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(54) **TURBOFAN AND AIR CONDITIONER IN WHICH SAME IS USED**

(57) A turbofan provided with a hub (10) connected with a drive shaft and driven in a rotating manner, an annular shroud (11) positioned facing the hub (10) and having an air suction opening formed therein, and a plurality of blades (12) having both ends joined between the hub (10) and the shroud (11) so that leading edges (13) on the inner circumferential side are positioned on the rotation direction side of trailing edges (14) on the outer circumferential side, wherein the plurality of blades (12) are configured such that the trailing edges (14) are made into recesses (14A) in the counter-air flow direction relative to joining parts (17, 18) to the hub (10) and the shroud (11).

FIG. 2A No. 59 (MOST APPROPRIATE SHAPE)

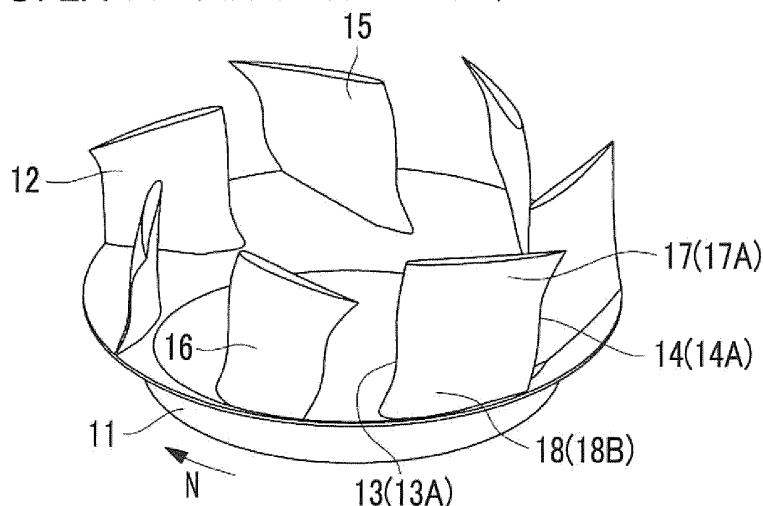


FIG. 2B No. 59 (LIMIT STREAMLINE)

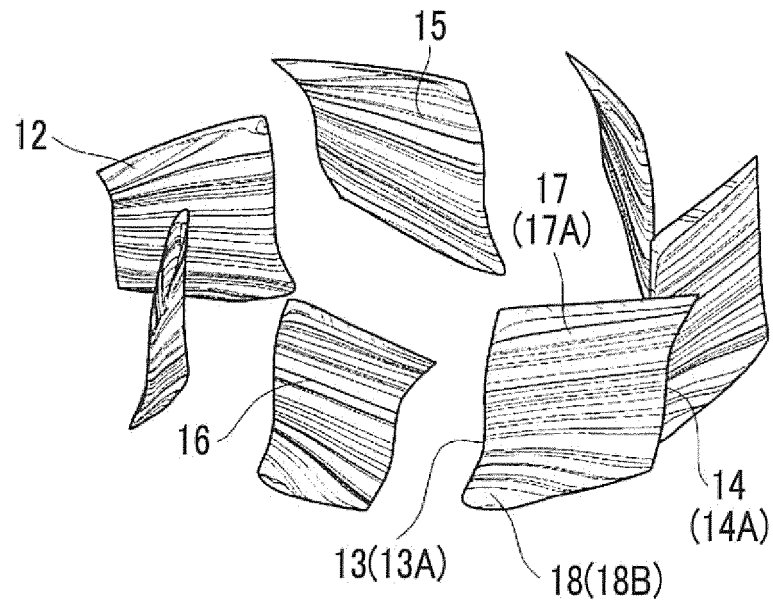
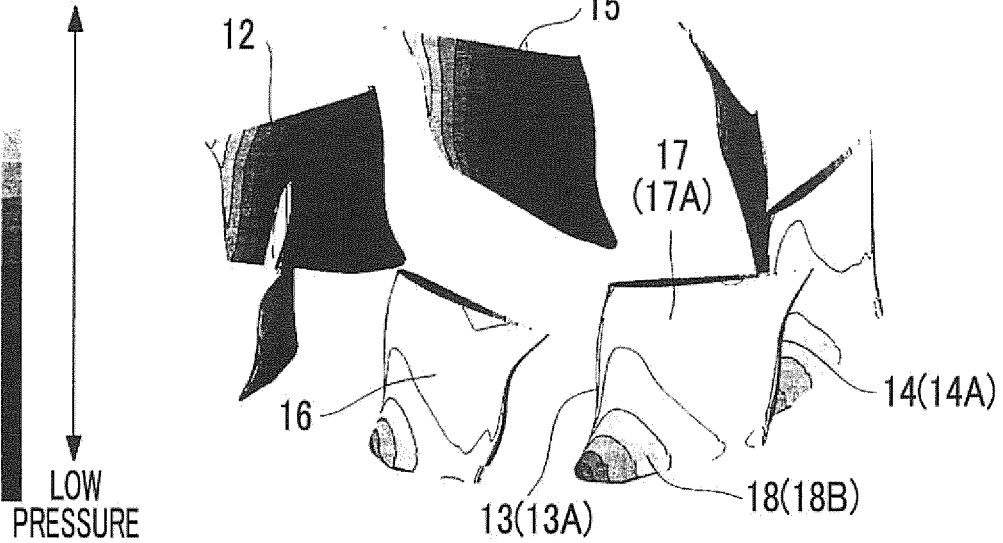


FIG. 2C No. 59 (STATIC PRESSURE CONTOUR)



Description

Technical Field

[0001] The present invention relates to a turbofan which blows out the air suctioned in an axial direction from a shroud side by changing a direction into a radial direction, and an air conditioner in which the same is used.

Background Art

[0002] A turbofan is configured of a hub which is driven in a rotating manner by a motor or the like, a shroud which is positioned facing the hub, and a plurality of blades which are positioned between the hub and the shroud. In the blade of the turbofan, a leading edge which is an end portion on an inner peripheral side is positioned further on a rotation direction side than a trailing edge which is an end portion on an outer peripheral side in many cases, or the blade of the turbofan is molded in a shape of a blade in many cases between the hub and the shroud, but a sectional shape thereof is generally a uniform two-dimensional shape in the axial direction due to a restriction or the like on molding (for example, refer to PTL 1 or the like). However, in recent years, the restriction of a manufacturing method has been eliminated, and a blade having a three-dimensional shape in the axial direction or a blade having a hollow shape has been suggested in many cases (for example, refer to PTL 2 to PTL 4).

[0003] Meanwhile, as a technology for targeting low noise or high efficiency and focusing on performance, for example, as illustrated in PTL 5 to PTL 7, a technology in which a structure in which the vicinity of a leading edge on a hub side of a blade is curved in the rotation direction or in a counter-rotation direction is achieved, and a horse-shoe-shaped swirl suppressing section is formed for suppressing a horseshoe-shape swirl generated at a joining part between the hub and the blade, a technology in which a dead water region reducing space is supposed to be formed between a blade and a shroud, and a part of the blade is formed to be curved in the counter-rotation direction, and is connected to an arc surface of the shroud via the bent portion, or a technology in which a hub side of a trailing edge of a blade is curved in both of the rotation direction and the counter-rotation direction, and an air flow can be accelerated in a trailing edge of the blade, are suggested.

[0004] In other words, in a case of a turbofan, in order to change the direction of the air flow suctioned in the axial direction into the radial direction, the air flow suctioned from an outer edge side of a suction opening is not curved and cut by an inertial force, and is likely to be a flow deviated to a hub side on the inside, the blade does not efficiently function at a location near the suction opening, efficiency deterioration is caused, a high-speed jet flow is generated by deviation of the air flow on a blow-out side, a counterflow is generated in the vicinity of the

suction opening, and noise is likely to increase. In addition, in a case of using the turbofan in an air conditioner, the air is suctioned from a quadrangular passage via a grill or a filter, the turbofan is operated in a non-axis symmetric pressure field surrounded by a heat exchanger of which the blow-out side has a quadrangular shape, and thus, it is difficult to realize a uniform flow across the entire spanwise direction (axial direction) of the fan, and as described above, various ideas targeting low noise or high efficiency are suggested.

Citation List

Patent Literature

[0005]

[PTL 1] Japanese Unexamined Patent Application Publication No. 2002-235695

[PTL 2] Japanese Unexamined Patent Application Publication No. 2007-170331

[PTL 3] Japanese Unexamined Patent Application Publication No. 2007-170771

[PTL 4] Japanese Unexamined Patent Application Publication No. 2010-216486

[PTL 5] Japanese Unexamined Patent Application Publication No. 2009-127541

[PTL 6] Pamphlet of International Application No. WO2009/069606

[PTL 7] Pamphlet of International Application No. WO2010/128618

Summary of Invention

Technical Problem

[0006] However, in the turbofan or the air conditioner in which the same is used, when a fan input which is a driving force of the turbofan is set to be an evaluation parameter, there is still room for improvement in the turbofan. In other words, reducing the fan input is always a problem, and from this point of view, when fluid analysis is performed with respect to the turbofan by a finite volume method, while there is a tendency that the air flow which is along the blade is likely to be separated from a blade surface on a suction surface on an outer peripheral side (trailing edge side) of the blade in a current turbofan, it is found out that a high static pressure region is generated on the pressure surface side of the blade, and accordingly, the speed of the air flow which is along the blade is reduced (a loss of the driving force is generated), and a fan efficiency deteriorates.

[0007] Considering the situation, an object of the invention is to provide a turbofan which can improve a fan efficiency and can reduce a fan input which is a driving force of a fan, by suppressing separation of an air flow on a suction surface on an outer peripheral side (trailing edge side) of the blade and by suppressing a decrease

in speed of the air flow on a pressure surface side of the blade, and an air conditioner in which the same is used.

Solution to Problem

[0008] In order to solve the above-described problem, the turbofan and the air conditioner in which the same is used of the present invention employs the following means.

[0009] In other words, according to a first aspect of the invention, there is provided a turbofan including: a hub which is connected to a motor drive shaft, and is driven in a rotating manner; an annular shroud which is positioned facing the hub and forms an air suction opening; and a plurality of blades having both end portions joined between the hub and the shroud so that leading edges on the inner peripheral side are positioned on a rotation direction side of trailing edges on the outer peripheral side, in which the plurality of blades are configured such that the trailing edges are made into recesses in the counter-air flow direction relative to joining parts to the hub and the shroud.

[0010] According to the aspect, since the plurality of blades are configured such that the trailing edges (also referred to as trailing edge lines) are made into recesses in the counter-air flow direction relative to joining parts to the hub and the shroud, compared to a case where the trailing edge lines of the blades are made into straight lines or into projections in the air flow direction, it is possible to improve separation of the air flow on a suction surface side of the blade, and to suppress disturbance of the air flow, and it is possible to improve a fan efficiency by reducing a high static pressure region generated on a pressure surface side of the blade and by suppressing a decrease in speed of the air flow (a loss of the driving force), and to reduce the driving force (fan input) of the fan. In other words, as the trailing edge lines of the blades are made into recesses in the counter-air flow direction, it is possible to reduce the radius of the region made into recesses to be smaller than an original shape, and in a case where the fan is rotated at the same rotation speed, it is possible to reduce an increase in pressure of the air flow that passes through the fan, and accordingly, at a location at which the separation on the shroud side of the suction surface is particularly easy, since the pressure (static pressure) in the vicinity of the trailing edge of the blade is reduced, and thus, the air is likely to flow as an air flow, and it is possible to suppress the separation. Meanwhile, on the pressure surface, influence on deviation of the air flow that passes through the fan to the hub side is substantial, distribution in which the pressure of the blade surface rapidly increases toward the hub side is illustrated, but as the trailing edge lines are made into recesses, it is possible to reduce the pressure (static pressure) in the vicinity of the trailing edge of the blade, to reduce the static pressure on the pressure surface, to improve a fan efficiency, and to reduce the fan input. Therefore, it is possible to further achieve high ef-

ficiency and low noise of the turbofan.

[0011] In addition, in the above-described turbofan, at the trailing edges of the blades, a center part in a spanwise direction of the blade may be made into recesses in the counter-air flow direction within a range of 25% to 75% in the spanwise direction.

[0012] According to the aspect, since the center part of the trailing edge line of the blade is made into recesses in the counter-air flow direction within a range of 25% to 75% in the spanwise direction of the blade, it is possible to join the blade to the hub and the shroud without influencing the function and performance of the joining part of the blade to the hub and the shroud. Therefore, it is possible to achieve low noise and high efficiency without disturbing the air flow in a hub side joining part and a shroud side joining part of the blade.

[0013] Furthermore, in any of the above-described turbofans, a recess amount (expressed as -) in the counter-air flow direction of the trailing edge of the blade may be within a range of $-0.0142D$ to $-0.0153D$, with respect to a fan outer diameter D .

[0014] According to the aspect, since the recess amount (expressed as -) in the counter-air flow direction of the trailing edge line of the blade is within a range of $-0.0142D$ to $-0.0153D$, with respect to a fan outer diameter D , it is possible to reduce the fan input which is the driving force of the turbofan to be in a preferable range. Therefore, it is possible to achieve high efficiency and low noise of the turbofan.

[0015] Furthermore, in any of the above-described turbofans, the leading edges of the blades may be made into recesses in an air flow direction or may be made into projections in the counter-air flow direction relative to joining parts to the hub and the shroud.

[0016] According to the aspect, since the leading edges (also referred to as leading edge lines) of the blades are made into recesses in the air flow direction or are made into projections in the counter-air flow direction relative to joining parts to the hub and the shroud, by displacing the leading edge lines into recesses in the air flow direction, there is also a case where a slight disturbance is generated in the air flow on the suction surface of the blade, but it is possible to reduce the high static pressure region on the pressure surface side, and to suppress the decrease in speed of the air flow. Meanwhile, by displacing the leading edge lines into projections in the counter-air flow direction, there is also a case where the high static pressure region on the pressure surface side slightly increases and a speed reduction suppressing effect of the air flow slightly deteriorates, but it is possible to suppress the disturbance of the air flow on the suction surface, and to suppress separation. In other words, the length in the air flow direction of the blade is shortened by making the leading edge lines of the blade into recesses in the air flow direction, and it is possible to reduce a friction loss between the air flow and the blade surface, and to reduce the fan input. However, when the leading edge lines are made into extreme recesses, the

blade length in the air flow direction with respect to the distance between adjacent blades becomes extremely short, and blade performance deteriorates. In addition, by making the leading edge lines of the blade into projections in the counter-air flow direction, the friction loss between the air flow and the blade surface generally increases. Meanwhile, since the length in the air flow direction of the blade is substantially long, by stably guiding the flow that flows in from the blade upstream side to the downstream side, it is possible to make it difficult to separate the flow by suppressing a peak value of the static pressure on the blade surface, to reduce the fan input, and to reduce fan noise. Therefore, in this case, it is also possible to sufficiently reduce the fan input, and to achieve high efficiency and low noise of the turbofan.

[0017] Furthermore, in the above-described turbofan, a recess amount (expressed as +) in the air flow direction of the leading edge of the blade may be within a range of $0.0091D$ to $0.0153D$, with respect to the fan outer diameter D , and a projection amount (expressed as -) in the counter-air flow direction may be $-0.0438D$ with respect to the fan outer diameter D .

[0018] According to the aspect, since the recess amount (expressed as +) in the air flow direction of the leading edge line is within a range of $0.0091D$ to $0.0153D$, with respect to the fan outer diameter D , and the projection amount (expressed as -) in the counter-air flow direction is $-0.0438D$ with respect to the fan outer diameter D , it is possible to reduce the fan input which is the driving force of the turbofan to be in a preferable range, and according to this, it is possible to achieve high efficiency and low noise of the turbofan.

[0019] Furthermore, in any of the above-described turbofans, at the leading edges of the blades, a center part in the spanwise direction of the blade may be made into recesses in the air flow direction or into projections in the counter-air flow direction within a range of 25% to 75% in the spanwise direction.

[0020] According to the aspect, since, the center part of the leading edge line of the blade is made into recesses in the air flow direction or into projections in the counter-air flow direction within a range of 25% to 75% in the spanwise direction of the blade, it is possible to join the blade with the hub and the shroud without influencing the function and performance of the joining part of the blade to the hub and the shroud. Therefore, it is possible to achieve low noise and high efficiency without disturbing the air flow at the hub side joining part and the shroud side joining part of the blade.

[0021] Furthermore, in any of the above-described turbofans, the joining part of the blade to the hub may be made into a smooth curved surface in the counter-rotation direction, and the joining part of the blade to the shroud may be made into a smooth curved surface in a rotation direction.

[0022] According to the aspect, since the joining part of the blade to the hub is configured to be a smooth curved surface in the counter-rotation direction, and the joining

part of the blade to the shroud is configured to be a smooth curved surface in the rotation direction, by making the joining part of the blade to the hub into a smooth curved surface in the counter-rotation direction, it is possible to set the joining part to be horizontally asymmetric, and to suppress stagnation of the air flow at the joining part. Meanwhile, by making the joining part of the blade to the shroud into a smooth curved surface in the rotation direction, it is possible to suppress separation of the flow on the suction surface side by a blade force and to make the air flow smooth. Therefore, it is possible to improve blade performance, and to achieve high efficiency by further reducing the fan input, and it is possible to suppress disturbance of the air flow, and to achieve low noise.

[0023] Furthermore, in the above-described turbofan, an angle (expressed as +) of the curved surface in the counter-rotation direction of the joining part of the blade to the hub may be within a range of 0.0563θ to 0.0972θ with respect to one pitch angle θ of the blade, and an angle (expressed as -) of the curved surface in the rotation direction of the joining part to the shroud may be within a range of -0.0154θ to -0.0972θ with respect to one pitch angle θ of the blade.

