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Miyakoda et al.

(54) **AXIAL FLOW FAN**

(75) Inventors: **Manabu Miyakoda**, Kyoto (JP); **Hironobu Nishida**, Kyoto (JP); **Suguru Yamada**, Kyoto (JP)

Correspondence Address:
VOLENTINE & WHITT PLLC
ONE FREEDOM SQUARE, 11951 FREEDOM DRIVE SUITE 1260
RESTON, VA 20190 (US)

(73) Assignee: **NIDEC CORPORATION**, Kyoto (JP)

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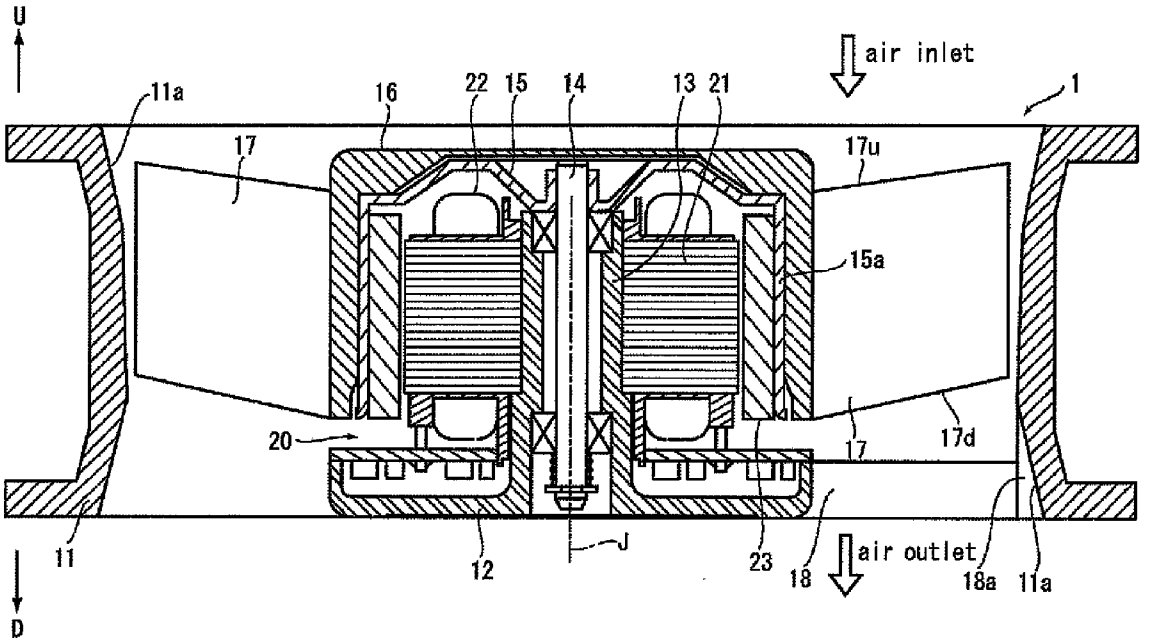
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(52) **U.S. Cl.** **417/354**; 415/119

(57) **ABSTRACT**

An axial flow fan includes a housing defining an air inlet and an air outlet, a motor mounted to the housing and an impeller including blades. The housing includes an expanded portion adjacent the air outlet. In the expanded portion, the inner diameter of the housing increases towards the air outlet so that the expanded portion has an inner end where its diameter is smallest. The trailing edge of each blade is inclined, with respect to a plane perpendicular to the axis of rotation of the impeller, so as to extend toward the air inlet from a radially innermost end of the edge to a radially outermost end of the edge. The radially outermost end of the trailing edge is disposed closer to the air inlet than the inner end of the expanded portion, and the radially innermost end of the of the trailing edge is disposed closer to the air outlet than inner end of the expanded portion.



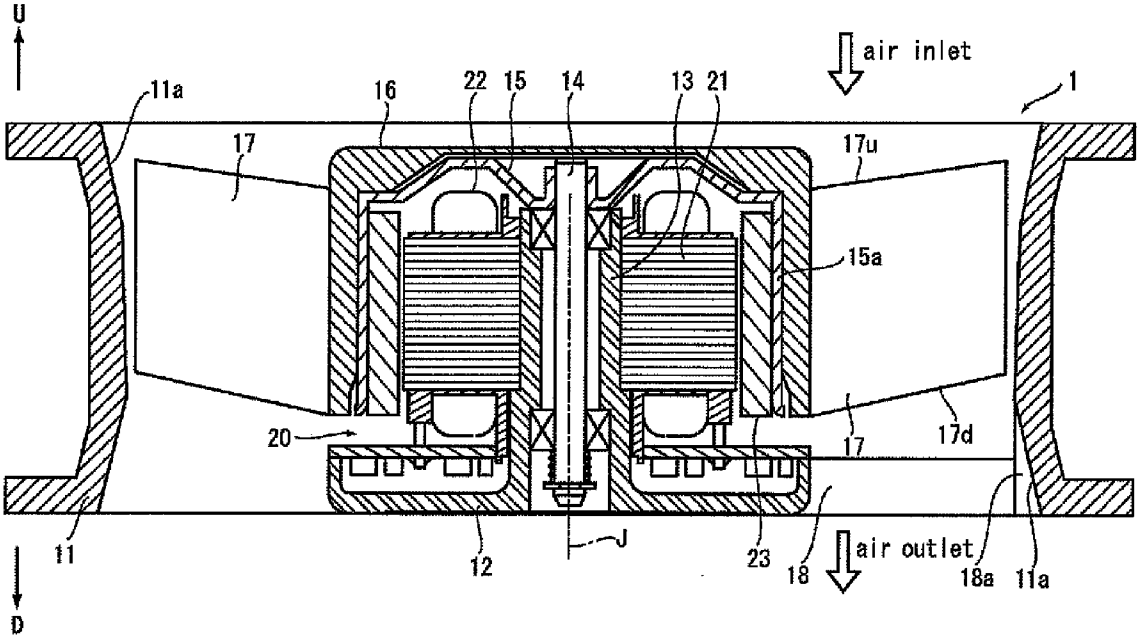

U
D
air inlet
air outlet
11a
16
22
15
14
13
21
1
17
17u
15a
20
17
17d
11
12
J
23
18
18a
11a

