DOUBLE-DUCTED FAN

CROSS-RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application No. 61/311,672 filed on March 8, 2010, which is incorporated herein by reference in its entirety.

FEDERALLY SPONSORED RESEARCH

[0002] The subject matter disclosed herein was developed with government support under grant no. W911W6-06-2-0008 awarded by the U.S. Army Research Office. The U.S. government has certain rights in the invention.

FIELD OF TECHNOLOGY

[0003] The present disclosure relates ducted fans. More specifically, the present disclosure relates to ducted fans for axial-flow rotors.

BACKGROUND

[0004] Axial-flowfan units include rotating, airfoil-based rotor blades in which the working fluid (e.g., air or other gas) principally flows parallel to the axis of rotation. Axial-flow rotor units are widely used in turbomachinery, such as jet engines, high-speed ship engines, and small-scale power stations. They are also used in industrial applications such as large-volume air separation plants, supplying blast furnace air or fluid catalytic cracking air, and propane dehydrogenation. Additionally, axial-flow rotor units can be used in cooling fans for homes, automobiles, locomotive vehicles, buses, marine vehicles, and aircrafts such as vertical and short take-off and landing (VSTOL) vehicles and uninhabited aerial vehicles.

[0005] In some situations, there can be inlet flow distortion at the inlet of the axial-flow rotor. For example, inlet flow distortion can occur when the inlet flow direction is not well aligned with the axis of rotation of the axial-flow rotor system. Conventional axial-flow ducted fan rotors are often used in VSTOL vehicles to generate the lift force required for hover-type flight. For example, the axial-flow ducted fan rotor can generate a downward-facing force required for hover-type flight. As shown in FIGS. 1A-1C, a conventional ducted fan 1000 includes a hub 100 having a front portion 101 and an end portion 115, a rotor 105 having a plurality of blades 107 rotatably coupled to the front portion 101 of the hub 100, and a duct 110 surrounding the blades 107 of the rotor 105. In the particular embodiment illustrated, the duct 110 is a cylindrical structure that surrounds the blades 107 of the rotor 105. The duct 110 is coupled to the hub 100 by a plurality of outlet vanes 109. In between the front portion 101 of the hub 100 and the duct 110 is the rotor inlet 125. The rotor inlet 125 includes an inlet lip 119 proximate to the leading edge of the duct 110. The illustrated conventional ducted fan has a single duct. During horizontal flight, cross-wise air flow encounters the outer surface of the duct 110. The cross-wise air flow separates between the top and the bottom of the -duct 110. The air-flow that travels across the leading edge of the duct 110 and past the inlet lip 119 enters the rotor inlet 125. However, as a result of the configuration of the conventional ducted fan, as air-flow enters the rotor inlet 125, there is flow distortion at the inlet lip 119 of the duct 110. This distortion will be referred to herein as inlet-flow separation. The cross-wise air-flow is moved and forced through the rotor inlet 125 by the rotating blades 107 of the rotor 105. The air-flow exits the rotor at the outlet beneath the outlet vanes 109.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] Various embodiments will now be described, by way of example only, with reference to the attached Figures, wherein:

[0007] FIG. 1A is a perspective view of a conventional ducted fan;

[0008] FIG. 1B is front of the conventional ducted fan illustrated in FIG. 1A;

[0009] FIG. 1C is a vertical cross-section view, taken along lines A-A, of the conventional ducted fan illustrated in FIG. 1A;

[0010] FIG. 2A is a perspective view of an exemplary double-ducted fan in accordance with the technology that is the subject matter of this disclosure;

[0011] FIG. 2B is a front view of the double-ducted fan illustrated in FIG. 2A;

[0012] FIG. 2C is a vertical cross-section view, taken along lines A-A, of the double-ducted fan illustrated in FIG. 2A;

[0013] FIG. 3A is a perspective view of another embodiment of a double-ducted fan in accordance with the technology that is the subject matter of this disclosure, which has a second duct that is shorter than the first duct;

[0014] FIG. 3B is a front view of the double-ducted fan illustrated in FIG. 3A;

[0015] FIG. 3C is a vertical cross-section view, taken along lines A-A, of the double-ducted fan illustrated in FIG. 3A;

[0016] FIG. 4A is a perspective view of another embodiment of a double-ducted fan in accordance with the technology that is the subject matter of this disclosure, which has eccentrically oriented ducts;

[0017] FIG. 4B is a front view of the double-ducted fan illustrated in FIG. 4A;

[0018] FIG. 4C is a vertical cross-section view, taken along lines A-A, of the double-ducted fan illustrated in FIG. 4A; and

[0019] FIG. 5 is a schematic partial cross-section view of the exemplary double-ducted fan illustrated in FIG. 2A illustrating the flow of air across the double-ducted fan.

[0020] FIG. 6A is a perspective view of an exemplary double-ducted fan, which has a second duct that is a partial duct;

[0021] FIG. 6B is a front view of the double-ducted fan illustrated in FIG. 6A;

[0022] FIG. 6C is a vertical cross-section view, taken along lines A-A, of the double-ducted fan illustrated in FIG. 6A;

[0023] FIG. 7A is a perspective view of an exemplary double-ducted fan in a wing, which has a second duct that is a partially integrated duct;

[0024] FIG. 7B is a side view of the double-ducted fan in a wing illustrated in FIG. 7A;

[0025] FIG. 7C is a front view of the double-ducted fan in a wing illustrated in FIG. 7A; and

[0026] FIG. 7D is a vertical cross-section view, taken along lines A-A, of the double-ducted fan in a wing illustrated in FIG. 7A.

DETAILED DESCRIPTION

[0027] It will be appreciated that for simplicity and clarity of illustration, where appropriate, reference numerals have been repeated among the different figures to indicate corresponding or analogous elements. In addition, numerous specific details are set forth in order to provide a thorough understanding of the embodiments described herein. However, it will be understood by those of ordinary skill in the art that the embodiments described herein can be practiced without these specific details. In other instances, methods, procedures and components have not been described in detail so as not to obscure the related relevant feature being described. Also, the description is not to be considered as limiting the scope of the embodiments described herein.

[0028] In VSTOL vehicles having ducted fan systems, such as the one illustrated in FIG. 1, can be adapted to horizontally move at a 90 degree angle of attack. During horizontal flight, the inlet flow direction can deviate from the axis of the rotation. The inlet flow distortion near the leading side of the ducted fan inlets can become more problematic with increasing vehicle speed. The inlet flow distortion passing through a typical axial flow fan rotor becomes increasingly damaging with elevated forward flight velocity. The inlet flow distortion occurring on the inner side of the lip section, also called lip separation, can limit the lift generation and controllability of the VSTOL. In general, the leading side of the rotor fan near the lip separation zone can breathe poorly when compared to the trailing side of the ducted fan. The trailing side total pressure can be higher than the total pressure observed near the leading side at the exit of the rotor. The flow near the leading side can be negatively influenced by a separated flow zone that is characterized as re-circulatory, low momentum and turbulent. Vibratory loads because of this separated flow zone can be excessive.

[0029] Conventional ducted fan systems also have a tip clearance loss that is proportional with the effective tip gap of the ducted fan design. The specific shape of the tip platform and the surface properties and arrangement designed onto the casing surface can influence the magnitude of tip clearance loss. This aerodynamic deficiency is measured as a significant total pressure loss near the tip at the exit of the rotor all around the circumference when the VSTOL is hovering with no horizontal flight. When the VSTOL transitions into a horizontal flight zone (for example, forward flight), the total pressure loss/deficit at the exit of the rotor near the leading side can be more significant than pressure loss during hovering. In addition to the conventional tip clearance energy loss, the rotor can generate additional losses near the leading side, because of the re-circulatory low momentum fluid entering into the rotor near the tip section. The inlet flow distortion entering into an axial fan rotor in horizontal flight can result in the loss of rotor's energy addition capability to the fluid near the leading side, an imbalance of the local mass flow rates between the leading side and trailing side, an imbalance of the total pressure resulting at the rotor exit between the leading side and trailing side, a significant loss of lifting ability due to highly non-axisymmetric and unnecessarily 3D fan exit jet flow, and unwanted nose-up pitching moment generation, which can each result from the local static distributions imposed on the duct inner surfaces.

[0030] Additionally, when a VSTOL ducted fan is in horizontal flight, because of the relative inlet flow dominantly parallel to its inlet plane, problems related to flow separation at the leading edge duct lip can be encountered. The inlet flow separation can lead to problems within the duct and may well result in a high nose-up pitching moment as the forward speed is increased. Furthermore, at high angle of attacks, the onset flow separation at the upstream duct lip can distort inlet air flow into the fan rotor. The distorted inlet flow can case an asymmetric loading of the ducted fan, which can increase the power required for un-accelerated flight, vibratory loads and noise level. Even more, fuel consumption can increase due to the distorted inlet flow. Also, the distorted inlet flow can cause non-uniformity of air flow through the rotor fan, which can complicate control of the vehicle.

[0031] The present disclosure presents a double ducted fan based on a fluid mechanics scheme of reducing and controlling the upstream lip separation of a ducted fan. For example, the double ducted fan can effectively reduce and control the upstream lip separation of a ducted fan operating at a high angle of attack during forward or horizontal flight.

[0032] A double-ducted fan according to the present technology includes a hub, a rotor fan rotatably coupled to the hub, a first duct, and a second duct, wherein the first duct circumscribes the rotor fan and the second duct circumscribes at least a portion of the first duct. The rotor fan has an inlet side and an outlet side. A channel is defined between the first duct and the second duct and is configured to direct air-flow cross-wise to the first duct, over a top of the first duct, into the inlet side of the rotor fan. The second duct is axially oriented upward from the first duct such that there is an axial distance between a leading edge of the first duct and a leading edge of the second duct. In one embodiment the second duct is oriented at an angle with respect to the first duct. In another embodiment, the first duct and the second duct are concentrically oriented. In another embodiment, the first duct and the second duct are eccentrically oriented. In at least one embodiment, the first duct is the inner or intermediate duct, and the second duct is the outer duct. The orientation and configuration of the first duct and second duct of the double-ducted fan reduces and controls the upstream lip separation during operation at high angles of attack. Also, with the double ducted fan disclosed herein, the lip separation near the leading side of the first duct can be significantly eliminated, thereby resulting in an enhanced balanced rotor exit flow filed between the leading side and the trailing side of the double ducted fan. It will be appreciated that other configurations and arrangements will be described below in relation to illustrated embodiments. One of ordinary skill will appreciate that the elements from the illustrated embodiments can be optionally included and arranged in various combinations to achieve the described benefits of the presently disclosed double-ducted fan.

