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(54) **THIN AIRFOIL CEILING FAN BLADE**

DECKENLÜFTERSCHAUFEL FÜR EINE DÜNNE TRAGFLÄCHE

PALE DE VENTILATEUR DE PLAFOND FORMANT UNE AILE MINCE

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US-A- D 612 476 US-A- 5 554 006
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Description

PRIORITY

[0001] This application claims priority to U.S. Provisional Patent Application Serial No. 61/588,932, filed January 20, 2012, entitled "Thin Airfoil Ceiling Fan Blade."

BACKGROUND

[0002] A variety of fan systems have been made and used over the years in a variety of contexts. For instance, various ceiling fans are disclosed in U.S. Pat. No. 7,284,960, entitled "Fan Blades," issued October 23, 2007; U.S. Pat. No. 6,244,821, entitled "Low Speed Cooling Fan," issued June 12, 2001; U.S. Pat. No. 6,939,108, entitled "Cooling Fan with Reinforced Blade," issued September 6, 2005; and U.S. Pat. No. D607,988, entitled "Ceiling Fan," issued January 12, 2010. Additional exemplary fans are disclosed in U.S. Pat. No. 8,079,823, entitled "Fan Blades," issued December 20, 2011; U.S. Pat. Pub. No. 2009/0208333, entitled "Ceiling Fan System with Brushless Motor," published August 20, 2009; and U.S. Pat. Pub. No. 2010/0278637, entitled "Ceiling Fan with Variable Blade Pitch and Variable Speed Control," published November 4, 2010, as well as U.S. Pat. Pub. No. 2007/0009364 A1, entitled "Blade for ceiling fan".

[0003] A fan blade or airfoil may include one or more upper air fences and/or one or more lower air fences at any suitable position(s) along the length of the fan blade or airfoil. Merely exemplary air fences are described in U.S. Pat. Pub. No. 2011/0081246, entitled "Air Fence for Fan Blade," published April 7, 2011. Alternatively, any other suitable type of component or feature may be positioned along the length of a fan blade or airfoil; or such components or features may simply be omitted.

[0004] The outer tip of a fan blade or airfoil may be finished by the addition of an aerodynamic tip or winglet. Merely exemplary winglets are described in U.S. Pat. No. 7,252,478, entitled "Fan Blade Modifications," issued August 7, 2007. Additional winglets are described in U.S. Pat. No. 7,934,907, entitled "Cuffed Fan Blade Modifications," issued May 3, 2011. Still other exemplary winglets are described in U.S. Pat. No. D587J99, entitled "Winglet for a Fan Blade," issued March 3, 2009. In some settings, such winglets may interrupt the outward flow of air at the tip of a fan blade, redirecting the flow to cause the air to pass over the fan blade in a perpendicular direction, and also ensuring that the entire air stream exits over the trailing edge of the fan blade and reducing tip vortex formation. In some settings, this may result in increased efficiency in operation in the region of the tip of the fan blade. In other variations, an angled extension may be added to a fan blade or airfoil, such as the angled airfoil extensions described in U.S. Pat. No. 8,162,613, entitled "Angled Airfoil Extension for Fan Blade," issued April 24, 2012. Other suitable structures that may be associated

with an outer tip of an airfoil or fan blade will be apparent to those of ordinary skill in the art. Alternatively, the outer tip of an airfoil or fan blade may be simply closed (e.g., with a cap or otherwise, etc.), or may lack any similar structure at all.

[0005] The interface of a fan blade and a fan hub may also be provided in a variety of ways. For instance, an interface component is described in U.S. Pat. No. 8,147,204, entitled "Aerodynamic Interface Component for Fan Blade," issued April 3, 2012. In addition, or in the alternative, the fan blade may include a retention system that couples the tip of a fan blade to an attachment point on the fan hub via a cable running through the fan blade, such as that disclosed in U.S. Pat. Pub. No. 2011/0262278, published October 27, 2011. Alternatively, the interface of a fan blade and a fan hub may include any other component or components, or may lack any similar structure at all.

[0006] Fans may also include a variety of mounting structures. For instance, a fan mounting structure is disclosed in U.S. Pat. No. 8,152,453, entitled "Ceiling Fan with Angled Mounting," issued April 10, 2012. Of course, a fan need not be mounted to a ceiling or other overhead structure, and instead may be mounted to a wall or to the ground. For instance, a fan may be supported on the top of a post that extends upwardly from the ground. Examples of such mounting structures are shown in U.S. Design Pat. No. D635,237, entitled "Fan with Ground Support," issued March 29, 2011; U.S. Design Pat. No. D641,075, entitled "Fan with Ground Support and Winglets," issued July 5, 2011; and U.S. Pat. App. No. 61/720,077, entitled "Fan Mounting System," filed October 30, 2012. Alternatively, any other suitable mounting structures and/or mounting techniques may be used in conjunction with examples described herein.

[0007] It should also be understood that a fan may include sensors or other features that are used to control, at least in part, operation of a fan system. For instance, such fan systems are disclosed in U.S. Pat. No. 8,147,182, entitled "Ceiling Fan with Concentric Stationary Tube and Power-Down Features," issued April 3, 2012; U.S. Pat. No. 8,123,479, entitled "Automatic Control System and Method to Minimize Oscillation in Ceiling Fans," issued February 28, 2012; U.S. Pat. Pub. No. 2010/0291858, entitled "Automatic Control System for Ceiling Fan Based on Temperature Differentials," published November 18, 2010; U.S. Provisional Patent App. No. 61/165,582, entitled "Fan with Impact Avoidance System Using Infrared," filed April 1, 2009; and U.S. Pat. App. No. 61/720,679, entitled "Integrated Thermal Comfort Control System Utilizing Circulating Fans," filed October 31, 2012. Alternatively, any other suitable control systems/features may be used in conjunction with examples described herein.

[0008] In some settings, it may be desirable to replicate or approximate the function of a winglet in a component that may be located at a position on a fan blade other than at the free end of the fan blade. For instance, such

components are disclosed in U.S. Pat. Pub. No. 2011/0081246, entitled "Air Fence For Fan Blade," published April 7, 2011. Such a component may provide an effect on fan efficiency similar to the effect provide by a winglet, albeit at one or more additional regions of the fan blade. In particular, such a component or accessory may serve as an aerodynamic guide or air fence, interrupting slippage of air along the length or longitudinal axis of the fan blade; and redirecting the air flow to a direction perpendicular to the longitudinal axis of the fan blade, above and/or below the fan blade.

[0009] In some ceiling fans, flat planar blades are used by inclining the blades at an angle of approximately ten to twenty degrees from the horizontal to displace airflow in a downward direction. These flat blades might not be aerodynamically efficient in some settings. Accordingly, to move a given volume of air, the fan must operate at a higher speed, thereby consuming more electricity. In addition, these flat blades might be manufactured from wood or fiberboard, harvested from trees, such as Monterey Pine, which typically take 25-30 years to reach maturity. Since the regrowth time of the raw materials may exceed the lifespan of the ceiling fan, continued production in this manner is not an environmentally sustainable practice.

[0010] While flat planar blades have been used, attempts have been made to improve upon ceiling fan blade designs. For example, Parker, et al, U.S. Pat. No. 6,039,541, issued March 21, 2000, describes a ceiling fan blade that includes the SD7032, GM15, MA409, and Hibbs 504 airfoils. Airfoils of this type may operate with higher coefficients of lift versus angle of attack at Reynolds numbers greater than 100,000. In the instance of a fan blade with a chord length of 10.16 centimeters (4 inches) and blade span with the root located 22.5 centimeters (9 inches) from the center of rotation and a tip located 76.2 centimeters (30 inches) from the center of rotation, operating at 50 rotations per minute may experience Reynolds numbers ranging from 8,000 at the root to 28,000 at the tip. While at 200 rotations per minute, the fan blade may experience Reynolds numbers ranging from 33,000 at the root to 110,000 at the tip. At speeds below 180 rotations per minute, the entire blade may experience Reynolds numbers less than 100,000. Accordingly, the airfoils described by Parker, et al. may operate below their optimal performance under the majority of operating conditions for the ceiling fan. Furthermore, airfoil blades of the types disclosed in Parker, et al. may increase manufacturing complexity since the airfoil thickness has a teardrop profile and varies substantially from leading edge to trailing edge. In some instances, to create this teardrop profile the blade must be manufactured by plastic injection molding or, alternatively, machined from a flat sheet material, which may result in significant waste. Thus, a need exists for an improved blade design that offers optimal airflow performance at the low Reynolds numbers experienced by a ceiling fan and is capable of being manufactured by simple techniques using

sustainable materials.

The fan blade may comprise a tip which is curved. A fan blade is proposed which is configured to mount to a rotating fan hub, the fan blade having the features of claim 1.

[0011] In addition, this fan blade may be such designed that the bottom surface of the root end is configured to terminate into a region which is parallel to a plane of rotation of the fan blade at a position proximal to the cut-out.

According to a further aspect, a fan assembly is proposed, having the features of claim 15.

[0012] While several systems and methods have been made and used for ceiling fan blades, it is believed that no one prior to the inventors has made or used the invention described in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] While the specification concludes with claims which particularly point out and distinctly claim this technology, it is believed this technology will be better understood from the following description of certain embodiments and examples taken in conjunction with the accompanying drawings, in which like reference numerals identify the same elements and in which:

FIG. 1 depicts a front perspective view of a fan having a plurality of ceiling fan blades according to an embodiment of the invention attached thereto;

FIG. 2 depicts an exploded perspective view of the fan of FIG. 1;

FIG. 3 depicts a side elevation view of the fan of FIG. 1;

FIG. 4 depicts a plan view of the ceiling fan blade of FIGS. 1-3;

FIG 4A depicts a cross-sectional view of the ceiling fan blade of FIG. 4 taken along section line A-A of FIG. 4;

FIG 4B depicts a cross-sectional view of the ceiling fan blade of FIG. 4 taken along section line B-B of FIG. 4;

FIG 4C depicts a cross-sectional view of the ceiling fan blade of FIG. 4 taken along section line C-C of FIG. 4;

FIG 5 depicts a combination cross-sectional view of the blade sections shown in FIGS. 4A-4C, showing the relative curvature of each section;

FIG. 6 depicts a front elevation view of the fan blade of FIGS. 1-5;

FIG. 7 depicts a perspective view of an alternative fan having a plurality of exemplary ceiling fan blades which are not part of the claimed subject-matter attached thereto;

FIG. 8 depicts an exploded perspective view of the fan of FIG. 7;

FIG. 9 depicts a plan view of the exemplary fan blade of FIG. 7; and

FIG. 10 depicts an elevation view taken from a root end of the fan blade of FIG. 9.