FIG. 1

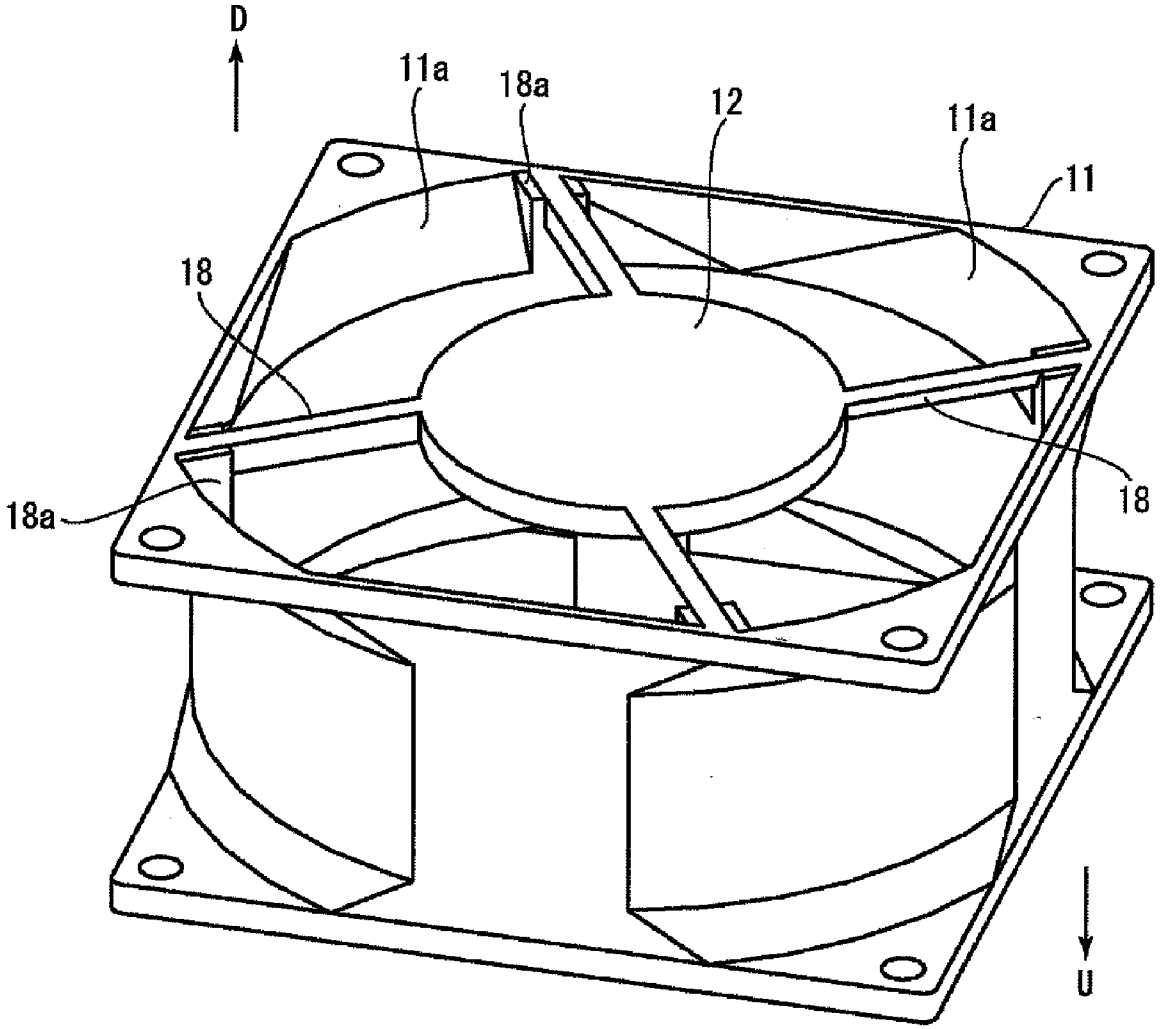


FIG. 2

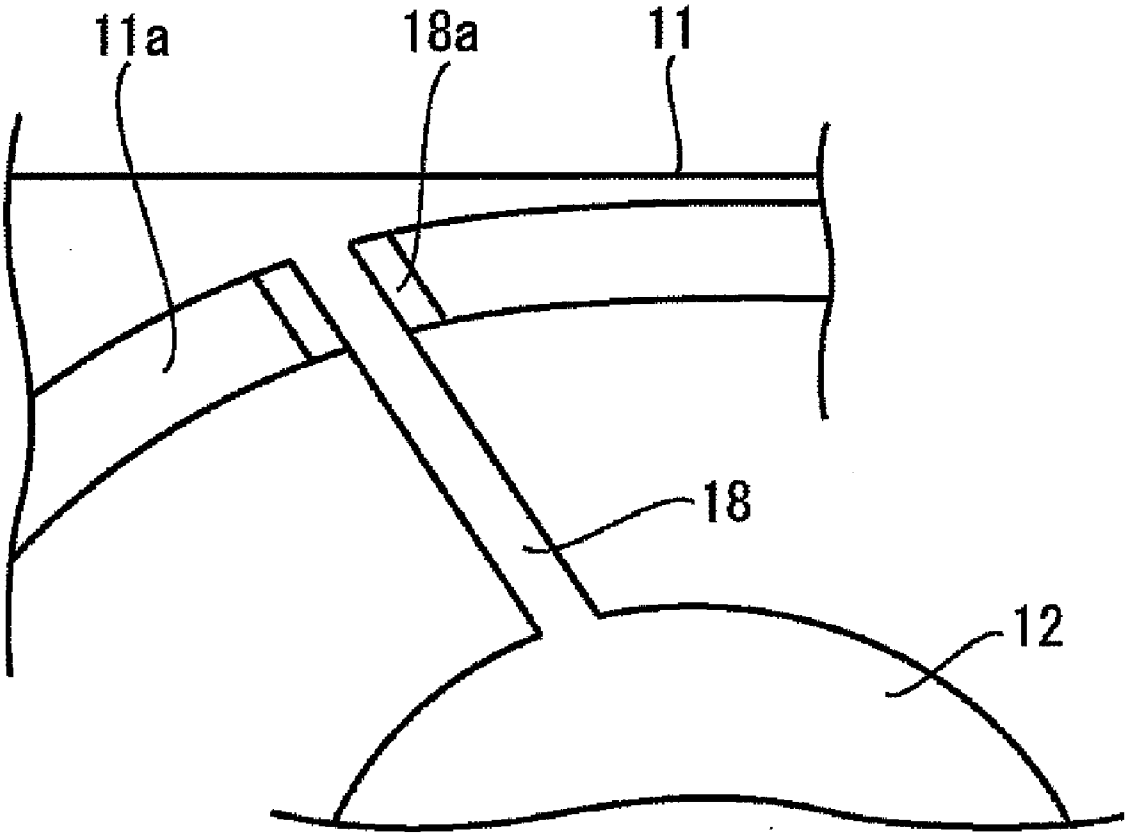


FIG. 3

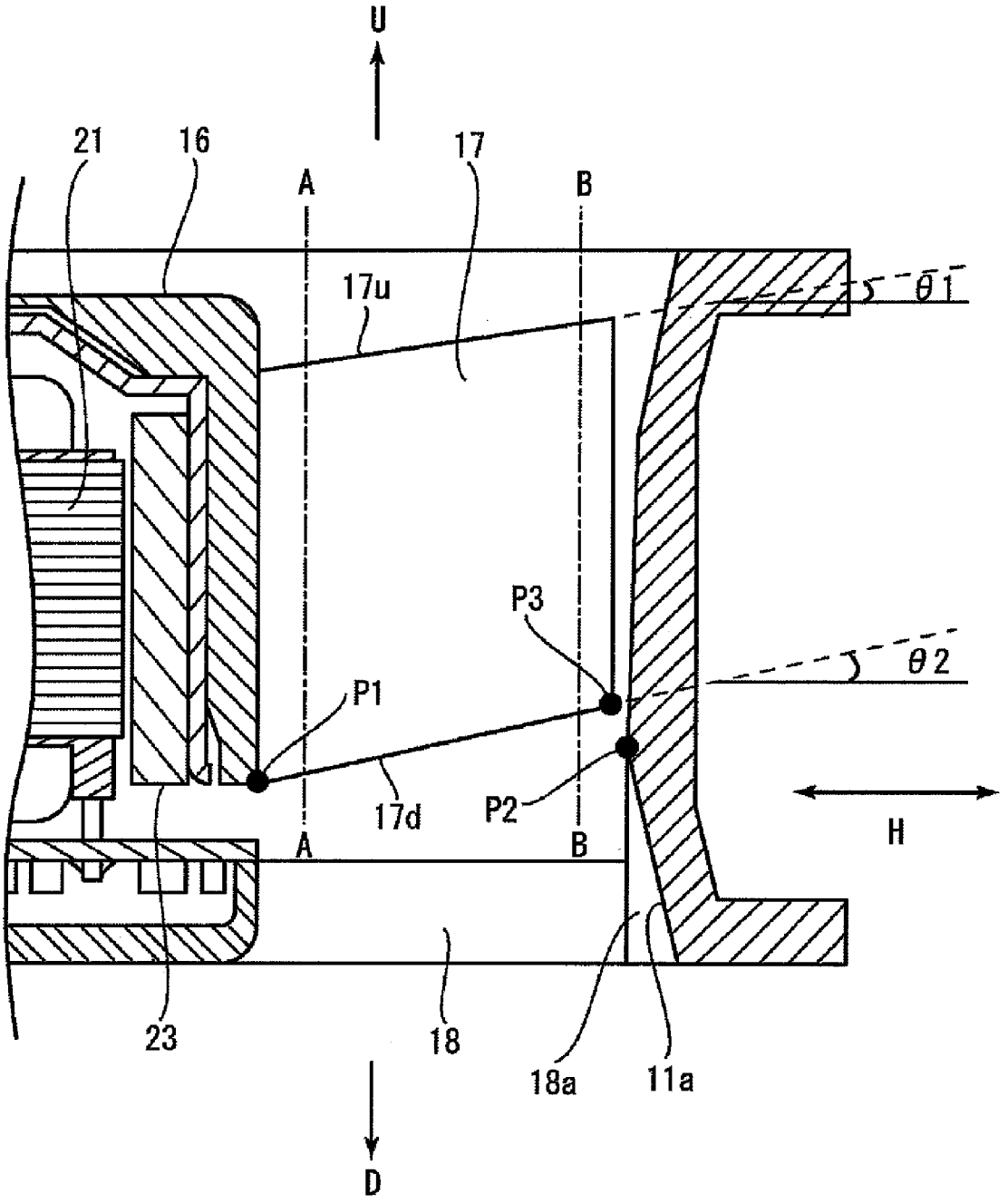


FIG. 4

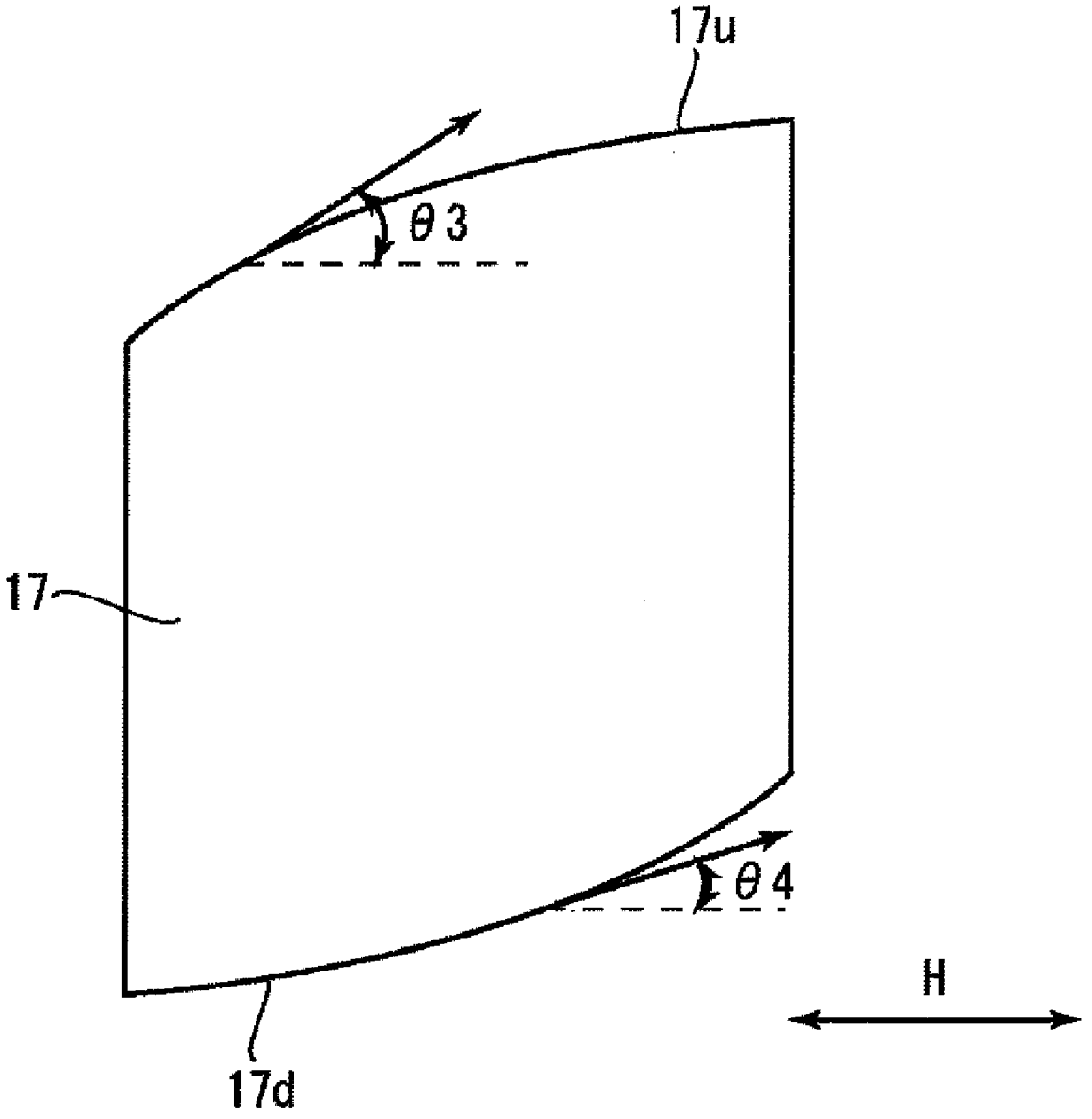


FIG. 5

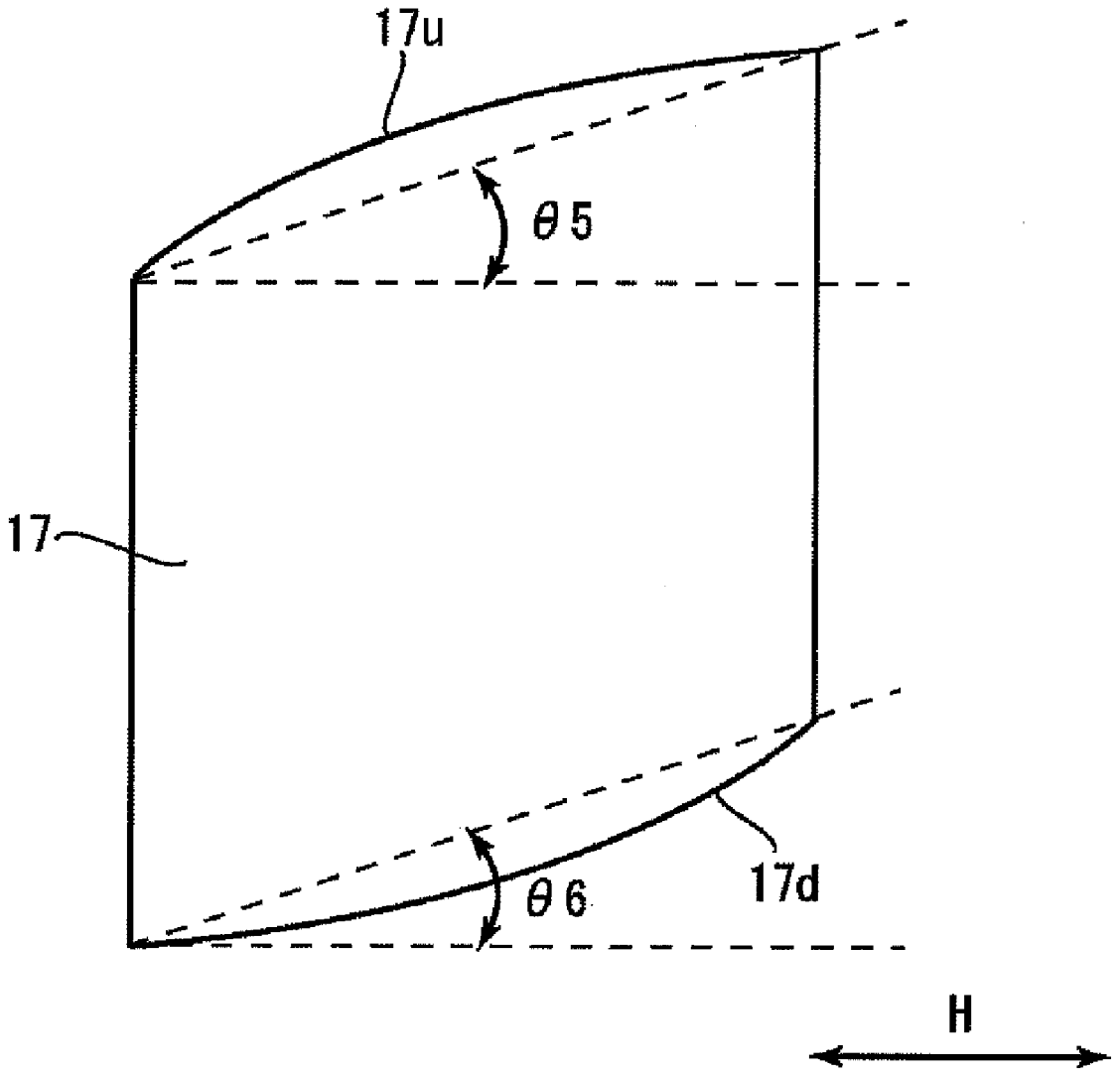


FIG. 6

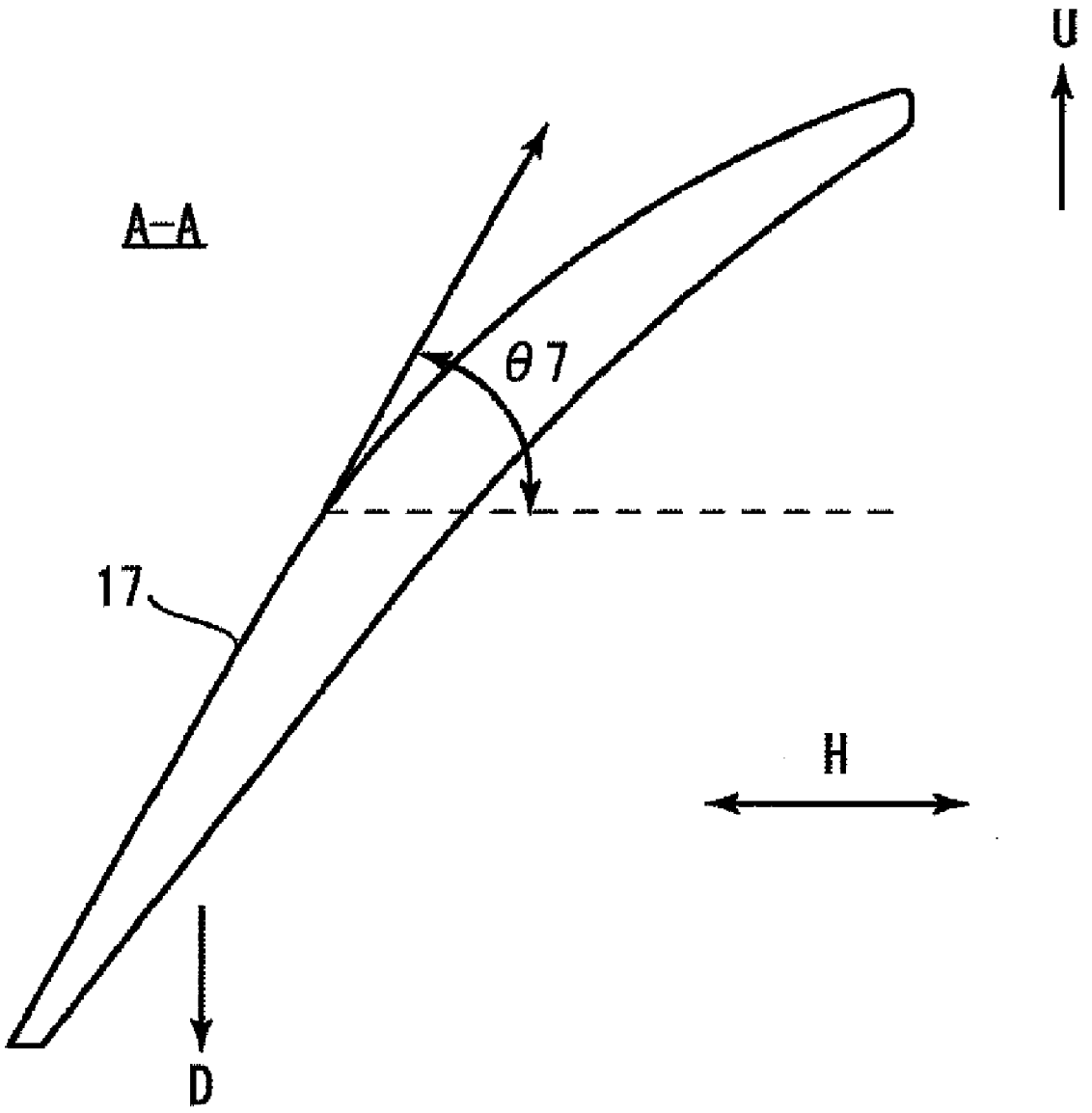


FIG. 7A

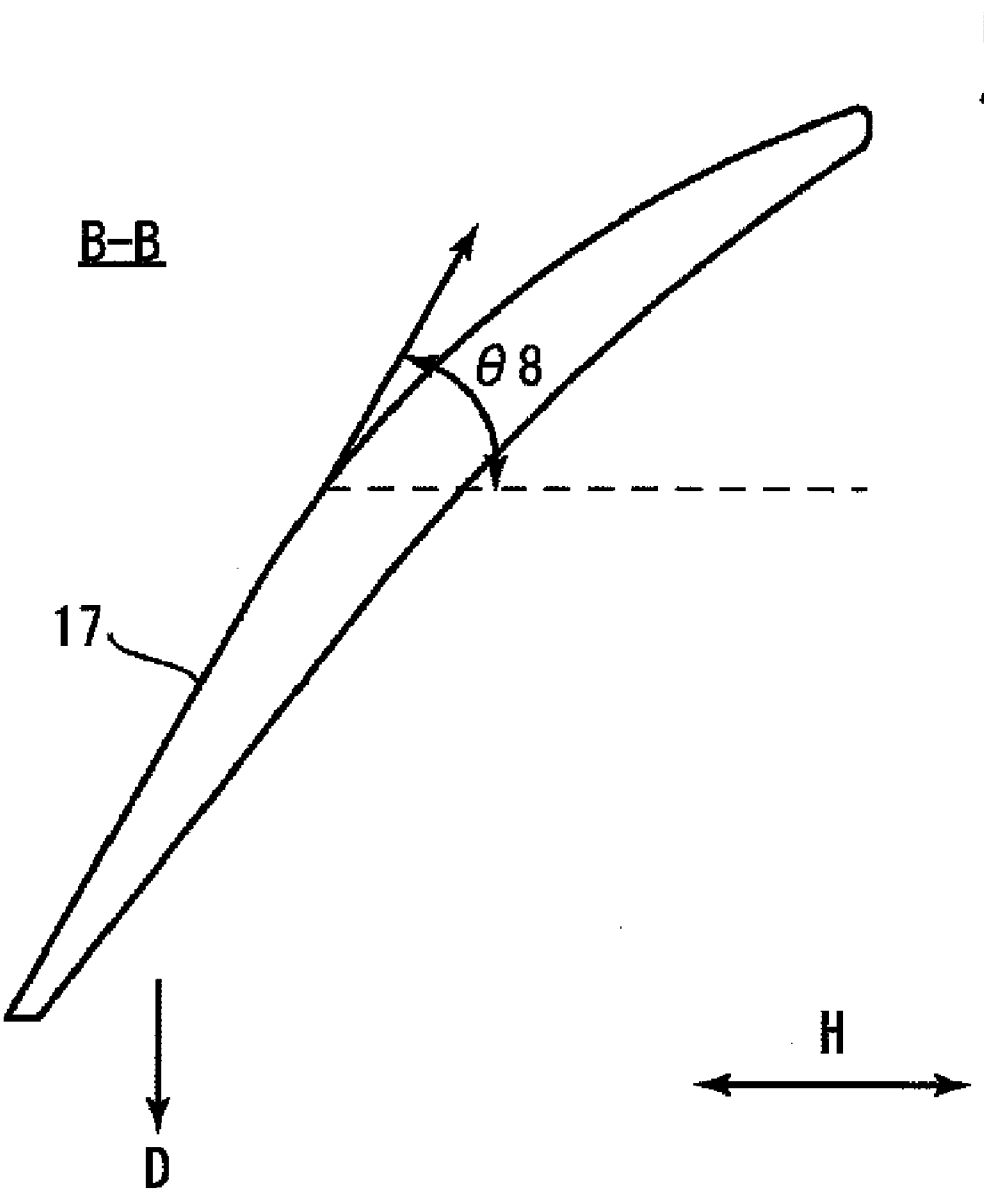


FIG. 7B

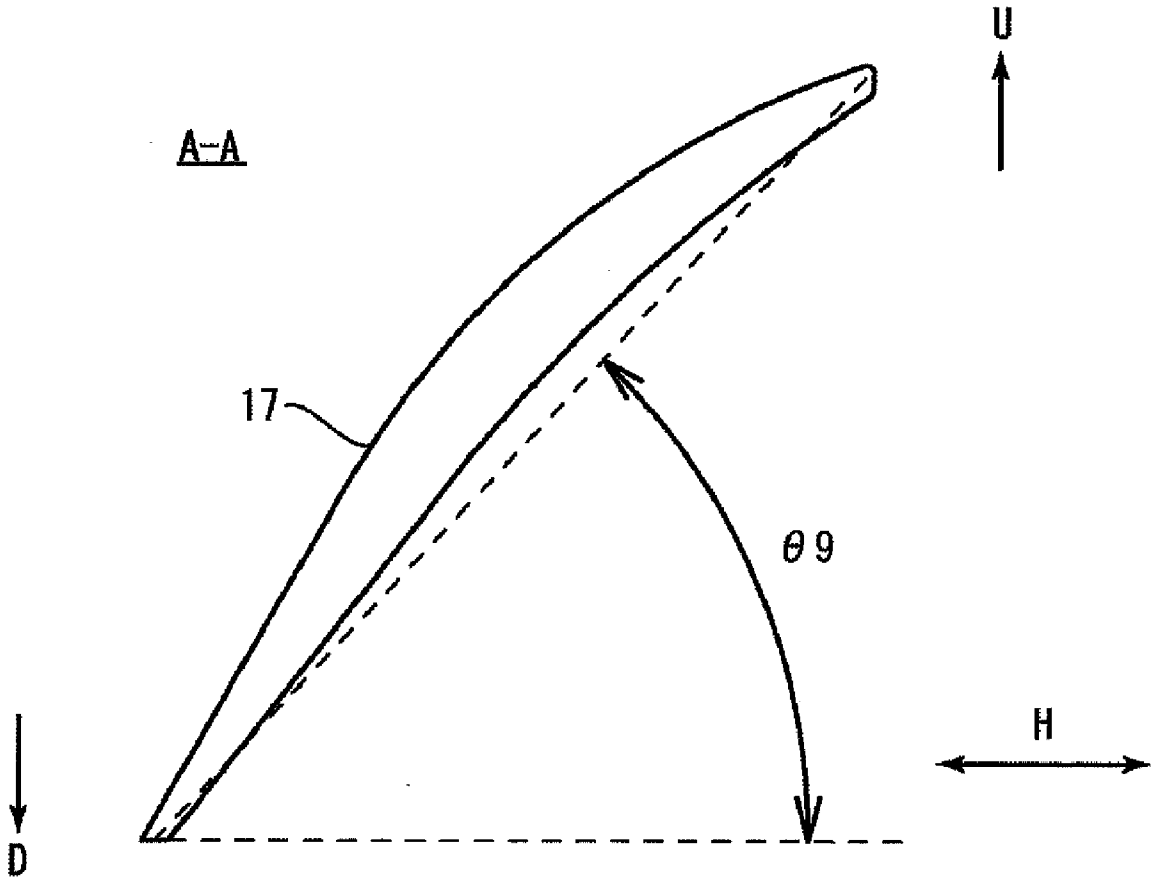


FIG. 8A

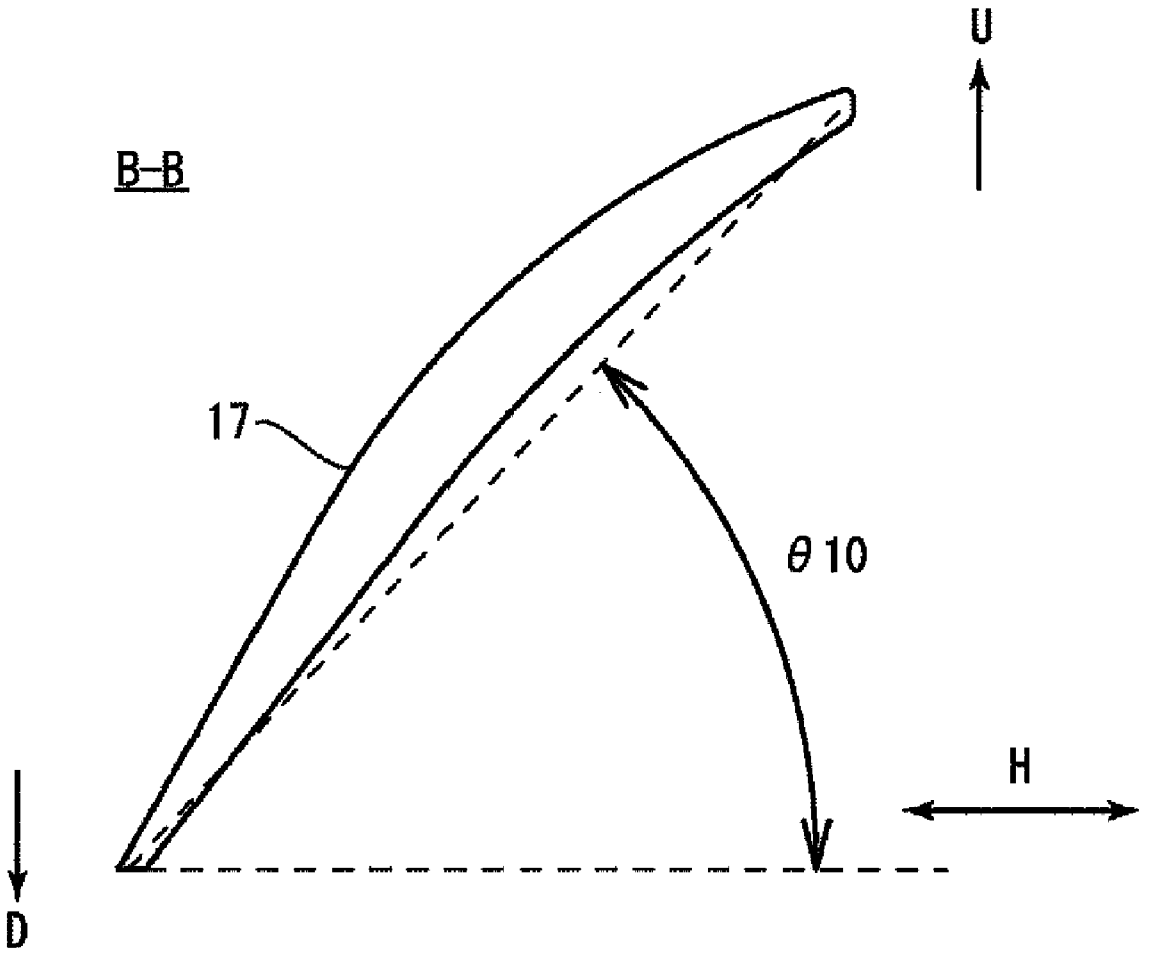


FIG. 8B

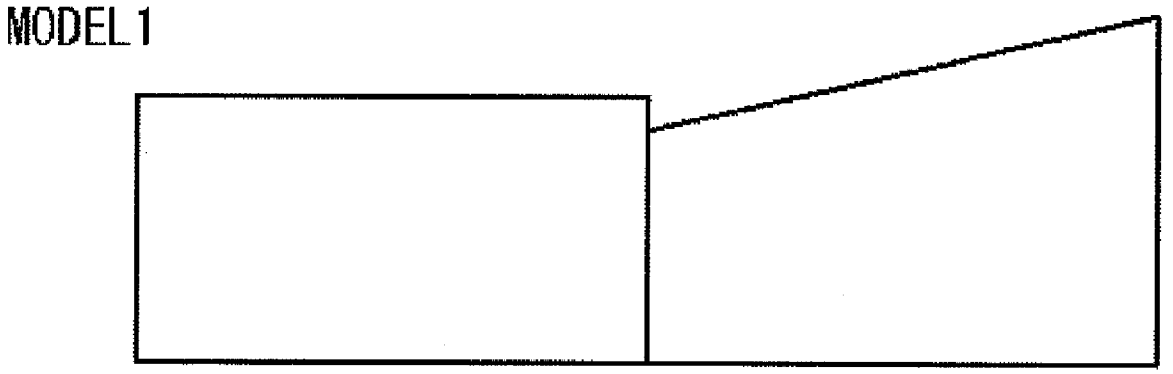


FIG. 9A

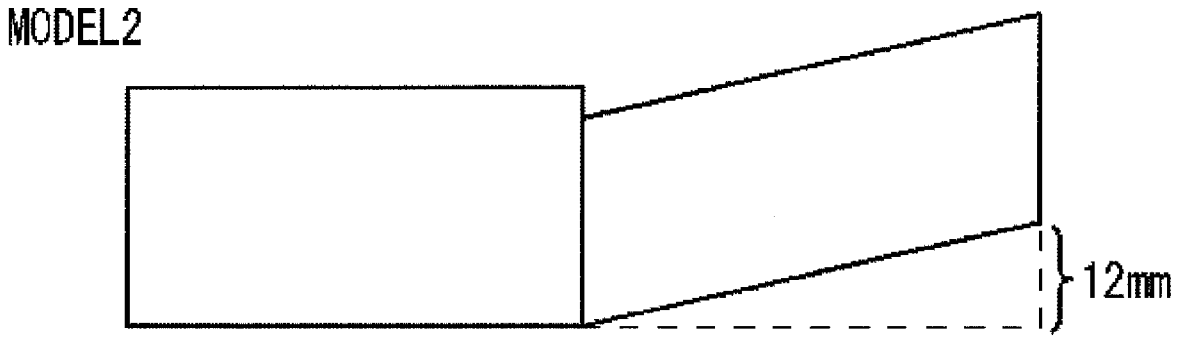


FIG. 9B

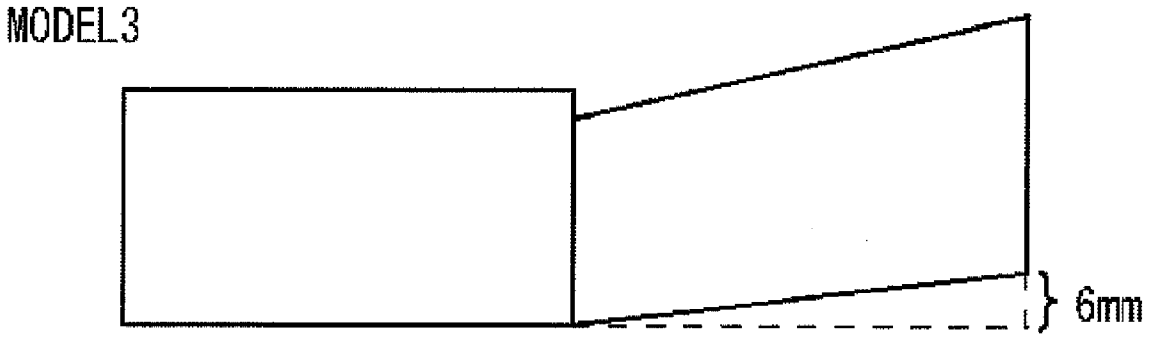


FIG. 9C

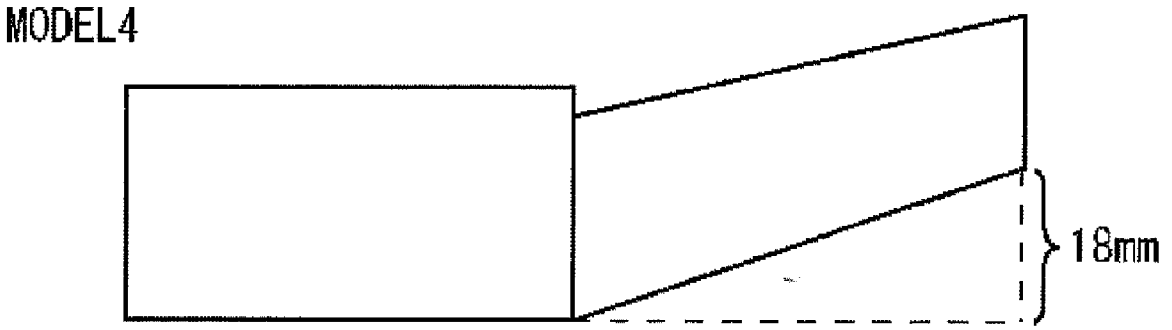


FIG. 9D

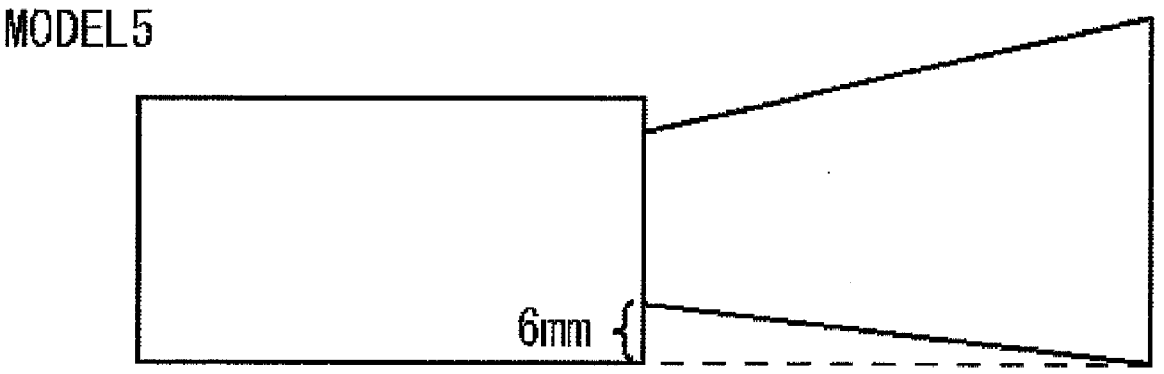


FIG. 9E

	rotation speed (min-1)	MAX flow (CFM)	MAX static pressure (in-H20)	noise (dBA)
MODEL1	11774	66.45	1.769	62.66
MODEL2	13660	69.44	2.005	61.53
MODEL3	12688	68.06	1.887	61.62
MODEL4	14457	69.69	2.076	61.22
MODEL5	12461	67.91	1.841	60.89

FIG. 10

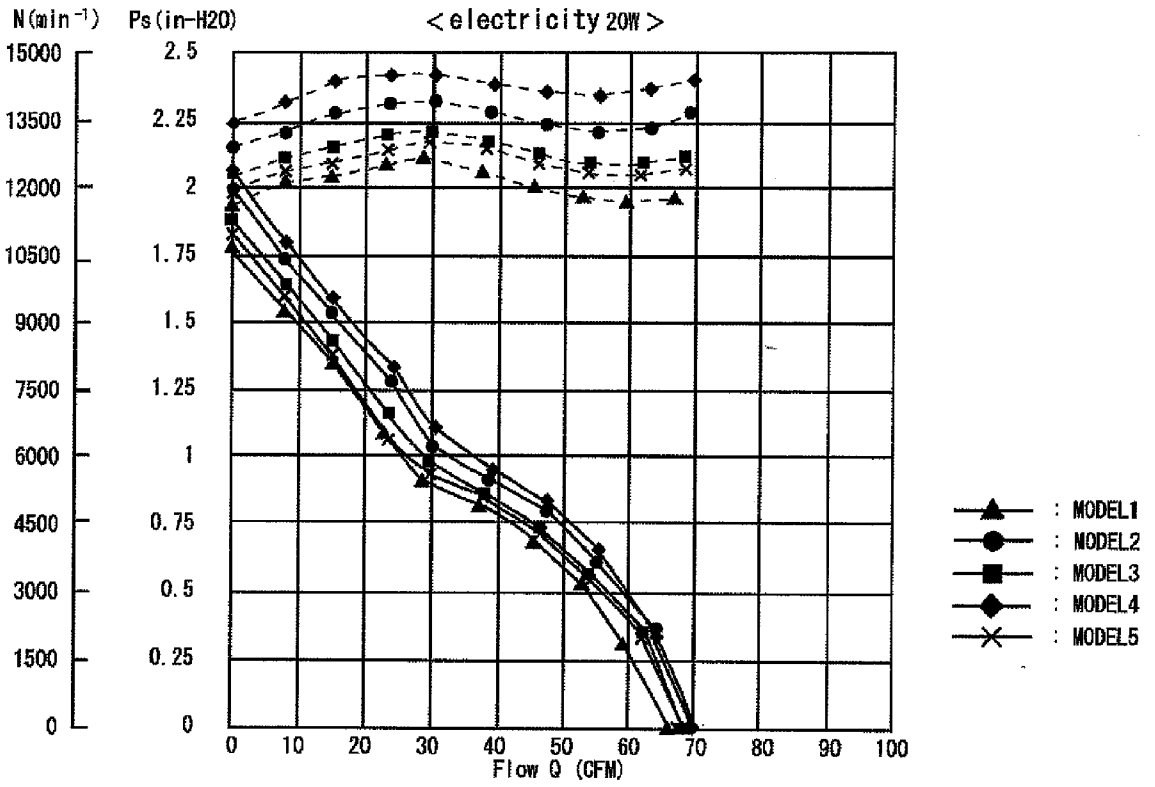

