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(54) **FAN ASSEMBLY**

(57) Briefly, embodiments of a fan for moving a volume of compressible fluid from an upstream side to a downstream side may comprise a vortex circulation channel formed within a shroud substantially surrounding the blades of the fan. As a portion of one or more blades of the fan moves within the vortex circulation channel, a vortex that is formed and confined within the channel may reduce formation of a vortex within the fan working area, thereby bringing about an increase in a volume of the compressible fluid capable of being moved by the fan. In an embodiment, a fin or other protrusion disposed on a tip portion of a blade may additionally increase flow of a compressible fluid through a fan. In an embodiment, use of a wraparound leading edge of a fan shroud may bring about further increases in volume of compressible fluid flow.

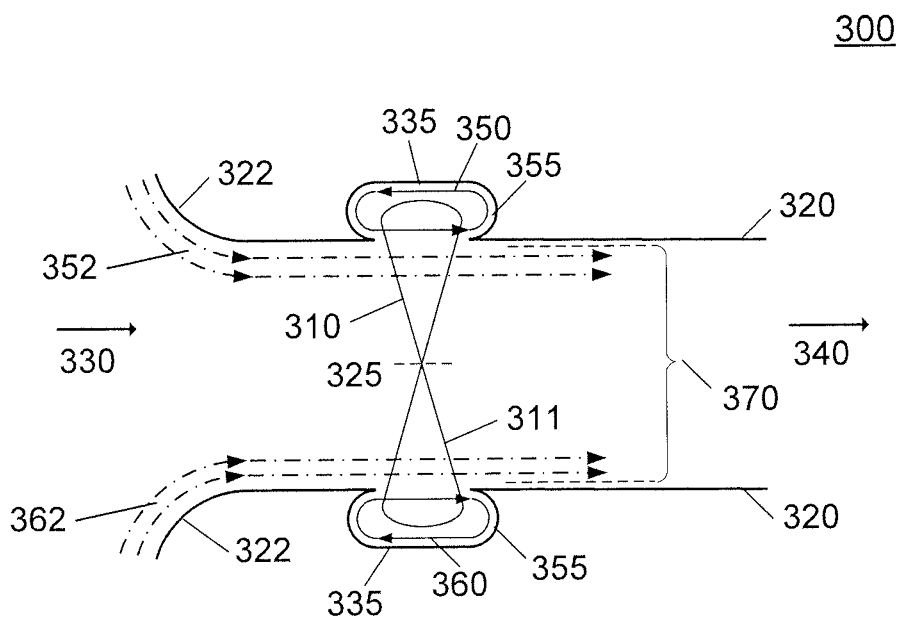

FIG. 3

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Description

BACKGROUND

1. Field

[0001] This disclosure relates to equipment that may be utilized to move a compressible fluid, such as portable fans, and, more particularly, to a reduced-footprint high-volume fan shroud and blade assembly.

2. Information

[0002] At times, a fan may be utilized to move a compressible fluid, such as ambient air, for example, to bring about ventilation, forced-air cooling, heating, drying, fumigating, cleaning, and so forth. In many applications, a fan may consume a large external footprint to bring about movement of a volume of air, for example, via the fan's working area. In turn, a large external footprint may increase overall dimensions of the fan, which may limit portability of the fan. Accordingly, improving a fan's throughput and/or reducing a fan's external footprint may represent an area of continued interest and/or development.

BRIEF DESCRIPTION OF DRAWINGS

[0003] Claimed subject matter is particularly pointed out and/or distinctly claimed in the concluding portion of the specification. However, both as to organization and/or method of operation, together with objects, features, and/or advantages thereof, claimed subject matter may be understood by reference to the following detailed description if read with the accompanying drawings in which:

FIG. 1 is a perspective view of an example axial fan, wherein a plurality of fan blades rotate in a plane within a volume substantially surrounded by a fan shroud;

FIG. 2 is a schematic view of an axial fan, showing fan blades rotating in a plane within a volume substantially surrounded by a shroud;

FIG. 3 is a schematic view of an example axial fan, showing fan blades rotating in a plane within a volume substantially surrounded by a shroud, according to an embodiment;

FIG. 4 is a schematic view of an example axial fan showing fan blades rotating in a plane within a volume substantially surrounded by a shroud according to an embodiment;

FIGs. 5A-5D illustrate one or more fan blades that may include a fin-shaped or other type of projection according to embodiments;

FIG. 6A is a schematic view showing fan blades rotating in a plane within a volume substantially surrounded by a shroud;

FIG. 6B is a schematic view of a portion of an axial fan within shroud having a wraparound forward edge according to an embodiment;

FIGs. 6C-6D are schematic views of inlet vanes, such as those shown in FIG. 6B, according to embodiments;

FIGs. 6E-6F are schematic views of inlet vanes showing an increase in fan working area according to an embodiment;

FIG. 7A is a schematic diagram showing velocity gradients at various points along an aerodynamic surface of a fan blade;

FIG. 7B is a schematic diagram showing velocity gradients at various points along an aerodynamic surface of a primary blade responsive to a presence of secondary blade according to an embodiment;

FIG. 7C is a schematic diagram showing various dimensions of a primary blade and a secondary blade according to an embodiment;

FIG. 7D is a schematic diagram showing possible orientation angles of secondary blade relative to a chord line of a primary blade according to an embodiment; and

FIG. 8A is a schematic diagram showing cross section of a fan shroud, vortex pocket, and arc-shaped inlet vanes according to an embodiment;

FIG. 8B is a schematic diagram showing a primary and secondary blade, wherein the primary blade comprises an increasing pitch toward the blade hub, according to an embodiment; and

FIG. 8C provides a diagram showing a numerical example utilized in determining, or at least estimating, blade pitch of sections of the primary and secondary blades of FIG. 8B.

[0004] Reference is made in the following detailed description to accompanying drawings, which form a part hereof, wherein like numerals may designate like parts throughout the figures to indicate corresponding and/or analogous components. It will be appreciated that components illustrated in the figures have not necessarily been drawn to scale, such as for simplicity and/or clarity of illustration. For example, dimensions of some components may be exaggerated relative to other components. Further, it is to be understood that other embodiments may be utilized. Furthermore, structural and/or other changes may be made without departing from claimed subject matter.

DETAILED DESCRIPTION

[0005] Reference throughout this specification to "one example," "one feature," "one embodiment," "an example," "a feature," "an implementation," or "an embodiment" means that a particular feature, structure, or characteristic described in connection with the feature, example, or embodiment is included in at least one feature, example, or embodiment of claimed subject matter. Thus, appearances of the phrase "in one example," "an example," "in one implementation," "an implementation," "an embodiment," or "in one embodiment" in various places throughout this specification are not necessarily all referring to the same feature, example, or embodiment. Particular features, structures, or characteristics may be combined in one or more examples, features, or embodiments.

[0006] As previously mentioned herein, a fan may be utilized to move ambient air, for example, in various applications such as ventilation, forced-air cooling, heating, drying, fumigating, cleaning, and so forth. In many applications, a fan may consume a large external footprint so as to be capable of moving a significant volume of ambient air, or other type of compressible fluid, for example. However, responsive to a fan consuming a large external footprint, portability, performance, and storage volume of a fan may be negatively impacted. Thus, reducing physical size and improving throughput of a fan, such as via improved fan blade and/or fan shroud design, for example, may represent a continued area of interest.

[0007] Particular types of fans may comprise one or more blades, rotating in a plane, and disposed or situated within a shroud, such as a cylindrically-shaped, stationary shroud, as one possible example. Use of a cylindrically-shaped, stationary shroud may operate to confine and to direct a volume of a compressible fluid, such as ambient air, for example, from an upstream side of the blades of the fan, which may correspond to a region towards the front of the fan blades, to a downstream side, which may correspond to a region towards the rear of the fan blades. However, in many instances, as one or more fan blades rotate in a plane about a central axis, thereby driving a compressible fluid from an upstream side of the volume enclosed by a cylindrically-shaped shroud to a downstream side, pressure at the downstream side may increase relative to pressure at the upstream side. Accordingly, a portion of the volume of the compressible fluid may be redirected towards an opposite direction, such as from a downstream side of the fan blades towards an upstream side of the fan blades. In some instances, compressible fluid flow in the opposite direction may be localized to within a gap-like region that defines a spacing between a tip portion of the one or more rotating blades and the inner surface of the cylindrically-shaped shroud. In many applications, fluid flow from a downstream side of a volume enclosed by a cylindrically-shaped shroud, through a gap-like region or spacing between a tip portion of a blade, and into an upstream side of the volume may undesirably impact a fan’s capability to move large volumes of compressible fluid.

[0008] As the compressible fluid flows in the opposite direction (e.g., a downstream side towards an upstream side), such as through a gap-like region or spacing between a tip portion of a rotating blade and the inner surface of a cylindrically-shaped shroud, a portion of the oppositely-directed fluid may collide with the compressible fluid flowing from the upstream side towards the downstream side. In response to such colliding, at least a portion of the oppositely directed fluid may be redirected towards the center of the cylindrically-shaped volume confined by the cylindrically-shaped, stationary shroud. Responsive to redirection of the fluid towards the center of the cylindrically-shaped volume, the direction of the opposing fluid may be further modified so as to begin flowing from the upstream side of the volume enclosed by the cylindrically-shaped shroud towards the downstream side. As the fluid encounters higher pressure at the downstream side of the cylindrically-shaped volume, a portion of the fluid may be deflected towards the perimeter of the volume, where the fluid may again be permitted to flow through a gap-like region or spacing between a tip portion of a blade and the inner surface of the cylindrically-shaped shroud.

[0009] Under certain circumstances, such fluid circulation, which may begin with flow of a compressible fluid from a downstream side to an upstream side, followed by redirection of the flow toward a center portion of the cylindrically-shaped volume, towards the downstream side, and (again) in a direction towards the upstream side, may be referred to as a "vortex." Under certain circumstances, a vortex (such as illustrated in FIG. 2 herein) may operate to separate laminar flow, particularly near outer portions of a cylindrically-shaped volume. Such boundary layer separation of a compressible fluid, may operate to bring about unsteady or turbulent flow at an upstream side of a cylindrically-shaped volume. In embodiments, such boundary layer separation operates to impede normal upstream-to-downstream flow of a compressible fluid by constricting or narrowing an effective working area available for movement of a volume of the compressible fluid. Such constricting or narrowing of an effective working area available for movement of a volume of compressible fluid, may be understood utilizing an expression substantially in accordance with:

$$\text{Flow Volume } \alpha \text{ (Diameter)}^2 \qquad (1)$$

Wherein "α" indicates proportionality in expression (1). Thus, in accordance with expression (1), flow volume of a fan is proportional to the square of a diameter of a channel through which a compressible fluid may flow. Thus, in one possible example simply to illustrate the concept, responsive to a narrowing of a cylindrically shaped volume from, for example, 20.0 cm to 18.0 cm (10.0%) may give rise to a decrease in fan flow volume of approximately 19.0% in accordance with an example application of expression (1):

$$(20.0)^2 - (18.0)^2 = 76.0$$

$$76.0/400.0 = 0.19$$

$$=> 19.0\%$$

[0010] Accordingly, as can be seen by applying expression 1, narrowing or constricting of a working area through which a compressible fluid may flow (such as a 10.0% reduction in diameter of the working area) brings about a reduction in the volume of compressible fluid flow that is proportional to the square of the reduction in the diameter of the flow channel (such as by 19.0%). Accordingly, to compensate for such reduction flow volume of the compressible fluid, an angular velocity (e.g., fan blade speed in revolutions per minute) of the one or more blades may be increased accordingly in order to maintain a flow volume of the compressible fluid. Such increased angular velocity of one or more blades of a fan may be brought about, for example, by increasing primary power supplied to a fan in order to maintain movement of a particular volume of compressible fluid. In other instances, a fan motor or other type of driving element may experience an increased load, which may also bring about an increase in power primary power supplied to a fan. In other instances, to maintain a particular volume of flow of a compressible fluid, a diameter of cylindrically-shaped shroud may be increased. However, such increases in a diameter of a cylindrically-shaped shroud may bring about undesirable increases in fan footprint, for example.

