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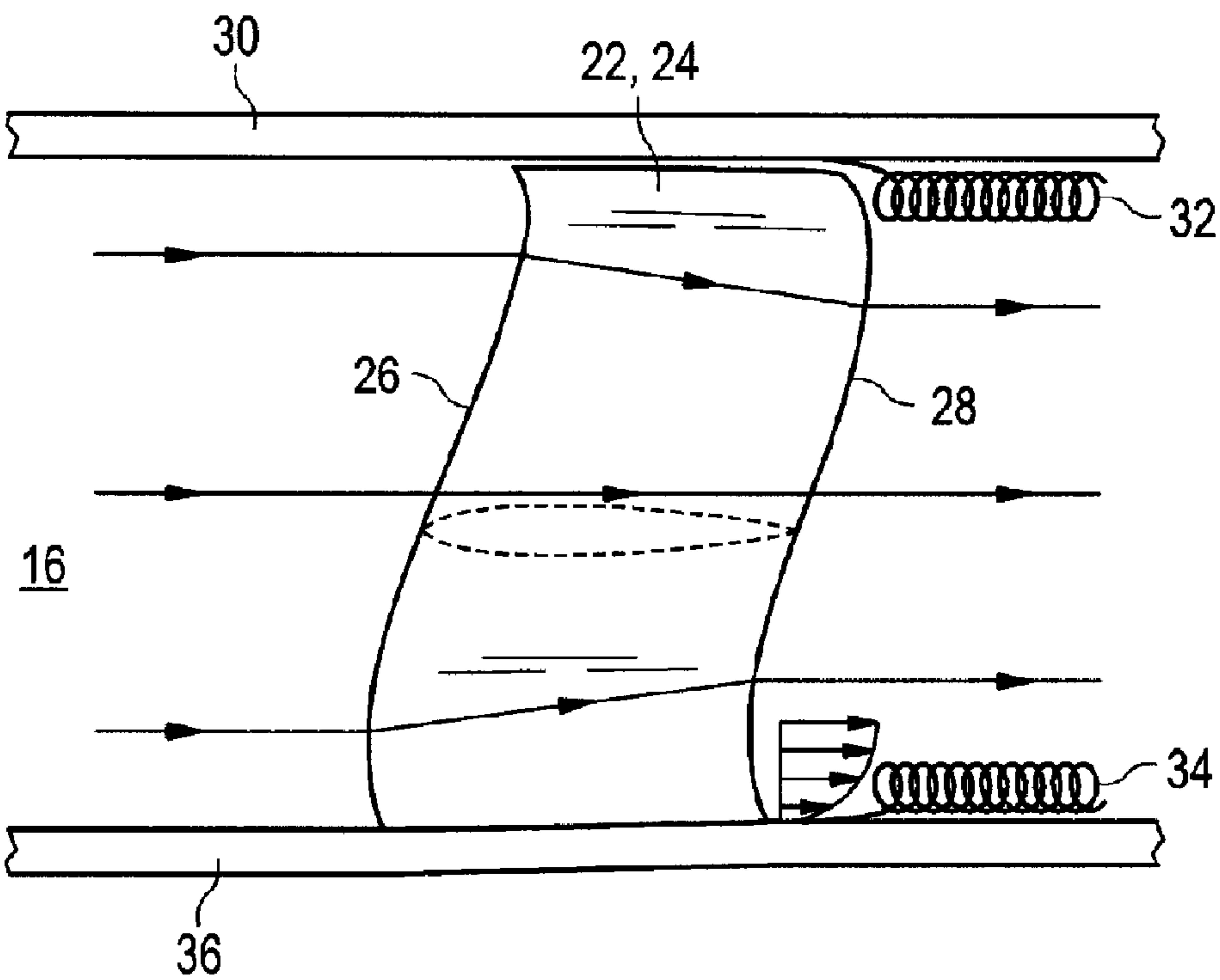
(54) Titre : LAME POURVUE D'UN PROFIL EN FORME DE « S » POUR COMPRESSEUR DE TURBOMACHINE AXIALE
(54) Title: BLADE WITH AN S-SHAPED PROFILE FOR AN AXIAL TURBOMACHINE COMPRESSOR



(57) Abrégé/Abstract:
A subsonic rotor and/or stator blade profile (22, 24) of an axial turbomachine compressor, such as a turbojet. The blade has a leading edge (26) with an S-shaped lateral profile in its mid-plane. Specifically, the profile includes, from its inner end to the outer end, a first convex portion including the foremost part of the blade, and a second concave portion including the rearmost area of the blade. This profile enables the fluid flow between 20% and 80% of the blade's length to be redistributed. This so-called "sweep" profile increases the performance of the stage with such blades because it reduces blade tip vortex losses as well as secondary losses.

Abstract

A subsonic rotor and/or stator blade profile (22, 24) of an axial turbomachine compressor, such as a turbojet. The blade has a leading edge (26) with an S-shaped lateral profile in its mid-plane. Specifically, the profile includes, from its inner end to the outer end, a first convex portion including the foremost part of the blade, and a second concave portion including the rearmost area of the blade. This profile enables the fluid flow between 20% and 80% of the blade's length to be redistributed. This so-called "sweep" profile increases the performance of the stage with such blades because it reduces blade tip vortex losses as well as secondary losses.

Description

BLADE WITH AN S-SHAPED PROFILE FOR AN AXIAL TURBOMACHINE COMPRESSOR

Background of the invention

[0001] The invention relates to the field of axial turbomachines, more particularly to the compressors of such machines. The invention relates to the blades of such machines.