[0033] As shown in FIGS. 2A-2C, the double-ducted fan 2000 includes a hub 200 having a front portion 201 and an end portion 215. The end portion 215 of the hub can be the tail cone. A motor and electrical wiring for the double-ducted fan 2000 can be housed in the hub 200 and covered by the tail cone. While the illustrated hub 200 is an elongated structure, one of ordinary skill in the art will appreciate that the hub 200 can be a rotor hub, a rectangular structure, an elliptical structure, a conical structure, or any other aerodynamic structure than can be coupled with a rotor fan 205 and implemented in an axial-flow system.

[0034] A rotor fan 205 having a plurality of blades 207 is rotatably coupled to the front portion 201 of the hub 200. The rotor fan 205 has an inlet side 225 and an outlet or exit side. The double-ducted fan 2000 has a first duct 210 and a second duct 220. In the particular embodiment illustrated, the first duct 210 and the second duct 220 are cylindrical structures. The first duct circumscribes the rotor fan 205. In other words, the first duct 210 is coupled to the rotor 200 such that the first duct 210 surrounds the rotor 205 and is radially spaced from the hub 200. As seen in the illustrated embodiment, the first duct 210 is coupled to the hub 200 at the trailing edge 217 of the first duct 210 by a plurality of outlet vanes 209. The first duct 210 has a leading edge 213, a trailing edge 217, and a first length 255 between the leading edge 213 and the trailing edge 217. An inlet 225 is formed between the first duct 210 and the rotor 200 on an inlet side of the rotor fan 205. Air-flow can enter the rotor fan 205 and pass through the rotor blades 207 to the outlet or exit side of the rotor 205. For example, air can pass from the inlet 225 to the outlet of the rotor fan 205 when the double-ducted fan 2000 is in operation during horizontal motion and while the rotational axis of 205 is oriented at a 90 degree angle of attack with respect to the ground. The inlet 225 includes an inlet lip 219 proximate to the leading edge 213 of the first duct 210.

[0035] A second duct 220 circumscribes the first duct 210 and can be radially spaced from the first duct 210. The second duct 220 is held in plane by a plurality of struts (not shown) radially attached to the first duct 210. The second duct 220 is coupled to the first duct such that the rotor 205 is at the center of the double-ducted fan 2000. In the illustrated embodiment, the first duct 210 and the second duct 220 are concentric. In at least one embodiment, the second duct 220 is stationary with respect to the first duct 210. As shown in FIG. 2C, the second duct 220 has a leading edge 245, a trailing edge 240, and a second length 250 between the leading edge 245 and the trailing edge 240. For example, in the illustrated embodiment, the second duct 220 has a second length 250 greater than the first length 255 of the first duct 210. In other words, the second duct 220 is longer in length than the first duct 210. Also, as seen in FIG. 2C, the leading edge 245 of the second duct 220 can have a duct lip 247 or an outer lip. Additionally, the leading edge 213 of the first duct 210 has an inlet lip 219.

[0036] The second duct 220 can be oriented axially-upward with respect to the leading edge 213 of first duct 210 as illustrated in FIG. 2C. For example, the second duct 220 can be oriented such that the leading edge 245 of the second duct 220 is oriented axially-upward from the leading edge 213 of the first duct 210. In other words, the leading edge 245 of the second duct 220 is located forward and upward from the leading edge 213 of the first duct 210. As illustrated in FIG. 2C, the second duct 220 has a second length 250 longer than the first length 255 of the first duct 210. The trailing edge 250 of the second duct 220 and the trailing edge 217 of the first duct 210 are axially aligned so that there is an axial distance 260 between the leading edge 245 of the second duct and the leading edge 213 of the first duct 210. A channel 230 is formed between the first duct 210 and the second duct 220. The channel 230 can be a converging-diverging channel. For example, the width 275 of the channel 230 can vary from the trailing edges 217, 240 of the first and second ducts 210 and 220,to the leading edges 213, 245 of the first and second duct 210, 220 (e.g., the width 275 can increase or decrease). As the first duct 210 and the second duct 220 are concentric, the shape of the converging-diverging channel 230 does not vary circumferentially around the rotor 200. Also as shown in FIG. 2C, the first duct 210 and the second duct 220 have an airfoil shape. However, in alternative embodiments, the first duct 210 and the second duct 220 can have a circular shape, a cylindrical shape, an oval shape, or any other shape that permits air flow into the inlet 225 of the rotor 205.

[0037] In the embodiment illustrated in FIGS. 2A-2C, during horizontal flight, cross-wise air-flow will encounter the second duct 220 (e.g. air-flow will move from the left to the right in FIG. 2C). As the cross-wise air-flow encounters the duct lip 247, a portion of the air-flow will travel upwards towards the leading edge 245 of the second duct 220, and a portion of the air-flow will travel downwards towards the trailing edge 240 of the second duct 220. The air-flow that travels across the leading edge 245 will flow across the leading edge 213 of the first duct 210, over the inlet lip 219, and into the rotor inlet 225. The air-flow that travels towards the trailing edge 240 of the second duct 220 will travel upwards through the channel 230, over the leading edge 213 of the first duct 210 and the inlet lip 219, and into the rotor inlet 225. The upward air travel in channel 230 is local near the inlet lip separation zone of the system. Because the air-flow encounters the second duct 220 first during horizontal flight, the air-flow is separated at the second duct 220 before it encounters the inlet lip 219 of the first duct 210. Thus, the air-flow entering the rotor inlet 225 is substantially uniform, and the inlet separation that would typically occur in conventional ducted fans is reduced. As a more uniform air-flow profile enters the rotor inlet 225, more uniform air-flow exits the rotor 205, thereby reducing energy loss, total pressure imbalance, and mass-flow rate imbalance that can be associated with air-flow distortion. Also, with the double-ducted fan 2000 having a second duct 210 that is longer than the first duct 210 can provide for a higher duct thrust in the hover position or hovering flight of the vehicle as compared to conventional single-ducted fans. The double ducted fan 2000 having a second duct 210 that is longer than the first duct 210 may generate a slightly elevated level of pitch-up moment that may force the leading side of the vehicle up in horizontal flight. Although the pitch-up moment effect for 2000 is slightly exaggerated when compared to prior art 1000, the vertical lift improvement of the double ducted fan 2000 is highly effective.

[0038] As shown in FIGS. 3A-3C, another embodiment of the double-ducted fan 3000 includes a hub 300 having a front portion 301 and an end portion 315. A rotor fan 305 having a plurality of blades 307 is rotatably coupled to the front portion 301 of the hub 300. A first duct

310 is coupled to the rotor 300 such that the first duct 310 surrounds the rotor 305 and is radially spaced from the hub 300. The first duct 310 has a leading edge 313, a trailing edge 317, and a first length 355 between the leading edge 313 and the trailing edge 317. As seen in the illustrated embodiment, the first duct 310 is coupled to the hub 300 at the trailing edge 317 of the first duct 310 by a plurality of outlet vanes 309. An inlet 325 is formed between the first duct 310 and the rotor 300 through which air-flow can pass when the double-ducted fan 3000 is in operation during horizontal motion and while the rotational axis of the rotor fan 305 oriented at a 90 degree angle of attack with respect to the ground. The inlet 325 includes an inlet lip 319 proximate to the leading edge 313 of the first duct 310.

[0039] A second duct 320 is radially spaced from the first duct. The second duct 320 is held in place by a plurality of struts (not shown) radially attached to the first duct 310. The second duct 320 is coupled to the first duct such that the rotor 305 is at the center of the double-ducted fan 3000. In the illustrated embodiment, the first duct 310 and the second duct 320 are concentric with the second duct 320 is stationary with respect to the first duct 310. In the illustrated embodiment, the first duct 310 and the second duct 320 are axisymmetric structures; however, one of ordinary skill in the art will appreciate that the first duct 310 and second duct 320 can be any structure that permit axial air-flow into the inlet 325 of the rotor fan 305.

[0040] As shown in FIG. 3C, the second duct 320 has a leading edge 345, a trailing edge 340, and a second length 350 between the leading edge 345 and the trailing edge 340. For example, in the illustrated embodiment, the second duct 320 has a second length 350 so that the second duct 320 is shorter than the first duct 310. In comparison to the embodiment shown in FIGS. 2A-2C, the embodiment illustrated in FIGS. 3A-3C has a second duct 320 that is shorter than the first duct 310.

[0041] As illustrated in FIG. 3C, the second duct 320 is oriented axially-upward with respect to the first duct 310. For example, the second duct 320 is oriented such that the leading edge 335 of the second duct 320 is oriented axially-upward from the leading edge 313 of the first duct 310. In other words, the leading edge 345 of the second duct 320 is located forward and upward from the leading edge 313 of the first duct 310. Additionally, the trailing edge 340 of the second duct 320 and the trailing edge 317 of the first duct 310 are axially aligned so that there is an axial distance 360 between the leading edge 345 of the second duct and the leading edge 313 of the first duct 310. A channel 330 is formed between the first duct 310 and the second duct 320. As illustrated in FIG. 3C, the channel 330 can be a converging-diverging channel. For example, the width 375 of the channel 330 can vary from between the trailing edges 317, 340 of the first and second ducts 310, 320 to the leading edges 313, 345 of the first and second duct 310, 320 (e.g., the width 375 can increase or decrease). As the first duct 310 and the second duct 320 are axisymmetric, the converging-diverging channel width 330 does not vary circumferentially around the rotor 300. Also as shown in FIG. 3C, the first duct 310 and the second duct 320 have an airfoil shape. However, in alternative embodiments, the first duct 310 and the second duct 320 can have a cylindrical shape, an oval shape, a wing or any other shape that permits axial air flow into the inlet 325 of the rotor 305. In all of these arrangements it is essential that air flow enters into the second channel 330 near the trailing edge 340 of the second duct. This air flow entering near the trailing edge 340 is in opposite direction to that of the first duct 310 especially near the leading side of the vehicle in horizontal flight.

