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(54) Title: A FLOW ASSEMBLY FOR AN AXIAL TURBOMACHINE

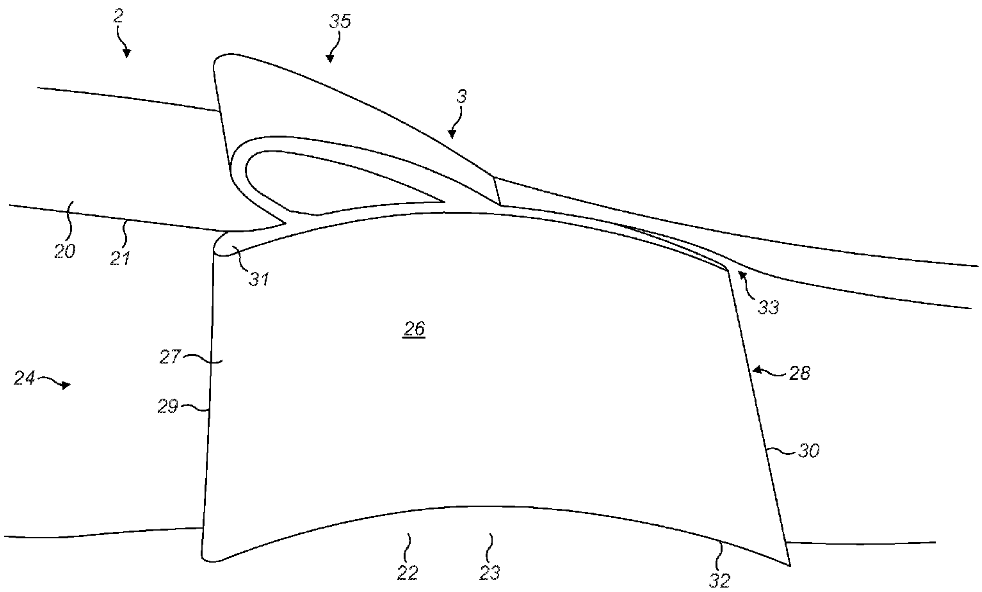

FIG. 2

(57) Abstract: A flow assembly for an axial turbomachine is disclosed. The flow assembly comprises: an outer shroud; an inner hub; and, at least one blade mounted to one of the shroud and hub and comprising pressure and suction surfaces. The other one of the shroud and hub comprises a wall and the or each blade extends towards the wall such that a clearance gap is provided therebetween. The flow assembly is configured such that, in use, fluid flows through the flow assembly from an upstream side to a downstream side of the flow assembly. The wall comprises a recirculation channel comprising an outlet and an inlet located between the outlet and the downstream side of the flow assembly. The recirculation channel is configured such that when fluid flows through the flow assembly from the upstream side to the downstream side, fluid flow from the pressure surface side of the at least one blade enters the inlet and flows along the recirculation channel to be expelled from the outlet to impede leakage of fluid flow in the clearance gap from the pressure surface

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side to the suction surface side of the or one of the blades.

A flow assembly for an axial turbomachine

Technical Field

The present invention relates to a flow assembly for an axial turbomachine. The present invention also relates to an axial turbomachine comprising a flow assembly, and to an aircraft comprising an axial turbomachine.

Background of the Invention

Axial turbomachines are used in applications such as air-conditioning, power generation, and propulsion systems amongst others. Axial turbomachines generally comprise one or more fans, compressors, and/or turbines. Compressors are generally formed by stages, wherein each stage comprises a half-stage comprising a set of stator (static) blades and a half-stage comprising a set of rotor (rotating) blades. Each stage works on the fluid to impart a rate of change of momentum to the working fluid such that a pressure differential is created across the thickness of a blade along its span. Thus, by having a number of stages aligned axially, the pressure of the working fluid can be gradually increased as it passes through the compressor.

In order to prevent excessive wear between the blades and the hub or shroud wall of the compressor casing, the blades are sized so that a clearance gap exists between the blade tip and the respective wall. However, due to the pressure difference between the high pressure on the pressure surface side of the blade and the low pressure on the suction surface side of the blade, fluid flow tends to leak over the blade tip from the pressure side to the suction side via the clearance gap.

This leakage flow has adverse effects including reducing the rate of change of momentum in the axial and circumferential flow directions and producing secondary flow structures within the axial flow. These adverse effects cause an efficiency drop of the compressor stage and in more extreme situations can cause a blade to stall. Such a stall can progress circumferentially from blade to blade, setting up a rotating stall. If the stall becomes so severe that the compressor stage is not able to create the downstream high pressure that is required for the proper functioning of the device, compressor surge can occur which causes an axial oscillation of the flow in the compressor. Vibrations from stall and surge can also damage compressor components as well as dramatically reduce the compressors efficiency.

Several technologies have been proposed to mitigate the leakage flow and its effects on a compressor stage and usually these fall within one of three principles. The first is to remove the clearance gap by connecting the blade to an end wall ring that rotates with the blade. However, this increases the complexity and weight of the compressor. The second is the use of three-dimensional blade design to reduce the blade tip loading which is cost-intensive and increases the complexity of the compressor. The third is the design of restrictive flow paths using, for example, plenums or slots to resist the leakage flow. Such designs increase the complexity of the compressor without necessarily improving its efficiency.

Summary of the Invention

According to one aspect of the present invention, there is provided a flow assembly for an axial turbomachine comprising an outer shroud, an inner hub, and at least one blade mounted to one of the shroud and hub and comprising pressure and suction surfaces, wherein the other one of the shroud and hub comprises a wall and the or each one blade extends towards the wall such that a clearance gap is provided therebetween, the flow assembly configured such that, in use, fluid flows through the flow assembly from an upstream side to a downstream side of the flow assembly, wherein the wall comprises a recirculation channel comprising an outlet and an inlet located between the outlet and the downstream side of the flow assembly, the recirculation channel configured such that when fluid flows through the flow assembly from the upstream side to the downstream side, fluid flow from the pressure surface side of the at least one blade enters the inlet and flows along the recirculation channel to be expelled from the outlet to impede leakage of fluid flow in the clearance gap from the pressure surface side to the suction surface side of the or one of the blades.

By impeding the fluid flow in the clearance gap, efficiency losses can be minimised such that the efficiency of a device in which the flow assembly is provided is increased. This means, for example, that an axial turbomachine can be operated a higher speeds before stall or surge conditions are experienced.

Preferentially, the impediment is obtained by the expulsion of flow having its momentum vector aimed against the leakage flow thereby opposing its advance.

In one embodiment, the fluid flow which flows along the recirculation channel is expelled from the outlet with momentum in the axial direction towards the clearance gap such that the flow exiting the recirculation channel is configured to impede the reversal of axial fluid flow caused by the leakage of fluid flow from the pressure surface side of the at least one blade, via the clearance gap, to the suction surface side of the at least one blade.

In one embodiment, the other one of the outer shroud and inner hub comprises a wall. The wall of the outer shroud and/or inner hub may extend circumferentially. The walls of the outer shroud and inner hub may define together with the blade(s) a fluid flow path through the compressor stage.

In one embodiment, the blade and wall are rotatable relative to each other.

The one or more blades may extend radially. The flow assembly may have a central axis that extends between the upstream and downstream sides of the flow assembly. In some embodiments, the inner hub and/or outer shroud rotates about the central axis of the flow assembly.

In one embodiment, when fluid flows through the flow assembly from the upstream side to the downstream side, fluid flow from the pressure surface side of the blade enters the inlet and flows along the recirculation channel to be expelled from the outlet to impede fluid flow in the clearance gap in the opposite direction to the axial direction.

In some embodiments, the recirculation channel is configured to accelerate fluid flow from the inlet towards the outlet. The cross-sectional area of at least a portion of the recirculation channel may reduce in the direction from the inlet to the outlet. Optionally, the recirculation channel may be configured to reversibly accelerate fluid flow from the inlet towards the outlet.

Therefore, the momentum of the recirculated fluid flow is increased and so it is more effective at impeding the fluid flow through the clearance gap.

In some embodiments, the flow assembly is configured such that, in use, fluid flows through the flow assembly from an upstream side to a downstream side of the flow assembly in an axial direction, wherein the inlet of the recirculation channel is located downstream of the outlet in the axial direction of the said fluid flow.

The recirculation channel may further comprise inner and outer walls and, preferably, the inner and outer walls comprise smooth surfaces. The recirculation channel may follow a non-linear path. In one embodiment, at least a portion of the recirculation channel follows a generally curved path. In some embodiments, the recirculation channel extends generally in a U-shape from the inlet to the outlet.

The outlet of the recirculation channel may be configured such that the fluid expelled from the outlet is directed towards the clearance gap.

In some embodiments, the outlet is inclined relative to the central axis of the flow assembly such that fluid expelled from the outlet is directed towards the downstream side of the flow assembly. In one such embodiment, the outlet is inclined relative to the central axis of the flow assembly by an angle in the range of 5 to 45 degrees. Thus, the fluid flow exiting the outlet of the recirculation channel is directed downstream and generally opposite to the leakage flow in the clearance gap to impede the leakage flow.

In some embodiments, the inlet is inclined relative to the central axis of the flow assembly such that fluid entering the inlet is directed towards the upstream side of the flow assembly. In one such embodiment, the inlet is inclined relative to the central axis of the flow assembly by an angle in the range of 30 to 60 degrees. The inclined inlet allows the reverse axial momentum of the high pressure flow to be used in generating a higher axial momentum for the fluid flow at the outlet.

In some embodiments, the recirculation channel is inclined relative to the radial direction. The recirculation channel may be inclined upstream relative to the axial direction. The inlet and/or outlet may be inclined upstream relative to the axial direction. Preferably, the recirculation channel is located such that the outlet is downstream of the leading edge and the inlet is upstream of the trailing edge.

