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Sonoda et al.

(54) **INNER PERIPHERAL SURFACE SHAPE OF CASING OF AXIAL-FLOW COMPRESSOR**

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(52) **U.S. Cl.** **415/210.1**

(57) **ABSTRACT**

A generating line of a casing surrounding an outer periphery of vanes of a stator disposed downstream of a rotor of the axial-flow compressor includes: a recessed region recessed outward in a radial direction from a position forward of a front edge of each of the vanes to a position rearward of a rear edge of the vane; and a protruding region bulging inward in the radial direction at an intermediate position of the recessed region in a front-rear direction thereof. Thus, a distribution of static pressure in the radial direction on a surface of the vane is improved by a first recessed portion forward of the protruding region, and the static pressure on the tip side is raised by a second recessed portion rearward of the protruding region.

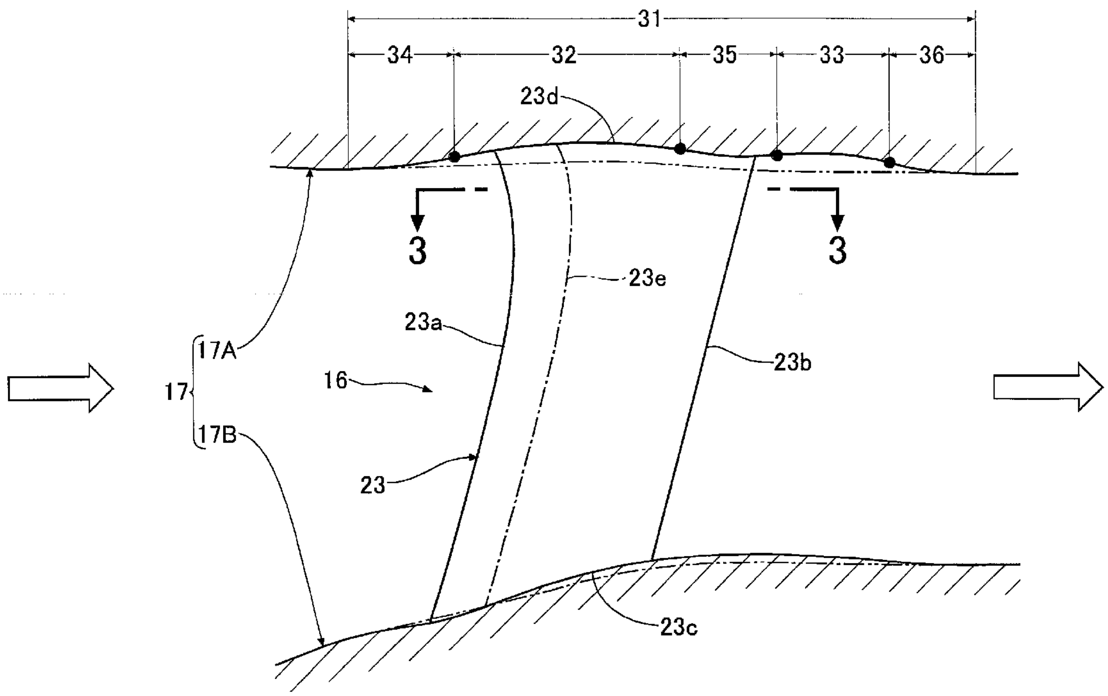


FIG.1