[0042] Similar to the embodiment illustrated in FIGS. 2A-2C, for the embodiment illustrated in FIGS. 3A-3C, during horizontal flight, cross-wise air-flow will encounter the second duct 320 before it encounters the leading edge 313 of the first duct 310 (e.g., air-flow will move from the left to the right in FIG. 3C). As the cross-wise air-flow encounters the duct lip 347, a portion of the air-flow will travel upwards towards the leading edge 345 of the second duct 320, and a portion of the air-flow will travel downwards towards the trailing edge 340 of the second duct 320. The air-flow that travels across the leading edge 345 will flow across the leading edge 313 of the first duct 310, over the inlet lip 319, and into the rotor inlet 325. The air-flow that travels towards the trailing edge 340 of the second duct 320 will travel upwards through the channel 330, over the leading edge 313 of the first duct 310 and the inlet lip 319, and into the rotor inlet 325. Compared to the embodiment illustrated in FIG. 2C, as a result of the shorter second duct 320, the air-flow at the trailing edge 340 is further directed upward into the channel 330 by the trailing edge 317 of the first duct 310. Because the air-flow encounters the second duct 320 first during horizontal flight, the air-flow is separated at the second duct 320 before it encounters the inlet lip 319 of the first duct 310. The upward air flow in the converging diverging channel 330 adjusts the static pressure distribution near the leading edge 313 of the first duct and inlet lip 319 of the first duct. This static pressure adjustment that is unique double ducted fan concept described in this document generates an effective flow/circulation control effect near the inlet lip 319 of the first duct. The circulation control effect near inlet lip 319 of the first duct 310 effectively eliminates inlet lip separation of the flow directed into the rotor inlet 325. Thus, the air-flow entering the rotor inlet 325 is substantially uniform, and the inlet separation that would typically occur in conventional ducted fans is reduced. As a more uniform air-flow profile enters the rotor inlet 325, more uniform air-flow exits the rotor 305, thereby reducing energy loss, total pressure imbalance, and mass-flow rate imbalance that can be associated with air-flow distortion. Additionally, the double ducted fan 3000 having a second duct 320 shorter than the first duct 310, the thrust generated by the double ducted fan can be increased and enhanced as compared to conventional single-ducted fans. Furthermore, with the embodiment illustrated in FIGS. 3A-3C, the VSTOL can operate in a horizontal flight without enhancing the nose-up pitching moment of the vehicle. In other words, the illustrated embodiment enhances thrust and reduces nose-up pitching moment in forward flight without substantial drag loss as compared to conventional ducted fans. There is also an additional benefit of reducing flow induced vibrations originating near the inlet lip section 319 of the first duct 310 because the double ducted fan effectively eliminates inlet lip separation driven recirculatory flow at downstream of inlet lip 319 of the first duct 310.

[0043]

[0044] In at least one embodiment, for example, FIGS. 3A-3C, the size of the leading edge 313 of the first duct 310 can be used as the basis of the arrangement of the second duct 320 with respect to the first duct 310. For example, the diameter of the leading edge 313 of the first duct 310 can be the parameter that is used as the basis for determining the arraignment of the second duct 320 with respect to the first duct 310. For example in FIGS.3A-3C, the second duct 320 can be an airfoil that is relatively cambered. The second duct 320 can also have a leading edge that is set to two-thirds the diameter of the leading edge 313 of the first duct 310. The angular orientation and the axial position of the second duct 320 can provide the control and enhancement of flow near the leading side of the rotor 305. The leading edge 345 of the second duct 320 can be shifted upwardly in the vertical direction with respect to the leading edge 313 of the first duct 310. The vertical distance 360 between the leading edge 345 of the second duct 320 and the leading edge 313 of the first duct 310 can be one-third the diameter of the leading edge 313 of the first duct 310. The horizontal distance between the leading edge 313 of the first duct 310 and the leading edge 345 of the second duct 320 can be four times the diameter of the leading edge 313 of the first duct 310. The axial chord 350 of the second duct 320 can be five times the diameter of the leading edge 313 of first duct 310. Also, the separation distance or the width 375 of the channel 330 between the first duct 310 and the second duct 320 can be 0.8 times the diameter of the leading edge 313 of the first duct 310. The various combinations of the relative separation distances between the first duct 310 and 320 and the chord lines of the airfoils in the first duct 310 and the second duct 320 can be used to optimize the lip separation control effectiveness for various edgewise flight velocities of the double ducted fan based vehicles.

[0045] Also illustrated in FIGS. 3A-3C is the converging-diverging channel 375 defined by the first duct 310 and the second duct. The channel 375 begins at the leading edge 313 of the first duct 310 and terminates at the trailing edge 340 of the second duct 320 and has a length measured from the leading edge 313 to the trailing edge 340. In FIGS. 3A-3C, the channel 375 can have a length that is approximately five times the diameter of the leading edge 313 of the first duct 310. The width 325 of the channel 375 at the entrance of the channel 375 can be approximately equal to the diameter of the leading edge 313 of the first duct. The entrance of the channel 375 is at the trailing edge 340 of the second duct 320. Due to the geometry and orientation of the first and second ducts 310, 320, there is a vertically upward net flow through the channel 375 beginning proximate to the trailing edge 340 of the second duct 320 and upward towards the leading edge 313 of the first duct 310. The dynamic pressure at the entrance of the channel 375 can provide the vertically upward net flow. The diverging width 325 of the channel 375 provides the deceleration of the flow through the throat. The deceleration of the flow can adjust the static pressure gradient therein prior to the inlet flow's interaction with the leading edge 313 of the first duct 31. The self-adjusting dynamic pressure of the inlet flow entering the channel 375 can be proportional with the square of the forward flight velocity of the vehicle.

[0046] The flow of air into the inlet 325 of the rotor 305 is vertically down, moving from the leading edge 313 of the first duct 310 to the trailing edge 317 of the first duct 310 towards the exit or outlet of the rotor 305. The vertically down flow direction can be provided by the relatively low stagnation pressure at the inlet 325. Also, the vertically down flow can be induced by the static pressure field of the flow exiting the rotor 305, thereby generating a thrust force for the vehicle. Therefore, with such a geometry and arrangement of the first and second ducts 310, 320, the lip 347 of the second duct 320 in cooperation with the first duct 310 can reduce the lip separation normally observed in conventional single ducted fans. As the lip separation is reduced, a more balanced rotor exit flow can be observed, thereby providing enhanced control, and efficiency of horizontal flight. Reduced lip separation is also related to lowered vibrations of the flight vehicle.

[0047] As shown in FIGS. 4A-4C, another embodiment of the double-ducted fan 4000 includes a hub 400 having a front portion 420 and an end portion 415. A rotor fan 405 having a plurality of blades 407 is rotatably coupled to the front portion 401 of the hub 400. A first duct 410 is coupled to the rotor fan 405 such that the first duct 410 surrounds the rotor fan 405 and is radially spaced from the hub 400. The first duct 410 has a leading edge 413, a trailing edge 417, and a first length 455 between the leading edge 413 and the trailing edge 417. As shown in the illustrated embodiment, the first duct 410 is coupled to the hub 400 at the trailing edge 417 of the first duct 410 by a plurality of outlet vanes 409. An inlet 425 or throat is formed between the first duct 410 and the rotor 400 through which air flow can pass when the double-ducted fan 4000 is in operation during horizontal motion and while oriented at a 90 degree angle of attack with respect to the ground. The inlet 425 includes an inlet lip 419 proximate to the leading edge 413 of the first duct 410.

[0048] A second duct 420 is radially spaced from the first duct. The second duct 420 is coupled to the first duct such that the rotor 405 is at the center of the double-ducted fan 4000. The second duct 420 has a leading edge 445, a trailing edge 440, and a second length 450 between the leading edge 445 and the trailing edge 440. For example, as illustrated in FIG. 4C, the second duct 420 has a second length 450 is shorter in than the first length 455 of the first duct 410. However, in at least one alternative embodiment, the second duct 420 can have a second length 450 longer than the first length 455 of the first duct 410. In the illustrated embodiment, the first duct 410 and the second duct 420 are cylindrical structures; however, one of ordinary skill in the art will appreciate the first duct 410 and the second duct 420 can be any structure that will direct cross-wise air-flow into the inlet 425 of the rotor fan 405.

[0049] As compared to the embodiment illustrated in FIGS. 2A-3C, the illustrated embodiment of FIGS. 4A-4C show the first duct 410 and the second duct 420 eccentrically oriented. As illustrated in FIG. 4C, the second duct 420 is oriented axially-upward with respect to the first duct 410. For example, the second duct 420 is oriented such that the leading edge 445 of the second duct 420 is oriented axially-upward from the leading edge 413 of the first duct 410. The trailing edge 440 of the second duct 420 and the trailing edge 417 of the first duct 410 are aligned such that there is an axial distance 460 between the leading edge 445 of the second duct and the leading edge 413 of the first duct 410. A channel 430 is formed between the first duct 410 and the second duct 420. As illustrated in FIG. 4C, the channel 430 is a converging-diverging channel. For example, the width 475 of the channel 430 can vary from the trailing edges 417, 440 of the first and second ducts 410, 420 to the leading edges 413, 435 of the first and second duct 410, 420 (e.g., the width 475 can increase or decrease). As the first duct 410 and the second duct 420 are eccentric, the width 475 and shape of the converging-diverging channel 430 can vary circumferentially around the rotor 400. For example, the width 475 of the portion of the converging-diverging channel 430 where the first duct 410 is closest to the inner wall of the second duct 420 (the width 475 to the left of the central axis 465 in FIG. 4C) is smaller than the width of the portion of the converging-diverging channel 400 where the first duct 410 is further from the inner wall of the second duct 420 (the width 475to the right of the central axis 465 in FIG. 4C). With the embodiment illustrated in FIGS. 4A-4C, the second duct 420 can be movable with respect to the first duct 410 and the hub 400. Also as shown in FIG. 4C, the first duct 410 and the second duct 420 have an airfoil shape. However, in alternative embodiments, the first duct 410 and the second duct 420 can have a cylindrical shape, an oval shape, or any other shape that permits axial air flow into the inlet 445 of the rotor 405.