By having the outlet downstream of the leading edge and the inlet upstream of the trailing edge, the present invention takes advantage of the pressure difference between the opposing surfaces of a blade rather than the axial pressure differences before and after the blade. Therefore, a section of the recirculation channel is only activated when the blade passes it, rather than constantly providing a recirculating flow. The location of the inlet upstream of the trailing edge is advantageous because the inlet can be placed in the region of the highest pressure on the pressure surface side of the blade so as to encourage a recirculation flow with the highest momentum. The location of the outlet downstream of the leading edge is advantageous because the outlet can be placed in the region in which the leakage flow is the strongest. Therefore, the main portion of the leakage flow can be directly impeded and opposed by the recirculation flow, leading to increased efficiency of in the flow assembly.

Preferably, the recirculation channel is configured such that a section of the inlet and a corresponding section of the outlet are on opposite sides of a section of the blade when the blade is aligned with the sections of the inlet and the outlet. That is, the recirculation channel may be configured to recirculate fluid flow from the pressure surface side to the suction surface side of any one blade when the blade is rotated relative to the wall.

For example, the recirculation channel may recirculate fluid flow from the pressure surface side of one blade to the suction surface side of the same blade. Alternatively, the recirculation channel may recirculate fluid flow from the pressure surface side of one blade to the suction surface side of another blade. The other blade may be a blade adjacent to the blade from which the recirculated fluid flow originates or a blade that is multiple pitches away from the blade from which the recirculated fluid flow originates. In some embodiments, the recirculation channel may recirculate fluid flow from the pressure surface side of one blade to the suction surface side of multiple blades.

The inlet of the recirculation channel may be located at the location of maximum diffusion along the pressure surface of the blade at a predetermined condition.

Preferably, the recirculation channel is activated to recirculate fluid flow from the inlet to the outlet by the pressure difference between fluid that is proximate the pressure surface of the blade and fluid that is proximate the suction surface of the blade axially upstream of the inlet.

In an embodiment, the recirculation channel extends circumferentially at least partly about a central axis of the flow assembly. Preferably, the recirculation channel extends circumferentially substantially 360 degrees about the central axis of the flow assembly. Thus, a pitchwise-periodic flow regime can be created in which fluid flow characteristics are pitchwise-periodic in the flow assembly.

The recirculation channel may comprises one or more struts configured to structurally fix the recirculation channel walls relative to one another whilst providing minimal flow resistance through the recirculation channel. In some embodiments, the struts may be shaped to influence the flow through the recirculation channel.

In one embodiment, the blade comprises a trailing edge and a leading edge, and the recirculation channel may be located such that the inlet and/or outlet are axially downstream of the leading edge and/or axially upstream of the trailing edge of the blade. Preferably, the inlet and outlet of the recirculation channel are located between the leading and trailing edges of the blade(s) in the axial direction.

The flow assembly may be configured such that a chord line extending between the leading and trailing edges of the blade is inclined relative to the axial direction.

In some embodiments, the outlet is located between 5% and 43% of the chord line length of the blade tip axially downstream of the leading edge of the blade and preferentially at 15% of the chord length. In some embodiments, the inlet is located between 40% and 70% of the chord line length of the blade tip axially downstream of the leading edge of the blade and preferentially at 50% of the chord length.

In some embodiments, the outlet is located between 4% and 43% of the mid-span chord length of the blade axially downstream of the leading edge of the blade and preferentially at 14% of the chord length. In some embodiments, the inlet is located between 32% and 72% of the mid-span chord length of the blade axially downstream of the leading edge of the blade and preferentially at 52% of the chord length.

The outlet may comprise a ridge configured to impede a separated flow bubble. The ridge may be located in proximity to a downstream edge of the outlet. The downstream edge of the outlet may be chamfered. The ridge limits the length that the separation bubble can encroach into the recirculation channel and thereby helps to maintain the efficiency of the recirculation channel as the velocity of the fluid flow increases. The chamfered edge provides a volume for the existence of the separated flow which does not have such a large effect on the momentum of the fluid flow exiting the recirculation channel.

In one embodiment, the blade is mounted to the inner hub and the outer shroud comprises the wall. Alternatively, the blade may be mounted to the outer shroud and the inner hub may comprise the wall. In one embodiment, the blade is a rotor blade and is moved, preferably rotated, relative to the recirculation channel. In another embodiment, the blade is a stator vane.

The flow assembly may be a compressor half-stage for an axial turbomachine.

According to another aspect of the present invention, there is provided an axial turbomachine comprising a flow assembly.

According to yet another aspect of the invention, there is provided an aircraft comprising an axial turbomachine comprising the flow assembly. The aircraft may be a high-speed jet.

Brief Description of the Drawings

So that the invention may be more fully understood, embodiments thereof will now be described, by way of example only, with reference to the accompanying drawings in which:

Fig. 1 shows a schematic perspective view of a section of a known compressor stage and the fluid flows therein;
Fig. 2 shows a schematic perspective side view of a section of a compressor stage according to an embodiment of the present invention;
Fig. 3 shows a schematic perspective side view of a section of the compressor stage of Fig. 2;
Fig. 4 shows a schematic radially outward looking cross-section of the compressor stage shown in Fig. 2;
Fig. 5 shows a perspective schematic cross-sectional side view of the compressor stage of Fig. 2, with a blade of the compressor stage in a first position; and
Fig. 6 shows a perspective schematic cross-sectional side view of the compressor stage of Fig. 2, with the blade in a second position.

Detailed Description

Referring first to Fig. 1, a schematic perspective view of a section of a known axial turbomachine 1 is shown. The axial turbomachine 1 comprises a compressor 2 that comprises one or more compressor stages 3. Each stage comprises one or more rotor flow passages and one or more stator flow passages.

Each compressor stage 3 comprises a half-stage 3A comprising one or more rotating rotor blades 5 and a half-stage (not shown) comprising one or more static stator blades (not shown).

The axial turbomachine 1 may be used to provide thrust for an aircraft (not shown), such as a fast jet. In Fig. 1, a shroud wall 4 of the rotor flow passage of the compressor 2 of the axial turbomachine 1 has been cut away to more clearly illustrate a section of the compressor half-stage 3A.

The rotor blades 5 are mounted to a hub 6 which is located on a central, axially extending axis of the axial turbomachine 1. The central axis of the axial turbomachine 1 is the axis about which the hub 6 rotates and it is parallel to the general axial direction of the fluid flow through the compressor stage 3 and, more generally, through the axial turbomachine 1 shown by arrow (A). The fluid flows through the compressor stage 3 from an upstream side 1A to a downstream side 1B of the compressor half-stage 3A

The hub 6 is rotatable such that the rotor blades 5 rotate relative to the shroud wall 4. The hub 6 is rotated by fluid flow which is ejected from a combustion chamber (not shown) downstream of the compressor 2 into a turbine (not shown). In the turbine, the fluid flow works on turbine rotor blades (not shown) mounted to a spool (not shown) connected to the hub 6. The work performed on the turbine rotor blades by the fluid flow causes the turbine rotor blades to rotate the spool, which in turn rotates the hub 6 and the rotor blades 5 of the compressor stage 3 mounted thereto. The fluid flow is subsequently expelled through a nozzle (not shown). Alternatively, the hub 6 is rotated by a separate drive (not shown). In some embodiments, the turbine is omitted.

Each rotor blade 5 comprises a leading edge 11 and a trailing edge 12. The leading edge 11 is the first part of the rotor blade 5 to encounter the incoming fluid flow and the trailing edge 12 is the last part of the rotor blade 5 to encounter the incoming fluid flow. Therefore, the leading edge 11 is upstream of the trailing edge 12. A straight line between the leading and trailing edges 11 and 12 is known as a chord line. The chord line of each rotor blade 5 is inclined relative to the axial direction (A) to control the rate of change of momentum that each rotor blade 5 imparts to the incoming fluid flow. It will be appreciated that the fluid flow may enter each stage at an angle relative to the axial direction (A), for example, following a spiral path through the compressor stage 3 having both axial and circumferential components, but that the fluid flows generally in the axial direction (A) through each compressor stage 3 from the upstream side 1A to the downstream side 1B of the compressor half-stage 3A.

The leading and trailing edges 11 and 12 of each rotor blade 5 are connected by upper and lower surfaces. The lower surface forms a pressure surface 13 and the upper surface forms a suction surface 14. There exists a higher pressure of fluid proximate the pressure surface 13 of each rotor blade 5 compared to a lower pressure of fluid proximate to the suction surface 14 of the same rotor blade 5. Thus, there also exists a pressure gradient between adjacent rotor blades 5 such that there is a pressure increase from the suction surface 14 of a first rotor blade 5 to the pressure surface 13 of an adjacent second rotor blade 5 during normal fluid flow conditions.

Each rotor blade 5 is mounted on the hub 6 such that they are spaced equidistantly, resulting in a pitchwise/circumferentially periodic rotor section of the compressor stage 3. Each rotor blade 5 extends radially outwardly from the hub 6 towards an inner surface 16 of the shroud wall 4 and terminates in a blade tip 17 which shows the aerofoil profile of that end section of the rotor blade 5. In order to avoid mechanical wearing of the blade tip 17 on the inner surface 16 of the shroud wall 4, the rotor blade 5 does not extend all the way to the inner surface 16 of the shroud wall 4. Instead, a clearance gap 18 is provided between each blade tip 17 and the inner surface 16 of the shroud wall 4. A skilled person will recognise that the blades 5 may have a different configuration to that described above. For instance, in one embodiment (not shown), the blades are not spaced equidistantly.