[0024] According to the aspect, since the angle (expressed as +) of the curved surface in the counter-rotation direction of the joining part of the blade to the hub is within a range of 0.0563θ to 0.0972θ with respect to one pitch angle θ of the blade, and the angle (expressed as -) of the curved surface in the rotation direction of the joining part to the shroud is within a range of -0.0154θ to -0.0972θ with respect to one pitch angle θ of the blade, it is possible to suppress stagnation of the air flow at the hub side joining part, to suppress the separation of the air flow on the suction surface side by the blade force, and to further improve the blade performance. Therefore, it is possible to reduce the fan input which is the driving force of the turbofan to be in a preferable range, and to achieve high efficiency and low noise of the turbofan.

[0025] Furthermore, in any of the above-described turbofans, the joining part of the blade to the hub may be made into a smooth curved surface in the rotation direction, and the joining part of the blade to the shroud may be made into a smooth curved surface in the counter-rotation direction.

[0026] According to the aspect, since the joining part of the blade to the hub is made into a smooth curved surface in the rotation direction, and the joining part of the blade to the shroud is made into a smooth curved surface in the counter-rotation direction, by making the joining part of the blade to the hub into a smooth curved surface in the counter-rotation direction, it is possible to set the joining part to be horizontally asymmetric, and to suppress stagnation of the air flow at the joining part. In addition, by making the joining part of the blade to the shroud into a smooth curved surface in the rotation direction, it is possible to make the air flow on the suction surface side in the vicinity of the shroud smooth, and to suppress separation. Therefore, it is possible to improve

blade performance, and to achieve high efficiency by further reducing the fan input, and it is possible to suppress disturbance of the air flow, and to achieve low noise.

[0027] Furthermore, in the above-described turbofan, an angle (expressed as -) of the curved surface in the rotation direction of the joining part of the blade to the hub may be -0.0768θ with respect to one pitch angle θ of the blade, and an angle (expressed as +) of the curved surface in the counter-rotation direction of the joining part to the shroud may be 0.0031θ with respect to one pitch angle θ of the blade.

[0028] According to the aspect, since the angle (expressed as -) of the curved surface in the rotation direction of the joining part of the blade to the hub is -0.0768θ with respect to one pitch angle θ of the blade, and the angle (expressed as +) of the curved surface in the counter-rotation direction of the joining part to the shroud is 0.0031θ with respect to one pitch angle θ of the blade, it is possible to suppress stagnation of the air flow at the hub side joining part, to suppress the separation of the air flow on the suction surface side in the vicinity of the shroud, and to further improve the blade performance. Therefore, it is possible to reduce the fan input which is the driving force of the turbofan to be in a preferable range, and to achieve high efficiency and low noise of the turbofan.

[0029] In addition, in any of the above-described turbofans, the joining part of the blade to the hub may be made into a smooth curved surface in the rotation direction, and the joining part of the blade to the shroud may be made into a smooth curved surface in the rotation direction.

[0030] According to the aspect, since the joining part of the blade to the hub is made into a smooth curved surface in the rotation direction, and the joining part of the blade to the shroud is made into a smooth curved surface in the rotation direction, by making the joining part of the blade to the hub into a smooth curved surface in the counter-rotation direction, it is possible to set the joining part to be horizontally asymmetric, and to suppress stagnation of the air flow at the joining part. Meanwhile, by making the joining part of the blade to the shroud into a smooth curved surface in the rotation direction, it is possible to suppress separation of the flow on the suction surface side by the blade force, and to make the air flow smooth. Therefore, it is possible to improve blade performance, and to achieve high efficiency by further reducing the fan input, and it is possible to suppress disturbance of the air flow, and to achieve low noise.

[0031] Furthermore, in the above-described turbofan, the angle (expressed as -) of the curved surface in the rotation direction of the joining part of the blade to the hub may be -0.0154θ with respect to one pitch angle θ of the blade, and the angle (expressed as -) of the curved surface in the rotation direction of the joining part to the shroud may be -0.0461θ with respect to one pitch angle θ of the blade.

[0032] According to the aspect, since the angle (ex-

pressed as -) of the curved surface in the rotation direction of the joining part of the blade to the hub is -0.0154θ with respect to one pitch angle θ of the blade, and the angle (expressed as -) of the curved surface in the rotation direction of the joining part to the shroud is -0.0461θ with respect to one pitch angle θ of the blade, it is possible to suppress stagnation of the air flow at the hub side joining part, to suppress the separation of the air flow on the suction surface side by the blade force, and to further improve the blade performance. Therefore, it is possible to reduce the fan input which is the driving force of the turbofan to be in a preferable range, and to achieve high efficiency and low noise of the turbofan.

[0033] Furthermore, according to a second aspect of the invention, there is provided an air conditioner including: a fan which suctions and blows out indoor air; and a heat exchanger which is positioned on any of a suction side and a blow-out side of the blower, and cools or heats the indoor air, in which the fan is configured of the turbofan according to any of the above-described turbofans.

[0034] According to the aspect, since the fan suctions the indoor air, cools or heats the indoor air by the heat exchanger, and blows out the temperature-adjusted air into an indoor space, is configured to be any of the above-described turbofans, it is possible to reduce the fan input which is the driving force of the turbofan, and to achieve high efficiency and low noise of the turbofan. Therefore, it is possible to achieve higher performance and lower noise of the air conditioner.

Advantageous Effects of Invention

[0035] According to the turbofan of the invention, it is possible to improve separation of the air flow on the suction surface side of the blade, and to suppress disturbance of the air flow, and it is possible to reduce the high static pressure region generated on the pressure surface side of the blade, and to improve the fan efficiency by suppressing the decrease in speed (a loss of the driving force) of the air flow, and to reduce the driving force (fan input) of the fan, and thus, it is possible to achieve higher efficiency and lower noise of the turbofan.

[0036] According to the air conditioner of the invention, it is possible to reduce the fan input which is the driving force of the turbofan, and to achieve high efficiency and low noise of the turbofan, and thus, it is possible to achieve higher performance and lower noise of the air conditioner.

Brief Description of Drawings

[0037]

Fig. 1 is an exploded perspective view of an air conditioner according to one embodiment of the present invention.

Fig. 2 is a view illustrating a fan shape (A) of a turbofan employed in the air conditioner, a limit stream-

line (B) on a blade surface, and a static pressure contour (C) on the blade surface.

Fig. 3 is a comparison view of shapes (A) to (E) of the turbofan which is used when fluid analysis is performed with respect to the turbofan by a finite volume method.

Fig. 4 is a comparison view of limit streamline (A) to (E) on the blade surface of each of the turbofans.

Fig. 5 is a comparison view of static pressure contours (A) to (E) on the blade surface of each of the turbofans.

Fig. 6 is a comparison view of displacement shapes (B) and (C) with respect to an original shape (A) of a blade leading edge, which is used as a design parameter of each of the turbofans.

Fig. 7 is a comparison view of displacement shapes (B) and (C) with respect to an original shape (A) of a blade trailing edge, which is used as a design parameter of each of the turbofans.

Fig. 8 is a comparison view of displacement shapes (B) and (C) with respect to an original shape (A) of a curved shape on a blade hub side, which is used as a design parameter of each of the turbofans.

Fig. 9 is a comparison view of displacement shapes (B) and (C) with respect to an original shape (A) of a curved shape on a blade shroud side, which is used as a design parameter of each of the turbofans.

Fig. 10 is a view of an overlapping part of two blades after rotating all of the blades around a rotating shaft, which is used as a design parameter of each of the turbofans.

Fig. 11 is a view of an overlapping part of two blades, illustrating displacement of a leading edge and a trailing edge of the blade which is used as a design parameter of each of the turbofans.

Fig. 12 is a view of an overlapping part of two blades, illustrating a displaced state of the leading edge and the trailing edge of the blade, which is used as a design parameter of each of the turbofans.

Fig. 13 is a schematic view for illustrating a blade force of each of the turbofans.

Fig. 14 is a table illustrating a design parameter (A) and a objective function (B) which are used in analyzing each of the turbofans.

Fig. 15 is a table illustrating a value of a design parameter in an analysis result by the finite volume method.

Fig. 16 is a bar graph illustrating a comparison result of a objective function D' (a ratio between each input and an input of original shape with respect to the same air flow rate).

Fig. 17 is a graph illustrating a correlation between the objective function D' and a design parameter (1).

Fig. 18 is a graph illustrating a correlation between the objective function D' and a design parameter (2).

Fig. 19 is a graph illustrating a correlation between the objective function D' and a design parameter (3).

Fig. 20 is a graph illustrating a correlation between

the objective function D' and a design parameter (4).

Description of Embodiments

[0038] Hereinafter, one embodiment of the present invention will be described by using Figs. 1 to 20.

[0039] In Fig. 1, an exploded perspective view of an air conditioner according to one embodiment of the present invention is illustrated.

[0040] An air conditioner 1 according to the embodiment is a ceiling bury type air conditioner 1, but the present invention is not limited to the ceiling bury type air conditioner 1, and it is needless to say that the present invention may be employed in other types of air conditioner 1.

[0041] The ceiling bury type air conditioner 1 includes a substantially rectangular unit main body 2 which is hanged and installed by a bolt or the like in the ceiling; a four-sided ceiling panel 3 including an indoor air suction opening 4 and a temperature-adjusted air blow-out opening 5 which are provided on a lower surface of the unit main body 2; a bell mouth 6 which is positioned in the unit main body 2 to face the indoor air suction opening 4 of the ceiling panel 3; a turbofan (fan) 7 which is installed to be fixed to the ceiling of the unit main body 2 to face the bell mouth 6; and a quadrangular heat exchanger 8 which is installed in the unit main body 2 to surround the turbofan (fan) 7.

[0042] The turbofan 7 is a fan having a casingless structure including: a motor 9 which is installed to be fixed to the ceiling of the unit main body 2; a hub (main plate) 10 which is joined to a rotating shaft 9A of the motor 9, and is driven in a rotating manner by the motor 9; an annular shroud (side plate) 11 which is positioned to face the hub (main plate) 10; and a plurality of blades 12 having both end portions joined between the hub (main plate) 10 and the shroud (side plate) 11. In the plurality of blades 12 of the turbofan 7, a leading edge (there is also a case of being referred to as a leading edge line) 13 on an inner peripheral side is positioned on the rotation direction N side of a trailing edge (there is also a case of being referred to as a trailing edge line) 14 on an outer peripheral side.

[0043] Regarding the turbofan 7 of the embodiment, as illustrated in Fig. 2A, the shape of the blade 12 is investigated as follows, and according to this, an air flow on a suction surface 15 side of the blade 12 is illustrated as a fine streamline that has a small sudden change in interval (no separation) similar to a limit streamline (a line which visualizes a flow of a blade surface in a shape of a line) illustrated in Fig. 2B, and a static pressure on a pressure surface 16 side of the blade 12 is set to have no high static pressure region, or to have extremely small high static pressure region similar to a static pressure contour view illustrated in Fig. 2C, and is set such that a decrease in speed (loss) of the air flow is suppressed and a fan input which is a driving force of the turbofan 7 is reduced.

[0044] In the embodiment, the performance of the turbobfan 7 is supposed to be evaluated regarding the fan input which is the driving force of the turbobfan 7 as a parameter, is analyzed by a finite volume method in a state where the turbobfan 7 is mounted on the air conditioner 1, and sets the shape of the blade 12 based on the analysis. In order to perform the fluid analysis, as illustrated in Fig. 14A, by using four design parameters, such as (1) displacement (moving amount) of the leading edge 13 of the blade 12, (2) displacement (moving amount) of a trailing edge 14 of the blade 12, (3) curve (rotation angle) of a hub side joining part 17 of the blade 12, and (4) curve (rotation angle) of a shroud side joining part 18 of the blade 12, the evaluation is performed with respect to the parameter study of 41 cases. Furthermore, by regarding a first shape (No. 31) in the parameter study as a base, the most appropriate shape (No. 59) is acquired.

[0045] Figs. 2A and 3A to 3E illustrate shapes of a fan (No. 59) having the most appropriate shape, fans which are the first (No. 31), the second (No. 32), and the third (No. 06) among 41 cases evaluated in the parameter study, a fan (No. 0) having an original shape which is an evaluation reference, and a fan (No. 14) which is in the lowest place (41-st) in evaluation. Specific shapes of the fans illustrated in Figs. 2A and 3A to 3E will be described later, but as illustrated in Fig. 3D, the fan having an original shape has a configuration in which the shape of a section of the blade 12 is a uniform two-dimensional shape in an axial direction, both of the leading edge line 13 and the trailing edge line 14 of the blade 12 are parallel straight lines, and the hub side joining part 17 and the shroud side joining part 18 which join both ends of the blade 12 with the hub 10 and the shroud 11 are joined substantially perpendicularly with the hub 10 and the shroud 11.

[0046] In addition, regarding the fan shape of the case No. 14 which is in the lowest place which is the 41-st place in the evaluation, as illustrated in Fig. 3E, compared to the fan having an original shape illustrated in Fig. 3D, the leading edge line 13 of the blade 12 is made into a recess 13A in the air flow direction, the trailing edge line 14 is made into a projection 14B in the air flow direction, the hub side joining part 17 is made into a curved surface 17A curved in the counter-rotation direction, and the shroud side joining part 18 is made into a curved surface 18A curved in the counter-rotation direction.

[0047] Furthermore, in Figs. 4A to 4E and 5A to 5E, views in which limit streamlines and static pressure contours of each of the fans that correspond to the fan shape illustrated in Figs. 3A to 3E, are compared to each other, are illustrated.

[0048] Here, the shapes and the configurations of the above-described four design parameters (1) to (4) will be described in detail based on Figs. 6 to 9.

(1) As illustrated in Fig. 6, the displacement (moving amount) of the leading edge 13 of the blade 12

means a case where the leading edge line 13 is made into the recess 13A (the moving amount is expressed as +) by making the leading edge line 13 into a recess in the air flow direction relative to the joining parts 17 and 18 to the hub 10 and the shroud 11 as illustrated in Fig. 6B, or a case where the leading edge line 13 is made into a projection 13B (the moving amount is expressed as -) by making the leading edge 13 swell in the counter-air flow direction as illustrated in Fig. 6C, comparing to the original shape which is illustrated in Fig. 6A and in which the leading edge 13 of the blade 12 has a shape of a straight line. (2) As illustrated in Fig. 7, the displacement (moving amount) of the trailing edge 14 of the blade 12 means a case where the trailing edge line 14 is made into a recess 14A (the moving amount is expressed as -) by making the trailing edge line 14 into a recess in the counter-air flow direction relative to the joining parts 17 and 18 to the hub 10 and the shroud 11 as illustrated in Fig. 7B, or a case where the trailing edge line 14 is made into the projection 14B (the moving amount is expressed as +) by making the trailing edge line 14 swell in the air flow direction as illustrated in Fig. 7C comparing to the original shape which is illustrated in Fig. 7A and in which the trailing edge 14 of the blade 12 has a shape of a straight line. (3) As illustrated in Fig. 8, the curve (rotation angle) of the hub side joining part 17 of the blade 12 means a rotation angle (the rotation angle is expressed as +) with respect to the hub 10 when the hub side joining part 17 of the blade 12 is made into the curved surface 17A curved in the counter-rotation direction (counterclockwise direction) as illustrated in Fig. 8B, or a rotation angle (the rotation angle is expressed as -) with respect to the hub 10 when the hub side joining part 17 is made into a curved surface 17B curved in the rotation direction (clockwise direction) as illustrated in Fig. 8C, comparing to the original shape which is illustrated in Fig. 8A and in which the hub side joining part 17 of the blade 12 is joined substantially perpendicularly with the hub 10 side. (4) As illustrated in Fig. 9, the curve (rotation angle) of the shroud side joining part 18 of the blade 12 means a rotation angle (the rotation angle is expressed as +) with respect to the shroud 11 when the shroud side joining part 18 of the blade 12 is made into the curved surface 18A curved in the counter-rotation direction (counterclockwise direction) as illustrated in Fig. 9B, or a rotation angle (the rotation angle is expressed as -) with respect to the shroud 11 when the shroud side joining part 18 is made into a curved surface 18B curved in the rotation direction (counterclockwise direction) as illustrated in Fig. 9C, comparing to the original shape which is illustrated in Fig. 9A and in which the shroud side joining part 18 of the blade 12 is joined substantially perpendicularly with the shroud 11 side.

[0049] In addition, at the joining parts 17 and 18 of the blade 12 to the hub 10 and the shroud 11, as illustrated in Fig. 10, all of the blades are curved in the counter-rotation direction (counterclockwise direction) or in the rotation direction (clockwise direction) with respect to a center O of the rotating shaft 9A such that the angle made by the blade 12 and the air flow does not change.

[0050] Furthermore, regarding the displacement (moving amount) of the leading edge 13 and the trailing edge 14 of the blade 12, as illustrated in Fig. 11, by setting the outer diameter direction of the blade 12 to be a + direction, on a camber line and an extending line thereof in the blade 12, the displacement is performed into recesses or projections. In other words, as illustrated in Fig. 12, the displacement of the leading edge 13 and the trailing edge 14 of the blade 12 is moved only by the same amount along the camber line within a substantial range of 25% to 75% of the blade height in the spanwise direction (rotating shaft direction) on both of the leading edge 13 side and the trailing edge 14 side, and the leading edge 13 and the trailing edge 14 are made into recesses or projections. In addition, the hub 10 and the shroud 11 are configured to be connected to each other by a smooth curved line.

[0051] In addition, in Fig. 13, a blade force BF of the turbofan 7 is exploded.

[0052] The blade force BF of the turbofan 7 corresponds to a pressure gradient that acts between the plurality of blades (blades 12), and is a force given by the blade to the air flow which is a fluid, and as illustrated in Fig. 13, by inclining the blades (blades 12), the blade force BF acts in the direction perpendicular to the blade surface. The blade force BF achieves an action for suppressing separation on the suction surface side by pressing the air flow onto the wall surface (in Fig. 13, a wall surface of the shroud 11).