[0050] Similar to the embodiment illustrated in FIGS. 2A-3C, for the embodiment illustrated in FIGS. 4A-4C, during horizontal flight, cross-wise air-flow will encounter the second duct 420 before it encounters the leading edge 413 of the first duct 410 (e.g., air-flow will move from the left to right in FIG. 4C). However, unlike the embodiments illustrated in FIGS. 2A-3C, the embodiment illustrated in FIGS. 4A-4C permits a converging-diverging channel 430 that can vary depending on the angle of attack which the double-ducted fan 4000 is oriented. As the cross-wise air-flow encounters the duct lip 447, a portion of the air-flow will travel upwards towards the leading edge 445 of the second duct 420, and a portion of the air-flow will travel downwards towards the trailing edge 440 of the second duct 420. The air-flow that travels across the leading edge 445 will flow across the leading edge 413 of the first duct 410, over the inlet lip 419, and into the rotor inlet 425. The air-flow that travels towards the trailing edge 440 of the second duct 420 will travel upwards through the channel 430, over the leading edge 413 of the first duct 410 and the inlet lip 419, and into the rotor inlet 425. Compared to the embodiments illustrated in FIG. 2C and 3C, as a result of the eccentric first duct 410 and second duct 420, the channel 430 can be opened or closed to permit air-flow at the trailing edge 440 of the second duct 420 to be directed upward into the channel 430 and over and into the rotor inlet 425. Adjusting the width 475 of the converging-diverging channel 430 allows for more controlled air-flow into the rotor inlet 425. Because the air-flow encounters the second duct 420 first during horizontal flight, the air-flow is separated at the second duct 420 before it encounters the inlet lip 419 of the first duct 410. Thus, the air-flow entering the rotor inlet 425 is substantially uniform, and the inlet separation that would typically occur in conventional ducted fans is reduced. As a more uniform air-flow profile enters the rotor inlet 425, more uniform air-flow exits the rotor fan 405, thereby reducing energy loss, total pressure imbalance, and mass-flow rate imbalance that can be associated with air-flow distortion. Additionally, as the illustrated embodiment in FIGS. 4A-4C provide for a variable throat 475, the double ducted fan 4000 allows for a greater range of operation as compared to conventional ducted fans. Also, the illustrated embodiment enhances the accuracy of lip flow control over a wider forward flight velocity range as compared to conventional ducted fans.

[0051] FIGS. 6A-6C illustrate another embodiment of the double-ducted fan described herein. FIGS. 6A-6C are substantially similar to the double-ducted fans illustrated in FIGS. 2A-4C, but differ in that the second duct 620 is a partial duct. Common elements between the double-ducted fans illustrated in FIGS. 2A-4C are shown in FIGS. 6A-6C except that the reference numerals are in the 600 series. As shown in FIGS. 6A-6C, the double-ducted fan 6000 includes a hub 600 having a front portion 620 and an end portion 615. A rotor fan 605 having a plurality of blades 607 is rotatably coupled to the front portion 601 of the hub 600. A first duct 610 is coupled to the rotor fan 605 such that the first duct 610 surrounds the rotor fan 605 and is radially spaced from the hub 600. The first duct 610 has a leading edge 613, a trailing edge 617, and a first length 655 between the leading edge 613 and the trailing edge 617. As shown in the illustrated embodiment, the first duct 610 is coupled to the hub 600 at the trailing edge 617 of the first duct 610 by a plurality of outlet vanes 609. An inlet 625 is formed between the first duct 610 and the rotor 600 through which air flow can pass when the double-ducted fan 6000 is in operation during horizontal motion and while oriented at a 90 degree angle of attack with respect to the ground. The inlet 625 includes an inlet lip 619 proximate to the leading edge 613 of the first duct 610.

[0052] A second duct 620 is radially spaced from the first duct 610. The second duct 620 is a partial duct. For example, the second duct 620 can be shaped as a partial circumferential segment of a duct that is radially spaced from the first duct 610, as illustrated in FIG. 6A. The second duct 620 is coupled to the first duct 610 such that the rotor 605 is at the center of the double-ducted fan 6000. The second duct 620 has a leading edge 645, a trailing edge 640, and a second length 650 between the leading edge 645 and the trailing edge 640. For example, as illustrated in FIG. 6C, the second duct 620 has a second length 650 is shorter in than the first length 655 of the first duct 610. However, in at least one alternative embodiment, the second duct 620 can have a second length 650 longer than the first length 655 of the first duct 610. In the illustrated embodiment, the first duct 610 and the second duct 620 are cylindrical structures; however, one of ordinary skill in the art will appreciate the first duct 610 and the second duct 620 can be any structure that will direct cross-wise air-flow into the inlet 625 of the rotor fan

605. Additionally, as illustrated in FIGS. 6A-6C, the second duct 620 is positioned proximate to the leading side of the first duct 610. In the embodiment illustrated in FIGS. 6A-6C, the trailing ledge 640 of the second duct 620 and the trailing edge 617 of the first duct 610 are aligned such that there is an axial distance 660 between the leading edge 645 of the second duct and the leading edge 613 of the first duct 610. Because the air-flow encounters the second duct 620 first during horizontal flight, the air-flow is separated at the second duct 620 before it encounters the inlet lip 619 of the first duct 610. Thus, the air-flow entering the rotor inlet 625 is substantially uniform, and the inlet separation that would typically occur in conventional ducted fans is reduced. As a more uniform air-flow profile enters the rotor inlet 625, more uniform air-flow exits the rotor fan 605, thereby reducing energy loss, total pressure imbalance, and mass-flow rate imbalance that can be associated with air-flow distortion.

[0053] Similar to the embodiment illustrated in FIGS. 2A-4C, for the embodiment illustrated in FIGS. 6A-6C, during horizontal flight, cross-wise air-flow will encounter the second duct 420 before it encounters the leading edge 613 of the first duct 610 (e.g., air-flow will move from the right to the left in FIG. 6C). However, unlike the embodiments illustrated in FIGS. 2A-4C, the embodiment illustrated in FIGS. 6A-6C, the second duct 620 is a circumferential segment of a duct. As the overall weight VSTOL vehicles is an important factor in VSTOL vehicle design, the weight of the fans that provided the lift and propulsion of the VSTOL vehicle is important. The double-ducted fan 6000 illustrated in FIG. 6A having a partial second duct 620 reduces the weight added by the double-ducted fan 6000 to the VSTOL vehicle while still providing effective control of the inlet lip separation during horizontal flight. The partial second duct 620 can be manufactured in a deployable style so that the distance betwwen the first duct 610 and the partial second duct 620 can be controlled in function of horizontal flight speed. The partial secont duct 620 can be fully retracted in the first few seconds of the flight of the vehicle during which horizontal vehicle speed is zero or very low. The second duct 620 could be deployed to form the converging diverging channle between the first duct 610 and the partial second duct 620. The partial second duct 620 could also be manufactured as a light weight sheet metal curved thin shell or a composite or light weight durable curved thin shell.

[0054] FIGS. 7A-7D illustrate another embodiment of the double-ducted fan described herein. FIGS. 7A-7D are substantially similar to the double-ducted fans illustrated in FIGS. 2A-4C and 6A-6C, but differ in that the second duct 720 is integrated with the first duct 710. Common elements between the double-ducted fans illustrated in FIGS. 2A-4C and 6A-6C are shown in FIGS. 7A-7D except that the reference numerals are in the 700 series. As shown in FIGS. 7A-7D, the double-ducted fan 7000 includes a hub 700 having a front portion 720 and an end portion 715. A rotor fan 705 having a plurality of blades 707 is rotatably coupled to the front portion 601 of the hub 700. A first duct 710 is coupled to the rotor fan 705 such that the first duct 710 surrounds the rotor fan 705 and is radially spaced from the hub 700. The first duct 710 has a leading edge 713, a trailing edge 717, and a first length 755 between the leading edge 713 and the trailing edge 717. As shown in the illustrated embodiment, the first duct 710 is coupled to the hub 700 at the trailing edge 717 of the first duct 710 by a plurality of outlet vanes 709. An inlet 725 or throat is formed between the first duct 710 and the rotor 700 through which air flow can pass when the double-ducted fan 7000 is in operation during horizontal motion and while oriented at a 90 degree angle of attack with respect to the ground. The inlet 725 includes an inlet lip 719 proximate to the leading edge 713 of the first duct 710.