It has been found that the clearance gap 18 between the blade tip 17 of each rotor blade 5 and the inner surface 16 of the shroud wall 4 allows fluid flow under pressure on the pressure surface 13 side of each rotor blade 5 to leak over the blade tip 17, via the clearance gap 18, to the suction surface 14 side of the rotor blade 5 where the fluid flow is under a lower pressure. The leakage flow is shown in Fig. 1 by the arrow labelled (L). The leakage fluid flow (L) flows over the blade tip 17 substantially perpendicularly to the chord line of the rotor blade 5. Therefore, due to the inclination of the chord line of the rotor blade 5 to the axial direction, the leakage fluid flow (L) over the blade tip 17 and through the clearance gap 18 flows upstream relative to the axial direction (A) and generally axial fluid flow. The upstream component of the leakage fluid flow (L) creates a region of reverse fluid flow through the clearance gap 18 and more generally through the compressor half-stage 3A.

The resulting interaction between the main generally axial fluid flow and the leakage fluid flow (L) is that the axial fluid flow is separated from the suction surface 14 of the rotor blades 5 and a vortex, indicated by the arrow labelled (V), is created that extends downstream. If the vortex flow (V) resulting from the leakage flow (L) becomes large enough, it can divert the axial fluid flow over the suction surface 14 of the adjacent rotor blade 5 instead of between the two adjacent rotor blades 5. Therefore, the efficiency of the compressor stage 3, and of the overall compressor 2, is reduced.

In this way, stall may progress around the compressor stage 3 from one rotor blade 5 to the next rotor blade 5 in a direction opposite to the rotation of the rotor blades 5. In the event of the leakage flow (L) reducing the pressure rise through the compressor stage 3 significantly, the pressure upstream of the compressor stage 3 may not be sufficient to support the larger pressure downstream of the compressor stage 3 and compressor surge may occur in which the fluid flow oscillates violently in the axial direction (A) and may cause damage to the rotor blades 5 or to other components of the compressor 2.

Referring now to Figs. 2 to 6, there is shown a section of the rotor flow passage of a flow assembly 3A of an axial turbomachine 1 according to an embodiment of the present invention. In the present embodiment, the flow assembly 3A comprises a half-stage 3A of a compressor stage 3 of a compressor 2 of an axial turbomachine 1. The half-stage 3A comprises one or more rotating rotor blades 5. Each compressor stage 3 may further comprise a half-stage (not shown) comprising one or more static stator blades (not shown).

Figs. 2 and 3 show schematic cross-sectional views of the rotor flow passage of the half-stage 3A comprising a shroud wall 20 which extends in a circumferential direction. An inner surface 21 of the shroud wall 20 defines a radial outer boundary for the fluid flow through the compressor stage 3. The half-stage 3A further comprises a hub wall 22 which extends in a circumferential direction. An outer surface 23 of the hub wall 22 defines a radial inner boundary for the fluid flow through the half-stage 3A. The shroud wall 20 circumferentially surrounds the hub wall 22 such that the shroud wall 20 is an outer wall and the hub wall 22 is an inner wall.

As shown in Fig. 2, the shroud wall 20 radially converges along the axial direction (A) such that the distance between the inner surface 21 of the shroud wall 20 and the outer surface 23 of the hub wall 22 reduces in the axial direction (A), i.e. in the direction of the axial fluid flow (A) through the compressor stage 3 from the upstream side 1A to the downstream side 1B of the compressor half-stage 3A. As the fluid flow is compressed by a rise in pressure due to a change in its circumferential velocity, the volume it occupies is reduced and so the volume that it flows through must be reduced to avoid pressure losses and a reduction in axial velocity. The convergence of the shroud wall 20 reduces the cross-sectional area through which the fluid flow must pass and therefore contributes to maintaining an appropriate axial velocity component of the fluid that undergoes compression as it passes through the compressor stage 3. The inner surface 21 of the shroud wall 20 and the outer surface 23 of the hub wall 22 define radially a fluid flow path 24 between them through the compressor stage 3. Thus, fluid is able to flow along the fluid flow path 24 to pass through the compressor stage 3 in the axial direction (A).

The half-stage 3A further comprises at least one blade 26 mounted to the hub wall 22. The blade 26 is mounted to the hub wall 22 such that it extends generally radially outwards towards the shroud wall 20. The hub wall 22 is rotatable, driven by a turbine (not shown) or by a separate drive (not shown), relative to the shroud wall 20. Therefore, the blade 26 is a rotor blade which is rotatable relative to the shroud wall 20.

The blade 26 comprises a pressure surface 27 and a suction surface 28 which extend between a leading edge 29 and a trailing edge 30. The trailing edge 30 is downstream of the leading edge 29, as previously described in relation to Fig. 1. The blade 26 further comprises a blade tip 31 and a root 32. The blade tip 31 is provided at the opposite end of the blade 26 to the root 32. The root 32 is mounted on the hub wall 22. The root 32 may be attached to the hub wall 22 or integrally formed therewith. In some embodiments, the blade 26 may have a larger or different aerofoil profile at the root 32 than at the tip 31. The blade 26 may be swept and/or comprise a twist and/or a lean and/or a root fillet to improve the aerodynamic efficiency. The blade 26 may also comprise root and/or tip fillets.

The blade tip 31 does not contact the inner surface 21 of the shroud wall 20. Instead, a clearance gap 33 is provided between the blade tip 31 of the blade 26 and the inner surface 21 of the shroud wall 20.

The half-stage 3A further comprises a recirculation channel 35 which is configured to passively recirculate fluid flow, shown by the arrow labelled (R) in Fig. 3, from the pressure surface 27 side of the blade 26 to the suction surface 28 side of the blade 26 when the blade 26 is rotated relative to the shroud wall 20. The recirculation channel 35 may passively recirculate the said fluid flow when the blade 26 is rotated relative to the recirculation channel 35.

The recirculation channel 35 is configured to direct the recirculated fluid flow (R) towards the clearance gap 33 between the blade tip 31 of the blade 26 and the inner surface 21 of the shroud wall 20. By redirecting fluid flow with momentum in the axial direction (A) towards the clearance gap 33, the recirculation channel 35 can impede the reversal of the axial fluid flow (A) caused by the leakage fluid flow (L) from the pressure surface 27 side of the blade 26 over the blade tip 31, via the clearance gap 33, to the suction surface 28 side of the blade 26.

The recirculation channel 35 comprises an inlet 36 and an outlet 37. The inlet 36 is located downstream of the outlet 37. More specifically, the inlet 36 is located axially downstream of the outlet 37, as will be described in more detail hereinafter. Furthermore, the recirculation channel 35 is axially located within the compressor stage 3 such that the inlet 36 and the outlet 37 of the recirculation channel 35 are downstream of the leading edge 29 of the blade 26 and upstream of the trailing edge 30 of the blade 26. In other words, the inlet 36 and the outlet 37 of the recirculation channel 35 are axially located in the compressor half-stage 3A between 0 and 100% of the chord line length of the blade 26, for example, the chord line length of the blade tip 31. In the present embodiment, the recirculation channel 35 is formed in the shroud wall 20 such that the inlet 36 to and outlet 37 from the recirculation channel 35 comprise apertures in the inner surface 21 of the shroud wall 20.

Referring to Fig. 4, it can be seen that, when the blade 26 is rotated relative to the inlet 36 of the recirculation channel 35, it is the pressure surface 27 of the blade 26 that causes an area of local high pressure in the vicinity of the inlet 36 to the recirculation channel 35. Axially upstream of the inlet 36 is the outlet 37 of the recirculation channel 35. The respective portion of the outlet 37 has already been passed by the blade 26 and so it is proximate to the suction surface 28 of the blade 26 that is in an area of local low pressure. Due to the difference in pressure between the pressure surface 27 and the suction surface 28 of the blade 26, fluid flow is recirculated through the recirculation channel 35 from axially downstream on the pressure surface 27 side of the blade 26 to axially upstream on the suction surface 28 side of the blade 26. The recirculated fluid flow (R) is directed towards the clearance gap 33 and so its momentum in the axial direction of the main fluid flow (A) impedes the reverse fluid flow caused by the leakage flow (L) over the blade tip 31 through the clearance gap 33. This reduces the effect of the leakage flow (L) and, therefore, increases the efficiency of the compressor stage 3 and may extend the operating envelope of the compressor 2.

It will be understood that the flow in the recirculation channel 35 is generally axial but may comprise a tangential component. The tangential component of the recirculation fluid flow (R) in the recirculation channel 35 is dependent upon the operating condition of the half stage 3A. That is, the flow in the recirculation channel 35 is dependent upon the rotational speed U of the blade(s) 26 and upon the downstream pressure of the fluid flow.

Depending on the operating condition of the half-stage 3A, the recirculation channel 35 may recirculate fluid flow from the pressure surface side of one blade 26 to the suction surface side of the same blade 26. For example, in an embodiment where the blade 26 is not moving relative to the recirculation channel 35 or where the blade 26 is rotating at a speed that is approximately an integer multiple of the fluid flow speed in the recirculation channel 35 or where the tangential component of the flow in the recirculation fluid flow (R) in the recirculation channel 35 is substantially equal to the rotational speed U of the blade 26.

Alternatively, depending on the operating condition of the half-stage 3A, the recirculation channel 35 may recirculate fluid flow from the pressure surface side of one blade 26 to the suction surface side of another blade. The other blade may be a blade adjacent to the blade 26 from which the recirculated fluid flow (R) originates or a blade that is multiple pitches away from the blade 26 from which the recirculated fluid flow originates. In such a situation, the tangential component of the recirculated fluid flow (R) in the recirculation channel 35 is offset from the rotational speed U of the blades

26. In some embodiments, the recirculation channel 35 may recirculate fluid flow from the pressure surface side of one blade to the suction surface side of multiple blades.