[0014] It is contemplated that various embodiments or examples of the technology may be carried out in a variety of other ways, including those not necessarily depicted in the drawings. The accompanying drawings incorporated in and forming a part of the specification illustrate several aspects of the present technology, and together with the description serve to explain the principles of the technology.

DETAILED DESCRIPTION

[0015] Other examples, features, aspects, embodiments, and advantages of the technology will become apparent to those skilled in the art from the following description, which is by way of illustration, one of the best modes contemplated for carrying out the technology. As will be realized, the technology described herein is capable of other different and obvious aspects, all without departing from the technology. Accordingly, the drawings and descriptions should be regarded as illustrative in nature and not restrictive. The scope of the protection is solely defined by the appended claims.

I. Fan Overview

[0016] Referring to FIG. 1, a fan (10) of the present embodiment comprises a support (20), a motor (30) (shown in FIG. 2), and a plurality of fan blades (50). While three fan blades (50) are shown, it should be understood that any other suitable number of fan blades (50) may be used. Fan blades (50) of the present embodiment may define a fan diameter ranging from approximately 0.5 meters (1.64 feet), inclusive, to approximately 5 meters (16.4 feet), inclusive. In the present embodiment, fan blades (50) define a fan diameter of approximately 1.5 meters (4.92 feet). Alternatively, fan (10) and/or fan blades (50) may have any other suitable dimensions.

[0017] Support (20) is configured to be coupled to a surface or other structure at a first end such that fan (10) is substantially attached to the surface or other structure. Support (20) of the present embodiment comprises an elongate metal tube-like structure that couples fan (10) to a ceiling, though it should be understood that support (20) may be constructed and/or configured in a variety of other suitable ways as will be apparent to one of ordinary skill in the art in view of the teachings herein. In one version, support (20) is configured to couple to an electrical junction box (not shown) located within or on a ceiling. With support (20) comprising an elongate metal tube, wires or other power supply or control members are extended through support (20) to motor (30). By way of example only, support (20) need not be coupled to a ceiling or other overhead structure, and instead may be coupled to a wall or to the ground. For instance, support (20) may be positioned on the top of a post that extends up-

wardly from the ground. Alternatively, support (20) may be mounted in any other suitable fashion at any other suitable location. This includes, the teachings of the patents, patent publications, or patent applications cited herein. By way of example only, support (20) may be configured in accordance with the teachings of U.S. Pat. Pub. No. 2009/0072108, entitled "Ceiling Fan with Angled Mounting," published March 19, 2009. As yet another alternative, support (20) may have any other suitable configuration.

[0018] As shown in FIG. 2, fan (10) of the present embodiment includes a motor (30) that is coupled to fan blades (50). Motor (30) of the present embodiment is coupled to fan blades (50) via fasteners (32). Fasteners (32) may include screws, bolts, clips, clamps, and/or any other suitable fastener (32) for coupling fan blades (50) to motor (30). Alternatively, fasteners (32) may be omitted and fan blades (50) may be adhesively attached or integrally formed with a portion of motor (30) such that fan blades (50) rotate when motor (30) is operated. In the present embodiment, a blade shoe (40) is interposed between motor (30) and each fan blade (50). In some versions, blade shoe (40) may comprise a rubber, synthetic rubber, or other vibratory buffering material such that fan blades (50) are substantially isolated from vibrations of motor (30) and/or other portions of fan (10). Alternatively, blade shoe (40) may comprise a plastic, metal, wood, composite, and/or any other material. Of course it should be understood that blade shoe (40) is merely optional and may be omitted.

[0019] In some versions, motor (30) comprises an AC induction motor having a drive shaft, though it should be understood that motor (30) may alternatively comprise any other suitable type of motor (e.g., a permanent magnet brushless DC motor, a brushed motor, an inside-out motor, etc.). In the present embodiment, motor (30) is fixedly coupled to support (20) and is configured to rotate fan blades (50) relative to support (20) such that air is propelled by fan (10) away from the structure to which support (20) is coupled. In an alternative version, shown in FIGS. 7-10, a hub (430) may be included in addition to, or instead of, blade shoes (40). In the version shown in FIGS. 7-10, which is not part of the claimed subject-matter, hub (430) comprises an annular member having a plurality of holes (432) disposed about the circumference to which fan blades (50) may be coupled. Hub (430) is coupled to motor (30) such that rotation of hub (430) by motor (30) rotates fan blades (50). Of course motor (30) may be constructed in accordance with at least some of the teachings of U.S. Pat. Pub. No. 2009/0208333, entitled "Ceiling Fan System with Brushless Motor," published August 20, 2009. Furthermore, fan (10) may include control electronics that are configured in accordance with at least some of the teachings of U.S. Pat. Pub. No. 2010/0278637, entitled "Ceiling Fan with Variable Blade Pitch and Variable Speed Control," published November 4, 2010. Of course, motor (30), blade shoe (40), and/or hub (430) may have any other suitable compo-

nents, configurations, functionalities, and operability, as will be apparent to those of ordinary skill in the art in view of the teachings herein.

[0020] In the present embodiment, fan (10) further includes a top cover (34). Top cover (34) comprises a dome-shaped component configured to enclose the top of motor (30). Top cover (34) is attached to support (20) to form a dome over the top of motor (30) when motor (30) is coupled to support (20). In some versions, top cover (34) is threadably coupled to support (20). In other versions, top cover (34) may be integrally formed with support (20), coupled via fasteners (not shown), or otherwise attached to support (20) and/or motor (30). When fan blades (50) of the embodiment shown in FIGS. 1-3 are coupled to motor (30), fan blades (50) and top cover (34) substantially enclose motor (30), as seen best in FIG. 1.

[0021] Fan blades (50) of the embodiment shown in FIGS. 1-6 each include an arcuate cutout (54) at a root end (52) of each fan blade (50). When fan blades (50) are coupled to motor (30), arcuate cutouts (54) form a cylindrical aperture (56). A semi-transparent lens (48) is inserted into aperture (56). A sensor (not shown) is mounted within aperture (56) and is configured to receive infrared signals from a remote control (not shown) or other source. The sensor is coupled to a motor control module that is operable to control fan (10). Fan (10) may be further configured in accordance with at least some of the teachings of the fan systems disclosed in U.S. Pat. Pub. No. 2009/0097975, entitled "Ceiling Fan with Concentric Stationary Tube and Power-Down Features," published April 16, 2009; U.S. Pat. Pub. No. 2009/0162197, entitled "Automatic Control System and Method to Minimize Oscillation in Ceiling Fans," published June 25, 2009; U.S. Pat. Pub. No. 2010/0291858, entitled "Automatic Control System for Ceiling Fan Based on Temperature Differentials," published November 18, 2010; and U.S. Provisional Patent App. No. 61/165,582, entitled "Fan with Impact Avoidance System Using Infrared," filed April 1, 2009. Still further configurations for lens (48), arcuate cutouts (54), aperture (56), and the sensor will be apparent to one of ordinary skill in the art in view of the teachings herein. Of course, it should be understood that lens (48), arcuate cutouts (54) and aperture (56) are merely optional and may be omitted.

[0022] While some merely exemplary features of fan (10) have been described herein, it should be understood that fan (10) may have other features, components, and/or configurations as will be apparent to one of ordinary skill in the art in view of the teachings herein.

II. Fan Blades

[0023] A single fan blade (50) is shown plan form in FIG. 4 having a root end (52), a tip (70), a leading edge (80) and a trailing edge (90). Sections A-A, B-B, and C-C are shown in FIG. 4 and correspond to cross-sectional FIGS. 4A, 4B, and 4C, respectively. Sections A-A, B-B,

and C-C will be discussed in greater detail below. As noted above, root end (52) of the present embodiment comprises an arcuate cutout (54) configured to permit lens (48) be inserted in a central aperture (56) formed when fan blades (50) are mounted. Root end (52) further includes a pair of openings (58) that permit fasteners (32) to extend therethrough to couple fan blade (50) to motor (30) and/or hub (42). As shown in FIGS. 1-3, root end (52) of the present embodiment fan blade (50) comprises a domed sector that corresponds to an approximately 120 degree sector of a dome for the present fan (10) having three fan blades (50). The domed sector of root end (52) is substantially flat, or parallel, relative to the plane of rotation for fan blades (50) at or near arcuate cutout (54). The domed sector curves upwardly toward motor (30) and/or support (20). Root end (52) may of course include an approximately 180 degree, 90 degree, 60 degree, 45 degree and/or any other sector portion of a dome. Of course other root ends (52) will be apparent to one of ordinary skill in the art in view of the teachings herein.

[0024] Fan blade (50) also includes a transition region (60) extending from root end (52), shown best in FIGS. 4 and 6. In the present embodiment, transition region (60) comprises a first portion (62), an inflection portion (64), and a second portion (66). First portion (62) comprises an extension of the domed sector of root end (52) that terminates at inflection portion (64). Inflection portion (64) of the present embodiment comprises a quasi-parabolic shaped portion that extends from leading edge (80) to trailing edge (90) and transitions fan blade (50) from the upwardly extending domed shape of first portion (62) to a planar portion. Second portion (66) extends from inflection portion (64) and transitions fan blade (50) from the planar inflection portion (64) to the downwardly curved root airfoil profile (100), shown in FIG. 4A. By way of example only not part of the claimed subject-matter, a non-dimensional matrix of coordinates in Table 1 below generally describes the surface formed by transition region (60) and airfoil profile (100). It should be understood that the domed sector of root end (52) is omitted from the coordinates in Table 1. In addition, the Z coordinate corresponds to the vertical height of the point at the transition point from root end (52) (e.g., a height of 0 corresponds to where root end (52) ends and transition region (60) begins), the X coordinate corresponds to the longitudinal distance from a central point about which blade (50) rotates, and the Y coordinate corresponds to the chord-wise position, where negative coordinates approach trailing edge (90) and positive coordinates approach leading edge (80).

