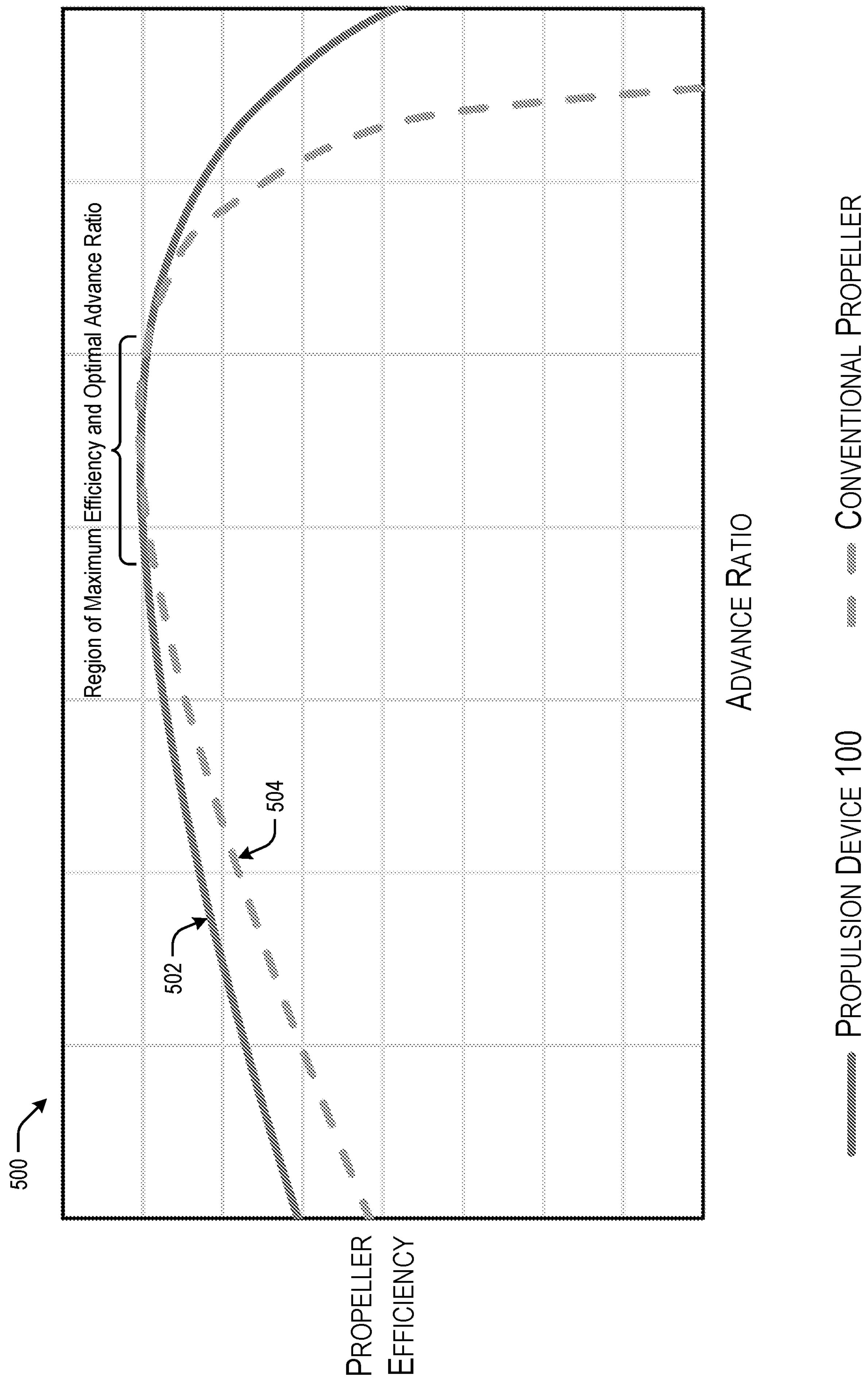
500
Region of Maximum Efficiency and Optimal Advance Ratio
502
504
Propeller Efficiency
Advance Ratio
Propulsion Device 100
Conventional Propeller

