

FAN BLADES AND MODIFICATIONS

PRIORITY

- [0001] This application 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.

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 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

[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] 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

- [0019] 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.

[0020] 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 that hub mounting members 12 may be provided in a variety of alternative configurations.

[0021] 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 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.

[0022] 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.

[0023] 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.

[0024] 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 (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.

[0025] 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).

[0026] 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).

[0027] 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).

[0028] 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.

[0029] 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.

[0030] 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. 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:

[0031] [1] $x = a(\cos(t))$, and

[0032] [2] $y = b(\sin(t))$,

[0033] where

[0034] a = length of primary radius,

[0035] b = length of secondary radius, and

[0036] t = angle of rotation of a radius about the origin (e.g., in radians).

[0037] 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 $b = 2$.

[0038] Coordinates for a second ellipse may be obtained using these equations:

[0039] [3] $x_2 = x(\cos(\Theta)) - y(\sin(\Theta))$, and

[0040] [4] $y_2 = y(\cos(\Theta)) + x(\sin(\Theta))$,

[0041] where

[0042] x_2 = the second "x" coordinate after a counterclockwise rotation of the first ellipse through Θ radians about the origin, and

- [0043] y_2 = the second “y” coordinate after a counterclockwise rotation of the first ellipse through Θ radians about the origin.
- [0044] 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. 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).
- [0045] 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 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).
- [0046] 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.
- [0047] 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.
- [0048] 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.

[0049] 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.

[0050] 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.

[0051] 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).

[0052] 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).

- [0053] 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.
- [0054] 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.
- [0055] 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.
- [0056] 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.
- [0057] The following may be applied to any fan blade, including by way of example only, fan blade (30) or fan blade (50):
- [0058] 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, 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 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.

[0059] 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 that 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).

[0060] 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, including but not limited to adhesives. Accordingly, it will be understood that openings (22) are optional.

[0061] 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.

[0062] 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)) 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).

[0063] 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 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.

[0064] 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.

[0065] 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.

[0066] 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 addition, it will be appreciated that all or any portion of fan blade (30 or 50) may have one or more twists for any purpose.

[0067] 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. 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 that winglets (70) may be used with any other suitable fan blades.

[0068] 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 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 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 that vertical member (72) may have any suitable number of corners (84).

[0069] Other variations of vertical member (72) will be apparent to those of ordinary skill in the art.

[0070] 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). Those of ordinary skill in the art will appreciate that winglet mounting members (90) may be provided in a variety of alternative configurations.

[0071] 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) 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.

[0072] 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, it will be appreciated that openings (100) are optional.

[0073] It will also be appreciated 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). Still other configurations will be apparent to those of ordinary skill in the art.

[0074] 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 that there exists a variety of configurations for providing fan blade (30 or 50) with winglet (70).

[0075] While vertical member (72) is shown as being substantially perpendicular to mounting member (90), it will be appreciated 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.

[0076] While winglet (70) is specifically described herein as a modification to fan blades (30 or 50), it will be appreciated that winglet (70) may be used to modify any other fan blades.

[0077] In one embodiment, winglet (70) is formed from homogenous continuum of molded plastic. However, it will be appreciated 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, it will be appreciated that winglet may be made by any suitable method of manufacture.

[0078] It will also be appreciated 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.

[0079] 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.

[0080] 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.

[0081] The following two tables illustrate efficiencies that may be obtained by adding winglets (70) to a fan having a 14 foot diameter:

[0082] 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

[0083] 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

[0084] 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.

[0085] 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.

What is claimed is:

1. A fan blade configured to mount to a rotating fan hub, the fan blade comprising:
 - 5 (a) a top surface having a generally elliptical curvature, wherein the curvature of the top surface is based on a first ellipse;
 - (b) a bottom surface having a generally elliptical curvature, wherein the curvature of the bottom surface is based on a second ellipse;
 - (c) a leading edge, wherein the top surface and bottom surface each
10 terminate at the leading edge; and
 - (d) a trailing edge, wherein the top surface and bottom surface each terminate at the trailing edge.
2. The fan blade of claim 1, further comprising: a first radius of curvature
15 proximate the leading edge, and a second radius of curvature proximate the trailing edge, wherein the first radius of curvature is lower than the second radius of curvature.
3. The fan blade of claim 1, wherein the curvature of the second ellipse is
20 dependent on the curvature of the first ellipse.
4. The fan blade of claim 1, wherein the fan blade is substantially hollow.

