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(54) **COMPRESSOR APPARATUS**

(57) A compressor apparatus includes: an inner flowpath surface 450; an outer flowpath surface 472; an array of stator airfoils 452 extending between the inner and outer flowpath surfaces 450, 472; and an array of airfoil-shaped splitter vanes 552 extending from at least one of the inner and outer flowpath surfaces, the splitter vanes 552 alternating with the stator airfoils 452, wherein at least one of a chord dimension of the splitter vanes 552 at the roots thereof and a span dimension of the splitter vanes 552 is less than a corresponding dimension of the stator airfoils 452.

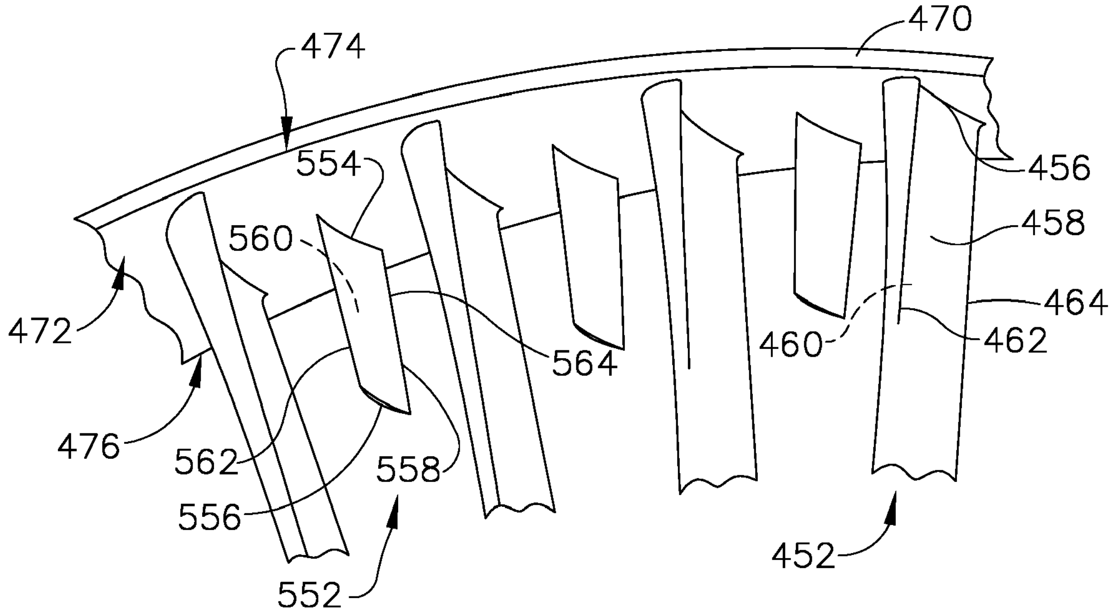

FIG. 12

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Description

[0001] This invention relates generally to turbomachinery compressors and more particularly relates to rotor and stator airfoils of such compressors.

[0002] A gas turbine engine includes, in serial flow communication, a compressor, a combustor, and turbine. The turbine is mechanically coupled to the compressor and the three components define a turbomachinery core. The core is operable in a known manner to generate a flow of hot, pressurized combustion gases to operate the engine as well as perform useful work such as providing propulsive thrust or mechanical work. One common type of compressor is an axial-flow compressor with multiple stages each including a rotating disk with a row of axial-flow airfoils, referred to as rotor blades. Typically, this type of compressor also includes stationary airfoils alternating with the rotor airfoils, referred to as stator vanes. The stator vanes are typically bounded at their inner and outer ends by arcuate endwall structures (e.g. a hub or a case).

[0003] For reasons of thermodynamic cycle efficiency, it is generally desirable to incorporate a compressor having the highest possible pressure ratio (that is, the ratio of inlet pressure to outlet pressure). It is also desirable to include the fewest number of compressor stages. However, there are well-known inter-related aerodynamic limits to the maximum pressure ratio and mass flow possible through a given compressor stage.

[0004] It is known to reduce weight, improve rotor performance, and simplify manufacturing by minimizing the total number of compressor airfoils used in a given rotor or stator row. However, as airfoil count is reduced the accompanying reduced endwall solidity tends to cause the airflow in the endwall region of the airfoil to undesirably separate from the airfoil surface.

[0005] Accordingly, there remains a need for a compressor that is operable with sufficient stall range and an acceptable balance of aerodynamic and structural performance.

BRIEF DESCRIPTION OF THE INVENTION

[0006] This need is addressed by an axial compressor having a stator vane row including stator vane airfoils and splitter airfoils.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] The invention may be best understood by reference to the following description taken in conjunction with the accompanying drawing figures in which:

FIG. 1 is a cross-sectional, schematic view of a gas turbine engine that incorporates a compressor apparatus;

FIG. 2 is a perspective view of a portion of a rotor of a compressor apparatus;

FIG. 3 is a top plan view of a portion of a rotor of a compressor apparatus;

FIG. 4 is an aft elevation view of a portion of a rotor of a compressor apparatus;

FIG. 5 is a side view taken along lines 5-5 of FIG. 4;

FIG. 6 is a side view taken along lines 6-6 of FIG. 4;

FIG. 7 is a perspective view of a portion of a rotor of an alternative compressor apparatus;

FIG. 8 is a top plan view of a portion of a rotor of an alternative compressor apparatus;

FIG. 9 is an aft elevation view of a portion of a rotor of an alternative compressor apparatus;

FIG. 10 is a side view taken along lines 10-10 of FIG. 9;

FIG. 11 is a side view taken along lines 11-11 of FIG. 9;

FIG. 12 is a perspective view of a portion of a stator of a compressor apparatus;

FIG. 13 is another perspective view of the stator of FIG. 12;

FIG. 14 is a side view of a stator vane shown in FIG. 12; and

FIG. 15 is a side view of a splitter vane shown in FIG. 12.

DETAILED DESCRIPTION OF THE INVENTION

[0008] Referring to the drawings wherein identical reference numerals denote the same elements throughout the various views, FIG. 1 illustrates a portion of a gas turbine engine, generally designated 10. The engine 10 has a longitudinal centerline axis 11 and includes, in axial flow sequence, a fan 12, a low-pressure compressor or "booster" 14, and a high-pressure compressor ("HPC") 16.

[0009] It will be understood that the fan 12 and booster 14 are driven by a low-pressure turbine ("LPT") which is not illustrated in FIG. 1, via an inner shaft 18. The rotating fan 12 operates to generate a pressurized fan flow of air, some of which enters the booster 14 and the HPC 16, and some of which is discharged through a bypass duct 20. The rotating booster 14 supercharges the flow into the HPC 16.

[0010] It will be further understood that the HPC 16 is driven by a high-pressure turbine ("HPT") which is not illustrated in FIG.1, via an outer shaft 22. The rotating HPC operates to generate a core flow which passes through a core of the engine 10.

[0011] While the illustrated example is a high-bypass turbofan engine, the principles of the present invention are equally applicable to other types of engines such as low-bypass turbofans, turbojets, and turboshafts.

[0012] It is noted that, as used herein, the terms "axial" and "longitudinal" both refer to a direction parallel to the centerline axis 11, while "radial" refers to a direction perpendicular to the axial direction, and "tangential" or "circumferential" refers to a direction mutually perpendicular to the axial and tangential directions. As used herein, the terms "forward" or "front" refer to a location relatively upstream in an air flow passing through or around a component, and the terms "aft" or "rear" refer to a location relatively downstream in an air flow passing through or around a component. The direction of this flow is shown by the arrow "F" in FIG. 1. These directional terms are used merely for convenience in description and do not require a particular orientation of the structures described thereby.

[0013] The HPC 16 is configured for axial fluid flow, that is, fluid flow generally parallel to the centerline axis 11. This is in contrast to a centrifugal compressor or mixed-flow compressor. The HPC 16 includes a number of stages, each of which includes a rotor comprising a row of airfoils or blades mounted to a rotating disk, and row of stationary airfoils or vanes. The vanes serve to turn the airflow exiting an upstream row of blades before it enters the downstream row of blades.

[0014] FIGS. 2-6 illustrate a portion of a rotor 38 constructed according to a first exemplary embodiment of the present invention and suitable for inclusion in the HPC 16. As an example, the rotor 38 may be incorporated into one or more of the stages in the aft half of the HPC 16, particularly the last or aft-most stage.

[0015] The rotor 38 includes a disk 40 with a web 42 and a rim 44. It will be understood that the complete disk 40 is an annular structure mounted for rotation about the centerline axis 11. The rim 44 has a forward end 46 and an aft end 48. An annular flowpath surface 50 extends between the forward and aft ends 46, 48.

