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CUFFED FAN BLADE MODIFICATIONS

Richard Michael Aynsley

J. Carey Smith

Richard W. Fizer

PRIORITY

[0001] This application is a continuation-in-part of U.S. Patent Application Serial No. 11/777,344, entitled "Fan Blade Modifications," filed July 13, 2007, which is incorporated by reference herein, and which is a continuation of U.S. Patent Application Serial No. 11/046,341, entitled "Fan Blade Modifications," filed January 28, 2005, now U.S. Patent No. 7,252,478, which is incorporated by reference herein, and which claims priority from the disclosure of U.S. Provisional Patent Application Serial No. 60/589,945, entitled "Fan Blades and Modifications," filed July 21, 2004, which is incorporated by reference herein.

BACKGROUND OF THE INVENTION

[0002] The present invention relates generally to fan blades and fan blade modifications, and is particularly directed to an airfoil suitable for use with a fan blade and a winglet suitable for use with a fan blade.

[0003] People who work in large structures such as warehouses and manufacturing plants may be exposed to working conditions that range from being uncomfortable to hazardous. The same may also apply in agricultural settings, such as in a structure that is full of livestock. On a hot day, the inside air temperature may reach a point where a person or other animal is unable to maintain a healthy or otherwise desirable body temperature. In areas where temperatures are uncomfortably or unsafely high, it may be desirable to have a device operable to create

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or enhance airflow within the area. Such airflow may, in part, facilitate a reduction in temperature in the area.

[0004] Moreover, some activities that occur in these environments, such as welding or operating internal combustion engines, may create airborne contaminants that can be deleterious to those exposed. The effects of airborne contaminants may be magnified if the air flow in the area is less than ideal. In these and similar situations, it may be desirable to have a device operable to create or enhance airflow within the area. Such airflow may, in part, facilitate the reduction of deleterious effects of contaminants, such as through dilution and/or removal of contaminants.

[0005] In certain structures and environments, a problem may arise with heat gathering and remaining near the ceiling of the structure. This may be of concern where the area near the floor of the structure is relatively cooler. Those of ordinary skill in the art will immediately recognize disadvantages that may arise from having this or other imbalanced air/temperature distribution. In these and similar situations, it may be desirable to have a device operable to create or enhance airflow within the area. Such airflow may, in part, facilitate de-stratification and the inducement of a more ideal air/temperature distribution.

[0006] It may also be desirable to have a fan capable of reducing energy consumption. Such a reduction of energy consumption may be effected by having a fan that runs efficiently (e.g., less power is required to drive the fan as compared to other fans). A reduction of energy consumption may also be effected by having a fan that improves air distribution, thereby reducing heating or cooling costs associated with other devices.

BRIEF DESCRIPTION OF THE DRAWINGS

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- [0007] The accompanying drawings incorporated in and forming a part of the specification illustrate several aspects of the present invention, and together with the description serve to explain the principles of the invention; it being understood, however, that this invention is not limited to the precise arrangements shown. In the drawings, like reference numerals refer to like elements in the several views. In the drawings:
- [0008] Fig. 1 is a plan view of a hub for mounting fan blades.
- [0009] Fig. 2 is a cross-sectional view of an exemplary fan blade airfoil.
- [0010] Fig. 3 is a cross-sectional view of an alternative exemplary fan blade airfoil
- [0011] Fig. 4 depicts a graph showing two ellipses.
- [0012] Fig. 5 depicts a portion of the graph of Fig. 4.
- [0013] Fig. 6 is side view of an exemplary winglet fan blade modification
- [0014] Fig. 7 is a cross-sectional view of the winglet of Fig. 6.
- [0015] Fig. 8 is a top view of the winglet of Fig. 6.
- [0016] Fig. 9 is an end view of the fan blade of Fig. 2 modified with the winglet of Fig. 6.
- [0017] Fig. 10 is an exploded perspective view of the winglet-blade assembly of Fig. 9.
- [0018] Fig. 11 is a perspective view of an exemplary alternative winglet.
- [0019] Fig. 12 is a perspective view of the winglet of Fig. 11 mounted to a fan blade.
- [0020] Fig. 13 is a cross-sectional view of the winglet-blade assembly of Fig. 12.

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[0021] Reference will now be made in detail to the present preferred embodiment of the invention, an example of which is illustrated in the accompanying drawings.

DETAILED DESCRIPTION OF AN EMBODIMENT OF THE INVENTION

[0022] Referring now to the drawings in detail, wherein like numerals indicate the same elements throughout the views, Fig. 1 shows exemplary fan hub (10), which may be used to provide a fan having fan blades (30 or 50). In the present example, fan hub (10) includes a plurality of hub mounting members (12) to which fan blades (30 or 50) may be mounted. In one embodiment, fan hub (10) is coupled to a driving mechanism for rotating fan hub (10) at selectable or predetermined speeds. A suitable hub assembly may thus comprise hub (10) and a driving mechanism coupled to hub (10). Of course, a hub assembly may include a variety of other elements, including a different hub, and fan hub (10) may be driven by any suitable means. In addition, fan hub (10) may have any suitable number of hub mounting members (12).