Prior art

[0002] WO 2009/103528 A2 discloses different blade geometries for axial turbomachines, including compressors of axial turbomachines. It discloses in particular a geometry in which the blade's leading edge has a sinusoidal S-shaped profile. This interpretation combines blade profiling across its overall section (or its chord) as well as perpendicular to it. In other words, this interpretation combines both so-called "sweep" and "lean" profiles respectively. The so-called "sweep" profile is along its length by a "displacement" of the section in a direction along its axial chord. The "displacement" mentioned above is essentially an offset in a given direction of the stack of blade sections along its length, the offset possibly changing direction. The so-called "lean" profile is along its length by a "displacement" of the section in a direction perpendicular to that of its axial chord. This combination of geometry has been shown as being able to reduce secondary vortices, leakage losses and shock losses. It should be noted that the shock losses cannot, in principle, affect the compressor blades of low-pressure turbomachines but only the fan and those of the transonic compressor upstream of the combustion chamber, or the turbine blades downstream of the combustion chamber. This interpretation does not suggest any exact blade profile parameters and, moreover, does not detail the precise effect of each of the profiling mechanisms disclosed.

[0003] U.S. Patent Application No. 2010/0215503 A1 discloses a “sweep” blade profile for transonic or supersonic applications. This interpretation focuses on reducing the combined shock losses to maintain the blade’s integrity. It identifies that profiling towards the front of the blade (“forward sweep”) causes stress concentration at the leading edge at the blade root; this stress concentration is primarily due to the blade’s centre of gravity being shifted forwards. To solve this problem, this interpretation provides a “sweep”” profile towards the back at the outer part of the blade to compensate for the shift in the centre of gravity.

[0004] In the case of subsonic applications, such as those found in boosters, including low-pressure compressors of axial turbomachines, flow losses are virtually nonexistent. However, other types of losses are present; these include vortex losses generated by rotor blade tip leakage as well as secondary losses associated with the fluid flow along the inner and outer walls of the fluid stream.

Summary of the invention

The technical problem

[0005] The invention aims to provide a blade geometry that overcomes at least one of the problems mentioned above. More particularly, the invention aims to propose a blade geometry for subsonic applications able to reduce aerodynamic losses due, especially, to the fluid flow along the blade.

Technical solution

[0006] The invention relates to a subsonic blade of an axial turbomachine intended to be located radially on the said machine comprising a leading edge and a trailing edge, two aerodynamic surfaces opposite to each other, extending over the length of the blade and connecting the leading edge to the trailing edge with the leading edge having a lateral profile that is S-shaped, wherein the foremost part of the leading edge is at a position comprised between 3% and 20% of the blade length, and/or the rearmost part of the leading edge is at a position comprised between 85% and 97% of the blade length.

[0007] The blade profile under consideration is that laterally in the mid-plane of the blade.

[0008] The blade length is the length of its aerodynamic part, that is to say, regardless of its means of fixing.

[0009] The foremost and/or rearmost parts can be pointed or almost straight.

[0010] The terms “foremost” and “rearmost” are to be interpreted in relation to the main direction of fluid flow across the blade aerofoils.

[0011] According to an embodiment of the invention, the foremost part of the leading edge is at a position comprised between 5% and 17% of the length of the blade, preferably between 7% and 15% of the length of the blade, and/or the rearmost part of the leading edge is at a position comprised between 87% and 95% of the blade length, preferably between 90% and 95% of the blade length.

[0012] According to an embodiment of the invention, the profile of the leading edge comprises, from its inner end to its outer end, a first convex portion containing the foremost part, and a second concave portion containing the rearmost part.

[0013] According to an embodiment of the invention, the first and/or second part of the leading edge is at a maximum distance from a straight line passing through the inner and outer ends of the leading edge that is between 5 and 15% of the corresponding blade chord length. The chord length is the axial length of the chord along a direction perpendicular to the blade’s main axis, and/or in the direction of fluid flow along the aerodynamic surfaces.

[0014] The first and second sections of the leading edge are such that their respective maximum distances from the straight line passing through the inner and outer ends of the leading edge do not differ by more than 40%, preferably 30%, more preferably 20% from each other.

[0015] According to an embodiment of the invention, the leading edge profile includes an area or a point of inflection between the first and second sections, the said area or point being between 40% and 60%, preferably between 45% and 55% along the length of the blade.

[0016] According to an embodiment of the invention, the profile of the leading edge comprises or corresponds to a polynomial function passing through the inner and outer ends of the said edge and through a point or the point of the foremost area and a point or the point of the very rearmost area.

[0017] According to an embodiment of the invention, the profile of the leading edge comprises or includes or a Bezier function or B-spline defined with respect to the inner and outer ends of the said edge, and through a point or the point of the foremost area and a point or the point of the very rearmost area.

[0018] According to an embodiment of the invention, the trailing edge has a profile generally parallel to the leading edge, the distance between the said edges not varying by more than 10%, preferably 5%.

[0019] According to an embodiment of the invention, the length of the foremost part of the leading edge is longer, preferably by 50%, of the total length of the blade less the length of the rearmost part of the leading edge.

[0020] According to an embodiment of the invention, the slope of the leading edge at its outer end is greater, preferably by 20%, more preferably by 35%, even more preferably by 50% than the slope of the said profile at its inner end.

[0021] According to an embodiment of the invention, the maximum slope of the leading edge profile lies between the rearmost part of the profile and its outer end.

[0022] According to an embodiment of the invention, the leading edge and/or trailing edge is/are lie in a plane corresponding to the mid-plane of the blade, and that within a tolerance of 10%, preferably 5%, more preferably 1% of the length of the blade.

[0023] The invention also relates to an axial turbomachine compressor, comprising a rotor with at least one rotor blade stage and a stator with at least one stator blade stage, wherein the blades of at least one of the rotor and stator stages are in accordance with the invention.

[0024] The invention also relates to an axial turbomachine, such as a jet engine, comprising a compressor wherein the compressor is in accordance within the invention.

