A fan apparatus includes a ducted housing with an axis of rotation including a first section and a second section. The fan apparatus further includes a first plurality of vanes being radially coupled within the first section and a second plurality of vanes being radially coupled within the second section. Additionally, the fan apparatus includes an impeller with a plurality of blades rotatably disposed within the ducted housing between the first plurality of vanes and the second plurality of vanes for rotary motion about the axis of rotation. The first plurality of vanes are stationary in a first arrangement to guide an inflow of air towards the impeller. The plurality of blades are rotary in a second arrangement to have a rotational direction substantially opposite to the inflow of air guided by the first arrangement. The second plurality of vanes are stationary in a third arrangement to diffuse an outflow of air substantially along the axis of rotation.
DUCTED FAN WITH INLET VANES AND DESWIRL VANES

BACKGROUND OF THE INVENTION

[0001] The present invention relates generally to air processing techniques, and in particular to a fan apparatus having improved output capacity.

[0002] Developments and operations of high density integrated circuits, high-power electronics, avionics, and advanced telecommunication equipment usually are associated with the generation of large amounts of heat. How to dissipate this heat quickly and effectively is an important concern. A widely used solution is air cooling with a fan apparatus. Conventional cooling fans typically run at relatively low rotational speeds, e.g., 15,000 RPM (rotations per minute) or lower. In order to drive up the rotational speeds, a ducted fan can be used to provide more air flow at high pressure while keeping the size of the ducted fan frame the same.

[0003] One conventional ducted fan configuration includes just a single set of stationary vanes (usually used as inlet guide vanes) followed by a single rotating impeller. The flow of air processed by such a conventional ducted fan is deficient in the flow’s directional guidance and is lacking in output capacity in terms of pressure enhancement. Another configuration of a ducted fan is that an even-numbered rotating and stationary vane sets are alternatively grouped together. This configuration has been used in some traditional aircraft engine compressors. But, it is not suit for new small form-factor aircraft propulsion systems for UAV’s (unmanned air vehicles).

[0004] Therefore, the prior art is lacking to meet the specific requirements mentioned above and beyond in terms of the particular constructional improvements of the invention described in detail hereinafter.

BRIEF SUMMARY OF THE INVENTION

[0005] The nature of the improvements for a ducted fan with both inlet guide vanes and deswirl vanes is brought out more clearly in the detailed description hereinafter of an embodiment of the present invention.

[0006] Embodiments of the present invention relate generally to air processing techniques, and in particular to a fan apparatus that integrally combines a rotating impeller disposed between an upstream set of stationary inlet guide vanes and a downstream set of stationary deswirl vanes. Merely by way of example, such fan apparatus is constructed in a ducted housing with unique arrangements for the rotating impeller blades and upstream/downstream stationary vanes for enhancing fan performance at high rotational speeds. But it would be recognized that the invention has a much broader range of applicability.

[0007] In a specific embodiment, the present invention provides a fan apparatus. The fan apparatus includes a ducted housing with an axis of rotation including a first section and a second section. Additionally, the fan apparatus includes a first plurality of vanes being radially coupled within the first section and a second plurality of vanes being radially coupled within the second section. Moreover, the fan apparatus includes an impeller with a plurality of blades rotateably disposed within the ducted housing between the first plurality of vanes and the second plurality of vanes for rotation about the axis of rotation. With respect to the ducted housing, the first plurality of vanes are stationary in a first arrangement to guide an inflow of air towards the impeller. The plurality of blades are rotary in a second arrangement to have a rotational direction substantially opposite to the inflow of air guided by the first arrangement. The second plurality of vanes are stationary in a third arrangement to diffuse an outflow of air substantially along the axis of rotation.

[0008] In another specific embodiment, the present invention provides a ducted fan apparatus. The ducted fan apparatus includes a housing enclosing an interior volume from a first end section to a second end section along an axis of rotation. The ducted fan apparatus further includes a first plurality of vanes being radially connected a stationary center core with respective surface positions of the interior volume of space near the first end section. Additionally, the ducted fan apparatus includes a second plurality of vanes being radially connected a stationary central structure with respective surface positions of the interior volume of space near the second end section. Moreover, the ducted fan apparatus includes an impeller including a plurality of blades rotatably disposed between the first plurality of vanes and the second plurality of vanes within the interior volume of space for rotary motion about the axis of rotation. Accordingly, each of the first plurality of vanes is in airfoil shape arranged with a first inlet angle and a first exit angle associated with a first tangential direction relative to the axis of rotation. Each of the plurality of blades is in airfoil shape arranged with a second exit angle and a second inlet angle associated with a second tangential direction relative to the axis of rotation.

[0009] In an alternate embodiment, the invention provides an apparatus for fluid flow processing application. The apparatus includes a ducted housing including a first section and a second section. The first section is mounted with the second section to share an axis of rotation. Additionally, the apparatus includes a fan unit disposed within the ducted housing. The fan unit consists of a first plurality of vanes, an impeller, and a second plurality of vanes. The first plurality of vanes are fixedly connected between the ducted housing and a stationary center core within the first section. The second plurality of vanes are fixedly connected between the ducted housing and a stationary central structure within a portion of the second section. The impeller includes a plurality of blades disposed between the first plurality of vanes and the second plurality of vanes for rotary motion about the axis of rotation. Correspondingly, the stationary center core and the stationary central structure are co-axial with the axis of rotation. The first plurality of vanes are arranged in a first arrangement for redirecting an inflow of fluid substantially along the axis of rotation to a direction substantially opposite to rotational direction of the plurality of blades. The plurality of blades are arranged in a second arrangement to swirl the redirected inflow of fluid, the second arrangement being associated with the first arrangement.