[0016] An array of compressor blades 52 extend from the flowpath surface 50. Each compressor blade extends from a root 54 at the flowpath surface 50 to a tip 56, and includes a concave pressure side 58 joined to a convex suction side 60 at a leading edge 62 and a trailing edge 64. As best seen in FIG. 5, each compressor blade 52 has a span (or span dimension) "S1" defined as the radial distance from the root 54 to the tip 56, and a chord (or chord dimension) "C1" defined as the length of an imaginary straight line connecting the leading edge 62 and the trailing edge 64. Depending on the specific design of the compressor blade 52, its chord C1 may be different at different locations along the span S1. For purposes of the present invention, the relevant measurement is the chord C1 at the root 54.

[0017] As seen in FIG. 4, the flowpath surface 50 is not a body of revolution. Rather, the flowpath surface 50 has a non-axisymmetric surface profile. As an example of a non-axisymmetric surface profile, it may be contoured with a concave curve or "scallop" 66 between each adjacent pair of compressor blades 52. For comparison purposes, the dashed lines in FIG. 4 illustrate a hypothetical cylindrical surface with a radius passing through the roots 54 of the compressor blades 52. It can be seen that the flowpath surface curvature has its maximum radius (or minimum radial depth of the scallop 66) at the compressor blade roots 54, and has its minimum radius (or maximum radial depth "d" of the scallop 66) at a position approximately midway between adjacent compressor blades 52.

[0018] In steady state or transient operation, this scalloped configuration is effective to reduce the magnitude of mechanical and thermal hoop stress concentration at the airfoil hub intersections on the rim 44 along the flowpath surface 50. This contributes to the goal of achieving acceptably-long component life of the disk 40. An aerodynamically adverse side effect of scalloping the flowpath 50 is to increase the rotor passage flow area between adjacent compressor blades 52. This increase in rotor passage through flow area increases the aerodynamic loading level and in turn tends to cause undesirable flow separation on the suction side 60 of the compressor blade 52, at the inboard portion near the root 54, and at an aft location, for example approximately 75% of the chord distance C1 from the leading edge 62.

[0019] An array of splitter blades 152 extend from the flowpath surface 50. One splitter blade 152 is disposed between each pair of compressor blades 52. In the circumferential direction, the splitter blades 152 may be located halfway or circumferentially biased between two adjacent compressor blades 52, or circumferentially aligned with the deepest portion d of the scallop 66. Stated another way, the compressor blades 52 and splitter blades 152 alternate around the periphery of the flowpath surface 50. Each splitter blade 152 extends from a root 154 at the flowpath surface 50 to a tip 156, and includes a concave pressure side 158 joined to a convex suction side 160 at a leading edge 162 and a trailing edge 164. As best seen in FIG. 6, each splitter blade 152 has a span (or span dimension) "S2" defined as the radial distance from the root 154 to the tip 156, and a chord (or chord dimension) "C2" defined as the length of an imaginary straight line connecting the leading edge 162 and the trailing edge 164. Depending on the specific design of the splitter blade 152, its chord C2 may be different at different locations along the span S2. For purposes of the present invention, the relevant measurement is the chord C2 at the root 154.

[0020] The splitter blades 152 function to locally increase the hub solidity of the rotor 38 and thereby prevent the above-mentioned flow separation from the compressor blades 52. A similar effect could be obtained by simply increasing the number of compressor blades 152, and therefore reducing the blade-to-blade spacing. This, however, has the undesirable side effect of increasing aerodynamic surface area frictional losses which would manifest as reduced aerodynamic efficiency and increased rotor weight. Therefore, the dimensions of the splitter blades 152 and their position may be selected to prevent flow separation while minimizing their surface area. The splitter blades 152 are positioned so that their trailing edges 164 are at approximately the same axial position as the trailing edges of the compressor blades 52, relative to the rim 44. This can be seen in FIG. 3. The span S2 and/or the chord C2 of the splitter blades 152 may be some fraction less than unity of the corresponding span S1 and chord C1 of the compressor blades 52. These may be referred to as "part-span" and/or "part-chord" splitter blades. For example, the span S2 may be equal to or less than the span S1. Preferably for reducing frictional losses, the span S2 is 50% or less of the span S 1. More preferably for the least frictional losses, the span S2 is 30% or less of the span S1. As another example, the chord C2 may be equal to or less than the chord C1. Preferably for the least frictional losses, the chord C2 is 50% or less of the chord C1.

[0021] The disk 40, compressor blades 52, and splitter blades 152 may be constructed from any material capable of withstanding the anticipated stresses and environmental conditions in operation. Non-limiting examples of known suitable alloys include iron, nickel, and titanium alloys. In FIGS. 2-6 the disk 40, compressor blades 52, and splitter blades 152 are depicted as an integral, unitary, or monolithic whole. This type of structure may be referred to as a "bladed disk" or "blisk". The principles of the present invention are equally applicable to a rotor built up from separate components (not shown).

[0022] FIGS. 7-11 illustrate a portion of a rotor 238 constructed according to a second exemplary embodiment of the present invention and suitable for inclusion in the HPC 16. As an example, the rotor 238 may be incorporated into one or more of the stages in the aft half of the HPC 16, particularly the last or aft-most stage.

[0023] The rotor 238 includes a disk 240 with a web 242 and a rim 244. It will be understood that the complete disk 240 is an annular structure mounted for rotation about the centerline axis 11. The rim 244 has a forward end 246 and an aft end 248. An annular flowpath surface 250 extends between the forward and aft ends 246, 248.

[0024] An array of compressor blades 252 extend from the flowpath surface 250. Each compressor blade 252 extends from a root 254 at the flowpath surface 250 to a tip 256, and includes a concave pressure side 258 joined to a convex suction side 260 at a leading edge 262 and a trailing edge 264. As best seen in FIG. 10, each compressor blade 252 has a span (or span dimension) "S3" defined as the radial distance from the root 254 to the tip 256, and a chord (or chord dimension) "C3" defined as the length of an imaginary straight line connecting the leading edge 262 and the trailing edge 264. Depending on the specific design of the compressor blade 252, its chord C3 may be different at different locations along the span S3. For purposes of the present invention, the relevant measurement is the chord C3 at the root 254.

[0025] The compressor blades 252 are uniformly spaced apart around the periphery of the flowpath surface 250. A mean circumferential spacing "s" (see FIG. 9) between adjacent compressor blades 252 is defined as $s=2\pi r/Z$, where "r" is a designated radius of the compressor blades 252 (for example at the root 254) and "Z" is the number of compressor blades 252. A nondimensional parameter called "solidity" is defined as c/s, where "c" is equal to the blade chord as described above. In the illustrated example, the compressor blades 252 may have a spacing which is significantly greater than a spacing that would be expected in the prior art, resulting in a blade solidity significantly less than would be expected in the prior art.

[0026] As seen in FIG. 9, the flowpath surface 250 is depicted as a body of revolution (i.e. axisymmetric). Optionally, the flowpath surface 250 may have a non-axisymmetric surface profile as described above for the flowpath surface 50.

[0027] The reduced blade solidity will have the effect of reducing weight, improving rotor performance, and simplify manufacturing by minimizing the total number of compressor airfoils used in a given rotor stage. An aerodynamically adverse side effect of reduced blade solidity is to increase the rotor passage flow area between adjacent compressor blades 252. This increase in rotor passage through flow area increases the aerodynamic loading level and in turn tends to cause undesirable flow separation on the suction side 260 of the compressor blade 252, at the inboard portion near the root 254, and at an aft location, for example approximately 75% of the chord distance C3 from the leading edge 262, also referred to as "hub flow separation". For any given rotor design, the compressor blade spacing may be intentionally selected to produce a solidity low enough to result in hub flow separation under expected operating conditions.

[0028] An array of splitter blades 352 extend from the flowpath surface 250. One splitter blade 352 is disposed between each pair of compressor blades 252. In the circumferential direction, the splitter blades 352 may be located halfway or circumferentially biased between two adjacent compressor blades 252. Stated another way, the compressor blades 252 and splitter blades 352 alternate around the periphery of the flowpath surface 250. Each splitter blade 352 extends from a root 354 at the flowpath surface 250 to a tip 356, and includes a concave pressure side 358 joined to a convex suction side 360 at a leading edge 362 and a trailing edge 364. As best seen in FIG. 11, each splitter blade 352 has a span (or span dimension) "S4" defined as the radial distance from the root 354 to the tip 356, and a chord (or chord dimension) "C4" defined as the length of an imaginary straight line connecting the leading edge 362 and the trailing edge

364. Depending on the specific design of the splitter blade 352, its chord C4 may be different at different locations along the span S4. For purposes of the present invention, the relevant measurement is the chord C4 at the root 354.