[0023] As shown in Figs. 1 through 3, each hub mounting member (12) has top surface (14) and bottom surface (16), which terminate into leading edge (18) and trailing edge (20). In addition, each hub mounting member (12) includes opening (22) formed through top surface (14) and going through bottom surface (16). In the present example, opening (22) is sized to receive fastener (26). Each hub mounting member (12) is configured to receive fan blade (30 or 50). Those of ordinary skill in the art will appreciate in view of the present disclosure that hub mounting members (12) may be provided in a variety of alternative configurations.

[0024] In one embodiment, fan blades (30 or 50) are mounted to the hub assembly disclosed in U.S. Patent No. 6,244,821. Of course, fan blades (30 or 50) may be mounted to any other hub and/or hub assembly. A

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suitable hub assembly may be operable to rotate hub (10) at any suitable angular speed. By way of example only, such angular speed may be anywhere in the range of approximately 7 and 108 revolutions per minute.

[0025] Fig. 2 shows a cross section of exemplary fan blade (30) having curled trailing edge (38), mounted to hub (10). The cross section is taken along a transverse plane located at the center of fan blade (30), looking toward hub (10). Fan blade (30) has top surface (32) and bottom surface (34), each of which terminate into leading edge (36) and trailing edge (38). As shown, trailing edge (38) has a slope of approximately 45° relative to portion of top surface (32) that is proximate to trailing edge (38) and portion of bottom surface (34) that is proximate to trailing edge (38). Of course, trailing edge (38) may have any other suitable slope, such as 0° by way of example only, to the extent that it comprises a single, flat surface. Other suitable trailing edge (38) configurations will be apparent to those of ordinary skill in the art in view of the teachings herein.

[0026] In the present example, fan blade (30) is substantially hollow. A plurality of ribs or bosses (40) are located inside fan blade (30). As shown, when hub mounting member (12) is inserted into fan blade (30), ribs or bosses (40) are positioned such that they contact top surface (14), bottom surface (16), leading edge (18), and trailing edge (20) of hub mounting member (12). Bosses (40) thus provide a snug fit between fan blade (30) and hub mounting member (12). Alternative configurations for fan blade (30), including but not limited to those affecting the relationship between fan blade (30) and hub mounting member (12), will be apparent to those of ordinary skill in the art in view of the teachings herein.

[0027] As used herein, terms such as “chord,” “chord length,” “maximum thickness,” “maximum camber,” “angle of attack,” and the like, shall be ascribed the same meaning ascribed to those terms as used in the art of airplane wing or other airfoil design. In one embodiment, fan blade

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(30) has a chord length of approximately 6.44 inches. Fan blade (30) has a maximum thickness of approximately 16.2% of the chord; and a maximum camber of approximately 12.7% of the chord. The radius of leading edge (36) is approximately 3.9% of the chord. The radius of trailing edge (38) quadrant of bottom surface (34) is approximately 6.8% the chord. In an alternate embodiment, fan blade (30) has a chord of approximately 7 inches. In another embodiment, fan blade (30) has a chord of approximately 6.6875 inches. Of course, any other suitable dimensions and/or proportions may be used.

[0028] By way of example only, fan blade (30) may display lift to drag ratios ranging from approximately 39.8, under conditions where the Reynolds Number is approximately 120,000, to approximately 93.3, where the Reynolds Number is approximately 250,000. Of course, other lift to drag ratios may be obtained with fan blade (30).

[0029] In one embodiment, fan blade (30) displays drag coefficients ranging from approximately 0.027, under conditions where the Reynolds Number is approximately 75,000, to approximately 0.127, where the Reynolds Number is approximately 112,500. Of course, other drag coefficients may be obtained with fan blade (30).

[0030] In one example, under conditions where the Reynolds Number is approximately 200,000, fan blade (30) moves air such that there is a velocity ratio of approximately 1.6 at bottom surface (34) at trailing edge (38) of fan blade (30). Other velocity ratios may be obtained with fan blade (30).

[0031] In one embodiment, fan blade (30) provides non-stall aerodynamics for angles of attack between approximately -1° to 7° , under conditions where the Reynolds Number is approximately 112,000; and angles of attack between approximately -2° to 10° , where the Reynolds number is approximately 250,000. Of course, these values are merely exemplary.

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[0032] Fig. 3 shows a cross section of another exemplary fan blade (50) having generally elliptical top surface (52) and bottom surface (54), each of which terminate in leading edge (56) and trailing edge (58), mounted to hub (10). The cross section is taken along a transverse plane located at the center of fan blade (50), looking toward hub (10). In the present example, fan blade (50) is hollow. A plurality of bosses (60) are located inside fan blade (50). As shown, when hub mounting member (12) is inserted into fan blade (50), bosses (60) are positioned such that they contact top surface (14), bottom surface (16), leading edge (18), and trailing edge (20) of hub mounting member (12). Bosses (60) thus provide a snug fit between fan blade (50) and hub mounting member (12). Alternative configurations for fan blade (50), including but not limited to those affecting the relationship between fan blade (50) and hub mounting member (12), will be apparent to those of ordinary skill in the art in view of the teachings herein.

