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- (54) Title: TURBINE ROTOR BLADES HAVING MID-SPAN SHROUDS

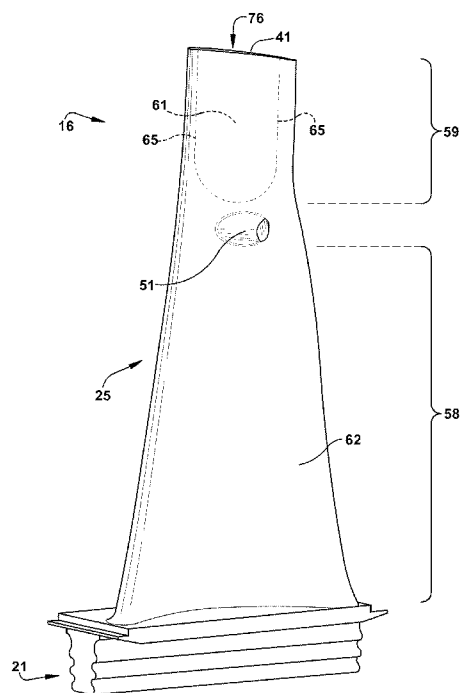


Figure 8

(57) Abstract: A rotor blade for use in a turbine of a combustion turbine engine is described. The rotor blade may include an airfoil that extends from a connection with a root. The rotor blade may further include a mid-span shroud configured to engage a corresponding mid-span shroud on at least one neighboring rotor blades during operation. Outboard of the mid-span shroud, the airfoil may include an outboard region that is substantially hollow, and inboard of the mid-span shroud, the airfoil may include an inboard region that is substantially solid.



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TURBINE ROTOR BLADES HAVING MID-SPAN SHROUDS**BACKGROUND OF THE INVENTION**

[001] The present application relates generally to apparatus, methods and/or systems concerning the design and operation of turbine rotor blades. More specifically, but not by way of limitation, the present application relates to apparatus and systems pertaining to turbine rotor blades and configurations of turbine rotor blades having mid-span shrouds.

[002] In a combustion turbine engine, it is well known that air pressurized in a compressor is used to combust a fuel in a combustor to generate a flow of hot combustion gases, whereupon such gases flow downstream through one or more turbines so that energy can be extracted therefrom. In accordance with such a turbine, generally, rows of circumferentially spaced turbine rotor blades extend radially outwardly from a supporting rotor disc. Each blade typically includes a dovetail that permits assembly and disassembly of the blade in a corresponding dovetail slot in the rotor disc, as well as an airfoil that extends radially outwardly from the dovetail and interacts with the flow of the working fluid through the engine. The airfoil has a generally concave pressure side and generally convex suction side extending axially between corresponding leading and trailing edges and radially between a root and a tip. It will be understood that the blade tip is spaced closely to a radially outer stationary shroud for minimizing leakage therebetween of the combustion gases flowing downstream between the turbine blades.

[003] Shrouds at the tip of the airfoil or tip shrouds often are implemented on aft stages or rotor blades to provide damping and reduce the over-tip leakage of the working fluid. Given the length of the rotor blades in the aft stages, the damping function of the tip shrouds provides a significant performance benefit. However, taking full advantage of the damping function is difficult considering the weight that the tip shroud adds to the assembly and the other design criteria which include enduring thousands of hours of operation exposed to high temperatures and extreme mechanical loads. Thus, while large tip shrouds are desirable because they seal the gas path more effectively and may be designed to provide more significant connection between neighboring rotor blades, which may improve damping, one of ordinary skill in the art will appreciate that larger tip shrouds are troublesome because of the increased pull load on the rotor blade.

[004] Another consideration is that the output and efficiency of gas turbine engines improve as the size of the engine and, and more specifically, the amount of air able to pass through it

increase. The size of the engine, however, is limited by the operable length of the turbine blades, with longer turbine rotor blades enabling enlargement of the flow path through engine. Longer rotor blades, though, incur increased mechanical loads, which place further demands on the blades and the rotor disc that holds them. Longer rotor blades also decrease the natural vibrational frequencies of the blades during operation, which increases the vibratory response of the rotor blades. This additional vibratory load place even further demands on rotor blade design, which may further shorten the life of the component and, in some cases, may cause vibratory loads that damage other functions of the turbine engine. One way to address the vibratory load of longer rotor blades is through the use of shrouds that connect adjacent rotor blades to each other. As mentioned, though, the added weight of the shroud may negate much of the benefit.

[005] One way to address this is to position the shroud lower on the airfoil of the rotor blade. That is, instead of adding the shroud to the tip of the rotor blade, the shroud is positioned near the middle radial portion of the airfoil. As used herein, such a shroud will be referred to as a “mid-span shroud.” At this lower (or more inboard) radius, the mass of the shroud causes a reduced level of stress to the rotor blade. However, this type of shroud leaves a portion of the airfoil of the rotor blade unrestrained, which is the portion of the airfoil that extends outboard of the mid-span shroud. This cantilevered portion of the airfoil typically results in lower frequency vibration and increased vibratory loads, which may be damaging to the engine. A novel rotor blade design that reduced or limited these loads would have value in the market for such products.

BRIEF DESCRIPTION OF THE INVENTION

[006] The present application thus describes a rotor blade for use in a turbine of a combustion turbine engine. The rotor blade may include an airfoil that extends from a connection with a root. The airfoil may include a concave pressure sidewall and a convex suction sidewall extending axially between corresponding leading and trailing edges and radially between a root and an outboard tip. The rotor blade may further include a mid-span shroud configured to engage a corresponding mid-span on at least one neighboring rotor blades during operation. Outboard of the mid-span shroud, the airfoil includes an outboard region that is substantially hollow. Inboard of the mid-span shroud, the airfoil includes an inboard region that is substantially solid.