[0025] The invention may increase the efficiency of the engine in which the blades are implemented by reducing blade tip vortex losses as well as a reduction in secondary losses. The so-called "sweep" profile of the invention can generate radial velocity components in the fluid along the blade, especially at the leading edge. These radial components can redistribute the fluid flow over that portion of the blade comprising substantially between 20% and 80% of its length.

[0026] The particular profile of the leading edge, especially its asymmetry, enables the flow across the central part of the blade to be optimally redistributed.

Brief description of the drawings

[0027] Figure 1 is a schematic illustration of an axial turbomachine.

[0028] Figure 2 is a sectional view of a low-pressure compressor section of an axial turbomachine such as that in Figure 1, in which the blades of the invention could be used.

[0029] Figure 3 is a diagram showing the rotor and stator blades of one stage of axial compressor as well as vector diagrams of the fluid velocities.

[0030] Figure 4 is a sectional view of a blade in accordance with the invention.

[0031] Figure 5 an enlarged view of the blade profile in Figure 4, illustrating its geometry.

Description of the embodiments

[0032] Figure 1 illustrates schematically an axial turbomachine 2. In this case it is a double-flow turbojet. The turbojet 2 consists essentially of a first compressor stage, called a low-pressure compressor 8, a second compressor stage, called a high pressure compressor 10, a combustion chamber 12 and one or more turbine stages 14. In operation, the mechanical power of the turbine 14 is transmitted through the central shaft to the rotor 4 and drives the two compression stages 8 and 10. These latter include a plurality of rotor blade rows associated with stator blade rows. The rotation of the rotor thus generates a flow of air and progressively compresses it up to the entrance of the combustion chamber 12. An inlet fan commonly called a turbofan 6 is coupled to the rotor 4 and generates an air flow which is divided into a primary flow 16 passing through the different stages of the turbomachine mentioned above and a secondary flow 18 passing through an annular passage (shown in part) running the length of the machine which then rejoins the main flow at the turbine outlet.

[0033] The amount of air bypassing the engine varies, depending on the engine. It is greater if the engine is designed to fly at low speeds. This proportion is called the bypass ratio, the ratio of the cold mass flow (called secondary) to the hot mass flow (called primary). Military engines optimised for supersonic flight can reach a bypass ratio below 1, while aircraft engines for airliners, optimised for cruising at around Mach 0.8, have bypass ratios of between 5 and 10. Such engines derive most of their thrust from the cold flow (80%), the hot stream representing 20% of the thrust.

[0034] Figure 2 is a sectional view of a low-pressure compressor of an axial turbomachine such as that of Figure 1. The diagram shows a portion of the inlet fan or turbofan 6 and the flow splitter nose 20 separating the primary flow 16 and the secondary flow 18. The rotor 4 includes several rows of rotor blades 22. The housing supports several rows of stator blades 24. Each pair of rotor and associated stator blade rows forms one compressor stage of the compressor 8.

[0035] Figure 3 shows velocity vector diagrams for the fluid passing through a compressor stage. The rotor stage 22 accelerates the fluid flow resulting from the energy transmitted by the transmission shaft. The stator stage 24 converts the kinetic energy into pressure because of the shape of the stator. The vector diagram to the left of the rotor stage 22 corresponds to the fluid entering the said stage. The vector $U_1=\omega R$ corresponds to the rotational speed of the rotor blades. The vector W_1 is the relative rotor entry velocity of the fluid and the vector V_1 is the absolute rotor entry velocity of the fluid, and is the vector sum of the vectors U_1 and W_1. The vector diagram to the right of the rotor stage 22 corresponds to the fluid leaving the said stage. Vector U_2, the rotational speed of the rotor blades, is identical to vector U_1. It can be seen that the fluid is accelerated, the output vector V_2 being substantially longer than the input vector V_1. It can also be seen that the change in direction of vector W_1 generates a change in direction of the fluid exit velocity vector V_2. The exit angle α_2 is substantially larger than the entry angle α_1. The output vector V_2 is then substantially in the same direction as the leading edge angle of the stator blades 24. The stator blades 24 deflect and decelerate the accelerated fluid and this deceleration is converted into a pressure increase. The stator exit velocity V_3 is smaller and at a narrower angle α_3.

[0036] In the following description, the terms "external(s)" and "internal(s)" will be used to describe the position of components in the fluid stream. These terms refer to the generally circular cross section of the fluid stream; "external(s)" refers to a position farther from the centre of the circle, i.e. the axis of rotation of the machine, and "internal(s)" refers to a position that is nearer to the centre.

[0037] Figure 4 shows a blade in accordance with the invention and its effect on the flow. This may be either a rotor or a stator blade. Figure 4 shows a rotor blade. Its "sweep" profile, that is to say relative to the stacking of its section in a direction substantially corresponding to its chord, is clearly visible. It can be seen that that the leading edge 26 and the trailing edge 28 both have a similar S-shaped profile. The S-shaped profile is such that the inner half of the leading edge is convex and the outer half is concave. The leading edge profile and the body of the blade have the effect of generating a radial velocity component in the fluid stream bounded by the inner wall 36 and the outer wall 30. This component is generated primarily for the fluid moving near the walls, the aim being to remove the moving fluid from the said walls. The concentration of the fluid flow in the stream reduces losses due to blade tip leakage vortices. These losses are mainly a result of the mechanical clearance between the rotor blade tips and the corresponding stator wall.

They are illustrated by the vortex 32 arising from the mechanical clearance between the blade tip 22 and the wall 30.

[0038] Concentrating the fluid flow in the stream can also reduce secondary losses related to the velocity gradient along the fixed walls. This is illustrated for the wall 36. It generates vortices 34 which constitute so-called secondary losses. These losses are normally present on the inner wall 36 and the outer wall 30.