[0010] Many benefits are achieved by applying embodiments of the present invention. Certain embodiments of the invention provide a ducted fan apparatus with a unique com-
bination of a single rotating impeller disposed between two sets of stationary vanes. This can be configured to operate at relative high rotational speeds of 30,000 rpm or higher compared to conventional cooling fan running at speed of 15,000 rpm or lower. Additionally, the ducted fan configured according to certain embodiment of the present invention also advantageously differs from convention ducted fans with either a single set of stationary vanes at upstream or downstream of a rotating impeller. The advantage relies on the improved pressure compression characteristics. For example, the ducted fan according to an embodiment of the present invention can provide more air flow with pressure enhanced by about 20% while keeping the same fan frame size. Thus, the cooling efficiency of the fan is greatly improved. This is especially useful for effectively dissipate heat generated by many high-power and dense electronics, avionics, and telecommunication equipments. Alternatively, the ducted fan structure according certain embodiments of the present invention can also be applied for a small aircraft propulsion systems such as UAV’s due to the superior performance on high rotational speeds to handle large amount of air flow with high pressure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG. 1 is a schematic cross-sectional view of a ducted fan apparatus according to an embodiment of the present invention;

[0012] FIG. 2 is a 3-D prospective view of the ducted fan with relative location-and-orientation for all blades according to embodiments of the present invention;

[0013] FIG. 3 is a cut-off version of the ducted fan shown in FIG. 2;

[0014] FIG. 4 is a schematic view of orientations of stationary inlet guide vanes and stationary deswirl vanes relative to the rotating impeller blades according to an embodiment of the present invention;

[0015] FIG. 5 is an exemplary side view of the orientations of an impeller blade relative to an upstream stationary inlet guide vane and a downstream deswirl vane according to an embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0016] FIG. 1 is a schematic cross-sectional view of a ducted fan apparatus according to an embodiment of the present invention. This diagram is merely an example, which should not unduly limit the scope of the claims herein. One of ordinary skill in the art would recognize many variations, alternatives, and modifications. As shown, a fan apparatus includes three sets of blades sequentially disposed within a ducted housing 100 which has an interior surface enclosing an interior volume of space. In one embodiment, the ducted housing 100 includes a first section 101 and a second section 102 and is substantially symmetric around an axis of rotation 140. In one example, the first section 101 is located upstream of the second section 102 when the ducted fan apparatus is used for processing a flow of fluid including air. The interior volume of space is a cylindrical shape around the axis of rotation 140. In another example, the interior volume of space within the first section can have a different interior diameter from that within the second section. Additionally, the exterior body of the ducted housing 100 can be, but not limited to, a boxed shape. In one example, with a cross-section in a square shape. Other variations in both interior or exterior shape of the ducted housing can be possible and should not unduly limit the scope of the claims herein. For example, the first section 101 can be either integrally coupled to the second section 102 or mechanically detachable from the second section 102. In yet another example, the first section 101 has different exterior shape or size from that the second section 102.

[0017] In one embodiment, the three sets of blades include a first plurality of vanes 110 disposed within a portion of the interior volume of space of the ducted housing 100. In particular, each of the first plurality of vanes 110 is radially disposed around a hub 111 and fixedly coupled to respective positions on the interior surface within the first section 101. In a specific embodiment, the hub 111 is a stationary structure with respect to the ducted housing 100 so that the first plurality of vanes 110 fixedly coupled with the interior surface are also stationary with respect to the ducted housing 100. In an example, the first section 101 consisting a set of stationary vanes is mounted to the second section 102 of the ducted housing 100 by several screws from corresponding corner regions. Of course, there can be many alternatives, variations, and modifications. For example, each of the first plurality of vanes 110 can be radially arranged in a substantially symmetrical arrangement around the hub 111 coaxial with the axis of rotation 140. In one embodiment, the arrangement of the first plurality of stationary vanes 110 is configured to be an upstream structure of the ducted fan apparatus, including a specific airfoil shape with a leading edge and a trailing edge unique curvatures, and orientation, for receiving and guiding an inflow of air or other working fluid. Additionally, the arrangement delivers the guided inflow of air towards downstream structures of the ducted fan apparatus. More details about the ducted fan apparatus and associated flow processing mechanism according to certain embodiments of the present invention can be found throughout this specification and more particularly below.

[0018] Referring to FIG. 1, the three sets of blades include a plurality of blades 120 rotatably disposed downstream of the plurality of vanes 110 along the axis of rotation 140 within a portion of second section 102. In particular, the plurality of blades 120 radially coupled about a rotary hub to form an impeller 121 (enclosed within a dashed line box). The rotary hub is coupled to a shaft 122 coaxial with the axis of rotation 140 so that the plurality of blades or simply the impeller blades 120 are able to rotate about the axis of rotation 140. As shown, the shaft 122 rotatably couples to a stator 124 through bearings 125. The stator 124 draws power and torque from an electromagnetic stator windings 123.