[0053] Hereinafter, the shapes and the configurations of the blade 12 of which the fan input of the turbofan 7 is set to be reduced, will be described in detail based on the above-described contents.

[Most Appropriate Fan Shape (Case No. 59)]

[0054] Fig. 2A is a perspective view of the turbofan 7 including the blade 12 which has the most appropriate shape of the case No. 59.

[0055] The blade 12 is configured such that the leading edge line 13 is made into the recess 13A (refer to Fig. 6B) in the air flow direction, and the trailing edge line 14 is made into the recess 14A (refer to Fig. 7B) in the counter-air flow direction.

[0056] In addition, the joining part (hub side joining part) 17 to the hub 10 of the blade 12 is made into the curved surface 17A (refer to Fig. 8B) which is curved in the counter-rotation direction (counterclockwise direction), and the joining part (shroud side joining part) 18 to the shroud 11 of the blade 12 is made into the curved surface 18B (refer to Fig. 9C) which is curved in the ro-

tation direction (clockwise direction). In addition, at the hub side joining part 17 and the shroud side joining part 18, as illustrated in Fig. 10, all of the blades are curved around the center O of the rotating shaft such that the angle made by the blade 12 and the air flow does not change.

[0057] Furthermore, in the leading edge line 13 and the trailing edge line 14, as illustrated in Figs. 11 and 12, as the center part in the spanwise direction (rotating shaft direction) of the blade 12 moves by the same amount on the camber line and the extending line thereof of the blade 12 within a range of 25 to 75% of a dimension in the spanwise direction, the leading edge line 13 is made into the recess 13A in the air flow direction and the trailing edge line 14 is made into the recess 14A in the counter-air flow direction.

[0058] In the blade 12 having the most appropriate shape, when the outer diameter of the turbofan 7 is set to be D [m] (refer to Figs. 10 and 12) and one pitch angle of the blade 12 is set to be θ [°] (refer to Fig. 10), as described in the table of Fig. 15, the above-described design parameters (1) to (4) include (1) the displacement (moving amount) of the leading edge (pull-LE) 13 of the blade 12 is made into the recess 13A having approximately 0.0153D in the air flow direction (expressed as +), and (2) the displacement (moving amount) of the trailing edge (pull-TE) 14 of the blade 12 is made into the recess 14A having approximately -0.0153D in the counter-air flow direction (expressed as -).

[0059] In addition, (3) the curve (rotation angle) of the hub side joining part 17 of the blade 12 is made into the curved surface 17A having 0.0972 θ in the counter-rotation direction (counterclockwise direction, expressed as +), and (4) the curve (rotation angle) of the shroud side joining part 18 of the blade 12 is made into the curved surface 18B having -0.0972 θ in the rotation direction (clockwise direction, expressed as -).

[Fan Shape of Case No. 31 (First)]

[0060] In Fig. 3A, a perspective view of the turbofan 7 having a blade shape of the case No. 31 (first) is illustrated.

[0061] The blade 12 is the same as the blade 12 having the most appropriate shape, the leading edge line 13 is configured to be made into the recess 13A (refer to Fig. 6B) in the air flow direction, and the trailing edge line 14 is configured to be made into the recess 14A (refer to Fig. 7B) in the counter-air flow direction.

[0062] In addition, the joining part 17 (hub side joining part) to the hub 10 of the blade 12 is configured to be made into the curved surface 17A (refer to Fig. 8B) curved in the counter-rotation direction (counterclockwise direction), and the joining part (shroud side joining part) 18 to the shroud 11 of the blade 12 is configured to be made into the curved surface 18B (refer to Fig. 9C) curved in the rotation direction (clockwise direction). In addition, at the hub side joining part 17 and the shroud side joining

part 18, as illustrated in Fig. 10, all of the blades are curved around the center O of the rotating shaft such that the angle made by the blade 12 and the air flow does not change.

[0063] Furthermore, in the leading edge line 13 and the trailing edge line 14, as illustrated in Figs. 11 and 12, as the center part in the spanwise direction (rotating shaft direction) of the blade 12 moves by the same amount on the camber line and the extending line thereof of the blade 12 within a range of 25 to 75% of a dimension in the spanwise direction, the leading edge line 13 is made into the recess 13A in the air flow direction and the trailing edge line 14 is made into the recess 14A in the counter-air flow direction.

[0064] In the blade 12 of the case No. 31 (first), as illustrated in the table of Fig. 15, the above-described design parameters (1) to (4) include (1) the displacement (moving amount) of the leading edge (pull-LE) 13 of the blade 12 is made into the recess 13A having approximately 0.0153D with respect to the air flow direction (expressed as +), and (2) the displacement (moving amount) of the trailing edge (pull-TE) 14 of the blade 12 is made into the recess 14A having approximately -0.0153D with respect to the counter-air flow direction (expressed as -).

[0065] In addition, (3) the curve (rotation angle) of the hub side joining part 17 of the blade 12 is made into the curved surface 17A having 0.05630 in the counter-rotation direction (counterclockwise direction, expressed as +), and (4) the curve (rotation angle) of the shroud side joining part 18 of the blade 12 is made into the curved surface 18B having -0.01540 in the rotation direction (clockwise direction, expressed as -).

[Fan Shape of Case No. 32 (Second)]

[0066] In Fig. 3B, a perspective view of the turbofan 7 having a blade shape of the case No. 32 (second) is illustrated.

[0067] The blade 12 is the same as the blade 12 having the most appropriate shape, the leading edge line 13 is configured to be made into the recess 13A (refer to Fig. 6B) in the air flow direction, and the trailing edge line 14 is configured to be made into the recess 14A (refer to Fig. 7B) in the counter-air flow direction.

[0068] Meanwhile, the joining part 17 (hub side joining part) to the hub 10 of the blade 12 is configured to be made into the curved surface 17B (refer to Fig. 8C) curved in the rotation direction (clockwise direction), and the joining part (shroud side joining part) 18 to the shroud 11 of the blade 12 is configured to be made into the curved surface 18A (refer to Fig. 9B) curved in the counter-rotation direction (counterclockwise direction). In addition, at the hub side joining part 17 and the shroud side joining part 18, as illustrated in Fig. 10, all of the blades are curved around the center O of the rotating shaft such that the angle made by the blade 12 and the air flow does not change.

[0069] Furthermore, in the leading edge line 13 and

the trailing edge line 14, as illustrated in Figs. 11 and 12, as the center part in the spanwise direction (rotating shaft direction) of the blade 12 moves by the same amount on the camber line and the extending line thereof of the blade 12 within a range of 25 to 75% of a dimension in the spanwise direction, the leading edge line 13 is made into the recess 13A in the air flow direction and the trailing edge line 14 is made into the recess 14A in the counter-air flow direction.

[0070] In the blade 12 of the case No. 32 (second), as illustrated in the table of Fig. 15, the above-described design parameters (1) to (4) include (1) the displacement (moving amount) of the leading edge (pull-LE) 13 of the blade 12 is made into the recess 13A having approximately 0.0091D with respect to the air flow direction (expressed as +), and (2) the displacement (moving amount) of the trailing edge (pull-TE) 14 of the blade 12 is made into the recess 14A having approximately -0.0142D in the counter-air flow direction (expressed as -).

[0071] In addition, (3) the curve (rotation angle) of the hub side joining part 17 of the blade 12 is made into the curved surface 17B having -0.07680 in the rotation direction (clockwise direction, expressed as -), and (4) the curve (rotation angle) of the shroud side joining part 18 of the blade 12 is made into the curved surface 18A having 0.00310 in the counter-rotation direction (counterclockwise direction, expressed as +).

[Fan Shape of Case No. 06 (Third)]

[0072] In Fig. 3C, a perspective view of the turbofan 7 having a blade shape of the case No. 06 (third) is illustrated.

[0073] In the blade 12, the leading edge line 13 is configured to be made into the projection 13B (refer to Fig. 6C) in the counter-air flow direction, and the trailing edge line 14 is configured to be made into the recess 14A (refer to Fig. 7B) in the counter-air flow direction.

[0074] Meanwhile, the joining part 17 (hub side joining part) to the hub 10 of the blade 12 is configured to be made into the curved surface 17B (refer to Fig. 8C) curved in the rotation direction (clockwise direction), and the joining part (shroud side joining part) 18 to the shroud 11 of the blade 12 is configured to be made into the curved surface 18B (refer to Fig. 9C) curved in the counter-rotation direction (counterclockwise direction). In addition, at the hub side joining part 17 and the shroud side joining part 18, as illustrated in Fig. 10, all of the blades are curved around the center O of the rotating shaft such that the angle made by the blade 12 and the air flow does not change.

[0075] Furthermore, in the leading edge line 13 and the trailing edge line 14, as illustrated in Figs. 11 and 12, as the center part in the spanwise direction (rotating shaft direction) of the blade 12 moves by the same amount on the camber line and the extending line thereof of the blade 12 within a range of 25 to 75% of a dimension in the spanwise direction, the leading edge line 13 is configured

to be made into the projection 13B in the counter-air flow direction and the trailing edge line 14 is configured to be made into the recess 14A in the counter-air flow direction.

[0076] In the blade 12 of the case No. 06 (third), as illustrated in the table of Fig. 15, the above-described design parameters (1) to (4) include (1) the displacement (moving amount) of the leading edge (pull-LE) 13 of the blade 12 is made into the projection 13B having approximately $-0.0438D$ in the counter-air flow direction (expressed as -), and (2) the displacement (moving amount) of the trailing edge (pull-TE) 14 of the blade 12 is made into the recess 14A having approximately $-0.0153D$ in the counter-air flow direction (expressed as -).

[0077] In addition, (3) the curve (rotation angle) of the hub side joining part 17 of the blade 12 is made into the curved surface 17B having -0.0154θ in the rotation direction (clockwise direction, expressed as -), and (4) the curve (rotation angle) of the shroud side joining part 18 of the blade 12 is made into the curved surface 18B having -0.0461θ in the rotation direction (clockwise direction, expressed as -).

[0078] Incidentally, regarding the original blade shape of the case No. 0, as illustrated in Fig. 15, any of four design parameters (1) to (4) is set to be 0. In addition, regarding the blade shape of the case No. 14 (41-st) which is in the lowest place in evaluation, (1) the displacement (moving amount) of the leading edge (pull-LE) 13 of the blade 12 is made into the recess 13A having approximately $0.0153D$ in the air flow direction (expressed as +), (2) the displacement (moving amount) of the trailing edge (pull-TE) 14 is made into the projection 14B having approximately $0.0438D$ in the air flow direction (expressed as +), (3) the curve (rotation angle) of the hub side joining part 17 of the blade 12 is made into the curved surface 17A having 0.0563θ in the counter-rotation direction (expressed as +), and (4) the curve (rotation angle) of the shroud side joining part 18 is made into the curved surface 18A having 0.0358θ in the counter-rotation direction (expressed as +).

[0079] By the above-described configuration, according to the embodiment, the following operational effects are achieved.

[0080] In the turbofan 7 and the air conditioner 1, the indoor air suctioned from the indoor air suction opening 4 of the ceiling panel 3 by the rotation of the turbofan 7 is suctioned in the axial direction from an opening portion on the shroud 11 side of the turbofan 7 via the bell mouth 6. The air flow suctioned to the turbofan 7 is blown out after changing the direction into the radial direction by the plurality of blades 12, is cooled or heated in the process of passing through the heat exchanger 8 positioned to surround the turbofan 7, and accordingly, the air flow is blown out to the indoor space from the four temperature-adjusted air blow-out openings 5 provided on four sides of the ceiling panel 3 as the temperature-adjusted air, and is provided for conditioning the air in the indoor space.

[0081] In a case of the turbofan 7, in order to change

the direction of the air flow suctioned in the axial direction into the radial direction (centrifugal direction), in particular, the air flow suctioned from the vicinity of the outer edge (shroud 11 side) of the suction opening is not bent and cut by an inertial force, and is likely to be a flow deviated to the hub 10 side on the inside of the fan, the blade 12 does not efficiently function on a side near the shroud 11, efficiency deterioration is caused, a high-speed jet flow is generated by deviation of the air flow on a blow-out side, a counterflow is generated on the suction side, and aerodynamic noise is likely to increase. In addition, in a case of using the turbofan in the air conditioner 1, the air is suctioned from a quadrangular air duct, the turbofan is operated in a non-axis symmetric pressure field surrounded by the quadrangular heat exchanger 8 in many cases, and it is difficult to realize a uniform flow across the entire spanwise direction of the fan.

[0082] Here, in the turbofan 7 according to the embodiment, regarding four items of the above-described (1) to (4) illustrated in Fig. 14A as design parameters, the fluid analysis by the finite volume method is parametrically performed, and the shape of the blade 12 is set based on the values of the design parameters. In addition, in Fig. 14B, the definition of an objective function D' is illustrated. In addition, in a list of Fig. 15, values of the design parameters in the analysis result by the finite volume method are summarized.

[0083] In the list of Fig. 15, the results of only 6 cases in total including the fan having the most appropriate shape of the case No. 59, three fans including the first (case No. 31) which is in the highest place in the evaluation in the parameter study with respect to 41 cases, the second (case No. 32), and the third (case No. 06) having a high evaluation result in the parameter study with respect to 41 cases, the original fan (case No. 0) which is regarded as an evaluation reference, and the 41-st fan (case No. 14) which is in the lowest place in the evaluation, are described.

[0084] Furthermore, in Fig. 16, with respect to the above-described objective function D' , the values of the above-described six cases are compared to each other and are illustrated in the bar graph, and in Figs. 17 to 20, graphs illustrating a correlation between the objective function D' and the design parameter (1), the objective function D' and the design parameter (2), the objective function D' and the design parameter (3), and the objective function D' and the design parameter (4), are illustrated.

[0085] As can be apparent from the analysis results, in the turbofan 7 of the embodiment, since the center part of the trailing edge line 14 of the plurality of blades 12 is configured to be made into the recess 14A in the counter-air flow direction within the range of 25 to 75% in the spanwise direction (rotating shaft direction) as illustrated in Fig. 2A or Figs. 3A to 3C, the air flow on the suction surface 15 side of the blade 12 can be a fine streamline of which the rapid change of the interval is small (no separation) similar to limit streamline (a case where the flow

of the blade surface is visualized in a line shape) illustrated in Fig. 2B or Figs. 4A to 4C.

[0086] In other words, in the original shape of the case No. 0 or in the case No. 14 which is in the lowest place in the evaluation, a location X at which the air flow on the suction surface 15 side of the blade 12 is disturbed is seen as illustrated by the limit streamline illustrated in Figs. 4D and 4E), the separation is generated in the air flow, but the most appropriate shape of the case No. 59 illustrated in Fig. 2A or Figs. 3A to 3C or in any of the case No. 31, the case No. 32, and the case No. 6 which are the first to the third in the evaluation, the location X at which the air flow is disturbed in the limit streamline of the suction surface 15 does not exist, and it is determined that the separation on the suction surface 15 is improved.

[0087] In addition, on the pressure surface 16 of the blade 12 by the rotation of the turbofan 7, the static pressure (blade surface pressure) is distributed, but as the static pressure increases or as the high static pressure region increases, the speed of the air flow which is along the blade 12 is reduced, the fan efficiency deteriorates due to the loss. In the turbofan 7 of the embodiment, regarding the high static pressure region, as illustrated in the static pressure contour views illustrated in Fig. 2C or Figs. 5A to 5C, compared to the cases illustrated in Figs. 5D and 5E, it is possible to reduce the pressure or to reduce the region.

[0088] In other words, in the original shape of the case No. 0 or in the case No. 14 which is in the lowest place in the evaluation, a high static pressure region Y generated on the pressure surface 16 of the blade 12 is generated as a relatively large region Y as illustrated in Figs. 5D and 5E. However, in the most appropriate shape of the case No. 59 or in the case No. 31, the case No. 32, and the case No. 6 which are the first to the third in evaluation, which are illustrated in Fig. 2C or Figs. 5A to 5C, the high static pressure region Y is not generated or an extremely small region Y is generated, a decrease in speed of the air flow is not generated, and it is determined that the fan efficiency does not deteriorate by the loss caused by the increase in speed.

[0089] In this manner, as the trailing edge line 14 of the blade 12 is made into the recess 14A in the counter-air flow direction, it is possible to improve separation of the air flow on the suction surface 15 side of the blade 12, and to suppress disturbance of the air flow, and it is possible to reduce the high static pressure region Y distributed on the pressure surface 16 side, to improve the fan efficiency by suppressing the decrease in speed of the air flow, and to reduce the fan input which is the driving force of the turbofan 7 as illustrated in Figs. 16 and 18.

[0090] This is because, as the trailing edge line 14 of the blade 12 is made into the recess 14A in the counter-air flow direction, the radius of the region made into the recess becomes smaller than the original shape, and in a case where the turbofan 7 is rotated at the same rotation speed, it is possible to reduce the pressure rise of the air flow that passes through the turbofan 7 and according to

this, at a location at which the separation on the shroud 11 side of the suction surface 15 is particularly easy, the pressure (static pressure) in the vicinity of the trailing edge 14 of the blade 12 is reduced, and thus, the flow becomes easy as the air flow, and it is possible to suppress the separation.

[0091] Meanwhile, on the pressure surface 16, the influence on the deviation of the air flow that passes through the turbofan 7 to the hub 10 side is substantial, the distribution in which the pressure of the surface of the blade 12 is also oriented to the hub 10 side and rapidly rises, is illustrated, but by making the trailing edge line 14 into the recess 14A, it is possible to reduce the pressure (static pressure) in the vicinity of the trailing edge 14 of the blade 12, and to reduce the static pressure on the pressure surface 16, and thus, it is possible to improve the fan efficiency of the turbofan 7, and to reduce the fan input, and accordingly, it is possible to achieve lower noise and higher efficiency of the turbofan 7.