[0039] Figure 5 illustrates in more detail the blade profile 22, 24. The leading edge 26 is characterised by a number of different points. Point A is at the outer end of the blade tip. Point B is the most downstream point. Point D is the furthest upstream and Point E is the inner end of the leading edge, at the blade root. Point C is a point of inflection between the convex inner portion and the outer concave portion. It is where the leading edge 26 changes curvature.

[0040] The leading edge 26 has length H. Point D is at a distance H_1 and Point B is at a distance H_2. H_1 is between 3% and 20% of the total length H. H_2 is between 85% and 97% of the total length H. As can be seen in the figure, Point B is closer to the outer end at Point A than Point D is to the inner end at Point E.

[0041] The amplitudes of the convex portion C-D-E and the concave portion C-B-A of the leading edge can be expressed by the distances S_1 and S_2, respectively, compared to a straight line passing through Points A and E. These distances are preferably between 5 and 15% of the average width of the blade.

[0042] The profile of the leading edge 26 may be a polynomial function passing through the points A, B, D and E, preferably of degree greater than or equal to 3. It may also be a Bezier function or B-spline defined by the four points mentioned above.

[0043] The profile of the trailing edge 28 may be similar to that of the leading edge 26 in particular because of spatial constraints and when the stator and rotor blades are in accordance with the invention.

[0044] The parameters characterising the leading edge profile are also applicable to the trailing edge. The same letters are used to characterise these letters and are distinguished from those of the leading edge by adding a prime symbol ('). All the remarks made about the leading edge can also be applied to the trailing edge.

[0045] The increase in performance provided by the design of the invention compared with an already optimised stage is of the order of one percent or a few tenths of a percent.

Claims

1. Subsonic blade of an axial turbomachine, intended to be located radially on said turbomachine, comprising

   a leading edge;

   a trailing edge;

   two aerodynamic surfaces on opposite sides to each other, extending over the length of the blade, with each one joining the leading edge to the trailing edge;

   the leading edge having an S-shaped lateral profile; and

   wherein the foremost part of the leading edge is at a position comprised between 3% and 20% of the length of the blade, preferably between 7% and 15% of the length of the blade, and/or the rearmost part of the leading edge is at a position comprised between 85% and 97% of the length of the blade.

2. Subsonic blade in accordance with Claim 1 wherein the foremost part of the leading edge is at a position comprised between 5% and 17% of the length of the blade, preferably between 7% and 15% of the length of the blade, and/or the rearmost part of the leading edge is at a position comprised between 87% and 95%, preferably between 90% and 95% of the length of the blade.

3. Subsonic blade in accordance with Claim 1 or 2 wherein the profile of the leading edge comprises, from its inner end to its outer end, a first convex portion containing the foremost part, and a second concave portion containing the rearmost part.

4. Subsonic blade in accordance with Claim 3 wherein the first and/or second portions of the leading edge is at a maximum distance from a straight line passing through the inner and outer ends of the leading edge that is between 5 and 15% of the corresponding length of the blade.

5. Subsonic blade in accordance with any one of Claims 3 and 4 wherein the leading edge profile includes an area or a point of inflection between the first and second

portions, the said area or point being at a distance between 40% and 60%, preferably between 45% and 55% along the length of the blade.

6. Subsonic blade in accordance with any one of Claims 1 to 5 wherein the profile of the leading edge comprises or corresponds to a polynomial function passing through the inner and outer ends of the said edge, through a point or the point of the foremost area and a point or the point of the rearmost area.

7. Subsonic blade in accordance with any one of Claims 1 to 6 wherein the profile of the leading edge comprises or corresponds to a Bezier function or a B-spline defined with respect to the inner and outer ends of the said edge, through a point or the point of the foremost area and a point or the point of the rearmost area.

8. Subsonic blade in accordance with any one of Claims 1 to 7 wherein the trailing edge has a profile generally parallel to the leading edge, the distance between the said edges not varying by more than 10%, preferably 5%.

9. Subsonic blade in accordance with one of Claims 1 to 8 wherein the length of the foremost part of the leading edge is greater than, preferably by 50%, of the total length of the blade less the length of the rearmost part of the leading edge.

10. Subsonic blade in accordance with any one of Claims 1 to 9 wherein the slope of the leading edge at its outer end is greater, preferably by 20%, more preferably by 35%, even more preferably by 50% than the slope of the said profile at its inner end.

11. Subsonic blade in accordance with any one of Claims 1 to 10 wherein the maximum slope of the leading edge profile lies between the rearmost part of the profile and its outer end.

12. Subsonic blade in accordance with any one of Claims 1 to 10 wherein the leading edge and/or trailing edge is/are lie in a plane corresponding to the mid-plane of the blade, and that within a tolerance of 10% preferably 5%, more preferably 1% of the length of the blade.

13. Axial turbomachine compressor, comprising a rotor with at least one rotor blade stage and a stator with at least one stator blade stage; wherein the blades of at least one of the rotor and stator stages are in accordance with any one of the Claims 1 to 12.