[0011] However, as described herein, to address these issues (and potentially others), in particular embodiments of claimed subject matter, a cylindrically-shaped shroud may comprise, for example, a vortex circulation channel. In particular embodiments, a vortex circulation channel may be formed within the cylindrically-shaped shroud and may be sized to accept one or more blade tips or outer portions of rotating fan blades. The vortex circulation channel, which may encircle or surround the tip or outer portion of the one or more blades of a rotating fan, may operate to confine a vortex generated in response to rotational motion of the one or more blades of the fan as the blades move along the length of the channel. Accordingly, in embodiments, a vortex generated by rotational motion of the one or more blades of the fan may be precluded from narrowing or constricting of a working area through which a compressible fluid may flow. Consequently, and in accordance with expression (1), a capacity to move a volume of a compressible fluid from an upstream side to a downstream side may be advantageously maintained or increased without increasing primary power supplied to a fan. Confinement of a vortex generated in response to rotational motion of one or more blades of the fan may bring about additional advantages and/or benefits, such as bringing about a reduction in a footprint of a fan shroud/fan assembly, and claimed subject matter is not limited in this respect.

[0012] FIG. 1 is a perspective view of an example axial fan 100, wherein a plurality of fan blades rotate in a plane within a volume substantially surrounded by a fan shroud. In FIG. 1, cylindrically-shaped shroud 130 surrounds blades

140, which operate to transport a volume of a compressible fluid from upstream side 110 to downstream side 120. Although eight of blades 140 are shown as being capable of rotational motion, as referenced schematically via arrow 152, in a plane about axis 150, claimed subject matter is intended to embrace fans incorporating any number of blades, such as a single blade, two blades, three blades, six blades, 10 blades, and so forth. In FIG. 1, blades 140 are depicted as being canted or tilted, such as along the length of the blade, at an angle relative to a plane of rotational motion. However, blades 140 may be tilted at any appropriate angle, such as an angle of between 5.0° and 60.0°, such as at any portion along the length of the blades 140, for example, and claimed subject matter is not limited in this respect.

[0013] In FIG. 1, responsive to rotational motion of fan blades 140 about axis 150, an increased pressure may form at downstream side 120 relative to upstream side 110. In embodiments, such increased pressure may bring about movement of a portion of the compressible fluid from downstream side 120 in a direction toward upstream side 110. In FIG. 1, movement of a compressible fluid from downstream side 120 toward upstream side 110, as shown by arrows 115, may occur between gap-like regions or spacings between a tip or outer portion of one or more of blades 140 and an inner surface of cylindrically-shaped shroud 130. As compressible fluid flowing through the gap-like regions meets with compressible fluid flowing from upstream side 110, a vortex may form (as shown in greater detail in FIG. 2), which may operate to constrict or narrow an effective working area available for transporting the compressible fluid.

[0014] FIG. 2 is a schematic view of an axial fan 200, showing fan blades rotating in a plane within a volume substantially surrounded by a shroud (such as shroud 130 of FIG. 1). In FIG. 2, shroud 220 is shown as substantially surrounding fan blades 210 and 211 as vortices circulate from a downstream side to an upstream side. Responsive to rotation of fan blades 210 and 211, such as in a plane perpendicular to axis 225 relative to shroud 220, a compressible fluid may move from upstream side 230 to downstream side 240. Responsive to movement of a volume of a compressible fluid towards downstream side 240, pressure may increase at downstream side 240 relative to upstream side 230. In response to a pressure increase, a portion of compressible fluid accumulated at downstream side 240 may be transported back towards upstream side 230, such as through gap-like region 215 between tip portions of fan blade 210 and shroud 220. As portions of the compressible fluid meet with incoming fluid from upstream side 230, the portions of the compressible fluid may be redirected towards axis 225 and further redirected towards downstream side 240, thereby forming vortex 250.

[0015] Similarly, vortex 260 may also form responsive to a portion of the compressible fluid from downstream side 240 flowing through a gap-like region 216 defining a spacing between a tip portion of fan blade 211 and shroud 220, as shown near the bottom of FIG. 2. In like manner, vortices may form between gap-like regions between additional tip portions of the blades of a fan and shroud 220. Thus, as shown in FIG. 2, a presence of vortices, such as vortices 250 and 260, may operate to narrow or constrict a working area through which a volume of a compressible fluid may flow. In FIG. 2, a narrowing of a working area through which a compressible fluid may flow is indicated by bracket 270. Compressible fluid flow lines 252 and 262, which begin near lip 222 of shroud 220 are shown as deflecting inward towards axis 225 responsive to the presence of vortices 250 and 260.

[0016] FIG. 3 is a schematic view of an example axial fan, showing fan blades rotating in a plane within a volume substantially surrounded by a shroud, according to an embodiment 300. In FIG. 3, shroud 320 is shown as substantially surrounding fan blades 310 and 311 as a vortex circulation channel operates to confine a vortex. As fan blades 310 and 311 rotate about axis 325 relative to shroud 320, a compressible fluid may move from upstream side 330 to downstream side 340. Responsive to movement of a volume of a compressible fluid towards downstream side 340, pressure may increase at downstream side 340 relative to upstream side 330. Responsive to a pressure increase, a portion of compressible fluid accumulated at downstream side 340 may begin to move in opposite direction towards upstream side 330, for example.

[0017] However, as a compressible fluid moves from downstream side 340 to upstream side 330, at least a fraction of the compressible fluid may enter vortex circulation channel 335, located above blade 310 in FIG. 3, which may initiate a counterclockwise rotation of the compressible fluid within channel 335. In an embodiment, the fraction of the compressible fluid may move in a counterclockwise direction defined by boundary 355 of vortex circulation channel 335. After moving in a direction defined by boundary 355 of vortex circulation channel 335, the fraction of the compressible fluid may progress to an upstream side of the vortex circulation channel. Responsive to motion of blade 310, the fraction of the compressible fluid may continue moving in a counterclockwise direction, thereby circulating within vortex circulation channel 335. In embodiments, such circulation of the fraction of the compressible fluid within vortex circulation channel 335 may bring about decreased pressure within the channel, thereby drawing additional compressible fluid from downstream side 340. Accordingly, vortex circulation channel 335 may assist in bringing about vortex 350, which may be substantially confined within the circulation channel.

[0018] Likewise, as a compressible fluid moves from downstream side 340 to upstream side 330, at least a fraction of the compressible fluid may enter vortex circulation channel 335, located below blade 311 in FIG. 3, which may initiate a clockwise rotation of the compressible fluid within vortex circulation channel 335. In an embodiment, the fraction of the compressible fluid may move in a clockwise direction defined by boundary 355 within vortex circulation channel 335 in a curling-like motion. After moving in a direction defined by boundaries 355 of vortex circulation channel 335, the fraction of the compressible fluid may progress to an upstream side of the vortex circulation channel. Responsive to motion of blade 311, the fraction of the compressible fluid may continue motion in a clockwise direction, thereby circulating within vortex circulation channel 335. In embodiments, such circulation of the fraction of the compressible fluid within vortex circulation channel 335 may bring about a decreased pressure within the vortex circulation channel, thereby drawing additional compressible fluid from downstream side 340. Accordingly, vortex circulation channel 335 may assist in bringing about vortex 360, which may be substantially confined within the circulation channel.

[0019] In like manner, vortices, such as vortices 350 and 360 may form within, and remain substantially confined within, vortex circulation channel 335 as additional blades of a fan rotating relative to shroud 320 in a plane about axis 325. Accordingly, as distinguished from the arrangement of FIG. 2, confining vortices to within a vortex circulation channel, such as described in connection with the confinement of vortices 350 and 360, may preclude or reduce narrowing or constricting of a working area through which a volume of compressible fluid may flow. Thus, as shown in FIG. 3, flow lines 352 and 362 indicate substantially laminar flow through at least a considerable portion of the volume defined by shroud 320. In FIG. 3, an absence, or at least a reduction, of narrowing of a working area through which a compressible fluid may flow is indicated by bracket 370. Flow lines 352 and 362, which begin near forward edge 322 of shroud 320 are shown as remaining substantially parallel to indicate the substantial confinement of vortices 350 and 360 to within a volume defined by vortex circulation channel 335.

[0020] FIG. 4 is a schematic view of an example axial fan 400, showing fan blades rotating in a plane within a volume substantially surrounded by a shroud according to an embodiment. FIG. 4 shows confinement of a vortex within a circulation channel along with relative dimensional properties according to an embodiment. In the embodiment of FIG. 4, certain features are exaggerated so as to illustrate, for example, radius of blade assembly 410 (R_1) as well as a radius of curvature of upstream-faced and downstream-faced semicircular regions of vortex circulation channel 435 (R_2). In the embodiment of FIG. 4, upper and lower tips or outer portions of blade assembly 410 are shown within vortex circulation channel 435 as blade assembly 410 rotates about axis 425 to draw a compressible fluid from upstream side 430 to downstream side 440. In embodiments, a ratio between the radius of blade assembly 410 (as referenced via R_1) to a radius of curvature of vortex circulation channel 435 (as referenced via R_2) may vary between 10.0:1.0 and 100.0:1.0. In a particular embodiment, the ratio R_1:R_2 may be equal to about 48:1. However, claimed subject matter is intended to embrace all usable ratios of a radius of a fan blade or fan blade assembly (e.g., R_1) to a radius of curvature of a vortex circulation channel (e.g., R_2), virtually without limitation. In the embodiment of FIG. 4, vortex circulation channel 435 additionally comprises protruding edge 438, located proximate with an upstream side of the vortex circulation channel, which operates to direct flow of the compressible fluid towards the plane of rotation of blade assembly 410. Vortex circulation channel 435 may further comprise protruding edge 439, located proximate with a downstream side of the channel, which, in cooperation with protruding edge 438, operate to confine a vortex within circulation channel 435.

[0021] FIGs. 5A and 5B illustrate one or more fan blades that may include a fin-shaped or other type of projection according to embodiments 500 and 550. In FIG. 5A (embodiment 500), blades 510 include fin 520 or other projection, which move within a vortex circulation channel, for example, as shown by dotted lines 522 and 524. In particular embodiments, fin 520, or other projection, may be positioned on an aerodynamic surface of a blade at a predefined distance from the leading edge and proximate to a blade tip. As described in greater detail in connection with FIG. 5B (embodiment 550), presence of fin 520 may operate to reduce occurrence of stray vortices, such as, for example, vortices indicated by arrows 570 FIG. 5B that may form in response to rotation of blades 510 about axis 530. Accordingly, if tip portions of blades 510, comprising fins 520, traverse a vortex circulation channel, as shown by dotted lines 522 at 524, vortex 350 (of FIG. 3) for example, may form exclusive of stray or parasitic vortices such as, for example, vortices indicated by arrows 570 FIG. 5B. In embodiments, formation of a single vortex, such as vortex 350 within a vortex circulation channel, may bring about increased flow volume of, for example, a fan operating to transport a volume of the compressible fluid from an upstream side to a downstream side.

[0022] In FIG. 5B (embodiment 550), blade 560 is shown in detail as advancing during nominal rotation of the blade about an axis, such as in a direction as referenced via arrow 565. Blade 560 may operate in a manner similar to that of blades 310 and 311 as described in FIG. 3. As blade 560 of FIG. 5B advances through a medium of a compressible fluid, such as ambient air, a volume of the compressible fluid in contact with or proximate with an aerodynamic surface of blade 560 may comprise a decreased pressure (as indicated by $P\downarrow$ in FIG. 5B) relative to a pressure of a volume of the compressible fluid located opposite an aerodynamic surface of blade 560 (as indicated by $P\uparrow$ in FIG. 5B). Responsive to a difference in pressure, compressible fluid emanating from locations opposite an aerodynamic surface of the blade may be drawn towards an aerodynamic surface of tip portion 566 of blade 560, as shown by arrows 570 in FIG. 5B. However, as the compressible fluid is drawn to a region located in contact with or proximate with an aerodynamic surface of blade 560, the compressible fluid may encounter fin 580. In embodiments, fin 580 operates to deflect the compressible fluid towards a trailing edge portion of blade 560, as indicated by arrow 590. Thus, at least in particular embodiments, fin 580 may interrupt formation of stray vortices, such as tip vortices, for example, by redirecting compressible fluid flow drawn over a tip portion of advancing blade 560.