TABLE 1

Z	X	Y

(continued)

Z	X	Y
0	0.0892	-0.01
0	0.0991	-0.009
0	0.1072	-0.008
0	0.1145	-0.007
0	0.1209	-0.006
0	0.1263	-0.005
0	0.1305	-0.004
0	0.1337	-0.003
0	0.1358	-0.002
0	0.137	-0.001
0	0.1373	0
0	0.1366	0.001
0	0.1351	0.002
0	0.1327	0.003
0	0.1294	0.004
0	0.1252	0.005
0	0.1201	0.006
0	0.1141	0.007
0	0.1071	0.008
0	0.0989	0.009
0	0.0888	0.01
0.005	0.0986	-0.01
0.005	0.1273	-0.009
0.005	0.1897	-0.008
0.005	0.1452	-0.007
0.005	0.1471	-0.006
0.005	0.1521	-0.005
0.005	0.1564	-0.004
0.005	0.1595	-0.003
0.005	0.1614	-0.002
0.005	0.1621	-0.001
0.005	0.1617	0
0.005	0.1602	0.001
0.005	0.1578	0.002
0.005	0.1544	0.003
0.005	0.1501	0.004
0.005	0.145	0.005

(continued)

Z	X	Y
0.005	0.139	0.006
0.005	0.1322	0.007
0.005	0.1248	0.008
0.005	0.1166	0.009
0.01	0.4002	-0.007
0.01	0.3408	-0.006
0.01	0.286	-0.005
0.01	0.1931	-0.004
0.01	0.1902	-0.003
0.01	0.1913	-0.002
0.01	0.1909	-0.001
0.01	0.1892	0
0.01	0.1863	0.001
0.01	0.1824	0.002
0.01	0.1776	0.003
0.01	0.1718	0.004
0.01	0.1653	0.005
0.01	0.1581	0.006
0.01	0.1503	0.007
0.01	0.1421	0.008
0.015	0.4724	-0.007
0.015	0.4133	-0.006
0.015	0.3586 -0.005	
0.015	0.3085	-0.004
0.015	0.2616	-0.003
0.015	0.2246	-0.002
0.015	0.2212	-0.001
0.015	0.2175	0
0.015	0.2126	0.001
0.015	0.2067	0.002
0.015	0.2	0.003
0.015	0.1926	0.004
0.015	0.1846	0.005
0.015	0.1762	0.006
0.015	0.1675	0.007
0.015	0.1585	0.008
0.02	0.5299	-0.007

(continued)

Z	X	Y
0.02	0.4852	-0.006
0.02	0.4308	-0.005
0.02	0.3807	-0.004
0.02	0.3352	-0.003
0.02	0.2942	-0.002
0.02	0.2551	-0.001
0.02	0.2442	0
0.02	0.2369	0.001
0.02	0.2289	0.002
0.02	0.2204	0.003
0.02	0.2115	0.004
0.02	0.2023	0.005
0.02	0.1929	0.006
0.02	0.1834	0.007
0.02	0.1745	0.008
0.025	0.5627	-0.006
0.025	0.5024	-0.005
0.025	0.4526	-0.004
0.025	0.4072	-0.003
0.025	0.3662	-0.002
0.025	0.3296	-0.001
0.025	0.2975	0
0.025	0.2696	0.001
0.025	0.2502	0.002
0.025	0.2395	0.003
0.025	0.2297	0.004
0.025	0.2203	0.005
0.025	0.2117	0.006
0.025	0.2042	0.007
0.025	0.1988	0.008
0.03	0.5734	-0.005
0.03	0.5241	-0.004
0.03	0.4789	-0.003
0.03	0.438	-0.002
0.03	0.4014	-0.001
0.03	0.3692	0
0.03	0.3412	0.001

(continued)

5

10

15

20

25

30

35

40

45

50

Z	X	Y
0.03	0.3175	0.002
0.03	0.2977	0.003
0.03	0.2818	0.004
0.03	0.2696	0.005
0.03	0.2614	0.006
0.03	0.2566	0.007
0.03	0.2548	0.008
0.035	0.595	-0.004
0.035	0.5502	-0.003
0.035	0.5095	-0.002
0.035	0.473	-0.001
0.035	0.4408	0
0.035	0.4128	0.001
0.035	0.3891	0.002
0.035	0.3693	0.003
0.035	0.3535	0.004
0.035	0.3414	0.005
0.035	0.333	0.006
0.035	0.328	0.007
0.035	0.3264	0.008
0.04	0.6211	-0.003
0.04	0.5808	-0.002
0.04	0.5445	-0.001
0.04	0.5124	0
0.04	0.4844	0.001
0.04	0.4606	0.002
0.04	0.4409	0.003
0.04	0.4252	0.004
0.04	0.4133	0.005
0.04	0.4051	0.006
0.04	0.4005	0.007
0.04	0.3994	0.008

[0025] Of course, it should be understood that other configurations for transition region (60) and/or other regions of fan blade (50) may be used. In some versions, inflection portion (64), having only second portion (66) transition to root airfoil profile (100) directly. Still further constructions for transition region (60), etc., will be ap-

parent to one of ordinary skill in the art in view of the teachings herein.

[0026] Referring now to FIG. 4A, a cross-sectional root airfoil profile (100) is shown taken along section A-A of FIG. 4. Root airfoil profile (100) comprises a top surface (102), a bottom surface (104), a leading edge (106), and a trailing edge (108). Root airfoil profile (100) of the present embodiment comprises a curved airfoil having a substantially constant thickness (110) and a substantially constant radius of curvature (120). By way of example only, thickness (110) may range from approximately 1 millimeter (0.03937 inches), inclusive, to approximately 5 millimeters (0.19685 inches), inclusive. In the embodiment shown, thickness (110) is approximately 4 millimeters (0.15748 inches) though this is merely one embodiment. Still further values for thickness (110) will be apparent to one of ordinary skill in the art in view of the teachings herein. Also by way of example only, radius of curvature (120) is measured from a center point (118) and may range from approximately 2 meters (6.56167 feet), inclusive, to approximately 5 meters (16.4042 feet), inclusive. In the embodiment shown, radius of curvature (120) is approximately 3.7 meters (12.1391 feet). Still further values for radius of curvature (120) will be apparent to one of ordinary skill in the art in view of the teachings herein. In the embodiment shown in FIG. 4A, root airfoil profile (100) is defined when radius of curvature (120) is swept through a root angle (122). Root angle (122) of the present embodiment is approximately 14 degrees, though it should be understood that this is merely exemplary and other smaller and/or larger root angles (122) will be apparent to one of ordinary skill in the art in view of the teachings herein. Furthermore, leading edge (106) and trailing edge (108) comprise rounded surfaces connecting top surface (102) to bottom surface (104), though this is merely optional. Leading edge (102) and trailing edge (104) of the present embodiment form rounded surfaces having a radius of curvature substantially equal to thickness (110). Thus, as shown in FIG. 4A, a substantially constant thickness root airfoil profile (100) is formed.

[0027] FIG. 4B depicts a cross-sectional intermediate airfoil profile (200) taken along section B-B of FIG. 4 at an approximate midpoint between root airfoil profile (100) and tip airfoil profile (300), discussed in greater detail below. It should be understood that while the term intermediate is used, it does not necessarily connote that the shape, size, or values defining intermediate airfoil profile (200) are in between those of root airfoil profile (100) and tip airfoil profile (300). Intermediate airfoil profile (200) of the present embodiment comprises a top surface (202), a bottom surface (204), a leading edge (206), and a trailing edge (208). Intermediate airfoil profile (200) of the present embodiment is substantially identical to root airfoil profile (100) and has a substantially identical thickness (110) and is defined by a substantially identical radius of curvature (120) with the exception that radius of curvature (120) is swept through an intermediate angle (222). By way of example only, intermediate angle (222)

is approximately 12.5 degrees, though of course other smaller and/or larger intermediate angles (222) will be apparent to one of ordinary skill in the art in view of the teachings herein.

[0028] FIG. 4C shows a cross-sectional tip airfoil profile (300) taken along section C-C of FIG. 4 at an approximate tip (70) of fan blade (50). Tip airfoil profile (300) of the present embodiment comprises a top surface (302), a bottom surface (304), a leading edge (306), and a trailing edge (308). Tip airfoil profile (300) of the present embodiment is substantially identical to root airfoil profile (100) and has a substantially identical thickness (110) and is defined by a substantially identical radius of curvature (120) with the exception that radius of curvature (120) is swept through a tip angle (322). By way of example only, tip angle (322) is approximately 7 degrees, though of course other smaller and/or larger tip angles (322) will be apparent to one of ordinary skill in the art in view of the teachings herein.

[0029] FIG. 5 depicts a composite overlay of the cross-sections of FIGS. 4A-4C. As noted above, root airfoil profile (100), intermediate airfoil profile (200), and tip airfoil profile (300) are substantially identical in shape and thickness with the exception of each being formed by sweeping radius of curvature (120) to various angle (122, 222, 322). In some versions, the tip angle (322) is a minimum value for the angles through which radius of curvature (120) is swept while root angle (122) is a maximum value for fan blade (50). Though, it should be understood that tip angle (322) need not necessarily be the minimum value for the angles through which radius of curvature (120) is swept and/or root angle (122) need not necessarily be the maximum value for the angles through which radius of curvature (120) is swept. In addition, or in the alternative, angles (122, 222, 322) may linearly increase in value from tip angle (322) to root angle (122). In other versions, angles (122, 222, 322) may increase in value logarithmically, parabolically, cubically, and/or in any other manner from tip angle (322) to root angle (122). Referring briefly to FIG. 6, fan blade (50) is also configured to have a blade rise angle (98). In the embodiment shown, blade rise angle (98) corresponds to the angle formed between the plane in which the fan rotates and the top surface of fan blade (50). Thus, the absolute height of each fan blade (50) increases from root end (52) to tip (70). By way of example only, blade rise angle (98) may be an angle of approximately 0 degrees, inclusive, to approximately 20 degrees, inclusive. More specifically, blade rise angle (98) may be from 2.5 degrees, inclusive, to 5 degrees, inclusive. In the embodiment shown, blade rise angle (98) is approximately 3.8 degrees. Still further configurations for airfoil profiles (100, 200, 300) and/or fan blade (50) will be apparent to one of ordinary skill in the art in view of the teachings herein. By way of example only, flaps, slats, extensions, electrical or mechanical actuators, and/or other features may be added to fan blades (50).