14. Axial turbomachine comprising a compressor, wherein the compressor is in accordance with Claim 13.

FIG 1

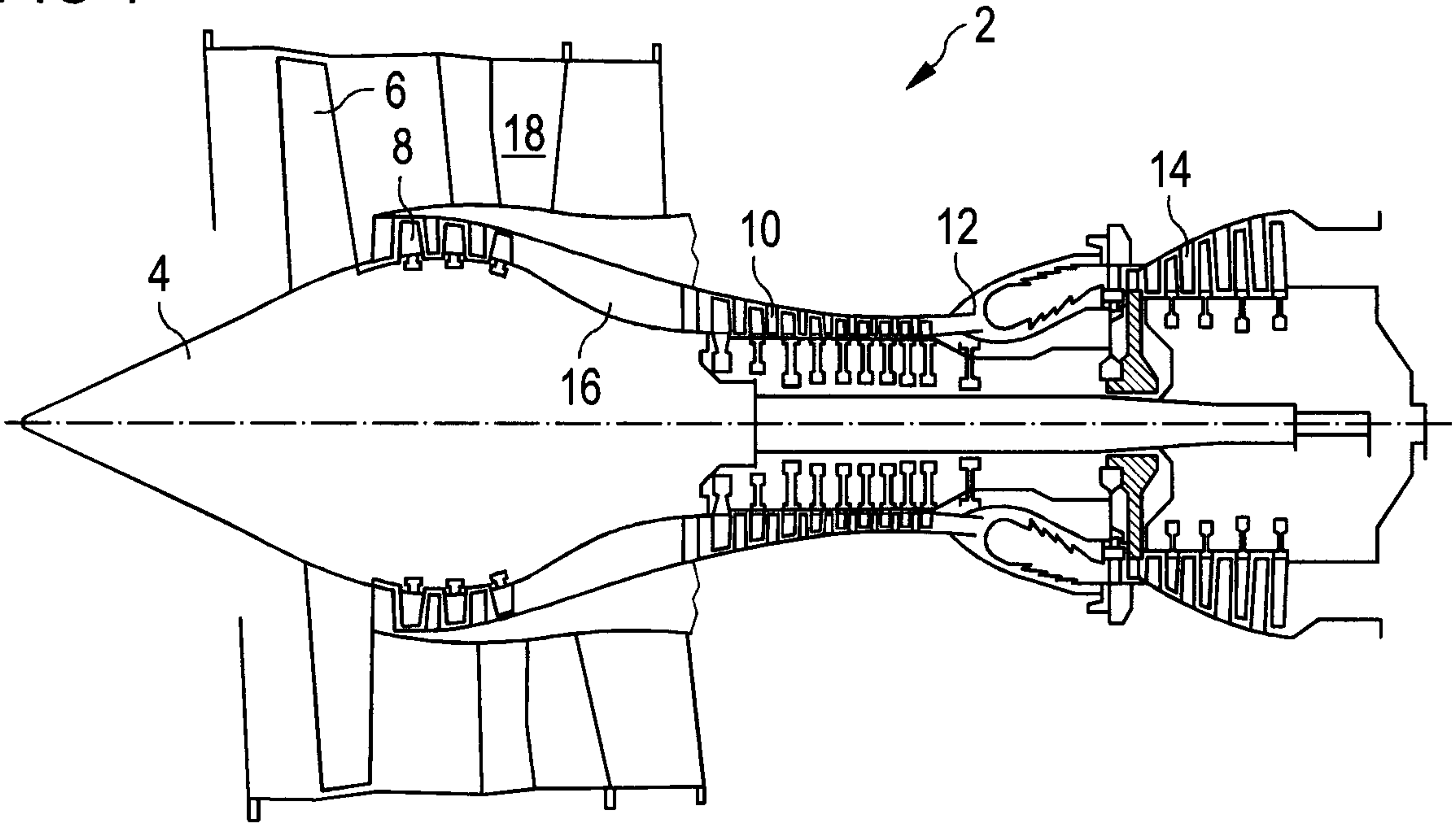


FIG 2

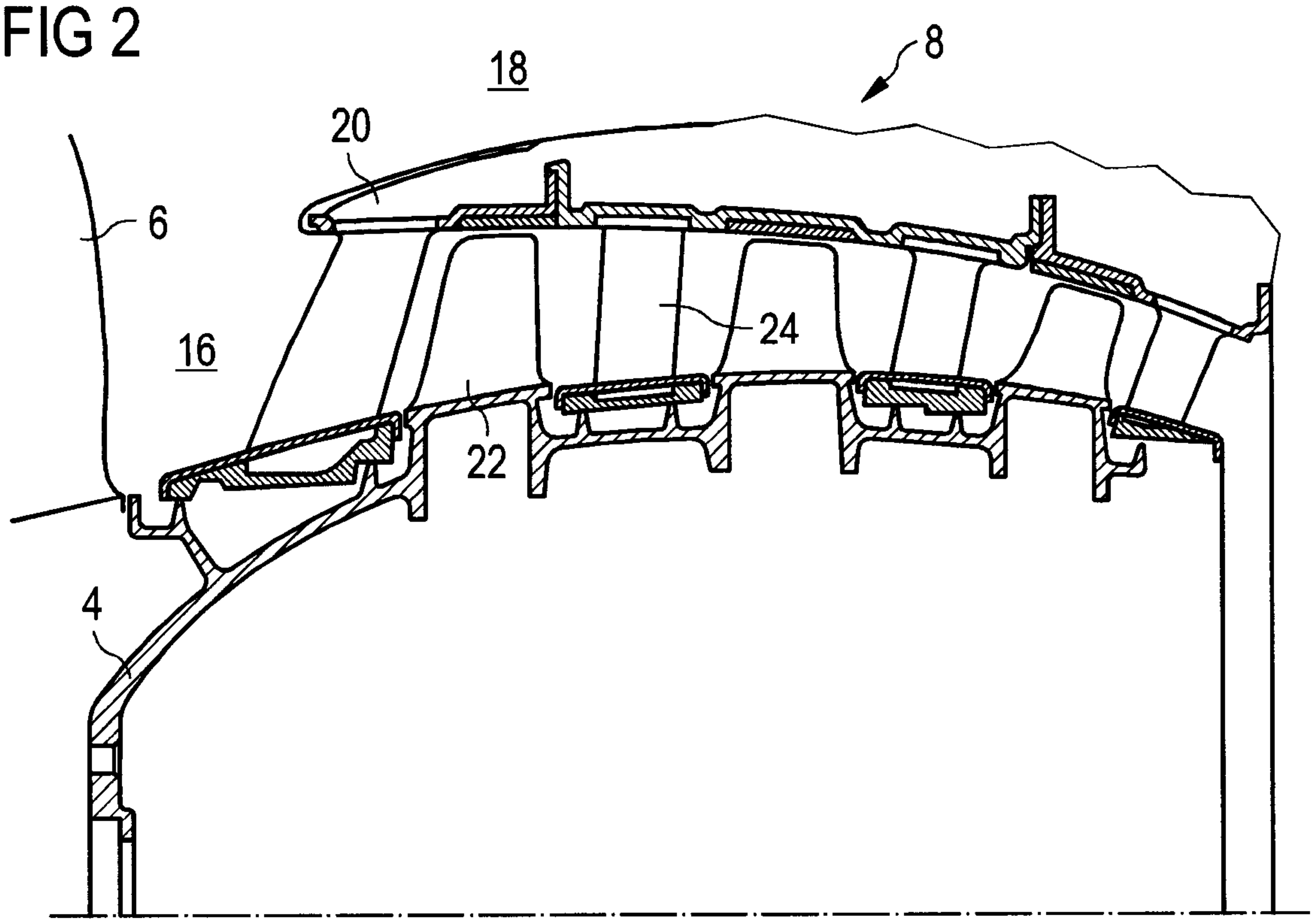
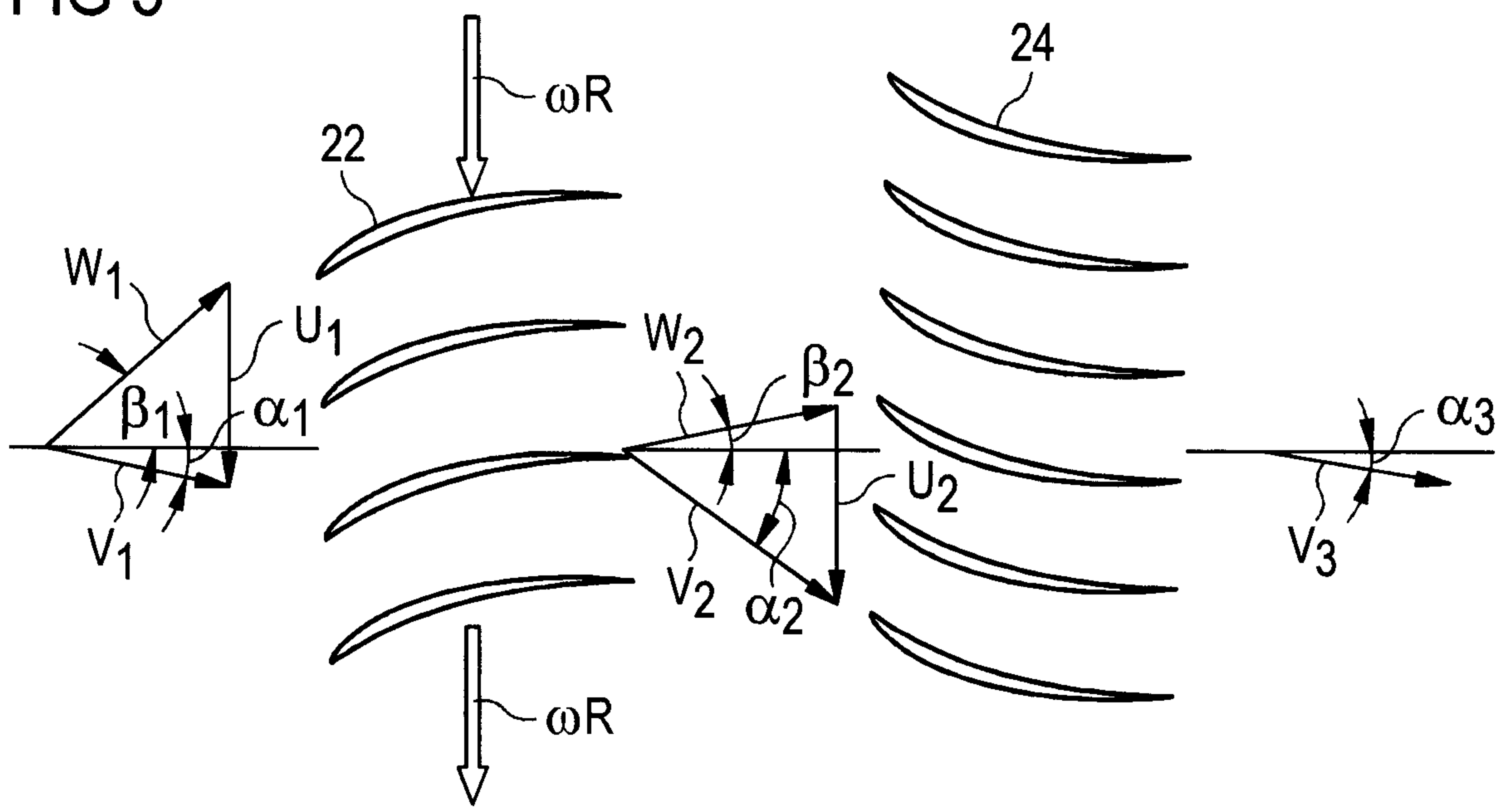