[0029] The splitter blades 352 function to locally increase the hub solidity of the rotor 238 and thereby prevent the above-mentioned flow separation from the compressor blades 252. A similar effect could be obtained by simply increasing the number of compressor blades 252, and therefore reducing the blade-to-blade spacing. This, however, has the undesirable side effect of increasing aerodynamic surface area frictional losses which would manifest as reduced aerodynamic efficiency and increased rotor weight. Therefore, the dimensions of the splitter blades 352 and their position may be selected to prevent flow separation while minimizing their surface area. The splitter blades 352 are positioned so that their trailing edges 364 are at approximately the same axial position as the trailing edges 264 of the compressor blades 252, relative to the rim 244. This can be seen in FIG. 8. The span S4 and/or the chord C4 of the splitter blades 352 may be some fraction less than unity of the corresponding span S3 and chord C3 of the compressor blades 252. These may be referred to as "part-span" and/or "part-chord" splitter blades. For example, the span S4 may be equal to or less than the span S3. Preferably for reducing frictional losses, the span S4 is 50% or less of the span S3. More preferably for the least frictional losses, the span S4 is 30% or less of the span S3. As another example, the chord C4 may be equal to or less than the chord C3. Preferably for the least frictional losses, the chord C4 is 50% or less of the chord C3.

[0030] The disk 240, compressor blades 252, and splitter blades 352 using the same materials and structural configuration (e.g. monolithic or separable) as the disk 40, compressor blades 52, and splitter blades 152 described above.

[0031] Several portions of the engine 10 shown in FIG. 1 incorporate stator structures, defined herein as stationary airflow-turning elements. For example, the bypass duct 20 includes an array of airflow-shaped fan outlet guide vanes ("OGVs") 400 bounded at inboard and outboard ends by a core cowl 402 and a fan cowl 404, respectively. The booster 14 includes several rows of airflow-shaped booster guide vanes 406 bounded at inboard and outboard ends, respectively by an inner band 408 and a casing 410. Finally, the HPC 16 includes several rows of airflow-shaped compressor stator vanes 452 bounded by an inner band 444 and a casing 470, respectively. For the purposes of this document, the OGVs 400, booster guide vanes 406, and compressor stator vanes 452 may all be considered to be "stator airfoils".

[0032] FIGS. 12 and 13 illustrate a portion of one row of the compressor stator vanes 452. The illustrated stator vanes 452 may be incorporated into one or more of the stages of the HPC 16. Furthermore, the stator vanes 452 constitute "stator airfoils" which are conceptually representative of any stator structure, and the principles described herein could optionally be incorporated into the outlet guide vanes 400 and/or the booster guide vanes 406.

[0033] The inner band 444 defines an annular inner flowpath surface 450 extending between forward and aft ends 446, 448. The casing 470 defines an annular outer flowpath surface 472 extending between forward and aft ends 474, 476.

[0034] The stator vanes 452 extend between the inner and outer flowpath surfaces 450, 472. Each stator vane 452 extends from a root 454 at the inner flowpath surface 450 to a tip 456 at the outer flowpath surface 472, and includes a concave pressure side 458 joined to a convex suction side 460 at a leading edge 462 and a trailing edge 464. As best seen in FIG. 14, each stator vane 452 has a span (or span dimension) "S5" defined as the radial distance from the root 454 to the tip 456, and a chord (or chord dimension) "C5" defined as the length of an imaginary straight line connecting the leading edge 462 and the trailing edge 464. Depending on the specific design of the stator vane 452, its chord C5 may be different at different locations along the span S5. For purposes of the present invention, the relevant measurement would be the chord C5 at the root 454 or tip 456.

[0035] The stator vanes 452 are uniformly spaced apart around the periphery of the inner flowpath surface 450. The stator vanes 452 have a mean circumferential spacing "s", defined as described above (see FIG. 13). A nondimensional parameter called "solidity" is defined as c/s, where "c" is equal to the vane chord as described above. In the illustrated example, the stator vanes 452 may have a spacing which is significantly greater than a spacing that would be expected in the prior art, resulting in a vane solidity significantly less than would be expected in the prior art.

[0036] As seen in FIGS. 12 and 13, the inner and outer flowpath surfaces 450, 472 are depicted as bodies of revolution (i.e. axisymmetric structures). Optionally, either or both of the inner or outer flowpath surfaces 450, 472 may have a non-axisymmetric surface profile as described above for the flowpath surface 50.

[0037] The reduced vane solidity will have the effect of reducing weight, improving stator performance, and simplify manufacturing by minimizing the total number of airfoils used in a given stator stage. An aerodynamically adverse side effect of reduced stator solidity is to increase the rotor passage flow area between adjacent stator vanes 452. This increase in stator passage through flow area increases the aerodynamic loading level and in turn tends to cause undesirable flow separation on the suction side 460 of the stator vane 452, at the inboard portion near the root 454, and at an aft location, for example approximately 75% of the chord distance C5 from the leading edge 462, also referred to as "hub flow separation". It also tends to cause undesirable flow separation on the suction side 460 of the stator vane 452, at the outboard portion near the tip 456, and at an aft location, for example approximately 75% of the chord distance C5 from the leading edge 462, also referred to as "case flow separation". Generally, both of these conditions may be referred to as "endwall separation". For any given stator design, the stator vane spacing may be intentionally selected to produce a solidity low enough to result in endwall separation under expected operating conditions.

[0038] To counter this adverse side effect, one or both of the inner and outer flowpath surfaces 450, 472 may be provided with an array of splitter vanes. In the example shown in FIG. 12, an array of splitter vanes 552 extend radially inward from the outer flowpath surface 472. One splitter vane 552 is disposed between each pair of stator vanes 452. In the circumferential direction, the splitter vanes 552 may be located halfway or circumferentially biased between two adjacent stator vanes 452. Stated another way, the stator vanes 452 and splitter vanes 552 alternate around the periphery of the outer flowpath surface 472. Each splitter vane 552 extends from a root 554 at the outer flowpath surface 472 to a tip 556, and includes a concave pressure side 558 joined to a convex suction side 560 at a leading edge 562 and a trailing edge 564. As best seen in FIG. 15, each splitter vane 552 has a span (or span dimension) "S6" defined as the radial distance from the root 554 to the tip 556, and a chord (or chord dimension) "C6" defined as the length of an imaginary straight line connecting the leading edge 562 and the trailing edge 564. Depending on the specific design of the splitter vane 552, its chord C6 may be different at different locations along the span S6. For purposes of the present invention, the relevant measurement is the chord C6 at the root 554.

[0039] The splitter vanes 552 function to locally increase the hub solidity of the stator and thereby prevent the above-mentioned flow separation from the stator vanes 452. A similar effect could be obtained by simply increasing the number of stator vanes 452, and therefore reducing the vane-to-vane spacing. This, however, has the undesirable side effect of increasing aerodynamic surface area frictional losses which would manifest as reduced aerodynamic efficiency and increased stator weight. Therefore, the dimensions of the splitter vanes 552 and their position may be selected to prevent flow separation while minimizing their surface area. The splitter vanes 552 are positioned so that their trailing edges 564 are at approximately the same axial position as the trailing edges 464 of the stator vanes 452, relative to the outer flowpath surface 472. This can be seen in FIG. 15. The span S6 and/or the chord C6 of the splitter vanes 552 may be some fraction less than unity of the corresponding span S5 and chord C5 of the stator vanes 452. These may be referred to as "part-span" and/or "part-chord" splitter vanes. For example, the span S6 may be equal to or less than the span S5. Preferably for reducing frictional losses, the span S6 is 50% or less of the span S5. More preferably for the least frictional losses, the span S6 is 30% or less of the span S5. As another example, the chord C6 may be equal to or less than the chord C5. Preferably for the least frictional losses, the chord C6 is 50% or less of the chord C5.

[0040] FIG. 13 illustrates an array of splitter vanes 652 extending radially outward from the inner flowpath surface 450. One splitter vane 652 is disposed between each pair of stator vanes 652. Other than the fact that they extend from the inner flowpath surface 450, the splitter vanes 652 may be identical to the splitter vanes 552 described above, in terms of their shape, circumferential position relative to the stator vanes 452, and their span and chord dimensions. As noted above, splitter vanes may optionally be incorporated at the inner flowpath surface, or the outer flowpath surface 472, or both.

[0041] The compressor apparatus described herein with splitter blades and/or splitter vanes increases the endwall solidity level locally, reduces the endwall aerodynamic loading level locally, and suppresses the tendency of the airfoil portion adjacent the endwall to want to separate in the presence of the non-axisymmetric contoured endwall flowpath surface, or with a reduced airfoil count on an axisymmetric flowpath. The use of a partial-span and/or partial-chord splitter blade or vane is effective to keep the solidity levels of the middle and upper sections of the airfoil unchanged from a nominal value, and therefore to maintain middle and upper airfoil section performance.

[0042] The foregoing has described a compressor apparatus. All of the features disclosed in this specification (including any accompanying claims, abstract and drawings), and/or all of the steps of any method or process so disclosed, may be combined in any combination, except combinations where at least some of such features and/or steps are mutually exclusive.