[007] These and other features of the present application will become apparent upon review of the following detailed description of the preferred embodiments when taken in conjunction with the drawings and the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[008] These and other features of this invention will be more completely understood and appreciated by careful study of the following more detailed description of exemplary embodiments of the invention taken in conjunction with the accompanying drawings, in which:

[009] Figure 1 is a schematic representation of an exemplary combustion turbine engine in which embodiments of the present application may be used;

[010] Figure 2 is a sectional view of the compressor in the combustion turbine engine of Figure 1;

[011] Figure 3 is a sectional view of the turbine in the combustion turbine engine of Figure 1;

[012] Figure 4 is a perspective view of an exemplary turbine rotor blade having a tip shroud of conventional design;

[013] Figure 5 is a perspective view of an exemplary turbine rotor blade having a mid-span shroud that may be used with embodiments of the present invention;

[014] Figure 6 is a perspective view of turbine rotor blades having mid-span shrouds as in Figure 5 in an installed condition;

[015] Figure 7 is a top view of turbine rotor blades having mid-span shrouds as in Figure 5 in an installed condition;

[016] Figure 8 is a side view of a turbine rotor blade having a mid-span shroud and internal configuration according to an embodiment of the present invention;

[017] Figure 9 is a side view of a turbine rotor blade having a mid-span shroud and internal configuration according to an alternative embodiment of the present invention;

[018] Figure 10 is a top cross-sectional view of the outboard region of an exemplary turbine rotor blade in accordance with an embodiment of the present invention;

[019] Figure 11 is a top cross-sectional view of the outboard region of an exemplary turbine rotor blade in accordance with an alternative embodiment of the present invention;

[020] Figure 12 is a top cross-sectional view of the outboard region of an exemplary turbine rotor blade in accordance with an alternative embodiment of the present invention; and

[021] Figure 13 is a top cross-sectional view of the inboard region of an exemplary turbine rotor blade in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[022] As an initial matter, it will be appreciated that to discuss the invention of the present application, it may be necessary to select terminology to refer to and describe particular components within a combustion turbine engine. Whenever possible, common industry terminology will be used and employed in a manner consistent with its accepted meaning. However, it is meant that any such terminology be given a broad meaning and not narrowly construed such that the meaning intended herein and the scope of the appended claims is unreasonably restricted. Those of ordinary skill in the art will appreciate that often a particular component may be referred to using several different terms. In addition, what may be described herein as being single part may include and be referenced in another context as consisting of multiple components, or, what may be described herein as including multiple components may be referred to elsewhere as a single part. As such, in understanding the scope of the present invention, attention should not only be paid to the terminology and description provided herein, but also to the structure, configuration, function, and/or usage of the component, particularly as provided in the appended claims.

[023] In addition, several descriptive terms may be used regularly herein, and it should prove helpful to define these terms at the onset of this section. Accordingly, these terms and their definitions, unless stated otherwise, are as follows. As used herein, “downstream” and “upstream” are terms that indicate a direction relative to the flow of a fluid, such as the working fluid through the turbine engine or, for example, the flow of air through the combustor or coolant through one of the turbine’s component systems. As such, the term “downstream” corresponds to the direction of flow of the fluid, and the term “upstream” refers to the direction opposite to the flow. The terms “forward” and “aft”, without any further specificity, refer to directions, with “forward” referring to the forward or compressor end of the engine, and “aft” referring to the aft or turbine end of the engine. The term “radial” refers to movement or position perpendicular to an axis. It is often required to describe parts that are at differing radial positions with regard to a center axis. In cases such as this, if a first component resides closer to the axis than a second component, it will be stated herein that the first component is “radially inward” or “inboard” of the second component. If, on the other hand, the first component resides further from the axis than the second component, it may be stated herein that the first component is “radially outward” or “outboard” of the second component. The term “axial”

refers to movement or position parallel to an axis. Finally, the term “circumferential” refers to movement or position around an axis. It will be appreciated that such terms may be applied in relation to the center axis of the turbine, or, when referring to components within a combustor, the center axis of the combustor.

[024] By way of background, referring now to the figures, Figures 1 through 3 illustrate an exemplary combustion turbine engine in which embodiments of the present application may be used. It will be understood by those skill in the art that the present invention is not limited to this type of usage. As stated, the present invention may be used in combustion turbine engines, such as the engines used in power generation and airplanes, steam turbine engines, and other type of rotary engines. Figure 1 is a schematic representation of a combustion turbine engine 10. In general, combustion turbine engines operate by extracting energy from a pressurized flow of hot gas produced by the combustion of a fuel in a stream of compressed air. As illustrated in Figure 1, combustion turbine engine 10 may be configured with an axial compressor 11 that is mechanically coupled by a common shaft or rotor to a downstream turbine section or turbine 13, and a combustor 12 positioned between the compressor 11 and the turbine 12.

[025] Figure 2 illustrates a view of an exemplary multi-staged axial compressor 11 that may be used in the combustion turbine engine of Figure 1. As shown, the compressor 11 may include a plurality of stages. Each stage may include a row of compressor rotor blades 14 followed by a row of compressor stator blades 15. Thus, a first stage may include a row of compressor rotor blades 14, which rotate about a central shaft, followed by a row of compressor stator blades 15, which remain stationary during operation. The compressor stator blades 15 generally are circumferentially spaced one from the other and fixed about the axis of rotation. The compressor rotor blades 14 are circumferentially spaced and attached to the shaft; when the shaft rotates during operation, the compressor rotor blades 14 rotate about it. As one of ordinary skill in the art will appreciate, the compressor rotor blades 14 are configured such that, when spun about the shaft, they impart kinetic energy to the air or fluid flowing through the compressor 11. The compressor 11 may have other stages beyond the stages that are illustrated in Figure 2. Additional stages may include a plurality of circumferential spaced compressor rotor blades 14 followed by a plurality of circumferentially spaced compressor stator blades 15.