N(min⁻¹)
Ps(in-H2O)
<electricity 20W>
15000
13500
12000
10500
9000
7500
6000
4500
3000
1500
0
2.5
2.25
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
0 10 20 30 40 50 60 70 80 90 100
Flow Q (CFM)
: MODEL1
: MODEL2
: MODEL3
: MODEL4
: MODEL5

FIG. 11

AXIAL FLOW FAN

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] The present invention relates to an axial flow fan. More particularly, the present invention relates to an axial flow fan used to cool the inside of an electronic device such as a computer.

[0003] 2. Description of the Related Art

[0004] Electronic devices have been generating higher amounts of heat as the number and/or capacity of their electronic components and processing units has expanded to meet current demand for higher performance devices. However, such devices will fail if the temperature of their electronic components or processor units becomes too high. Therefore, a fan is typically used to cool the electronic components and processor units of an electronic device.

[0005] For example, a large amount of heat is released from a micro processor unit (MPU) and various electronic components of a computer server or a personal computer during the normal course of their operation. The MPU and various electronic components will operate unstably, though, if they become too hot. Moreover, the heat normally generated during operation can even damage the MPU and/or various one of the electronic components to the extent that they no longer function. In order to obviate such a problem, an axial flow fan is incorporated in the package of the computer server or personal computer to diffuse the heat so that the temperature of the components and MPU within the package is maintained at a level at which they will operate stably and will not be damaged.

[0006] To this end, an axial flow fan can be used in either of two ways. One of these ways is to use the fan as an exhaust fan, i.e. to incorporate the fan into the package of the electronic device such that the fan discharges hot air produced within the package to the outside of the package. The other way is to use the fan as a cooling fan, i.e., to use the fan to blow cool air directly onto the electronic component and/or MPU (the heat-generating element). In either of these cases, the volume and the static pressure of the airflow generated by the fan are the most important factors in determining the effectiveness of the fan at preventing the electronic device from overheating. The volume refers to the volume of air that is displaced by the blades of the fan during a rotation of the blades. The static pressure is a measure of the pressure head of the air.

[0007] In general, a load applied to the fan reduces the volume. Thus, the volume is low in an axial flow fan producing a small static pressure, whereas the volume is not as low in an axial flow fan producing a larger static pressure. Therefore, maximizing the volume and static pressure maximizes the effectiveness of the axial flow fan.