[0023] In FIG. 5B (embodiment 550), fin 580 comprises a length referenced via "L," which may comprise a length of between about 25.0% and about 100.0% of the width (as referenced via W_1) of blade 560, for example, as shown schematically in FIG. 5C. However, it should be noted that in other implementations, fin 580 may comprise a length of less than 25.0% relative to blade width W_1 or to comprise a length of greater than 100.0% of blade width W_1, and claimed subject matter is not limited in this respect. In addition, vertical dimension H_1 of fin 580, shown in FIG. 5C, may range between about 10.0% and about 50.0% relative to blade width W_1. However, it should be noted that in other implementations, fin 580 may comprise a vertical dimension less than 10.0% relative to blade vertical dimension H_2, or may comprise a vertical dimension greater than about 50% relative to blade width W_1, and claimed subject matter is not limited in this respect.

[0024] A compressible fluid, as indicated by reference designator 576 in FIG. 5B, may additionally be drawn towards an aerodynamic surface of a trailing portion of blade 560 as indicated by arrow 575 of FIG. 5B responsive to a pressure differential between a region located opposite an aerodynamic surface of blade 560 and a region proximate with an aerodynamic surface of blade 560. However, in embodiments, trailing edge 585 of blade 560 may provide a stopping or blocking function so as to restrict or preclude a compressible fluid from colliding with a flow of the compressible fluid from an aerodynamic surface of blade 560, such as indicated by line 590. In particular embodiments, restricting compressible fluid drawn from regions located opposite an aerodynamic surface of blade 560, may increase fan efficiency, flow volume, and/or aerodynamics of blade 560. Restricting compressible fluid drawn from a region opposite an aerodynamic surface of blade 560 may bring about additional benefits and/or advantages, and claimed subject matter is not limited in this respect.

[0025] In particular embodiments, such as shown in FIG. 5C a portion of a trailing edge of blade 560, may comprise a width W_2 of between about 10.0% and about 40.0% of the width of blade 560 (W_1). However, claimed subject matter is intended to embrace trailing edge portions of blades comprising a width of less than 10.0% (such as 5.0%) or greater than 40.0% (such as up to 100.0%) of a width of blade 560, and claimed subject matter is not limited in this respect. In another embodiment, such as shown in FIG. 5D, fin 582 may be raised toward a trailing edge portion of blade 565. In an embodiment, fin 582 may comprise a vertical dimension (H_{1A} in FIG. 5D) between 1.0% and 50.0% of the width of blade 560 (W_1).

[0026] FIG. 6A is a schematic view showing fan blades rotating in a plane within a volume substantially surrounded by a shroud. In the example of FIG. 6A, a compressible fluid is drawn towards axial fan 600 from various regions at upstream side 606, as referenced via flow lines 615. However, compressible fluid that makes contact with forward edge 622 at discontinuity 622A may bring about formation of vortex 624 formed proximate with a surface of forward edge 622. Accordingly, although the quarter-circle shape of forward edge 622 may operate to decrease turbulence, a presence of discontinuity 622A may nonetheless assist in creating vortex 624 and to bring about an at least semi-laminar flow of a compressible fluid entering the axial fan of FIG. 6A. In particular implementations, formation of vortex 624 may operate to interrupt or separate laminar flow along forward edge 622, thus reducing volume of compressible fluid flow from upstream side 606 to downstream side 608, for example. In a similar manner, although not shown in FIG. 6A, vortices similar to vortex 624 may form at regions located around a circular perimeter of forward edge 622. Inlet vanes 618 may operate to align flow, such as represented by flow lines 615, so as to increase laminar flow through the volume defined by shroud 620.

[0027] FIG. 6B is a schematic view of a portion of an axial fan within a shroud having a semicircular or radiused forward edge portion according to an embodiment 625. As shown in FIG. 6B, forward edge 632 comprises a shape that is at least approximately semicircular to permit a compressible fluid, as indicated by flow lines 635, to wraparound forward edge 632 so as to initiate substantially laminar flow into a volume defined by shroud 630, for example. In embodiments, such laminar flow precludes formation of vortices, such as vortex 624, which may form near an upper portion of forward edge 622 of FIG. 6A. In the embodiment of FIG. 6B, arc-shaped vanes 638 may be oriented so as to guide and/or align laminar flow, thereby preventing formation of vortices as the flow wraps around the reduced shroud inlet radius and/or responsive to rotational motion of the blades of blade assembly 610 as a compressible fluid flows from upstream side 626 to downstream side 628. In particular embodiments, wraparound forward edge 632 cooperates with arc-shaped vanes 638 bring about relatively high flow volume of compressible fluid through a relatively small inlet area. It should be noted that although forward edge 632 is shown as comprising a substantially semicircular shape subtending an approximately 180° angle, embodiments of claimed subject matter may comprise forward edges that subtend angles less than 180°, such as 135°, 150°, and so forth, or may comprise shapes that subtend greater than 180°, such as 270°, 300°, or 360° (e.g., in which forward and edge 632 wraps completely around to terminate at a point on shroud 630).

[0028] For example, at least in particular embodiments, arc-shaped vanes 638 may give rise to redirection of the flow of compressible fluid in addition to redirection of the flow brought about by the drawing or pulling force generated by the rotational motion of the blades of blade assembly 610. In embodiments, responsive to providing redirecting surfaces, such as by way of a plurality of arc-shaped vanes 638, a reduction in the likelihood of separation of the compressible fluid from the surrounding shroud may be achieved. Further, a plurality of arc-shaped vanes 638 may additionally operate to maintain velocity and laminar flow of the compressible fluid, such as inlet regions on subsequent vanes near a boundary of the surrounding shroud. Arc-shaped vanes 638 operating in concert with semicircular-shaped forward edge 632 may bring about additional advantages, and claimed subject matter is not limited in this respect.

[0029] FIG. 6C is a schematic view of inlet vanes, such as those shown in FIG. 6B, according to an embodiment 650. In embodiment 650, arc-shaped inlet vanes 658A-658G are shown comprising airfoils having incrementally decreasing curvatures beginning with larger curvatures toward forward edge 652 and smaller curvatures away from forward edge 652. Accordingly, arc-shaped inlet vane 658A, which may be positioned relatively close to forward edge 652, may comprise a curvature and length greater than arc-shaped inlet vanes 658B-658G. Arc-shaped inlet vane 658B, shown in FIG. 6C as positioned radially inward from arc-shaped inlet vane 658A is shown as comprising a curvature and length less than arc-shaped inlet vane 658A. As shown in FIG. 6C, arc-shaped inlet vanes 658C, 658D, 658E, 658F, and 658G comprise successively decreasing arc angles as well as successively reduced curvatures. In embodiments, arc-shaped inlet vanes 658A-658G operate to maintain laminar flow (referenced via 655) of a compressible fluid at a first side of forward edge 652, such as region 662, to a second side of inlet vanes 658A-658G, such as region 664.

[0030] FIG. 6D is a schematic view of inlet vanes, such as those shown in FIG. 6B, according to an embodiment 675. As shown in FIG. 6D, arc-shaped inlet vanes 658A-658G approximate an arc shape that subtends from point 680 located at the center of semicircular-shaped forward edge 678. In particular embodiments, such arrangement and orientation of arc shaped-inlet vanes brings about an increased ability to maintain a laminar flow of a compressible fluid at a first side of forward edge 672, such as region 660A, to a second side of inlet vanes 658A-658G, such as region 660B.

[0031] FIGs. 6E and 6F represent schematic views of inlet vanes showing an increase in fan working area according to an embodiment. In FIG. 6E, inlet vanes 688, which may be similar to inlet vanes 618 of FIG. 6A, for example, operate to draw a compressible fluid toward a volume defined by shroud 686. As shown in FIG. 6E, shroud 686 may comprise a taper as referenced via T. In embodiments, such taper may operate to narrow a volume through which a compressible fluid may flow. In particular embodiments, radius R_4 may comprise a value approximately in the range of between 5.0% and 20.0% of fan inlet dimension H_3. Taper T of FIG. 6E may comprise a value approximately in the range of 3.0%-7.0% of fan inlet dimension H_3. Accordingly, in one possible example to illustrate, assume H_3 = 64.77 cm (25.50 inches), $2R_4$ = 2(3.18) cm (2.50 inches), T = 1.27 cm (0.5 inch), and H_4 = 58.41 (23.0 inches). Accordingly, a working area of such a fan may be computed as follows:

$$\text{Fan Working Area} = \pi \ \text{X} \ (58.41/2)^2 = 2679.1 \text{ cm}^2 \quad (2)$$

[0032] In FIG. 6F, inlet vanes similar to inlet vanes 658A-658B of FIG. 6D operate to draw a compressible fluid toward a volume defined by shroud 692. As shown in FIG. 6F, shroud 692 comprises a wraparound forward edge such as shown in FIG. 6B, which brings about laminar flow that may preclude formation of vortices, such as vortex 624 of FIG. 6A. In particular embodiments, forward edge 672 of shroud 692 may be formed utilizing a smaller radius of curvature than forward edge 622 of FIG. 6E. Additionally, tapering of an inner surface of shroud 692 may be unnecessary. Accordingly, in a particular embodiment, a radius (R_5) of forward edge 672 may comprise a value approximately in the range of between 1.0% and 7.5% of fan inlet dimension H_5. In one example to illustrate, assume H_5 = 64.77 cm (25.5 inches), R_5 = 1.07 cm (0.42 inches), and H_6 = 59.94 cm (23.60 inches). Accordingly, a working area of a fan may be computed as follows:

$$\text{Fan Working Area} = \pi \ \text{x} \ (59.94/2)^2 = 2820.4 \text{ cm}^2 \qquad (3)$$

[0033] Thus, as evidenced by comparing the fan working area referenced by (2) with the fan working area referenced by (3), an embodiment of claimed subject matter may bring about an approximately 5.0% increase in a fan working area. Such an increase in fan working area may be realized as a consequence of utilizing a wraparound forward edge, such as shown in the embodiments of FIG. 6B, 6C, 6D, and 6F. By utilizing a wraparound forward edge, a vortex, such as vortex 624, as shown in FIG. 6A, may be precluded from forming, which may increase laminar flow into a volume formed by shroud surrounding a fan blade. A wraparound forward edge may bring about additional benefits and/or advantages, and claimed subject matter is not limited in this respect. In one possible embodiment, use of a wraparound forward edge may reduce the need for a flange mounted to a forward portion of an axial fan, which may add approximately 2.5 cm to, for example, H_3 in FIG. 6E.

[0034] As previously mentioned herein, such as with respect to FIG. 2, in many instances, as one or more fan blades rotate in a plane about a central axis, thereby driving a compressible fluid from an upstream side of the volume enclosed by a cylindrically-shaped shroud to a downstream side, pressure at the downstream side may increase relative to pressure at the upstream side. Accordingly, under certain circumstances, as described with respect to FIG. 7B-7D herein, rotating blades of a fan, according to particular embodiments of claimed subject matter, may utilize a primary blade and a secondary blade located, for example, at a trailing edge of a primary blade.

[0035] FIG. 7A, which is followed by FIGs. 7B-7D, is a schematic diagram showing velocity gradients at various points along an aerodynamic surface of fan blade 725. FIG. 7A shows a velocity gradient formed responsive to a compressible fluid, such as air, flowing over an aerodynamic surface of, for example, fan blade 725, as indicated by arrow 720, located at a low-pressure of fan blade 725, as referenced via P↓ in FIG. 7A. A low-pressure side of fan blade 725 (P↓) may correspond, for example, to upstream side 110 of FIG. 1. At point 702 of FIG. 7A, for example, as a distance from an aerodynamic surface increases, a velocity of a compressible fluid may also increase until reaching a constant velocity value, referenced via V_c in legend 715 of FIG. 7A. Similarly, at additional points along an aerodynamic surface of fan blade 725, such as points 704, 706, 708, as a distance from the aerodynamic surface increases, velocity of the compressible fluid increases before reaching a constant value.