[0043] Each feature disclosed in this specification (including any accompanying claims, abstract and drawings) may be replaced by alternative features serving the same, equivalent or similar purpose, unless expressly stated otherwise. Thus, unless expressly stated otherwise, each feature disclosed is one example only of a generic series of equivalent or similar features.

[0044] The invention is not restricted to the details of the foregoing embodiment(s). The invention extends any novel one, or any novel combination, of the features disclosed in this specification (including any accompanying claims, abstract and drawings), or to any novel one, or any novel combination, of the steps of any method or process so disclosed.

[0045] Various aspects and embodiments of the present invention are defined by the following numbered clauses:

1. A compressor apparatus comprising:

    an arcuate inner wall defining an inner flowpath surface;

    an arcuate outer wall defining an outer flowpath surface;

an array of axial-flow stator airfoils extending between the inner and outer flowpath surfaces, wherein the stator airfoils each have a root, a tip, a leading edge, and a trailing edge, wherein the stator airfoils have a chord dimension and are spaced apart by a circumferential spacing, the ratio of the chord dimension to the circumferential spacing defining a stator airfoil solidity parameter; and

an array of airfoil-shaped splitter vanes extending from at least one of the inner and outer flowpath surfaces, the splitter vanes alternating with the stator airfoils, wherein the splitter vanes each have a root, a tip, a leading edge, and a trailing edge;

wherein at least one of a chord dimension of the splitter vanes at the roots thereof and a span dimension of the splitter vanes is less than the corresponding dimension of the stator airfoils.

2. The apparatus of clause 1 wherein the splitter vanes extend from both the inner and outer flowpath surfaces.

3. The apparatus of clause 1 or clause 2, wherein the stator airfoil solidity parameter is selected to as to result in flow separation under normal operating conditions.

4. The apparatus of any preceding clause, wherein at least one of the inner and outer flowpath surfaces is not a body of revolution.

5. The apparatus of any preceding clause, wherein each of the splitter vanes is located approximately midway between two adjacent stator airfoils.

6. The apparatus of any preceding clause, wherein the splitter vanes are positioned such that their trailing edges are at approximately the same axial position as the trailing edges of the stator airfoils, relative to the inner and outer flowpath surfaces.

7. The apparatus of any preceding clause wherein the span dimension of the splitter vanes is 50% or less of the span dimension of the stator airfoils.

8. The apparatus of any preceding clause wherein the span dimension of the splitter vanes is 30% or less of the span dimension of the stator airfoils.

9. The apparatus of any preceding clause wherein the chord dimension of the splitter vanes at the roots thereof is 50% or less of the chord dimension of the stator airfoils at the roots thereof.

10. The apparatus of any preceding clause wherein the chord dimension of the splitter vanes at the roots thereof is 50% or less of the chord dimension of the stator airfoils at the roots thereof.

11. A compressor apparatus comprising:

a rotor comprising:

a disk mounted for rotation about a centerline axis, an outer periphery of the disk defining a rotor flowpath surface;

an array of airfoil-shaped axial-flow compressor blades extending radially outward from the rotor flowpath surface, wherein the compressor blades each have a root, a tip, a leading edge, and a trailing edge, wherein the compressor blades have a chord dimension and are spaced apart by a circumferential spacing, the ratio of the chord dimension to the circumferential spacing defining a blade solidity parameter;

an array of airfoil-shaped splitter blades alternating with the compressor blades, wherein the splitter blades each have a root, a tip, a leading edge, and a trailing edge;

wherein at least one of a chord dimension of the splitter blades at the roots thereof and a span dimension of the splitter blades is less than the corresponding dimension of the compressor blades;

a stator comprising:

an arcuate inner wall defining an inner flowpath surface;

an arcuate outer wall defining an outer flowpath surface;

an array of axial-flow stator airfoils extending between the inner and outer flowpath surfaces, wherein the stator airfoils each have a root, a tip, a leading edge, and a trailing edge, wherein the stator airfoils have a chord dimension and are spaced apart by a circumferential spacing, the ratio of the chord dimension to the circumferential spacing defining a stator airfoil solidity parameter; and

an array of airfoil-shaped splitter vanes extending from at least one of the inner and outer flowpath surfaces, the splitter vanes alternating with the stator airfoils, wherein the splitter vanes each have a root, a tip, a leading edge, and a trailing edge;

wherein at least one of a chord dimension of the splitter vanes at the roots thereof and a span dimension of the splitter vanes is less than the corresponding dimension of the stator airfoils.

12. The apparatus of any preceding clause wherein the blade solidity parameter is selected to as to result in hub flow separation under normal operating conditions.

13. The apparatus of any preceding clause wherein the rotor flowpath surface is not a body of revolution.

14. The apparatus of any preceding clause wherein the rotor flowpath surface includes a concave scallop between adjacent compressor blades.

15. The apparatus of any preceding clause wherein the scallop has a minimum radial depth adjacent the roots of the compressor blades, and has a maximum radial depth at a position approximately midway between adjacent compressor blades.

16. The apparatus of any preceding clause wherein each splitter blade is located approximately midway between two adjacent compressor blades.

17. The apparatus of any preceding clause wherein the splitter blades are positioned such that their trailing edges are at approximately the same axial position as the trailing edges of the compressor blades, relative to the disk.

18. The apparatus of any preceding clause wherein the span dimension of the splitter blades is 50% or less of the span dimension of the compressor blades.

19. The apparatus of any preceding clause wherein the span dimension of the splitter blades is 30% or less of the span dimension of the compressor blades.

20. The apparatus of any preceding clause wherein the chord dimension of the splitter blades at the roots thereof is 50% or less of the chord dimension of the compressor blades at the roots thereof.

21. The apparatus of any preceding clause wherein the chord dimension of the splitter blades at the roots thereof is 50% or less of the chord dimension of the compressor blades at the roots thereof.

Claims

1. A compressor apparatus comprising:

an arcuate inner wall defining an inner flowpath surface (450);
an arcuate outer wall defining an outer flowpath surface (472);
an array of axial-flow stator airfoils (452) extending between the inner and outer flowpath surfaces, wherein the stator airfoils (452) each have a root, a tip, a leading edge, and a trailing edge, wherein the stator airfoils (452) have a chord dimension and are spaced apart by a circumferential spacing, the ratio of the chord dimension to the circumferential spacing defining a stator airfoil solidity parameter; and
an array of airfoil-shaped splitter vanes (552, 652) extending from at least one of the inner and outer flowpath surfaces, the splitter vanes (552, 652) alternating with the stator airfoils (452), wherein the splitter vanes (552, 652) each have a root, a tip, a leading edge, and a trailing edge;

wherein at least one of a chord dimension of the splitter vanes (552, 652) at the roots thereof and a span dimension of the splitter vanes (552, 652) is less than the corresponding dimension of the stator airfoils (452).

2. The apparatus of claim 1 wherein the splitter vanes (552, 652) extend from both the inner and outer flowpath surfaces (450, 472).

3. The apparatus of claim 1 or claim 2, wherein the stator airfoil solidity parameter is selected to as to result in flow separation under normal operating conditions.

4. The apparatus of any preceding claim, wherein at least one of the inner and outer flowpath surfaces is not a body of revolution.

5. The apparatus of any preceding claim, wherein each of the splitter vanes (552, 652) is located approximately midway between two adjacent stator airfoils (452).

6. The apparatus of any preceding claim, wherein the splitter vanes (552, 652) are positioned such that their trailing edges are at approximately the same axial position as the trailing edges of the stator airfoils (452), relative to the inner and outer flowpath surfaces (450, 472).

7. The apparatus of any preceding claim, wherein the span dimension of the splitter vanes (552, 652) is 50% or less of the span dimension of the stator airfoils (452).

8. The apparatus of any preceding claim, wherein the span dimension of the splitter vanes (552, 652) is

30% or less of the span dimension of the stator airfoils (452).

9. The apparatus of any preceding claim, wherein the chord dimension of the splitter vanes (552, 652) at the roots thereof is 50% or less of the chord dimension of the stator airfoils (452) at the roots thereof.

10. The apparatus of any preceding claim, wherein the chord dimension of the splitter vanes (552, 652) at the roots thereof is 50% or less of the chord dimension of the stator airfoils (452) at the roots thereof.

11. The apparatus of claim 1 compressor further comprising:

a rotor comprising:

a disk (40) mounted for rotation about a centerline axis, an outer periphery of the disk (40) defining a rotor flowpath surface (50);
an array of airfoil-shaped axial-flow compressor blades (52) extending radially outward from the rotor flowpath surface (50), wherein the compressor blades (52) each have a root, a tip, a leading edge, and a trailing edge, wherein the compressor blades (52) have a chord dimension and are spaced apart by a circumferential spacing, the ratio of the chord dimension to the circumferential spacing defining a blade solidity parameter;
an array of airfoil-shaped splitter blades (152) alternating with the compressor blades (52), wherein the splitter blades (152) each have a root, a tip, a leading edge, and a trailing edge;

wherein at least one of a chord dimension of the splitter blades (152) at the roots thereof and a span dimension of the splitter blades (152) is less than the corresponding dimension of the compressor blades (52).