[0019] In a specific embodiment, each impeller blade 120 is characterized by an airfoil shape having a leading edge and a trailing edge with corresponding curvatures and orientations relative to the axis of rotation 140. The leading edge of each impeller blade 120 is near the trailing edges of stationary vanes 110. Thus, the impeller 121 is configured to be a specific flow processing tool of the ducted fan apparatus through its rotary motion. In particular, the arrangement of the plurality of vanes 110 upstream of the impeller blades 120 is configured to transform an axial inflow of air into a swirl flow of air. Especially, the ducted fan configuration according to embodiments of the present invention provides a desired flow processing apparatus for operating the impeller at high rotational speeds. In one example, the impeller 121 is designed to operate at high rotational speeds of 30,000 rpm or higher. More details about the advantageous structures and function-
ality of the ducted fan apparatus according to certain embodiments of the present invention will be given later.

[0020] Referring to FIG. 1, again, a third set of blades is a plurality of vanes 130 disposed downstream of the impeller 121 within another portion of the second section 102. In particular, each of the plurality of vanes 130 is radially connected between a stationary hub 131 and corresponding interior surface position of the ducted housing 100. Therefore, each of the plurality of vanes 130 again is a stationary blade with respect to the ducted housing 100.

[0021] In another specific embodiment, the plurality of vanes 130 are arranged in another special arrangement downstream of the impeller 121, acting as an important part of the flow processing operation of the ducted fan apparatus. Each vane 130 includes an airfoil shape with a leading edge and a trailing edge formed in certain curvatures for its curved side surfaces and corresponding orientations with respect to the axis of rotation 140. In particular, the leading edge of each stationary airfoil shaped vane 130 is near the trailing edges off the rotary impeller blades 120. In one embodiment, the arrangement of the plurality of stationary vanes 130 downstream of the impeller blades 120 within the ducted housing 100 effectively is configured to deswirl the swirl flow of air and generate an axial outflow of air with improved capacity in terms of pressure enhancement. More detail descriptions about the advantageous structures and functionality of the ducted fan apparatus according to certain embodiments of the present invention will be found in following paragraphs.

[0022] FIG. 2 is a 3-D perspective view of the ducted fan apparatus for processing a flow of working fluid according to certain embodiments of the present invention. This diagram is merely an example, which should not unduly limit the scope of the claims herein. One of ordinary skill in the art would recognize many variations, alternatives, and modifications. As shown, the ducted fan apparatus includes a housing 100 having three sectional parts: a first section 101, a first portion 102a of a second section (enclosed within the dashed line box region next to first section 101), and a second portion 102b of the second section. The housing 100 encloses an interior volume of space. Correspondingly within interior volume of the first section 101, the ducted fan apparatus includes a first set of stationary vanes 110 disposed around an inlet hub 111. Within interior volume of the first portion 102a of the second section, the ducted fan apparatus includes an impeller 121 which includes a plurality of blades 120 configured to rotate about an axis of rotation 140. Additionally, within interior volume of the second portion 102b of the second section, the ducted fan apparatus further includes a second set of stationary vanes 130 disposed around an exit hub 131. In another embodiment, the first section 101 is shown to be a detachable element that can be screw-mounted with the second section (102a and 102b) by several screws at one or more corner regions.

[0023] The ducted fan apparatus is designed for processing a fluid flow 160 substantially along the axis of rotation 140. The first section 101 is designed to be an inlet for the fluid flow 160 and an end region of the second section to be an exit for the fluid flow 160. At the inlet the fluid to be processed is associated with a pressure \( P_1 \), and at the exit the fluid after the processing by the ducted fan is associated with another pressure \( P_2 \). Typical ducted fan with rotary impeller alone was able to achieve a pressure enhancement \( \Delta P = P_2 - P_1 \). According to certain embodiments, the ducted fan apparatus of the present invention can substantially improve fluid pressure enhancement performance. Depending on the flow characteristics, by disposing one set of stationary vanes upstream of the rotary impeller and another set of stationary vanes downstream of the impeller for the ducted fan apparatus can enhance the fluid pressure by 20-40% comparing to using the impeller alone. In one example, \( \Delta P \) can be enhanced by about 20% or higher. In another example, \( \Delta P \) can be enhanced by about 40% or higher. More details about the fluid processing of the ducted fan apparatus according to embodiments of the present invention can be found throughout the specification and particularly below.

[0024] As illustrated by FIG. 2, the first set of stationary vanes 110 are fixedly coupled between an inlet hub 111 and parts of the interior surface within the first section 101. Four vanes are shown, though the number of vanes is not limited to four. The inlet hub 111 is coaxial with the axis of rotation 140 and has a conical shape for facilitating axial inflow of the fluid. Additionally, each of the stationary vanes 110 is a properly curved blade and is radially arranged around the inlet hub 111 for facilitating both the flow reception and an intended flow redirection. In one example, the flow 160 near the inlet is guided into the first set of vanes 110 substantially in a direction along the axis of rotation 140. Subsequently, the flow 160 is redirected by the curved blades to an off-axis direction towards later section of the ducted fan apparatus, as indicated in FIG. 2 by downward arrow head with dashed line 161. Therefore, the first set of stationary vanes 110 are also called inlet guide vanes in certain part of the specification.