[0036] However, as shown in FIG. 7A, at point 710, for example, a compressible fluid from a side of fan blade 725 opposite an aerodynamic surface, such as region 724, for example, may swirl around a trailing edge portion of fan blade 725 as shown by arrow 716. As previously mentioned, such an increase in pressure may be due, at least in part, to rotation of one or more fan blades rotating in a plane about a central axis, which may thereby drive a compressible fluid from an upstream side of the volume enclosed by a cylindrically-shaped shroud to a downstream side. In FIG. 7A, a high-pressure side of fan 725 (e.g., a side opposite an aerodynamic surface of fan blade 725) referenced via P↑ may correspond to, for example, to downstream side 120 of FIG. 1. Further, as fan blade 725 rotates with increasing velocity, which may operate to increase downstream pressure in a cylindrical volume enclosed by a shroud, pressure at or near a side opposite an aerodynamic surface of fan blade 725, referenced via P↑, may increase.

[0037] In FIG. 7A, as fan blade 725 advances so as to transport a volume of a compressible fluid from an upstream side to a downstream side, for example, velocity of the compressible fluid at or proximate to a trailing edge portion of fan blade 725 may decrease to a value below 0.0, which may indicate turbulent flow at, for example, point 710 of fan blade 725. Such turbulent flow, referenced via flow field 717, may indicate flow of the compressible fluid in a direction opposite to that of arrow 720. Responsive to oppositely-directed flow of a compressible fluid, a decrease in a volume of the compressible fluid that may be moved by rotation of fan blade 725 may occur. Oppositely-directed flow of compressible fluid may bring about additional undesirable effects, and claimed subject matter is not limited in this respect. It may be appreciated that turbulent flow, such as referenced via flow field 717, for example, may increase as a velocity of compressible fluid flowing over an aerodynamic surface, such as an aerodynamic surface of fan blade 725, increases.

[0038] FIG. 7B is a schematic diagram showing velocity gradients at various points along an aerodynamic surface of a primary blade responsive to a presence of a secondary blade according to an embodiment 750. In embodiment 750, arrow 770 indicates flow of the compressible fluid over an aerodynamic surface of primary blade 775. Thus, at points 752, 754, 756, and 758, a velocity gradient may be formed in which a velocity of the compressible fluid increases as a distance from an aerodynamic surface increases. However, as shown in FIG. 7B, a secondary blade 778, which may be positioned proximate with a trailing edge of an aerodynamic surface of primary blade 775, may bring about a directed flow of the compressible fluid through a gap separating secondary blade 778 from primary blade 775 as indicated by arrow 780. Thus, swirling of a compressible fluid around a trailing edge portion of primary blade 775, as described in connection with FIG. 7A, for example, may be suppressed. In response, a velocity gradient that does not approach 0.0, or negative values, at point 760 (wherein point 760 corresponds to a location on a trailing edge of primary blade 775) may be formed.

[0039] Responsive to an absence of a formation of oppositely-directed flow of the compressible fluid, a flow volume of a fan utilizing one or more of primary blade 775, operating in combination with secondary blade 778, may be significantly increased without, or with only a minimal increase, in angular velocity of fan blade 775. In addition, in embodiments, utilizing one or more of primary blade 775 operating in combination with secondary blades 778 may permit an axial fan, for example, to operate efficiently and effectively even at relatively low ranges of tangential blade velocity and/or angular velocity. Further, as flow volume of a fan utilizing one or more of primary blade 775 and secondary blade 778 increases, which may give rise to an increase in pressure at or near a side opposite to an aerodynamic surface of fan blade 775, a larger volume of a compressible fluid may be available for movement through a gap separating secondary blade 778 from primary blade 775 (referenced via arrow 780). An added benefit of an embodiment similar to that of FIG. 7B may additionally comprise a reduction in audible noise responsive to turbulence created by a collision of oppositely-directed compressible fluid, such as described with reference to FIG. 7A. An additional benefit of an embodiment similar to that of FIG. 7B may additionally comprise a possibility of reducing a number of primary blades 775 and secondary blades 778, such as for example, from an eight-bladed fan, such as shown in FIG. 1, for example, to a six-bladed fan. Use of a secondary blade, such as secondary blade 778, for example, may bring about additional advantages in operation of an axial fan, and claimed subject matter is not limited in this respect. Such additional advantages may include, for example, an increase in structural integrity of one or more blades of a fan, in which a secondary blade, which may be coupled via structural elements to a primary blade, may operate as a truss to provide structural support to a primary blade.

[0040] FIG. 7C is a schematic diagram showing various dimensions of a primary blade and a secondary blade according to an embodiment 790. In particular exemplary embodiments, a width dimension of a secondary blade, referenced via W_{sb} in FIG. 7C, may comprise between 20.0% and 75.0% of the width of primary blade 775. In embodiments, a secondary blade, such as secondary blade 778, may be disposed along the entire length, or any portion thereof, of primary blade 775, and claimed subject matter is not limited in this respect. In addition, a gap between primary blade 775 and secondary blade 778 referenced via L_g in FIG. 7C, may comprise between 2.0% and 100.0% of the width of primary blade 775, although claimed subject matter is not limited in this respect. Thus, in particular embodiments, a gap between primary blade 775 and secondary blade 778 may comprise between 2.0% and 75.0% of the width of primary blade 775, for example. In an embodiment, a gap between primary blade 775 and secondary blade 778 may comprise approximately 35.0% of the width of primary blade 775.

[0041] In embodiments, a leading edge of a secondary blade, such as secondary blade 778, may overlap with a trailing edge portion of a primary blade, such as primary blade 775, as referenced via W_g in FIG. 7C. Such overlap, in this context, is defined as an amount, such as a percentage of primary blade width (W_{sb}) is disposed directly over (at least in the orientation of FIG. 7C) an aerodynamic surface of secondary blade 778. In embodiments, a primary blade, such as primary blade 775, for example, may overlap a secondary blade, such as secondary blade 778, for example, by an amount of between 0.0% and approximately 75.0% (W_g/W_{sb} = 0.0 to 0.75), although claimed subject matter is not limited in this respect. In an embodiment, a primary blade, such as primary blade 775, for example, may overlap a secondary blade, such as secondary blade 778 by approximately 25.0% ($W_g/W_{sb} \sim 0.25$). It should be noted that claimed subject matter is intended to embrace any overlap of a primary blade with respect to a secondary blade, virtually without limitation.

[0042] FIG. 7D is a schematic diagram showing possible orientation angles of secondary blade 778 relative to a chord line of primary blade 775 according to an embodiment 795. In FIG. 7D, a chord line of secondary blade 778 may comprise approximately 5.0° (referenced via A in FIG. 7D) in relation to chord line 796 of primary blade 775. In another embodiment, a chord line of secondary blade 778 may comprise approximately 60.0° (referenced via B in FIG. 7D) in relation to chord line 796 of primary blade 775. It should be noted that claimed subject matter is intended to embrace any angular orientations of secondary blade 778 in relation to chord line 796 of primary blade 775, such as 2.0°, 10.0°, 30.0°, and so forth.

[0043] It may be appreciated, that at a perimeter portion, such as a tip portion, for example, of an axial fan, a tangential velocity may approach a relatively large value. Accordingly, at a tip portion of a blade of an axial fan, width of a primary blade and a secondary blade may approach a relatively small value while maintaining an ability to move a relatively large volume of a compressible fluid from an upstream side to a downstream side. Further, at a tip portion of a blade of an axial fan, an orientation of a secondary blade may comprise a relatively small value, such as a value between 0.0° and, for example, 20.0°, just as an example. However, at locations along a primary fan blade closer to a central axis of rotation of an axial fan, tangential velocity of a blade of an axial fan may be significantly reduced with respect to tangential velocity of a tip portion of a primary fan blade. Under such circumstances, an orientation angle of a secondary blade relative to a chord line of a primary blade may comprise a value significantly larger value, such as a value that approaches 35°, 40°, or even, for example, an angle of 60° or larger.

[0044] FIG. 8A is a schematic diagram showing a cross section of a fan shroud, vortex pocket, and arc-shaped inlet vanes according to an embodiment 800. In FIG. 8A, a volume of the compressible fluid is shown as flowing through arc-shaped vanes 858. Flow lines 852, which are depicted as being of approximately equal length, illustrate a constant velocity profile of a flow of the compressible fluid from upstream side 826 to downstream side 828. For clarity, one or more fan blades, which may bring about movement of a volume of compressible flow, are not shown in FIG. 8A.

[0045] FIG. 8B is a schematic diagram showing a primary and secondary blade, wherein the primary blade comprises an increasing pitch toward the blade hub, according to an embodiment 850. In the embodiment of FIG. 8B, hub 890 may correspond to a location, such as toward a center region of an axial fan, at which a primary blade and a secondary blade may attach, for example. In embodiments, the primary and secondary blades of FIG. 8B may advance, such as during axial rotation of the primary and secondary blades, as referenced via arrows 891.

[0046] As shown in FIG. 8B, a primary blade, which may comprise primary blade section 875A, may comprise a width referenced via W_{pb2}, which may correspond to width W_{pb} of the primary blade of FIG. 7C, described herein. Additionally, a secondary blade, which may comprise secondary blade section 878A may comprise a width referenced by W_{sb2}, which may correspond to width W_{sb} of the secondary blade of FIG. 7C described herein. Further, a gap between primary blade section 875A and secondary blade section 878A may be referenced via L_{g2}, which may correspond to a gap between primary blade 775 and secondary blade 778 of FIG. 7C. Thus, the primary blade of embodiment 850 (FIG. 8B) comprises a plurality of primary blade sections, such as primary blade section 875A, 875B,..., 8751. Additionally, the secondary blade of embodiment 850 comprises a plurality of secondary blade sections, such as secondary blade section 878A, 878B,..., 878I, for example.

[0047] In addition, although not shown explicitly in FIG. 8B, primary blade section 875I comprises a width greater than W_{pb2}, for example. Further, although secondary blade sections 878A, 878B, and 878I appear to comprise and least an approximately constant width (e.g., $W_{sb3} \approx W_{sb2}$), it is contemplated that in a number of embodiments, W_{sb3} may be greater than W_{sb2}, or less than W_{sb2}, and claimed subject matter is not limited in this respect. For example, in a particular embodiment, a secondary blade located at a perimeter, away from hub 890 (e.g., W_{sb2}) may comprise a width of approximately 20.0% of a primary blade (e.g., W_{pb2}). In a particular embodiment, a secondary blade located proximate to hub 890 (e.g., W_{sb3}) may comprise a width of approximately 75.0% of the width of a primary blade located proximate to hub 890, such as primary blade 878I, for example. In a particular embodiment, sections of the secondary blades, which may comprise all of secondary blades 878A, 878B,..., 8781, for example, may comprise a width of approximately 50.0% of the width of a primary blade positioned at a perimeter of the primary blade of embodiment 850. However, claimed subject matter is intended to embrace embodiments in which any of the sections of secondary blade comprise a width of approximately 20.0% of a primary blade to a width of approximately 75% of the primary blade.

[0048] As shown in FIG. 8B, primary blade sections closer to hub 890, such as, for example, primary blade section 8751, a blade pitch may comprise a much larger angle, such as an angle between about 30.0° and about 60.0°, for example, than a blade pitch more distant from hub 890. In particular embodiments, such adjustment in blade pitch may bring about constant velocity flow of a compressible fluid, such as shown in FIG. 8A. To illustrate, as primary blade sections 875A, ..., 875I and secondary blade sections 878A, ..., 8781 rotate in a plane at a particular angular velocity (revolutions/minute) about hub 890, primary blade section 875A and secondary blade section 878A may comprise a higher tangential velocity (meters/second) than, for example, primary blade section 875I and secondary blade section 8781, for example. Accordingly, an increased pitch of primary blade section 875I and secondary blade section 878I, relative to primary blade section 875A and secondary blade section 878A, respectively, may bring about movement of a substantially constant volume of compressible fluid between, for example, a combination of blade sections 875A/878A compared to a combination of blade sections 8751/8781.