[0033] As shown, fan blade (50) has a lower radius of curvature toward its leading edge (56), as compared to a higher radius of curvature toward its trailing edge (58). The curvatures of fan blade (50) may be obtained, at least in part, through the generation of two ellipses using the following formulae. In view of the teachings herein, those of ordinary skill in the art will appreciate that a first ellipse, with its origin at the intersection of Cartesian x and y axes, may be generated by these equations:

[0034] [1] $x = a(\cos(t))$, and

[0035] [2] $y = b(\sin(t))$,

[0036] where

[0037] a = length of primary radius,

[0038] b = length of secondary radius, and

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- [0039] t = angle of rotation of a radius about the origin (e.g., in radians).
- [0040] Accordingly, a first ellipse may be generated using the foregoing equations. Similarly, a set of coordinates for the first ellipse may be obtained using equations [1] and [2]. Exemplary first ellipse (200) is illustrated in the graph depicted in Fig. 4, where $a = 3$ and $b = 2$.
- [0041] Coordinates for a second ellipse may be obtained using these equations:
- [0042] [3] $x_2 = x(\cos(\Theta)) - y(\sin(\Theta))$, and
- [0043] [4] $y_2 = y(\cos(\Theta)) + x(\sin(\Theta))$,
- [0044] where
- [0045] x_2 = the second “x” coordinate after a counterclockwise rotation of the first ellipse through Θ radians about the origin, and
- [0046] y_2 = the second “y” coordinate after a counterclockwise rotation of the first ellipse through Θ radians about the origin.
- [0047] Thus, the dimensions of the second ellipse are dependent on the dimensions of the first ellipse. Exemplary second ellipse (300) is illustrated in the graph depicted in Fig. 4, where $\Theta = 0.525$ radians. In view of the teachings herein, it will be appreciated that, where a first and second ellipse are plotted in accordance with equations [1] through [4], the two ellipses may intersect at four points (“ellipse intersections”). Fig. 4 shows four ellipse intersections (400) between first ellipse (200) and second ellipse (300).
- [0048] The curvature of top surface (52) and bottom surface (54) may be based, at least in part, on the curvature of the first and second ellipses between two consecutive ellipse intersections. An example of such a segment of first ellipse (200) and second ellipse (300) is shown in Fig. 5, which depicts the portion of ellipses (200 and 300) between

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consecutive ellipse intersections (400). Accordingly, equations [1] through [4] may be used to generate surface coordinates for at least a portion of top surface (52) and bottom surface (54) of fan blade (50).

[0049] In view of the teachings herein, it will be appreciated that the chord length-to-thickness ratio of fan blade (50) may vary with the amount of rotation, Θ , relative the two ellipses.

[0050] Of course, portions of fan blade (50) may deviate from the curvature of the first and second ellipses. By way of example only, and as shown in Fig. 3, leading edge (56) may be modified to have a generally circular curvature. Other deviations will be apparent to those of ordinary skill in the art in view of the teachings herein.

[0051] In one embodiment, fan blade (50) is created using equations [1] through [4] with $a = 3$ units, $b = 2$ units, and $\Theta = 0.525$ radians. In this embodiment, fan blade (50) is fit with circular leading edge (56) having a diameter of 3.5% of chord length. This leading (56) edge curvature is fit tangentially to that of top surface (52) and bottom surface (54). Such a fit may be envisioned by comparing Figs. 3 and 5. Of course, other dimensions may be used.

[0052] In one embodiment, fan blade (50) has a chord length of approximately 7.67 inches. In another embodiment, fan blade has a chord length of approximately 7.687 inches. Of course, fan blade (50) may have any other suitable chord length.

[0053] In the present example, the radius of leading edge (56) is approximately 3.5% of the chord. The maximum thickness of fan blade (50) is approximately 14.2% of the chord. The maximum camber of fan blade (50) is approximately 15.6% of the chord. Of course, any other suitable dimensions and/or proportions may be used.

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- [0054] In one example, a fan having a 24-foot diameter and comprising ten fan blades (50) mounted at an angle of attack of 10° produces a thrust force of approximately 5.2 lb. when rotating at approximately 7 revolutions per minute (rpm), displacing approximately 87,302 cubic feet per minute (cfm). When rotating at approximately 14 rpm, the fan produces a thrust force of approximately 10.52 lb., displacing approximately 124,174 cfm. When rotating at approximately 42 rpm, the fan produces a thrust force of approximately 71.01 lb., displacing approximately 322,613 cfm. Other thrust forces and/or displacement volumes may be obtained with a fan having fan blades (50).
- [0055] By way of example only, fan blade (50) having an angle of attack of approximately 10° may display lift to drag ratios ranging from approximately 39, under conditions where the Reynolds Number is approximately 120,000, to approximately 60, where the Reynolds Number is approximately 250,000. Other lift to drag ratios may be obtained with fan blade (50).
- [0056] In one embodiment, fan blade (50) provides non-stall aerodynamics for angles of attack between approximately 1° to 11° , under conditions where the Reynolds Number is approximately 112,000; for angles of attack between approximately 0° and 13° , where the Reynolds number is approximately 200,000; and for angles of attack between approximately 1° to 13° , where the Reynolds number is approximately 250,000. Of course, these values are merely exemplary.
- [0057] In one example, a fan having a 14-foot diameter and comprising ten fan blades (50) is rotated at approximately 25 rpm. The fan runs at approximately 54 watts, with a torque of approximately 78.80 inch-pounds (in.lbs.) and a flow rate of approximately 34,169 cfm. The fan thus has an efficiency of approximately 632.76 cfm/Watt.