[0030] Fan blade (50) of the present embodiment is manufactured from thin sheets of material laminated to-

gether. For instance, fan blade (50) may be constructed by combining individual sheets with adhesive between each layer and forcing the sheets together under pressure in a shaped mold to form fan blade (50) shown in FIGS. 1-6. By way of example only, fan blade (50) may be manufactured using 7 layers of 0.5 millimeter (0.019685 inches) thick bamboo veneer that are compressed together as described above. Of course other thicknesses and/or number of layers may be used. Alternatively, other types of wooden veneer may be used or may be combined with other woods to form composite fan blades (50). In yet a further alternative, fan blade (50) may be formed from of a thermoplastic resin that is injected into a mold for fan blade (50) to achieve the desired profile. Further still, fan blade (50) may be formed from a single layer of plastic that is heated and bent or inserted into a mold to form the profile of fan blade (50). In still a further alternative, fan blade (50) may be formed from layers of fiberglass matting or carbon fiber composite materials combined with epoxy resins. In yet another alternative, layers of wood veneer or other materials (e.g., carbon fiber, fiberglass, etc.) may initially be layered within a mold and plastic or another resin may be injected or otherwise added to form fan blade (50). Of course still further constructions for fan blade (50) will be apparent to one of ordinary skill in the art in view of the teachings herein.

III. Exemplary Alternative Fan

[0031] FIGS. 7-10 depict an alternative fan not part of the claimed subject-matter (400) having a support (410), a motor (420), a hub (430), and a plurality of fan blades (450). Support (410) and motor (420) of the present example may be constructed in substantial accordance with support (20) and motor (30) described above. Hub (430), shown best in FIG. 8, comprises an annular member disposed about and coupled to motor (420) such that rotation of motor (420) rotates hub (430). Hub (430) further includes a plurality of holes (432) to which fasteners (434) may be coupled to substantially fixedly coupled fan blades (450) with hub (430). Accordingly, when motor (420) rotates, fan blades (450) and hub (430) also rotate. It should be understood that additional components, such as grommets or other vibratory-reducing members may be included between fan blades (450) and hub (430) and/or between hub (430) and motor (420). In the present example, fan (400) further includes a top cover (412) having a circular center (not shown) and a plurality of rectangular fan extensions (414). In the present example, rectangular fan extensions (414) curve downwardly relative to support (410) and are configured to nest within top recesses (454) formed in fan blades (450), described below, to form a substantially smooth transition between top cover (414) and fan blades (450).

[0032] A circular bottom cover (416) includes a plurality of upwardly projecting reshaped tabs (418) disposed about the circumference of bottom cover (416) and a cen-

tral lens (419). Lens (419) may be constructed in accordance with lens (48) described above. Bottom cover (416) is configured to couple to a bottom portion of fan blades (450) via tabs (418) inserting into recesses (not shown) formed in fan blades (450) and then being rotated such that an axial projection from each tab locks into the recesses. Accordingly, when bottom cover (416) is coupled to fan blades (450), a substantially smooth lower surface for fan (400) is formed. Of course it should be understood that bottom cover (416) may couple to fan blades (450) through other attachment members, such as screws, bolts, clips, clamps, straps, resilient tabs, etc. In addition, or in the alternative, bottom cover (416) may be directly coupled to motor (420). Fan (400) may be further configured in accordance with the teachings of fan (10) described above or in any other manner as will be apparent to one of ordinary skill in the art in view of the teachings herein.

[0033] Referring now to FIGS. 9-10, fan blade (450) of the present example comprises a root end (452), a tip (470), a leading edge (480), and a trailing edge (490). Fan blade (450) of the present example comprises airfoil profiles that substantially correspond to airfoil profiles (100, 200, 300) described above. In the present example, however, fan blade (450) comprises an alternative root end (452) and transition region (466). Transition region (466) of the present example comprises a tapered portion of fan blade (450) that transitions from root end (452) to airfoil profiles (100, 200, 300) for fan blade (450). Root end (452) of the present example includes a top recess (454) configured to receive a respective extension (414) therein. Thus, when extensions (414) are nested within respective top recesses (454) a substantially smooth transition is formed from top cover (414) to fan blades (450) for fan (400). In addition, one or more openings (456) are formed through a lower portion of root end (452) to permit fasteners (434) therethrough to substantially fixedly coupled fan blade (450) to hub (430) described above.

[0034] Root end (452) is further includes a recessed ledge (458) and an outer lip (460) disposed on opposing ends of root end (452). As shown in FIGS. 8-9, recessed ledge (458) corresponds to the side of fan blade (450) with leading edge (480) while outer lip (460) corresponds to the side of fan blade (450) with trailing edge (490). Accordingly, when fan blades (450) are assembled for fan (400), recessed ledge (458) nests with and below outer lip (460) of the fan blade (450) to form a substantially smooth and continuous surface from one fan blade (450) to the next. In the present example, fan blades (450) have root ends (452) with recessed ledges (458) and outer lips (460) disposed approximately 120 degrees from each other such that three fan blades (450) may be combined to form a substantially continuous fan blade structure (as shown in FIG. 7). Of course it should be understood that other angular relationships may be used as well (e.g., 180 degrees for a dual fan blade (450) assembly, 90 degrees for a four fan blade (450) assembly, 60 degrees

for a five fan blade (450) assembly, etc.). In addition, or in the alternative, fasteners (not shown) may be used to couple corresponding recessed ledges (458) and outer lips (460) together for fan blades (450). Further still, rubber grommets (not shown) or other vibratory-reducing members may be interposed between corresponding recessed ledges (458) and outer lips (460) to vibrationally isolate fan blades (450) from one another. In the present example, a pair of rib members (462) are provided within root end (452) to reinforce or otherwise provide additional rigidity to root end (452), though these are merely optional. Still further constructions for root end (452) and/or fan blade (450) will be apparent to one of ordinary skill in the art in view of the teachings herein.

[0035] Fan blade (450) of the present example is manufactured by a thermoplastic resin that is injected into a mold for fan blade (450) to achieve the desired profile. Alternatively, fan blade (450) may be formed from thin sheets of material laminated together and anchored to a thermoplastic or other material root end (452). For instance, fan blade (450) may be constructed by combining individual sheets with adhesive between each layer and forcing the sheets together under pressure in a shaped mold to form fan blade (450) shown in FIGS. 9-10 and anchored to root end (452). In one version, fan blade (450) may be manufactured using 7 layers of 0.5 millimeter (0.019685 inches) thick bamboo veneer that are compressed together as described above. Of course other thicknesses and/or number of layers may be used. Alternatively, other types of wooden veneer may be used or may be combined with other woods to form composite fan blades (450). Further still, fan blade (450) may be formed from a single layer of plastic that is heated and bent or inserted into a mold to form the profile of fan blade (450) which is subsequently joined to root end (452). In still a further alternative, fan blade (450) may be formed from layers of fiberglass matting or carbon fiber composite materials combined with epoxy resins. In yet another alternative, layers of wood veneer or other materials (e.g., carbon fiber, fiberglass, etc.) may initially be layered within a mold and plastic or another resin may be injected or otherwise added to form fan blade (450). Of course still further constructions for fan blade (450) will be apparent to one of ordinary skill in the art in view of the teachings herein.

[0036] Having shown and described an embodiment of the present invention, further adaptations of the methods and systems described herein may be accomplished by appropriate modifications by one of ordinary skill in the art without departing from the scope of the present invention defined in the appended claims. Several of such potential modifications have been mentioned, and others will be apparent to those skilled in the art. For instance, the examples, embodiments, geometries, materials, dimensions, ratios, steps, and the like discussed above are illustrative and are not necessarily required. Accordingly, the scope of the present invention should be considered in terms of the following claims and is un-

derstood not to be limited to the details of structure and operation shown and described in the specification and drawings.

Claims

1. A fan blade configured to mount to a rotating fan hub (42), the fan blade comprising:
 - a root end (52) configured to couple with the rotating fan hub (42),
 - a blade region;
 - a leading edge (80);
 - a trailing edge (90); and
 - a tip (70), wherein the leading edge (80) and trailing edge (90) terminate into the tip (70), wherein the root end (52) comprises a substantially concave domed sector when viewed from a side view towards the leading edge (80) and a transition region (60) extends between the root end (52) and the blade region, wherein the transition region (60) comprises a profile which transitions the root end profile to the blade region profile,
 - characterized in that** a profile of the blade region comprises a substantially convex top surface and bottom surface.
2. The fan blade of claim 1, wherein the root end (52) comprises an arcuate cutout (54).
3. The fan blade of claim 2, wherein the domed sector is configured to terminate into a region which is parallel to a plane of rotation of the fan blade at a position proximal to the arcuate cutout (54).
4. The fan blade of claim 3, wherein the transition portion comprises a first portion (62), an inflection portion (64), and a second portion (66).
5. The fan blade of claim 4, wherein the first portion (62) comprises an extension of the concave domed sector of the root end which terminates at the inflection portion (64).
6. The fan blade of claim 5, wherein the inflection portion (64) comprises a quasi-parabolic shaped portion that extends from the leading edge (80) to the trailing edge (90) and transitions the fan blade from the extension of the concave domed sector of the first portion (62) to a planar portion.
7. The fan blade of claim 6, wherein the second portion (66) extends from the inflection portion (64) and the planar portion to the profile of the blade region.
8. The fan blade of claim 7, wherein the top surface of

the profile of the blade region comprises: a first top convex curvature proximal to the second portion (66) of the transition region, and a second top convex curvature proximal to the tip (70).

9. The fan blade of claim 8, wherein the bottom surface of the profile of the blade region comprises a first bottom convex curvature proximal to the second portion (66) of the transition region, and a second bottom convex curvature proximal to the tip (70).

10. The fan blade of claim 9, wherein the top surface of the blade region transitions from the first top convex curvature to the second top convex curvature along a length of the blade region.

11. The fan blade of claim 10, wherein the bottom surface of the blade region transitions from the first bottom convex curvature to the second bottom convex curvature along the length of the blade region.

12. The fan blade of claim 11, wherein the bottom surface of the blade region slopes upward along the length of the blade region.