[0049] FIG. 8C provides a diagram showing a numerical example utilized in determining, or at least estimating, blade pitch of sections of the primary and secondary blades of FIG. 8B according to an embodiment 895. In a nonlimiting example, just to illustrate a sample computation of pitch angle of primary and secondary blade sections, the following assumptions are made:

Blade Length: 45.72 cm (18.0 inches)
Desired Air Velocity: 1097.28 meter/min. (3600 feet/min.)
Desired Fan Speed: 3000.0 revolutions/min.

Thus, in a nonlimiting embodiment, to compute a blade pitch angle for a primary blade section immediately adjacent, for example, to a fan blade hub, such as primary blade section 875I and secondary blade section 8781 of FIG. 8B, the vector diagram 892 of FIG. 8C may be utilized. In vector diagram 892, a desired air velocity of 1097.28 meter/min. may form a vertically-oriented vector. To form the horizontally-oriented vector of diagram 892, at a point near a fan blade hub, such as at a distance of 7.62 cm (0.25 feet) from a central axis of rotation and expression substantially in accordance with expression (4) may be utilized:

$$3000.0 \text{ rev./min. x } 7.62 \text{ cm x } 2\pi = 143{,}634.0 \text{ cm/min.} = 1436.34 \text{ meter/min.} \qquad (4)$$

Thus, in accordance with vector diagram 892, the blade pitch angle for a primary and/or secondary blade sections, such as primary blade section 875I and secondary blade section 8781, of FIG. 8B for example, which may be positioned approximately 7.62 cm from a central axis of rotation of hub 890 may comprise an angle having a tangent (e.g., $\tan^{-1}$ of (1097.28/1436.34)) or 37.38° ($\tan^{-1}$ (1097.28/1436.34) = 37.38°).

[0050] Likewise, continuing with a nonlimiting embodiment, to compute a blade pitch angle for a primary blade section located near a perimeter of a fan blade hub, such as primary blade section 875A and secondary blade section 878A of FIG. 8B, the vector diagram 894 of FIG. 8C may be utilized. In vector diagram 894, a desired air velocity of 1097.28 meter/min. may form a vertically-oriented vector. To form the horizontally-oriented vector of diagram 894, at a point away from fan blade hub 890, such as at a distance of 22.86 cm (9.0 inches) from a central axis of rotation and expression substantially in accordance with expression (4) may be utilized:

$$3000.0 \text{ rev./min. x } 22.86 \text{ cm x } 2\pi = 430{,}900.0 \text{ cm/min.} = 4309.01 \text{ meter/min.} \qquad (5)$$

Thus, in accordance with vector diagram 894, the blade pitch angle for a primary and/or secondary blade section, such as primary blade section 875A and secondary blade section 878A, of FIG. 8B for example, which may be positioned approximately 22.86 cm from a central axis of rotation of hub 890 may comprise an angle having a tangent (e.g., $\tan^{-1}$) of 1097.28/4309.01 or 14.29° ($\tan^{-1}$ (1097.28/4309.01) = 14.29°).

[0051] Accordingly, utilizing vector diagrams 892 and 894 of FIG. 8C and expressions (4) and (5) pitch angles of primary blade sections and secondary blade sections may be computed. Although the preceding example computes pitch angles for primary and secondary blade sections positioned nearby hub 890 and at a perimeter (e.g., away from hub 890) additional vector diagrams similar to 892 and 894, as well as one or more of expressions (4) and (5), may be utilized to compute pitch angles for additional sections of the primary and secondary blades of FIG. 8B. It should be noted that although a specific example has been utilized, such as a blade length of 45.72 cm, a desired air velocity of

1097.28 meter/min., and a desired fan speed of 3000.0 revolutions/min., claimed subject matter is intended to embrace a wide variety of blade lengths, desired air velocities, desired fan speeds, and other performance parameters, virtually without limitation.

[0052] It should also be noted that although primary blade section 875I has been described as positioned approximately 7.62 cm from a central axis of rotation of hub 890, in particular embodiments, it may be advantageous to reduce a cross-sectional area of hub 890. In embodiments, reduction of a cross-sectional area of hub 890 may operate to increase fan working area, as described in relation to expressions (2) and (3). For example, in accordance with expression (6) a Fan Working Area may be decreased by cross-sectional area occupied by a fan hub, such as hub 890 of FIG. 8B, as follows:

$$(\text{Fan Working Area})_{\text{Effective}} = (\text{Fan Area}) - \text{Hub Area} \qquad (6)$$

Accordingly, an effective Fan Working Area (e.g., $(\text{Fan Working Area})_{\text{Effective}}$) of expression (6), may correspond to a cross-sectional area computed utilizing a tip-to-tip diameter of the blades of a fan, and wherein the Hub Area of expressions (6) comprises a cross-sectional area of the hub to which one or more blades of a fan may attach. Thus, in accordance with expression (6), an effective Fan Working Area of 2500.0 cm^2, computed utilizing the tip-to-tip diameter, may be significantly reduced by the presence of a hub having a radius of, for example, 4.0 cm, as computed substantially in accordance with expression (7), below:

$$(\text{Fan Working Area})_{\text{Effective}} = 2500.0\ \text{cm}^2 - \pi(4.0\ \text{cm})^2 \qquad (7)$$

$$= 2450.0\ \text{cm}^2$$

Accordingly, embodiments of claimed subject matter may operate to advantageously reduce a cross-sectional area of a hub, such as hub 890, to which one or more fan blades may attach. Further, as a hub to which fan blades may attach is reduced in cross-sectional area, a pitch angle of one or more blades of a fan may be adjusted (e.g., increased), utilizing, for example, expressions (4) and (5). Such increases in pitch angle of primary and/or secondary blades, in addition to reducing a cross-sectional area of a hub to which fan blades may attach, may provide a constant velocity profile of a flow of the compressible fluid from an upstream side (e.g., 826 of FIG. 8A) to a downstream side (e.g., 828 of FIG. 8A).

[0053] It should additionally be noted that although the example of FIGs. 8B and FIG. 8C have utilized a pitch angle of a secondary blade section equal to that of a pitch angle of a primary blade section, such as primary blade section 875I and secondary blade section 878I comprising a pitch angle of 37.38°, one or more secondary blade sections may be angled with respect to a corresponding primary blade section. Thus, in accordance with FIG. 7C (embodiment 795) a secondary blade section may comprise an angle of between approximately 5.0° and 60.0° with respect to a chord line of a primary blade section.

[0054] It should further be noted that at a perimeter portion of a primary blade, such as primary blade section 875A, for example, tangential velocity may comprise a relatively high value, which may bring about a relatively high value of lift generated by primary blade section 875A. Responsive to a relatively high value of lift, a relatively narrow blade (e.g., relatively small value for W_{pb2}) oriented at a relatively small pitch angle, such as approximately 14.0°, just as an example, may be capable of moving a significant volume of a compressible fluid from an upstream side of an axial fan to a downstream side, for example. Additionally, a relatively narrow section of a secondary blade, such as secondary blade section 878A, may also comprise a relatively narrow width (e.g. relatively low W_{sb2}). Further, a perimeter portion of a secondary blade, such as secondary blade section 878A, for example, may comprise a relatively lower orientation angle, such as an angle between 1.0° and 20.0° relative to a chord line primary blade section.

[0055] However, for sections of primary blade 875, which may be located closer to hub 890, such as primary blade section 875I, a tangential velocity may approach a relatively low value, which may give rise to relatively low values of lift compared to, for example, primary blade section 875A. Accordingly, as described in reference to FIG. 8B, primary blade sections located proximate with hub 890 may comprise a relatively large width and may be oriented at a relatively high pitch angle, such as approximately 37.0°, just to name an example, so as to maintain a capability to move a particular volume of a compressible fluid from an upstream side to a downstream side of an axial fan, for example. Thus, it can be appreciated that in embodiments, use of a secondary blade section, such as secondary blade section 8781, may assist in bringing about significant lift, and, consequently, significant movement of the compressible fluid. Under such circumstances, and potentially others, use of a secondary blade, as exemplified by secondary blade section 878I, may provide particular advantages in maintaining laminar flow and restricting movement of the compressible fluid from a high-pressure side (e.g., a side opposite an aerodynamic surface) of primary blade 875 to a low-pressure side (e.g., an aerodynamic surface) of primary blade 875.

[0056] It should be further noted that although the primary and secondary blades of the embodiment of FIG. 8B (embodiment 850) comprise nine primary and secondary blade sections, claimed subject matter is intended to embrace primary and secondary blades comprising any number of primary and secondary blade sections. Accordingly, claimed subject matter may embrace primary and secondary blades comprising fewer than nine sections, such as two sections, three sections, four sections, etc., as well as primary and secondary blades comprising greater than nine sections, such as 10 sections, 11 sections, and so forth, virtually without limitation.

[0057] In the present patent application, terms such as "over" and "under" are understood in a similar manner as the terms "up," "down," "top," "bottom," "upward," "downward," and so on, as previously mentioned. These terms may be used to facilitate discussion, but are not intended to necessarily restrict scope of claimed subject matter. For example, the term "over," as an example, is not meant to suggest that claim scope is limited to only situations in which an embodiment is right side up, such as in comparison with the embodiment being upside down, for example. Thus, if an object, as an example, is within applicable claim scope in a particular orientation, such as upside down, as one example, likewise, it is intended that the latter also be interpreted to be included within applicable claim scope in another orientation, such as right side up, again, as an example, and vice-versa, even if applicable literal claim language has the potential to be interpreted otherwise. Of course, again, as always has been the case in the specification of a patent application, particular context of description and/or usage provides helpful guidance regarding reasonable inferences to be drawn.

[0058] Unless otherwise indicated, in the context of the present patent application, the term "or" if used to associate a list, such as I, J, or K, is intended to mean I, J, and K, here used in the inclusive sense, as well as I, J, or K, here used in the exclusive sense. With this understanding, "and" is used in the inclusive sense and intended to mean I, J, and K; whereas "and/or" can be used in an abundance of caution to make clear that all of the foregoing meanings are intended, although such usage is not required. In addition, the term "one or more" and/or similar terms is used to describe any feature, structure, characteristic, and/or the like in the singular, "and/or" is also used to describe a plurality and/or some other combination of features, structures, characteristics, and/or the like. Likewise, the term "based on" and/or similar terms are understood as not necessarily intending to convey an exhaustive list of factors, but to allow for existence of additional factors not necessarily expressly described.

[0059] While there has been illustrated and/or described what are presently considered to be example features, it will be understood by those skilled in the relevant art that various other modifications may be made and/or equivalents may be substituted, without departing from claimed subject matter. Additionally, many modifications may be made to adapt a particular situation to teachings of claimed subject matter without departing from the central concept(s) described herein. Therefore, it is intended that claimed subject matter not be limited to particular examples disclosed, but that such claimed subject matter may also include all aspects falling within appended claims and/or equivalents thereof.

Claims

1. A fan shroud at least partially surrounding one or more blades of a fan, the fan shroud comprising:
a vortex circulation channel, formed within the fan shroud, sized to accept a tip portion of one or more blades of the fan during rotational motion of the one or more blades of the fan, the vortex circulation channel shaped to confine a vortex generated near the tip portion of the one or more blades of the fan during the rotational motion of the one or more blades of the fan.

2. The fan shroud of claim 1, wherein the vortex circulation channel comprises one or both of: (a) at least one protruding edge disposed at an upstream direction relative to a plane of the rotational motion of the one or more blades of the fan; and (b) at least one protruding edge disposed at a downstream direction from a plane of the rotational motion of the one or more blades of the fan.