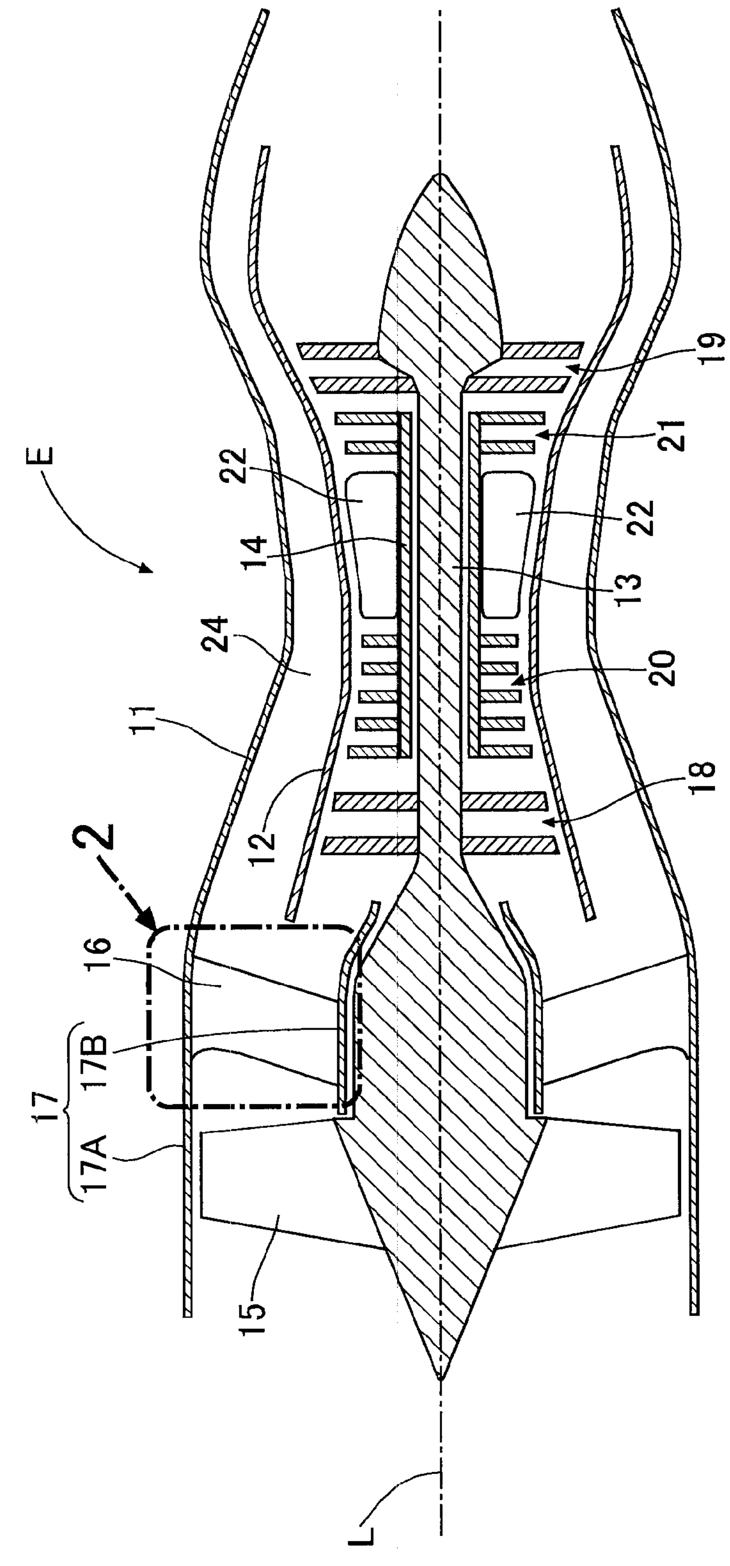


FIG.2

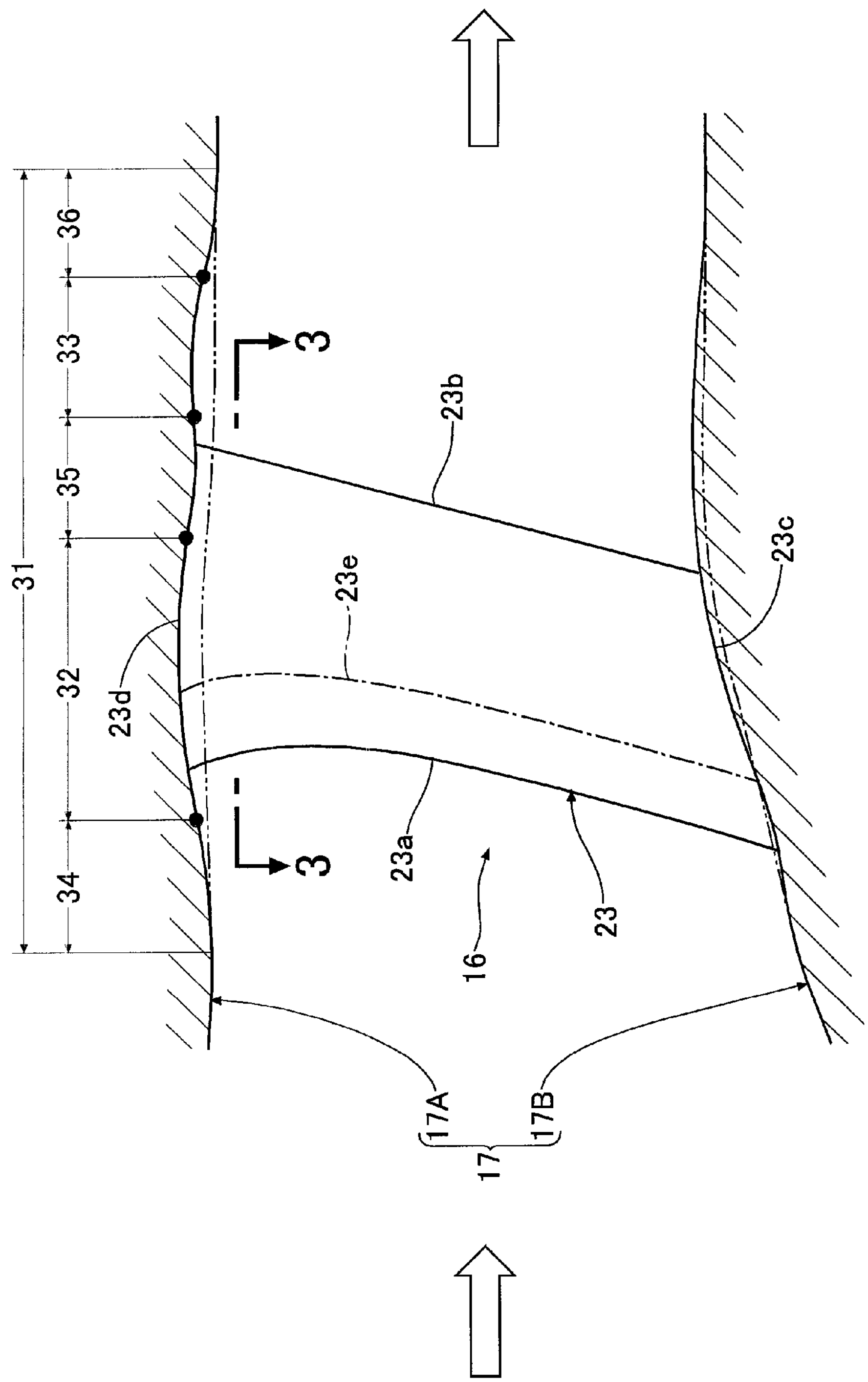


FIG.3A
EMBODIMENT

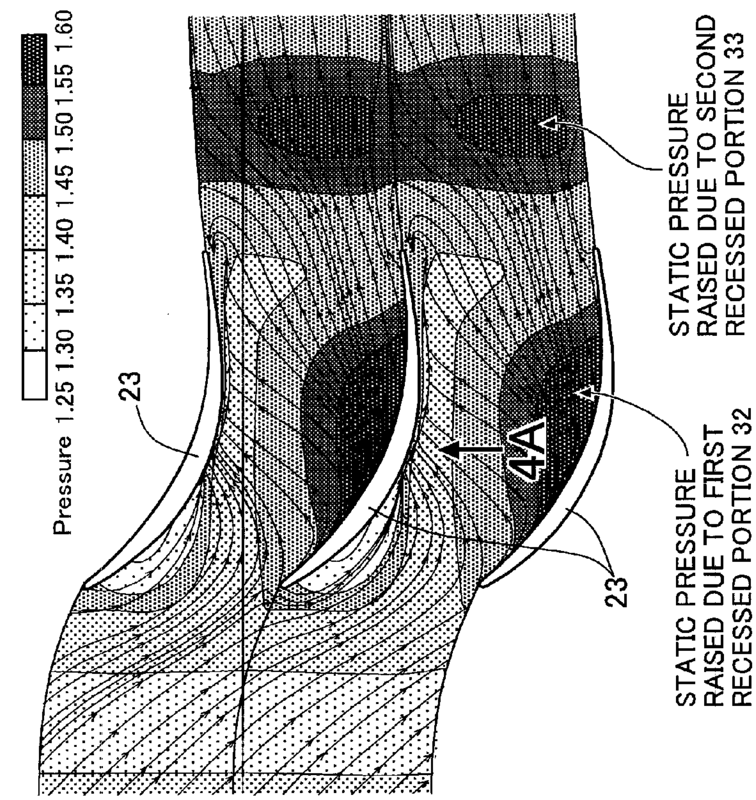


FIG.3B
COMPARATIVE EXAMPLE

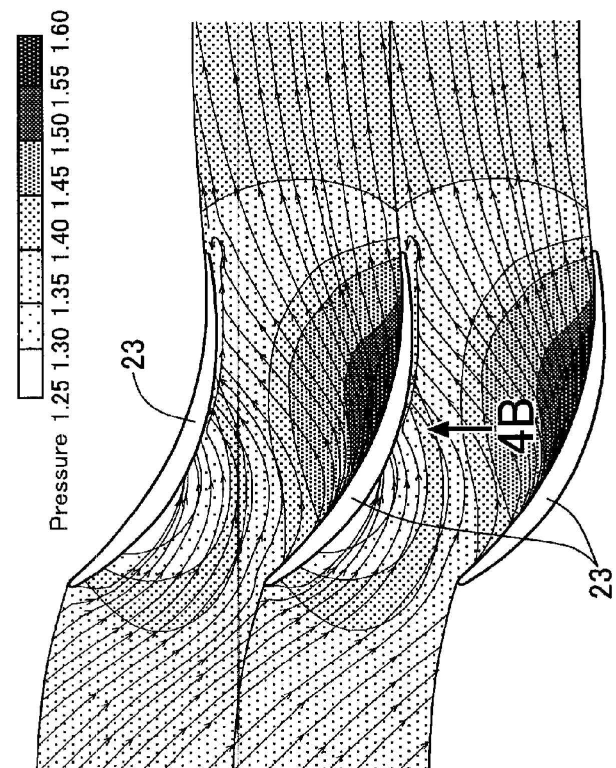


FIG.4A

EMBODIMENT
(SUCTION SURFACE)

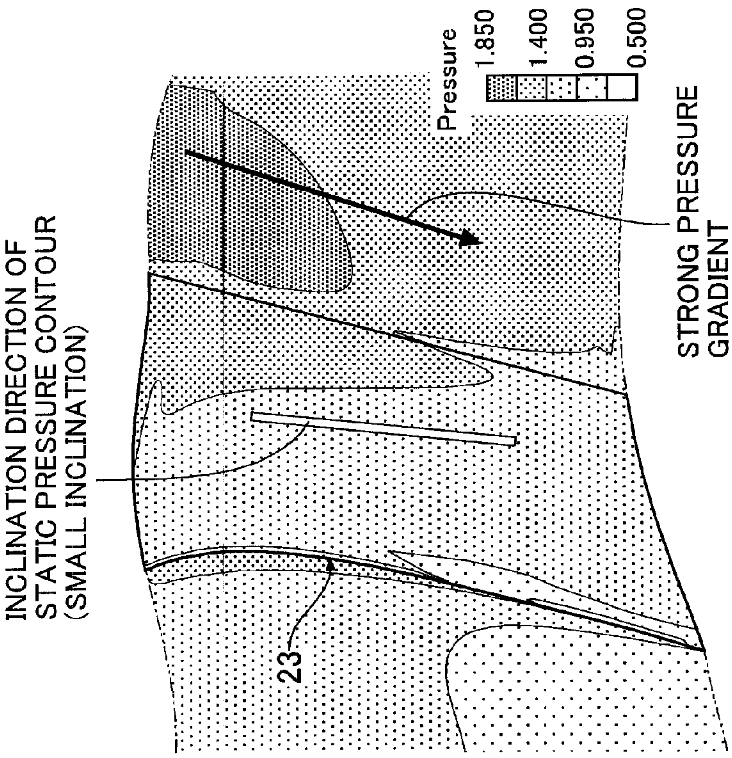


FIG.4B

COMPARATIVE EXAMPLE
(SUCTION SURFACE)

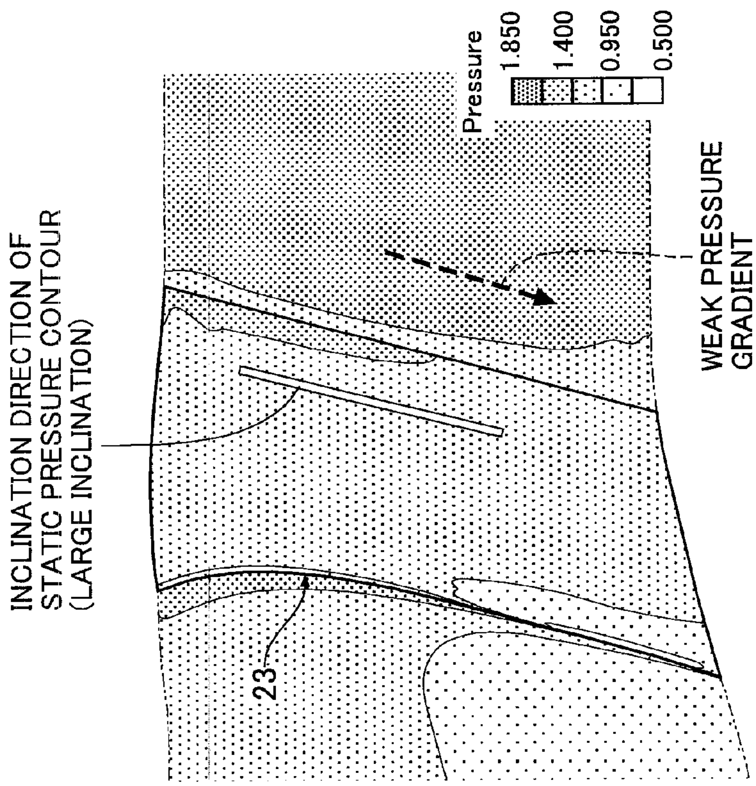


FIG.5A
EMBODIMENT
(SUCTION SURFACE)

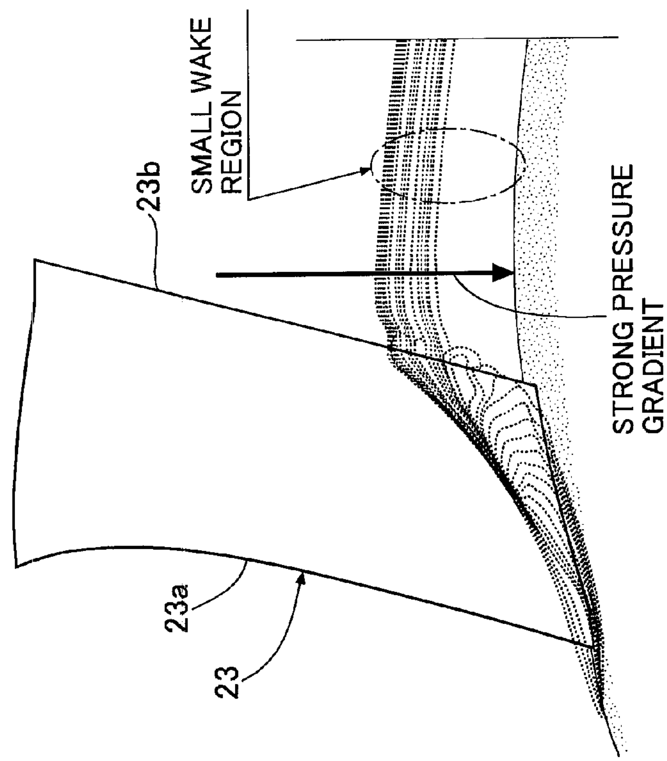


FIG.5B
COMPARATIVE EXAMPLE
(SUCTION SURFACE)