[0025] Downstream of the first set of stationary vanes 110, the impeller 121 having a plurality of blades 120 (or simply fan blades or impeller blades) is designed to rotate about the axis of rotation 140. In a specific embodiment, each of the plurality of impeller blades 120 has a properly curved shape and is radially disposed around a rotor in a special orientation. In one example shown in FIG. 2, the rotational direction is in a counter-clockwise direction 150 looked from the flow inlet. In this case, for every position surrounding the rotor, the off-axis direction 161 of the redirected flow from the first set of stationary vanes 110 becomes substantially opposite to the rotational directions 150 of the impeller 121. In another specific embodiment, the curvature of each impeller blade 120 and its relative orientation in association with the upstream stationary vane 110 determines, at least partially, fluid flow processing characteristics of the ducted fan apparatus. For example, the fluid flow is transformed from mostly an axial flow into a swirl flow with certain pressure enhancement. In one example, a ducted fan utilizing a set of stationary vanes upstream of an impeller according to certain embodiments of the present invention can achieve 10-20% pressure enhancement compared to a conventional ducted fan with an impeller alone. More details about the processing mechanism of the ducted fan apparatus can be found below.

[0026] Moreover, downstream of the impeller 121, a second set of stationary vanes 130 is fixedly disposed within the second portion 102b of the second section. Each of stationary vanes 130 has a properly curved shape and is arranged around a stationary hub with certain orientation in association with the plurality of impeller blades 120. Again arrangement combination of the second set of stationary vanes 130 and the plurality of impeller blades 120 collectively provide additional flow processing functionality of the ducted fan apparatus. For example, the second set of stationary vanes 130 effectively deswirls the swirl flow generated by the rotational impeller blades 120. Therefore, in certain part of the specifi-
cation, the second set of stationary vanes are also called deswirl vanes. Subsequently the deswirl vanes are configured to redirect the fluid flow 160 to an substantially axial outflow. FIG. 2 gives a schematic illustration of a whole journey of the fluid flow 160 from inlet to exit of the ducted fan apparatus. In addition, the fluid flow capacity is further enhanced by this stage of the ducted fan apparatus through a conversion of rotary kinetic energy to the fluid pressure. In one example, a ducted fan utilizing a set of stationary vanes downstream of an impeller according to certain embodiments of the present invention can achieve 10-20% pressure enhancement comparing to a conventional ducted fan with an impeller alone.

FIG. 3 is a cutaway view of the ducted fan apparatus shown in FIG. 2 to illustrate more structural details. In particular, the two sets of stationary vanes 110 and 130, the impeller with a plurality of impeller blades 120, some interior structures of the impeller, and the inlet hub 111 and exit hub 131 are illustrated. For example, the impeller is a cuffed electromagnetic motor including a shaft 122 rotatably coupled with a set of bearings 125, a stator 124 drawing torque power from a magnet windings 123. The stator 124 is also fixed with the exit hub 131. The conical shape of the inlet hub 111 is clearly revealed in this cutaway view. The exit hub 131 is shown as a straight cylinder shape and can be used as a housing for an impeller control board and other elements. Of course, other geometry shapes can be used for both inlet hub 111 and exit hub 131.

As shown above, merely by way of example, embodiments of the present invention provides a fan apparatus utilizing a ducted housing to enclose an impeller between two sets of stationary vanes, a first set of stationary vanes upstream of the impeller and another set of stationary vanes downstream of the impeller, for processing a fluid flow with enhanced output capacity. For example, the first set of stationary vanes, called inlet guide vanes, are disposed to an inlet section of the ducted housing for receiving and guiding an inflow of fluid. The second set of stationary vanes are disposed next to an exit of the ducted housing for guiding and diffusing an outflow of the fluid. The impeller itself, as an active fluid processing tool, is designed to create a swirl flow of fluid through its rotary motion at relatively high speeds. Overall the fluid flow processing characteristics of the fan apparatus is determined by the arrangements of each of those stationary vanes and rotary blades within the ducted housing.

According to an embodiment of the invention, the inlet guide vanes are fixedly arranged in unique setting angles (or orientation) in association with the rotating impeller blades relative to a common direction such as the axis of rotation. In one example, the arrangement of the inlet guide vanes allows the fan apparatus to draw a substantially axial inflow of fluid and redirect the fluid flow in a direction substantially opposite to rotational direction of the impeller. The arrangement of the impeller blades is able to transform the fluid flow delivered by the inlet guide vanes into a swirl flow of fluid. In a specific embodiment, the combination of the arrangement of the stationary inlet guide vanes and the arrangement of the rotary impeller blades in the fan apparatus, especially the curvature of each impeller blade, effectively provides an enhancement in fluid pressure. In addition, the arrangement of the second set of stationary vanes, called deswirl vanes, is designed to deswirl and redirect the swirl flow of fluid along the interior space of ducted housing. In one example, through the deswirl vanes, the swirl flow of fluid is transformed to an outflow of fluid in substantially axial direction. In another specific embodiment, the arrangement of the stationary deswirl vanes in association with the arrangement of the rotary impeller blades effectively provides additional enhancement in fluid pressure. In particular, the rotary kinetic energy of the swirl flow of fluid is converted into fluid pressure in above dwirling process. As an example, FIG. 2 schematically illustrates a whole path of an air flow processed by the ducted fan apparatus from an axial flow to a swirl flow and back to an axial flow, as indicated by a curved dash line 160. As a result, the air pressure is substantially enhanced from P1 before the flow inlet to P2 after the flow exit. Depending on flow characteristics and the arrangements of the blades in ducted fan apparatus, the fluid pressure enhancement P2-P1 can be improved 20-40% over a conventional ducted fan using an impeller alone.