[0092] In addition, making the trailing edge line 14 into the recess 14A in the counter-air flow direction may be performed within a range of 25 to 75% of the center part in the spanwise direction, and does not influence the functions and performance of the joining parts 17 and 18 to the hub 10 and the shroud 11, and it is possible to join the blade 12 with the hub 10 and the shroud 11. Therefore, without disturbance of the air flow at the hub side joining part 17 and the shroud side joining part 18, it is possible to achieve low noise and high efficiency.

[0093] Furthermore, by making the recess amount (expressed as -) in the counter-air flow direction of the trailing edge line 14 of the blade 12 to be within the range of -0.0142D to -0.0153D when the outer diameter of the turbofan 7 is set to be D, as illustrated in Figs. 16 and 18, it is possible to reduce the fan input which is the driving force of the turbofan 7 to be in a preferable range.

[0094] Meanwhile, in the turbofan 7 of the embodiment, the center part of the leading edge line 13 of the blade 12 is made into the recess 13A in the air flow direction relative to the joining parts 17 and 18 to the hub 10 and the shroud 11 as illustrated in Fig. 2A or Figs. 3A and 3B, or is made into the projection 13B in the counter-air flow direction as illustrated in Fig. 3C, within the range of 25 to 75% in the spanwise direction (rotating shaft direction).

[0095] In this manner, by displacing the leading edge line 13 to the recess 13A in the air flow direction, compared to the blade 12 having the most appropriate shape illustrated in Fig. 2, as illustrated in Fig. 4B, there is also a case where slight disturbance of the air flow is generated on the suction surface 15 side of the blade 12, but by reducing the high static pressure region on the pressure surface 16 side as illustrated in Fig. 5B, it is possible to suppress the decrease in speed of the air flow. Meanwhile, by displacing the leading edge line 13 to the projection 13B in the counter-air flow direction, as illustrated in Fig. 5C, the high static pressure region on the pressure surface 16 side slightly increases, and there is a case

where the speed reduction suppression effect of the air flow slightly deteriorates, but as illustrated in Fig. 4C, it is possible to suppress disturbance and separation of the air flow on the suction surface 15.

[0096] This is because, by making the leading edge line 13 of the blade 12 into the recess 13A in the air flow direction, the length in the air flow direction of the blade 12 is shortened, and it is possible to reduce friction loss between the air flow and the surface of the blade 12, and to reduce the fan input. However, when the leading edge line 13 is extremely made into the recess 13A, there is a concern that the blade length in the air flow direction with respect to the distance between the adjacent blades 12 is extremely shortened, and the performance of the blade 12 deteriorates. In addition, by making the leading edge line 13 of the blade 12 into the projection 13B in the counter-air flow direction, the friction loss between the air flow and the surface of the blade 12 generally increases. Meanwhile, since the length in the air flow direction of the blade 12 is substantially long, by stably guiding the flow that flows in from the blade upstream side to the downstream side, it is possible to make it difficult to separate the flow by suppressing a peak value of the static pressure on the surface of the blade 12, and to reduce the fan input, and it is possible to reduce the fan noise.

[0097] Therefore, in the embodiment, as illustrated in Fig. 16 and Figs. 17 and 18, it is possible to reduce the fan input which is the driving force of the turbofan 7 to be in a preferable range, and to achieve high efficiency and low noise of the turbofan 7.

[0098] In addition, in this case, as illustrated in Fig. 2A of Figs. 3A to 3C, since the center part of the leading edge line 13 of the blade 12 is made into the recess 13A in the air flow direction relative to the joining parts 17 and 18 to the hub 10 and the shroud 11, or is made into the projection 13B in the counter-air flow direction, within the range of 25 to 75% in the spanwise direction (rotating shaft direction), it is possible to join the blade 12 with the hub 10 and the shroud 11 without influencing the function and performance of the joining parts 17 and 18 to the hub 10 and the shroud 11. Therefore, it is possible to achieve low noise and high efficiency without disturbing the air flow at the hub side joining part 17 and the shroud side joining part 18.

[0099] In addition, in the leading edge line 13 of the above-described blade 12, since the recess amount (expressed as +) of the recess 13A in the air flow direction is set to be within the range of 0.0091D to 0.0153D with respect to fan outer diameter D, and the projection amount (expressed as -) of the projection 13B in the counter-air flow direction is -0.0438D with respect to fan outer diameter D, as illustrated in Figs. 16 and 18, it is possible to reduce the fan input which is the driving force of the turbofan 7 to be in a preferable range. According to this, it is possible to low noise and high efficiency of the turbofan 7.

[0100] Furthermore, in the turbofan 7 of the embodiment, as illustrated in Figs. 2A and 3A, the joining part

(hub side joining part) 17 to the hub 10 of the blade 12 is configured to be made into the smooth curved surface 17A in the counter-rotation direction, and the joining part (shroud side joining part) 18 to the shroud 11 of the blade 12 is configured to be made into the smooth curved surface 18B in the rotation direction.

[0101] In this manner, by making the joining part 17 to the hub 10 of the blade 12 into the smooth curved surface 17A in the counter-rotation direction, it is possible to set the joining part 17 to the hub 10 to be horizontally asymmetric, and to suppress stagnation of the air flow at the joining part 17, and by making the joining part to the shroud 11 of the blade 12 into the smooth curved surface 18B in the rotation direction, it is possible to suppress separation of the flow by the blade force BF and to make the air flow smooth. At the same time, as illustrated in Figs. 2B and 4A, it is possible to suppress the disturbance of the air flow on the suction surface 15 side of the blade 12, and as illustrated in Figs. 2C and 5A, it is possible to suppress the decrease in speed (a loss of the driving force) of the air flow by reducing the high static pressure region on the pressure surface 16 side of the blade 12.

[0102] Therefore, it is possible to improve blade performance of the turbofan 7, as illustrated in Figs. 16, 19 and 20, it is possible to achieve high efficiency by reducing the fan input which is the driving force of the turbofan 7, to suppress the disturbance of the air flow, and to achieve low noise.

[0103] In addition, in the embodiment, the angle (expressed as +) of the curved surface 17A in the counter-rotation direction of the joining part (hub side joining part) 17 to the hub 10 of the blade 12 is set to be within a range of 0.0563 θ to 0.0972 θ with respect to one pitch angle θ of the blade 12, and the angle (expressed as -) of the curved surface 18B in the rotation direction of the joining part (shroud side joining part) 18 to the shroud 11 is set to be within a range of -0.0154 θ to -0.0972 θ with respect to the one pitch angle θ of the blade.

[0104] Therefore, it is possible to suppress the stagnation of the air flow at the hub side joining part 17 of the blade 12, and it is possible to suppress the separation of the air flow on the suction surface 15 side by the blade force, and to further improve the performance of the blade 12, and according to this, as illustrated in Figs. 16, 19, and 20, by reducing the fan input which is the driving force of the turbofan 7 to be in a preferable range, it is possible to achieve high efficiency and low noise of the turbofan 7.

[0105] In addition, the present invention is not limited to the invention according to the embodiment, and can be appropriately changed within a range that does not depart from the spirit of the invention. For example, in the above-described embodiment, an example in which the invention is employed in the ceiling bury type air conditioner 1 in which the heat exchanger 8 is installed on the blow-out side of the turbofan 7 is described, but not being limited thereto, it is needless to say that it is also possible to employ the invention in the air conditioner 1

in the air conditioner or the like which suctions the temperature-adjusted air after exchanging heat through a heat exchanger having a shape of a flat surface and blows out the air to the indoor space from the upper and lower blow-out openings in the centrifugal direction. In addition, it is needless to say that the turbofan 7 itself may be employed in equipment other than the air conditioner.

Reference Signs List

[0106]

- 1 AIR CONDITIONER
- 7 TURBOFAN (FAN)
- 8 HEAT EXCHANGER
- 10 HUB
- 11 SHROUD
- 12 BLADE
- 13 LEADING EDGE (LEADING EDGE LINE)
- 13A RECESS
- 13B PROJECTION
- 14 TRAILING EDGE (TRAILING EDGE LINE)
- 14A RECESS
- 15 SUCTION SURFACE
- 16 PRESSURE SURFACE
- 17 JOINING PART (HUB SIDE JOINING PART)
- 17A, 17B CURVED SURFACE
- 18 JOINING PART (SHROUD SIDE JOINING PART)
- 18A, 18B CURVED SURFACE

Claims

1. A turbofan comprising:

a hub which is connected to a motor drive shaft, and is driven in a rotating manner;
 an annular shroud which is positioned facing the hub and forms an air suction opening; and
 a plurality of blades having both end portions joined between the hub and the shroud so that leading edges on the inner peripheral side are positioned on a rotation direction side of trailing edges on the outer peripheral side,
 wherein the plurality of blades are configured such that the trailing edges are made into recesses in a counter-air flow direction relative to joining parts to the hub and the shroud.

2. The turbofan according to claim 1, wherein, at the trailing edges of the blades, a center part in a spanwise direction of the blade is made into recesses in the counter-air flow direction within a range of 25% to 75% in the spanwise direction.

3. The turbofan according to claim 1 or 2,

wherein a recess amount (expressed as -) in the counter-air flow direction of the trailing edge of the blade is within a range of -0.0142D to -0.0153D, with respect to a fan outer diameter D.

4. The turbofan according to any one of claims 1 to 3, wherein the leading edges of the blades are made into recesses in an air flow direction or are made into projections in the counter-air flow direction relative to joining parts to the hub and the shroud.

5. The turbofan according to claim 4, wherein a recess amount (expressed as +) in the air flow direction of the leading edge of the blade is within a range of 0.0091D to 0.0153D, with respect to the fan outer diameter D, and a projection amount (expressed as -) in the counter-air flow direction is -0.0438D with respect to the fan outer diameter D.

6. The turbofan according to claim 4 or 5, wherein, at the leading edges of the blades, a center part in the spanwise direction of the blade is made into recesses in the air flow direction or into projections in the counter-air flow direction as described above within a range of 25% to 75% in the spanwise direction.

7. The turbofan according to any one of claims 1 to 3, wherein the joining part of the blade to the hub is made into a smooth curved surface in a counter-rotation direction, and the joining part of the blade to the shroud is made into a smooth curved surface in a rotation direction.

8. The turbofan according to claim 7, wherein an angle (expressed as +) of the curved surface in the counter-rotation direction of the joining part of the blade to the hub is within a range of 0.0563θ to 0.0972θ with respect to one pitch angle θ of the blade, and an angle (expressed as -) of the curved surface in the rotation direction of the joining part to the shroud is within a range of -0.0154θ to -0.0972θ with respect to one pitch angle θ of the blade.

9. The turbofan according to any one of claims 4 to 6, wherein the joining part of the blade to the hub is made into a smooth curved surface in the rotation direction, and the joining part of the blade to the shroud is made into a smooth curved surface in the counter-rotation direction.

10. The turbofan according to claim 9, wherein an angle (expressed as -) of the curved surface in the rotation direction of the joining part of the blade to the hub is -0.0768θ with respect to one pitch angle θ of the blade, and an angle (expressed as +) of the curved surface in the counter-rotation direction

of the joining part to the shroud is 0.0031θ with respect to one pitch angle θ of the blade.

11. The turbofan according to any one of claims 4 to 6, wherein the joining part of the blade to the hub is made into a smooth curved surface in the rotation direction, and the joining part of the blade to the shroud is made into a smooth curved surface in the rotation direction.
12. The turbofan according to claim 11, wherein an angle (expressed as -) of the curved surface in the rotation direction of the joining part of the blade to the hub is -0.0154θ with respect to one pitch angle θ of the blade, and an angle (expressed as -) of the curved surface in the rotation direction of the joining part to the shroud is -0.0461θ with respect to one pitch angle θ of the blade.
13. An air conditioner comprising:
 - a fan which suctions and blows out indoor air; and
 - a heat exchanger which is positioned on any of a suction side and a blow-out side of the blower, and cools or heats the indoor air, wherein the fan is configured of the turbofan according to any of claims 1 to 12.

Amended claims under Art. 19.1 PCT

1. (After amendment) A turbofan comprising:
 - a hub which is connected to a motor drive shaft, and is driven in a rotating manner;
 - an annular shroud which is positioned facing the hub and forms an air suction opening; and
 - a plurality of blades having both end portions joined between the hub and the shroud so that leading edges on the inner peripheral side are positioned on a rotation direction side of trailing edges on the outer peripheral side, wherein the plurality of blades are configured such that the trailing edges are made into recesses in a counter-air flow direction relative to joining parts to the hub and the shroud, and wherein the joining part of the blade to the hub is configured such that a smooth curved surface in a rotation direction or in a counter-rotation direction is formed across the entire air flow direction.
2. The turbofan according to claim 1, wherein, at the trailing edges of the blades, a center part in a spanwise direction of the blade is made into recesses in the counter-air flow direction within a range of 25% to 75% in the spanwise direction.

3. The turbofan according to claim 1 or 2, wherein a recess amount (expressed as -) in the counter-air flow direction of the trailing edge of the blade is within a range of $-0.0142D$ to $-0.0153D$, with respect to a fan outer diameter D .

4. The turbofan according to any one of claims 1 to 3, wherein the leading edges of the blades are made into recesses in an air flow direction or are made into projections in the counter-air flow direction relative to joining parts to the hub and the shroud.

5. The turbofan according to claim 4, wherein a recess amount (expressed as +) in the air flow direction of the leading edge of the blade is within a range of $0.0091D$ to $0.0153D$, with respect to the fan outer diameter D , and a projection amount (expressed as -) in the counter-air flow direction is $-0.0438D$ with respect to the fan outer diameter D .

6. The turbofan according to claim 4 or 5, wherein, at the leading edges of the blades, a center part in the spanwise direction of the blade is made into recesses in the air flow direction or into projections in the counter-air flow direction as described above within a range of 25% to 75% in the spanwise direction.

7. The turbofan according to any one of claims 1 to 3, wherein the joining part of the blade to the hub is made into a smooth curved surface in the counter-rotation direction, and the joining part of the blade to the shroud is made into a smooth curved surface in the rotation direction.

8. The turbofan according to claim 7, wherein an angle (expressed as +) of the curved surface in the counter-rotation direction of the joining part of the blade to the hub is within a range of 0.0563θ to 0.0972θ with respect to one pitch angle θ of the blade, and an angle (expressed as -) of the curved surface in the rotation direction of the joining part to the shroud is within a range of -0.0154θ to -0.0972θ with respect to one pitch angle θ of the blade.

9. The turbofan according to any one of claims 4 to 6, wherein the joining part of the blade to the hub is made into a smooth curved surface in the rotation direction, and the joining part of the blade to the shroud is made into a smooth curved surface in the counter-rotation direction.

10. The turbofan according to claim 9, wherein an angle (expressed as -) of the curved surface in the rotation direction of the joining part of the blade to the hub is -0.0768θ with respect to one pitch angle θ of the blade, and an angle (expressed as +)

of the curved surface in the counter-rotation direction of the joining part to the shroud is 0.0031θ with respect to one pitch angle θ of the blade.

11. The turbofan according to any one of claims 4 to 6,
wherein the joining part of the blade to the hub is made into a smooth curved surface in the rotation direction, and the joining part of the blade to the shroud is made into a smooth curved surface in the rotation direction.

12. The turbofan according to claim 11,
wherein an angle (expressed as -) of the curved surface in the rotation direction of the joining part of the blade to the hub is -0.0154θ with respect to one pitch angle θ of the blade, and an angle (expressed as -) of the curved surface in the rotation direction of the joining part to the shroud is -0.0461θ with respect to one pitch angle θ of the blade.

13. An air conditioner comprising:

a fan which suctions and blows out indoor air;
and
a heat exchanger which is positioned on any of a suction side and a blow-out side of the fan,
and cools or heats the indoor air,
wherein the fan is configured of the turbofan according to any of claims 1 to 12.