3. The fan shroud of any one of the preceding claims, wherein the confined vortex of the vortex circulation channel operates (a) to avoid impeding of the generated vortex into a working area defined by the shroud and/or (b) to substantially eliminate boundary layer separation in an upstream direction or in a downstream direction relative to a plane of the rotational motion of the one or more blades of the fan.

4. The fan shroud of any one of the preceding claims, wherein the one or more blades of the fan are capable of moving a volume of a compressible fluid from an upstream side to a downstream side relative to a plane of the rotational motion of the one or more blades of the fan.

5. The fan shroud of any one of the preceding claims, wherein the vortex circulation channel comprises an at least approximately semicircular profile in an upstream direction of a plane of the rotational motion of the fan, wherein optionally the ratio between a radius of a blade of the fan to a curvature of a semicircular portion of the vortex

circulation channel comprises a value of between 10.0:1.0 and 100.0:1.0.

6. The fan shroud of any one of the preceding claims, wherein the vortex circulation channel comprises an at least approximately semicircular profile in a downstream direction of a plane of the rotational motion of the fan.

7. The fan shroud of any one of the preceding claims, wherein the shroud comprises a wraparound forward edge, the wraparound forward comprising a radius of curvature of between about 2.0% and 5.0% of the radius of an area of an upstream side of the one or more blades of the fan.

8. A fan shroud and blade assembly, comprising:

one or more blades to move rotationally in a plane; and
a shroud, at least partially enclosing the one or more blades of the fan, the shroud comprising a vortex circulation channel formed on and sized to accept a tip portion of at least one of the one or more blades during rotational motion of the one or more blades of the fan, the vortex circulation channel to form a confined vortex at least partially in response to movement of the tip portion of the at least one of the one or more blades, and at least partially in response to a spacing between the tip portion of at least one of the one or more blades and the fan shroud.

9. The fan shroud and blade assembly of claim 8, wherein the shroud operates to direct a flow of a compressible fluid through the one or more blades, and wherein the confined vortex is formed from the compressible fluid during the rotational motion of the one or more blades.

10. The fan shroud and blade assembly of claim 8 or 9, wherein the vortex circulation channel additionally comprises at least one protruding edge disposed in an upstream direction relative to a plane of the rotational motion of the one or more blades, wherein optionally the vortex circulation channel additionally comprises at least one protruding edge disposed in a downstream direction from the plane of rotational motion of the one or more blades.

11. The fan shroud and blade assembly of any one of claims 8 to 10, wherein the confined vortex of the vortex circulation channel operates to substantially eliminate boundary layer separation in an upstream direction or in a downstream direction, relative to the one or more blades, during rotational motion of the one or more blades.

12. The fan shroud and blade assembly of any one of claims 8 to 11, wherein at least a portion of the vortex circulation channel comprises an approximately semicircular profile having a radius of curvature of between 1/10 and 1/100 of the radius of the one or more blades.

13. A system to move a volume of a compressible fluid, comprising:

a shroud to substantially surround one or more blades of a fan; and
a vortex circulation channel formed within the shroud to accept a portion of at least one of the one or more blades of the fan during rotational motion of one or more blades of the fan, the vortex circulation channel to form a vortex to circulate a portion of the compressible fluid, the vortex to avoid interference with a working area defined by the shroud.

14. The system of claim 13, wherein the vortex circulation channel is formed within the shroud and sized to accept a portion of all of the blades of the fan during rotational motion of the blades of the fan.

15. The system of claim 13 or 14, wherein the vortex circulation channel comprises a first approximately semicircular-shaped region at an upstream side of the blades of the fan and a second semicircular-shaped region at a downstream side of the blades of the fan, wherein optionally one or more of the first approximately semicircular-shaped region and the second semicircular-shaped region comprises a profile having a radius of curvature of between 1/10 and 1/100 of the at least one of the one or more blades of the fan.

150

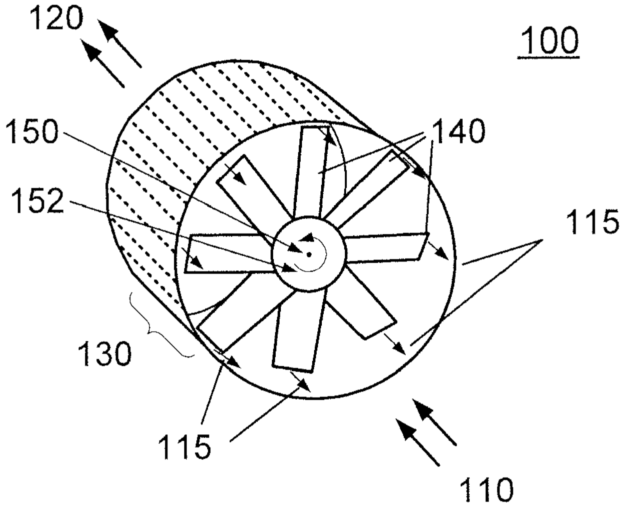

FIG. 1

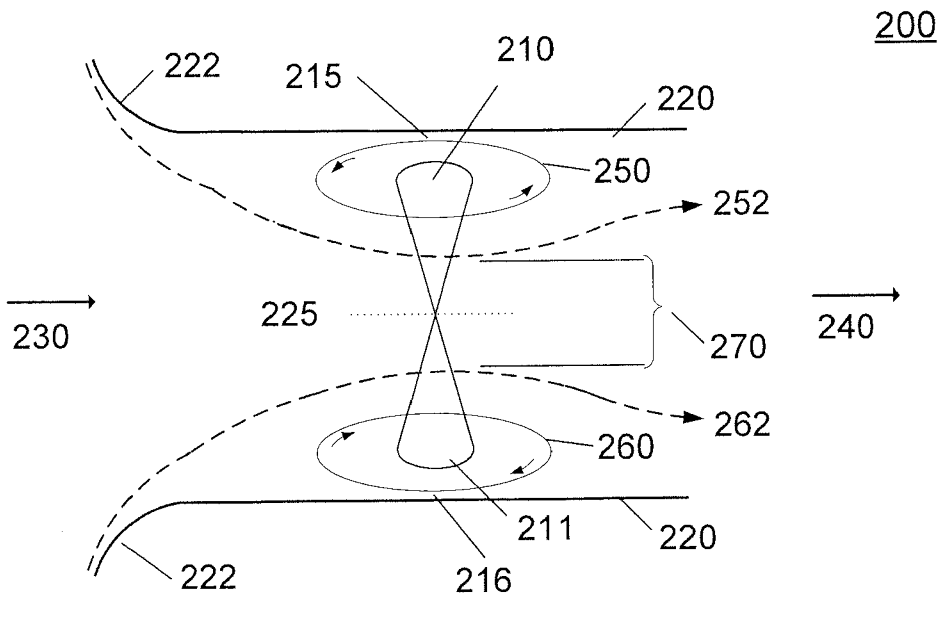

FIG. 2

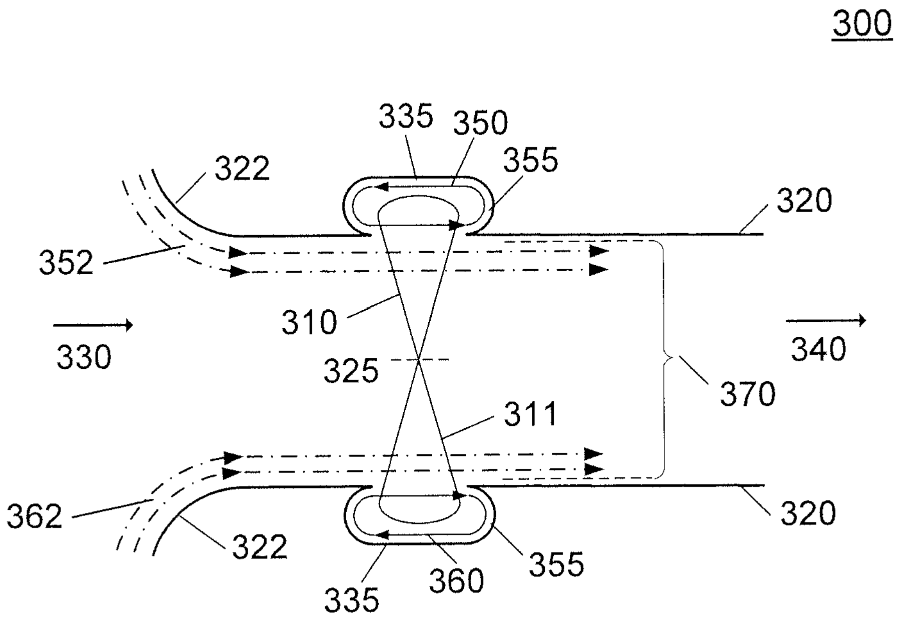
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FIG. 3

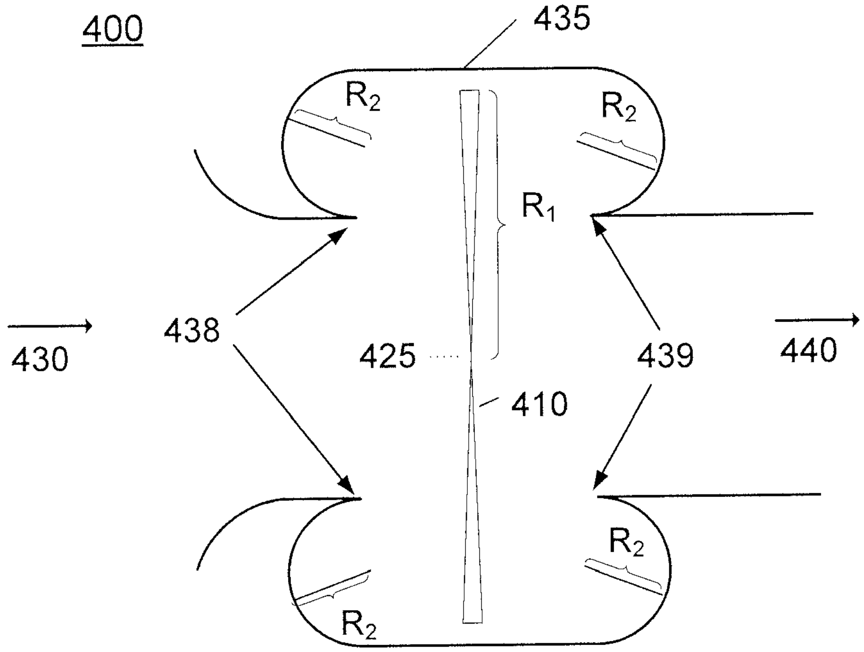
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FIG. 4