Computational fluid dynamic simulations have shown that the use of the momentum of the recirculated flow (R) to counteract the leakage flow (L) reduces, if not eliminates, the magnitude of the reverse flow in the vicinity of the blade tip 31 caused by the leakage flow (L). Firstly, the momentum of the leakage flow (L) in the opposite direction to the generally axial flow (A) is opposed or cancelled out by the momentum of the recirculated fluid flow (R) exiting the outlet 37 of the recirculation channel 35.

Furthermore, the recirculation channel 35 is configured to accelerate the speed of the recirculated fluid flow (R) from the inlet 36 to the outlet 37. The recirculated fluid flow (R) is accelerated towards the outlet 37 of the recirculation channel 35 because the cross-sectional area of the recirculation channel 35 reduces along the recirculation fluid flow (R) path from the inlet 36 to the outlet 37. By accelerating the recirculating fluid flow (R) to the outlet 37 of the recirculation channel 35, the recirculated fluid flow (R) is more effective at counteracting the reversal of fluid flow caused by the leakage flow (L) over the blade tip 31 because of its increased momentum. The converging recirculation channel 35 also helps the recirculation fluid flow (R) exiting the outlet 37 to be focused and directed towards the clearance gap 33.

The recirculation channel 35 may be configured to reversibly, or substantially reversibly, accelerate the recirculation fluid flow (R) from the inlet 36 to the outlet 37, as can be most clearly seen in Figs. 5 and 6. This enables the recirculated fluid flow (R) to accelerate more efficiently in the recirculation channel 35 such that the recirculated fluid flow (R) has a greater axial momentum where it is ejected from the outlet 37 of the recirculation channel 35 then where it enters the recirculation channel from the inlet 36. The flow through the recirculation channel 35 may be substantially isentropic.

In the present embodiment, the recirculation channel 35 comprises an inner surface 38 and an outer surface 39. The inlet 36 may comprise upstream and downstream edges 40, 42, the upstream edge 40 being located nearer to the upstream side of the flow assembly than the downstream edge 42. The outlet 37 may comprise upstream and downstream edges 43, 41, the upstream edge 43 being located nearer to the upstream side of the flow assembly than the downstream edge 41. The inner surface 38 extends from the upstream edge 40 of the inlet 36 to the downstream edge 41 of the outlet 37 whereas the outer surface 39 extends from the downstream edge 42 of the inlet 36 to the upstream edge 43 of the outlet 37.

The schematic cross-sectional side views of Figs. 5 and 6 show a slice of the blade 26 with the outlet 37 running on top of the suction surface 28 side of the blade 26 and the inlet 36, axially downstream of the outlet 37, running on top of the pressure surface 27 side of the blade 26.

The distance between the inner and outer surfaces 38, 39 of the recirculating channel 35 reduces from the inlet 36 towards the outlet 37 so that the cross-sectional area of the recirculation channel 35 reduces to accelerate the recirculated fluid flow (R) towards the outlet 37. The inner and outer surfaces 38 and 39 of the recirculation channel 35 are configured to converge over at least a portion of the length of the recirculation channel 35 such that the recirculated fluid flow (R) is accelerated reversibly in the recirculation channel 35. In some embodiments, the inner and outer surfaces 38 and 39 of the recirculation channel 35 are configured to converge over the entire length of the recirculation channel 35 such that the recirculated fluid flow (R) is accelerated reversibly in the recirculation channel 35. In addition, the inner and outer surfaces 38 and 39 of the recirculation channel 35 are smooth to aid with the reversible acceleration of the recirculated flow (R).

As can be seen in the cross-sectional side views of Figs. 5 and 6, the recirculation channel 35 generally extends in a U-shape from the inlet 36 to the outlet 37. The U-shaped recirculation channel 35 is inclined relative to the axial direction (A) and to the radial direction. That is, the U-shaped recirculation channel 35 is inclined upstream relative to the radial direction and axial direction (A) so that a bend section 45 of the recirculation channel 35, which is connected to the inlet 36 and the outlet 37 by two conduits 46 and 47, is located closer to the outlet upstream 37 than to the inlet downstream 36. The conduits 46 and 47 may be profiled. A portion of each conduit 46 and 47 may extend in a substantially linear path. The conduits 46 and 47 may comprise first and second straight sections respectively.

The conduit 46, which fluidly connects the inlet 36 to the bend section 45, is inclined upstream relative to the axial direction (A). The conduit 46 may be inclined relative to the axial direction (A) and to the radial direction. In one embodiment, the conduit 46 is inclined relative to the axial direction (A) by angle Z1 (as shown in Fig. 5). Optionally, the conduit 46 is inclined in the range of 30 to 60 degrees to the axial direction (A) extending upstream from the inlet 36. The conduit 47, which fluidly connects the bend section 45 to the outlet 37 of the recirculation channel 35, is inclined upstream relative to the axial direction (A). The conduit 47 may be inclined relative to the axial direction (A) and to the radial direction. In one embodiment, the conduit 47 is inclined relative to the axial direction (A) by angle Z2 (as shown in Fig. 5). Optionally, the conduit 47 is inclined in the range of 5 to 45 degrees relative to the axial direction (A) extending upstream from the outlet 37. The axis of the first and second conduits 46 and 47 are considered to be a line through the centre points of the cross-sections of the converging inner and outer surfaces 38 and 39. The axis of the conduits 46 and 47 may be inclined relative to the axial direction (A) by angles Z1 and Z2 respectively. It will be understood that the inner and outer surfaces 38 and 39 of the first and second conduits 46 and 47 may deviate from this inclination angle by up to 10 degrees due to the convergence of the surfaces 38 and 39.

In the present embodiment, the downstream edge 41 of the outlet 37 is chamfered such to generate a substantially straight wall section 48 up to a ridge 49 in the inner surface 38. The ridge 49 is formed where the chamfered edge formed where the straight wall section 48 and the inner surface 38 meet. The edge 41 and the ridge 49 lock the position of a separated flow bubble that naturally generates over the inner surface 38 at the confluence of the leakage flow (L) and of the recirculated fluid flow (R). The ridge 49 prevents the separation line from back-tracking further into the recirculation channel 35 along surface 38 and from the resulting larger separation bubble obstructing the recirculated fluid flow (R). In some embodiments, the ridge may have a small raised protrusion on the chamfered straight wall section 48 to lock the position of the separation flow without adversely affecting the bulk of the recirculation flow R exiting through the outlet 37 of the recirculation channel 35.

Referring back to the schematic radial outward view of Fig. 4, which looks along the blade 26 towards the shroud wall 20, it can be seen that the chord line, shown by the dashed line X-X in Fig. 4, extending between the leading and trailing edges 29 and 30 of the blade 26, is inclined relative to the axial direction (A). The chord line X-X is inclined such that the leading edge 29 of the blade 26 is inclined towards the direction of rotation (U) of the blade 26. Therefore, due to the inclination of the blade 26 relative to the axial direction, a section 51 of the outlet 37, shown hatched in Fig. 4, which is proximate to the suction surface 28 side of the blade 26, is directly axially upstream of a section 52 of the inlet 36, shown hatched in Fig. 4, which is proximate to the pressure surface 27 side of the blade 26. Due to the local pressure field around the blade 26, high pressure fluid on the pressure surface 27 side of the blade is recirculated towards the low pressure fluid on the suction surface 28 side of the blade 26. The recirculation channel 35 can be optimised such that the inlet 36 and the outlet 37 are aligned axially on opposing sides of a predetermined section 53 of the blade 26.

For example, the inlet 36 to the recirculation channel 35 may be placed proximate to the location of the maximum diffusion along the pressure surface 27 of the blade 26 for a given operating condition, e.g. close to the stall, and/or the outlet 37 of the recirculation channel 35 may be placed proximate the location of the lowest pressure along the suction surface 28 side of the blade 26. Due to the recirculation channel 35 being configured to connect the two areas with the largest pressure difference, the acceleration of the recirculated fluid flow (R) can be maximised.

The outlet 37 of the recirculation channel 35 is preferably located within the range of 5% of the axial chord length to 45% of the axial chord length of the blade axially downstream of the leading edge of the blade. More preferably, the outlet 37 of the recirculation channel 35 is located within the range of 4% to 43% of the chord length of the blade. The outlet 37 of the recirculation channel 35 is preferentially located 15% of the chord length downstream of the leading edge 29. The inlet 36 of the recirculation channel 35 is preferably located within the range of 40% of the axial chord length of 70% of the axial chord length of the blade axially downstream of the leading edge of the blade. More preferably, the inlet 36 of the recirculation channel 35 is located within the range of 32% to 72% of the chord length of the blade. The inlet 36 of the recirculation channel is preferentially located 50% of the chord length axially downstream of the leading edge 29 of the blade.

The location of the outlet 37 of the recirculation channel 35 with respect to the axial chord length of the blade refers to the location of the upstream edge 43 of the outlet 37. The location of the inlet 36 of the recirculation channel 35 with respect to the axial chord length of the blade refers to the location of the downstream edge 42 of the inlet 36.

The locations outlined above of the outlet 37 and inlet 36 of the recirculation channel 35 relative to the axial chord of the blade are given with respect to a reference blade chord value. The reference blade chord for the values given above can be either the chord of the blade mid-span or the chord of the blade tip. Where the reference blade chord is the blade mid-span, the outlet 37 of the recirculation channel 35 is more preferably located at 14% of the chord and the inlet 36 of the recirculation channel is more preferably located at 52% of the chord.

Fig. 4 shows section 51 in which the edge 43 of surface 39 of the recirculation channel 35 is located axially upstream of the suction surface 28. In this preferential configuration, shown in the meridional plane in Fig. 5, the outlet 37 becomes exposed to the low pressure of the suction surface 28 and generates a recirculation flow (R) with an axial momentum that is adequate for controlling/contrasting the leakage flow (L). As the blade 26 advances in its direction of rotation, the blade tip 31 occludes the channel inlet 36 by the advancing pressure surface 27 of blade 26. This is generates the configuration shown in the meridional plane in Fig. 6, which shows the channel inlet 36 when partially occluded. This partial occlusion is detrimental to the recirculation flow (R), so that the blade 26 when positioned as in Fig. 5 provides more axial momentum for controlling the leakage flow (L) than when blade is positioned as in Fig. 6.