- 20 -

5. The fan blade of claim 1, wherein the fan blade is configured to receive a mounting member of a fan hub.
- 5 6. The fan blade of claim 5, wherein the fan blade is secured to the fan hub by at least one fastener.
7. The fan blade of claim 1, wherein the fan blade has a chord and a maximum thickness, wherein the maximum thickness is approximately 14.2% of the chord.
- 10 8. The fan blade of claim 1, wherein the fan blade has a chord and a maximum camber, wherein the maximum camber is approximately 15.6% of the chord.
9. The fan blade of claim 1, wherein the fan blade is mounted to a hub at an angle of attack between approximately -1° and approximately 13° , inclusive.
- 15 10. The fan blade of claim 1, wherein the fan blade is formed of extruded aluminum.
- 20 11. The fan blade of claim 1, wherein the fan blade has a length between approximately 4 feet and approximately 14 feet, inclusive.
12. The fan blade of claim 1, wherein the fan blade has a uniform cross section along the entire length of the fan blade.

13. The fan blade of claim 1, wherein the fan blade has a hub mounting end,
wherein an oblique cut is formed in the leading edge of the fan blade at the
hub mounting end.

5 14. The fan blade of claim 1, wherein the fan blade is substantially straight along
the entire length of the fan blade.

15. The fan blade of claim 1, wherein the first ellipse is generated based at least
in part on the following equations:

10
$$x=a(\cos(t)), \text{ and} \quad [1]$$

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

wherein x and y provide an x-y plot of the first ellipse,

15 wherein a=length of a primary radius,

wherein b=length of a secondary radius, and

wherein t=angle of rotation of a radius about an origin.

16. The fan blade of claim 15, wherein the second ellipse is generated based at
20 least in part on the following equations:

$$x_2=x(\cos(\theta))-y(\sin(\theta)), \text{ and} \quad [3]$$

$$Y_2=y(\cos(\theta))-x(\sin(\theta)), \quad [4]$$

wherein x_2 and Y_2 provide an x-y plot of the second ellipse,

wherein x and y are the same x and y obtained using equations [1] and [2], and

wherein Θ =a degree to which the first ellipse is rotated about the origin.

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17. The fan blade of claim 16, wherein Θ is approximately 0.525 radians.

18. The fan blade of claim 1, wherein the first ellipse and the second ellipse intersect at four intersection points when the first ellipse and the second ellipse are plotted on a common graph, wherein the generally elliptical curvature of the top surface and the generally elliptical curvature of the bottom surface are based on the curvature of the first ellipse and the second ellipse, respectively, in a region between a pair of the intersection points.

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15 19. A fan blade configured to mount to a rotating fan hub, the fan blade comprising:

(a) a top surface having a generally elliptical curvature, wherein the curvature of the top surface is based on a first ellipse;

(b) a bottom surface having a generally elliptical curvature, wherein the curvature of the bottom surface is based on a second ellipse;

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wherein the first ellipse and the second ellipse intersect at four intersection points when the first ellipse and the second ellipse are plotted on a common graph, wherein the generally elliptical curvature of the top surface and the generally elliptical curvature of the bottom surface are based

- 23 -

on the curvature of the first ellipse and the second ellipse, respectively, in a region between an adjacent pair of the intersection points.

20. A fan blade configured to mount to a rotating fan hub, the fan blade
5 comprising:
- (a) a top surface having a generally elliptical curvature, wherein the curvature of the top surface is based on a first ellipse;
 - (b) a bottom surface having a generally elliptical curvature, wherein the curvature of the bottom surface is based on a second ellipse;
- 10 wherein the formation of the second ellipse is based on the formation of the first ellipse.