12. A compressor apparatus comprising:

a rotor comprising:

a disk mounted for rotation about a centerline axis, an outer periphery of the disk defining a rotor flowpath surface;
an array of airfoil-shaped axial-flow compressor blades extending radially outward from the rotor flowpath surface, wherein the compressor blades each have a root, a tip, a leading edge, and a trailing edge, wherein the compressor blades have a chord dimension and are spaced apart by a circumferential spacing, the ratio of the chord dimension to the circumferential spacing defining a blade solidity parameter;
an array of airfoil-shaped splitter blades alternating with the compressor blades, wherein the splitter blades each have a root, a tip, a leading edge, and a trailing edge;
wherein at least one of a chord dimension of the splitter blades at the roots thereof and a span dimension of the splitter blades is less than the corresponding dimension of the compressor blades;

a stator comprising:

an arcuate inner wall defining an inner flowpath surface;
an arcuate outer wall defining an outer flowpath surface;
an array of axial-flow stator airfoils extending between the inner and outer flowpath surfaces, wherein the stator airfoils each have a root, a tip, a leading edge, and a trailing edge, wherein the stator airfoils have a chord dimension and are spaced apart by a circumferential spacing, the ratio of the chord dimension to the circumferential spacing defining a stator airfoil solidity parameter; and
an array of airfoil-shaped splitter vanes extending from at least one of the inner and outer flowpath surfaces, the splitter vanes alternating with the stator airfoils, wherein the splitter vanes each have a root, a tip, a leading edge, and a trailing edge;

wherein at least one of a chord dimension of the splitter vanes at the roots thereof and a span dimension of the splitter vanes is less than the corresponding dimension of the stator airfoils.

13. The apparatus of any preceding claim wherein the rotor flowpath surface includes a concave scallop between adjacent compressor blades.

14. The apparatus of claim 13 wherein the scallop has a minimum radial depth adjacent the roots of the compressor blades, and has a maximum radial depth at a position approximately midway between adjacent compressor blades.

15. The apparatus of any preceding claim wherein the splitter blades are positioned such that their trailing edges are at approximately the same axial position as the trailing edges of the compressor blades, relative to the disk.

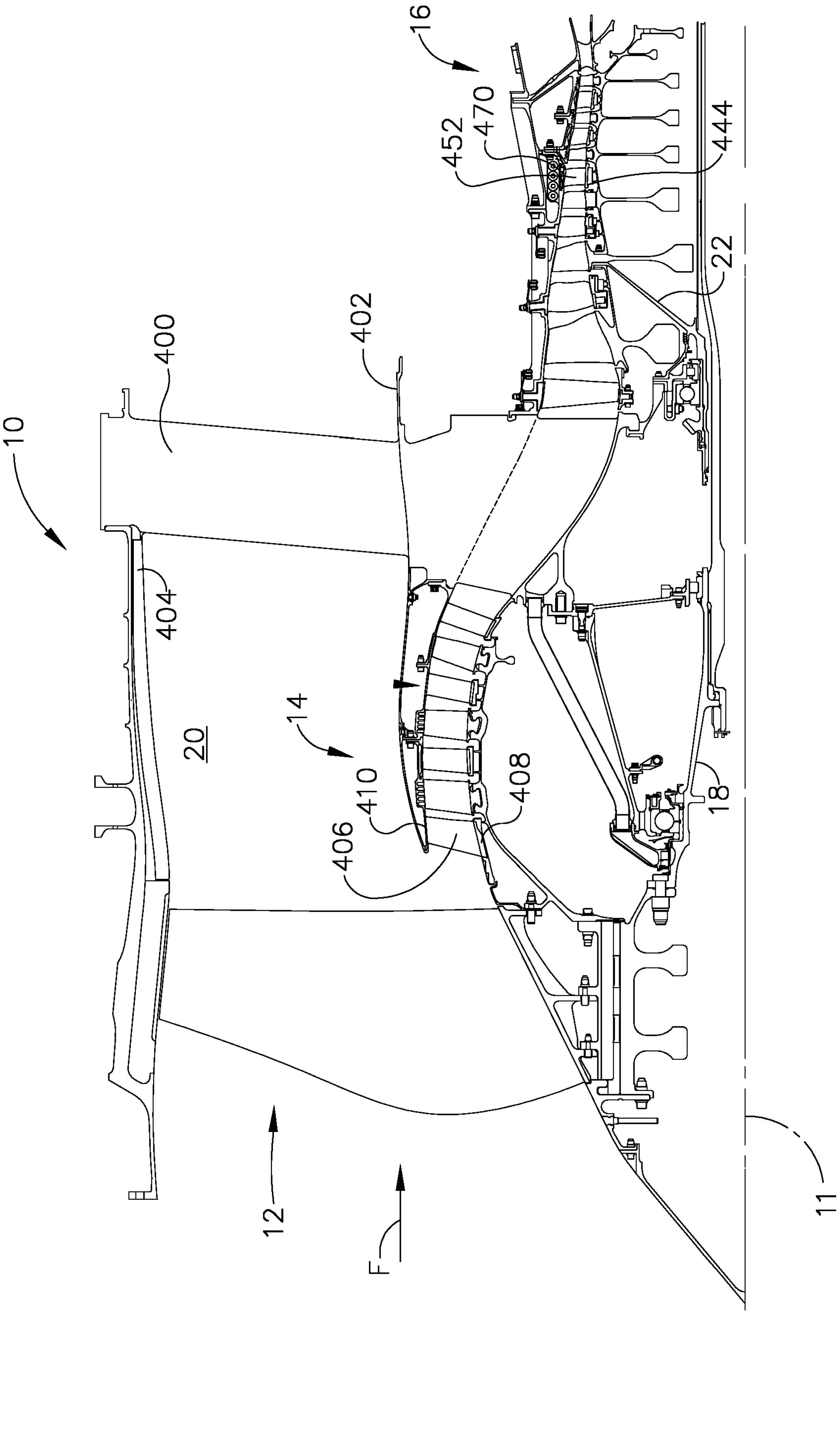

FIG. 1

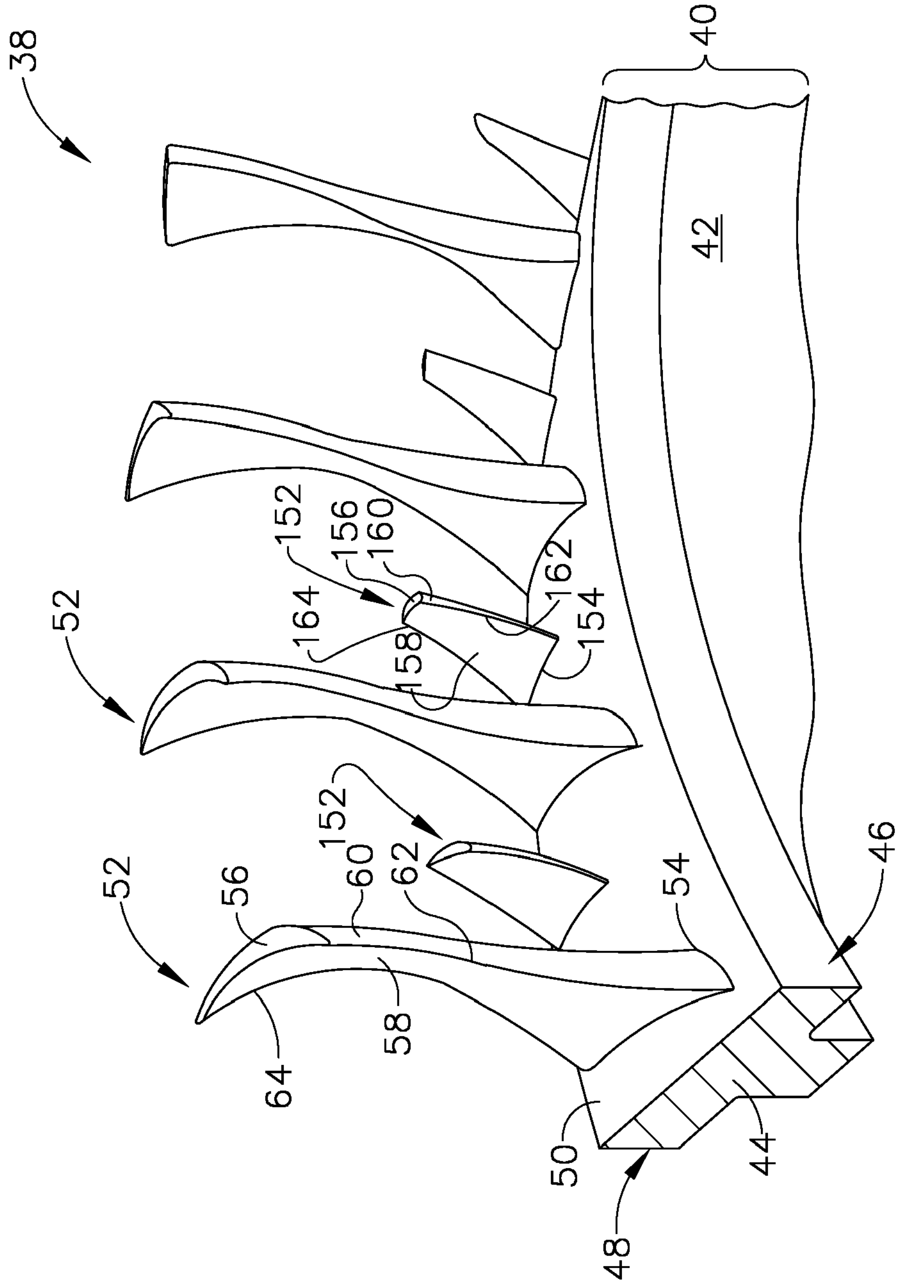
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FIG. 2