FIG. 4 is a schematic side view of orientations of stationary inlet guide vanes and stationary deswirl vanes relative to the rotating impeller blades according to an embodiment of the present invention. This diagram is merely an example, which should not unduly limit the scope of the claims herein. One of ordinary skill in the art would recognize many variations, alternatives, and modifications. As shown, a set of stationary inlet guide vanes 410 are disposed upstream of a set of rotating impeller blades 420 which are further disposed upstream of another set of stationary deswirl vanes 430. Each piece of either the stationary vane or rotary blade is oriented with a specific angle relative to a fixed reference direction associated with the ducted housing. For example, the reference direction can be an axis of rotation 440 associated with the rotating impeller blades. Correspondingly, the rotational direction 450 of the impeller blades is perpendicular to the axis of rotation 440 in the side view.

In one specific embodiment, the ducted fan apparatus for processing a fluid flow is aligned such that the axis of rotation 440 is substantially the same as the inflow direction 441 of the fluid, and also as in a preferred design, the same as the outflow direction 442 of the fluid. In one example, the impeller blades 420 rotate in a counter-clockwise (CCW) direction when looking from upstream to downstream direction along the flow. In the side view, the rotational direction 450 appears a vertical up direction. In this configuration, the stationary inlet guide vanes 410 are arranged with certain curvature and orientation for each vane so that an axial inflow 441 is received and then redirected to a direction 441a which is bent down against the rotational direction 450.

Accordingly, the impeller blades 420 each is specifically curved and oriented to facilitate the reception of the redirected flow 441a by the inlet vanes 410, and further cause a swirl flow of the fluid in a direction tilting towards the stationary deswirl vanes 430. The deswirl vanes 430 each is also properly curved to redirect the swirl flow substantially back to a axial direction. As shown in the side view, a deswirled flow 442a is curved up and guided into the deswirl vanes 430, then is diffused out as an outflow 442 substantially along axial direction.

FIG. 5 is an exemplary side view of the orientations of an impeller blade relative to an upstream stationary inlet guide vane and a downstream deswirl vane according to an embodiment of the present invention. This diagram is merely an example, which should not unduly limit the scope of the claims herein. One of ordinary skill in the art would recognize many variations, alternatives, and modifications. Embodiments of the present invention described throughout the specification have shown that the specific flow processing
characteristics of the ducted fan apparatus relies in the advantageous arrangements and relative orientations of the impeller blades as well as upstream/downstream stationary vanes.

[0034] As an example, FIG. 5 shows that each stationary vane or impeller blade in general has a certain curved airfoil shape for facilitating the fluidic flow. The orientation for each vane or blade of all three types can be defined in terms of its setting angle relative to a reference direction. In one embodiment, relative to a fluid flow direction from an inflow 500 (upstream of the ducted fan apparatus) to an outflow 560 (downstream of the ducted fan apparatus) each vane or blade is characterized by a leading edge and a trailing edge connected by respective two curved sides. For example, the upstream stationary inlet guide vane 510 includes a leading edge 511 and a trailing edge 512 with sides bending down in the side view. Orientation of the inlet guide vane 510 can be defined by an inlet angle α1 and an exit angle α2 relative to a direction in parallel to the axis of rotation 540. In particular, the inlet angle α1 is a tangential angle associated with the leading edge 511. In one example, the inlet angle α1 is between 0 to 10 degrees around the axis of rotation 540. In one embodiment the inlet angle α1 is substantially aligned with the axis of rotation for facilitating the inflow of fluid 500 along the axis of rotation 540. The inlet angle α1 shown in FIG. 5 is exaggerated in the graphical illustration and may be drawn as an angle tilted below the line of axis of rotation within the scope of the invention. Similarly, the exit angle α2 is a tangential angle associated with the trailing edge 512. In one example, the exit angle α2 is between 30 degrees and 60 degrees relative to the axis of rotation. In other words, the exit angle α2 is associated with a tangential direction 512/ associated with the trailing edge 512. As the inlet guide vane 510 is curved (bent down in FIG. 5) the tangential direction 512/ is to some degrees pointed to a direction against a rotational direction 550 of the impeller blade 520 (an up direction in the side view). Nevertheless, the inflow of fluid through the inlet vane 510 is then redirected towards the impeller blade 520 in the direction 512/ substantially against the rotational direction 550.