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- [0058] In another example, a fan having a 14-foot diameter and comprising ten fan blades (50) is rotated at approximately 37.5 rpm. The fan runs at approximately 82 watts, with a torque of approximately 187.53 inch-pounds (in.lbs.) and a flow rate of approximately 62,421 cfm. The fan thus has an efficiency of approximately 761.23 cfm/Watt.
- [0059] In yet another example, a fan having a 14-foot diameter and comprising ten fan blades (50) is rotated at approximately 50 rpm. The fan runs at approximately 263 watts, with a torque of approximately 376.59 inch-pounds (in.lbs.) and a flow rate of approximately 96,816 cfm. The fan thus has an efficiency of approximately 368.12 cfm/Watt.
- [0060] The following may be applied to any fan blade, including by way of example only, fan blade (30) or fan blade (50):
- [0061] In one embodiment, each fan blade (30 or 50) comprises a homogenous continuum of material. By way of example only, fan blades (30 and 50) may be constructed of extruded aluminum. However, in view of the teachings herein, it will be appreciated that fan blades (30 and/or 50) may be constructed of any other suitable material or materials, including but not limited to any metal and/or plastic. In addition, it will be appreciated in view of the teachings herein that fan blades (30 and/or 50) may be made by any suitable method of manufacture, including but not limited to stamping, bending, welding, and/or molding. Other suitable materials and methods of manufacture will be apparent to those of ordinary skill in the art in view of the teachings herein.
- [0062] When fan blade (30 or 50) is mounted to hub (10), hub mounting members (12) may extend into fan blade (30 or 50) approximately 6 inches, by way of example only. Alternatively, hub mounting members (12) may extend into fan blade (30 or 50) to any suitable length. It will also be appreciated in view of the teachings herein that

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hub (10) may have mounting members (12) that fit on the outside of fan blades (30 or 50), rather than inside. Alternatively, mounting members (12) may fit both partially inside and partially outside fan blades (30 or 50).

[0063] Fan blade (30 or 50) may also include one or more openings configured to align with openings (22) in hub mounting member (12). In this embodiment, when openings in fan blade (30 or 50) are aligned with openings (22) in hub mounting member (12), fastener (26) may be inserted through the openings to secure fan blade (30 or 50) to hub mounting member (12). In one embodiment, fastener (26) is a bolt. Other suitable alternatives for fastener(s) (26) will be apparent to those of ordinary skill in the art in view of the teachings herein, including but not limited to adhesives, welding, etc. Accordingly, it will be understood that openings (22) are optional.

[0064] Fan blade (30 or 50) may be approximately 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, or 14 feet long. Alternatively, fan blade (30 or 50) may be of any other suitable length. In one embodiment, fan blade (30 or 50) and hub (10) are sized such that a fan comprising fan blades (30 or 50) and hub (10) has a diameter of approximately 24 feet. In another embodiment, fan blade (30 or 50) and hub (10) are sized such that a fan comprising fan blades (30 or 50) and hub (10) has a diameter of approximately 14 feet. Other suitable dimensions will be apparent to those of ordinary skill in the art in view of the teachings herein.

[0065] In view of the teachings herein, it will be appreciated that all cross sections along the length of fan blade (30 or 50) need not be identical. In other words, the configuration of fan blade (30 or 50) need not be uniform along the entire length of fan blade (30 or 50). By way of example only, a portion of the "hub mounting end" of fan blade (30 or 50) (i.e. the end of fan blade (30 or 50) that will be mounted to hub (10))

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may be removed. In one example, an oblique cut is made to leading edge (56) of fan blade (50) to accommodate another blade (50) on hub (10).

[0066] Alternatively, fan blade (30 or 50) may be formed or constructed such that a portion of the hub mounting end or another portion is omitted, relieved, or otherwise “missing.” It will be appreciated in view of the teachings herein that the absence of such a portion (regardless of whether it was removed or never there to begin with) may alleviate problems associated with blades (30 or 50) interfering with each other at hub (10). Such interference may be caused by a variety of factors, including but not limited to chord length of fan blades (30 or 50). Of course, factors other than interference may influence the removal or other absence of a portion of fan blade (30 or 50). The absent portion may comprise a portion of leading edge (36 or 56), a portion of trailing edge (38 or 58), or both.

[0067] Alternatively, to address fan blade (30 or 50) interference at hub (10), the diameter of hub may be increased (e.g., such as without increasing the number of hub mounting members (12)). Alternatively, the chord of fan blades (30 or 50) may be reduced. Still other alternatives and variations of hub (10) and/or fan blades (30 or 50) will be apparent to those of ordinary skill in the art in view of the teachings herein.

[0068] In view of the teachings herein, those of ordinary skill in the art will appreciate that fan blade (30 or 50) may have a zero or non-zero angle of attack. By way of example only, when mounted to hub mounting member (12), fan blade (30 or 50) may have an angle of attack in the range of approximately -1° to 7° , inclusive; between -2° and 10° , inclusive; or approximately 7° , 8° , 10° , or 13° by way of example only. Of course, fan blade (30 or 50) may have any other suitable angle of attack. Fan blade (30 or 50) may be substantially straight along its length, and the angle of attack may be provided by having hub mounting member (12) with the desired angle of attack.