13. The fan blade of claim 12, wherein the top surface of the blade region slopes upward along the length of the blade region.

14. The fan blade of claim 13, wherein the leading edge (80) is located at a position higher than a position of the trailing edge (90).

15. A fan assembly comprising:

a fan motor (30);
a fan hub (42), wherein the fan hub (42) is attached to the fan motor (50), **characterized by** the fan blade of claim 14, wherein the fan blade is one of a plurality of similar fan blades mounted to the fan hub (42).

Patentansprüche

1. Ventilatorblatt, welches zur Montage an eine rotierende Ventilatornabe (42) ausgebildet ist, umfassend:

ein Flügelende (52), welches zum Ankoppeln an die rotierende Ventilatornabe (42) ausgebildet ist;
einen Flügelbereich;
eine Vorderkante (80);
eine Hinterkante (90); und
eine Spitze (70), wobei die Vorderkante (80) und die Hinterkante (90) in der Spitze (70) enden;
wobei das Flügelende (52) bei seitlicher Be-

trachtung in Richtung der Vorderkante (80) einen im Wesentlichen konkaven gewölbten Abschnitt aufweist und

wobei ein Übergangsbereich (60) sich zwischen dem Flügelende (52) und dem Blattbereich erstreckt, wobei der Übergangsbereich (60) ein Profil aufweist, welches das Flügelende in das Blattbereichprofil ändert,

dadurch gekennzeichnet,

dass ein Profil des Blattbereichs eine im Wesentlichen konvexe obere Fläche und eine untere Fläche aufweist.

2. Ventilatorblatt nach Anspruch 1, wobei das Flügelende (52) einen bogenförmigen Ausschnitt (54) aufweist.

3. Ventilatorblatt nach Anspruch 2, wobei der gewölbte Abschnitt ausgebildet ist, in einem Bereich zu enden, welcher in einer Position in der Nähe des bogenförmigen Ausschnitts (54) parallel zu einer Rotations-ebene des Ventilatorblatts ist.

4. Ventilatorblatt nach Anspruch 3, wobei der Übergangsabschnitt einen ersten Abschnitt (62), einen gebogenen Abschnitt (64) und einen zweiten Abschnitt (66) aufweist.

5. Ventilatorblatt nach Anspruch 4, wobei der erste Abschnitt (62) eine Verlängerung des konkaven gewölbten Abschnitts des Flügelendes aufweist, wobei die Verlängerung an dem gebogenen Abschnitt (64) endet.

6. Ventilatorblatt nach Anspruch 5, wobei der gebogene Abschnitt (64) einen quasiparabolischen Abschnitt aufweist, welcher sich von der Vorderkante (80) zu der Hinterkante (90) erstreckt und das Ventilatorblatt von der Verlängerung des konkaven gewölbten Abschnitts des ersten Abschnitts (62) zu einem ebenen Abschnitt ändert.

7. Ventilatorblatt nach Anspruch 6, wobei der zweite Abschnitt (66) sich von dem gebogenen Abschnitt (64) und dem ebenen Abschnitt zu dem Profil des Blattbereichs erstreckt.

8. Ventilatorblatt nach Anspruch 7, wobei die obere Fläche des Profils des Blattbereichs Folgendes aufweist: eine erste obere konvexe Biegung nahe dem zweiten Abschnitt (66) des Übergangsbereichs und eine zweite obere konvexe Biegung nahe der Spitze (70).

9. Ventilatorblatt nach Anspruch 8, wobei die Grundfläche des Profils des Blattbereichs eine erste untere konvexe Biegung nahe dem zweiten Abschnitt (66) des Übergangsbereichs und eine zweite untere kon-

vexe Biegung nahe der Spitze (70) aufweist.

10. Ventilatorblatt nach Anspruch 9, wobei die obere Fläche des Blattbereichs längs des Blattbereichs von der ersten oberen konvexen Biegung zu der zweiten oberen konvexen Biegung übergeht. 5
11. Ventilatorblatt nach Anspruch 10, wobei die untere Fläche des Blattbereichs längs des Blattbereichs von der ersten unteren konvexen Biegung zu der zweiten unteren konvexen Biegung übergeht. 10
12. Ventilatorblatt nach Anspruch 11, wobei die untere Fläche des Blattbereichs längs des Blattbereichs nach oben steigt. 15
13. Ventilatorblatt nach Anspruch 12, wobei die obere Fläche des Blattbereichs längs des Blattbereichs nach oben steigt. 20
14. Ventilatorblatt nach Anspruch 13, wobei die Vorderkante (80) höher angeordnet ist als die Hinterkante (90). 25
15. Ventilatoranordnung, umfassend: 25
einen Ventilatormotor (30);
eine Ventilatornabe (42), wobei die Ventilatornabe (42) an dem Ventilatormotor (50) befestigt ist, 30
gekennzeichnet durch
das Ventilatorblatt nach Anspruch 14, wobei das Ventilatorblatt eines aus einer Vielzahl von ähnlichen an der Ventilatornabe (42) montierten Ventilatorblättern ist. 35

Revendications

1. Pale de ventilateur réalisée à être montée à un moyeu de ventilateur (42), ladite pale de ventilateur comprenant : 40
un extrémité de pale (52) réalisé à être relié au moyeu de ventilateur (42) rotatif ; 45
une zone de pale ;
un bord avant (80) ;
un bord arrière (90) ; et
un bout (70), dans lequel le bord avant (80) et le bord arrière (90) se terminent dans le bout (70), 50
ledit extrémité de pale (52) comprenant une zone de dôme essentiellement concave lorsque vue du côté vers le bord avant (80), et
une zone de transition (60) s'étendant entre l'extrémité de pale (52) et la zone de pale, ladite zone de transition (60) comprenant un profil qui change l'extrémité de pale au profil de zone de 55

pale,

caractérisée en ce qu'un profil de la zone de pale comprend une surface supérieure essentiellement convexe et une surface inférieure.

2. Pale de ventilateur selon la revendication 1, dans laquelle l'extrémité de pale (52) comprend une encoche arquée (54).
3. Pale de ventilateur selon la revendication 2, dans laquelle la zone de dôme est réalisée à se terminer dans une zone qui est parallèle à un plan de rotation de la pale de ventilateur à une position proximale à l'encoche arquée (54).
4. Pale de ventilateur selon la revendication 3, dans laquelle la zone de transition comprend une première partie (62), une partie d'inflexion (64) et une deuxième partie (66).
5. Pale de ventilateur selon la revendication 4, dans laquelle la première partie (62) comprend une extension de la zone de dôme concave de l'extrémité de pale, ladite extension se terminant à la partie d'inflexion (64).
6. Pale de ventilateur selon la revendication 5, dans laquelle la partie d'inflexion (64) comprend une partie presque parabolique qui s'étend du bord avant (80) au bord arrière (90) et change la pale de ventilateur à partir de l'extension de la zone de dôme concave de la première partie (62) à une partie plane.
7. Pale de ventilateur selon la revendication 6, dans laquelle la deuxième partie (66) s'étend de la partie d'inflexion (64) et la partie plane au profil de la zone de pale.
8. Pale de ventilateur selon la revendication 7, dans laquelle la surface supérieure du profil de la zone de pale comprend les suivants : une première courbure supérieure convexe proximale à la deuxième partie (66) de la zone de transition et une deuxième courbure supérieure convexe proximale au bout (70).
9. Pale de ventilateur selon la revendication 8, dans laquelle la surface inférieure du profil de la zone de pale comprend une première courbure inférieure convexe proximale à la deuxième partie (66) de la zone de transition et une deuxième courbure inférieure convexe proximale au bout (70).
10. Pale de ventilateur selon la revendication 9, dans laquelle la surface supérieure de la zone de pale se change à partir de la première courbure supérieure convexe à la deuxième courbure supérieure convexe le long d'une longueur de la zone de pale.

11. Pale de ventilateur selon la revendication 10, dans laquelle la surface inférieure de la zone de pale se change à partir de la première courbure inférieure convexe à la deuxième courbure inférieure convexe le long de la longueur de la zone de pale. 5
12. Pale de ventilateur selon la revendication 11, dans laquelle la surface inférieure de la zone de pale monte le long de la longueur de la zone de pale. 10
13. Pale de ventilateur selon la revendication 12, dans laquelle la surface inférieure de la zone de pale monte le long de la longueur de la zone de pale.
14. Pale de ventilateur selon la revendication 13, dans laquelle le bord avant (80) est disposé plus haut que le bord arrière (90). 15
15. Ensemble de ventilateur, comprenant : 20
 - un moteur de ventilateur (30) ;
 - un moyeu de ventilateur (42), ledit moyeu de ventilateur (42) étant fixé au moteur de ventilateur (50),
 - caractérisé par** 25
 - la pale de ventilateur selon la revendication 14, ladite pale de ventilateur étant une d'une pluralité de pales de ventilateur similaires montées au moyeu de ventilateur (42).