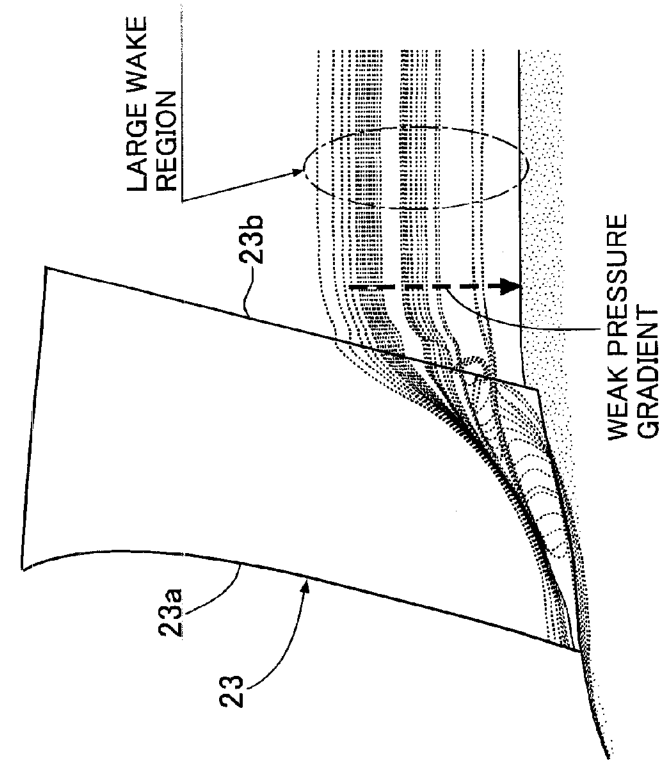


FIG.6A
EMBODIMENT

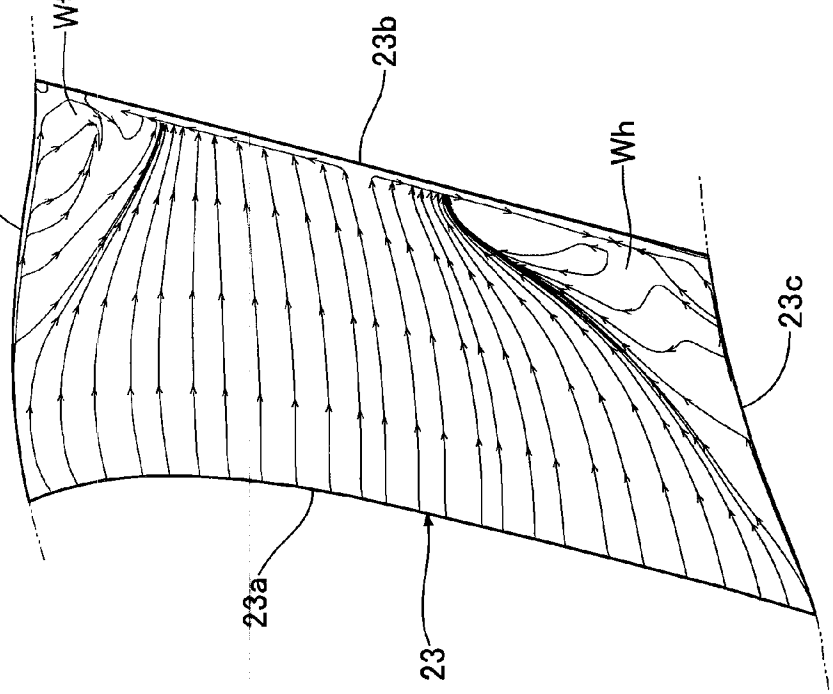


FIG.6B
COMPARATIVE EXAMPLE

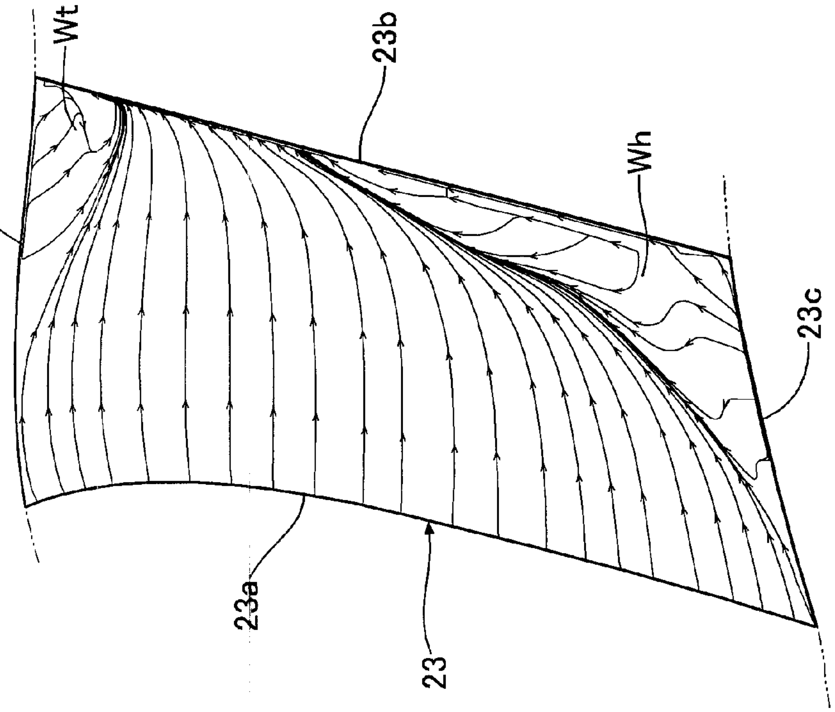
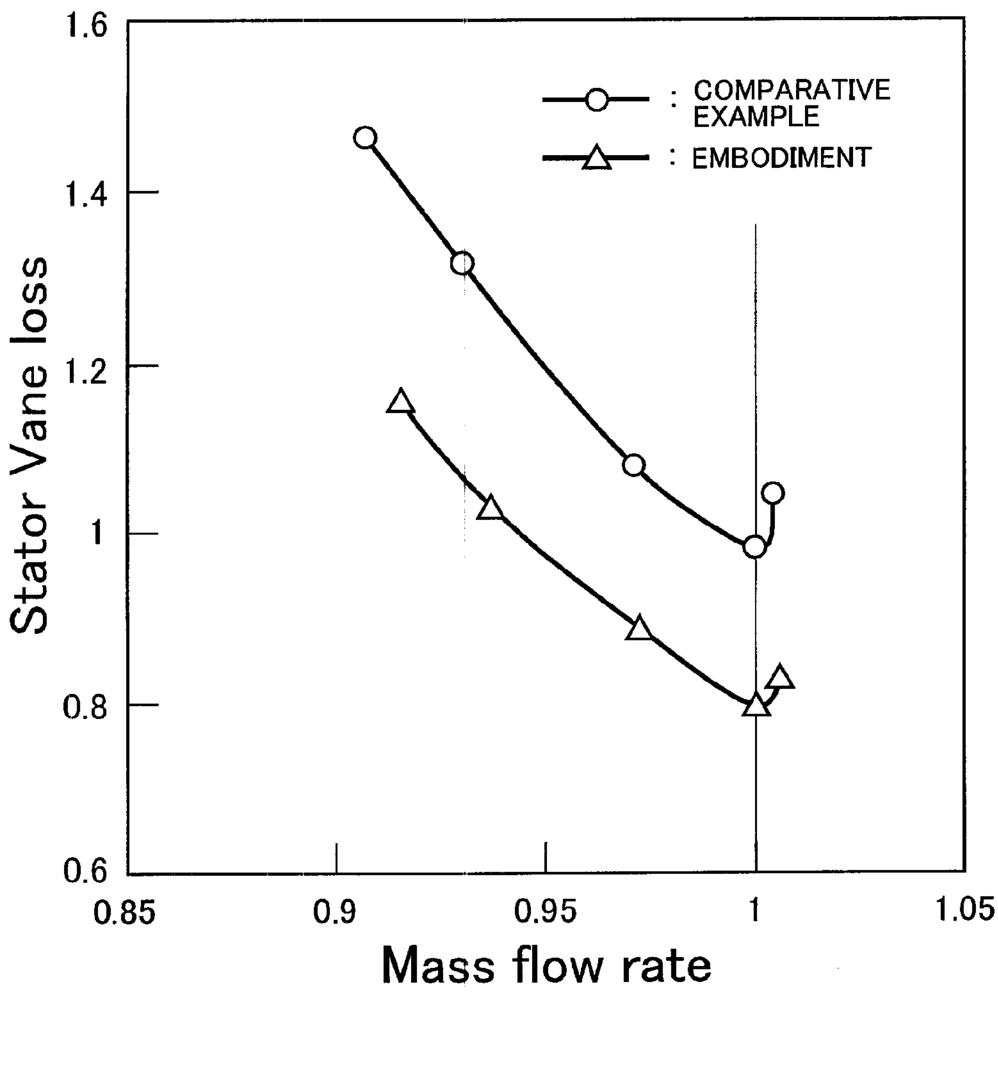
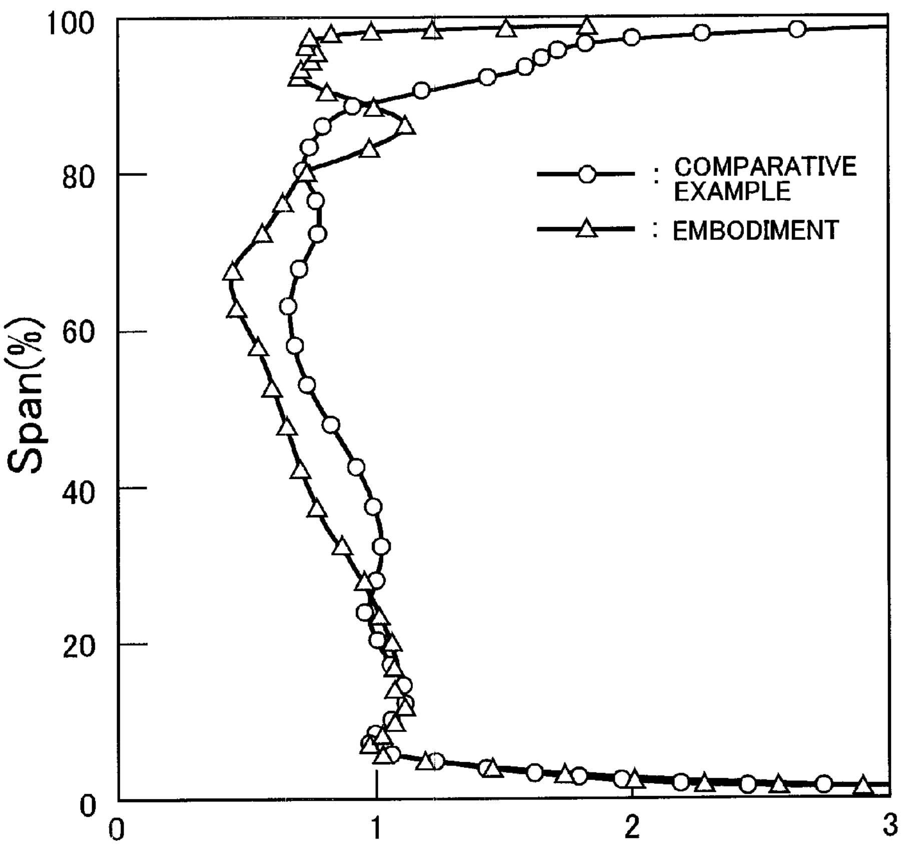


FIG.7



1.6
1.4
1.2
1
0.8
0.6
Stator Vane loss
0.85
0.9
0.95
1
1.05
Mass flow rate
: COMPARATIVE EXAMPLE
: EMBODIMENT

FIG.8


100
80
60
40
20
0
Span(%)
0
1
2
3
Stator Vane loss
: COMPARATIVE EXAMPLE
: EMBODIMENT

INNER PERIPHERAL SURFACE SHAPE OF CASING OF AXIAL-FLOW COMPRESSOR

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] The present invention relates to an inner peripheral surface shape of a casing of an axial-flow compressor, the casing surrounding an outer periphery of vanes of a stator which are disposed in a radial arrangement and downstream of a rotor of the axial-flow compressor.

[0003] 2. Description of the Related Art

[0004] An inner peripheral surface (a peripheral surface on a tip side) of a fan casing surrounding an outer periphery of a fan stator of a turbofan engine is formed to have a substantially cylindrical shape having the center at the position of a shaft. In many cases, the shape of a generating line thereof (a line at which a plane passing the shaft crosses the inner peripheral surface of the fan casing) is a straight line. In addition, in some cases, stator vanes of the fan stator of the turbofan engine extend from a hub side to a tip side while being swept rearward (inclining rearward) so as to reduce shock-wave loss and reduce noises.