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[0069] Alternatively, the angle of attack of hub mounting member (12) may be zero, and an angle of attack for fan blade (30 or 50) may be provided by a twist in fan blade (30 or 50). In other words, fan blade (30 or 50) may be substantially straight along the length to which hub mounting member (12) extends in fan blade (30 or 50), and a twist may be provided to provide an angle of attack for the remaining portion of fan blade (30 or 50). Such a twist may occur over any suitable length of fan blade (30 or 50) (e.g. the entire remainder of fan blade (30 or 50) length has a twist; or the twist is brief, such that nearly all of the remainder of fan blade (30 or 50) is substantially straight; etc.). Still other suitable configurations and methods for providing an angle of attack for all or part of fan blade (30) will be apparent to those of ordinary skill in the art in view of the teachings herein. In addition, it will be appreciated in view of the teachings herein that all or any portion of fan blade (30 or 50) may have one or more twists for any purpose.

[0070] Those of ordinary skill in the art will appreciate that a fan blade (e.g., 30 or 50) may be modified in a number of ways, in view of the teachings herein. Such modifications may alter the characteristics of fan performance. As illustrated in exemplary form in Figs. 6 through 10, one such modification may include winglet (70). While winglets (70) will be discussed in the context of fan blades (30 and 50), it will be appreciated in view of the teachings herein that winglets (70) may be used with any other suitable fan blades.

[0071] Winglet (70) of the present example includes vertical member (72). Vertical member (72) comprises flat inner surface (74) and rounded outer surface (76). Other suitable configurations for inner surface (74) and outer surface (76) will be apparent to those of ordinary skill in the art in view of the teachings herein. In the present example, the perimeter of vertical member (72) is defined by lower edge (78), upper edge (80), and rear edge (82). Each edge (78, 80, and 82) meets

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generally at respective corner (84). Thus, in the present example, vertical member (72) has three corners (84). As shown, each corner (84) is rounded. Accordingly, the term “corner,” as that term is used herein, shall not be read to require a sharp angle. In other words, a corner need not be limited to a point or region at which a pair of straight lines meet or intersect. While in the present example vertical member (72) is described as having three corners, it will be appreciated in view of the teachings herein that vertical member (72) may have any suitable number of corners (84).

[0072] Other variations of vertical member (72) will be apparent to those of ordinary skill in the art in view of the teachings herein.

[0073] Winglet (70) of the present example further includes winglet mounting member (90), which extends substantially perpendicularly from inner surface (74) of vertical member (72). As shown, winglet mounting member (90) is configured similar to hub mounting member (12). Winglet mounting member (90) has top surface (92) and bottom surface (94), which each terminate into leading edge (96) and trailing edge (98). In addition, each winglet mounting member (92) includes openings (100) formed through top surface (92) and bottom surface (94). In the present example, each opening (100) is sized to receive fastener (26). Winglet mounting member (90) is configured to be inserted into an end of fan blade (30 or 50). In view of the teachings herein, those of ordinary skill in the art will appreciate that winglet mounting members (90) may be provided in a variety of alternative configurations.

[0074] Fig. 9 shows a cross section of fan blade (30) with winglet (70) mounted thereto. The cross section is taken along a transverse plane located at the center of fan blade (30), looking toward winglet (70) (i.e. away from hub (10)). In the present example, and as shown in Figs. 9 and 10, winglet mounting member (90) is configured to fit in the end of fan blade (30 or 50). Like hub mounting member (12), winglet mounting member (90)

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fits snugly against bosses (40 or 60) in fan blade (30 or 50). In the present example, upper edge (80) of winglet (70) extends above top surface (32 or 52) of fan blade (30 or 50), in addition to extending beyond leading edge (36 or 56). Similarly, lower edge (78) of winglet (70) extends below bottom surface (34 or 54) of fan blade (30 or 50). Rear edge (82) of winglet (70) extends beyond trailing edge (38 or 58) of fan blade (30 or 50). Of course, winglets (70) and fan blades (30 or 50) may have any other relative sizing and/or configuration.

[0075] Fan blade (30 or 50) may have one or more openings, formed near the tip of fan blade (30 or 50) through top surface (32 or 52) and/or bottom surface (34 or 54), which is/are positioned to align with opening(s) (100) in winglet mounting member (90) when winglet mounting member (90) is inserted into fan blade (30 or 50), and which is/are sized to receive fastener (26). Winglets (70) may thus be secured to fan blades (30 or 50) with one or more fasteners (26). In one embodiment, fastener (26) is a bolt. In another embodiment, fastener (26) comprises a complimentary pair of thin head interlocking binding screws, such as screw posts occasionally used to bind a large volume of papers together (e.g., “male” screw with threaded outer surface configured to mate with “female” screw having threaded inner surface). However, any other suitable fastener(s) may be used, including but not limited to adhesives. Accordingly, in view of the teachings herein, it will be appreciated that openings (100) are optional.

[0076] It will also be appreciated in view of the teachings herein that winglet mounting member (90) need not be inserted into an end of fan blade (30 or 50). In other words, and similar to hub mounting members (12), winglet mounting member (90) may be made to fit on the outside of fan blades (30 or 50), rather than inside. Alternatively, winglet mounting members (90) may fit both partially inside and partially outside fan blades (30 or 50), including but not limited to in a

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configuration similar to that shown in Figs. 11-13. Still other configurations will be apparent to those of ordinary skill in the art in view of the teachings herein.