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FIG. 1

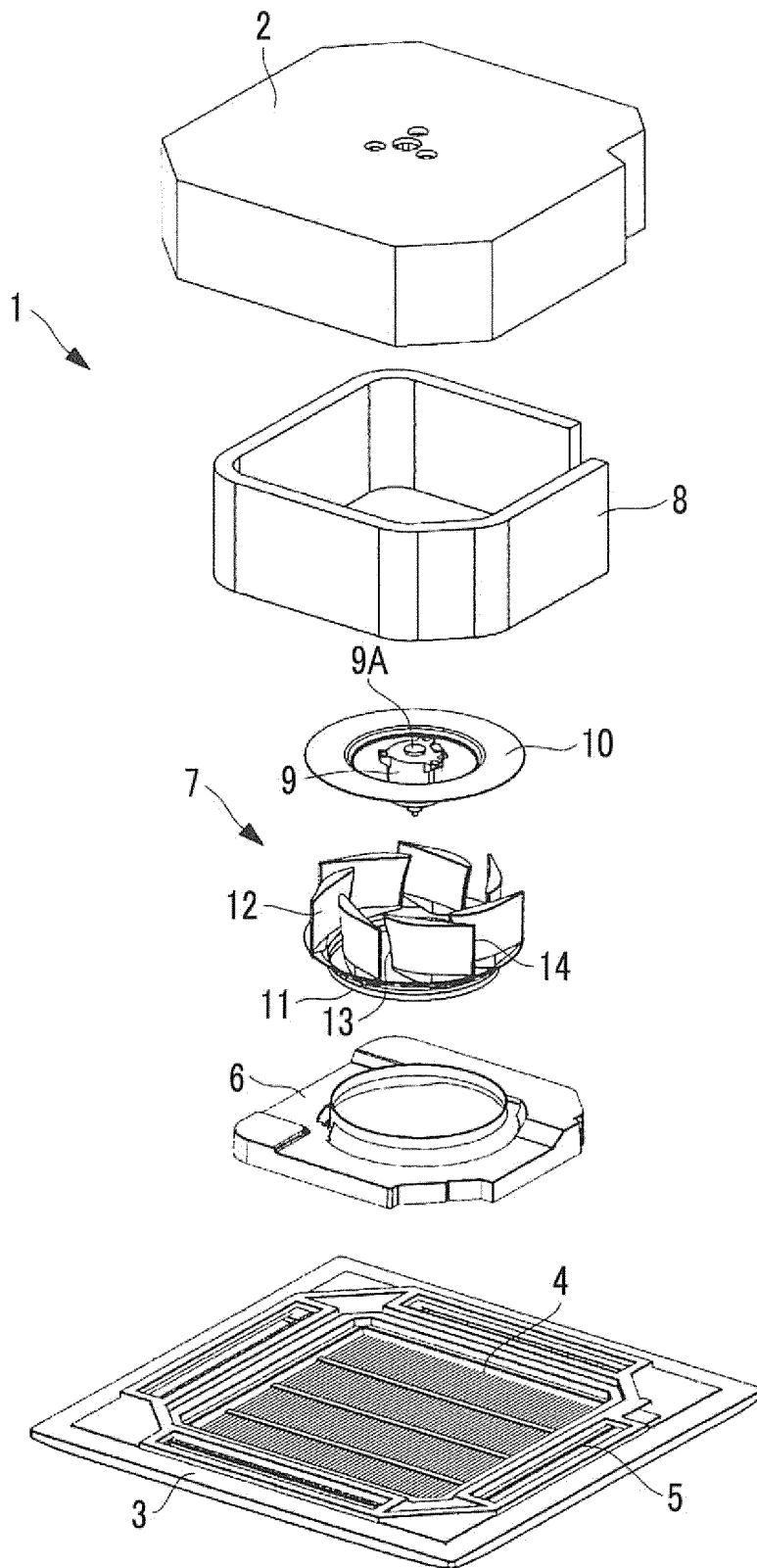


FIG. 2A No. 59 (MOST APPROPRIATE SHAPE)

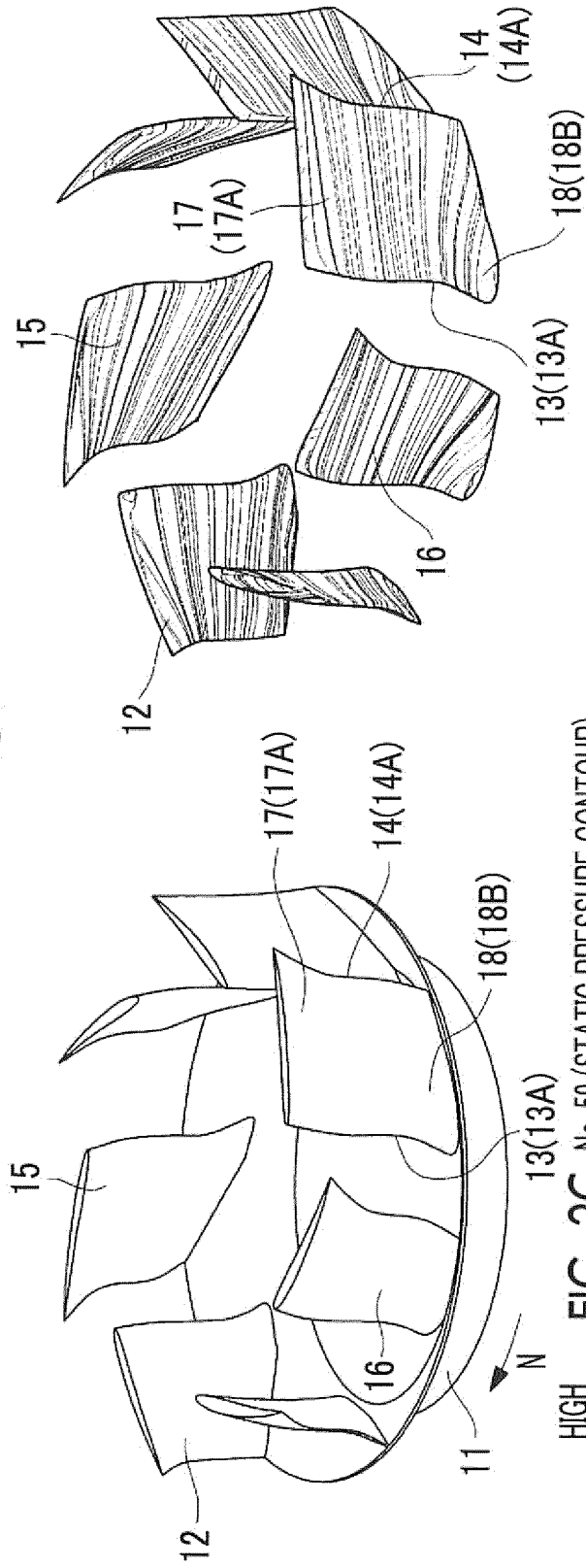


FIG. 2B No. 59 (LIMIT STREAMLINE)

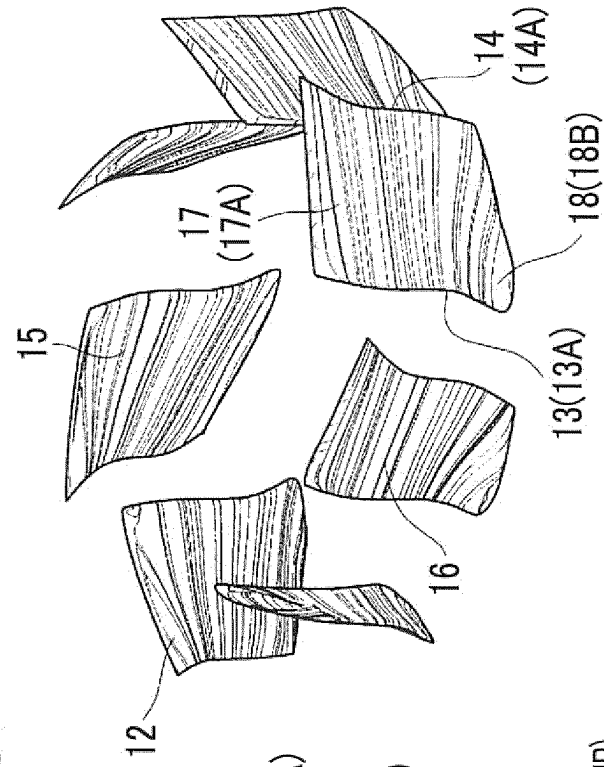


FIG. 2C No. 59 (STATIC PRESSURE CONTOUR)

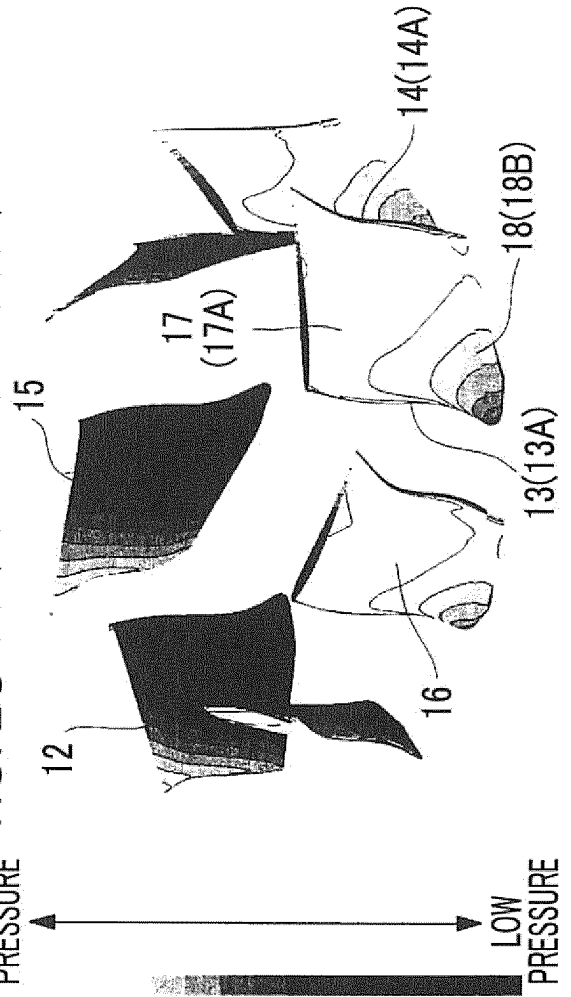


FIG. 3A No. 31 (FIRST)

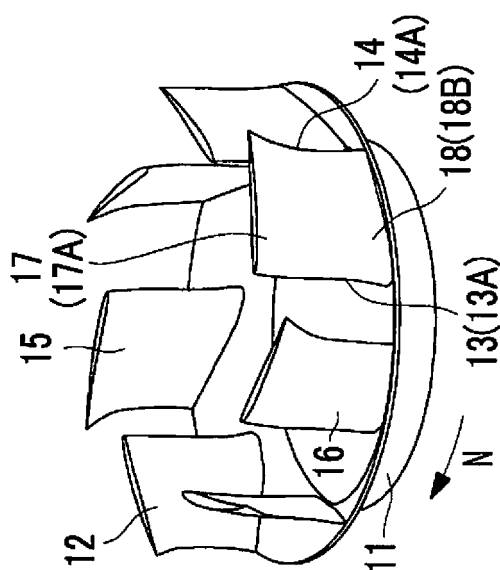


FIG. 3B No. 32 (SECOND)

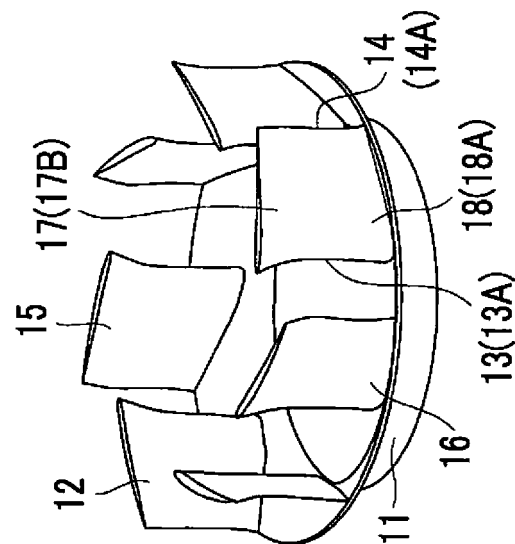


FIG. 3C No. 06 (THIRD)

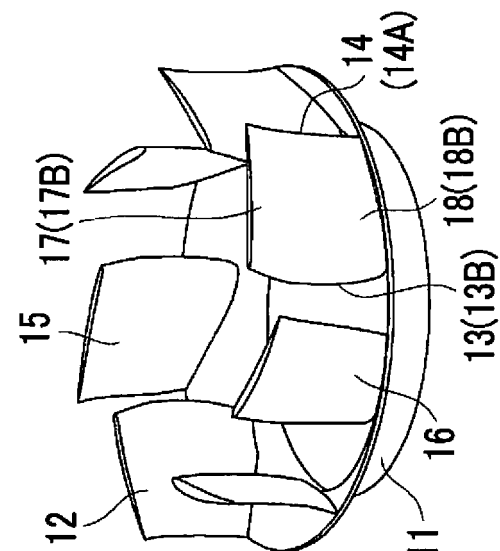


FIG. 3D ORIGINAL (No. 0)

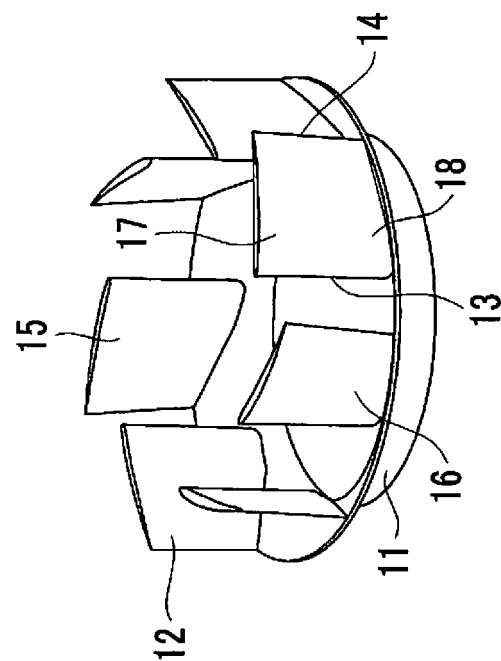


FIG. 3E No. 14 (41-ST)

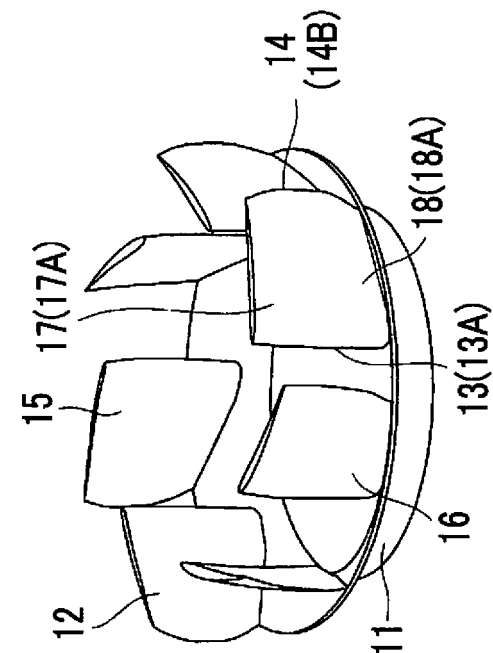


FIG. 4A No. 31 (FIRST)

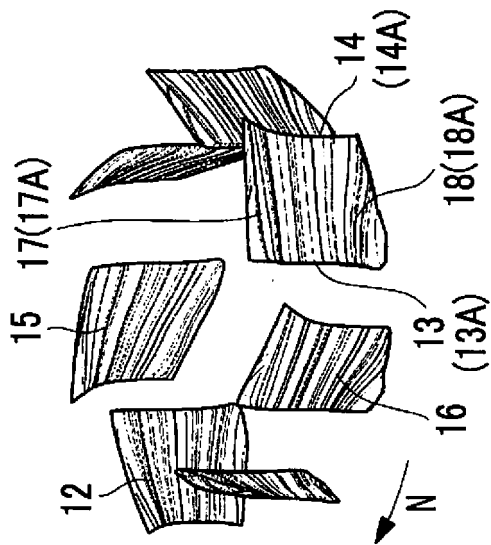


FIG. 4B No. 32 (SECOND)

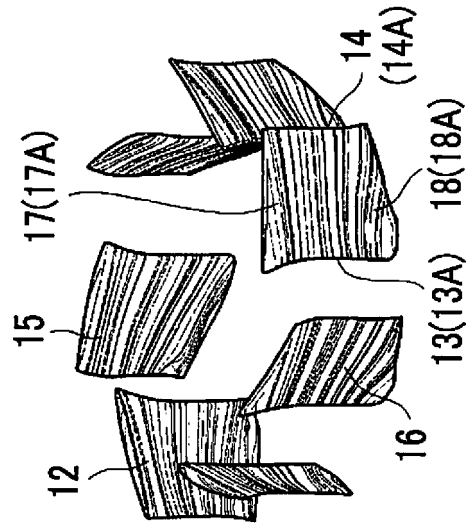


FIG. 4C No. 06 (THIRD)

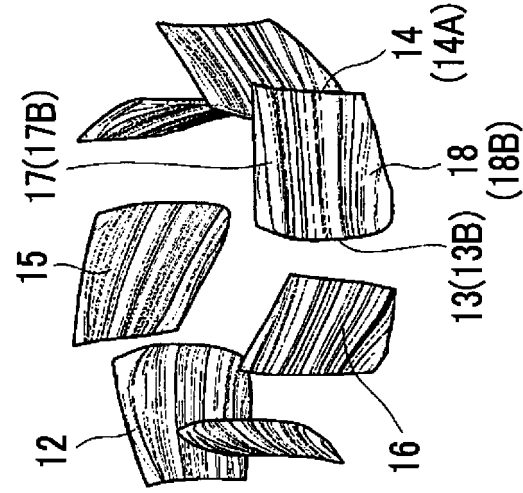


FIG. 4D ORIGINAL (No. 0)

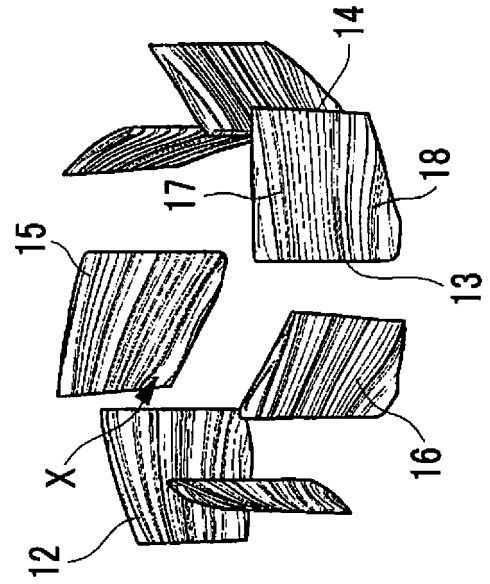


FIG. 4E No. 14 (41-ST)

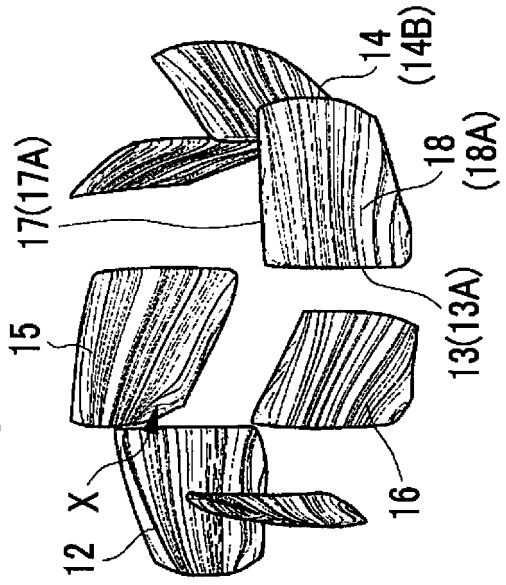


FIG. 5A No. 31 (FIRST)