[0005] Japanese Patent Application Laid-open No. 2008-274926 describes a fan casing surrounding an outer periphery of inlet guide vanes (stator vanes) of a turbine. The fan casing has an inner peripheral surface a generating line of which is in a shape including outer peripheral protruding portions Cv2, Cv4 protruding inward in a radial direction on the upstream side and outer peripheral recessed portions Cc2, Cc4 recessed outward in the radial direction on the downstream side. With this shape, a secondary flow flowing inward in the radial direction, i.e., from the tip side to the hub side, can thus be suppressed to reduce pressure loss.

[0006] In addition, Japanese Patent Application Laid-open No. 7-247996 describes a casing surrounding an outer periphery of stator vanes of a compressor of a gas turbine engine. The casing has an inner peripheral surface a generating line of which is in a shape including a recessed portion **18** recessed outward in a radial direction. With this shape, the flow rate on the back surface side (on the suction surface side) of the stator vanes is reduced to prevent separation, and thus pressure loss is reduced.

[0007] Meanwhile, in the case of stator vanes of a fan stator each being swept rearward from the hub side to the tip side, particularly, a low-momentum fluid migration flowing from the hub side to the tip side along the surfaces of the stator vanes is accelerated, so that the pressure loss is increased. This acceleration is caused by the phenomena that the static pressure gradient in a peripheral direction, i.e., from the pressure surface side to the suction surface side of the stator vane near an end wall at the hub side increases at the rear part of the cascade, and that a static pressure contour extending from the hub side to the tip side on the suction surface of each stator vane is inclined against a mainstream.

SUMMARY OF THE INVENTION

[0008] The present invention has been made in view of the aforementioned circumstances. An object of the invention is to suppress a low-momentum fluid migration flowing from a hub side to a tip side of stator vanes of an axial-flow compressor and thus to reduce the pressure loss.

[0009] In order to achieve the object, according to a first feature of the present invention, there is provided an inner peripheral surface shape of a casing of an axial-flow compressor, the casing surrounding an outer periphery of vanes of a stator which are disposed in a radial arrangement and rearwardly of a rotor of the axial-flow compressor, wherein a generating line of the casing comprises a recessed region and a protruding region, the recessed region being recessed outward in a radial direction from a position frontwardly of a front edge of each of the vanes to a position rearwardly of a rear edge of the vane, the protruding region bulging inward in the radial direction at an intermediate position of the recessed region in a front-rear direction.

[0010] According to a second feature of the present invention, in addition to the first feature, there is provided the inner peripheral surface shape of a casing of an axial-flow compressor, wherein the recessed region comprises a first recessed portion on a front side, a second recessed portion on a rear side, a first protruding portion continuous to a front portion of the first recessed portion, a second protruding portion forming said protruding region, and a third protruding portion continuous to a rear portion of the second recessed portion.

[0011] According to a third feature of the present invention, in addition to the second feature, there is provided the inner peripheral surface shape of a casing of an axial-flow compressor, wherein the first protruding portion, the first recessed portion, the second protruding portion, the second recessed portion, and the third protruding portion are smoothly continuous to each other.

[0012] According to a fourth feature of the present invention, in addition to any one of the first to third features, there is provided the inner peripheral surface shape of a casing of an axial-flow compressor, wherein each of the vanes is swept so that a tip-side end portion thereof is positioned rearwardly of a hub-side end portion thereof.

[0013] According to the above features, the generating line of the casing surrounding the outer periphery of the vane of the stator disposed rearwardly of the rotor of the axial-flow compressor includes the recessed region and the protruding region, the recessed region being recessed outward in the radial direction from the position frontwardly of the front edge of the vane to the position rearwardly of the rear edge of the vane, the protruding region bulging inward in the radial direction at the intermediate position of the recessed region in the front-rear direction thereof. Accordingly, the distribution of the static pressure in the radial direction on the surface of the vane is improved by a part of the recessed region frontwardly of the protruding region, and the static pressure on the tip side is raised by a part of the recessed region rearwardly of the protruding region. Thereby, a low-momentum fluid migration flowing from the hub side to the tip side is suppressed, and thus the pressure loss can be reduced.

[0014] In addition, the recessed region includes the first recessed portion on the front side, the second recessed portion on the rear side, the first protruding portion continuous to the front portion of the first recessed portion, the second protruding portion forming the protruding region, and the third protruding portion continuous to the rear portion of the second recessed portion, and is continuous among them smoothly. This makes smooth an air flow along the inner peripheral surface of the casing.

[0015] Moreover, the vane is swept so that the tip-side end portion thereof is positioned rearwardly of the hub-side end portion thereof. Thus, the shock-wave loss can be reduced, and noises can be reduced. Although the sweep of the vane makes it easier for the low-momentum fluid to move from the hub-side end portion to the tip-side end portion, the low-momentum fluid migration can be effectively suppressed due to the inner peripheral surface shape of the casing of the present invention.

[0016] Note that a fan rotor **15** in an embodiment corresponds to the rotor of the present invention; a fan stator **16** in the embodiment corresponds to the stator of the present invention; stator vanes **23** in the embodiment correspond to the vanes of the present invention; and a second protruding portion **35** in the embodiment corresponds to the protruding region of the present invention.

[0017] The aforementioned and other objects, features, and advantages will be clear from a description to be given in detail below of a preferable embodiment with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] FIG. **1** to FIG. **8** show the embodiment of the present invention:

[0019] FIG. **1** is a schematic view showing an overall configuration of a turbofan engine;

[0020] FIG. **2** is an enlarged view of a portion **2** in FIG. **1**;

[0021] FIGS. **3**A and **3**B are sectional views taken along a line **3-3** in FIG. **2**;

[0022] FIGS. **4**A and **4**B are views taken in directions of arrows **4**A and **4**B in FIGS. **3**A and **3**B, respectively;

[0023] FIGS. **5**A and **5**B are views showing wake states of stator vanes;

[0024] FIGS. **6**A and **6**B are views showing flow lines along suction surfaces of the stator vanes;

[0025] FIG. **7** is a graph showing changes of the total pressure loss involved with the change of the mass flow; and

[0026] FIG. **8** is a graph showing distribution of the total pressure loss of the stator vanes in a span direction.

DESCRIPTION OF THE PREFERRED EMBODIMENT

[0027] A description is given below of an embodiment of the present invention with reference to the attached drawings.

[0028] Note that in this specification, an upstream side and a downstream side of an air flow direction are defined as "front" and "rear", respectively, and an inner side in a radial direction and an outer side in the radial direction with an axis L being the center are defined as a hub side and a tip side, respectively.

[0029] As shown in FIG. **1**, a turbofan engine E for an aircraft includes an outer casing **11** and an inner casing **12** which have substantially cylindrical shapes and are rotary bodies with an axis L being the center. Inside the outer casing **11** and the inner casing **12**, a low-pressure shaft **13** and a high-pressure shaft **14** are coaxially arranged, the low-pressure shaft **13** being located on the axis L, the high-pressure shaft **14** being fitted around an outer periphery of the low-pressure shaft **13** in such a manner as to be freely and relatively rotatable.