[0035] Referring to FIG. 5, the impeller blade 520 also includes an airfoil shape with a leading edge 521 and a trailing edge 522. In one embodiment, the leading edge 521 is arranged to face the fluid flow in the direction 512/ redirected from the inlet guide vane 510 and is positioned to lead the trailing edge 522 in the rotational direction 550. In another embodiment, the impeller blade 520 is curved such that a concave side leads the convex side in the rotational direction 550 to direct a desired flow pressure enhancement. In particular, orientation of the impeller blade 520 according to above embodiments can be defined by an inlet angle β1 and an exit angle β2 relative to the axis of rotation 540. The inlet angle β1 is a concave side tangential angle associated with the leading edge 521. The exit angle β2 is a concave side tangential angle associated with the trailing edge 522. In one example, the inlet angle β1 is between 40 degrees and 80 degrees which may be selected based on a value of the exit angle α2 of the inlet guide vane 510. At the same time, the exit angle β2 is between 0 and 60 degrees and always is selected to be smaller than the inlet angle β1 by an angular difference Δβ=β1−β2>0. An math analysis has shown that a rotary motion of an impeller blade curved with such an inlet-to-exit angular difference is able to increase the fluid pressure by an amount proportional to the angular difference Δβ.

[0036] Additionally, as illustrated in FIG. 5, the tangential direction 521/ associated with the inlet angle β1 of the impeller blade 520 is disposed at some degrees opposite to the tangential direction 512/ associated with the exit angle β2 of the inlet guide vane 510, providing a modification of the fluid flow delivered towards the impeller blade. In a specific embodiment, adding a set of stationary inlet vane upstream of the impeller blades further enhance the pressure increase compared to that using the impeller blades alone (due to specific selection of inlet angle β1 and exit angle β2). The combination of the selection of angles α1, α2, β1, and β2 collectively determines the effective pressure increase in this stage of the ducted fan apparatus. In one example, the combination of the stationary inlet guide vane 510 arrangement and impeller blade 520 arrangement causes extra pressure enhancement by 10-20% depending on the flow characteristics and impeller rotational characteristics. In general, the selection criteria for these angles are further associated with, and are not limited to, flow characteristics for specific fluid type and density, flow rate and pressure as well as impeller rotational characteristics depending on natures of applications. For example, the ducted fan apparatus according to certain embodiments of the present invention can be applied to provide high speed air flow for high efficiency air cooling. In another example, the ducted fan apparatus according to certain embodiments of the present invention can be applied in small aircraft propulsion systems of UAV’s with relative high rotational speeds of 30,000 rpm or higher to provide sufficient fluid flow at high pressure within a limited fan frame size.

[0037] Referring to FIG. 5 again, a flow-processing result of the impeller blade 520 is to create a swirl flow of fluid through the rotary motion of the impeller blade in the direction 550. When looking the swirl flow of fluid locally relative to the concave side of the impeller blade 520, the fluid is pushed away by the impeller blade 520 substantially along a direction 522/ towards the stationary vane 530 downstream of the impeller. The stationary vane 530 is an airfoil shaped blade smoothly curved from a leading edge 531 to a trailing edge 532. In a specific embodiment, the leading edge 531 is disposed to face the fluid flow delivered by the rotating impeller blade 520. The trailing edge 532 is then disposed or oriented for diffuse a desired outflow 560 of the fluid. The curved and relative orientation of the stationary vane in association with the impeller blade according to certain embodiments of the invention further provide additional flow processing functionalities for the ducted fan apparatus.

[0038] In particular, orientation of the stationary vane 530 can be defined by an inlet angle α3 and an exit angle α4 relative to the axis of rotation 540. The inlet angle α3 is a tangential angle associated with the leading edge 531. The exit angle α4 is a tangential angle associated with the trailing edge 532. In one example, the inlet angle α3 is selected from 30 degrees to 60 degrees and the associated tangential direction is substantially opposite to the direction 522/ for facilitating the fluid flow to enter stationary vane 530. At the same time, the exit angle α4 is chosen to be substantially zero relative to the axis of rotation 540 for guiding the outflow 560 substantially along the axis of rotation 540. The exit angle α4 in FIG. 5 is exaggerated for illustration purpose and should still be within the scope of the invention if it is drawn as an angle below line of the axis of rotation.

[0039] In a specific embodiment, the orientation of the stationary vane 530 defined above in association with the arrangement of the impeller blade 520 collectively provide a
deswirling effect to the swirl flow of fluid by converting the rotary kinetic energy into fluid pressure. In particular, the concave side of the airfoil shaped vane 530 at least partially is able to slow down the fluid flow left the impeller blade 520 in direction 522/2. In this process, rotary kinetic energy of the fluid flow is effectively converted into static pressure in fluid. In one embodiment, adding a set of stationary vane down-stream of the impeller blade can effectively enhance the fluid pressure by the deswirling effect compared to that using the impeller alone. In one example, the combination of the impeller blade 520 arrangement and the deswirl vane 530 arrangement causes extra pressure enhancement by 10-20% depending on the flow characteristics and impeller rotational characteristics. Furthermore, the combination of an arrangement of set stationary inlet guide vanes upstream of the impeller blades and another arrangement of a set of stationary deswirl vanes downstream of the impeller blades can effectively enhance the fluid pressure up to 40% over conventional ducted fan including only an impeller.