[0008] Furthermore, because of the high performance offered by today's electronics, an increasing number of consumer electronics have been provided with axial flow fans. The axial flow fans of consumer electronics must operate quietly because they are used in the home. Therefore, another desired property of an axial flow fan is that it produces low levels of noise during its operation.

[0009] However, a conventional axial flow fan creates a significant amount of noise during its operation. Such noise is produced due to the rotation of a shaft of a motor of the fan, or by a vortex created within a space between the blades of the fan and the housing of the fan.

[0010] With respect to the latter, a conventional axial flow fan includes a motor and an integral impeller having a plurality of blades which are rotated by the motor to generate a flow of air. The conventional axial flow fan also includes a housing surrounding the blades at the radially outmost ends (tips) of the blades. Also, the motor is mounted to a central portion of a base disposed adjacent an outlet of the fan, and the central portion of the base and a side wall of the housing are connected by a plurality of support ribs. In such a configuration, the trailing edges of the blades are disposed close to the support ribs. Therefore, the support ribs interfere with the flow of air generated by the rotating blades. As a result, a vortex or turbulent flow which produces noise is created as the blades rotate relative to the support ribs.

[0011] Also, the housing is formed of a single member made of resin and is injection-molded. Resin injection molding is a process of injecting molten resin into an enclosed space formed between upper and lower molds, curing the resin to form a molded article having a shape corresponding to that of the enclosed space, and then separating the upper and lower molds and removing the molded article. Thus, the molded article must have a shape that allows the upper and lower molds to be separated. In the case of a conventional axial flow fan, the walls of the housing, the base, and the support ribs are formed unitarily as a molded article by the resin injection molding process.

[0012] The housing of the conventional axial flow fan also has inclined surfaces at the air inlet and air outlet, respectively, such that the air inlet and the air outlet each gradually expand toward the outside to maximize the volume of air that can be moved by the fan (taken in and discharged). That is, the inner diameter of the housing is greater at the air inlet and the air outlet than at the axial center of the housing. The above-described support ribs are connected to the inclined surface of the housing adjacent the air outlet.

[0013] However, a blind part is created at each of the locations where the inclined surface and the support ribs meet. In other words, the blind part can not be seen when the housing is viewed in the axial direction, i.e. in the direction in which the molds are to be separated from one another. Therefore, the housing is designed to have pedestals at the locations where the inclined surface and the support ribs meet. The pedestals not only reinforce these locations but facilitate the separation of the upper and lower molds.

[0014] The pedestals, though, increase the noise produced as the blades rotate relative to the support ribs of the housing adjacent the air outlet. In addition, the pedestals disturb the flow of the exhaust air and thus decrease the volume of air that is moved by the fan. Nevertheless, a housing having a unitary side wall and base for supporting the motor, etc., can not be formed without such pedestals by resin injection molding.

SUMMARY OF THE INVENTION

[0015] An axial flow fan according to one or more embodiments of the present invention creates a stream of air flowing approximately parallel to the axial direction of the fan. The axial flow fan includes a housing, a motor mounted to the housing, and an impeller rotated by the motor about an axis of rotation extending in the axial direction. The impeller includes an impeller cup supported by the motor so as to be rotatable about the axis of rotation, and a plurality of blades radiating outwardly from the impeller cup so as to rotate with the impeller cup to create the airflow.

[0016] The housing defines an air inlet and an air outlet at its axial ends, respectively, and a passage therein extending axially between the air inlet and the air outlet. The housing has a side wall that delimits the air passage. The side wall includes an expanded portion adjacent the air outlet, and in which the inner diameter thereof and hence, the cross-sectional area of the air passage, increases in the axial direction towards the air outlet from inside the housing.

[0017] A trailing edge of each blade, which faces the air outlet, is inclined with respect to a plane substantially perpendicular to the axis of rotation such that the trailing edge extends toward the air inlet of the housing from a radially innermost end of the edge where the blade joins the impeller cup to a radially outermost end of the edge at the tip of the blade. The inner end of the expanded portion of the housing is located, with respect to the axial direction, between the radially outermost end and the radially innermost end of the trailing edge of each blade.

[0018] In addition, the base of the housing may include a central portion which supports the motor and ribs that connect the central portion to the side wall of the housing. The ribs join the side wall at the expanded portion of the side wall adjacent the air outlet. A respective pedestal is provided at the location where the ribs meet the side wall and serve to allow upper and lower molds to be separated when the housing is formed by an injection molding process. According to the present invention, the tips of the blades are spaced in the axial direction from these pedestals owing to the inclination of the trailing edges of the blades.

[0019] An axial flow fan according to the one or more embodiments of the present invention generates little noise and the motor thereof consumes very little power during operation.

[0020] The axial flow fan may be utilized, for example, to deliver air to one or more heat-generating elements (such as a microprocessor) of an electronic device (such as a computer).

[0021] Other features, advantages and characteristics of the present invention will become more apparent from the following detailed description of preferred embodiments thereof made with reference to the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] FIG. **1** is a cross-sectional view of an embodiment of an axial flow fan of according to the present invention.

[0023] FIG. **2** is a perspective view of a housing of the axial flow fan.

[0024] FIG. **3** is an enlarged view of a portion of the housing having the air outlet of the fan.

[0025] FIG. **4** is an enlarged view of a section of the embodiment of the axial flow fan shown in FIG. **1**.

[0026] FIG. **5** is a side view of another form of a blade of an axial flow fan according to the present invention, and illustrates one way of defining the angle of inclination of the leading and trailing edges of the blade.

[0027] FIG. **6** is another side view of the blade shown in FIG. **5** and illustrates another way of defining the angle of inclination of the leading and trailing edges of the blade.

[0028] FIG. **7**A is a sectional view of a blade taken at line A-A in FIG. **4**.

[0029] FIG. **7**B is a sectional view of a blade taken at line B-B in FIG. **4**.

[0030] FIG. **8**A is a view similar to that of FIG. **7**A but illustrates another way to define the pitch of the section of the blade.

[0031] FIG. **8**B is a view similar to that of FIG. **7**B but illustrates the other way of defining the pitch of the section of the blade.

[0032] FIGS. **9**A to **9**E are schematic diagrams, respectively, of five different types of axial flow fans used in performance tests.

[0033] FIG. **10** is a table of results of the performance tests.

[0034] FIG. **11** is a graph of results of the performance tests.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0035] The non-limiting embodiments of the present invention will be described in detail with reference to FIGS. **1** through **11**. It should be noted, though, that the positional relationships of components and the orientation of the fan described in the specification merely refer to those as illustrated in the drawings. For instance, one side of the axial flow fan will be referred to as an upper side whereas the other side of the axial flow fan will be referred to as a lower side. That is, as illustrated in FIG. **1**, the axial flow fan will be described as being oriented with one side facing upward in the direction of arrow U and the other side thereof facing downward in the direction of arrow D. Obviously, the positional relationships of components and the orientation of the fan may differ in an actual device from those described and illustrated. Thus, the relative spatial terms in the specification, such as up/down and right/left, are not limiting in any particular sense. Also, it should be noted that the term "axial direction" as used in the specification refers to a direction parallel to the axis of rotation of the impeller of the fan, and the term "radial direction" as used in the specification refers to a direction perpendicular to the axis of rotation.

[0036] FIG. **1** illustrates an axial flow fan **1**, according to an embodiment of the invention, which can be installed in various types of electronic devices, such as in computer servers and personal computers, for cooling the electronic devices. To this end, the axial flow fan **1** takes in air at its upper side and discharges air from its lower side. Thus, in the following description, the upper side will be referred to as the air-inlet side of the fan and the lower side will be referred to as the air-outlet side of the fan.

[0037] As shown in FIG. **1**, the axial flow fan **1** has a housing **11** serving as a framework, a motor **20** disposed within and mounted to the housing **11**, and an impeller integrated with the motor **20** so as to be rotated by the motor **20** about axis of rotation J. As shown in FIG. **2**, the housing **11** has a substantially square profile as viewed in a direction along the axis of rotation J (hereinafter, a view along the axis of rotation J will be referred to as a plan view). Although the fan **1** is not particularly limited to having any particular size, the dimensions of the housing **11** may range from approximately 30×30 mm to approximately 100×100 mm by approximately 10 to 40 mm high (the height being the dimension taken along the axis of rotation J). The shape of the housing **11**, though, is not so limited. For instance, the profile of the housing **11** as viewed in plan may be rectangular or circular instead of square.

[0038] Furthermore, the housing **11** has openings at its axial ends respectively serving as an air inlet and an air outlet. The air inlet and the air outlet of the housing **11** are each defined by a square end wall of the housing **11**. A side wall connects these end walls and delimits a passageway extending axially between the air inlet and the air outlet. As shown in FIGS. **1** and **2**, the inner diameter of the side wall increases

in directions toward the air inlet and the air outlet so that the housing **11** has expanded portions **11***a* at the air inlet and air outlet, respectively. More specifically, the cross-sectional area of the passageway delimited by the expanded portion **11***a* of the housing **11** adjacent the air inlet becomes gradually larger the further one moves along the axis of rotation J towards the air inlet. Thus, a relatively large air inlet is provided so that a correspondingly great amount of air can be taken in. Similarly, the cross-sectional area of the passageway delimited by the expanded portion **11***a* of the housing **11** adjacent the air outlet becomes gradually larger the further one moves along the axis of rotation J towards the air outlet. Accordingly, exhaust air is smoothly discharged through the air outlet.

[0039] As shown in FIG. **2**, each expanded portion **11***a* is formed of four circumferentially spaced apart sections of the side wall, inclined with respect to the axis of rotation J, at each of the four corners of the housing **11**, respectively. Alternatively, each expanded portion **11***a* may be formed of one continuous section of the side wall of the housing **11** so as to have the shape of a frustum.

[0040] The housing **11** also has a base **12** at the lower side of the fan. The base **12** includes a substantially circular end portion, and four supporting ribs **18** extending from the outer periphery of the circular end portion. The supporting ribs **18** are connected to the (end wall of the) housing **11** at the lower side (air outlet) of the fan. The base **12** also includes a bearing retentive portion **13** projecting from the center of its circular end portion toward the upper side of the fan. The bearing retentive portion **13** has a hollow cylindrical shape whose central longitudinal axis is coincident with the axis of rotation J.