[0055] A second duct 720 integrally formed in the first duct 710. For example, in the embodiment illustrated in FIGS. 7A and 7B, the second duct 720 is integrally formed on a side 714 of the double-ducted fan 7000. With the second duct 720 integrally formed on the side 714, a mouth 721 is defined between the second duct 720 and the side 714 of the first duct 710. Also, a channel 730 is defined between the second duct 720 and the first duct 710 and defines an aperture at the upper surface 711 of the first duct 710. The channel 730 and the mouth 721 are in fluid communication, thereby allowing flowing air to enter through the mouth 721 and exit at the channel 730 into the inlet 725 of the rotor fan 705. The second duct 720 has a leading edge 745, a trailing edge 740, and a second length 750 between the leading edge 745 and the trailing edge 740. For example, as illustrated in FIG. 7D, the second duct 720 has a second length 750 is shorter in than the first length 755 of the first duct 710. However, in at least one alternative embodiment, the second duct 720 can have a second length 750 longer than the first length 755 of the first duct 710. In the illustrated embodiment, the first duct 710 and the second duct 720 are cylindrical structures; however, one of ordinary skill in the art will appreciate the first duct 710 and the second duct 720 can be any structure that will direct cross-wise air-flow into the inlet 725 of the rotor fan 705. Additionally, as illustrated in FIGS. 7A-7D, the second duct 720 is positioned proximate to the leading side of the first duct 710. The trailing edge 740 of the second duct 720 and the trailing edge 717 of the first duct 710 are aligned such that there is an axial distance 760 between the leading edge 745 of the second duct and the leading edge 713 of the first duct 710. The second duct 720 can be integrated and oriented with respect to the first duct 710 such that the flow decelerates at the apertured defined in the top surface 711 by the channel 730. Also as illustrated in FIGS. 7A and 7B, the side 714 of the first duct 710 can be chamfered at the corners of the side 714. The side geometry of of the first duct can be determined from the aerodynamic profiling of the vehicle or the wing section the first duct 710 is integrated into. The configuration as illustrated in FIGS. 7A-7D is an highly effective way of integrating a ducted fan into a wing or flight vehicle in which inlet lip separation avoidance is of critical importance. In areas other than the mouth 712 , the overal shape of the vehicle body 710 can be designed with great design flexibility imposed by aerodynamic and vehicle structural constraints.

[0056] Because the air-flow encounters the second duct 720 first during horizontal flight, the air-flow is separated by the second duct 720 and directed towards the mouth 721 and through the channel 730 before it encounters the inlet lip 719 of the first duct 710. Thus, the air-flow entering the rotor inlet 725 is substantially uniform, and the inlet separation that would typically occur in conventional ducted fans is reduced. As a more uniform air-flow profile enters the rotor inlet 725, more uniform air-flow exits the rotor fan 705, thereby reducing energy loss, total pressure imbalance, and mass-flow rate imbalance that can be associated with air-flow distortion.

[0057] Similar to the embodiment illustrated in FIGS. 2A-4C and 6A-6C, for the embodiment illustrated in FIGS. 7A-7D, during horizontal flight, cross-wise air-flow will encounter the second duct 720 before it encounters the leading edge 713 of the first duct 710 (e.g., air-flow will move from the right to the left in FIG. 7D). However, unlike the embodiments illustrated in FIGS. 2A-4C and 6A-6C, the embodiment illustrated in FIGS. 7A-

7D, the second duct 720 is integrated into the first duct 710. By integrating the second duct 720 with the first duct 710, the flow control at the inlet lip 719 can be enhanced. As the double-ducted fan 7000 travels in edge-wise or horizontal flight, the total pressure available just in front of the mouth 712 can drive the air flow into the second duct 720 through the channel 730. The velocity of the air flow passing through the mouth 721 and the channel730 decelerates as the air travels from the mouth 721 to through channel 730 and over the inlet lip 719. Additionally, integrating the second duct 720 into the first duct 710 can allow for a smooth and aerodynamic design for VSTOL vehicles, thereby enhancing the aerodynamic properties of the VSTOL vehicle. Also, the integrated second duct 720 with the first 710 can allows for the application of the double-ducted fan and the technical advantages thereof into a VSTOL vehicle having a lifting body-type cross-section, a VSTOL vehicle having lifting fans integrated into the vehicle fuselage. The inlet mouth 721 can be designed with variable turning vanes that may also continuously adjust the performance of the lip separation avoidance system at different edge-wise flight velocities in the embodiments illustrated in FIGS. 7A-7D .

[0058] The movement of air flow through the double-ducted fan as illustrated in any of the previously described embodiments will now be described. For purposes of brevity, the movement of air through the double-ducted fan will be described with respect to the illustrated embodiment in FIG. 5, which illustrates a double-ducted fan 5000 having a second duct 520 shorter than the first duct 510. FIG. 5 is a partial vertical cross-section view of an exemplary double-ducted fan 5000 in accordance with an exemplary embodiment. In particular, FIG. 5 is a vertical cross-section view the left side of the double-ducted fan 5000 with respect to the central axis 565. As illustrated in FIG. 5, the double-ducted fan 5000 includes a hub 500, a rotor (not shown) having a plurality of blades rotatably coupled to the hub 500, a first duct 510 axially spaced from the hub 5000 and surrounding the rotor, and a second duct 520 axially spaced from the first duct 510. An inlet 525 or throat is formed between the first duct 510 and the hub 500 which permits air flow to pass from the atmosphere through the blades of the rotor. The illustrated embodiment in FIG. 5 shows the second duct 520 have a length 550 shorter than the length 555 of the first duct 510. Additionally, the second duct 220 is oriented axially upward from the leading edge 513 of the first duct 510 such that the leading edge 535 of the second duct

520 is spaced an axial distance 560 from the leading edge 513 of the first duct 510. The second duct 520 has the cross-section of an air foil and is oriented at an angle with respect to the first duct 510. In the illustrated example, the second duct 520 is cambered away from the first duct 510 and with respect to the central axis 565 of the double-ducted fan 5000.

[0059] A channel 530 is formed between the second duct 520 and the first duct 510. In the particular embodiment illustrated in FIG. 5, the channel 530 is a converging-diverging channel whereby the width 575 of the channel 530 decreases from between the leading edges 513, 535 of the first duct 510 and the second duct 520 to between the trailing edges 517, 540 of the first duct 510 and the second duct 520. During operation in forward flight in which the double-ducted fan 5000 is oriented at a 90 degree angle of attack with respect to the ground, horizontal or cross-wise air flow (depicted as 5100) encounters the second duct 520. In the illustrated embodiment, air flow moves from the leading side of the double-ducted fan 5000, which is to the left of the central axis 565, to the trailing side (not shown) of the double-ducted fan, which is to the left of the central axis 565. The flow in the channel 530 is directed from the trailing edge 517 to the leading edge 513 of the first duct 510. In other words, the upward flow feature in the channel 530 belongs to a local region around the leading side of the second duct 520. When moving away from the leading side of the second duct 520, air-flow in the channel 530 is directed from top to below which is the same overall flow direction in rotor inlet 525. As a result of the orientation and shapes of the first duct 510 and the second duct 520, the horizontal air flow is directed upward through the channel 530, over the first duct 510, and downward into the inlet 525 of the rotor. The upward flow direction through the channel 530 and the downward flow into and through the inlet 525 provides for controlled inlet flow distortion and a reduced air flow separation near the inlet lip 519 of the leading side (the left side of the illustrated embodiment) of the double-ducted fan 5000. For example, since the cross-wise air flow encounters the leading edge 545 of the second duct 520, more uniform air-flow travels across the leading edges 545, 513 of the second duct 520 and the first duct 510. The inlet separation at the inlet lip 519 is thereby reduced allowing for less distorted air-flow that enters the rotor inlet 525. Additionally, the orientation and shapes of the first duct 510 and second duct 520 enhance the uniformity of rotor fan exit flow and reduce differentials between the leading side and trailing side of the double-ducted fan 5000. For example, because the portion of air-flow that is directed upwards through the channel 530 meets the portion of air-flow that travels across the leading edge 545 of the second duct 520, the air-flow is uniform as it travels across the leading edge 513 of the first duct 510. As a result, air flow from the rotor 500 at the exit or outlet of the rotor 500 can provide a thrust force to enhance the performance of the vehicle to which the double-ducted fan 5000 is coupled. Furthermore, the resulting shape of the double-ducted fan 5000 due to the orientation and shape of the first duct 510 and second duct 520 can reduce drag during forward flight. With any of the exemplary embodiments of the double-ducted fan described herein, the orientation and shape of the first duct and second duct can reduce the inlet lip separation or air flow separation at the inlet lip associated with conventional axial-flow rotor units, enhance the exit air flow of the ducted fan, enhance the thrust force of the ducted fan, and control inlet flow distortion that can be associated with conventional axial-flow rotor units.

[0060] It will be appreciated by those of ordinary skill in the art that any of the double-ducted fans disclosed herein can comprise from lightweight sturdy materials. For example, the double-ducted fans can be manufactured from a composite skin, and inflatable duct, aluminum, thin sheet metal, or other materials that are lightweight and durable to form airfoils, wings, and the ducts of double-ducted fans described herein.

[0061] The following figures illustrate a double-ducted fan per the subject technology. While the illustrated embodiments are particularly suited for a vertical or short-take-off-and-landing vehicle (VSTOL), one of ordinary skill in the art will appreciate that the double-ducted fan described could be implemented in an uninhabited aerial vehicle; a cooling fan for a train; a passenger bus; a marine vehicle; or any other vehicle that uses an axial-flow rotor unit. Additionally, the double-ducted fan could be implemented in any axial flow fan unit where there is an inlet flow distortion due to the inlet flow direction not being well-aligned with the axis of rotation of the axial fan unit. An appendix follows describing in details regarding the experimentation and testing results of the various embodiments of the double-ducted fan described herein. Various modifications to and departures from the disclosed embodiments will occur to those having skill in the art. The subject matter that is intended to be within the spirit of this disclosure is set forth in the following claims.

CLAIMS

1. A ducted air rotor comprising:

a hub;

a rotor fan having a plurality of blades rotatably coupled to the hub, said plurality of blades having an inlet side and an outlet side;

a first duct adapted to circumscribe the rotor fan;

a second duct adapted to circumscribe at least a portion of the first duct; and

a channel defined between the first duct and the second duct.

2. The ducted air rotor of claim 1, wherein the second duct is movable relative to the first duct to adjust at least a portion of the channel.

3. The ducted air rotor of claim 1, wherein said channel is oriented to direct air flow cross-wise to the first duct over a top of the first duct into the inlet side of the fan.

4. The ducted air rotor of claim 1, wherein the second duct is oriented axially upward from a leading edge of the first duct such that an axial distance is between the leading edge of the first duct and a leading edge of the second duct.