[026] Figure 3 illustrates a partial view of an exemplary turbine section or turbine 13 that may be used in the combustion turbine engine of Figure 1. The turbine 13 also may include a plurality of stages. Three exemplary stages are illustrated, but more or less stages may present in the turbine 13. A first stage includes a plurality of turbine buckets or turbine rotor blades 16,

which rotate about the shaft during operation, and a plurality of nozzles or turbine stator blades 17, which remain stationary during operation. The turbine stator blades 17 generally are circumferentially spaced one from the other and fixed about the axis of rotation. The turbine rotor blades 16 may be mounted on a turbine wheel or disc (not shown) for rotation about the shaft (not shown). A second stage of the turbine 13 also is illustrated. The second stage similarly includes a plurality of circumferentially spaced turbine stator blades 17 followed by a plurality of circumferentially spaced turbine rotor blades 16, which are also mounted on a turbine wheel for rotation. A third stage also is illustrated, and similarly includes a plurality of turbine stator blades 17 and rotor blades 16. It will be appreciated that the turbine stator blades 17 and turbine rotor blades 16 lie in the hot gas path of the turbine 13. The direction of flow of the hot gases through the hot gas path is indicated by the arrow. As one of ordinary skill in the art will appreciate, the turbine 13 may have other stages beyond the stages that are illustrated in Figure 3. Each additional stage may include a row of turbine stator blades 17 followed by a row of turbine rotor blades 16.

[027] In use, the rotation of compressor rotor blades 14 within the axial compressor 11 may compress a flow of air. In the combustor 12, energy may be released when the compressed air is mixed with a fuel and ignited. The resulting flow of hot gases from the combustor 12, which may be referred to as the working fluid, is then directed over the turbine rotor blades 16, the flow of working fluid inducing the rotation of the turbine rotor blades 16 about the shaft. Thereby, the energy of the flow of working fluid is transformed into the mechanical energy of the rotating blades and, because of the connection between the rotor blades and the shaft, the rotating shaft. The mechanical energy of the shaft may then be used to drive the rotation of the compressor rotor blades 14, such that the necessary supply of compressed air is produced, and also, for example, a generator to produce electricity.

[028] Figure 4 is a perspective view of an exemplary turbine rotor blade 16 that has a tip shroud 37 of conventional design. The turbine rotor blade 16 generally includes a root 21, which may include means by which the rotor blade 16 attaches to a rotor disc 41 (as shown in Figure 6), such as an axial dovetail configured for mounting in a corresponding dovetail slot in the perimeter of the rotor disc 41. The root 21 may include a shank that extends between the dovetail and a platform 24, with the platform 24 being disposed at the junction of the airfoil 25 and the root 21. The platform 24 defines a portion of the inboard boundary of the flowpath through the turbine engine 10. The airfoil 25 is the active component of the rotor blade 16 that intercepts the flow of the working fluid and induces the rotor disc 41 to rotate. As illustrated, at

the outboard tip of the rotor blade 16, the tip shroud 37 may be positioned. The tip shroud 37 essentially is an axially and circumferentially extending planar component that is perched atop the airfoil 25 and supported by it. As shown, positioned along the top of the tip shroud 37 may be one or more seal rails 38. Generally, seal rails 38 project radially outward from the outboard surface of the tip shroud 37 and extend circumferentially between opposite ends of the tip shroud 37 in the general direction of rotation. Seal rails 38 are formed to deter the flow of working fluid through the gap between the tip shroud 37 and the inner surface of the surrounding stationary components of the turbine 13. As discussed in more detail below, tip shrouds 37 may be formed with contact faces 55 such that the shrouds on adjacent rotor blades contact or engage each other, which typically damps vibration in the assembly and prolong the life of the rotor blade 16.

[029] Figure 5 provides a perspective view of an exemplary turbine rotor blade 16 which has a mid-span shroud 51 consistent with one that might be used with rotor blades 16 having an internal structural configurations in accordance with the present invention, as discussed in detail below. As is known in the art, a snubber or mid-span shroud 51 such as the one shown may be used to connect adjacent rotor blades 16. The linking of adjacent rotor blades 16 may occur between a shroud-to-shroud interface 54 (which is shown in Figure 7) at which a pressure side contact face 55 and a suction side contact face 56 contact each other. This linking of rotor blades 16 in this manner tends to increase the natural frequency of the assembly and damp operational vibrations, which means rotor blades 16 are subject to less mechanical stress during operation and degrade more slowly. Shrouds 51, however, add weight to the assembly, which tends to negate some of these benefits, particularly when the shroud is located at the outboard tip 41 of the rotor blade 16. As mentioned above, one way to lessen the impact of the added weight of the shroud is to position the shroud lower on the airfoil 25, as shown in Figure 5. At this lower (or more inboard) radius, the mass of the shroud 51 causes a reduction in the applied stress to the rotor blade. However, a mid-span shroud leaves a portion of the airfoil 25 unrestrained, i.e., the portion of the airfoil 25 that extends outboard of the mid-span shroud 51, and this cantilevered portion of the airfoil 25 results in a lower natural frequency and increased vibratory response during operation, which, as stated, increases may damage the rotor blades and the engine.

[030] Figure 6 is a perspective view of rotor blades 16 having mid-span shrouds 51 as they might be arranged in an installed condition. Figure 7 provides a top view of the same installed assembly. As shown, the mid-span shrouds 51 are configured to link or engage the shrouds 51

of the rotor blades 16 that are adjacent to them. This linking or engagement may occur at shroud-to-shroud interfaces 54 between the pressure side contact face 55 and the suction side contact face 56, as illustrated.