In some embodiments, when the blade 26 is in a first rotational position such that a portion (depicted by hatching at 52 in Fig. 4 for illustrative purposes) of the channel inlet 36 is downstream of the blade tip 31, as shown in Figs. 4 and 6, a corresponding portion (depicted by hatching at 51 in Fig. 4 for illustrative purposes) of the channel outlet 37 is upstream of the blade tip 31. Said portion of the channel outlet 37 may be directly axially upstream of the channel inlet 36. In some embodiments, where the blade 26 is in a first rotational position such that a portion of the channel inlet 36 is downstream of the blade tip 31, as shown in Figs. 4 and 5, the downstream edge 42 of said corresponding portion of the channel outlet 37 is downstream of the blade tip 31. This helps to alleviate occlusion of said corresponding portion of the channel inlet 36 by the advancing pressure surface 27 of blade 26 and thus increases the axial momentum of the recirculation flow for controlling the leakage flow (L). In some embodiments, where the blade 26 is in a first rotational position such that a portion of the channel outlet 36 is upstream of the blade tip 31, as shown in Fig. 5, the downstream edge 41 of said corresponding portion of the channel inlet 36 is upstream of the blade tip 31 and is spaced from the blade tip 31. This configuration has been found to be particularly advantageous at reducing leakage flow.

As can be seen from Fig. 4, when a portion of the channel inlet 36 is downstream of the blade tip 31, the portion of the channel inlet 36 is proximate to the pressure surface side 27 of the blade 26. An adjacent portion of the channel inlet 36 is located upstream of the blade tip 31 on the opposite, suction surface side 28 of the blade 26. That is, the adjacent portion of the channel inlet 36 is proximate to the suction surface side 28 of the blade 26. Similarly, when a portion of the channel outlet 37 is downstream of the blade tip 31, the portion of the channel outlet 37 is proximate to the pressure surface side 27 of the blade 26. An adjacent portion of the channel outlet 37 is located upstream of the blade tip 31 on the opposite, suction surface side 28 of the blade 26. That is, the adjacent portion of the channel outlet 37 is proximate to the suction surface side 28 of the blade 26. In embodiments in which the blade 26 rotates, the stream-wise position of individual portions of the inlet 36 and outlet 37 will vary with respect to the blade 26 as the blade 26 rotates.

As shown in Figs. 2 and 3, the recirculation channel 35 extends in the circumferential direction through the shroud wall 20. Preferably, the recirculation channel 35 extends completely around, or substantially completely around, the shroud wall 20, i.e. the recirculation channel 35 extends circumferentially 360 degrees, or substantially 360 degrees, around the shroud wall 20. Therefore, passive control of the recirculation channel 35 to reduce the effects of leakage flow (L) can be produced at any and all points on the rotational path of the blade 26 around its axis of rotation. Thus, the recirculation channel 35 has an infinite number of rotational symmetries.

Referring to Fig. 3, it can be seen that the recirculation channel 35 further comprises one or more support struts 55. In the present embodiment, the strut 55 extends between the inner and outer surfaces 38, 39 of the recirculation channel 35 to fix a cut-out portion 56 of the shroud wall 20 relative to the rest of the shroud wall 20. The strut 55 is preferentially a cylindrical cross-section of small wetted area, so it may pose minimal resistance to the recirculating flow (R) that is invariant upon the direction of the recirculating flow. There may be a plurality of struts 55 spaced around the recirculation channel 35. The plurality of struts 55 may, optionally, be spaced pitchwise periodic about the recirculation channel 35. In some embodiments, the plurality of struts 55 may be equidistantly spaced.

In the above described embodiments, the blade 26 is mounted to the hub wall 22 of the compressor 2 and is rotatable relative to the shroud wall 20 in which the recirculation channel 35 is located. However, it should be appreciated that in alternative embodiments (not shown), the flow assembly may instead, or additionally, comprise a blade, known as a stator vane. The stator blade may be mounted to the shroud wall 20 and the recirculation channel 35 may be located in the hub wall 22. Optionally, the hub wall 22 may be rotatable relative to the blade 26. In some embodiments (not shown), the flow assembly may comprise a blade 26, known as a stator vane, mounted to the shroud wall 20 and the recirculation channel 35 may be located in the hub wall 22 which is rotatable relative to the blade 26. The flow assembly may comprise a stator half-stage of a compressor stage.

In the present embodiment, the flow assembly 3A comprises a half-stage 3A of a compressor stage 3 of a compressor 2 of an axial turbomachine 1, wherein the half-stage 3A comprises one or more rotating rotor blades 5. However, in an alternative embodiment (not shown), the flow assembly comprises a half-stage comprising one or more static stator blades (not shown). Thus, the recirculation channel may circumferentially extend about the stator blade(s). Thus, the pressure difference of fluid on the pressure surface side and suction surface side of the stator blade(s) causes fluid to flow through the inlet of the recirculation channel to be expelled from the outlet thereof. The pressure difference may be due to the shape of the stator blade(s). The fluid expelled from the outlet is directed to impede leakage flow in the clearance gap. In some embodiments, the stator blade(s) are mounted to one of the shroud wall and hub wall and a recirculation channel is provided in the other one of the shroud wall and hub wall, wherein said other one of the shroud wall and hub wall is rotatable relative to the stator blade(s). Alternatively, said other one of the shroud wall and hub wall may not be rotatable relative to the stator blade(s).

In some embodiments, the compressor stage 3 comprises a half-stage 3A having one or more rotatable blades mounted to one of the shroud wall 20 and hub wall 22 of the compressor 2 and is rotatable relative to the other one of the shroud wall 20 and hub wall 22 and the compressor stage 3 further comprises a half-stage (not shown) having one or more stator blades mounted to said other one of the shroud wall 20 and hub wall 22. A recirculation channel may be provided in said other one of the shroud wall 20 and hub wall 22 to recirculate fluid from the pressure surface side to the suction surface side of the rotatable blade and/or a recirculation channel may be provided in said one of the shroud wall 20 and hub wall 22 to recirculate fluid from the pressure surface side to the suction surface side of the stator blade.

In some embodiments, the compressor 2 may comprise one or more compressor half-stages, which may comprise a stator vane and the recirculation channel 35 without any axially preceding or following rotatable blades. Alternatively, the compressor half-stages may comprise a rotatable blade 26 and the recirculation channel 35 without any axially preceding or following stator vanes.

The flow assembly 3A may comprise a plurality of blades 26. The plurality of blades 26 may be arranged equidistantly to extend from the shroud wall 20 or hub wall 22. The compressor stage 3 may also comprise a set of rotor blades with a recirculation channel 35 in the shroud wall 20 followed by a set of stator vanes with a recirculation channel 35 in the hub wall 22.

In some embodiments, the flow assembly 3A comprises a half-stage 3A of a compressor stage 3 of a compressor 2 of an axial turbomachine 1, wherein the half-stage 3A comprises one or more rotating rotor blades 5. Furthermore, as discussed above, in other embodiments (not shown), the flow assembly may comprise a half-stage comprising one or more static stator blades (not shown). Thus, the recirculation channel may circumferentially extend about the stator blade(s). However, it should be recognised that in alternative embodiments (not shown) the flow assembly is implemented in a different configuration of an axial turbomachine. In one such embodiment, the flow assembly comprises a ducted fan. The ducted fan may comprise a blade that is mounted to one of an outer shroud or inner hub and is rotatable relative to a wall of the other one of the outer shroud or inner hub. The wall comprises a recirculation channel configured such that fluid flow from the pressure surface side of the blade enters the inlet and flows along the recirculation channel to be expelled from the outlet when the blade is rotated to impede leakage flow in the clearance gap from the pressure surface side to the suction surface side of the blade.

In one embodiment, the axial turbomachine 1 is an axial turbomachine for an aircraft (not shown), for example, a high speed jet. In other embodiments (not shown), the axial turbomachine is for a different application, for example, flow transport, including air conditioning. In yet other embodiments (not shown), the axial turbomachine 1 is implemented in power generation or in a turbo-propulsion system.

In order to address various issues and advance the art, the entirety of this disclosure shows by way of illustration various embodiments in which the claimed invention(s) may be practiced and provide for a superior flow assembly for an axial turbomachine, a ducted fan, and an aircraft engine. The advantages and features of the disclosure are of a representative sample of embodiments only, and are not exhaustive and/or exclusive. They are presented only to assist in understanding and teach the claimed features. It is to be understood that advantages, embodiments, examples, functions, features, structures, and/or other aspects of the disclosure are not to be considered limitations on the disclosure as defined by the claims or limitations on equivalents to the claims, and that other embodiments may be utilised and modifications may be made without departing from the scope and/or spirit of the disclosure. Various embodiments may suitably comprise, consist of, or consist essentially of, various combinations of the disclosed elements, components, features, parts, steps, means, etc. In addition, the disclosure includes other inventions not presently claimed, but which may be claimed in future.

Claims

1. A flow assembly for an axial turbomachine comprising:
an outer shroud;
an inner hub; and,
at least one blade mounted to one of the shroud and hub and comprising pressure and suction surfaces,
wherein the other one of the shroud and hub comprises a wall and the or each blade extends towards the wall such that a clearance gap is provided therebetween, the flow assembly configured such that, in use, fluid flows through the flow assembly from an upstream side to a downstream side of the flow assembly,
wherein the wall comprises a recirculation channel comprising an outlet and an inlet located between the outlet and the downstream side of the flow assembly, the recirculation channel configured such that when fluid flows through the flow assembly from the upstream side to the downstream side, fluid flow from the pressure surface side of the at least one blade enters the inlet and flows along the recirculation channel to be expelled from the outlet to impede leakage of fluid flow in the clearance gap from the pressure surface side to the suction surface side of the or one of the blades.