5. The ducted air rotor of claim 1, wherein the second duct is oriented at an angle with respect to the first duct.

6. The ducted air rotor of claim 1, wherein the second duct is cambered.

7. The ducted air rotor of claim 1, wherein the second duct has an airfoil shape.

8. The ducted air rotor of claim 1, wherein the channel is a converging-diverging channel.

9. The ducted air rotor of claim 1, wherein the second duct is stationarily coupled to the first duct.

10. The ducted air rotor of claim 1, wherein the first duct and the second duct are concentrically oriented.

11. The ducted air rotor of claim 1, wherein the first duct and the second duct are eccentrically oriented.

12. The ducted air rotor of claim 11, wherein the second duct is axially movable with respect to the first duct to adjust a portion of the width of the channel.

13. The ducted air rotor of claim 1, wherein the first duct has a first length and the second duct has a second length greater than the first length.

14. The ducted air rotor of claim 1, wherein the first duct has a first length and the second duct has a second length less than the first length.

15. A ducted air rotor comprising:

a hub;

a rotor fan having a plurality of blades rotatably coupled to the hub, said plurality of blades having an inlet side and an outlet side;

a first duct adapted to circumscribe the rotor fan;

a second duct integrally formed in the first duct; and

a channel defined between the first duct and the second duct.

16. The ducted air rotor of claim 15, wherein:

the first duct comprises an upper surface and a side extending substantially perpendicular to the upper surface; and

the channel comprises a first end at the upper surface and a second end at the side.

17. The ducted air rotor of claim 15, wherein the first duct comprises at least one chamfered corner.

18. The ducted air rotor of claim 15, wherein the first duct has a first length and the second duct has a second length less than the first length.

19. The ducted air rotor of claim 15, wherein the first duct comprises a side, and the second duct is integrally formed in the side.

20. A ducted air rotor comprising:

a hub;

a rotor fan having a plurality of blades rotatably coupled to the hub, said plurality of blades having an inlet side and an outlet side;

a first duct adapted to circumscribe the rotor fan;

a partial duct adapted to circumscribe a portion of the first duct; and

a channel defined between the first duct and the partial duct.

21. The ducted air rotor of claim 20, wherein the first duct has a first length and the partial duct has a second length less than the first length.

22. The ducted air rotor of claim 20, wherein the partial duct is a cambered airfoil.

23. The ducted air rotor of claim 20, wherein the first duct has a leading edge and the partial duct has a leading edge, and wherein the partial duct is oriented axially upward from the leading edge of the first duct such that an axial distance is between the leading edge of the first duct and the leading edge of the partial duct.

24. The ducted air rotor of claim 20, wherein the partial duct is a segment of a duct.

25. The ducted air rotor of claim 20, wherein the partial duct is fixedly coupled to the first duct at a circumferential segment of the first duct.

ABSTRACT

A double-ducted fan includes a hub, a rotor fan having a plurality of blades rotatably coupled to the hub, a first duct, a second duct, and a channel defined between the first duct and second duct. The first duct circumscribes the rotor fan and the second duct circumscribes at least a portion of the first duct. The second duct can be oriented axially upward such that there is an axial distance is between the leading edges of the first duct and second duct. The channel can be configured to direct air flow cross-wise to the first duct over a top of the first duct into the inlet side of the fan. The second duct can be movable relative to the first duct to adjust at least a portion of the channel. The length of the first duct can be different from the length of the second duct.

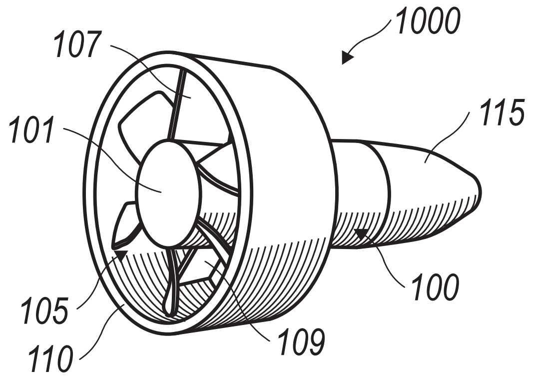


FIG. 1A
(PRIOR ART)

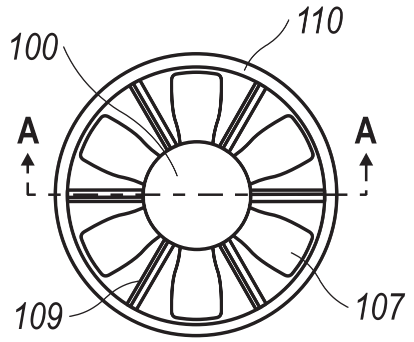


FIG. 1B
(PRIOR ART)

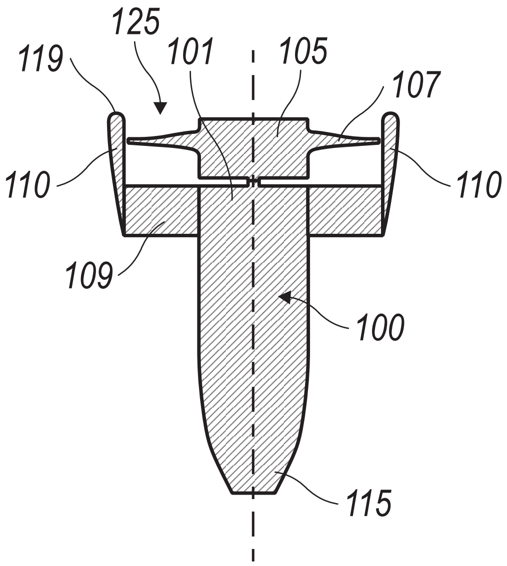


FIG. 1C
(PRIOR ART)