[031] Figure 8 is a side view of a rotor blade having a mid-span shroud 51 and internal structure or configuration (which is shown via the dotted lines) according to an embodiment of the present invention. Figure 9 is a similar view illustrating an alternative embodiment for the internal structure. As used herein and as depicted on Figures 8 and 9, the airfoil 25 may be described as having an inboard region 58, which is defined as the portion of the airfoil 25 that is radially inside or inboard of the mid-span shroud 51, and an outboard region 59, which is defined as the portion of the airfoil 25 that is radially outside or outboard of the mid-span shroud 51. According to embodiments of the present invention, the inboard region 58 is solid or substantially solid, and the outboard region 59 is hollow or substantially hollow. With this in mind and as used herein, a hollow region 61 is any region or space within the airfoil 25 that is hollow, such as a chamber or passaged formed therein, and a solid region 62 is any region or space within the airfoil 25 that is composed of a solid material. According to certain embodiments of the present invention, the outboard region 59 may include a substantial amount of hollow region 61 formed within it. As illustrated in Figures 8 and 9, the hollow region 61 of the outboard region 59 include a hollow chamber 65 that takes up much of the volume between a pressure sidewall 26 and a suction sidewall 27. In certain embodiments, such as the one illustrated in Figure 8, the inboard region 58 may include solid region 62 that takes up all of the volume between the pressure sidewall 26 and the suction sidewall 27. As illustrated in Figure 9, the inboard region may have solid region 62 that takes up almost within this portion of the airfoil 25, with the exception being a few interior cooling passages 81 configured to carry coolant to the hollow chamber 65 of the outboard region 59.

[032] The mid-span shroud 51, according to the present invention, may be defined broadly any shroud that is positioned inboard of an outboard tip 41 of the airfoil 25 and outboard of a platform 24. According to certain embodiments of the present invention, a mid-span shroud 51 is one positioned near the approximate radial center of the airfoil 25.

[033] A mid-span shroud 51 according to present invention also may be defined as a shroud disposed within a range of radial positions on the airfoil 25. According to certain embodiments of the present invention, the range of positions of a mid-span shroud 51 is defined between an inboard boundary of approximately 25% of the radial height of the airfoil 25 and an outboard boundary of approximately 75% of the radial height of the airfoil 25. According to other

embodiments of the present invention, as may be defined by the appended claims, the range of positions of a mid-span shroud 51 is defined between an inboard boundary of approximately 33% of the radial height of the airfoil 25 and an outboard boundary of approximately 66% of the radial height of the airfoil 25.

[034] As to other characteristics of the mid-span shroud 51 of the present invention, the mid-span shroud 51 may be described as a circumferentially extending projection that protrudes from at least one of the pressure sidewall 26 and the suction sidewall 27 of the airfoil 25. As shown in Figures 8 and 9, the mid-span shroud 51 may include a circumferential projection protruding from each of the pressure sidewall 26 and the suction sidewall 27. The mid-span shroud 51, as mentioned, may be configured to engage the mid-span shrouds 51 of neighboring rotor blades 16. The mid-span shroud 51 of the present invention may include a pressure side contact face 55 disposed at a distal end of the circumferential projection from the pressure sidewall 26 of the airfoil 25, and a suction side contact face 56 at a distal end of the circumferential projection from the suction sidewall 27. The pressure side contact face 55 may be configured to correspond to the suction side contact face 56 such that, when the rotor blade 16 is installed between two neighboring rotor blades having the same configuration or design, the mid-span shroud 51 of the rotor blade 16 links or engages both of the neighboring rotor blades 16 via contact between: a) the pressure side contact face 55 of the rotor blade 16 and the suction side contact face 56 of one of the neighboring rotor blades; and b) the suction side contact face 56 of the rotor blade 16 and the pressure side contact face 55 of the other neighboring rotor blade. The adjacent rotor blades 16 may contact each other at a shroud-to-shroud interface 54 that is defined between the contact faces of each of the mid-span shrouds 51.

[035] As mentioned, the hollow region 61 of the outboard region 59 may include a hollow chamber 65. As illustrated via the dotted lines of Figures 8 and 9, the hollow chamber 65 may have a profile similar in shape to the profile of the airfoil 25. The hollow chamber 65 may be the void that is defined between an inner surfaces of the pressure sidewall 26 and the suction sidewall 27. As illustrated in Figure 9, the hollow chamber 65 may include structure or connectors 66 that structurally support the outboard region 59 of the airfoil 25. The connectors 66 may connect the pressure sidewall 26 to the suction sidewall 27 of the airfoil 25.

[036] According to the present invention, Figures 10 through 12 illustrate several possible embodiments for the configuration of the connectors 66 formed within the chamber 65 of the outboard region 59. Figure 10 is a top cross-sectional view of the outboard region 59 of an exemplary rotor blade 16. As illustrated, the hollow chamber 65 may include a plurality of ribs

62. The ribs 62 may be configured to extend across the hollow chamber 65 between the suction sidewall 27 and the pressure sidewall 26. In an alternative embodiment, as illustrated in Figure 11, the connectors 66 may include a number of pins 63 that extend between the suction sidewall 27 and the pressure sidewall 26. The pins 63 may be more numerous and thinner than the ribs 62 of Figure 10. In another alternative, as illustrated in Figure 12, the connectors 66 may include one or more internal walls 73 that extend between the suction sidewall 27 and the pressure sidewall 26. The internal walls 73 may extend radially and be configured such that they separate the hollow chamber 65 into a plurality of chambers, as provided in the illustration.

[037] Figure 13 is a top cross-sectional view of the inboard region 58 of a rotor blade 16 in accordance with an embodiment of the present invention. It will be appreciated that Figure 13, for example, might be a cross-sectional view of the inboard region of Figure 9 in which a pair of interior cooling passages 81 stretch between a coolant source formed through the root 21 of the rotor blade 16 and the hollow chamber 61. As illustrated, but for the narrow cooling passages 81, the inboard region 58 is substantially solid in construction.

[038] The outboard region 59 of the airfoil 25 may be described as having a “hollowness percentage” that defines the percentage or portion of the volume of the outboard region 59 that is comprised of hollow region 61. In a similar manner, the inboard region 58 of the airfoil 25 may be described as having a “solidness percentage” that defines the portion of the volume of the inboard region 58 is comprised of solid region 62. In other embodiments of the present invention, the hollowness percentage of the outboard region 59 is at least 70%, and the solidness percentage of the inboard region 58 is at least 90%. In other embodiments of the present invention, the hollowness percentage of the outboard region 59 is at least 80%, and the solidness percentage of the inboard region 58 is at least 95%. In still other embodiments of the present invention, the hollowness percentage of the outboard region 59 is at least 90%, and the solidness percentage of the inboard region 58 is 100%.