FIG. 5

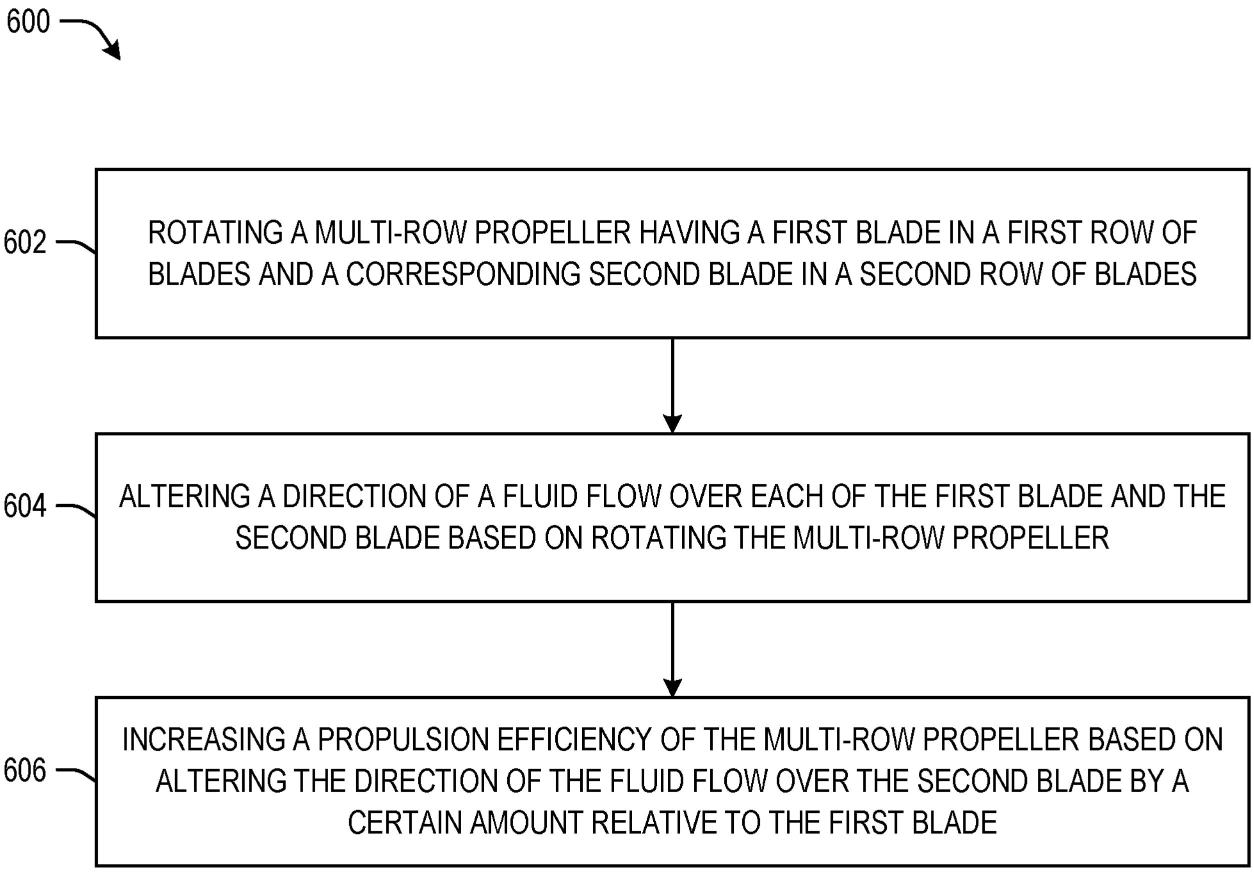
600
602
ROTATING A MULTI-ROW PROPELLER HAVING A FIRST BLADE IN A FIRST ROW OF BLADES AND A CORRESPONDING SECOND BLADE IN A SECOND ROW OF BLADES
604
ALTERING A DIRECTION OF A FLUID FLOW OVER EACH OF THE FIRST BLADE AND THE SECOND BLADE BASED ON ROTATING THE MULTI-ROW PROPELLER
606
INCREASING A PROPULSION EFFICIENCY OF THE MULTI-ROW PROPELLER BASED ON ALTERING THE DIRECTION OF THE FLUID FLOW OVER THE SECOND BLADE BY A CERTAIN AMOUNT RELATIVE TO THE FIRST BLADE

FIG. 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2023/071588

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - INV. - B63H 1/28 (2023.01)
ADD.

CPC - INV. - B63H 1/28 (2023.08)

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)
See Search History document

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
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Electronic database consulted during the international search (name of database and, where practicable, search terms used)
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C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2,242,642 A (BOGERT) 20 May 1941 (20.05.1941) entire document	1-20
A	US 2021/0354801 A1 (JARDINIANO) 18 November 2021 (18.11.2021) entire document	1-20
A	CN 201951703 U (GUANGZHOU FANYU YUEXIN SHIPBUILDING CO LTD) 31 August 2011 (31.08.2011) see machine translation	1-20
A	GB 431968 A (TRANSPORTS FLUVIAUX RAPIDES AU CONGO BELGE) 18 July 1935 (18.07.1935) entire document	1-20

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
03 October 2023	DEC 04 2023

Name and mailing address of the ISA/	Authorized officer
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