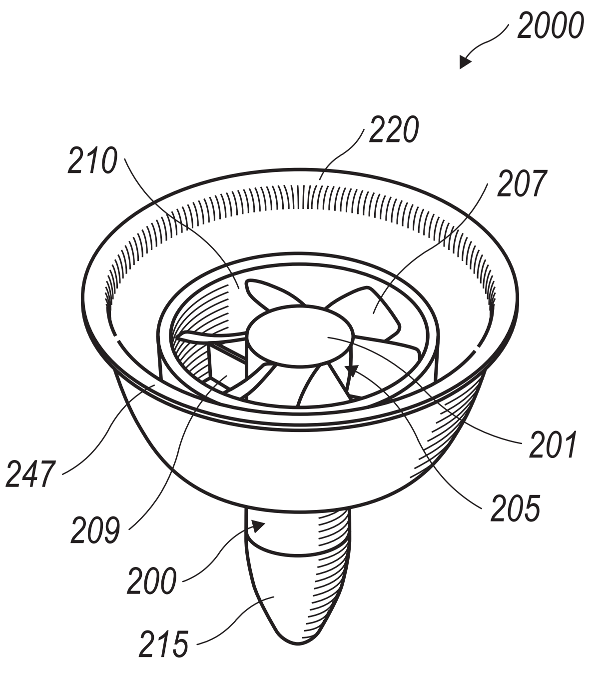


FIG. 2A

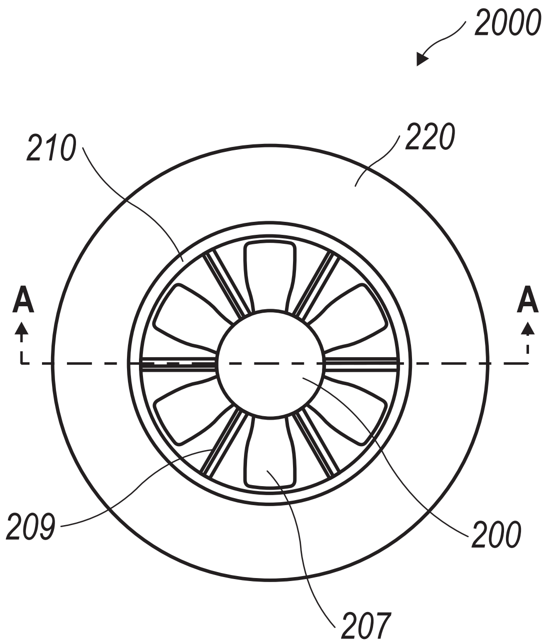


FIG. 2B

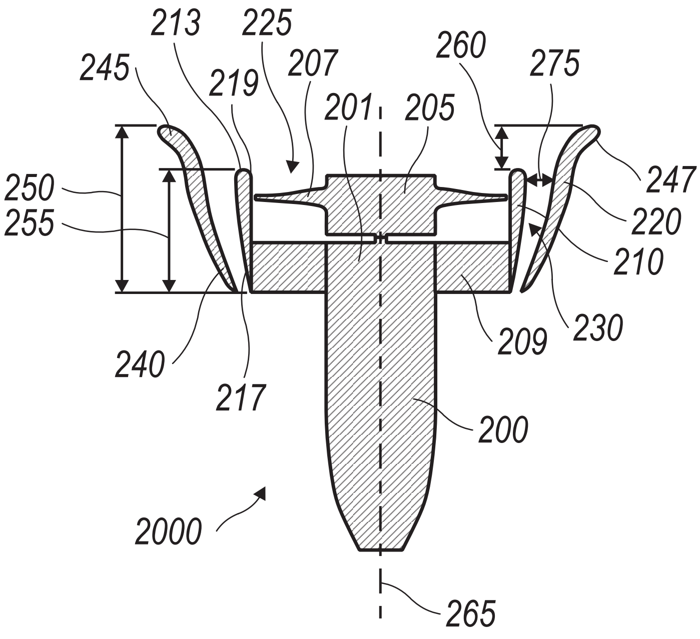


FIG. 2C

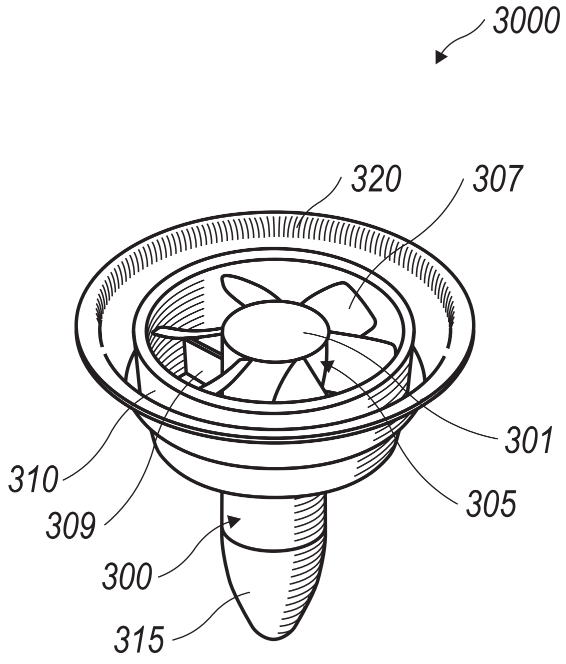


FIG. 3A

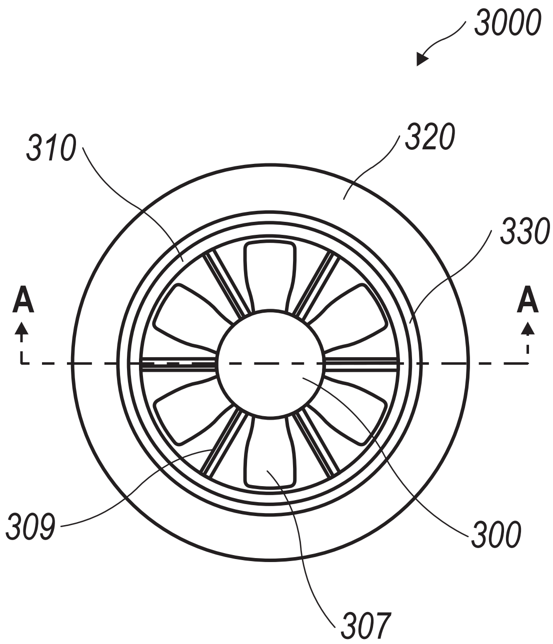


FIG. 3B

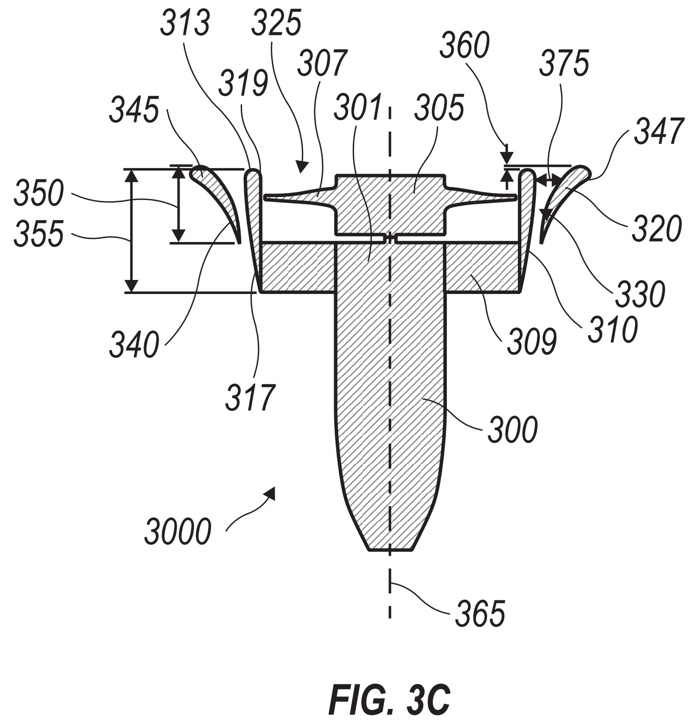


FIG. 3C

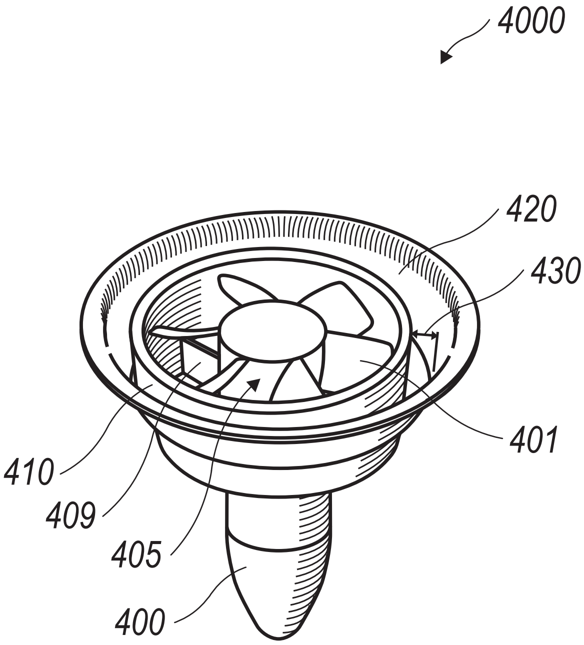


FIG. 4A

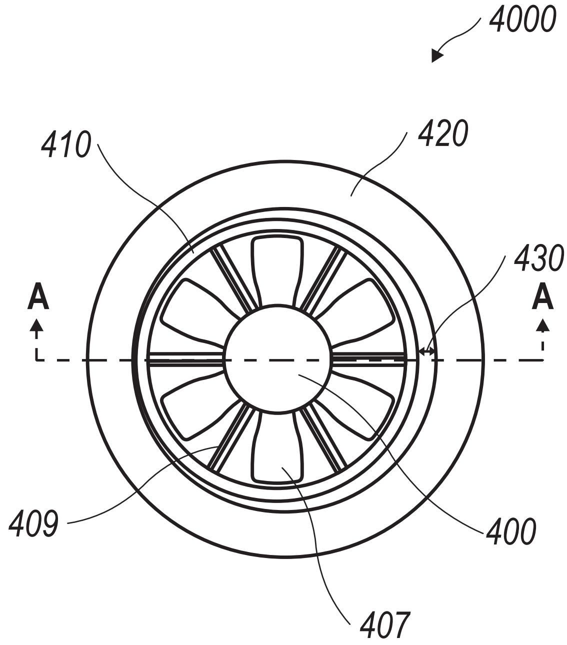


FIG. 4B

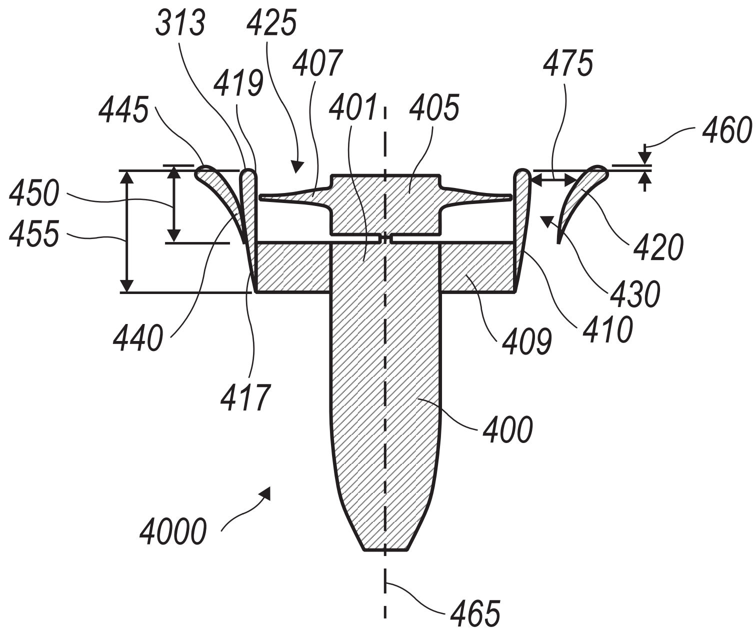
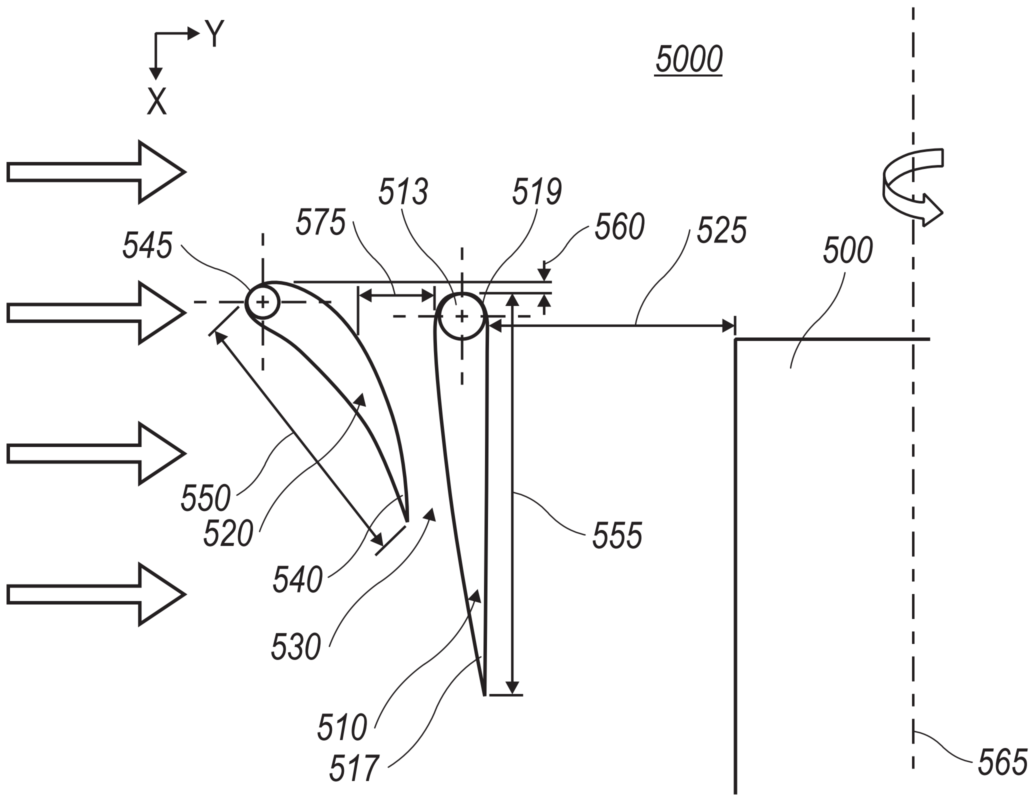