[039] In certain embodiments of the present invention, the solid region 62 of the outboard region 59 is limited to: a) a thin outer wall that along an inner surface defines the hollow chamber 65 in the airfoil 25 and along an outer surface defines the suction sidewall 27 and pressure sidewall 26 of the airfoil 25; and b) connectors 66 that span the hollow chamber 65 structurally connecting the pressure sidewall 26 to the suction sidewall 25. In such cases, the hollow region 61 of the inboard region 58 may be limited to a few interior cooling passages 81 configured to transport coolant across the inboard region 58 from a coolant source formed through the root 21 to the hollow chamber 65 of the outboard region 59. In other embodiments,

the solid region 62 of the outboard region 59 is limited to a thin outer wall that along an inner surface defines a hollow chamber 65 in the airfoil 25 and along an outer surface defines the suction sidewall 27 and pressure sidewall 26 of the airfoil 25. In such cases, the inboard region 58 may have no hollow region 61.

[040] In certain embodiments, the outboard tip 41 of the airfoil 25 has a tip plate 76 that encloses the hollow chamber 65 of the airfoil 25, as illustrated in Figure 9. The tip plate 76 may include film cooling apertures 82 that are configured to meter the release of a pressurized coolant within the hollow chamber 65 of the airfoil 25 during operation. In other embodiments, the outboard tip 41 of the airfoil 25 may include an open face 77, an example of which is shown in Figure 8, that opens to the hollow chamber 65 of the airfoil 25.

[041] It will be appreciated that, pursuant to the several embodiments discussed above, the present invention provides a manner by which the vibratory response of turbine rotor blades 16 may be reduced so to limit the damaging mechanical loads, which may be used, in particular, to enable the lengthening of rotor blades so that greater engine efficiencies are achieved. That is, the present invention teaches a method by which turbine rotor blades may be snubbed via mid-span shrouds 51 and configured internally to limit the vibratory response of the cantilevered portion that extends beyond the mid-span shroud 51. The method includes increasing the stiffness and decreasing the mass of the portion of the airfoil 25 outboard of the mid-span shroud 51 by hollowing out a significant portion of the region 25 and, in some embodiments, providing connecting structure through the hollowed region, while the region of the airfoil 25 that is inboard of the mid-span shroud 51 remains solid. In this manner, natural frequencies of the structure may be raised and harmful vibratory responses avoided, thereby allowing for longer turbine blades, which, in turn, may be used to enable larger turbine engines having greater output and efficiency.

[042] While the invention has been described in connection with what is presently considered to be the most practical and preferred embodiment, it is to be understood that the invention is not to be limited to the disclosed embodiment, but on the contrary, is intended to cover various modifications and equivalent arrangements included within the spirit and scope of the appended claims.

CLAIMS

1. A rotor blade for use in a turbine of a combustion turbine engine, the rotor blade comprising an airfoil that extends from a connection with a root, the airfoil including a concave pressure sidewall and a convex suction sidewall extending axially between corresponding leading and trailing edges and radially between the root and an outboard tip, the rotor blade further comprising:

a mid-span shroud configured to engage a corresponding mid-span shroud on at least one neighboring rotor blade during operation;

wherein:

outboard of the mid-span shroud, the airfoil includes an outboard region that is substantially hollow; and

inboard of the mid-span shroud, the airfoil includes an inboard region that is substantially solid.

2. The rotor blade of claim 1, wherein the mid-span shroud includes a circumferentially extending projection from at least one of the pressure sidewall and the suction sidewall of the airfoil.

3. The rotor blade of claim 1, wherein the mid-span shroud comprises a circumferential projection from each of the pressure sidewall and the suction sidewall of the airfoil;

wherein the mid-span shroud comprises a pressure side contact face at a distal end of the circumferential projection from the pressure sidewall and a suction side contact face at a distal end of the circumferential projection from the pressure sidewall;

wherein, upon installation, the pressure side contact face is configured to form a first shroud-to-shroud interface with the suction side contact face of a first neighboring rotor blade of a same design as the rotor blade; and

wherein, upon installation, the suction side contact face is configured to form a second shroud-to-shroud interface with the pressure side contact face of a second neighboring rotor blade of the same design as the rotor blade.

4. The rotor blade of claim 3, wherein the mid-span shroud comprises a shroud that is positioned inboard of an outboard tip of the airfoil and outboard of a platform of the rotor blade.

5. The rotor blade of claim 3, wherein the mid-span shroud comprises a shroud that is disposed within a range of positions on the airfoil; and wherein the range of positions is defined between an inboard boundary at 25% of a radial height of the airfoil and an outboard boundary at 75% of the radial height of the airfoil.

6. The rotor blade of claim 3, wherein the mid-span shroud comprises a shroud that is disposed within a range of positions on the airfoil; and wherein the range of positions is defined between an inboard boundary at 33% of a radial height of the airfoil and an outboard boundary at 66% of the radial height of the airfoil.

7. The rotor blade of claim 5, wherein the outboard region of airfoil comprises a portion of the airfoil that is outboard of the mid-span shroud, and wherein the inboard region of the airfoil comprises a portion of the airfoil that is inboard of the mid-span shroud;

wherein a hollow region comprises a region within the airfoil that is hollow; and

wherein a solid region comprises a region within the airfoil that is solid material.

8. The rotor blade of claim 7, wherein the hollow region of the outboard region of the airfoil comprises a hollow chamber.

9. The rotor blade of claim 8, wherein the hollow chamber comprises a connector extending therethrough that structurally connects the pressure sidewall to the suction sidewall of the airfoil.

10. The rotor blade of claim 9, wherein the connector comprises a plurality of ribs, a plurality of which extends across the hollow chamber from the suction sidewall to the pressure sidewall of the airfoil.

11. The rotor blade of claim 9, wherein the connector comprises a plurality of pins, a plurality of which extends across the hollow chamber from the suction sidewall to the pressure sidewall of the airfoil.