[0041] The motor **20** is mounted on the base **12**. The motor **20** is a brushless motor which has a rotary shaft **14** whose longitudinal axis coincides with the axis of rotation J. The rotary shaft **14** is received in the bearing retentive portion **13** of the base **12** and a bearing is interposed therebetween so that the shaft **14** is rotatable relative to the housing about the axis of rotation J.

[0042] The motor **20** also includes a support member **15** attached to an upper end of the shaft **14** so as to rotate about the axis J with the shaft **14**. The rotation support member **15** has with a disk-shaped portion centered on the upper end of the shaft **14** and a cylindrical portion **15***a* extending downwards from the outer periphery of the disk-shaped portion. Thus, the support member **15** is essentially cup-shaped.

[0043] The impeller of the axial flow fan **1** includes an impeller cup **16** whose opening faces in the downward direction D like the support member **15**. The impeller cup **16** extends over the cylindrical portion **15***a* of the support member **15** of the motor **20** and is attached thereto. The impeller also has a plurality of blades **17** integral with and extending outwardly from the impeller cup **16**. For example, the impeller has seven blades **17** which extend in radial directions, substantially perpendicular to the axis of rotation J, from the impeller cup **16** and are equally spaced from one another about the axis of rotation J.

[0044] The stator **21** of the motor **20** extends around the bearing retentive portion **13** of the base **12** of the housing **11**. The stator **21** has a stator core and a coil **22** comprising a wire wound around the stator core. A rotor magnet **23** of the motor **20** is fixed to an inner peripheral surface of the cylindrical portion **15***a* of the support member **15** so as to face the stator **21**.

[0045] In the axial flow fan **1** according to the embodiment of the present invention as described above, the impeller cup **16** and the plurality of the blades **17** are rotated about the axis of rotation J by the motor **20** when power is supplied to the coil of the stator **21**. The rotation of the blades **17** induces air into the housing **11** from the air inlet at the upper side of the fan and forcibly discharges the air out the air outlet at the lower side of the fan. In this way, air heated within an electronic device can be taken in through the air inlet and discharged from the electronic device by the fan to keep the electronic device cool. Alternatively, relatively cool air can be taken in through the air inlet and discharged by the fan onto an electronic component and the like within the electronic device to directly cool the electronic component and the like.

[0046] Referring still to FIG. **2**, the housing **11** and the base **12** are unitary. In other words, the housing **11** and the base **12** (including the circular end portion, bearing retentive portion **13** and supporting ribs **18**) are not separate parts that are assembled when the fan is being fabricated but are together a contiguous single part of the fan. In this respect, the housing **11** and the base **12** may be fabricated by resin injection molding. The molds used in such an injection molding process are preferably shaped to reinforce various portions thereof such as at the locations where the supporting ribs **18** join the housing **11**. More specifically, pedestals **18***a* are provided within the expanded portions **11***a* of the housing **11** as reinforcement at the locations where the supporting ribs **18** and the housing **11** meet.

[0047] Referring to FIG. **3**, a respective pedestal **18***a* supports both sides of the outer end of each supporting rib **18** in the circumferential direction of the base **12**. The pedestal **18***a* also extends in the axial direction of the fan over the entire extent of the expanded portion **11***a* (such that the pedestal fills a region of the space within the expanded portion as best shown in FIG. **1**).

[0048] The blades **17** of the axial flow fan **1** according to an embodiment of the present invention will now be described in more detail with reference to FIGS. **4**-**8**B.

[0049] Referring to FIG. **4**, each blade **17** has a leading edge **17***u* and a trailing edge **7***d* which are inclined, with respect to a horizontal plane H perpendicular to the axis of rotation J, towards the air inlet from radially innermost ends thereof adjacent the impeller cup **16** to radially outermost ends thereof at the tip of the blade. The tip of the blade, as shown in the figure, is formed by an edge that extends generally parallel to the axis of rotation J. The leading edge **17***u* is the edge of the blade **17** disposed closest to the air inlet and subtends an angle θ**1** with the horizontal plane H. The trailing edge **17***d* is the edge of the blade closest to the air outlet and subtends an angle θ**2** with the horizontal plane H.

[0050] In a preferred embodiment, for each of the blades **17**, the angle θ**2** at which the trailing edge **17***d* is inclined relative to horizontal is greater than the angle θ**1** at which the leading edge **17***u* is inclined relative to horizontal. In particular, the width of the blade **17** as measured in the axial direction is smaller at the tip of the blade, to which a large amount of work is assigned, than at the base of the blade (where the blade joins the impeller cup **16**). In this respect, the width of the blade **17** decreases slightly from the base of the blade to the tip of the blade. The relatively small width of the tip of the blade **17** thus results in a correspondingly small load being applied to the tip of the blade. Therefore, the motor **20** can be driven with little current. In other words, the fan can provide a high flow rate and static pressure very efficiently, i.e., the

motor consumes relatively low amounts of power. Alternatively, though, the angle of inclination θ**1** may be larger than the angle of inclination θ**2**, or the angle of inclination θ**1** and the angle of inclination θ**2** may be identical in some embodiments according to the present invention.

[0051] FIG. **4** also shows the positional relationship between the trailing edge **17***d* of the blade and the expanded portion of the housing **11** at the air outlet. As shown in FIG. **4**, the base (radially innermost) end P**1** of the trailing edge **17***d* of the blade **17** is located closer to the air outlet than that part P**2** of the expanded portion **11***a* whose inner diameter is smallest. Furthermore, the tip (radially outermost) end of the trailing edge **17***d* of the blade **17** is located closer to the air inlet than the same part P**2** of the expanded portion **11***a* of the housing (where the inner diameter is smallest). In other words, the narrowest part of the expanded portion **11***a* of the housing is located between the base end P**1** of the trailing edge **17***d* of the blade **17** and tip end P**3** thereof, in the axial direction of the fan. More specifically, the diameter of the passageway extending through the housing **11** starts to gradually increase toward the air outlet from a boundary (at P**2**) surrounding the axis of rotation J and where the diameter of the passageway extending through the housing **11** is smallest. Thus, an inner surface of the side wall of the housing has an inflection at the inner end of the expanded portion **11***a*, the inflection extending along the boundary (P**2**). The radially outermost end P**3** of the trailing edge **17***u* of the blade is disposed closer to the air inlet (upper side of the fan) than the boundary whereas the radially innermost end P**1** of the trailing edge **17***u* is located closer to the air outlet (lower side of the fan) than the boundary (at P**2**). Accordingly, the supporting ribs **18** and the pedestals **18***a* extending axially along the expanded portion **11***a* will not interfere with the airflow created by the rotation of the blades **17**, such that noise is kept to a minimum.

[0052] The larger an orthographically-projected area of the blade **17** in the direction of rotation (area through which the blade **17** passes, during its rotation, wherein the area lies in a plane which contains the axis of rotation J) is, the larger is the volume of air moved by the blade **17** due to its rotation about axis J. The volume of air that can be moved by the fan during a rotation of the impeller is compromised by the disposition of the radially outermost end P**3** of the trailing edge **17***d* of the blade **17**, i.e., due to the fact that the radially outermost end P**3** of the trailing edge **17***d* of the blade **17** is spaced in the axial direction towards the air inlet of the fan with respect to the part P**2** of the expanded portion of the housing having the smallest inner diameter. However, this loss in the volume of air is compensated for in the vicinity of the base of the blade. That is, the orthographically-projected area of the blade **17** in the vicinity of the base of the blade is relatively large because the base end P**1** of the trailing edge **17***d* of the blade **17** is located close to the air outlet. Accordingly, the axial flow fan according to the present invention can be characterized as being capable of moving a high volume of air without generating a considerable amount of noise.

[0053] The lower the noise, the faster the impeller can be rotated and hence, the greater is the volume of air which can be moved. In addition, static pressure produced in the air as a result of the operation of the axial flow fan is increased with the increase in the rotational speed of the impeller. Also, in the axial flow fan **1** according to the present invention, the base end P**1** of the trailing edge **17***d* of each blade **17** is located closer to the air outlet than the narrowest part P**2** of that expanded portion **11***a* of the housing which is adjacent the air outlet. That is, each blade **17** as a whole is located close to the air outlet and so, the leading edges **17***u* of the blades **17** will not project upwards through the air inlet of the housing **11**. Thus, the axial flow fan incorporated in an electronic device. Therefore, the axial flow fan **1** can realize the above-mentioned advantages—concerning the volume of air that can be moved, static pressure imparted to the air, and low noise—in an electronic device without the possibility of the blades coming into contact with electronic components of the device.

[0054] However, the present invention does contemplate embodiments in which part of the leading edge **17***u* of each blade **17** projects from the air inlet at the upper side of the housing **11**. In other words, respective parts of the blades **17** may protrude from the housing **11** at the upper side of the fan. For example, the angle of inclination of the leading edge **17***u* of the blade may be greater than that (θ**1**) shown in FIG. **4** (and may be greater than θ**2**), so that part of the tip of the blade projects upwards through the air inlet. In such embodiments, the fan will generate more suction on the air in inducing the air through the air inlet. Obviously, in such a case, the fan should be incorporated into an electronic device in such a way that electronic components are not present in the vicinity of the air inlet.

[0055] Also, in the embodiment of FIG. **1**, the leading edge **17***u* and the trailing edge **17***d* of each blade **17** extend straight (i.e., are linear edges) from the base to the tip of the blade **17**. Alternatively, as shown in FIGS. **5** and **6**, the leading edge **17***u* and the trailing edge **17***d* of each blade **17** may be curved between the base and the tip of the blade **17** (i.e., may be curvilinear edges). In this case, the angle of inclination of the curved edge may be given as the average of the angles of inclination of all of the tangents to the curve (the average of the angles subtended between each tangent and the horizontal plane H as taken at each of the points along the curve from the base to the tip of the blade **17**). FIG. **5** shows one of these angles θ**3** for the leading edge **17***u* and likewise, one such angle θ**4** for the trailing edge **17***d*. Alternatively, as shown in FIG. **6**, the angle of inclination of a curved edge of the blade can be given as the angle subtended between the horizontal plane H and a line connecting the base and the tip of the blade **17**. FIG. **6** thus shows the angle of inclination θ**5** for the curved leading edge **17***u*, and the angle of inclination **06** for the curved trailing edge **17***d* according to this method. It should be noted that embodiments of the present invention in which the leading and trailing edges of the blades **17** are curved can provide benefits and advantages similar to those described above in connection with the embodiment of FIG. **1**.