[0030] A fan rotor **15** is provided at a front end of the low-pressure shaft **13**, and a fan stator **16** is provided rearwardly of the fan rotor **15**. A front portion of the outer casing **11** forms an outer portion **17**A of a fan casing **17**. The fan rotor **15** faces, on a tip side thereof, an inner peripheral surface of the outer portion **17**A of the fan casing **17**. In addition, the fan stator **16** is fixed, on the tip side thereof, to the inner peripheral surface of the outer portion **17**A of the fan casing **17**, while the fan stator **16** is fixed, on a hub side thereof, to an outer peripheral surface of an inner portion **17**B of the fan casing **17**.

[0031] A low-pressure compressor **18** is provided to the low-pressure shaft **13** rearwardly of the fan stator **16**, and a low-pressure turbine **19** is provided to a rear end of the low-pressure shaft **13**. In addition, a high-pressure compressor **20** facing a rear portion of the low-pressure compressor **18** is provided at a front end of the high-pressure shaft **14**, and a high-pressure turbine **21** facing a front portion of the low-pressure turbine **19** is provided at a rear end of the high-pressure shaft **14**. Further, multiple combustion chambers **22** are disposed between the high-pressure compressor **20** and the high-pressure turbine **21**.

[0032] Thus, air compressed by the fan rotor **15** rotating together with the low-pressure shaft **13** is rectified by the fan stator **16**. Thereafter, part of the air is exhausted rearward through a bypass duct **24** formed between the outer casing **11** and the inner casing **12**. The remaining is supplied to the inside of the inner casing **12**, compressed by the low-pressure compressor **18** rotating together with the low-pressure shaft **13** and by the high-pressure compressor **20** rotating together with the high-pressure shaft **14**, and then mixed with fuel in the combustion chambers **22** to be supplied for combustion. The fuel gas exhausted from the combustion chambers **22** passes through the high-pressure turbine **21** to drive the high-pressure shaft **14**, further passes through the low-pressure turbine **19** to drive the low-pressure shaft **13**, and then is exhausted rearward from a rear end of the inner casing **12** to meet the air passing through the bypass duct **24**.

[0033] FIG. **2** shows one of stator vanes **23** of the fan stator **16** disposed between the outer portion **17**A and the inner portion **17**B of the fan casing **17**. In the stator vane **23**, a hub-side end portion **23***c* inward in a radial direction is connected to an outer peripheral surface of the inner portion **17**B of the fan casing **17**, and a tip-side end portion **23***d* outward in the radial direction is connected to the inner peripheral surface of the outer portion **17**A of the fan casing **17**. A front edge **23***a* and a rear edge **23***b* of the stator vane **23** are swept in such a manner that the tip-side end portion **23***d* deflects rearward relative to the hub-side end portion **23***c*. Accordingly, a ¼ cord line **23***e* of the stator vane **23** is also swept in such a manner that the tip side deflects rearward relative to the hub side. Thereby, an element in a cord direction of the flow rate of an air flow flowing along a surface of the stator vane **23** is reduced, and thus the critical Mach number is increased to delay an occurrence of a shock wave. Thus, the shock-wave loss can be reduced, and noises can be reduced.

[0034] The present invention is characterized by a shape, near the tip-side end portion **23***d* of the stator vane **23**, of the inner peripheral surface of the outer portion **17**A of the fan casing **17**. Since the fan casing **17** is basically a substantially cylindrical member which is a rotary body with the axis L being the center, a shape of an inner peripheral surface of the fan casing **17** is represented by a shape of a generating line (a line of intersection with a plane passing the axis L).

[0035] The shape of the generating line of the inner peripheral surface of the outer portion **17**A of the fan casing **17** to which the tip-side end portion **23***d* of the stator vane **23** is connected includes a recessed region **31** basically recessed outward in the radial direction from a position frontwardly of the front edge **23***a* to a position rearwardly of the rear edge **23***b*. The recessed region **31** includes a first recessed portion **32**, a second recessed portion **33**, a second protruding portion

35, a first protruding portion **34**, and a third protruding portion **36**. The first recessed portion **32** is located between a position slightly frontwardly of the front edge **23***a* of the tip-side end portion **23***d* of the stator vane **23** and a position slightly frontwardly of the rear edge **23***b* thereof. The second recessed portion **33** is located rearwardly of the rear edge **23***b* of the stator vane **23**. The second protruding portion **35** bulges inward in the radial direction at a position slightly frontwardly of the rear edge **23***b* in such a manner as to connect the first and second recessed portions **32**, **33**. The first protruding portion **34** connects a front end of the first recessed portion **32** to the inner peripheral surface of the outer portion **17**A of the fan casing **17**. The third protruding portion **36** connects a rear end of the second recessed portion **33** to the inner peripheral surface of the outer portion **17**A of the fan casing **17**. In other words, the recessed region **31** is formed by smoothly connecting the first protruding portion **34**, the first recessed portion **32**, the second protruding portion **35**, the second recessed portion **33**, and the third protruding portion **36** from the front to the rear. Positions of connecting points of the first protruding portion **34**, the first recessed portion **32**, the second protruding portion **35**, the second recessed portion **33**, and the third protruding portion **36** are inflexion points at which the direction of the curvature of the generating line changes.

[0036] Note that the dashed lines in FIG. **2** show the shapes of an inner peripheral surface of the fan casing **17** and an outer peripheral surface of the inner casing **12** in Comparative Example.

[0037] FIGS. **3**A and **3**B and FIGS. **4**A and **4**B show static pressure distributions around the stator vanes **23**. FIGS. **3**A and **3**B show static pressure distributions on a cross section (of the tip-side end portion **23***d* of the stator vane **23**) taken along the line **3-3** in FIG. **2**. FIGS. **4**A and **4**B show static pressure distributions on the suction surfaces (back surfaces) of the respective stator vanes **23** corresponding to views taken along the arrows **4**A and **4**B in FIGS. **3**A and **3**B. FIGS. **3**A and **3**B and FIGS. **4**A and **4**B show that darker color portions (densely shaded portions) exhibit higher pressures and lighter color portions (coarsely shaded portions) exhibit lower pressures.

[0038] According to the embodiment, the first and second recessed portions **32**, **33** are formed in the inner peripheral surface of the outer portion **17**A of the fan casing **17** to which the tip-side end portion **23***d* of the stator vane **23** is connected. Thus, the flow rate of the air flow flowing along the first and second recessed portions **32**, **33** is lowered, and thereby the static pressure is raised.