12. The rotor blade of claim 9, wherein the connector comprises an internal wall that divides the hollow chamber into a plurality of hollow chambers.

13. The rotor blade of claim 7, wherein the outboard region of the airfoil comprises a hollowness percentage that defines what portion of a volume of the outboard region is the hollow region; and

wherein the inboard region of the airfoil comprises a solidness percentage that defines what portion of a volume of the inboard region is the solid region.

14. The rotor blade of claim 13, wherein the outboard region being substantially hollow is defined as the outboard region having a hollowness percentage of at least 70%; and

wherein the inboard region being substantially solid is defined as the inboard region having the solidness percentage of at least 90%.

15. The rotor blade of claim 13, wherein the outboard region being substantially hollow is defined as the outboard region having a hollowness percentage of at least 80%; and

wherein the inboard region being substantially solid is defined as the inboard region having the solidness percentage of at least 95%.

16. The rotor blade of claim 13, wherein the outboard region being substantially hollow is defined as the outboard region having a hollowness percentage of at least 90%; and

wherein the inboard region being substantially solid is defined as the inboard region having the solidness percentage of 100%.

17. The rotor blade of claim 7, wherein the solid region of the outboard region is limited to: a) a thin outer wall that along an inner surface defines a hollow chamber in the airfoil and along an outer surface defines the suction sidewall and pressure sidewall of the airfoil; and b) pins that span the hollow chamber structurally connecting the pressure sidewall to the suction sidewall; and

wherein the hollow region of the inboard region is limited to narrow interior cooling passages configured to transport coolant across the inboard region from a coolant source formed through the root of the rotor blade to the hollow chamber of the outboard region.

18. The rotor blade of claim 7, wherein the solid region of the outboard region is limited to a thin outer wall that along an inner surface defines a hollow chamber in the airfoil and along an outer surface defines the suction sidewall and pressure sidewall of the airfoil; and

wherein the inboard region comprises no hollow region.

19. The rotor blade of claim 18, wherein the outboard tip of the airfoil comprises a tip plate that encloses the hollow chamber of the airfoil.

20. The rotor blade of claim 19, wherein the tip plate includes one or more film cooling apertures that, during operation, are configured to meter a release of the coolant flowing through the hollow chamber of the airfoil.

21. The rotor blade of claim 18, wherein the outboard tip of the airfoil comprises an open face opening to the hollow chamber of the airfoil.

22. A combustion turbine engine that includes:

a rotor blade comprising an airfoil that extends from a connection with a root, the airfoil including a concave pressure sidewall and a convex suction sidewall extending axially between corresponding leading and trailing edges and radially between the root and an outboard tip, the rotor blade further comprising:

a mid-span shroud configured to engage a corresponding mid-span shroud on at least one neighboring rotor blade during operation;

wherein, outboard of the mid-span shroud, the airfoil includes an outboard region that is substantially hollow, and, inboard of the mid-span shroud, the airfoil includes an inboard region that is substantially solid;

wherein a hollow region comprises a region within the airfoil that is hollow, and wherein a solid region comprises a region within the airfoil that is solid material;

wherein the outboard region of the airfoil comprises a hollowness percentage that defines what portion of a volume of the outboard region is the hollow region;

wherein the inboard region of the airfoil comprises a solidness percentage that defines what portion of a volume of the inboard region is the solid region; and

wherein the outboard region being substantially hollow is defined as the outboard region having a hollowness percentage of at least 70% and wherein the inboard region being substantially solid is defined as the inboard region having the solidness percentage of at least 90%.