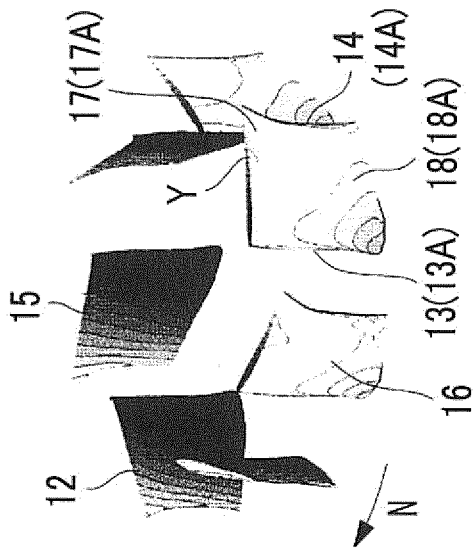


FIG. 5B No. 32 (SECOND)

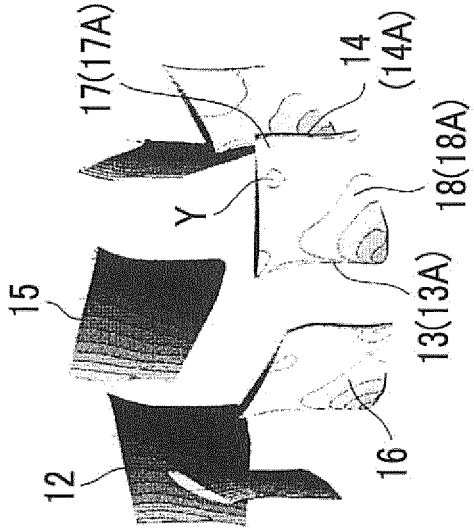


FIG. 5C No. 06 (THIRD)

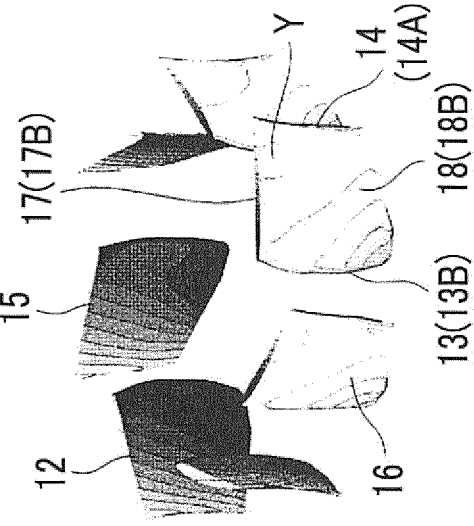


FIG. 5D ORIGINAL (No. 0)

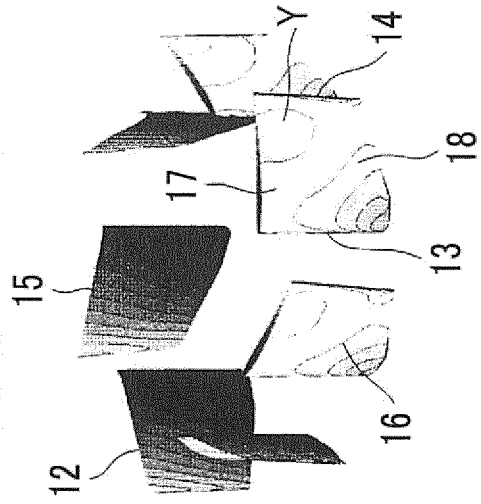


FIG. 5E No. 14 (41-ST)

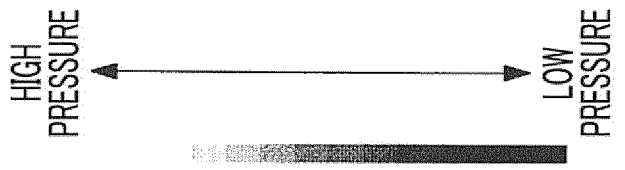
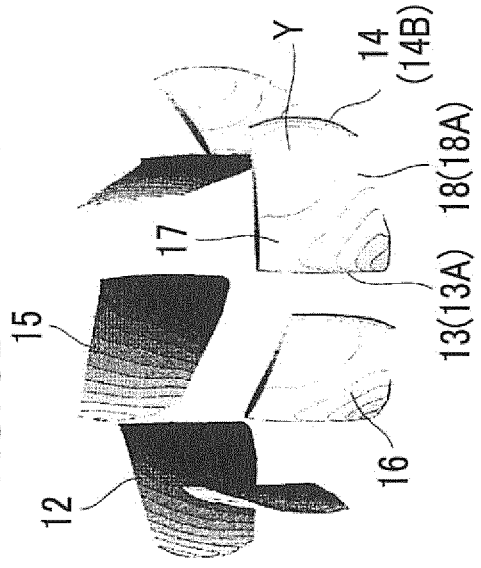