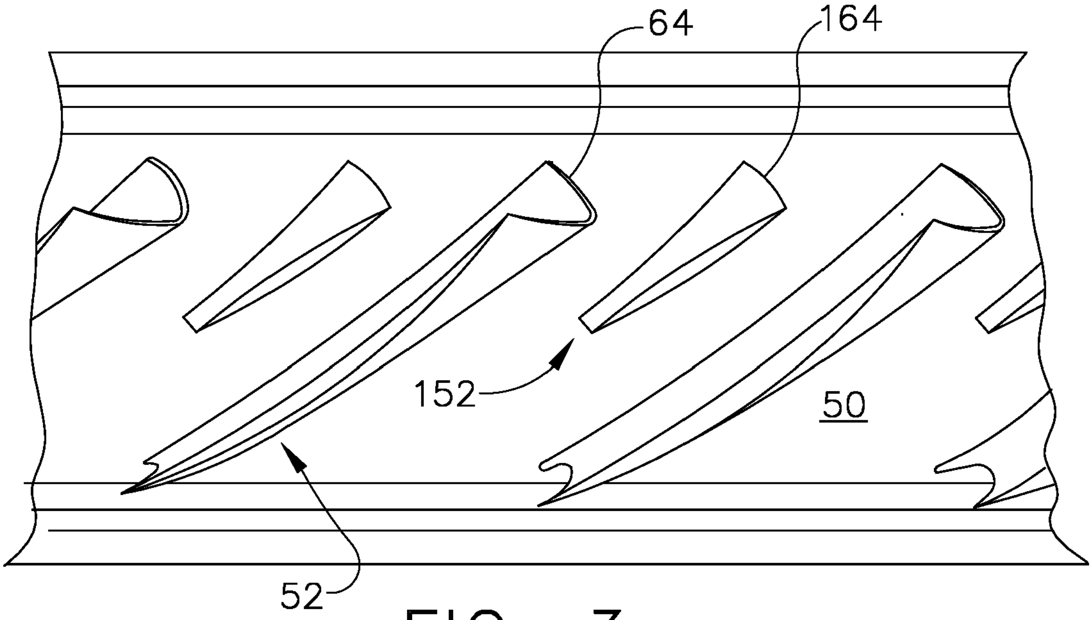

FIG. 3

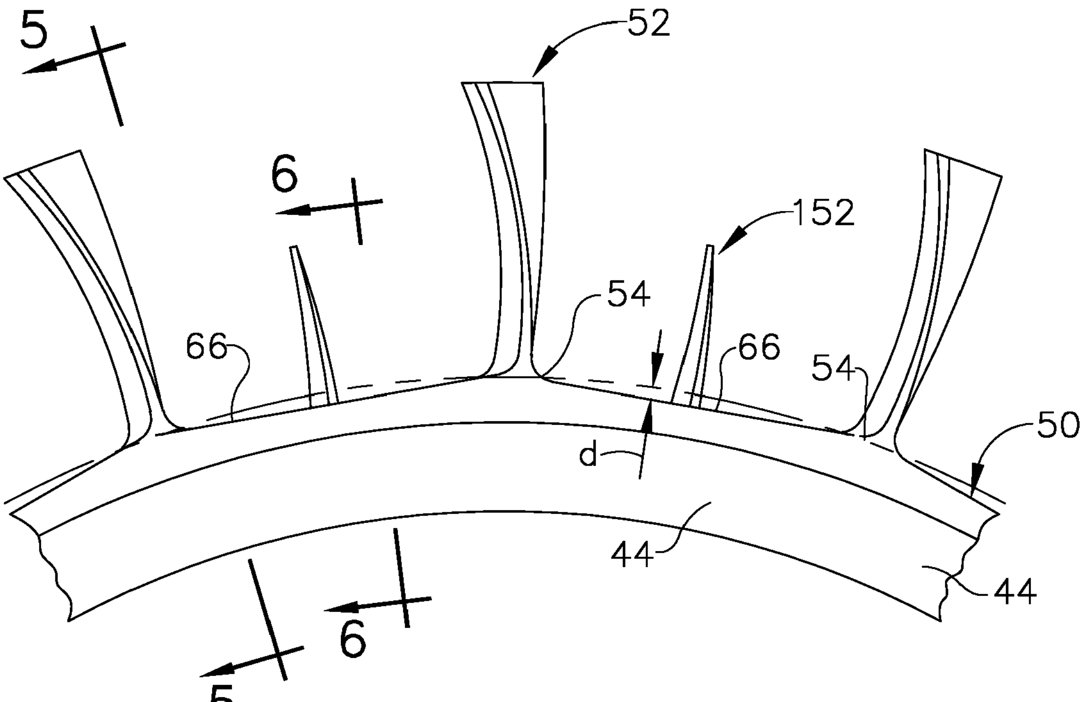

FIG. 4

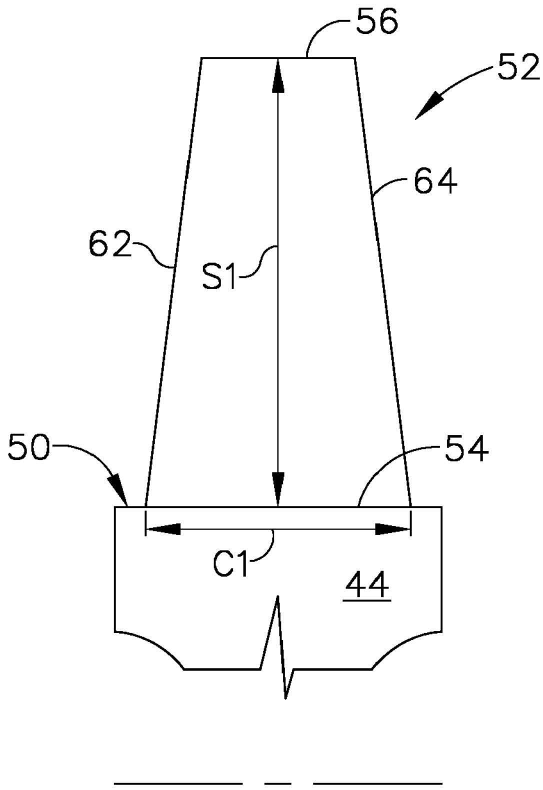

FIG. 5

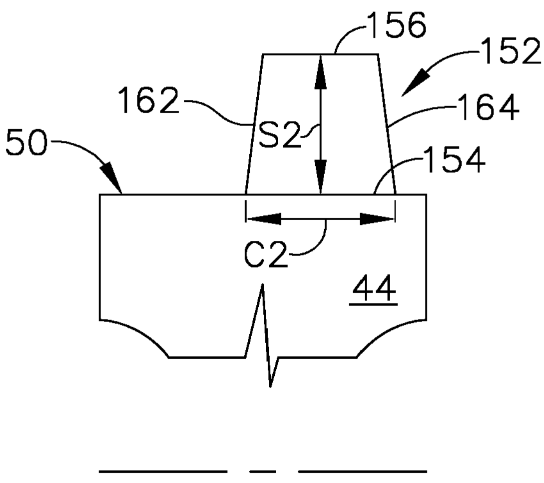

FIG. 6

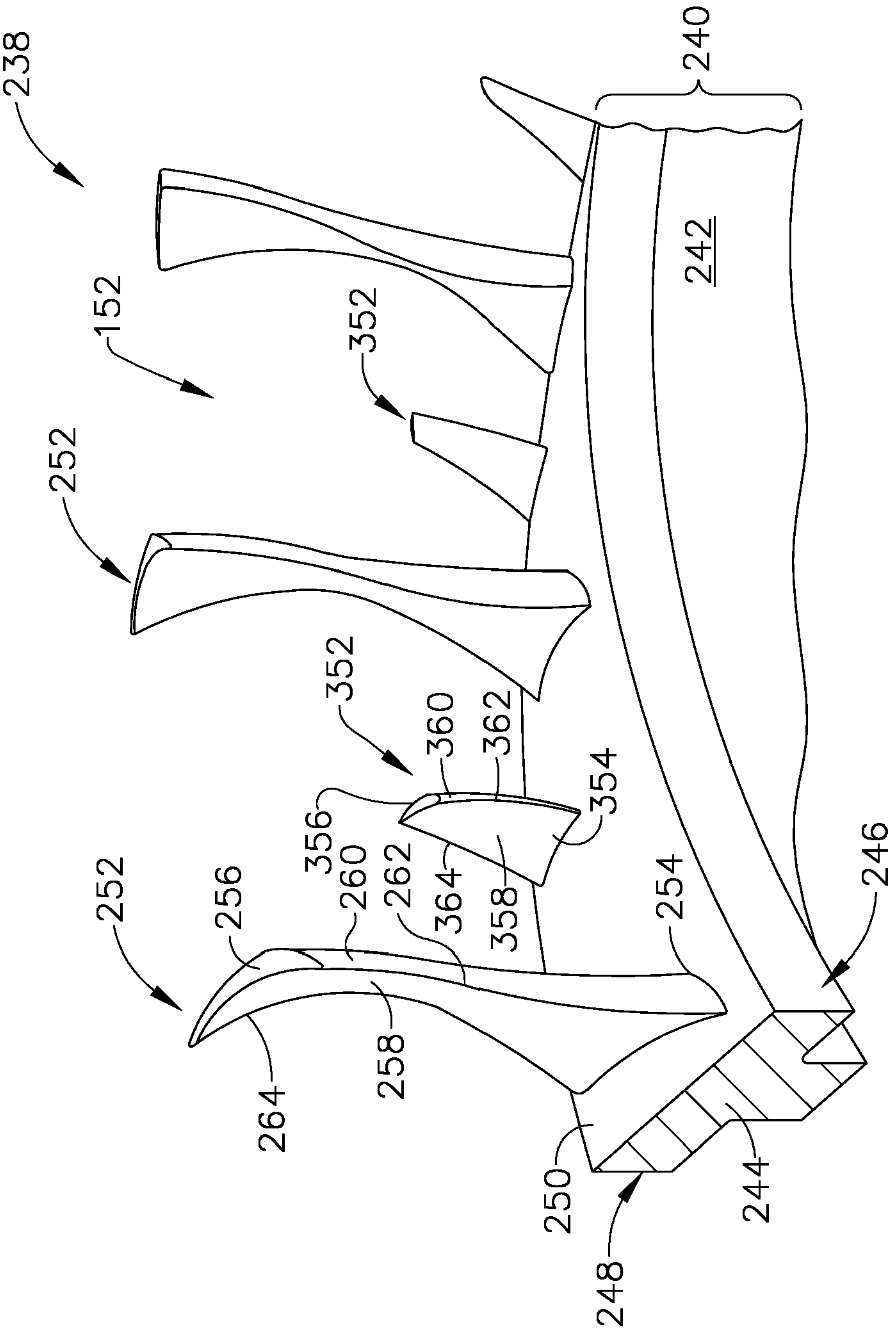
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FIG. 7