[0056] Next, the cross-sectional shape of the blade **17** will be described with reference to FIGS. **7**A and **7**B. In particular FIGS. **7**A and **7**B show radial cross sections of the blade **17**. The radial cross section of the blade refers to an area of the blade **17** cut by a cylindrical surface which has a central longitudinal axis coincident with the axis of rotation J. FIG. **7**A shows a radial cross section of the blade **17** as taken at line A-A of FIG. **4**. That is, FIG. **7**A shows the area of the blade **17** cut by a cylindrical surface which passes through the blade adjacent the base of the blade and which has a central longitudinal axis coincident with the axis of rotation J. FIG. **7**B, on the other hand, shows a radial cross section of the blade **17** as taken at line B-B of FIG. **4**. More specifically, FIG. **7**B shows the area of the blade **17** cut by a cylindrical surface which

passes through the blade adjacent the tip of the blade and which has a central longitudinal axis coincident with the axis of rotation J.

[0057] The inclination of the blade relative to horizontal plane H (a plane perpendicular to the axis of rotation J), and which may also be referred to as the pitch of the blade, varies in the radial direction of the blade. The pitch of the blade, for any arbitrary part of the blade along its length (between its base and tip), may be given as an average of the angles of inclination of the tangents to the upper surface of the blade at each point along the upper surface from the leading edge of the blade to the trailing edge of the blade. In this case, the upper surface of the blade **17** refers to that surface which faces the air inlet. Thus, FIG. **7**A shows one such angle of inclination **07**, namely the angle subtended between the horizontal plane H and a tangent to the upper surface of the blade, for the part of the blade near the base thereof. Similarly, FIG. **7**B shows one such angle of inclination **08**, namely the angle subtended between the horizontal plane H and a tangent to the upper surface of the blade, for the outer peripheral part of the blade.

[0058] When designing the pitch a of the portion of the blade **17** adjacent the base of the blade (FIG. **7**A) and the pitch of the portion of the blade **17** adjacent the tip of the blade (FIG. **7**B), the blade **17** is configured such that pitch α and the pitch β satisfy the following relationship:

$$\beta-5^\circ \leqq \alpha \leqq \beta+5^\circ.$$

[0059] When each of the blades **17** satisfies this relationship, air taken in through the air inlet is guided smoothly to the air outlet and is discharged efficiently.

[0060] Alternatively, the angle of inclination or the pitch of the blade, for any arbitrary part of the blade along its length (between its base and tip), may be given as the angle subtended between the horizontal plane H and a line connecting the leading edge and the trailing edge of the blade **17**. FIG. **8**A thus shows the angle of inclination θ**9** for the part of the blade near the base thereof. Similarly, FIG. **8**B shows the angle of inclination θ**10** for the part of the blade near the tip thereof.

[0061] In this case, the blade **17** is designed such that the angle of inclination θ**9** and the angle of inclination θ**10** satisfy the following relationship:

$$\theta 10-5^\circ \leqq \theta 9 \leqq \theta 10+5^\circ.$$

[0062] When each of the blades **17** satisfies this relationship, air taken in through the air inlet is guided smoothly to the air outlet and is discharged efficiently.

[0063] Performance tests were carried out to evaluate embodiments of an axial flow fan according to the present invention. In the performance tests, five different types of axial flow fans were used. FIGS. **9**A to **9**E respectively show the shapes of the blades of the five different types of axial flow fans (MODEL **1** to MODEL **5**) which were used in the performance tests. Among these, MODEL **4** (FIG. **9**D) is an axial flow fan employing blades according to the above-described embodiment of FIG. **1**. Specifically, the leading edge (the edge closest to the air inlet) and the trailing edge (the edge closest to the air outlet) of each blade were each inclined, relative to the horizontal (a plane perpendicular to the axis about which the blade rotates), so as to extend towards the air inlet from the base to the tip thereof, and the angle of inclination of the trailing edge was larger than the angle of inclination of the leading edge.

[0064] FIG. **9**A shows a blade having a trailing edge (the edge closest to the air outlet) is substantially horizontal (perpendicular to the axis of rotation). FIG. **9**B shows a blade of an embodiment according to the present invention, in which the angle of inclination of the leading edge and the angle of inclination of the trailing edge are substantially identical. FIG. **9**C shows a blade another embodiment according to the present invention, in which the angle of inclination of the leading edge is larger than the angle of inclination of the trailing edge. FIG. **9**E shows a blade in which the trailing edge is inclined, relative to the horizontal, so as to extend towards the air outlet from the base to the tip of the blade.

[0065] FIG. **10** shows results of the tests executed for the axial flow fans employing the five types of blades shown in FIGS. **9**A to **9**E. The rotation speeds indicated in the table are for a case of maximum air volume (when load is equal to zero), and the noise values are also for the case of maximum air volume. As indicated in this table, the largest rotation speed is obtained using MODEL **4**. Furthermore, MODEL **4** offers the largest values for maximum air volume and maximum static pressure. It can also be seen that excellent test results were obtained for noise with MODEL **4**.

[0066] FIG. **11** is a graph showing the results of the tests executed for the five types of axial flow fans having blades whose shapes are shown in FIGS. **9**A to **9**E, respectively. In the graph, each solid line indicates a relationship between the maximum static pressure and the maximum air volume (P-Q curve), whereas each dashed line indicates a relationship between the rotation speed and the maximum air volume. It can be seen also from the P-Q curves that the blade of MODEL **4**, which is an axial flow fan **1** according to the present invention based on the embodiment shown in FIG. **1**, offers excellent performance, especially with respect to rotation speed.

[0067] Finally, although the present invention has been described above by way of example in connection with embodiments thereof, the present invention is not limited to the described embodiments. Rather, variations of and modifications to the preferred embodiments will be apparent to those skilled in the art. Thus, variations of and modifications to the preferred embodiments are seen to be within the true spirit and scope of the invention as defined by the following claims.

What is claimed is:

1. An axial flow fan comprising:

a housing defining an opening serving as an air inlet through which air is taken into the fan, an opening serving as an air outlet through which air is discharged from the fan, and a passage extending in an axial direction of the fan between the air inlet and the air outlet, wherein the air inlet and the air outlet are located at axial ends of the passage, respectively,

the housing having a base, and a side wall delimiting the passageway,

the base including a central portion, and a plurality of ribs connecting the central portion to the side wall, the ribs extending adjacent the air outlet,

the side wall of the housing having an expanded portion adjacent the air outlet, the cross-sectional area of that portion of the passageway delimited by the expanded portion of the side wall increasing as taken along the axial direction of the fan towards the air outlet from inside the housing;

a motor mounted to the base; and

an impeller having an impeller cup mounted to the motor so as to be rotatable about an axis of rotation extending in

the axial direction, and a plurality of blades disposed about the axis of rotation and radiating outwardly from the impeller cup so as to rotate therewith, the side wall of the housing facing tips of and surrounding the blades,

each of the blades having a leading edge facing the air inlet and a trailing edge facing the air outlet, the trailing edge of each of the blades being inclined, with respect to a plane extending perpendicular to the axis of rotation, from a radially innermost end thereof proximate the impeller cup to a radially outermost end thereof at the tip of the blade, and

the expanded portion of the housing having an outer end at the air outlet and an inner end located inwardly from the outer end in the axial direction, the inner diameter of the expanded portion being smallest at its inner end such that an inner surface of the side wall of the housing has an inflection at the inner end of the expanded portion, the inflection extending along a boundary that surrounds the axis of rotation, and the inflection being located with respect to the axial direction between the radially outermost end and the radially innermost end of the trailing edge of each of the blades.

2. The axial flow fan according to claim **1**, wherein the housing is of a molded resin, and the housing includes a respective pedestal of resin at a location where each of the ribs joins the side wall of the housing.

3. The axial flow fan according to claim **2**, wherein the profile of the housing is approximately rectangular as viewed in the axial direction, whereby the housing has four corners.

4. The axial flow fan according to claim **3**, wherein the expanded portion of the housing comprises inclined surfaces adjacent the corners of the housing, respectively, the inclined surfaces being spaced from one another about the periphery of the housing, and each of the inclined surfaces being inclined relative to the axial direction in a radially outward direction from an inner end thereof to an outer end thereof at the air outlet.

5. The axial flow fan according to claim **4**, wherein each of the respective pedestals extends axially within and over the entire axial length of the expanded portion of the housing.

6. The axial flow fan according to claim **1**, wherein the leading edge of each of the blades is inclined, with respect to a plane extending perpendicular to the axis of rotation, towards the air inlet from a radially innermost end of the leading edge proximate the impeller cup to a radially outermost end of the leading edge at the tip of the blade.

7. The axial flow fan according to claim **6**, wherein the angle of inclination of the leading edge of each of the blades is different from the angle of inclination of the trailing edge thereof.

8. The axial flow fan according to claim **7**, wherein the angle of inclination of the leading edge of each of the blades is smaller than that of the trailing edge thereof.

9. The axial flow fan according to claim **7**, wherein the angle of inclination of the leading edge of each of the blades is approximately equal to that of the trailing edge thereof.

10. The axial flow fan according to claim **6**, wherein each of the leading and trailing edges of the blade extends linearly from the radially innermost end thereof to the radially outermost end thereof.

11. The axial flow fan according to claim **6**, wherein each of the leading and trailing edges of the blade is curved from the radially innermost end thereof to the radially outermost end thereof.

12. The axial flow fan according to claim **6**, wherein the leading edges of the blades are located entirely within the housing so as to not protrude from the air inlet.

13. The axial flow fan according to claim **1**, wherein each of the blades satisfies the following relationship:

$$(P_o)-5^\circ \leqq (P_i) \leqq (P_o)+5^\circ,$$

wherein P_i is a pitch of a radially inner section of the blade adjacent the impeller cup and P_o is a pitch of a radially outer section of the blade adjacent the tip of the blade, the pitch being a measure of the inclination of the section of the blade relative to a plane perpendicular to the axis of rotation, the section being that of the blade cut by a cylindrical surface which passes through the blade and which has a central longitudinal axis coincident with the axis of rotation.

14. An electronic device comprising a heat generating element and an axial flow fan according to claim **1**, wherein the axial flow fan is positioned to deliver air to the heat generating element.

15. The electronic device according to claim **14**, wherein the electronic device is a computer, and the heat generating element is a microprocessor.

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