FIG. 6A ORIGINAL SHAPE

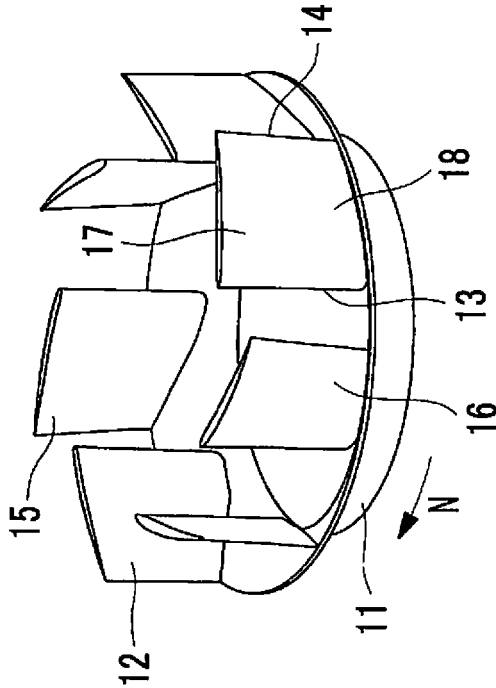


FIG. 6B RECESS

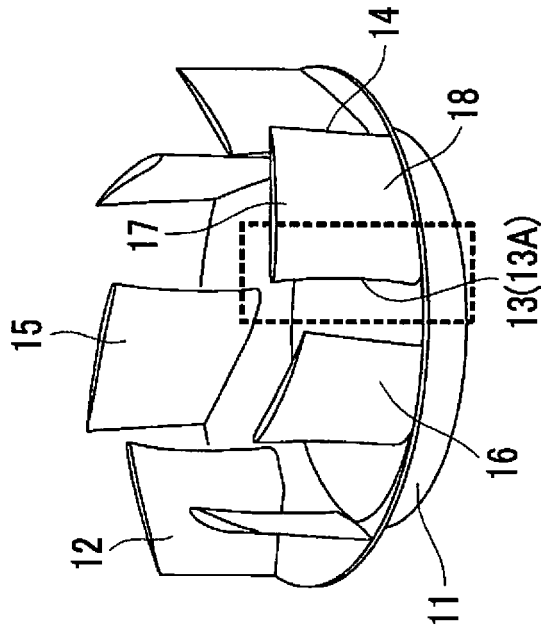


FIG. 6C PROJECTION

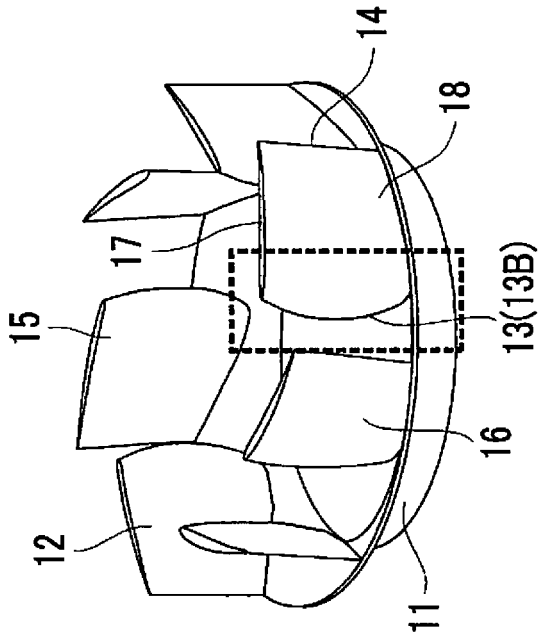


FIG. 7A ORIGINAL SHAPE

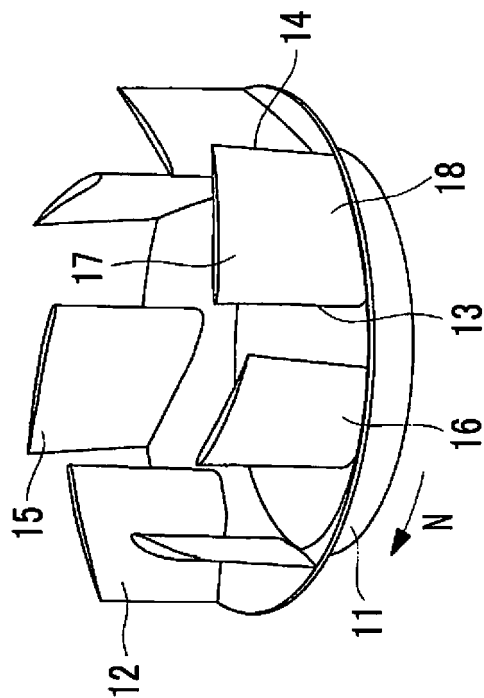


FIG. 7B RECESS

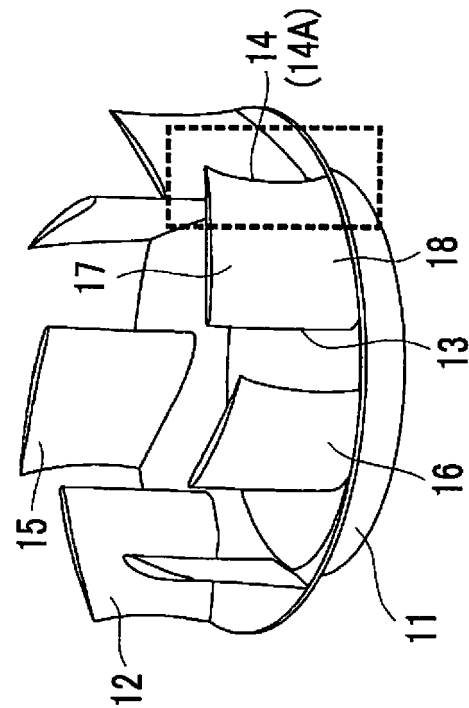


FIG. 7C PROJECTION

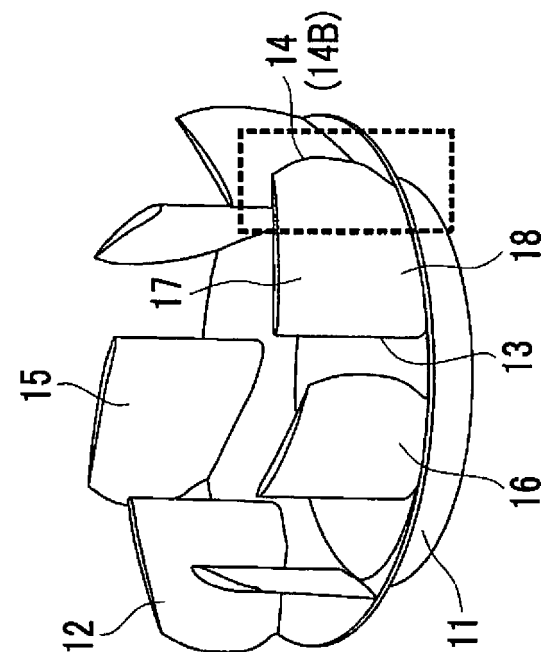


FIG. 8A ORIGINAL SHAPE

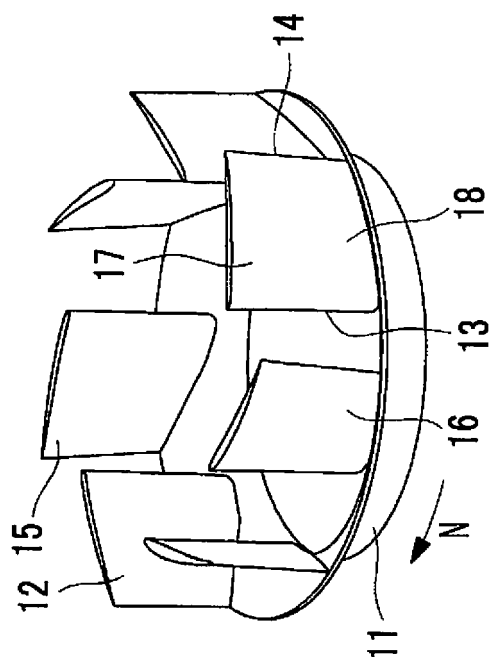


FIG. 8B CURVED IN COUNTER-ROTATION DIRECTION

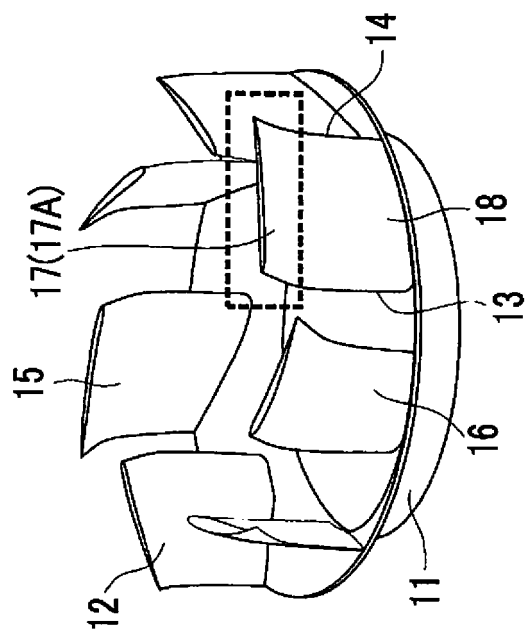


FIG. 8C CURVED IN ROTATION DIRECTION

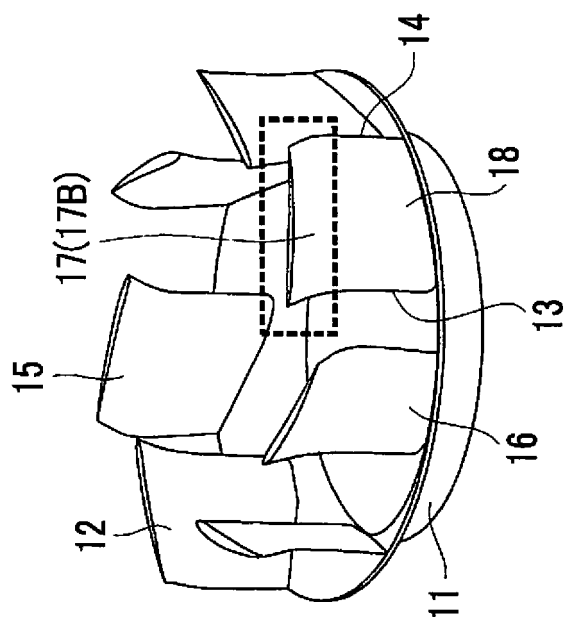


FIG. 9A ORIGINAL SHAPE

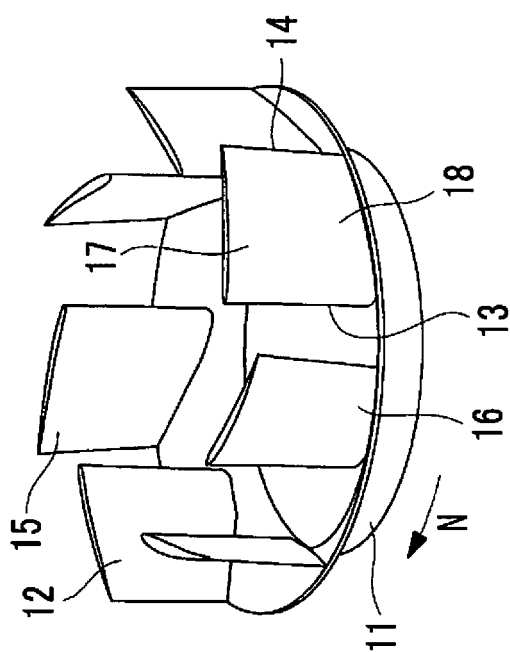


FIG. 9B CURVED IN COUNTER-ROTATION DIRECTION

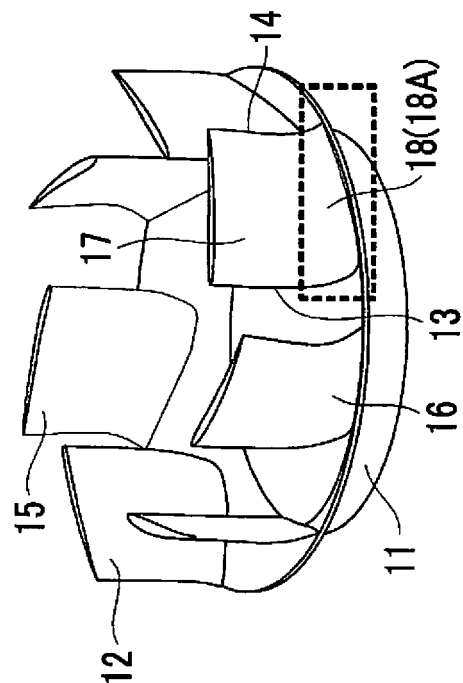


FIG. 9C CURVED IN ROTATION DIRECTION

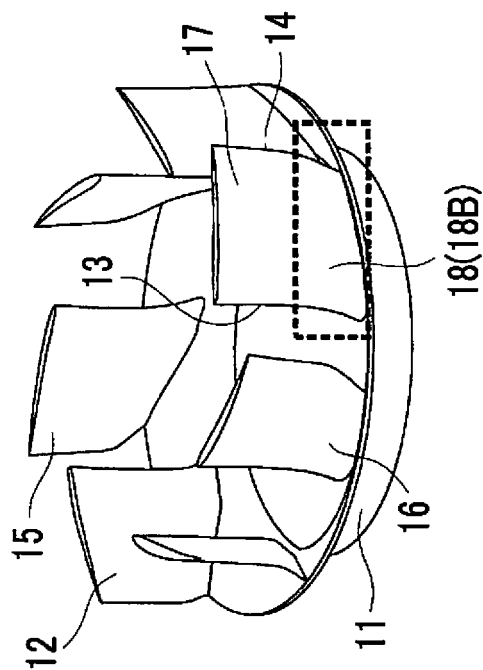


FIG. 10

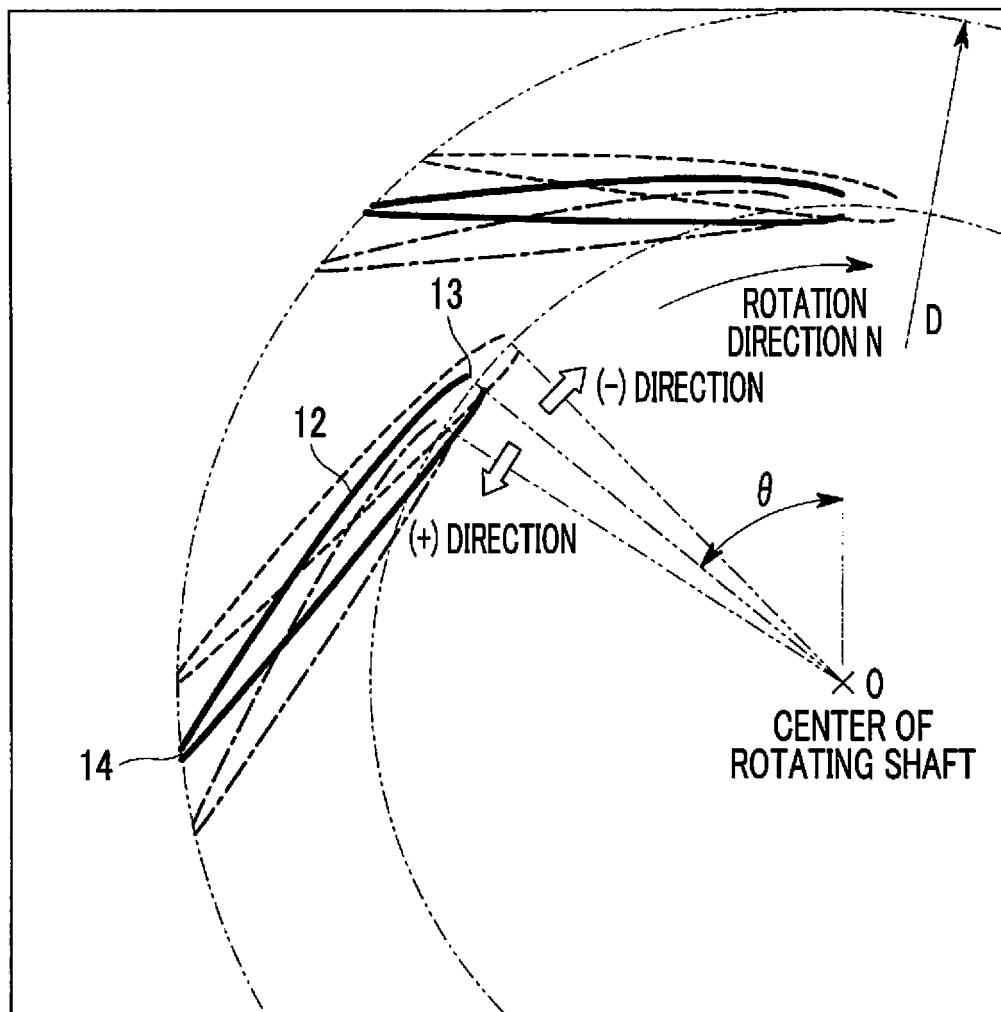


FIG. 11

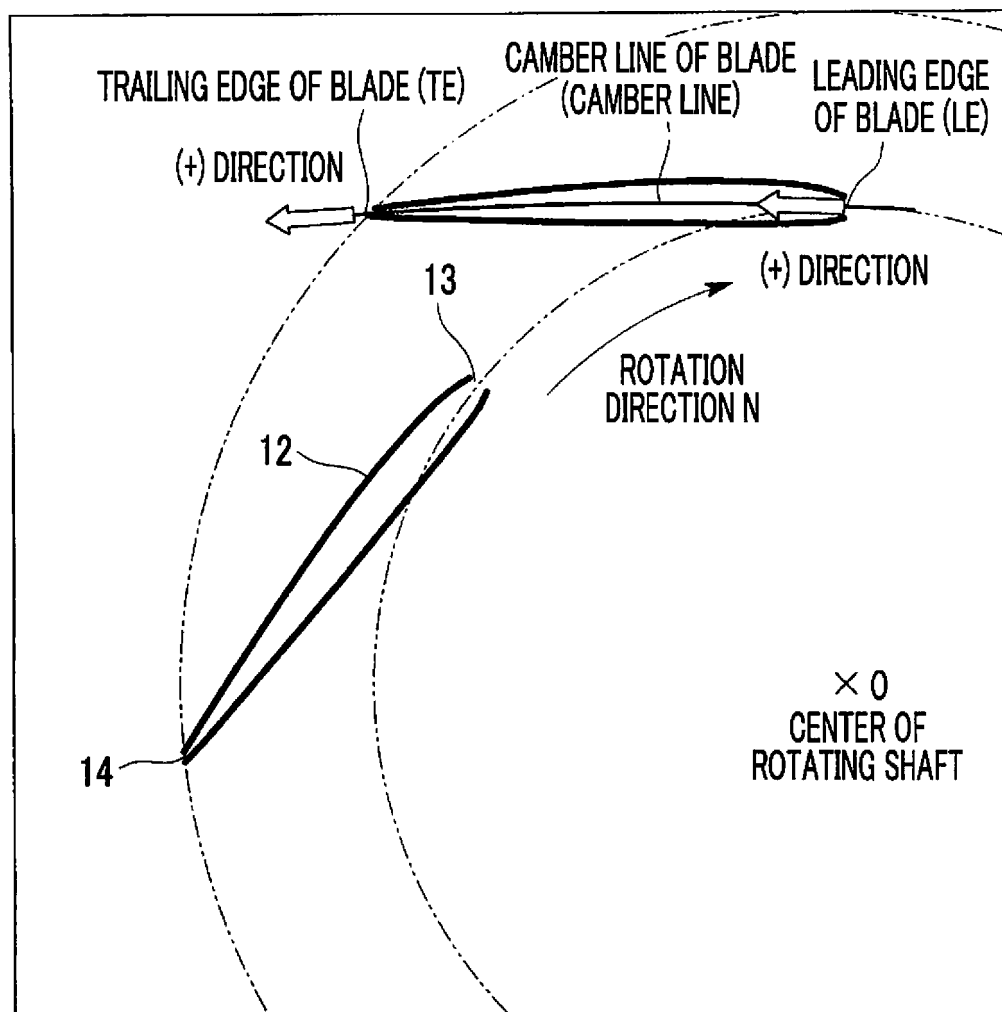


FIG. 12

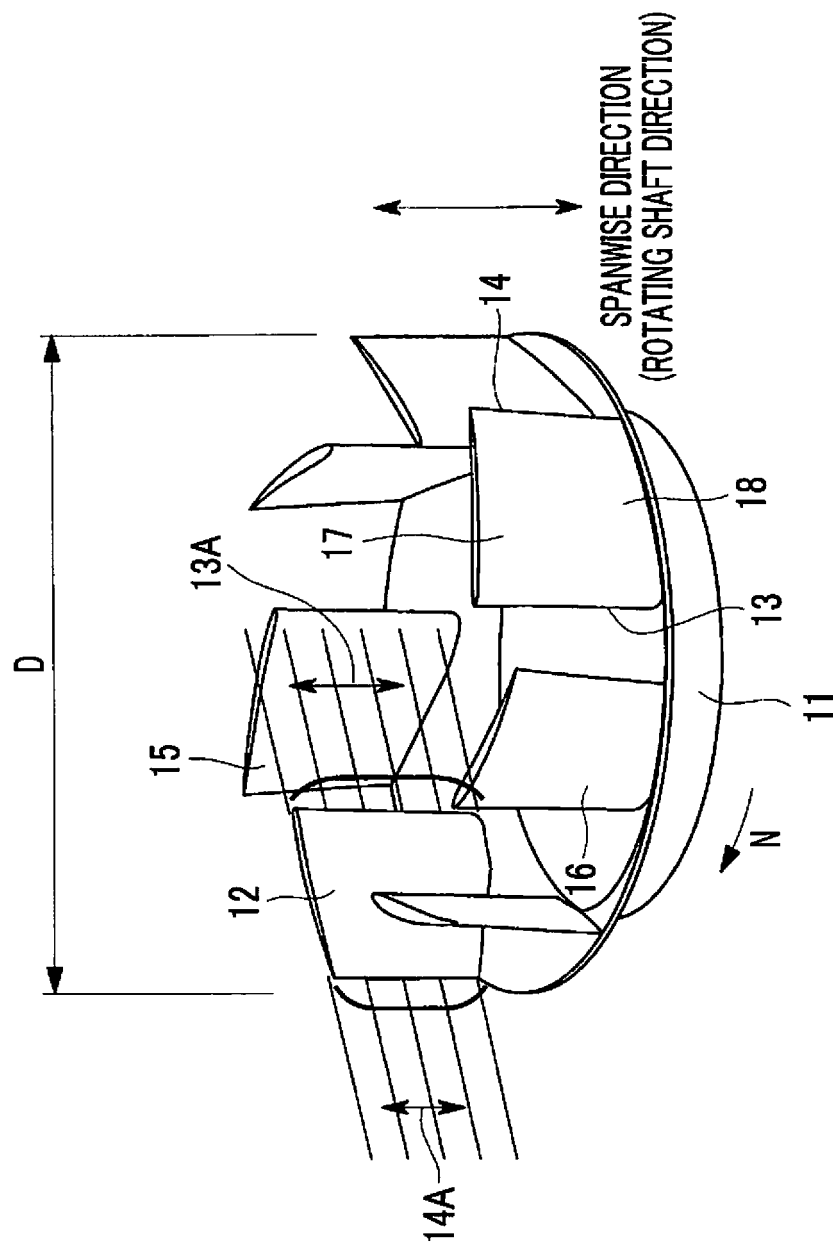


FIG. 13

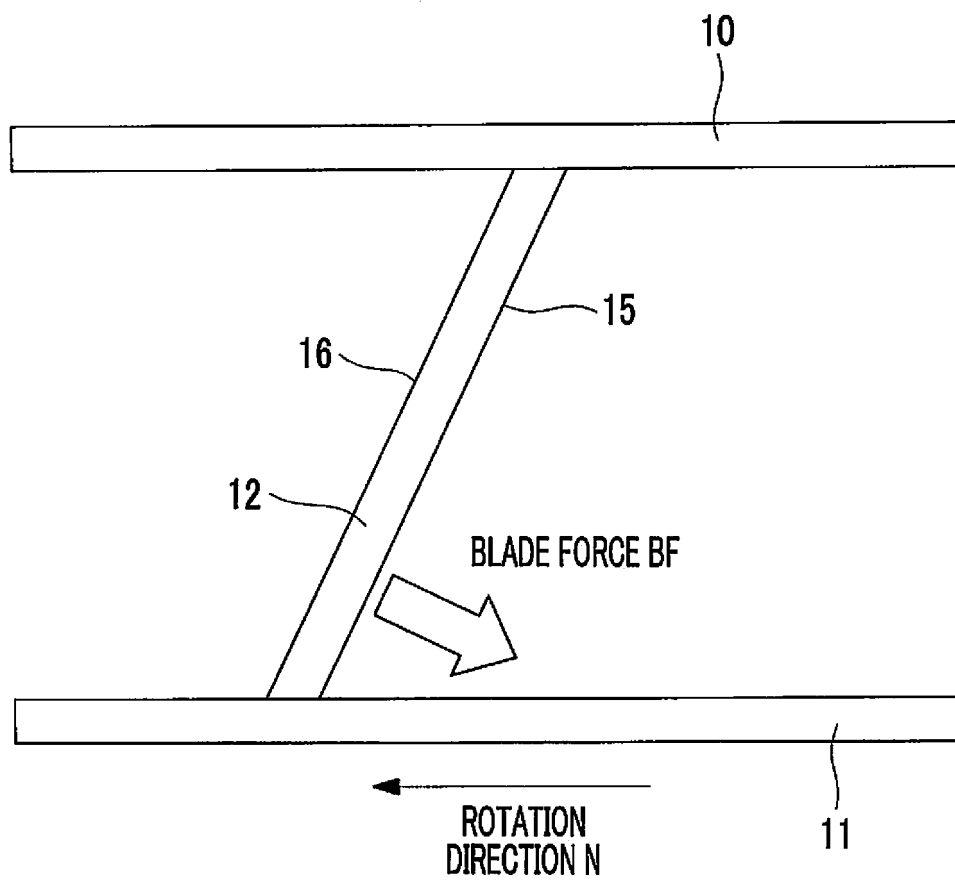


FIG. 14A DESIGN PARAMETER

NAME	MINIMUM VALUE	MAXIMUM VALUE	UNIT	REFERENCE
(1) pull-LE	-0.04376	0.01532	LENGTH BECOMES NON-DIMENSIONAL IN OUTER DIAMETER OF FAN	MOVE LEADING EDGE (25% TO 75% OF HEIGHT OF BLADE) IN CODE DIRECTION (OUTER DIAMETER DIRECTION IS +)
(2) pull-TE	-0.01532	0.04376	LENGTH BECOMES NON-DIMENSIONAL IN OUTER DIAMETER OF FAN	MOVE TRAILING EDGE (25% TO 75% OF HEIGHT OF BLADE) IN CODE DIRECTION (OUTER DIAMETER DIRECTION IS +)
(3) rota-hub	-0.09722	0.09722	ANGLE BECOMES NON-DIMENSIONAL AT ANGLE OF ONE PITCH OF BLADE	RANGE OF CURVE AND ROTATING HUB SIDE BLADE ROOT (JOINING PART) AROUND ROTATING SHAFT (COUNTERCLOCKWISE DIRECTION IS + WHEN VIEWED FROM HUB SIDE) IS 25% OF BLADE HEIGHT FROM HUB SIDE
(4) rota-shroud	-0.09722	0.09722	ANGLE BECOMES NON-DIMENSIONAL AT ANGLE OF ONE PITCH OF BLADE	RANGE OF CURVE AND ROTATING SHROUD SIDE BLADE ROOT (JOINING PART) AROUND ROTATING SHAFT (COUNTERCLOCKWISE DIRECTION IS + WHEN VIEWED FROM HUB SIDE) IS 25% OF BLADE HEIGHT FROM SHROUD SIDE

FIG. 14B OBJECTIVE FUNCTION

NAME	CONTENTS
D'	(AIR AMOUNT MATCHING INPUT OF EACH OF FAN SHAPES OF PARAMETER STUDY)/(FAN INPUT OF ORIGINAL SHAPE)

FIG. 15

	No.	pull-LE	pull-TE	rota-hub	rota-shroud
MOST APPROPRIATE	59	0.0153	-0.0153	0.0972	-0.0972
CASE	31	0.0153	-0.0153	0.0563	-0.0154
FIRST	32	0.0091	-0.0142	-0.0768	0.0031
SECOND	6	-0.0438	-0.0153	-0.0154	-0.0461
THIRD	0	0.0000	0.0000	0.0000	0.0000
ORIGINAL	14	0.0153	0.0438	0.0563	0.0358
41-ST					