[0040] Many benefits are achieved by applying embodiments of the present invention. Certain embodiments of the invention provide a ducted fan apparatus with a unique combination of a single rotating impeller disposed between two sets of stationary vanes. This can be configured to operate at relative high rotational speeds of 30,000 rpm or higher compared to conventional cooling fan running at speed of 15,000 rpm or lower. Additionally, the ducted fan configured according to certain embodiment of the present invention also advantageously differs from convention ducted fans with either a single set of stationary vanes at upstream or downstream of an rotating impeller. The advantage relies on the improved pressure compression characteristics. For example, the ducted fan according to an embodiment of the present invention can provide more air flow with pressure enhanced by about 20-40% while keeping the same fan frame size. Thus, the cooling efficiency of the fan is greatly improved. This is especially useful for effectively dissipate heat generated by many high-power and dense electronics, avionics, and telecommunication equipments. Alternatively, the ducted fan structure according certain embodiments of the present invention can also be applied for a small aircraft propulsion systems such as UAV’s due to the superior performance on high rotational speeds to handle large amount of air flow with high pressure.

[0041] It is also understood that the examples and embodiments described herein are for illustrative purposes only and that various modifications or changes in light thereof will be suggested to persons skilled in the art and are to be included within the spirit and purview of this application and scope of the applied claims.

What is claimed is:

1. A fan apparatus comprising: a ducted housing having an first section and a second section; an impeller having a plurality of blades rotatably disposed within the second section for rotary motion about an axis of rotation, the plurality of blades being arranged in a first arrangement radially about the axis of rotation; a first plurality of vanes fixedly disposed within the first section upstream of the impeller and arranged in a second arrangement radially about the axis of rotation; and a second plurality of vanes fixedly disposed within the second section downstream of the impeller and arranged in a third arrangement radially about the axis of rotation;

wherein:

- the second arrangement of the first plurality of vanes is stationary with respect to the ducted housing to redirect an axial inflow of air to a direction against direction of rotation of the impeller;
- the third arrangement of the second plurality of vanes is stationary with respect to the ducted housing to diffuse an outflow of air in a direction substantially along the axis of rotation.

2. The fan apparatus of claim 1 wherein each of the first plurality of vanes comprises an airfoil shape having a first leading edge facing the inflow of air and a corresponding first trailing edge.

3. The fan apparatus of claim 2 wherein:

- the first leading edge is associated with a first inlet angle measured about 10 degrees or less from a corresponding tangential direction to the axis of rotation;
- the first trailing edge is associated with a first exit angle measured about 30 degrees to 60 degrees from a corresponding tangential direction to the axis of rotation.

4. The fan apparatus of claim 1 wherein each of the plurality of blades comprises an airfoil shape having a second leading edge disposed near the first trailing edge and a corresponding second trailing edge.

5. The fan apparatus of claim 4 wherein:

- the second leading edge is associated a second inlet angle measured about 40 degrees to 80 degrees from a corresponding tangential direction to the axis of rotation;
- the second trailing edge is associated with a second exit angle measured about 0 degrees to 60 degrees from a corresponding tangential direction to the axis of rotation.

6. The fan apparatus of claim 5 wherein the second exit angle is smaller than the second inlet angle.

7. The fan apparatus of claim 5 wherein the first arrangement of the rotary impeller is associated with the second arrangement of the stationary first plurality of vanes to transform the axial inflow of air into a swirl flow of air with a first increase in air pressure.

8. The fan apparatus of claim 7 wherein the first increase in air pressure is proportional to a difference between the second inlet angle and the second exit angle.

9. The fan apparatus of claim 7 wherein the first increase in air pressure comprises a 10-to-20% pressure enhancement compared to use the rotary impeller alone.

10. The fan apparatus of claim 1 wherein each of the second plurality of vanes comprises an airfoil shape having a third leading edge disposed near the second trailing edge and a corresponding third trailing edge.

11. The fan apparatus of claim 10 wherein:

- the third leading edge is associated with a third inlet angle measured about 30 degrees to 60 degrees from a corresponding tangential direction to the axis of rotation;
- the third trailing edge is associated with a third exit angle measured about 10 degrees or less from a corresponding tangential direction to the axis of rotation.