2. The flow assembly according to claim 1 or claim 2, wherein the fluid flow which flows along the recirculation channel is expelled from the outlet with momentum in the axial direction towards the clearance gap such that the flow exiting the recirculation channel is configured to impede the reversal of axial fluid flow caused by the leakage of fluid flow from the pressure surface side of the at least one blade, via the clearance gap, to the suction surface side of the at least one blade.

3. The flow assembly according to claim 1 or claim 2, wherein the recirculation channel is configured to accelerate fluid flow from the inlet towards the outlet.

4. The flow assembly according to claim 3, wherein the cross-sectional area of at least a portion of the recirculation channel reduces in the direction from the inlet to the outlet.

5. The flow assembly according to claim 3 or claim 4, wherein the recirculation channel is configured to reversibly accelerate fluid flow from the inlet towards the outlet.

6. The flow assembly according to any one of the preceding claims, wherein the recirculation channel further comprises inner and outer walls and, preferably, the inner and outer walls comprise smooth surfaces.

7. The flow assembly according to any one of the preceding claims, wherein the recirculation channel extends generally in a U-shape from the inlet to the outlet.

8. The flow assembly according to claim 7, wherein the recirculation channel is inclined relative to the radial direction.

9. The flow assembly according to any one of the preceding claims, wherein the outlet is inclined relative to the central axis of the flow assembly such that fluid expelled from the outlet is directed towards the downstream side of the flow assembly and, preferably, the outlet is inclined by an angle in the range of 5 to 45 degrees.

10. The flow assembly according to any one of the preceding claims, wherein the inlet is inclined relative to the central axis of the flow assembly such that fluid entering the inlet flows towards the upstream side of the flow assembly and, preferably, the inlet is inclined by an angle in the range of 30 to 60 degrees.

11. The flow assembly according to any one of the preceding claims, wherein the recirculation channel is configured such that a section of the inlet and a corresponding upstream section of the outlet are on opposite sides of a section of the blade when the blade is aligned with the sections of the inlet and outlet.

12. The flow assembly according to any one of the preceding claims, wherein the inlet of the recirculation channel is located at the location of the maximum diffusion along the pressure surface of the blade at a predetermined working condition.

13. The flow assembly according to any one of the preceding claims, wherein the recirculation channel is activated to recirculate fluid flow from the inlet to the outlet by the pressure difference between fluid that is proximate the pressure surface of the blade and fluid that is proximate the suction surface of the blade axially upstream of the inlet.

14. The flow assembly according to any one of the preceding claims, wherein the recirculation channel extends circumferentially at least partially about a central axis of the flow assembly.

15. The flow assembly according to claim 14, wherein the recirculation channel extends circumferentially substantially 360 degrees about the central axis of the flow assembly.

16. The flow assembly according to any one of the preceding claims, wherein the recirculation channel comprises one or more struts configured to structurally fix the recirculation channel walls while providing minimal flow resistance through the recirculation channel.

17. The flow assembly according to any one of the preceding claims, wherein the blade comprises a trailing edge and a leading edge, and wherein the recirculation channel is located such that the inlet and/or outlet are axially downstream of the leading edge and/or axially upstream of the trailing edge of the blade.

18. The flow assembly according to claim 17, wherein the recirculation channel is located such that the outlet is downstream of the leading edge and the inlet is upstream of the trailing edge.

19. The flow assembly according to claim 17 or claim 18, wherein the outlet is located between 4% and 43% of the mid-span chord length of the blade axially downstream of the leading edge of the blade and preferentially at 14% of the mid-span chord length.

20. The flow assembly according to any one of claim 17 to claim 19, wherein the inlet is located between 32% and 72% of the mid-span chord length of the blade axially downstream of the leading edge of the blade and preferentially a 52% of the mid-span chord length of the blade.

21. The flow assembly according to any one of the preceding claims, wherein the outlet comprises a ridge configured to impede the growth of a separated flow bubble.

22. The flow assembly according to claim 21, wherein the ridge is located in proximity to a downstream edge of the outlet.

23. The flow assembly according to claim 22, wherein the downstream edge of the outlet is chamfered.

24. The flow assembly according to any one of the preceding claims, wherein the blade is mounted to the inner hub and the outer shroud comprises the wall.

25. The flow assembly according to any one of the preceding claims, wherein the blade is mounted to the outer shroud and the inner hub comprises the wall.

26. The flow assembly according to any one of the preceding claims, wherein the blade is a rotor blade and is moved, preferably rotated, relative to the recirculation channel.

27. The flow assembly according to any one of claims 1 to 25, wherein the blade is a stator blade.

28. The flow assembly according to any one of the preceding claims, wherein the flow assembly is a compressor half-stage for an axial turbomachine.