FIG 3


ωR
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24
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V1
W2
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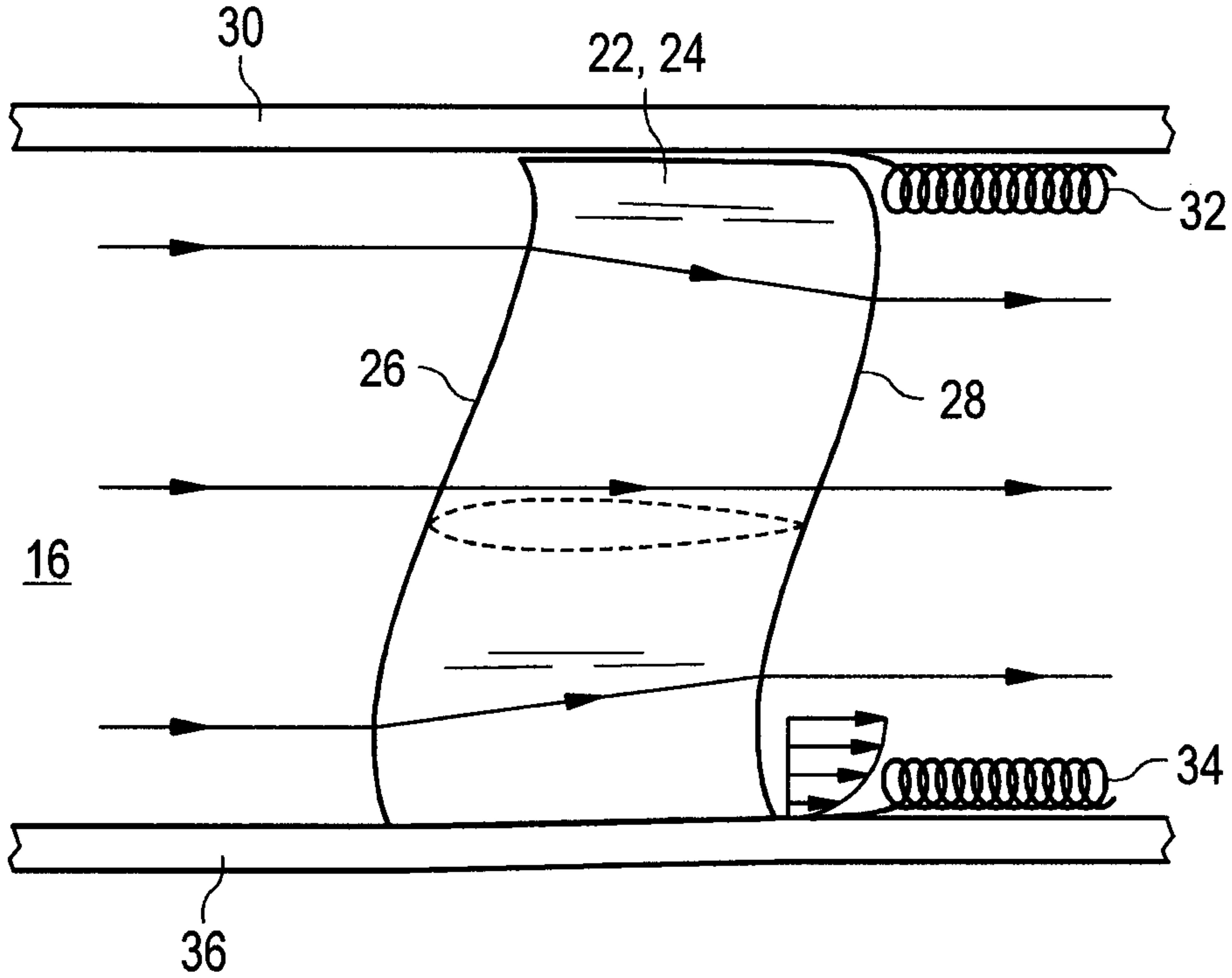
α3
V3
ωR