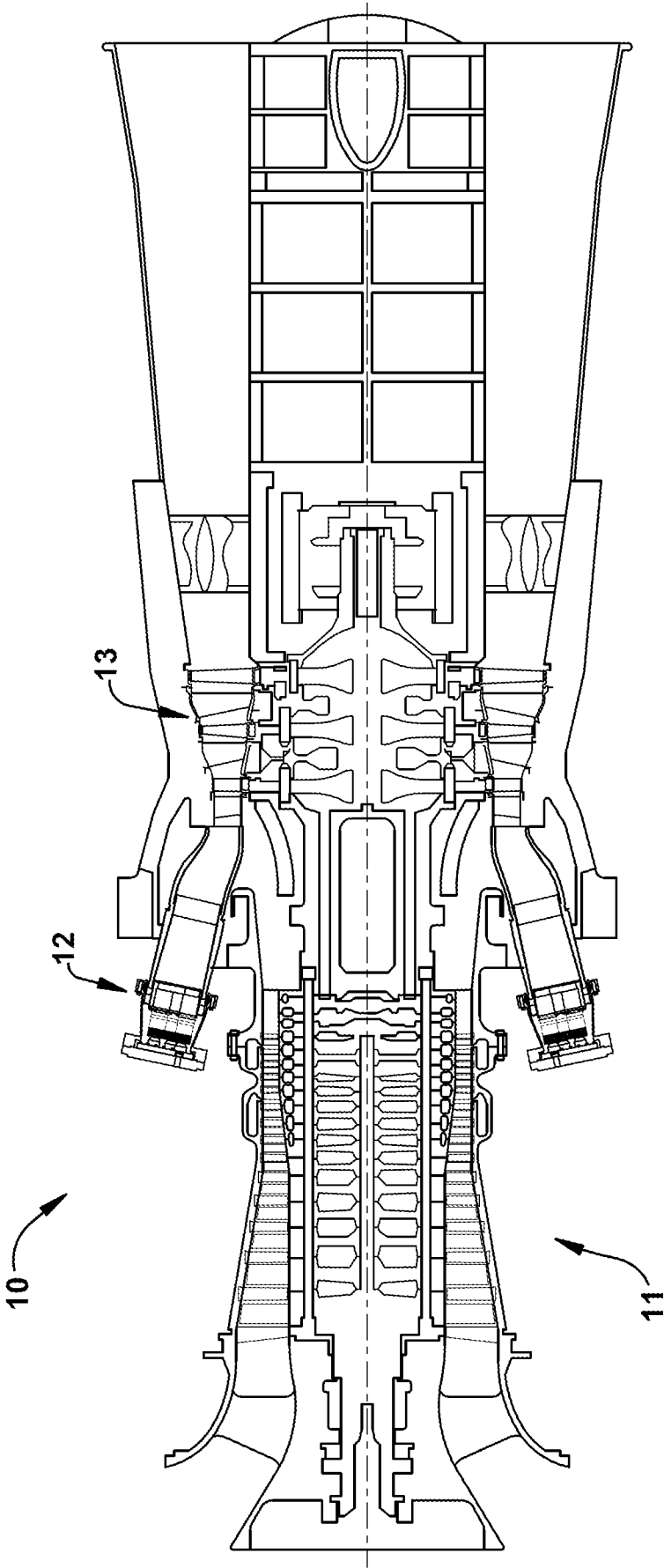


Figure1
(Prior Art)

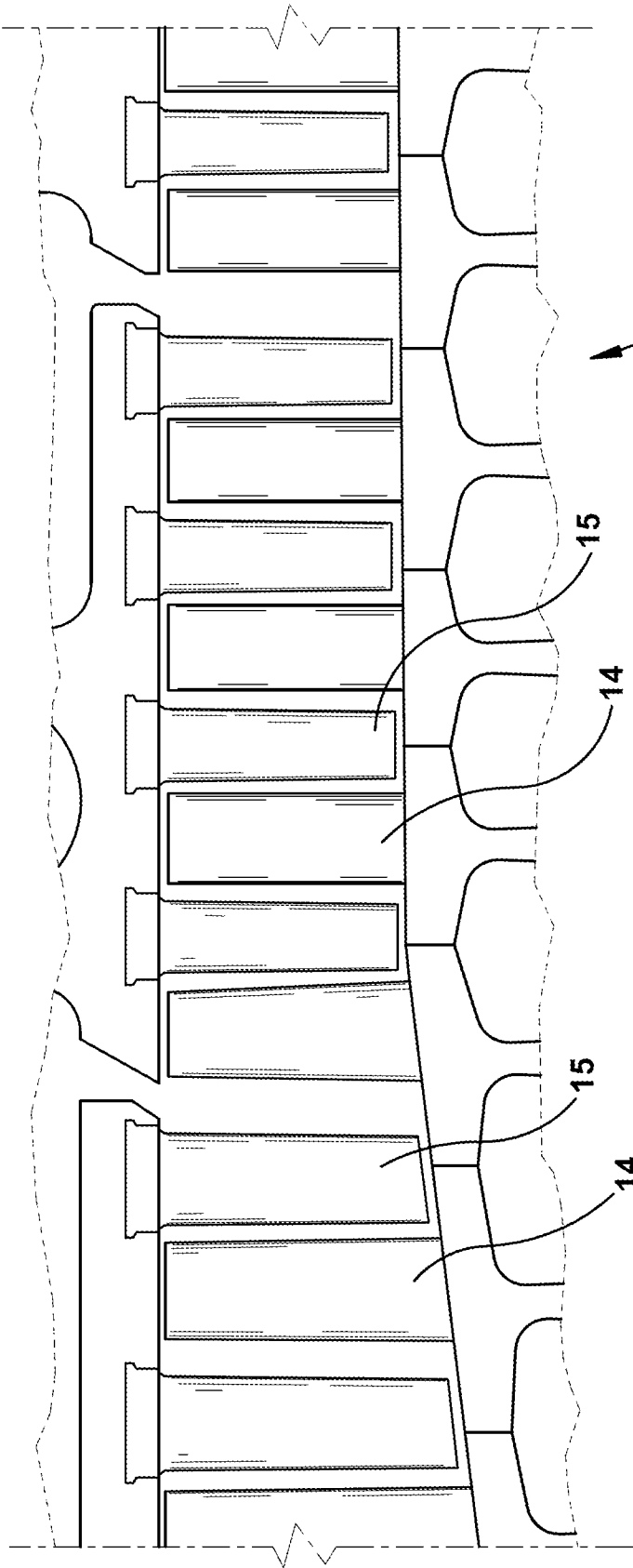


Figure 2
(Prior Art)