[0039] As is clear with reference to Comparative Example and the embodiment in FIG. **3**A to FIG. **5**B, it is proved that, due to an effect of the first recessed portion **32** of the fan casing **17**, the static pressure of the pressure surface of each of the stator vanes **23** in the embodiment is raised in comparison with Comparative Example (see FIGS. **3**A and **3**B). Furthermore, it is proved that, due to an effect of the second recessed portion **33** of the fan casing **17**, the static pressure rearwardly of the rear edge **23***b* of the stator vane **23** in the embodiment is raised in comparison with Comparative Example (see FIGS. **4**A and **4**B).

[0040] In addition, as is clear from FIGS. **4**A and **4**B, a static pressure contour along the suction surface of the stator vane **23** in the embodiment becomes upright in comparison with Comparative Example due to the effect of the first recessed portion **32** of the fan casing **17**. In other words, in the embodiment, the static pressure contour is approximately aligned with the radial direction. In contrast, in Comparative Example, the static pressure contour outward in the radial direction is swept back rearward. Accordingly, a static pressure distribution is formed in which a region (a lower side in the figure) inward in the radial direction, of the static pressure contour, exhibits a higher pressure and a region (an upper side in the figure) outward in the radial direction, of the static pressure contour, exhibits a lower pressure. This induces a secondary flow flowing from the hub-side end portion **23***c* to the tip-side end portion **23***d* of the stator vane **23**. On the other hand, in the embodiment, the static pressure contour has almost no sweepback angle, and thus the secondary flow is hardly induced.

[0041] Meanwhile, a rotor hub of the fan rotor **15** located frontwardly of the fan stator **16** has a diameter increased from the front to the rear in such a manner as to have a conical shape. This easily induces the secondary flow in the air flow passing along the stator vane **23** of the fan stator **16**, the secondary flow flowing from the inner side in the radial direction to the outer side in the radial direction. Moreover, when the stator vane **23** is swept, the air flow easily flows from the hub side to the tip side, making the secondary flow further stronger. As described above, when the secondary flow flowing from the inner side in the radial direction to the outer side in the radial direction along the stator vane **23** is generated, a low-momentum wake (a following wake) generated on the hub-side end portion **23***c* of the stator vane **23** easily spreads outward in the radial direction, as shown in Comparative Example in FIG. **5**B. This causes a problem of increased pressure loss in the fan stator **16**.

[0042] According to the embodiment, however, the static pressure contour along the suction surface of the stator vane **23** becomes upright due to the effect of the first recessed portion **32** of the fan casing **17**, so that the secondary flow flowing from the hub side to the tip side is suppressed. In addition, the static pressure rearwardly of the rear edge **23***b* of the tip-side end portion **23***d* of the stator vane **23** is raised due to the effect of the second recessed portion **33** of the fan casing **17**, so that the secondary flow flowing from the hub side to the tip side is suppressed. Thereby, as shown in the embodiment in FIG. **5**A, a region where the low-momentum wake spreads is minimized, and thus the pressure loss can be reduced.

[0043] FIGS. **6**A and **6**B show flow lines of the air flow along the suction surface of the stator vane **23**. Comparative Example shows that the air flow flowing in from the front edge **23***a* along the hub-side end portion **23***c* of the stator vane **23** deflects largely outward in the radial direction at the rear edge **23***b* to increase a wake region Wh on the hub side, while the embodiment shows that the secondary flow flowing from the hub side to the tip side is suppressed to reduce a wake region Wh on the hub side. Here, the static pressure rearwardly of the rear edge **23***b* of the tip-side end portion **23***d* of the stator vane **23** is raised due to the effect of the second recessed portion **33** of the fan casing **17**, and thereby the secondary flow flowing from the tip side to the hub side is generated, so that a wake region Wt on the tip side in the embodiment is slightly larger than that in Comparative Example. The wake regions, however, are made smaller as a whole, and thereby the pressure loss can be reduced.

[0044] FIG. **7** is a graph showing changes of the total pressure loss in changing the mass flow rate. It is proved that in the mass flow rate in an illustrated range, the total pressure loss in the embodiment is approximately 20% lower than the total pressure loss in Comparative Example.

[0045] FIG. **8** is a graph showing a distribution of the total pressure loss of the stator vane **23** in a span direction in a case of mass flow rate=1.0. It is proved that due to the increased wake region Wt on the tip side in the embodiment in some region (80% to 90% region in the span direction) on the tip side, the total pressure loss in the embodiment is increased in comparison with Comparative Example. However, the total pressure loss in the embodiment in the other region is lower than the total pressure loss in Comparison Example.

[0046] An embodiment of the present invention has been described above, but the present invention is not limited to the aforementioned embodiment, and various design changes can be made without departing from the gist of the present invention.

[0047] For example, in the embodiment, the present invention is applied to the fan casing **17** of the turbofan engine E for an aircraft, but is not only applicable to a turbofan engine for any application other than that for an aircraft but also applicable to a casing of an axial-flow compressor for any application.

[0048] In addition, although the stator vanes **23** in the embodiment are swept, the present invention is applicable to stator vanes which are not swept.

1. An inner peripheral surface shape of a casing of an axial-flow compressor, the casing surrounding an outer periphery of vanes of a stator which are disposed in a radial arrangement and rearwardly of a rotor of the axial-flow compressor, wherein

a generating line of the casing comprises a recessed region and a protruding region, the recessed region being recessed outward in a radial direction from a position frontwardly of a front edge of each of the vanes to a position rearwardly of a rear edge of the vane, the protruding region bulging inward in the radial direction at an intermediate position of the recessed region in a front-rear direction.

2. The inner peripheral surface shape of a casing of an axial-flow compressor according to claim **1**, wherein the recessed region comprises a first recessed portion on a front side, a second recessed portion on a rear side, a first protruding portion continuous to a front portion of the first recessed portion, a second protruding portion forming said protruding region, and a third protruding portion continuous to a rear portion of the second recessed portion.

3. The inner peripheral surface shape of a casing of an axial-flow compressor according to claim **2**, wherein the first protruding portion, the first recessed portion, the second protruding portion, the second recessed portion, and the third protruding portion are smoothly continuous to each other.

4. The inner peripheral surface shape of a casing of an axial-flow compressor according to claim **1**, wherein each of the vanes is swept so that a tip-side end portion thereof is positioned rearwardly of a hub-side end portion thereof.

5. The inner peripheral surface shape of a casing of an axial-flow compressor according to claim **2**, wherein each of the vanes is swept so that a tip-side end portion thereof is positioned rearwardly of a hub-side end portion thereof.

6. The inner peripheral surface shape of a casing of an axial-flow compressor according to claim **3**, wherein each of the vanes is swept so that a tip-side end portion thereof is positioned rearwardly of a hub-side end portion thereof.

* * * * *