30

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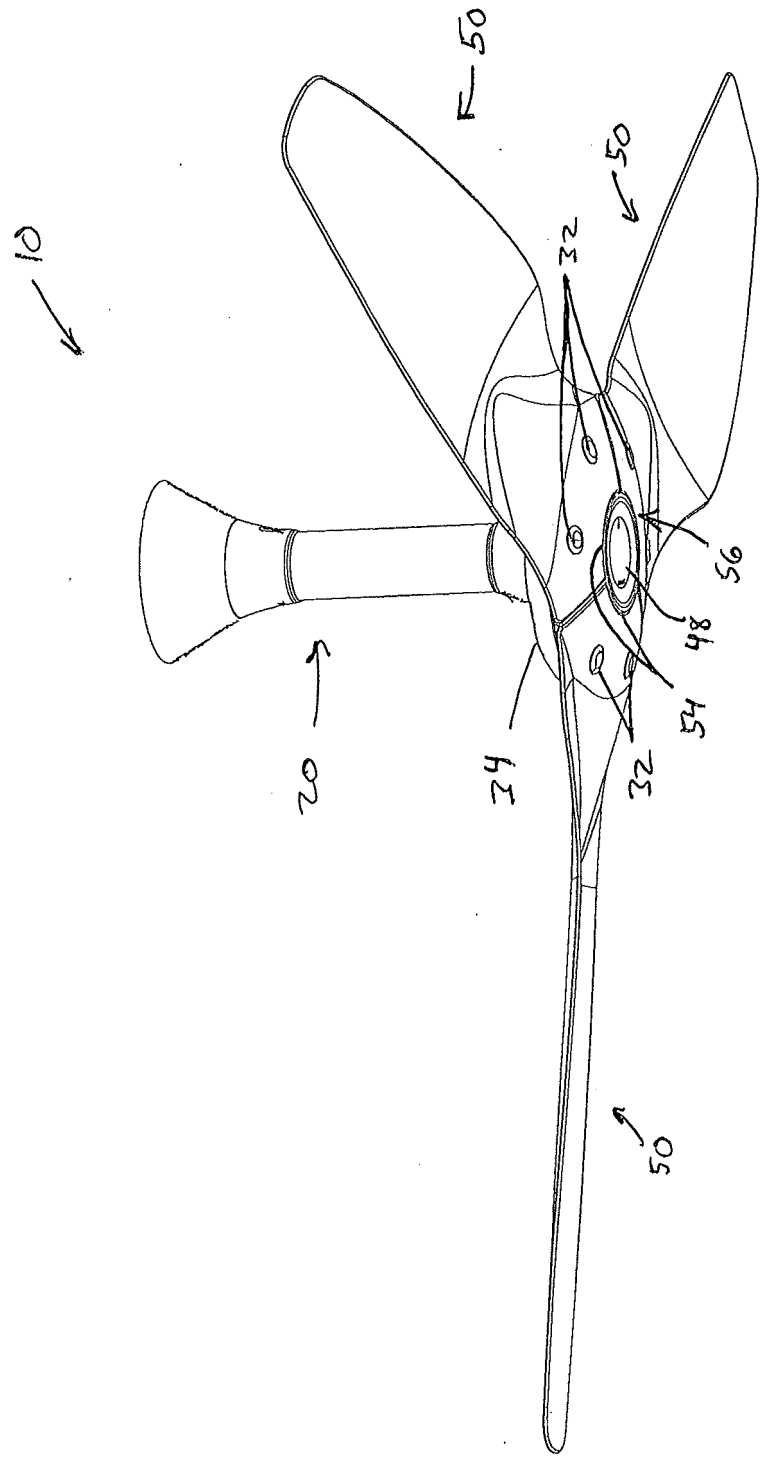
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50

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FIG. 1



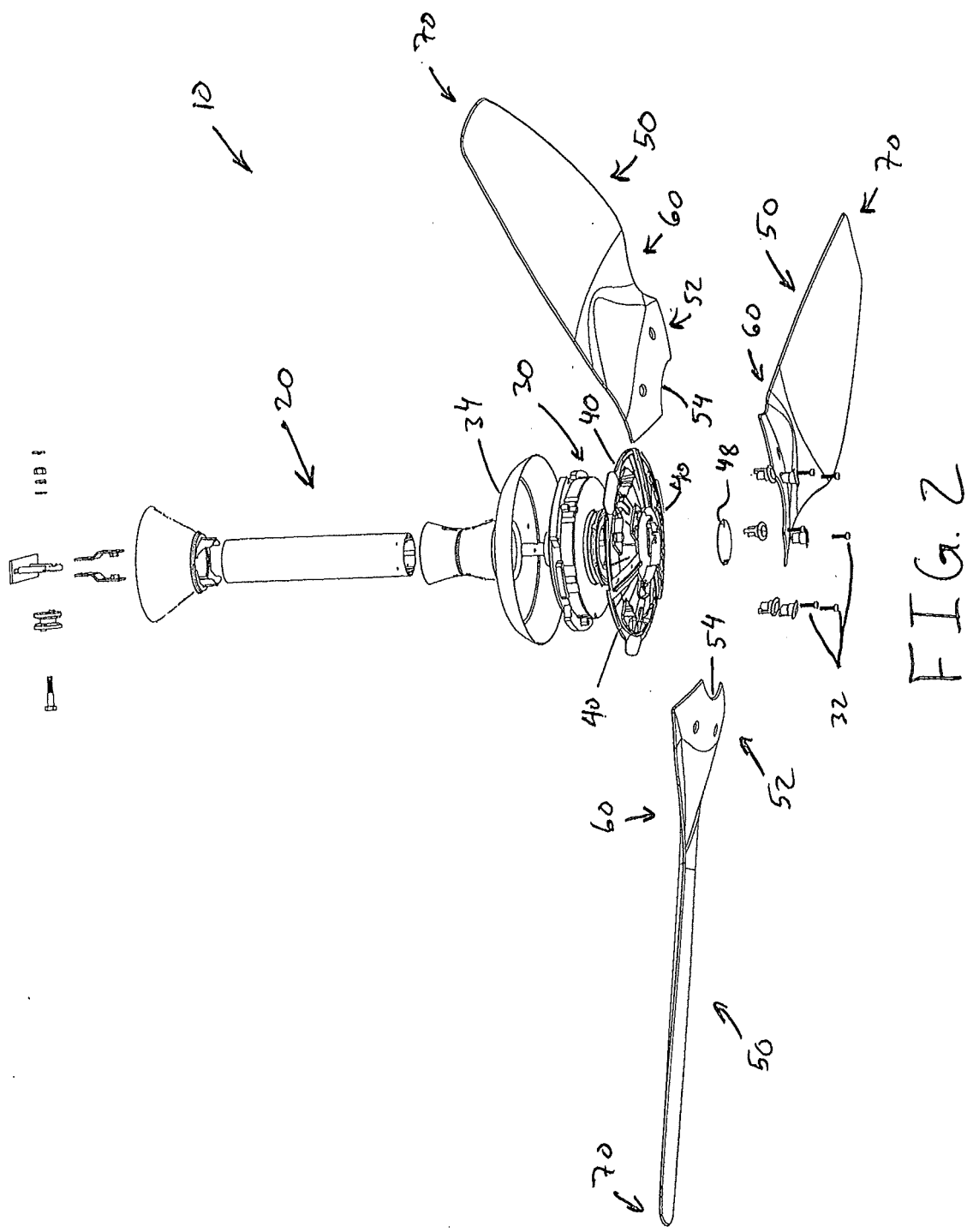
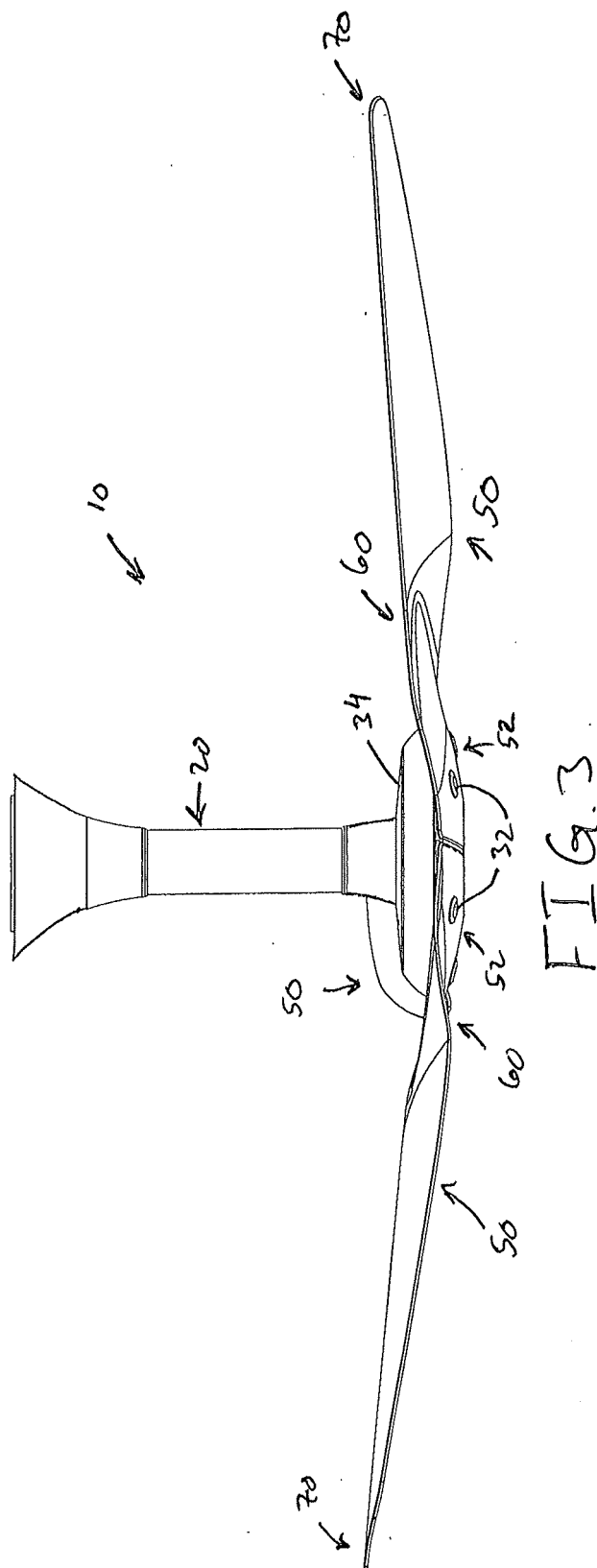