FIG 4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22, 24
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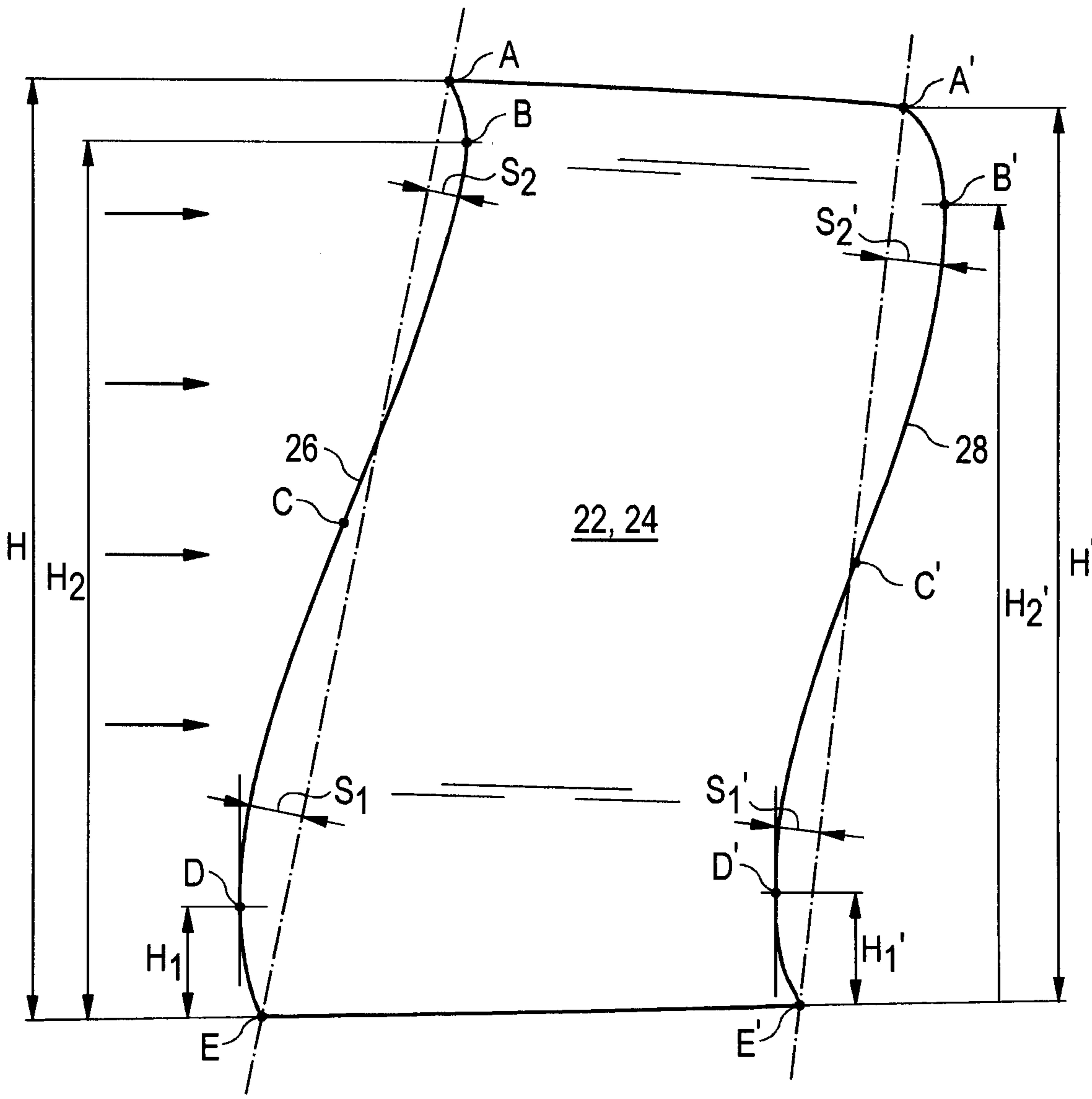
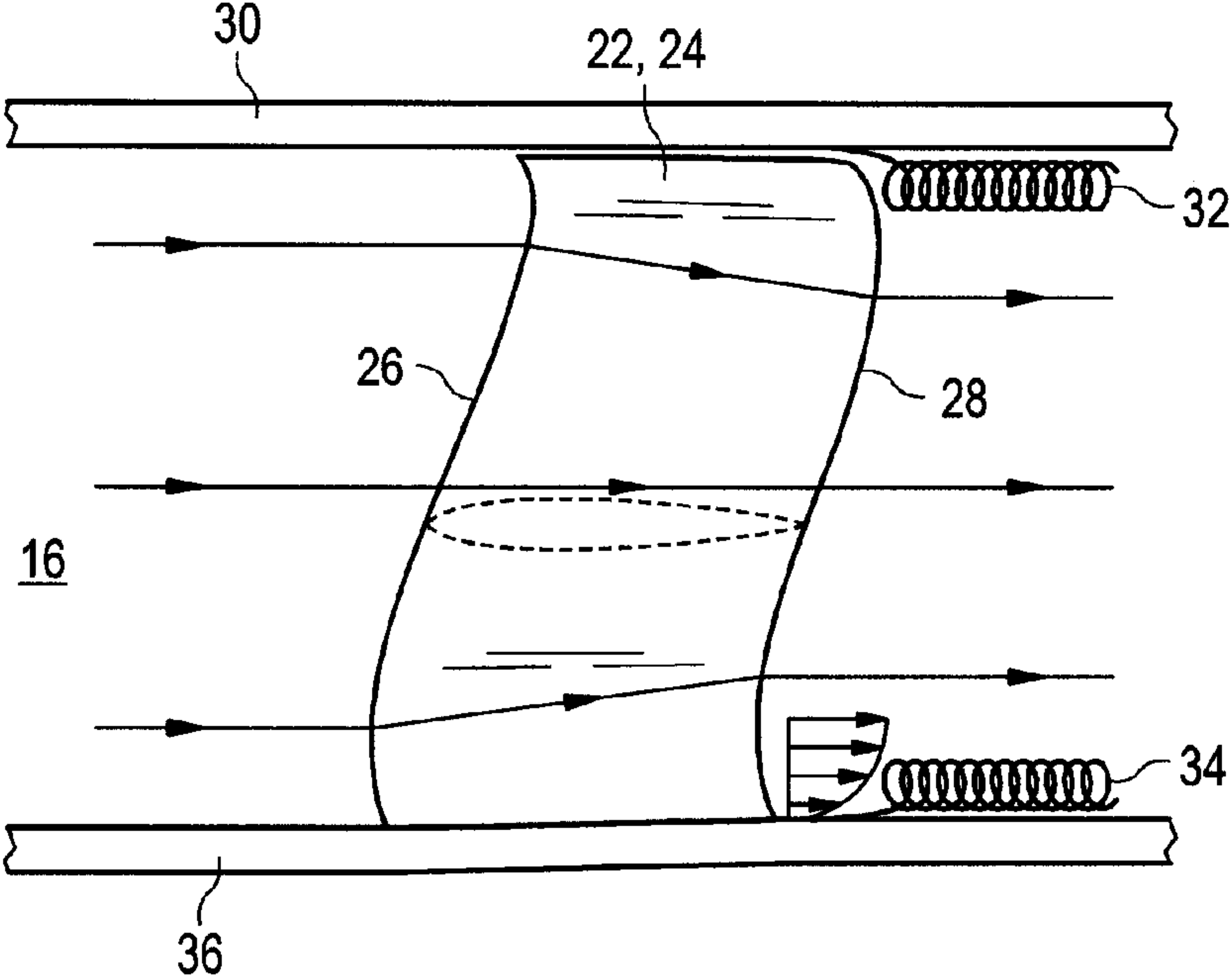
36

FIG 5





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22, 24
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