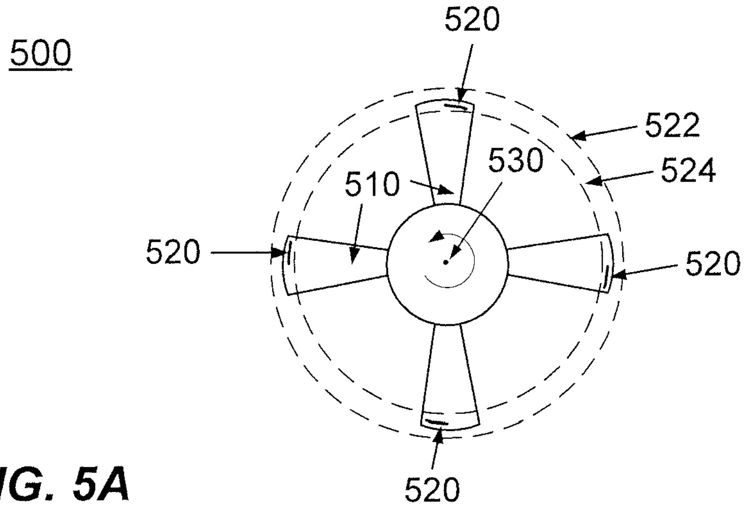

FIG. 5A

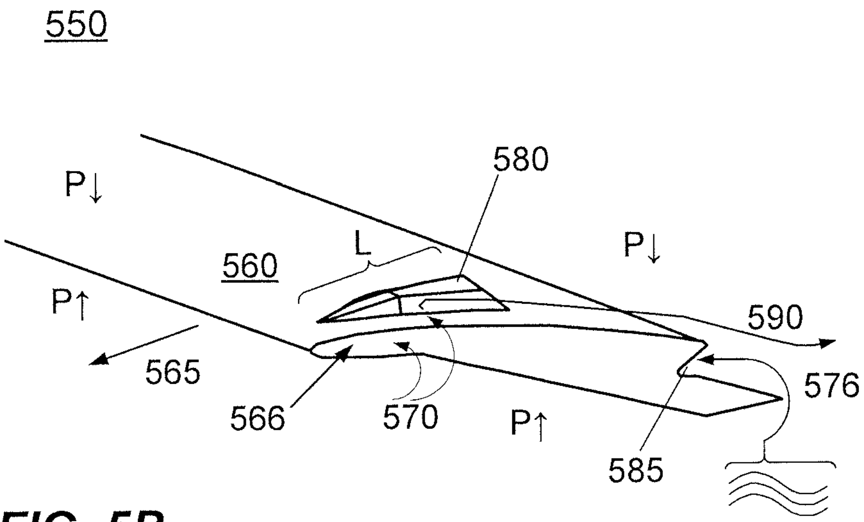

FIG. 5B

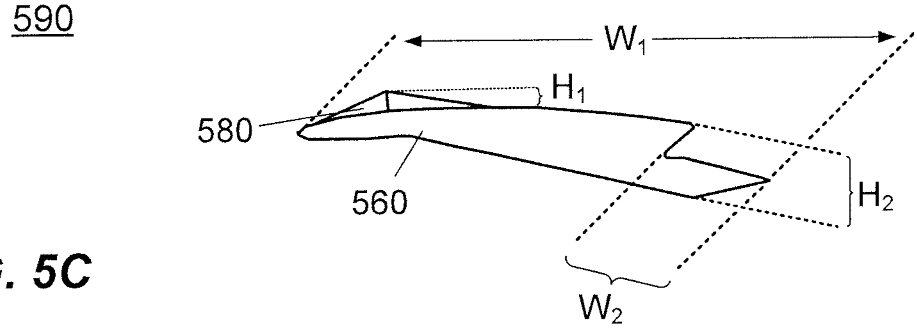

FIG. 5C

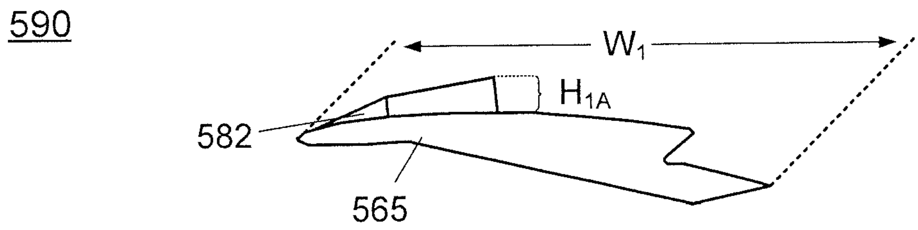

FIG. 5D

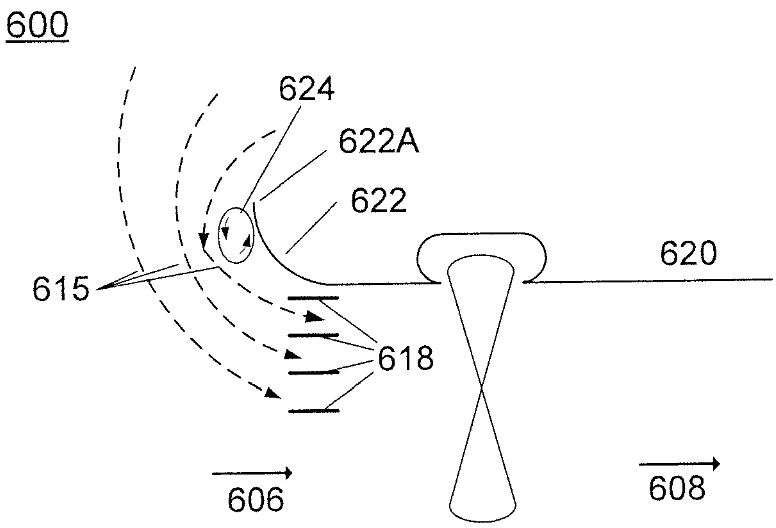

FIG. 6A

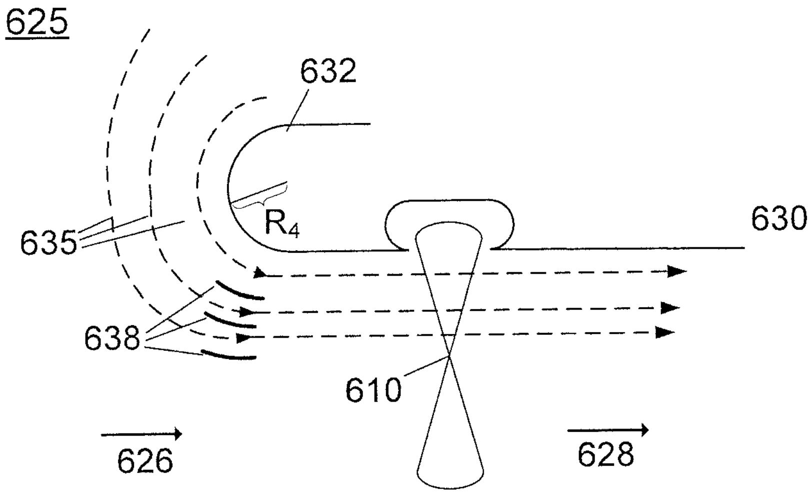

FIG. 6B

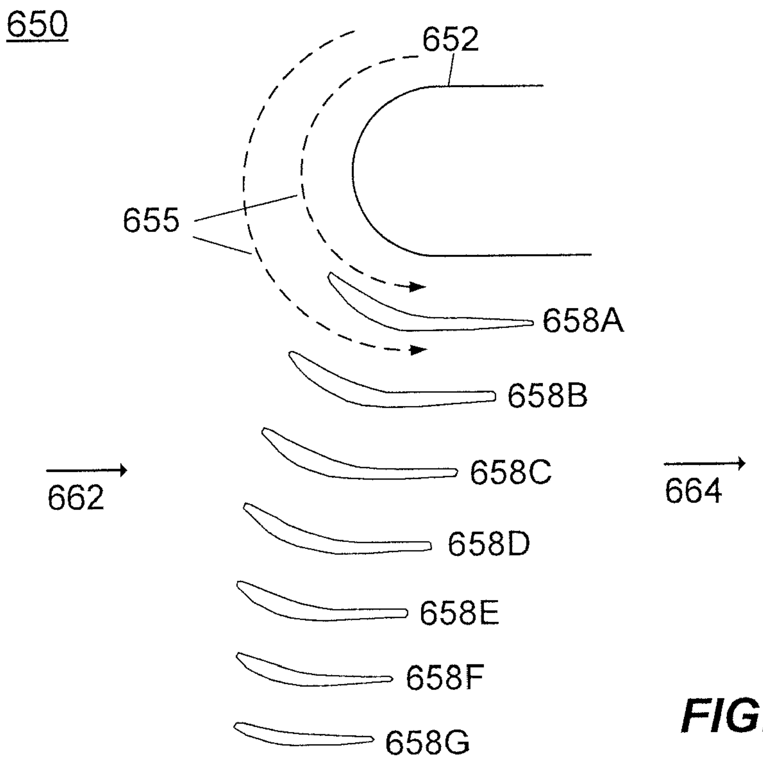
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FIG. 6C

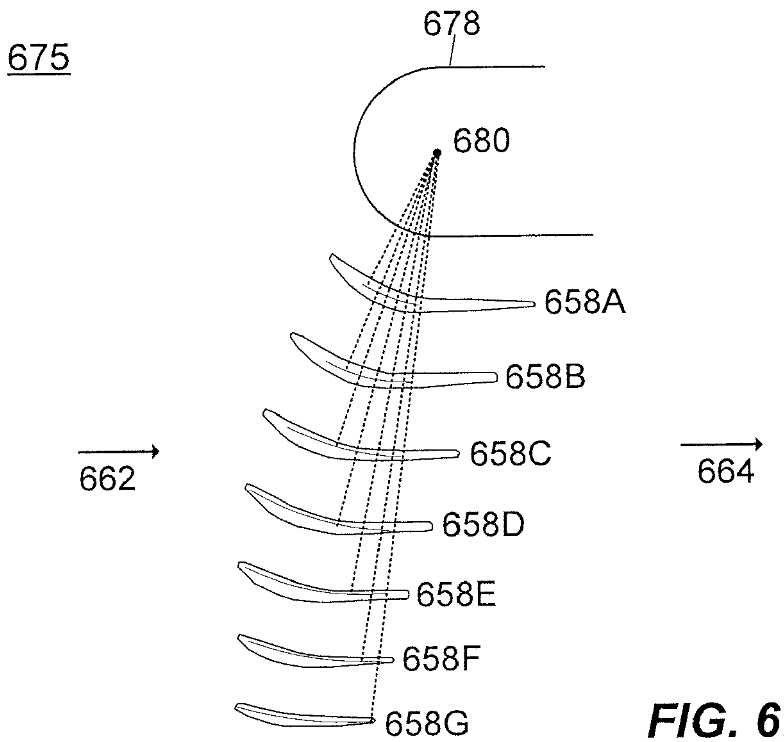
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FIG. 6D