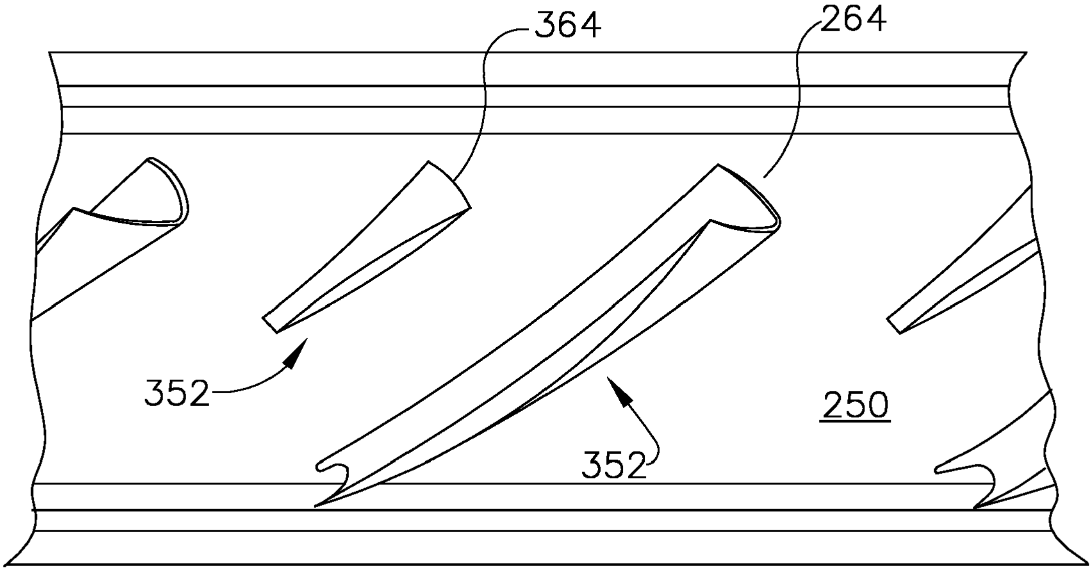

FIG. 8

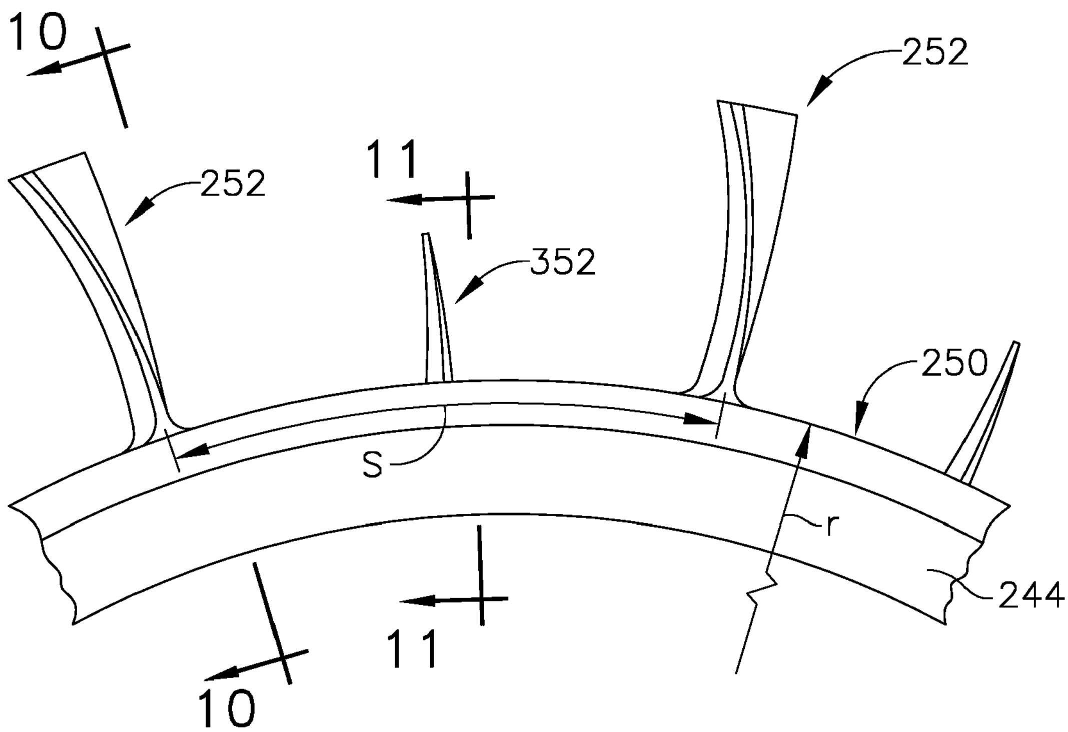

FIG. 9

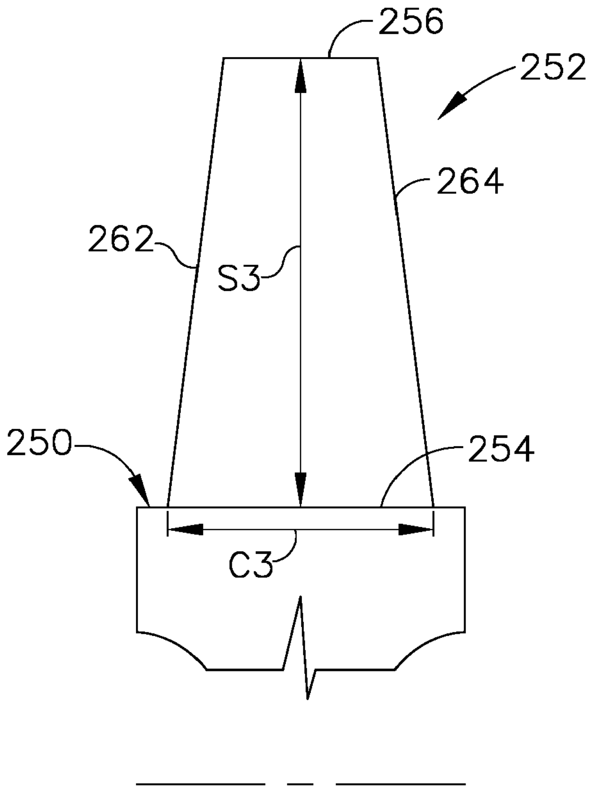

FIG. 10

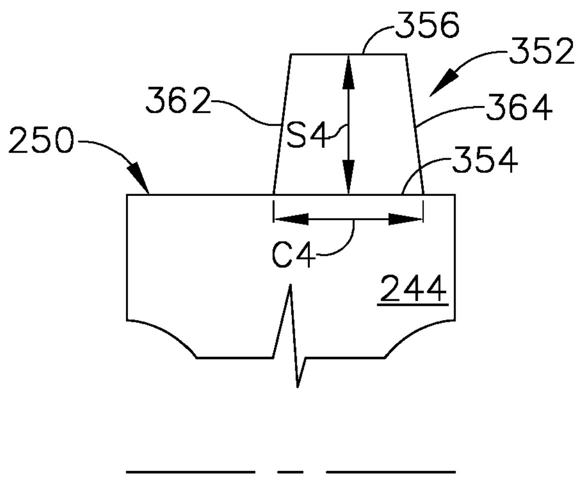

FIG. 11

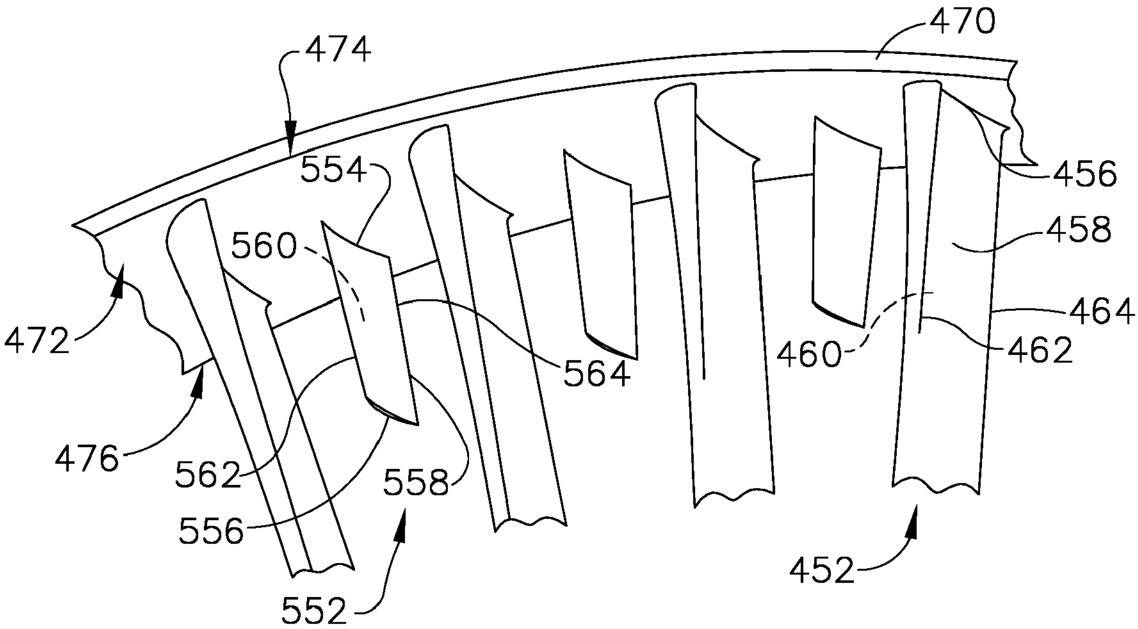
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FIG. 12

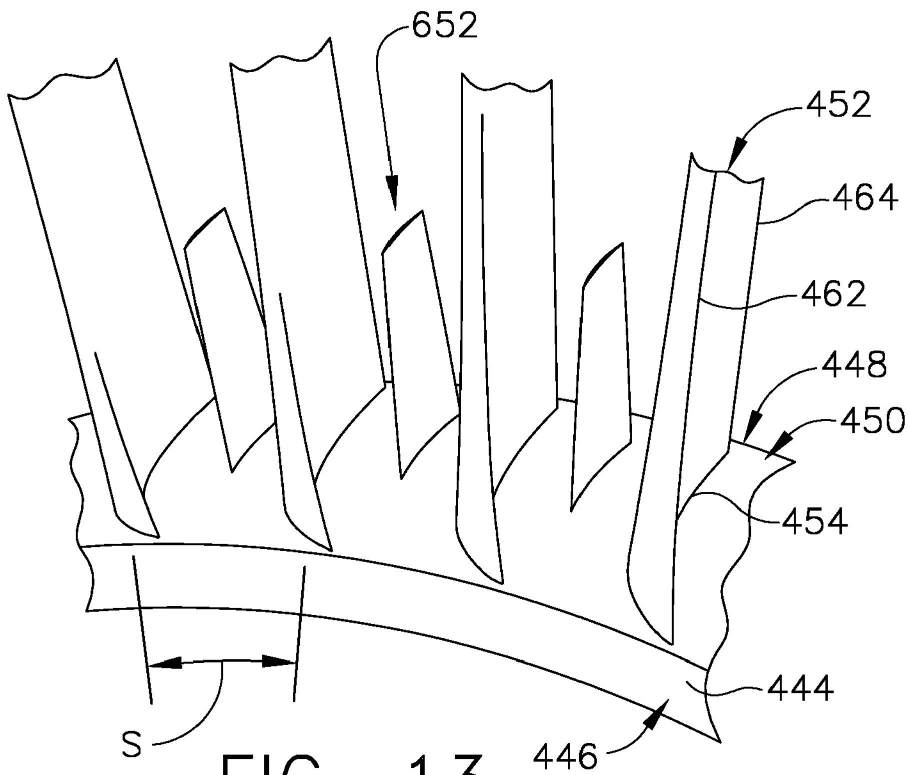
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FIG. 13

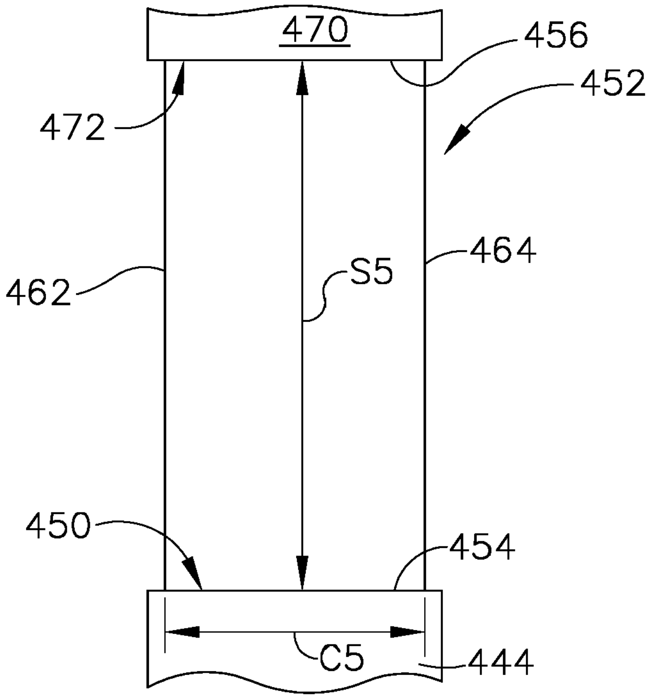
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FIG. 14

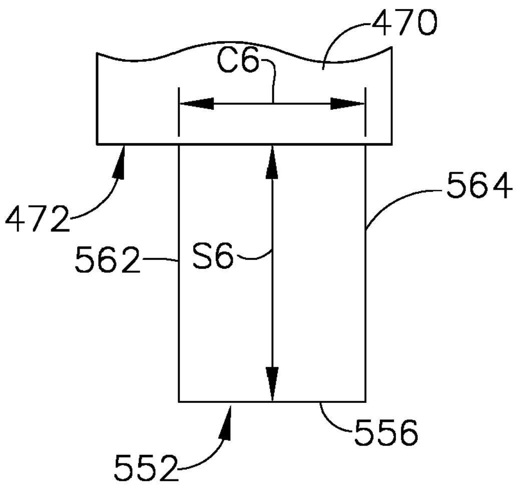
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FIG. 15

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EUROPEAN SEARCH REPORT

Application Number
EP 16 19 5207

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The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	16 February 2017	Raspo, Fabrice

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