FIG. 2



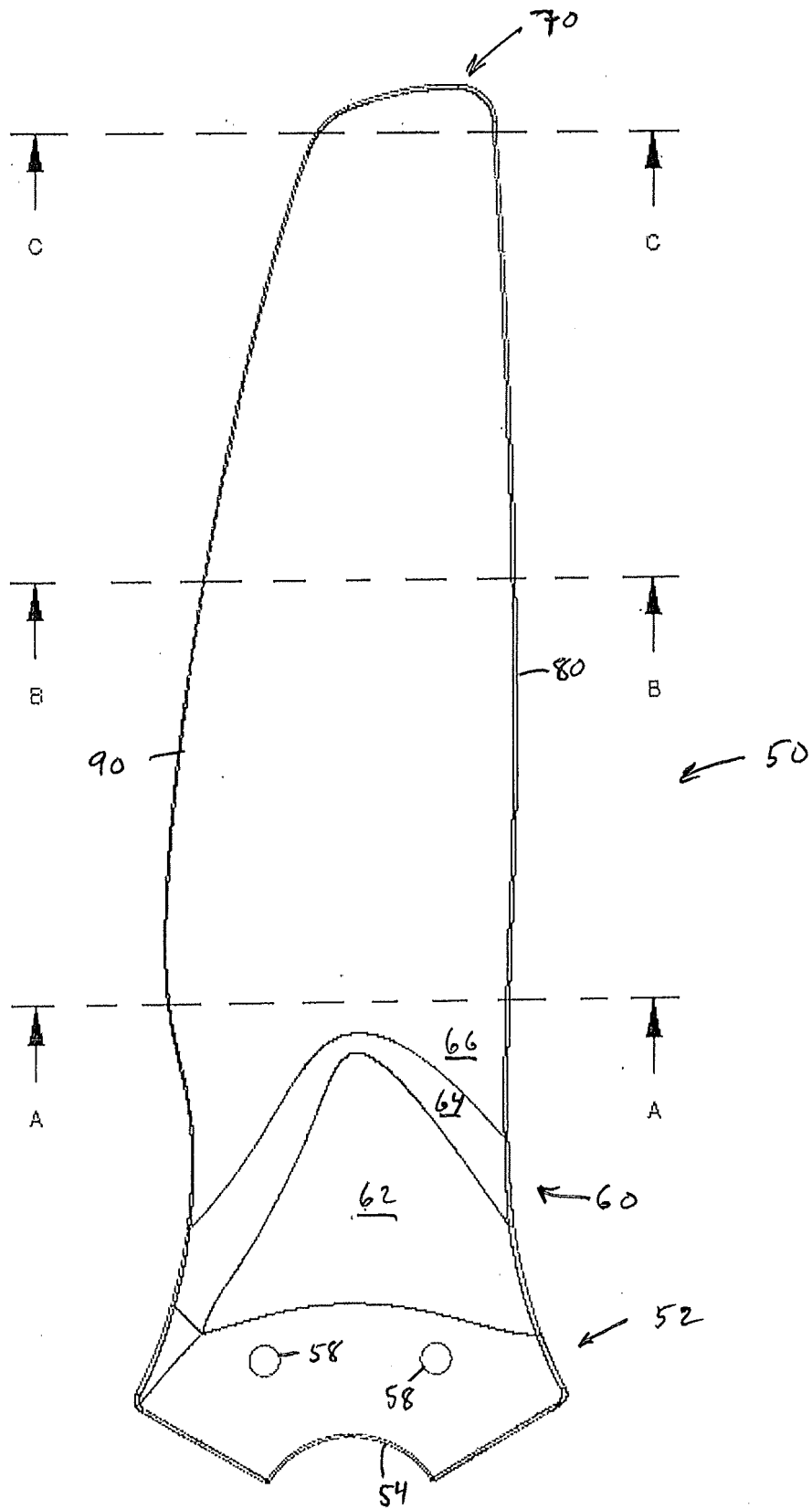
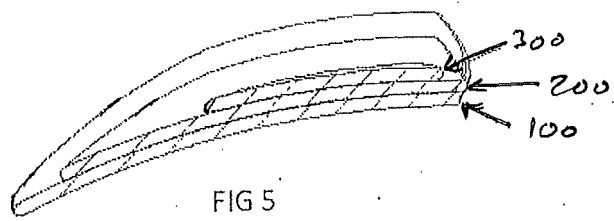
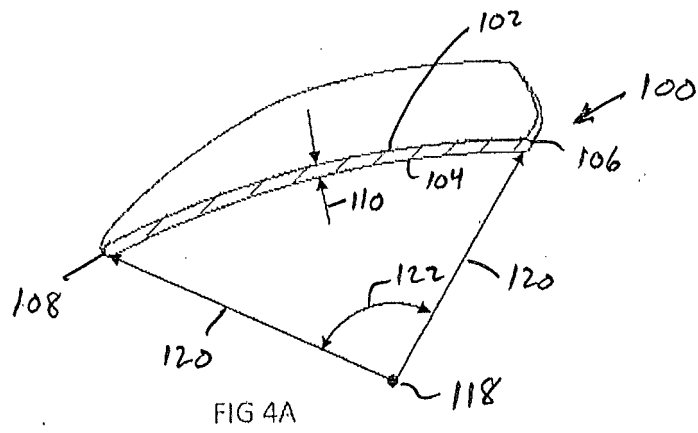
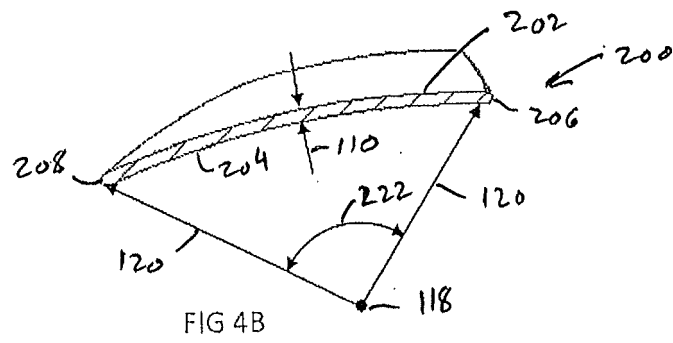
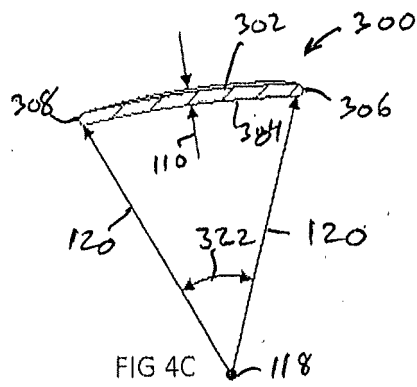