29. An axial turbomachine comprising a flow assembly according to any one of claims 1 to 28.

30. An aircraft comprising an axial turbomachine according to claim 29.

31. The aircraft according to claim 30, wherein the aircraft is a high speed jet.

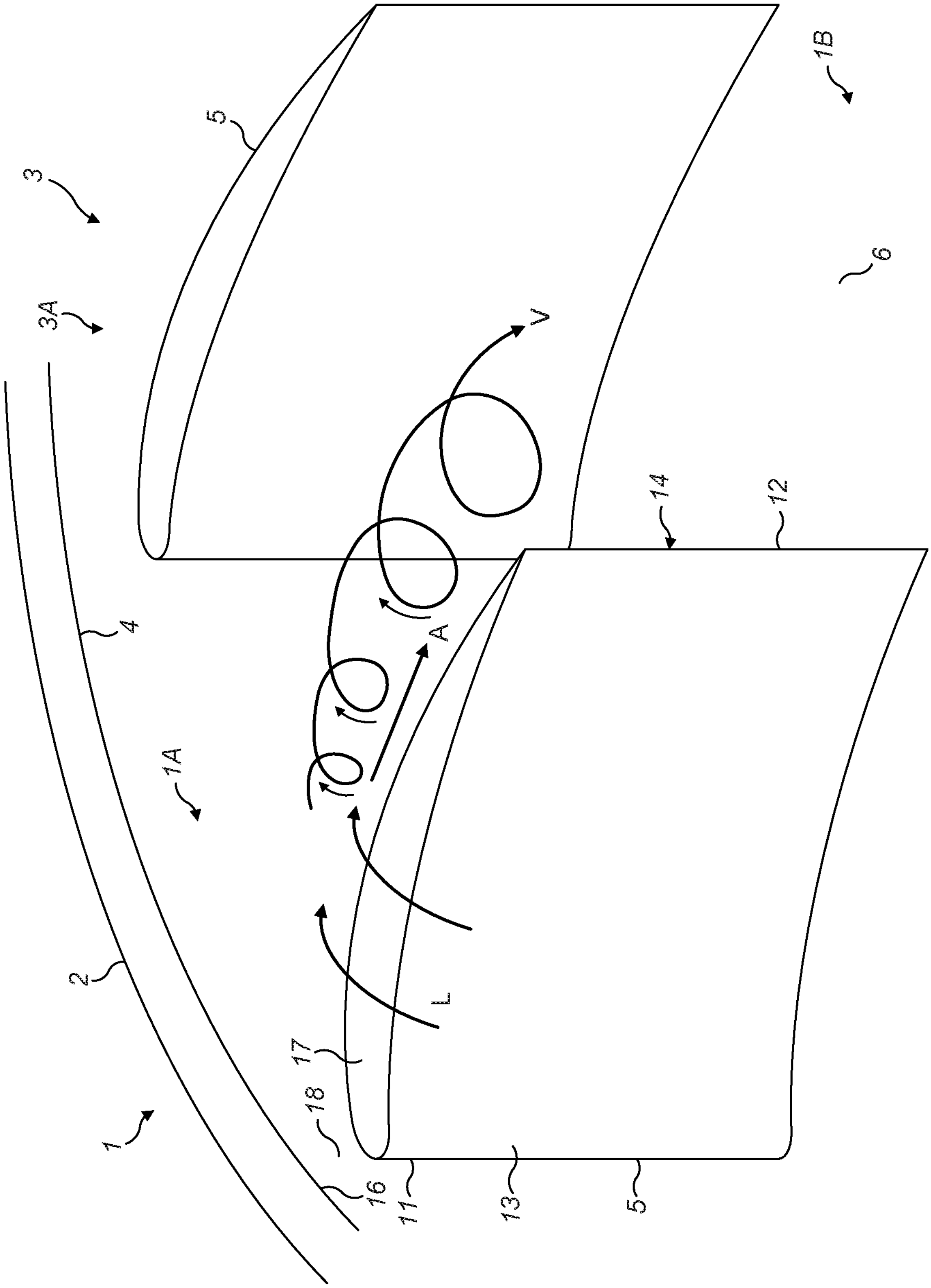

FIG. 1

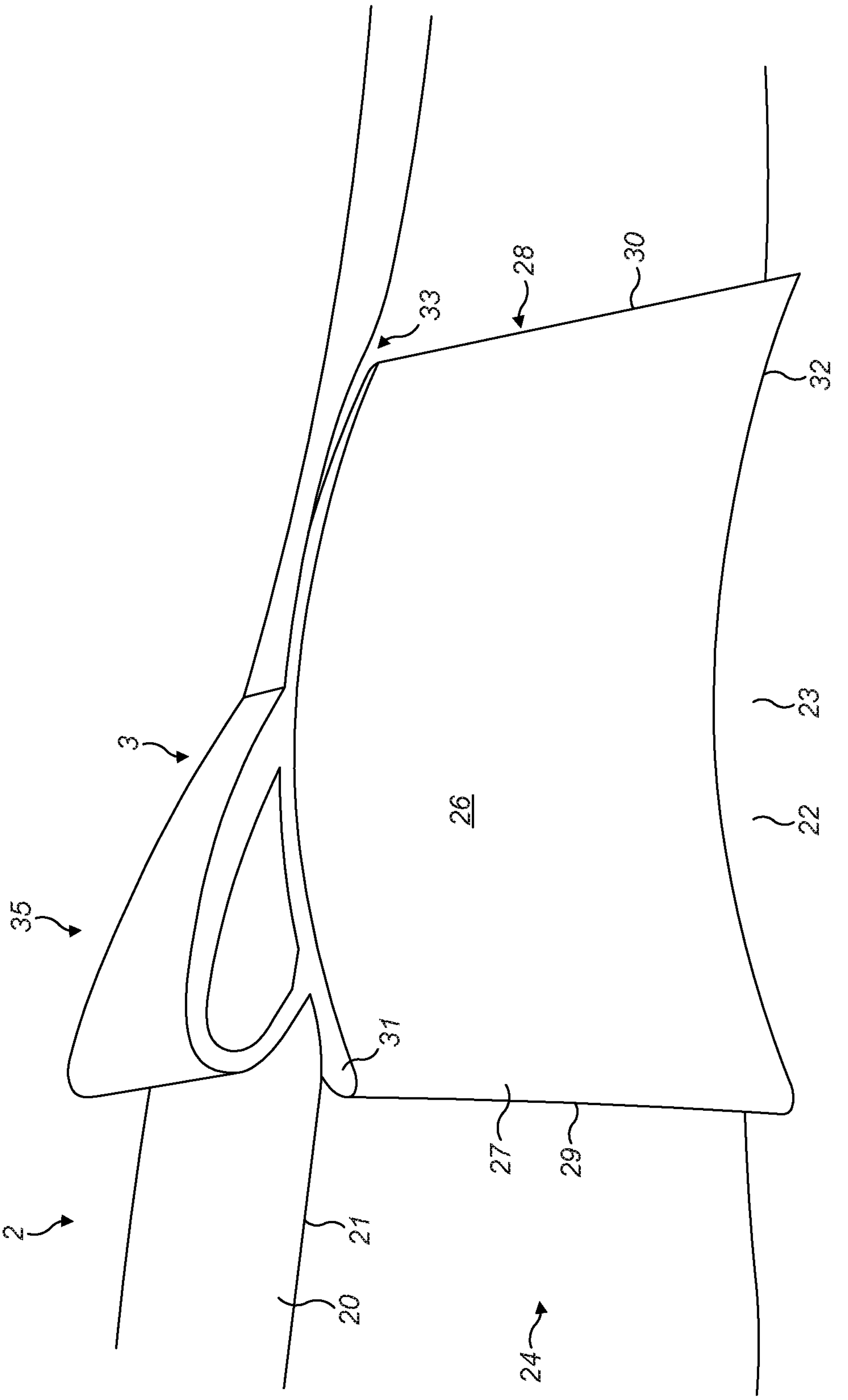

FIG. 2

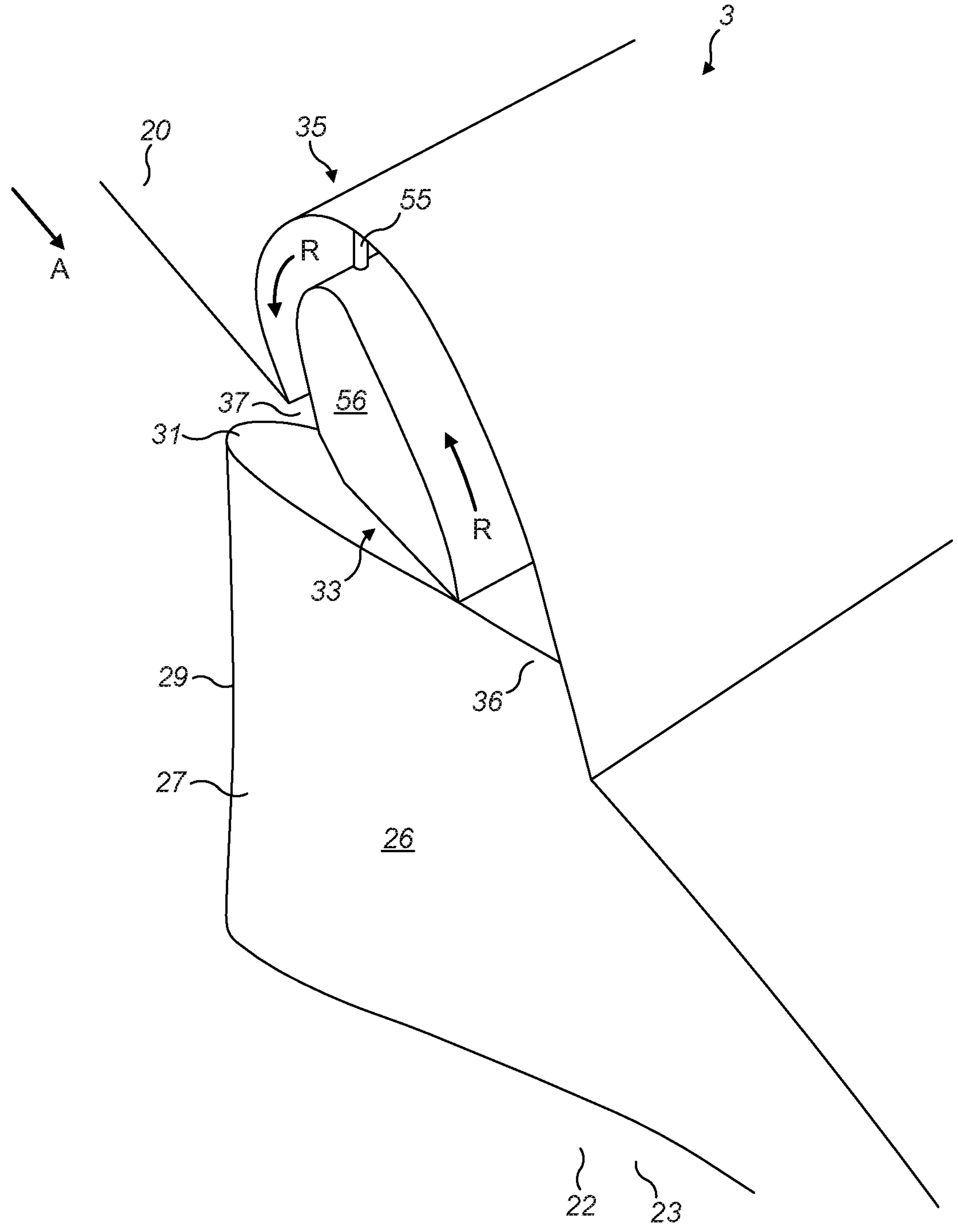

FIG. 3

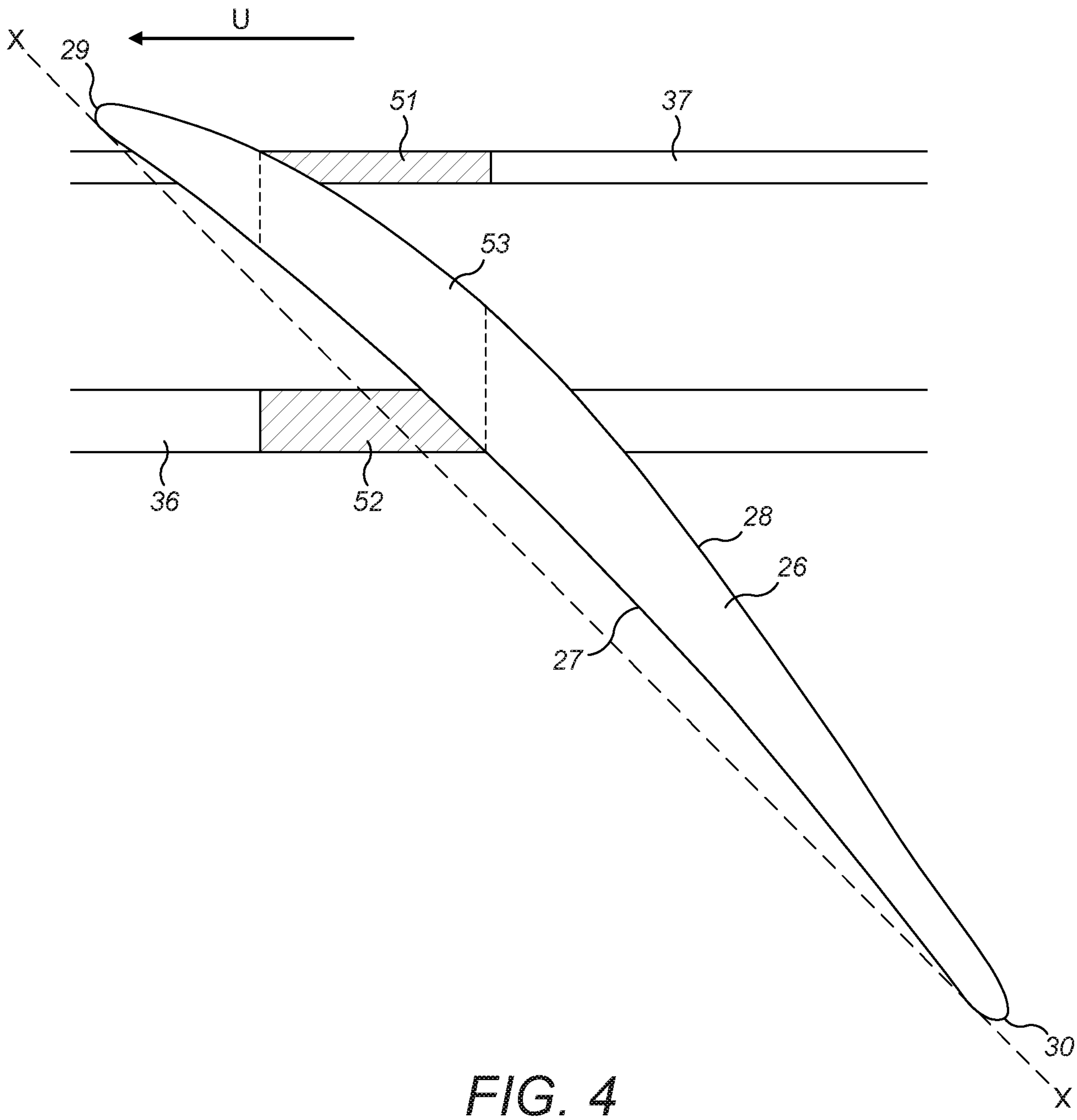

FIG. 4

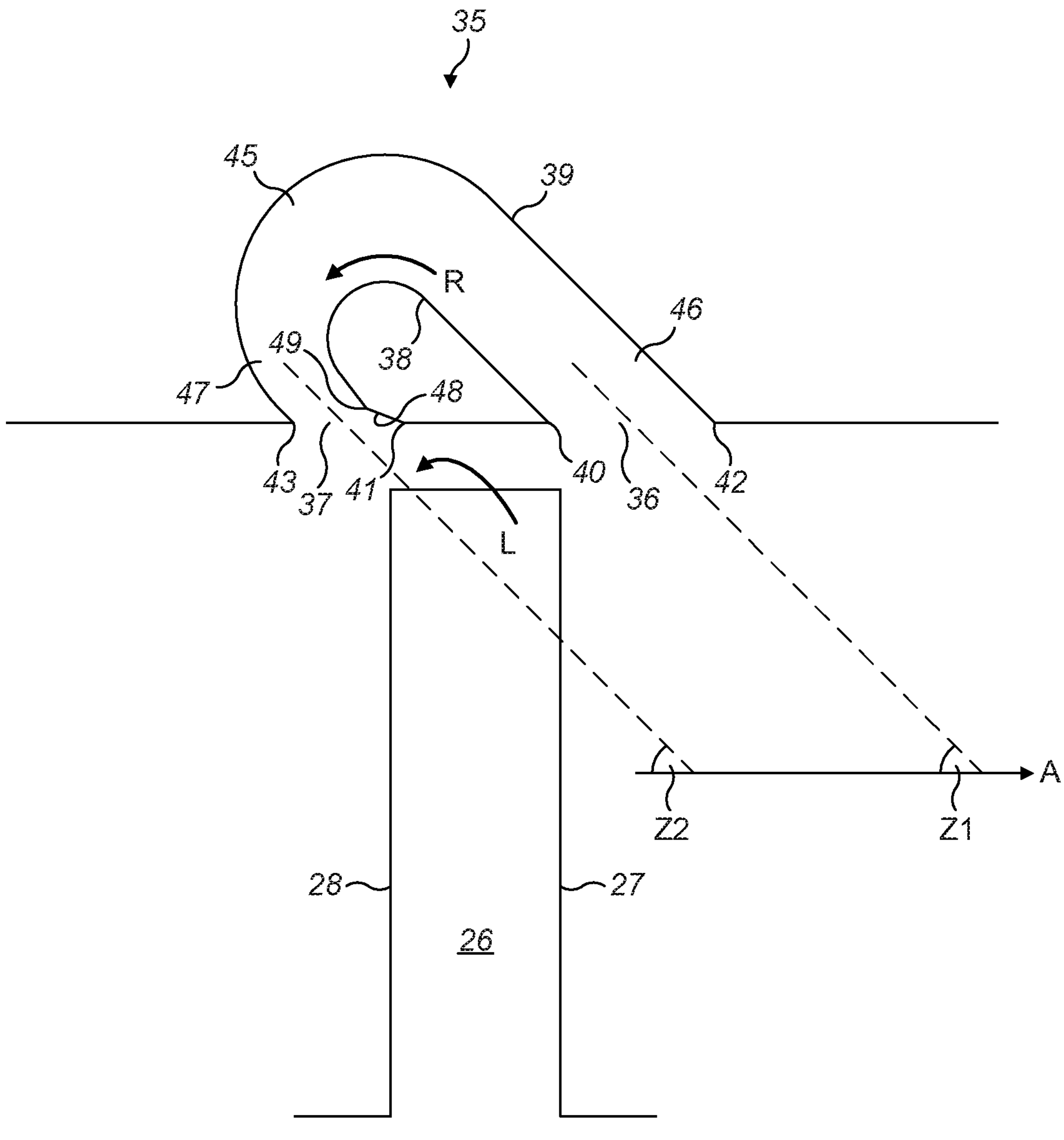

FIG. 5

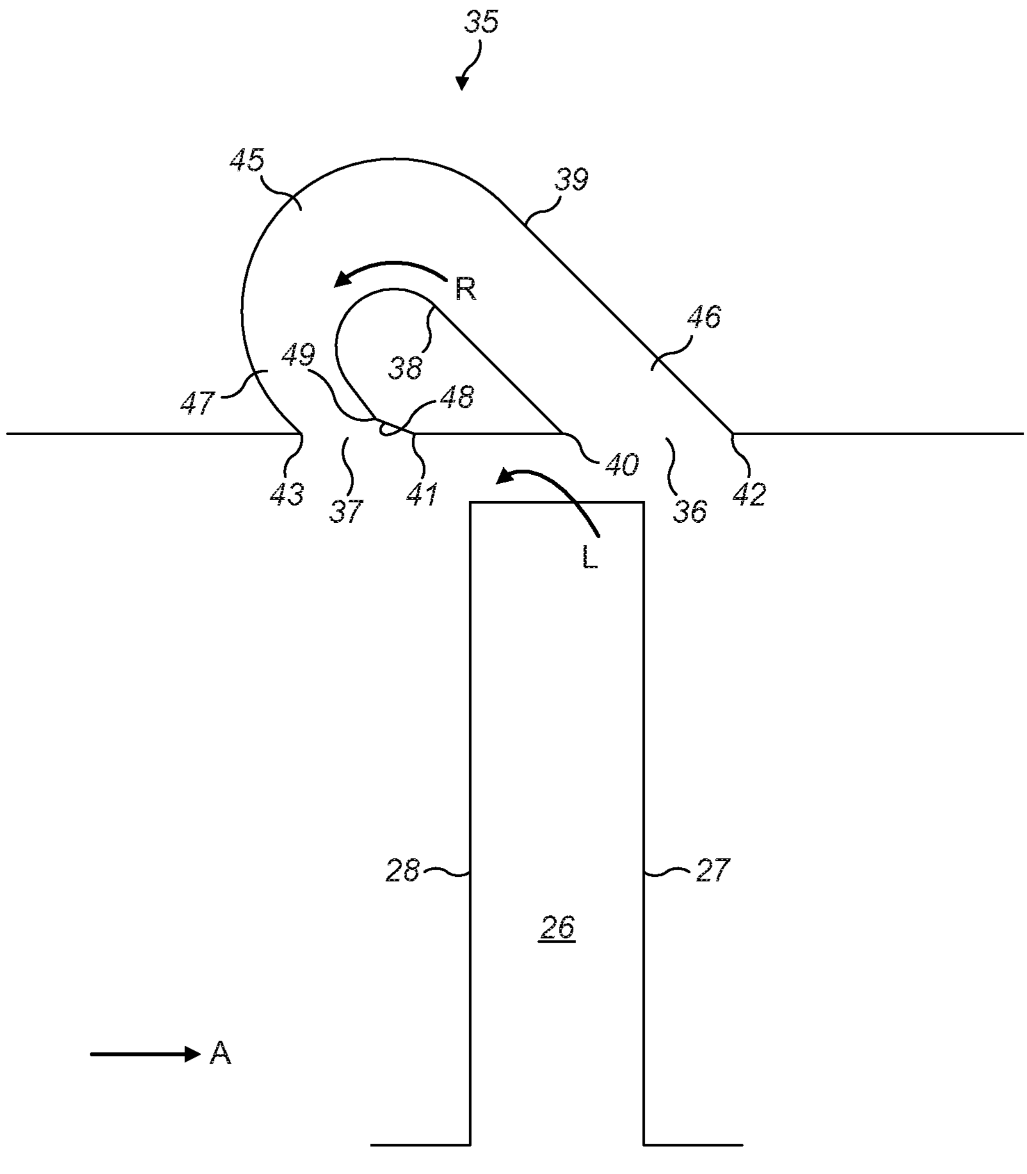

FIG. 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2018/053426

A. CLASSIFICATION OF SUBJECT MATTER
INV. F04D29/52 F04D29/68
ADD.

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)
F04D F01D

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	US 2009/290974 A1 (BAYERE ROMAIN [DE] ET AL) 26 November 2009 (2009-11-26) paragraphs [0006], [0032] - [0043] figures 2,3 claim 13 -----	1-17, 20-31 18,19
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X A	US 5 474 417 A (PRIVETT JOHN D [US] ET AL) 12 December 1995 (1995-12-12) column 1, lines 8-11 column 2, lines 1-10 column 3, line 14 - column 4, line 22 figures 3-5 -----	1-17, 20-31 18,19
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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
1 February 2019	11/02/2019

Name and mailing address of the ISA/	Authorized officer
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INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2018/053426

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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	paragraphs [0002], [0005], [0006], [0015] - [0019], [0021] - [0023], [0025] figures 2-7 -----	
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A	column 5, line 3 - column 6, line 35 figures 1-4 -----	25,27

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

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