[0077] In an alternate embodiment, winglet (70) lacks mounting member (90), and instead has a recess formed in inner surface (74) of vertical member (72). In this embodiment, the tip of fan blade (30 or 50) is inserted into winglet (70) for attachment of winglet (70) to fan blade (30 or 50). In yet another embodiment, fan blade (30 or 50) is integrally formed with winglet (70). Accordingly, those of ordinary skill in the art will appreciate in view of the teachings herein that there exists a variety of configurations for providing fan blade (30 or 50) with winglet (70).

[0078] While vertical member (72) is shown as being substantially perpendicular to mounting member (90), it will be appreciated in view of the teachings herein that these two members may be at any suitable angle relative to each other. Thus, and by way of example only, vertical member (72) may tilt inward or outward when winglet (70) is attached to fan blade (30 or 50). Alternatively, vertical member (72) may comprise more than one angle. In other words, vertical member (72) may be configured such that the top portion of vertical member and the bottom portion of vertical member each tilt inward when winglet is attached to fan blade (30 or 50). Other variations of winglet (70), including but not limited to angular variations, will be apparent to those of ordinary skill in the art in view of the teachings herein.

[0079] While winglet (70) is specifically described herein as a modification to fan blades (30 or 50), it will be appreciated in view of the teachings herein that winglet (70) may be used to modify any other fan blades.

[0080] In one embodiment, winglet (70) is formed from homogenous continuum of molded plastic. However, it will be appreciated in view of the

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teachings herein that winglet (70) may be made from a variety of materials, including but not limited to any suitable metal and/or plastic, and may comprise a plurality of pieces. In addition, in view of the teachings herein, it will be appreciated that winglet may be made by any suitable method of manufacture.

[0081] It will also be appreciated in view of the teachings herein that trailing vortices that form at or near the tips of fan blades (30 or 50) may increase lift near the tips of fan blades (30 or 50). Winglets (70) may inhibit the radial airflow over top surface (32 or 52) and/or bottom surface (34 or 54) near the tips of fan blades (30 or 50). Such inhibition may force air to flow more normally from leading edge (36 or 56) to trailing edge (38 or 58), thereby enhancing efficiency of a fan having fan blades (30 or 50) with winglets (70), at least at certain rotational speeds.

[0082] In one example, winglets (70) are attached to ends of fan blades (30 or 50) on a fan having a 6 foot diameter. With the addition of winglets (70), the air flow rate of the fan is increased by 4.8% at 171 rpm.

[0083] In another example, winglets (70) are attached to ends of fan blades (30 or 50) on a fan having a 14 foot diameter. With the addition of winglets (70), the air flow rate of the fan is increased by 4.4% at 75 rpm.

[0084] The following two tables illustrate efficiencies that may be obtained by adding winglets (70) to a fan having a 14 foot diameter:

[0085] Table 1: Fan Without Winglets (70)

Speed (rpm)	Max. Power (watt)	Avg. Power (watt)	Torque (in.lbs)	Flowrate (cfm)	Efficiency (cfm/watt)
12.5	54	50	17.86	0	0
25	66	54	78.80	34,169	632.76
37.5	125	82	187.53	62,421	761.23
50	339	263	376.59	96,816	368.12
62.5	700	660	564.01	110,784	167.85
75	1170	1140	839.75	129,983	114.02

[0086] Table 2: Fan With Winglets (70)

Speed (rpm)	Max. Power (watt)	Avg. Power (watt)	Torque (in.lbs)	Flowrate (cfm)	Efficiency (cfm/watt)
12.5	50	42	18.56	26,815	638.45
25	58	43	18.39	46,547	1,082.49
37.5	68	49	186.00	61,661	1,258.39
50	241	198	354.61	87,552	442.18
62.5	591	528	582.78	120,859	228.90
75	980	950	847.41	136,560	143.75

[0087] Of course, other values may be realized through use of winglets (70). In addition, suitable variations of winglets, including but not limited to alternative winglet configurations, will be apparent to those of ordinary skill in the art in view of the teachings herein.

[0088] One merely exemplary alternative winglet (170) is shown in Figs. 11-13. While winglets (170) of this example will be discussed in the context of fan blades (30, 50, and 800), it will be appreciated in view of the teachings herein that winglets (170) may be used with any other suitable fan blades. By way of example only, a suitable fan blade (800) may include any of the various fan blades disclosed in U.S. patent application serial no. 11/858,360, entitled "FAN BLADES," filed September 20, 2007, the disclosure of which is incorporated by reference herein.

[0089] Winglet (170) of the present example includes vertical member (172). Vertical member (172) comprises inner surface (174) and outer surface (176). While inner surface (174) and outer surface (176) of this particular example are substantially flat, other suitable configurations for inner surface (174) and outer surface (176) will be apparent to those of ordinary skill in the art in view of the teachings herein. In addition, as shown in Fig. 13, outer surface (176) includes a rounded transition region (177) about its perimeter, adjacent to inner surface

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(174). However, such a transition region (177) may have any other suitable configuration, or may be simply omitted altogether.

[0090] In the present example, the perimeter of vertical member (172) is defined by lower edge (178), upper edge (180), and rear edge (182). As shown, lower edge (178) and upper edge (180) each have a convex curvature, while rear edge (182) is substantially flat. However, any edge (178, 180, and/or 182) may have any other suitable configuration, such as convex, concave, flat, complex curvature, etc., including combinations thereof.