FIG 4



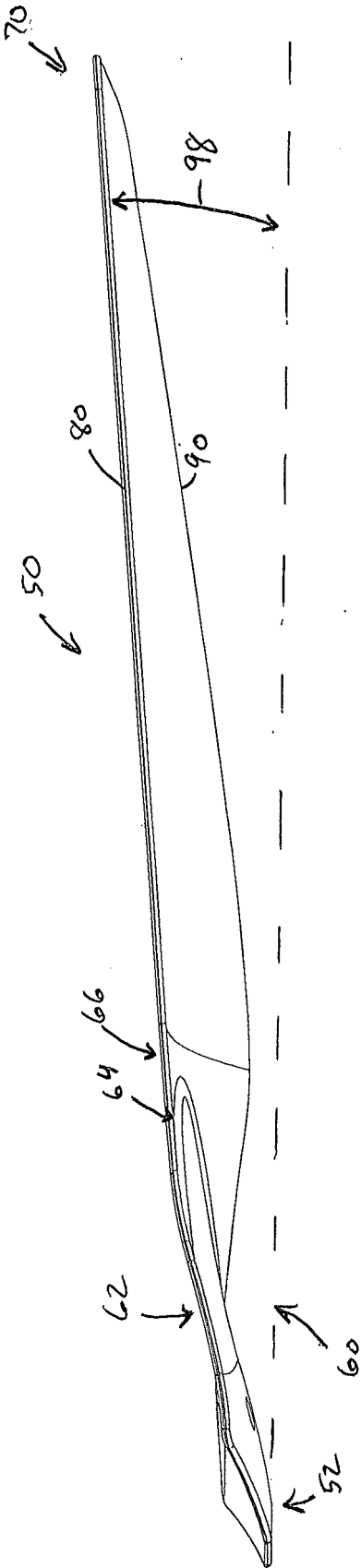


FIG. 6

FIG. 7

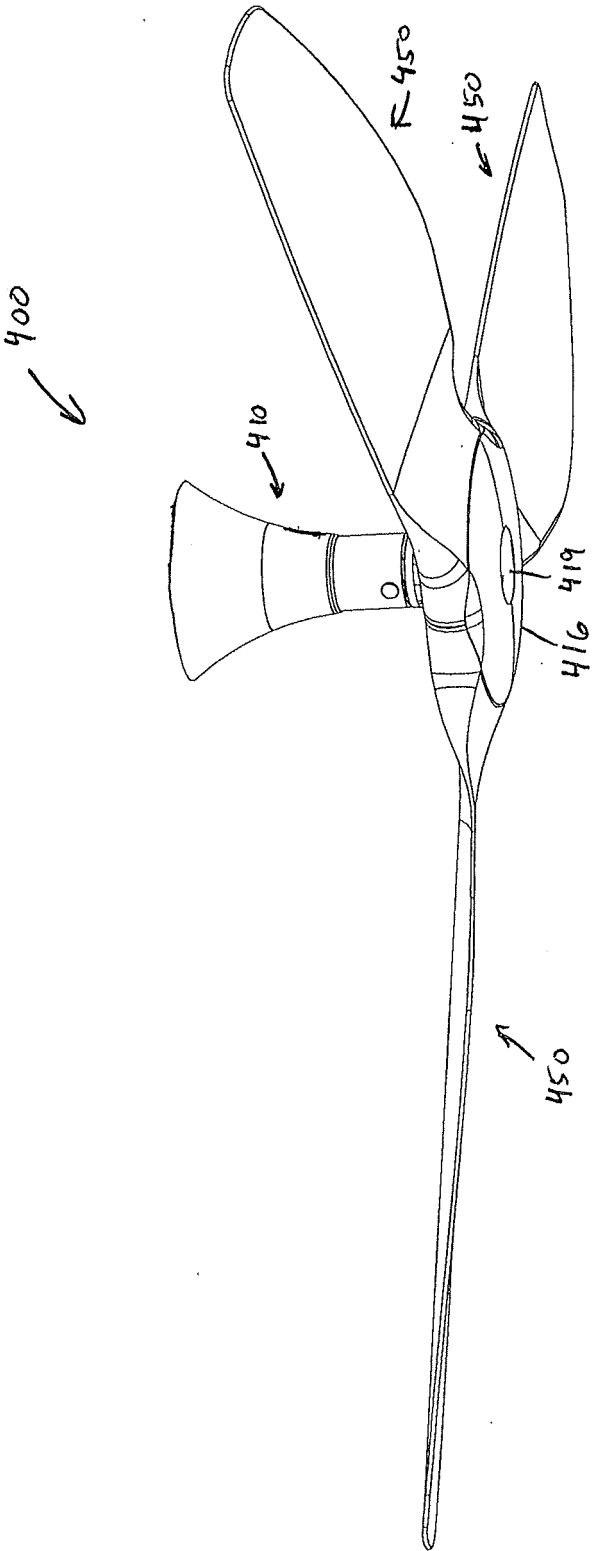
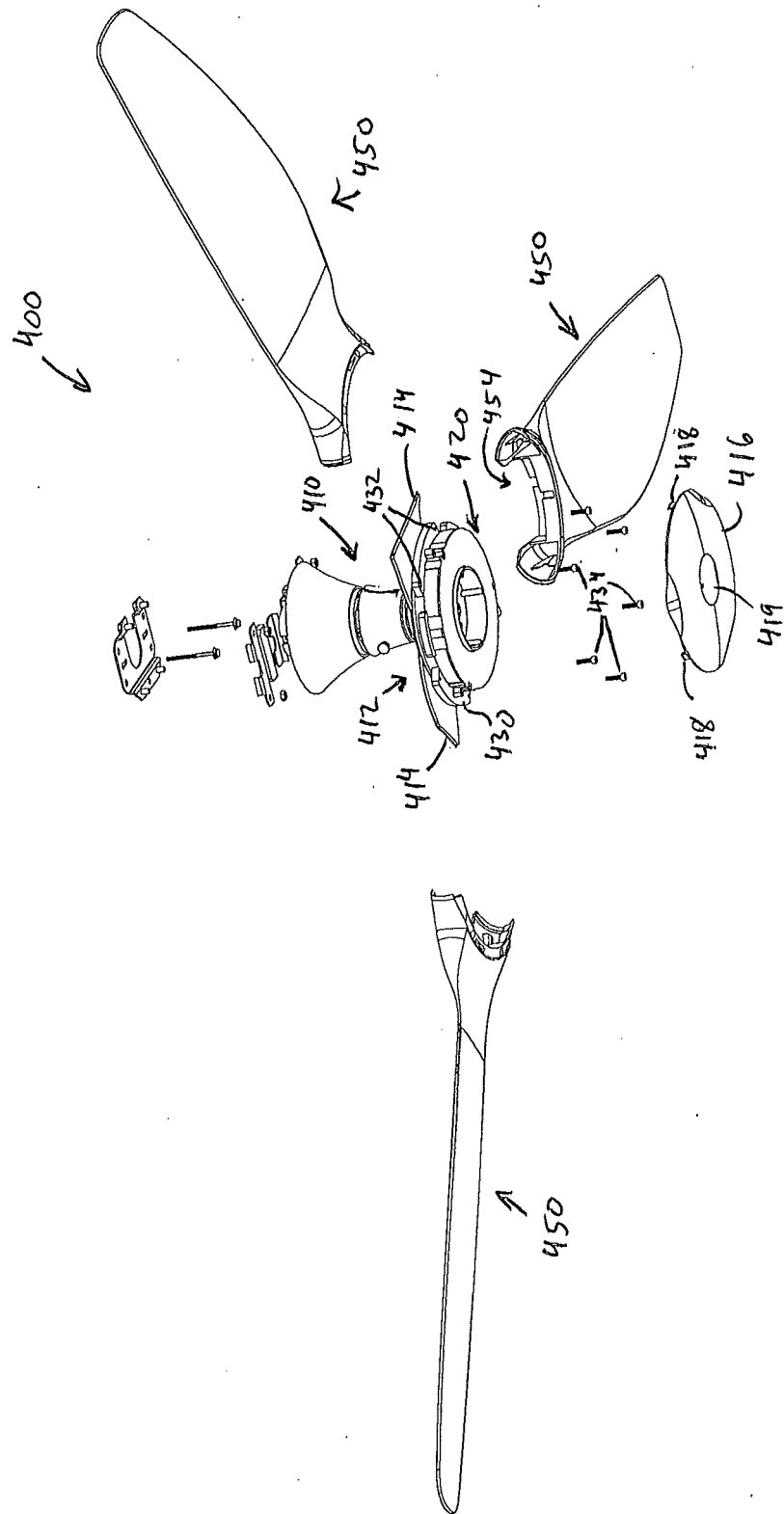


Fig. 2



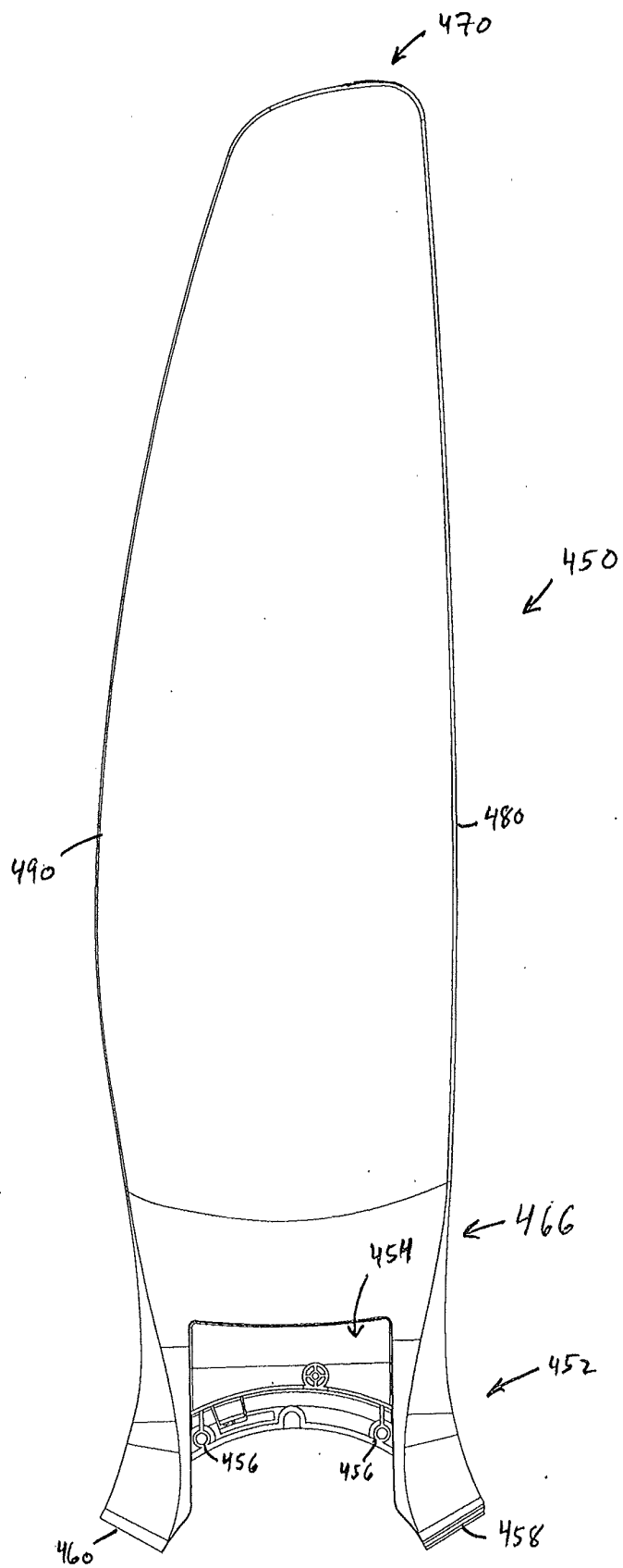
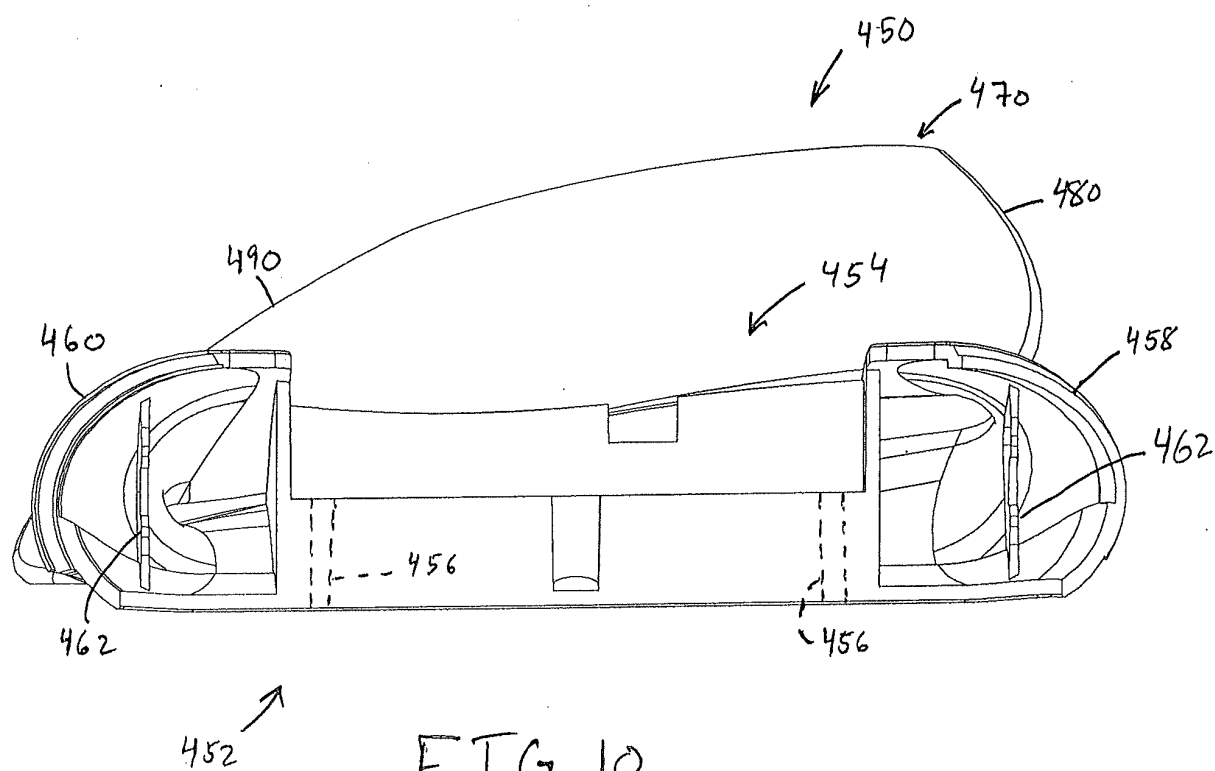


FIG. 9



REFERENCES CITED IN THE DESCRIPTION

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