FIG. 16

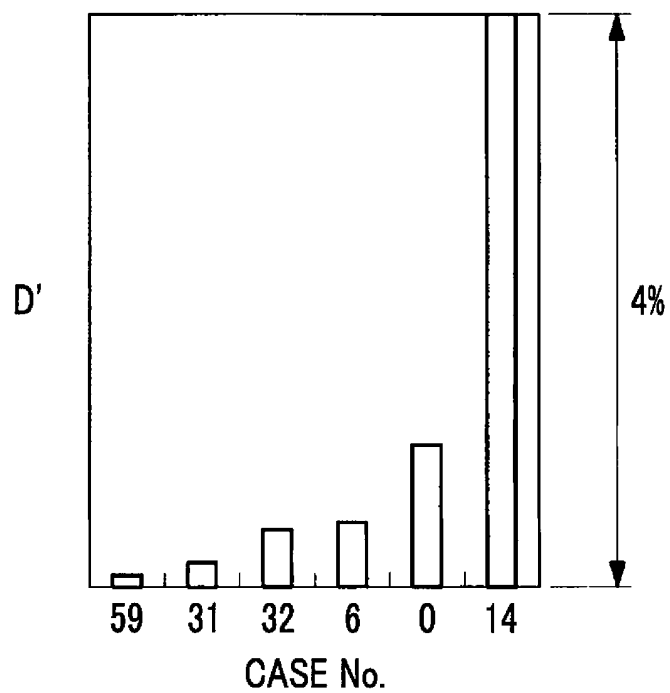


FIG. 17

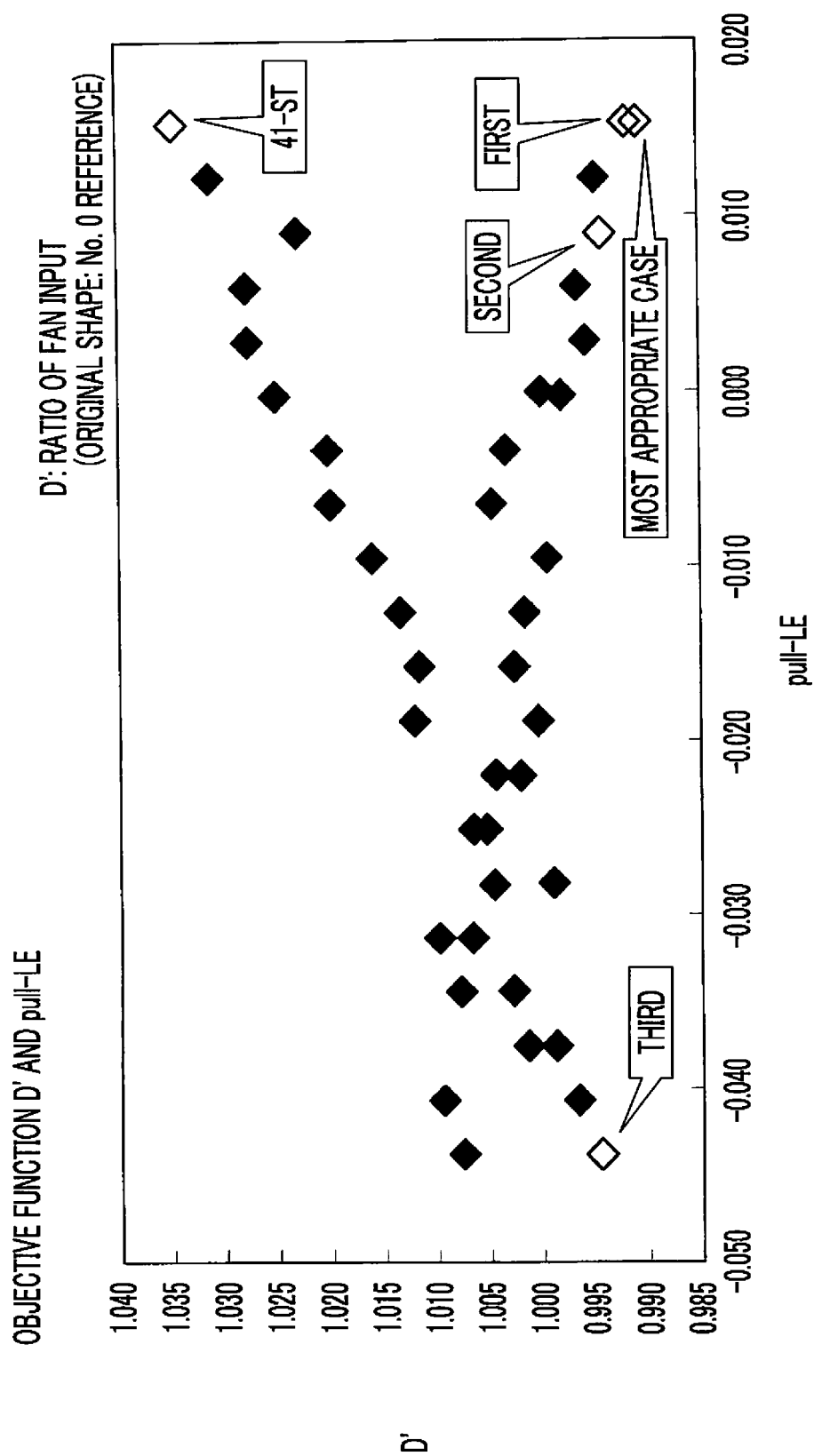


FIG. 18

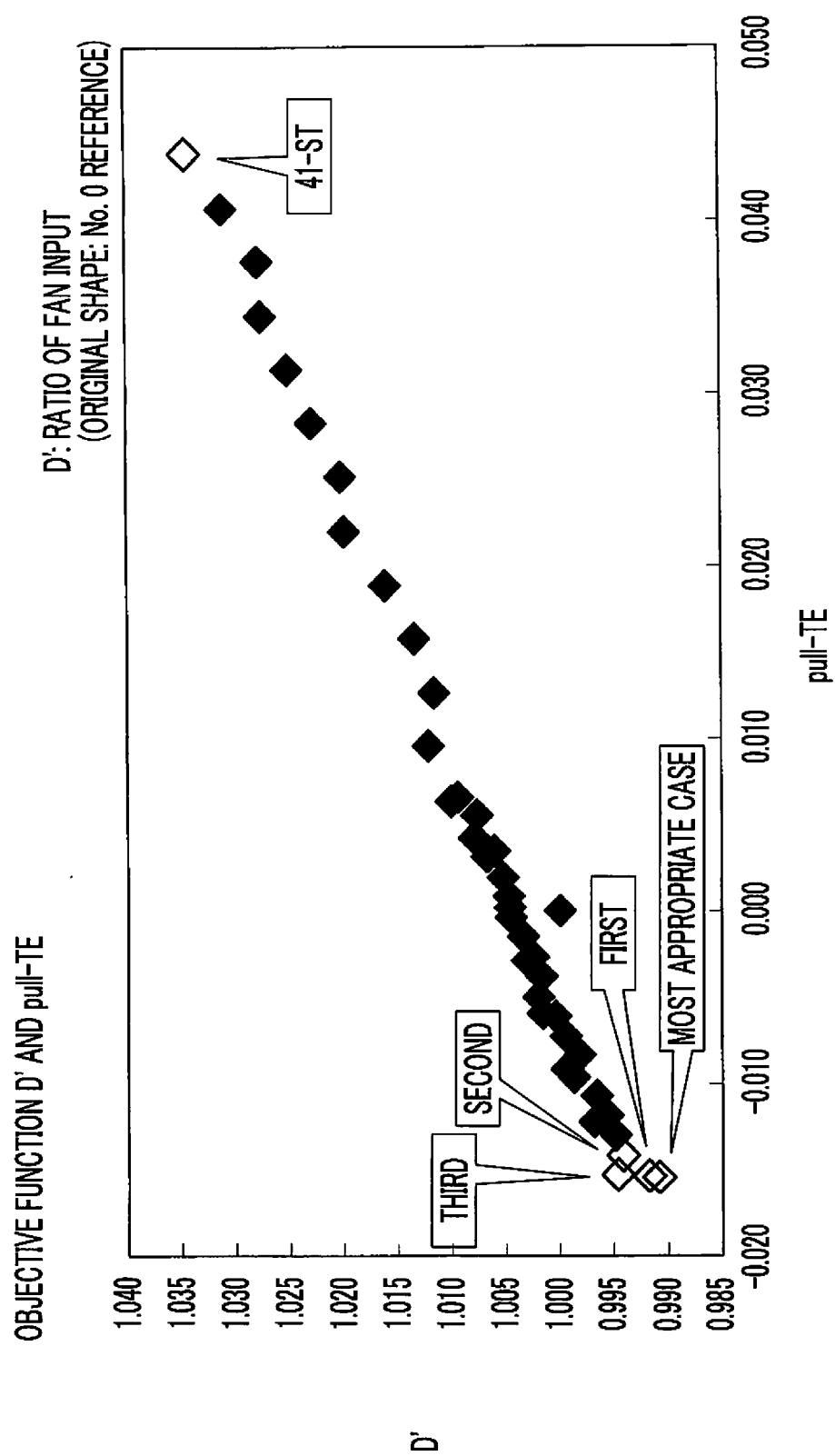


FIG. 19

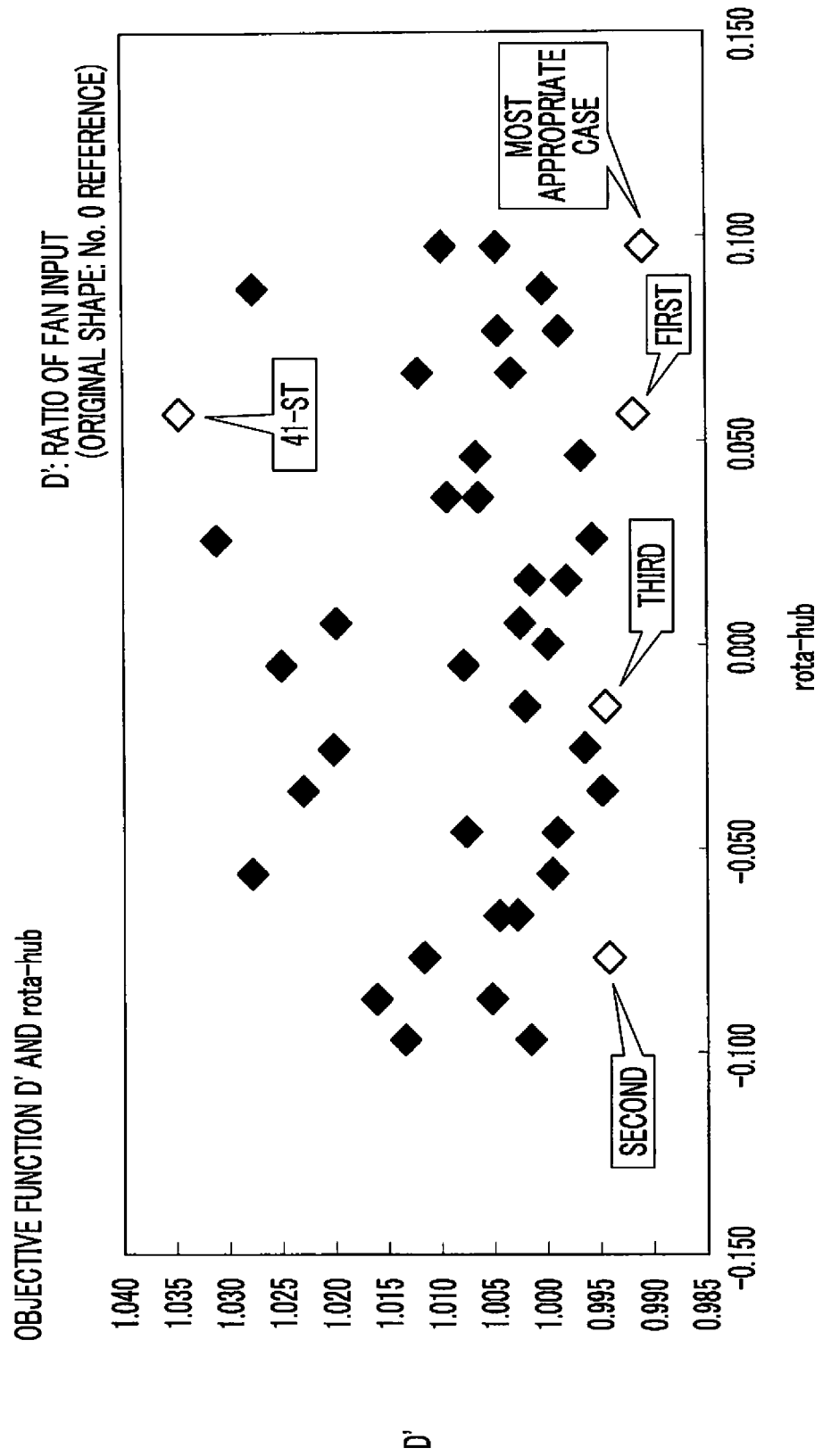
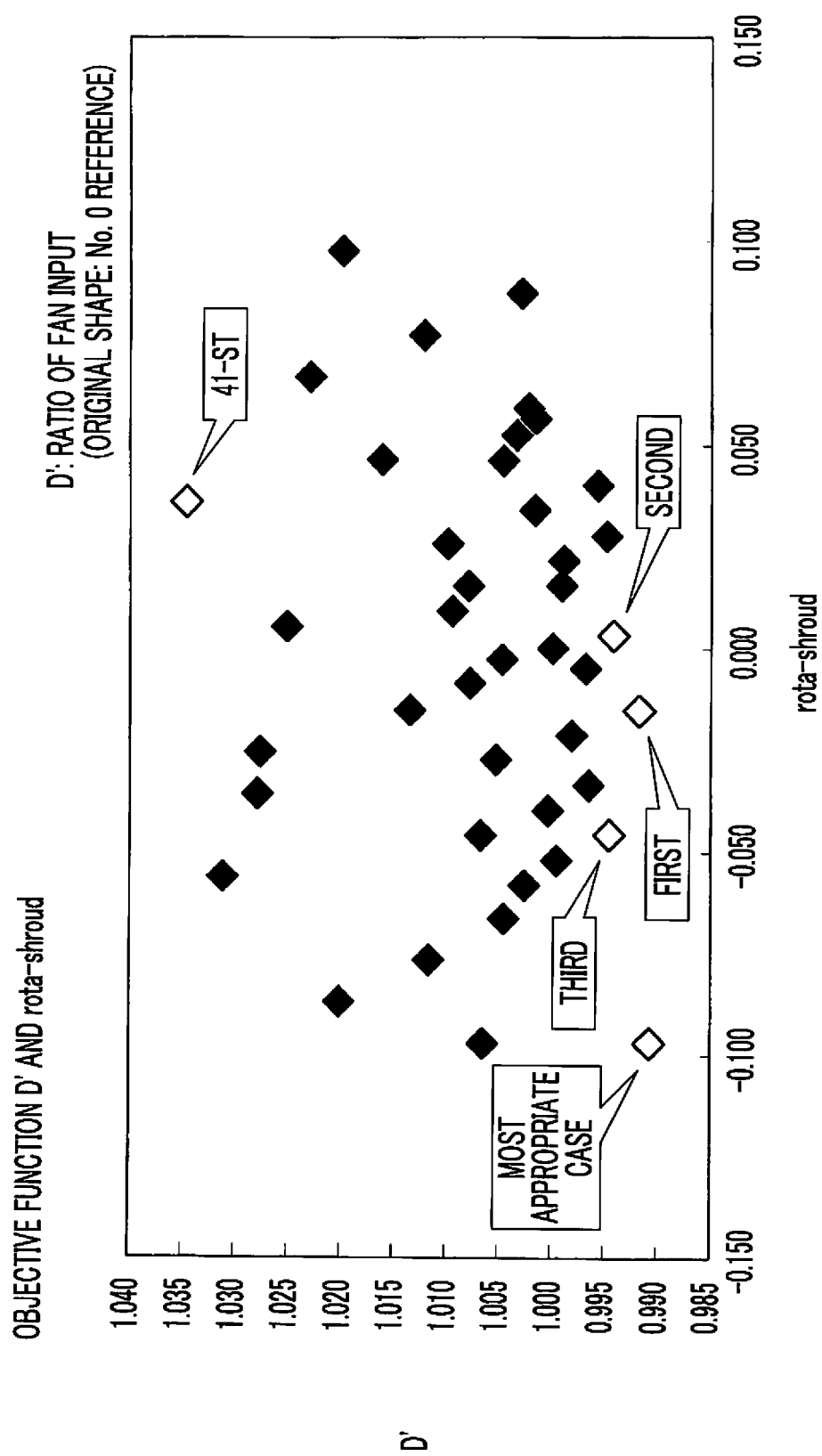


FIG. 20



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2016/076156

A. CLASSIFICATION OF SUBJECT MATTER

F04D29/30(2006.01)i, F04D29/28(2006.01)i, F04D29/66(2006.01)i, F24F1/00(2011.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

F04D29/30, F04D29/28, F04D29/66, F24F1/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho 1922-1996 Jitsuyo Shinan Toroku Koho 1996-2016

Kokai Jitsuyo Shinan Koho 1971-2016 Toroku Jitsuyo Shinan Koho 1994-2016

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	JP 2013-96378 A (Daikin Industries, Ltd.), 20 May 2013 (20.05.2013), claims 1, 5 to 6; paragraphs [0023] to [0054]; fig. 1 to 9 (Family: none)	1-3, 13 4-12
X Y	JP 2011-226448 A (Toshiba Carrier Corp.), 10 November 2011 (10.11.2011), claims 1 to 2, 4; paragraphs [0009] to [0027]; fig. 1 to 7 (Family: none)	1-3, 13 4-12

☒ Further documents are listed in the continuation of Box C.

☐ See patent family annex.

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Date of the actual completion of the international search
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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 2014/061642 A1 (Mitsubishi Electric Corp.), 24 April 2014 (24.04.2014), paragraphs [0020] to [0035]; fig. 1 to 4 & US 2015/0226227 A1 paragraphs [0030] to [0045]; fig. 1 to 4 & EP 2910793 A1 & CN 104736854 A	4-6, 9-12
Y	JP 2008-144667 A (Daikin Industries, Ltd.), 26 June 2008 (26.06.2008), paragraphs [0026] to [0034]; fig. 1 to 3 (Family: none)	4-6, 9-12
Y	WO 2009/069606 A1 (Daikin Industries, Ltd.), 04 June 2009 (04.06.2009), paragraphs [0039] to [0044]; fig. 6 to 11 & JP 2009-150380 A & JP 2009-174541 A & US 2010/0202886 A1 0075 to 0080; fig. 6 to 11 & EP 2213882 A1 & CN 101821513 A & KR 10-2010-0066561 A	7-12
A	WO 2009/128299 A1 (Mitsubishi Electric Corp.), 22 October 2009 (22.10.2009), entire text; all drawings & JP 2013-117233 A & EP 2264320 A1 & CN 101960150 A & AU 2009237152 A	1-13
A	JP 2013-124575 A (Mitsubishi Electric Corp.), 24 June 2013 (24.06.2013), entire text; all drawings (Family: none)	1-13

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REFERENCES CITED IN THE DESCRIPTION

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