12. The fan apparatus of claim 10 wherein the second increase of air pressure comprises a 10-to-20% pressure enhancement compared to use the rotary impeller alone.
14. A ducted fan apparatus comprising:
a housing having an interior surface enclosing an interior
volume of space;
a first plurality of vanes radially disposed about a first
stationary hub and connected to corresponding portions
of the interior surface of the housing;
an impeller including a plurality of blades disposed down-
stream of the first plurality of vanes radially within the
interior volume of space for rotary motion about an axis
of rotation;
a second plurality of vanes disposed downstream of the
impeller, the second plurality of vanes being radially
arranged about a second stationary hub and connected to
alternative corresponding portions of the interior surface
of the housing; and
wherein:
each of the first plurality of vanes has an airfoil shape
including a leading edge arranged with a first inlet
angle relative to the axis of rotation and a trailing edge
arranged with a first exit angle relative to the axis of
rotation, the first exit angle subtended in a direction
against direction of rotation of the impeller;
each of the plurality of blades has an airfoil shape includ-
ing a leading edge arranged with a second inlet angle rela-
tive to the axis of rotation and a trailing edge
arranged with a second exit angle relative to the axis of
rotation;
each of the second plurality of vanes has an airfoil shape
including a leading edge arranged with a third inlet
angle relative to the axis of rotation and a trailing edge
arranged with a third exit angle relative to the axis of
rotation.
15. The ducted fan apparatus of claim 14 wherein the rotary
motion of the impeller comprises operational rotation speeds
about 30,000 rpm or higher.
16. The ducted fan apparatus of claim 14 wherein the first
inlet angle is substantially equal to zero for facilitating an
axial inflow of fluid into the ducted fan.
17. The ducted fan apparatus of claim 16 wherein the first
exit angle is measured between 30 degrees and 60 degrees for
redirecting the axial inflow of fluid towards the impeller in the
direction against direction of rotation of the impeller.
18. The ducted fan apparatus of claim 16 wherein:
the second inlet angle is between 40 degrees and 80
degrees;
the second exit angle is between 0 degrees and 60 degrees
and is smaller than the second inlet angle by a angular
difference.
19. The ducted fan apparatus of claim 18 wherein the first
plurality of vanes and the plurality of blades collectively
cause a swirl flow of fluid with a first increase of fluid pressure
proportional to the angular difference.
20. The ducted fan apparatus of claim 19 wherein the first
increase of fluid pressure comprises a 10-20% pressure
enhancement compared to use the impeller alone.
21. The ducted fan apparatus of claim 19 wherein:
the third inlet angle is between 30 degrees and 60 degrees;
the third exit angle is substantially equal to zero for diffusing
an outflow of air substantially along the axis of rotation.
22. The ducted fan apparatus of claim 19 wherein the
plurality of blades and the second plurality of vanes collec-
tively deswirl the swirl flow of fluid by converting rotary
kinetic energy into pressure and cause a second increase of
fluid pressure.
23. The ducted fan apparatus of claim 22 wherein the second
increase of fluid pressure comprises a 10-20% pressure
enhancement compared to use the impeller alone.
24. The ducted fan apparatus of claim 14 wherein the first
stationary hub is a rounded cone shape for facilitating the
redirection of the axial inflow of fluid towards the rotary
impeller.
25. The ducted fan apparatus of claim 14 wherein the
second stationary hub is a housing of a control board for the
impeller.
26. An apparatus for processing fluid flow, the apparatus
comprising:
a ducted housing including a first section and a second
section, the first section being mounted with the second
section;
a set of blades disposed within the ducted housing, the set
of blades consisting a first plurality of stationary vanes,
a plurality of rotary blades, and a second plurality of
stationary vanes, the first plurality of stationary vanes
disposed within the first section upstream of the plurality
of rotary blades, the second plurality of stationary vanes
disposed downstream of the plurality of rotary blades
within the second section;
wherein:
the plurality of rotary blades are radially arranged in a
first arrangement about a rotor having an axis of rota-
tion;
the first plurality of stationary vanes are radially
arranged in a second arrangement about the axis of
rotation;
the second plurality of stationary vanes are radially
arranged in a third arrangement about the axis of
rotation;
the second arrangement is associated with the first
arrangement to guide an axial inflow of fluid to a
direction against direction of rotation of the rotary
blades;
the third arrangement is associated with the first arrange-
ment to generate an axial outflow of fluid with an
enhanced fluid pressure over the axial inflow of fluid.
27. The apparatus of claim 26 wherein the plurality of
rotary blades radially arranged in a first arrangement about a
rotor comprises an impeller capable of rotating with speeds of
30,000 rpm or higher.
28. The apparatus of claim 26 wherein:
the second arrangement comprises a first inlet angle and a
first exit angle for each of the first plurality of stationary
vanes;
the first arrangement comprises a second inlet angle and a
second exit angle for each of the plurality of rotary
blades;
the third arrangement comprises a third inlet angle and a
third exit angle for each of the second plurality of sta-
tionary vanes.
29. The apparatus of claim 28 wherein:
the first inlet angle is measured about 10 degrees or less
from a leading-edge tangential direction to the axis of
rotation;
the first exit angle is measured about 30 degrees to 60
degrees from a corresponding trailing-edge tangential
direction to the axis of rotation;
the second inlet angle is measured about 40 degrees to 80 degrees, depending on the first exit angle, from a leading-edge tangential direction to the axis of rotation; the second exit angle is measured about 0 degrees to 60 degrees from a corresponding trailing-edge tangential direction to the axis of rotation; the third inlet angle is a measured about 30 degrees to 60 degrees from a leading-edge tangential direction to the axis of rotation; the third exit angle is a substantially equal to zero from a corresponding trailing-edge tangential direction to the axis of rotation.

30. The apparatus of claim 29 wherein the second inlet angle is larger than the second exit angle so that the plurality of rotary blades cause a first increase of fluid pressure proportional to a difference between the second inlet angle and the second exit angle.

31. The apparatus of claim 29 wherein combination of the second arrangement and the first arrangement collectively causes a second increase of fluid pressure, the second increase is 10-20% greater than the first increase.

32. The apparatus of claim 29 wherein combination of the third arrangement and the first arrangement collectively causes a third increase of fluid pressure, the third increase is 10-20% greater than the first increase.

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