FIG. 4C


Y
X
5000
513
519
575
560
525
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520
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510
517
565

FIG. 5

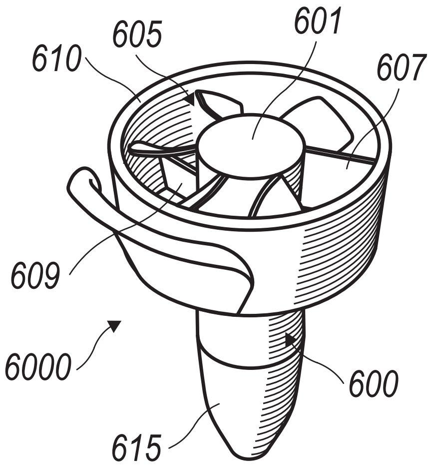

FIG. 6A

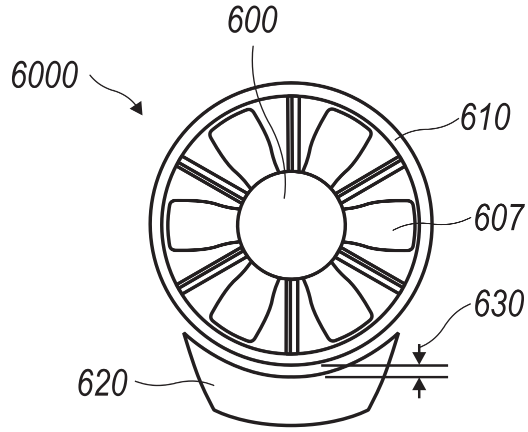

FIG. 6B

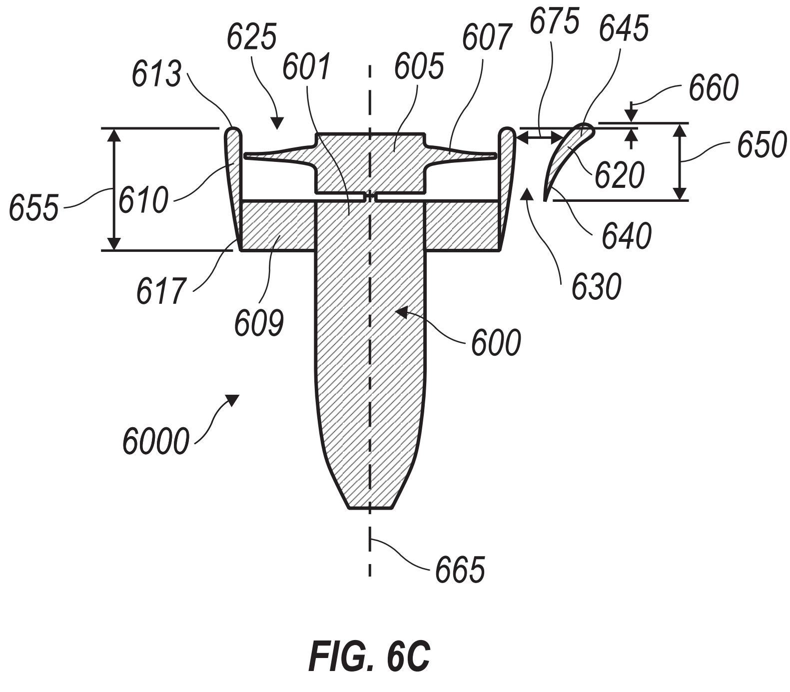

FIG. 6C

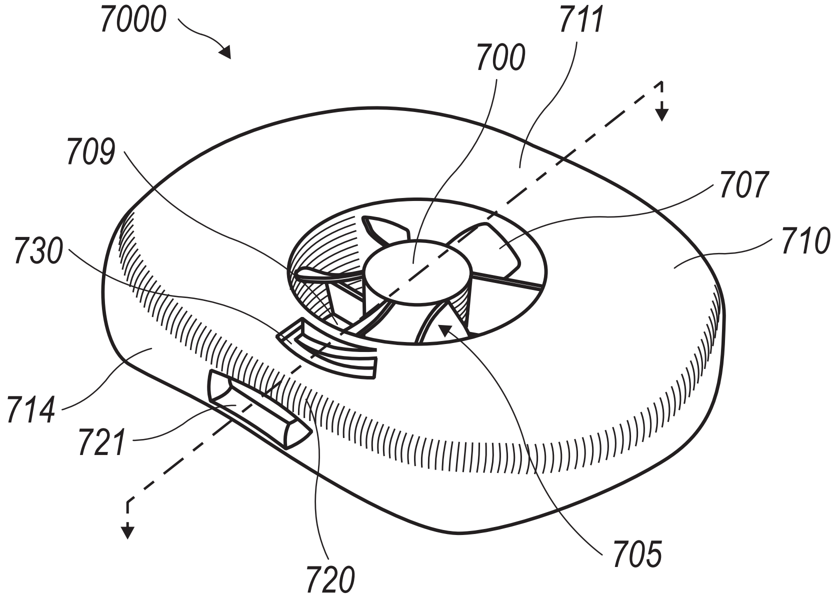
7000
711
700
709
707
710
730
714
721
720
705

FIG. 7A

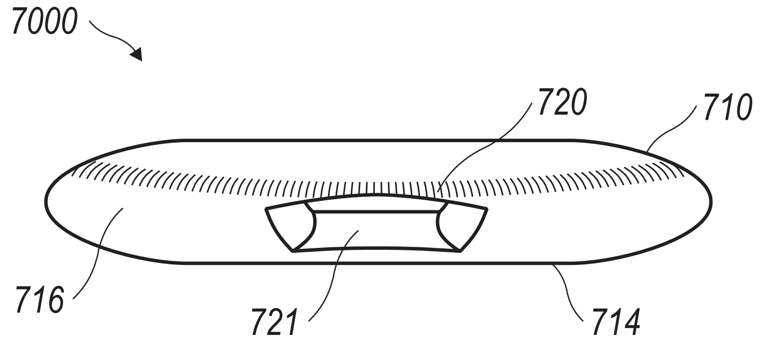
7000
720
710
716
721
714

FIG. 7B

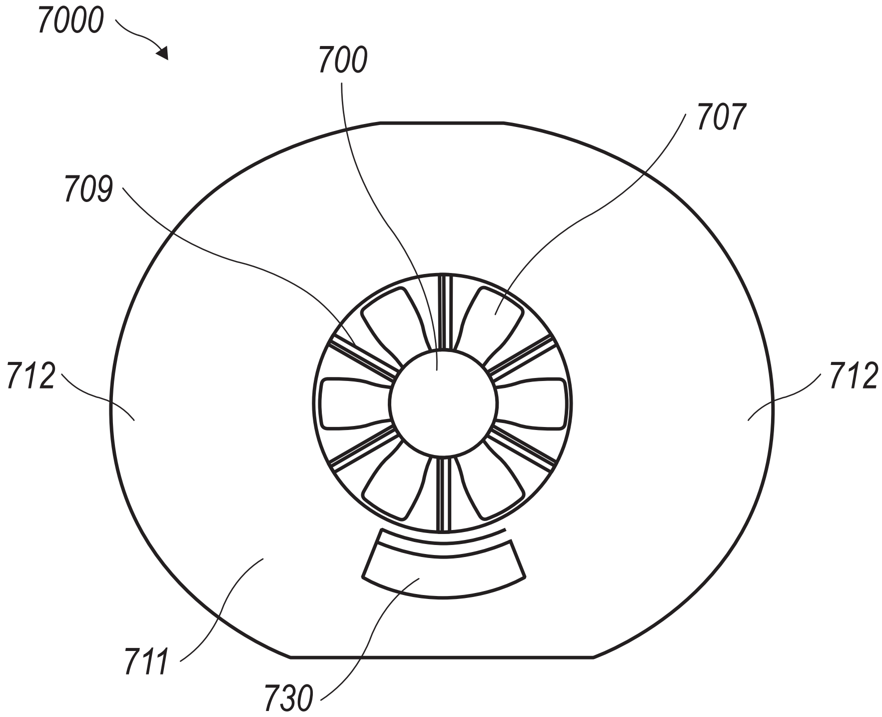
7000
700
707
709
712
712
711
730

FIG. 7C

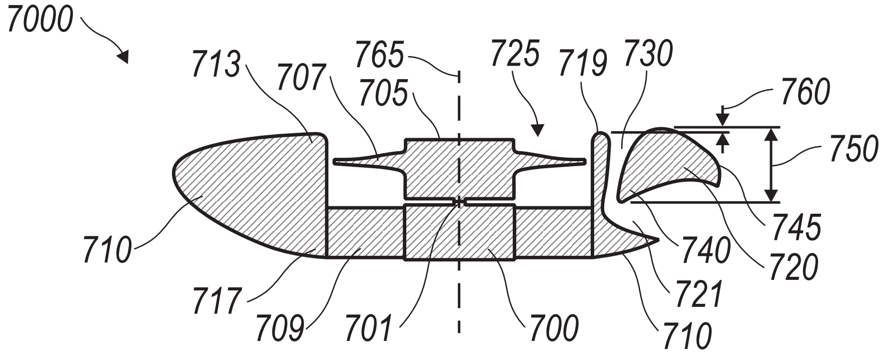
7000
713
707
765
705
725
719
730
760
750
745
740
720
721
710
700
701
709
717
710

FIG. 7D