[0091] Each edge (178, 180, and 182) meets generally at respective corner (184). Thus, in the present example, vertical member (172) has three corners (184). As shown, each corner (184) is rounded. Accordingly, the term “corner,” as that term is used herein, shall not be read to require a sharp angle. In other words, a corner need not be limited to a point or region at which a pair of straight lines meet or intersect. While in the present example vertical member (172) is described as having three corners, it will be appreciated in view of the teachings herein that vertical member (172) may have any suitable number of corners (184). By way of example only, a variation of winglet (170) may simply have a lower edge (178) and upper edge (180), each meeting at two corners (184). Other variations of vertical member (72) will be apparent to those of ordinary skill in the art in view of the teachings herein.

[0092] Winglet (170) of the present example further includes winglet mounting member (190), which extends substantially perpendicularly from inner surface (174) of vertical member (172). As shown, winglet mounting member (190) is configured similar to hub mounting member (12). Winglet mounting member (190) has top surface (192) and bottom surface (194), which each terminate into leading edge (196) and trailing edge (198). In addition, each winglet mounting member (92)

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includes an opening (101) formed through top surface (192). In the present example, each opening (101) is sized to receive fastener (126).

[0093] Winglet mounting member (190) is configured to be inserted into an end of a fan blade, such as fan blade (30 or 50) or any other fan blade, similar to winglet mounting member (90) discussed above. Those of ordinary skill in the art will appreciate in view of the teachings herein that winglet mounting members (190) may be provided in a variety of alternative configurations.

[0094] Winglet (170) of the present example also has a cuff (200) extending substantially perpendicularly from inner surface (174) of vertical member (172). As shown, a rounded transition area (202) is provided about the perimeter of cuff (200), adjacent to inner surface (174). However, transition area (202) may have any other suitable configuration, or may be omitted altogether. As is also shown, a recess (204) is formed in cuff (200) to accommodate and provide clearance for a fastener (126). As with other components described herein, recess (204) may be varied in any suitable way (e.g., provided as a countersink, opening, etc.), or may be omitted altogether.

[0095] Cuff (200) of the present example is configured to compliment the cross section of a fan blade (800) to which winglet (170) is secured. In particular, inner surface (206) of cuff (200) and outer surface (208) of cuff (200) each have a cross section or profile that is similar to the cross section or profile of fan blade (800). For instance, inner surface (206) may be configured such that cuff (200) provides a snug fit with fan blade (800), such that the interface between cuff (200) and fan blade (800) is substantially free of gaps. Similarly, inner surface (206) may provide an interference fit with a fan blade (800). In view of the teachings herein, it will be appreciated that, in some situations, a snug fit or interference fit between cuff (200) and fan blade (800) may reduce noise (e.g., whistling, etc.) and/or the likelihood of any gaps

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between the end of fan blade (800) and winglet (170) causing any adverse impact on the performance or efficiency of a fan using fan blade (800) and winglet (170). Alternatively, other results may be obtained.

[0096] It will also be appreciated in view of the teachings herein that, in other versions, inner surface (206) and/or outer surface (208) may have a configuration that is different from the cross section of fan blade (800). Furthermore, cuff (200) may be configured such that it is not defined by a continuous perimeter. For instance, one or more gaps (not shown) may be provided within the perimeter of cuff (200). Still other ways in which cuff (200) may be modified, substituted, or supplemented will be apparent to those of ordinary skill in the art in view of the teachings herein.

[0097] Fig. 12 shows a fan blade (800) with winglet (170) mounted thereto, while Fig. 13 shows a cross section of fan blade (800) with winglet (170) mounted thereto. Like hub mounting member (12), winglet mounting member (190) fits snugly against bosses (not shown) in fan blade (800). In the present example, upper edge (180) of winglet (170) extends above top surface (132) of fan blade (800), in addition to extending beyond leading edge (136). Similarly, lower edge (178) of winglet (170) extends below bottom surface (134) of fan blade (800). Rear edge (182) of winglet (170) extends beyond trailing edge (not shown) of fan blade (800). Of course, winglets (170) and fan blade (800) may have any other relative sizing and/or configuration.

[0098] In yet another embodiment (not shown), mounting member (190) is omitted from winglet (170), such that winglet (170) is secured to fan blade (800) via cuff (200). By way of example only, an opening, slot, or other feature (not shown) may be provided in cuff (200) in lieu of recess (204), such that a fastener (126) may be inserted through the feature in the cuff (200) and engaged with an opening formed in fan blade (800).

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In other embodiments, winglet (170) is welded to fan blade (800) or secured to fan blade (800) by an adhesive or using other structures or techniques. Other ways in which winglet (170) may be secured relative to a fan blade (800) will be apparent to those of ordinary skill in the art in view of the teachings herein.

[0099] It will also be appreciated in view of the teachings herein that winglet (70) described above may be modified to include a cuff (200) or a structure similar to cuff (200). Similarly, winglet (170) may be configured or modified in a manner similar to any of the variations of winglet (70) described above. Furthermore, either winglet (70, 170) may be secured to any fan blade (30, 50, or 800) described herein, or any other suitable fan blade.