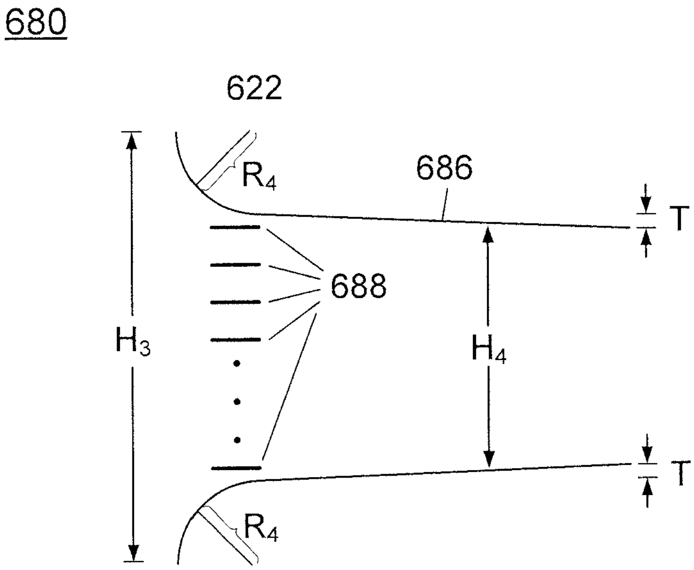

FIG. 6E

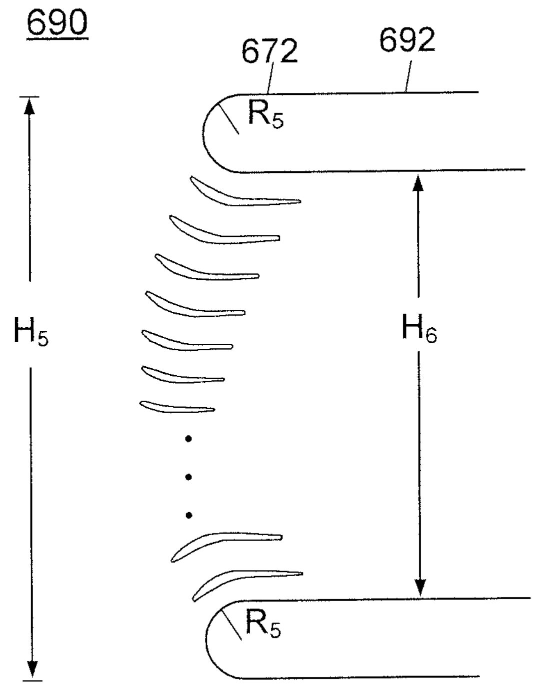

FIG. 6F

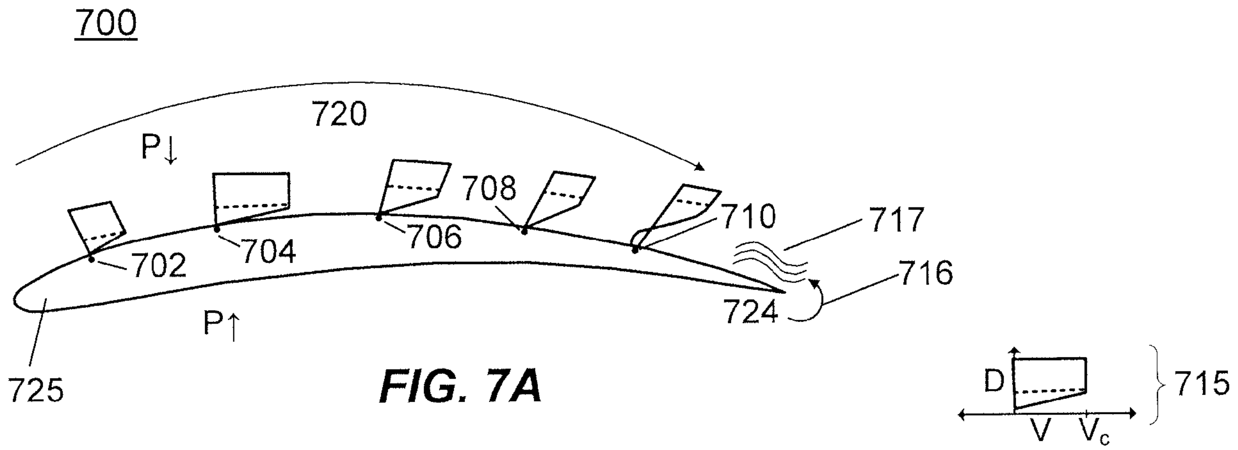

FIG. 7A

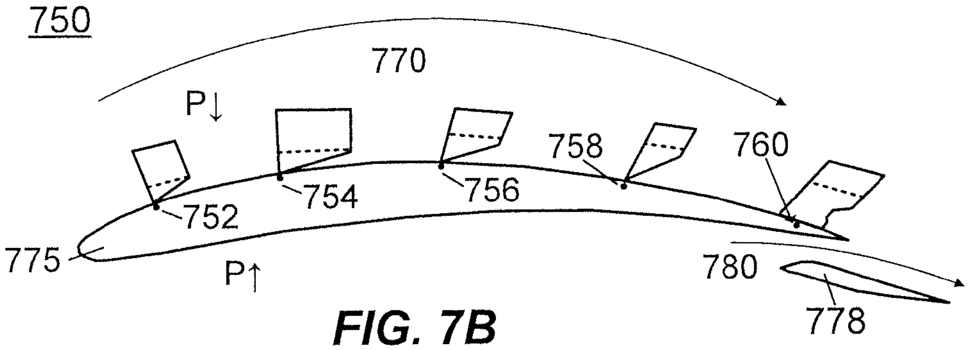

FIG. 7B

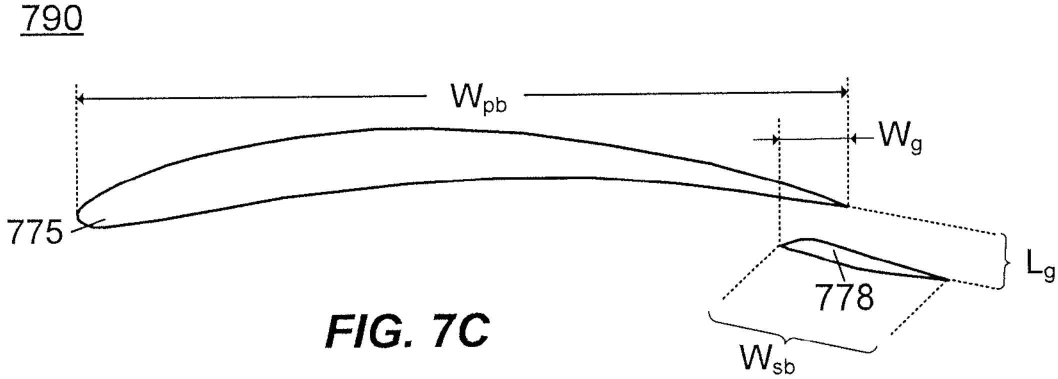

FIG. 7C

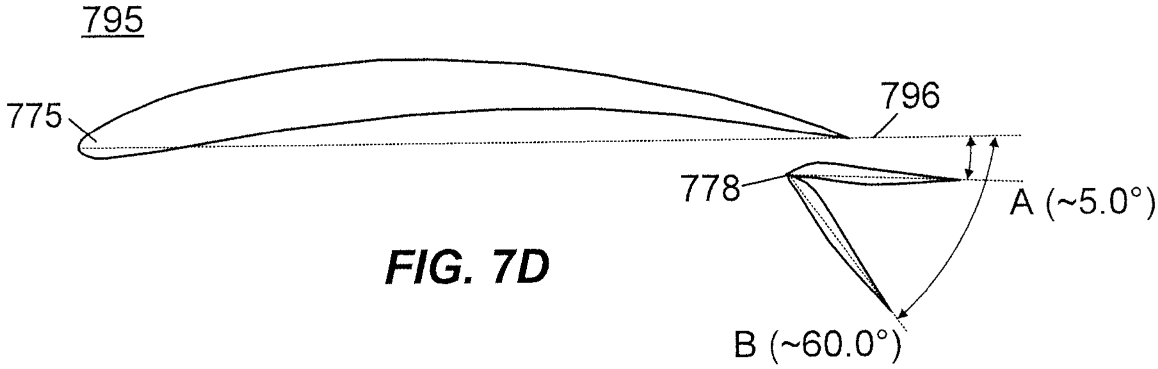

FIG. 7D

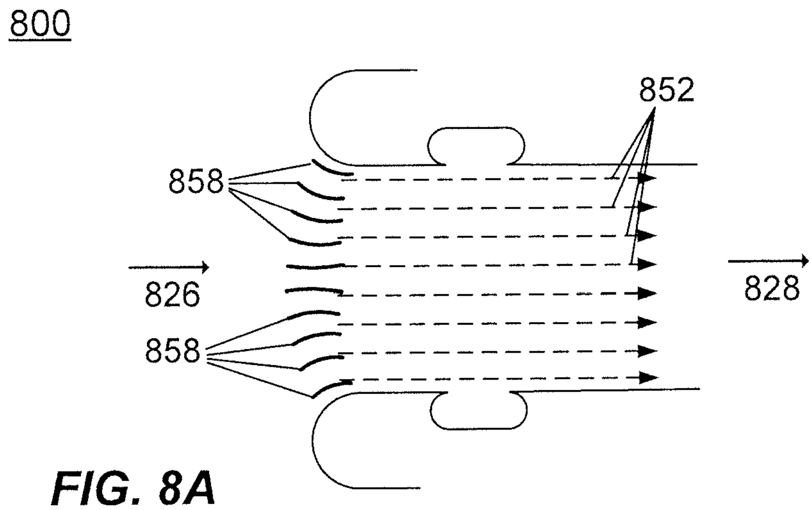

FIG. 8A

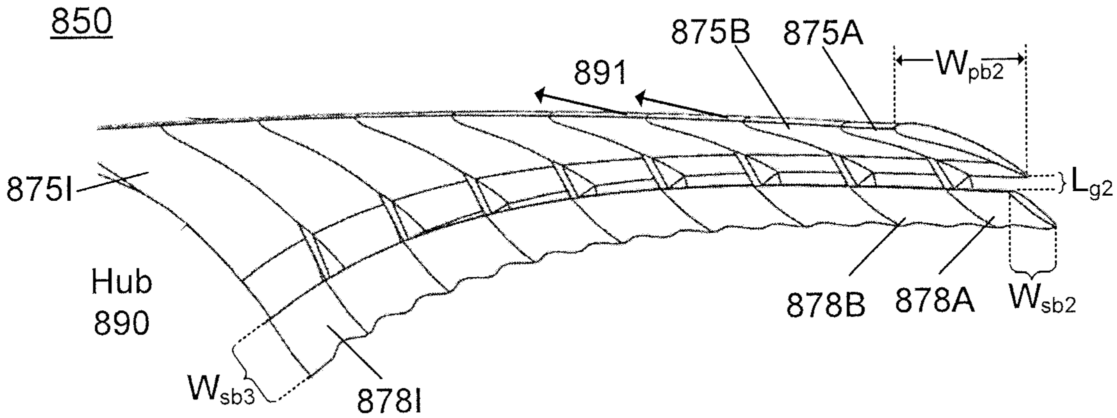

FIG. 8B

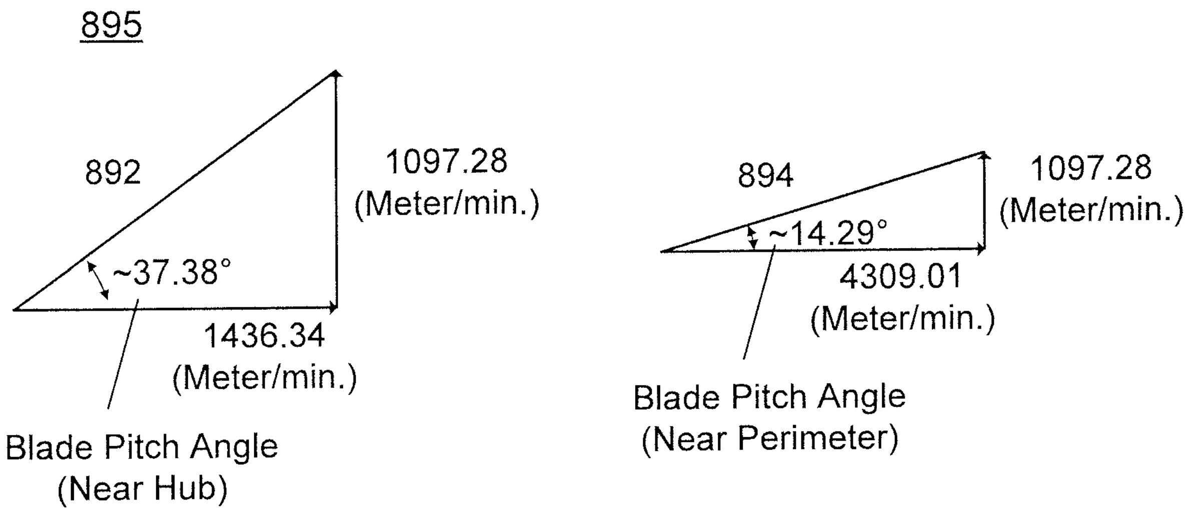

FIG. 8C

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EUROPEAN SEARCH REPORT

Application Number
EP 18 16 9577

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	US 2003/235495 A1 (RIVERS JOHN F [US]) 25 December 2003 (2003-12-25) * paragraphs [0004], [0027] - [0029], [0031] * * figures 2,3,5d *	1-15	INV. F04D19/00 F04D29/16 F04D29/52
X	FR 2 728 028 A1 (SARDOU MAX [FR]) 14 June 1996 (1996-06-14) * page 1, line 27 - page 2, line 3 * * figures 1,2,6-7c *	1-15	
X	DE 42 20 961 A1 (TURBOWERKE MEISEN VENTILATOREN [DE]) 5 January 1994 (1994-01-05) * column 1, lines 3-13 * * column 1, lines 36-56 * * column 3, lines 4-58 * * figures 1-4 *	1-4, 7-11,13, 14	
X	US 2007/231128 A1 (CALLAS JAMES J [US]) 4 October 2007 (2007-10-04) * paragraphs [0019] - [0021] * * figures 2,3 *	1-4, 8-11,13, 14	TECHNICAL FIELDS SEARCHED (IPC) F04D

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
The Hague	14 August 2018	Gombert, Ralf

CATEGORY OF CITED DOCUMENTS

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14-08-2018

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82