[00100] In summary, numerous benefits have been described which result from employing the concepts of the invention. The foregoing description of one or more embodiments of the invention has been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form disclosed. Obvious modifications or variations are possible in light of the above teachings. The one or more embodiments were chosen and described in order to best illustrate the principles of the invention and its practical application to thereby enable one of ordinary skill in the art to best utilize the invention in various embodiments and with various modifications as are suited to the particular use contemplated. It is intended that the scope of the invention be defined by the claims appended hereto.

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What is claimed is:

1. A winglet for a fan blade, comprising:
 - (a) a vertical member;
 - (b) a mounting member connected to the vertical member, wherein the mounting member is configured substantially secure the vertical member relative to a fan blade first end, wherein the fan blade is configured to be mounted to a fan hub at a second end of the fan blade, the second end being opposite the first end; and
 - (c) a cuff extending from the vertical member, wherein the cuff is configured to cover at least a portion of an interface between the first end of the fan blade and the vertical member.
2. The winglet of claim 1, wherein the cuff has an inner surface and an outer surface, wherein the inner surface has a profile configured to compliment a profile of the first end of the fan blade.
3. The winglet of claim 2, wherein the outer surface of the cuff is configured to further compliment the profile of the first end of the fan blade.
4. The winglet of claim 1, wherein the cuff includes a generally rounded transition area adjacent to the vertical member.
5. The winglet of claim 1, wherein the first end of the fan blade has an outer surface; and
wherein the cuff has an inner surface configured to provide a snug fit with the outer surface of the first end of the fan blade.
6. The winglet of claim 1, wherein the fan blade has a maximum thickness;

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wherein the vertical member comprises a perimeter defined by a lower edge, an upper edge, and a rear edge; and

wherein, when mounted to the first end of the fan blade, the rear edge of the vertical member has a length that is greater than the maximum thickness of the first end of the fan blade.

7. The winglet for a fan blade of claim 1, wherein the mounting member has a trailing edge;

wherein the vertical member comprises a perimeter defined by a lower edge, an upper edge, and a rear edge; and

wherein, when mounted to the first end of the fan blade having a trailing edge, the distance from the mounting member trailing edge to a point on the rear edge of the vertical member is greater than the distance from the mounting member trailing edge to the fan blade trailing edge at the first end.

8. The winglet for a fan blade of claim 1, wherein the vertical member comprises a perimeter defined by a lower edge, an upper edge, and a rear edge; and
wherein each of the edges meets generally at a respective corner.

9. The winglet for a fan blade of claim 8, wherein each of the corners is generally rounded.

10. The winglet for a fan blade of claim 1, wherein at least a portion of the mounting member is configured to fit inside the fan blade first end.

11. The winglet for a fan blade of claim 1, wherein the mounting member is configured to be substantially fixed to the fan blade first end by one or more fasteners.

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12. The winglet for a fan blade of claim 1, wherein the mounting member has a leading edge;

wherein the vertical member comprises a perimeter defined at least by a lower edge and an upper edge; and

wherein, when mounted to the first end of the fan blade having a leading edge, the distance from the mounting member leading edge to a point on the upper edge of the vertical member is greater than the distance from the mounting member leading edge to the fan blade leading edge at the first end.

13. The winglet for a fan blade of claim 1, wherein the mounting member has a bottom surface,

wherein the vertical member comprises a perimeter defined at least by a lower edge and an upper edge; and

wherein, when mounted to the first end of the fan blade having a bottom surface, the distance from the mounting member bottom surface to a point on the lower edge of the vertical member is greater than the distance from the mounting member bottom surface to any point on the fan blade bottom surface at the first end of the fan blade.

14. The winglet for a fan blade of claim 1, wherein the mounting member has a top surface,

wherein the vertical member comprises a perimeter defined at least by a lower edge and an upper edge; and

wherein, when mounted to the first end of the fan blade having a top surface, the distance from the mounting member top surface to a point on the upper edge of the vertical member is greater than the distance from the mounting member top surface to any point on the fan blade top surface at the first end of the fan blade.

15. A winglet for a fan blade, comprising:

(a) a vertical member; and

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- (b) a cuff extending from the vertical member, wherein the cuff is configured to cover an external portion of a fan blade first end, wherein the fan blade is configured to be mounted to a fan hub at a second end of the fan blade, the second end being opposite the first end.

16. The winglet of claim 15, further comprising a mounting member connected to the vertical member, wherein the mounting member is configured to mount the vertical member relative to the fan blade first end.

17. The winglet of claim 15, wherein the cuff has a perimeter configured to compliment a perimeter of the first end of the fan blade.

18. A fan, comprising:

- (a) a hub, the hub being operable to rotate;
- (b) a plurality of fan blades, each fan blade having a first end and a second end, wherein each fan blade is mounted to the hub at a respective first end, wherein the second end of each fan blade is opposite the first end of the corresponding fan blade; and
- (c) a winglet mounted to the second end of each fan blade, wherein each winglet comprises a vertical member and a cuff member, wherein at least a portion of each second end is configured to be inserted into the cuff member of the corresponding winglet.

19. The fan of claim 18, wherein each fan blade second end and each respective winglet vertical member defines an interface, wherein each winglet cuff substantially covers each corresponding interface.

20. The fan of claim 18, wherein each fan blade defines a corresponding chord, wherein each vertical member has a length that is greater than the chord of each corresponding fan blade.