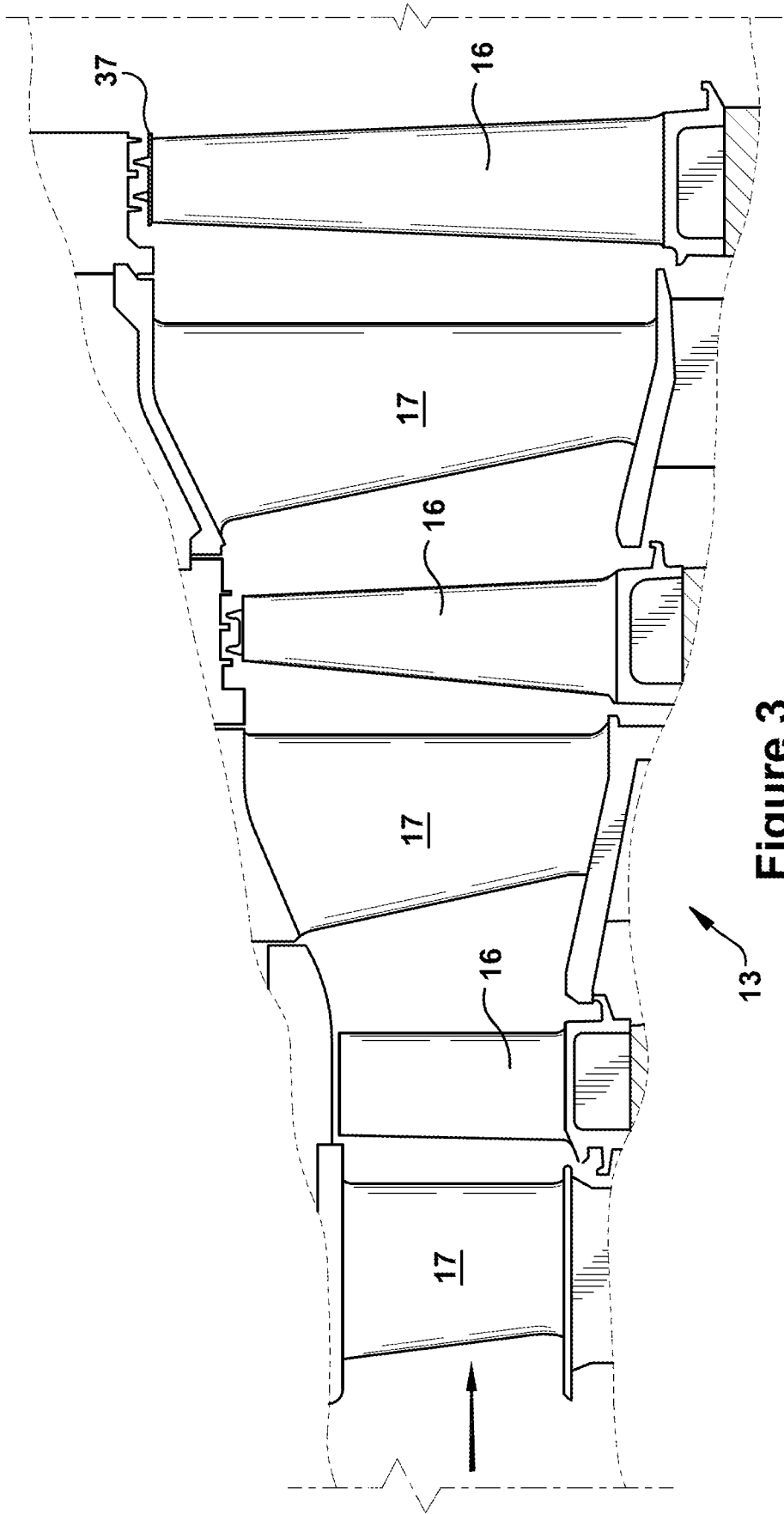


Figure 3
(Prior Art)

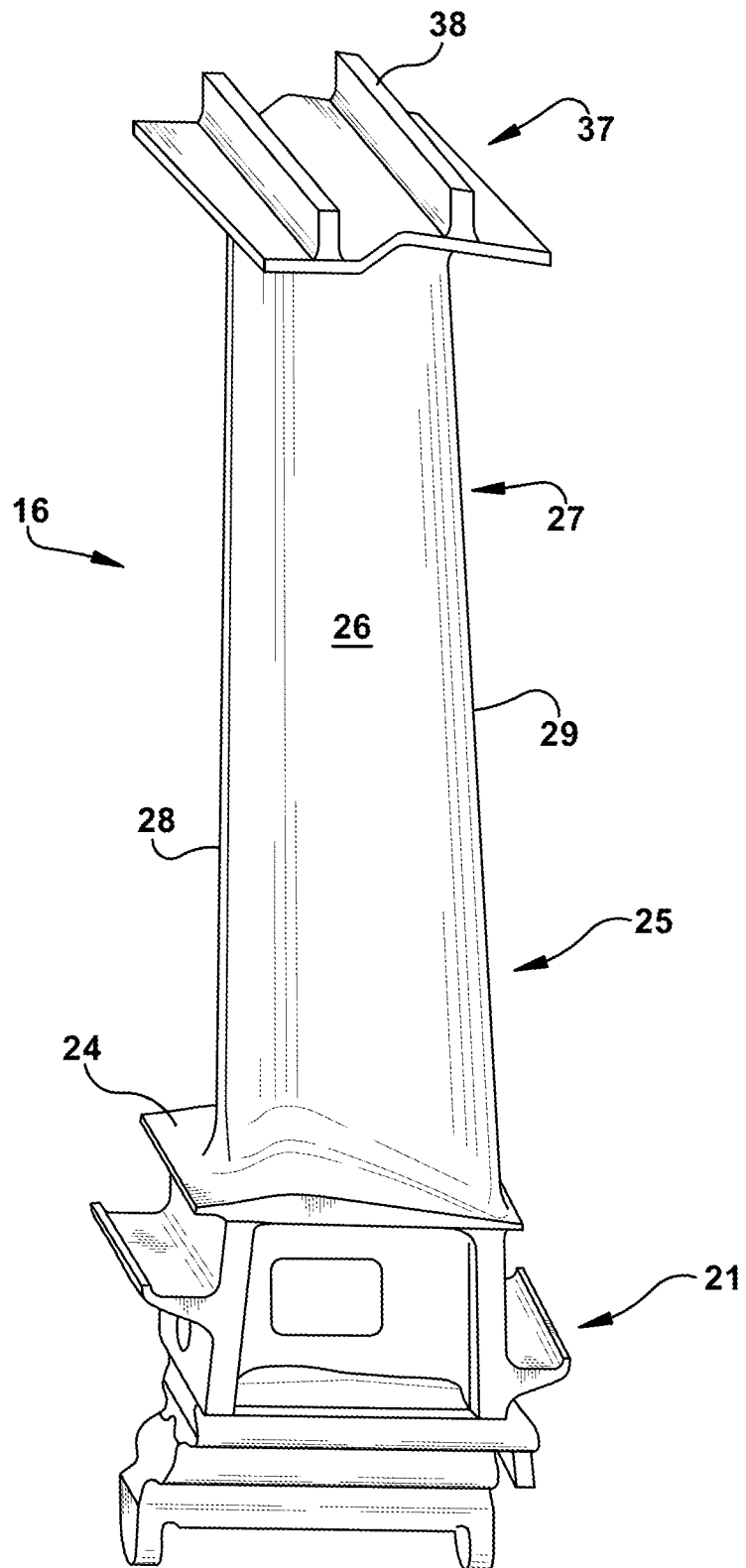


Figure 4
(Prior Art)

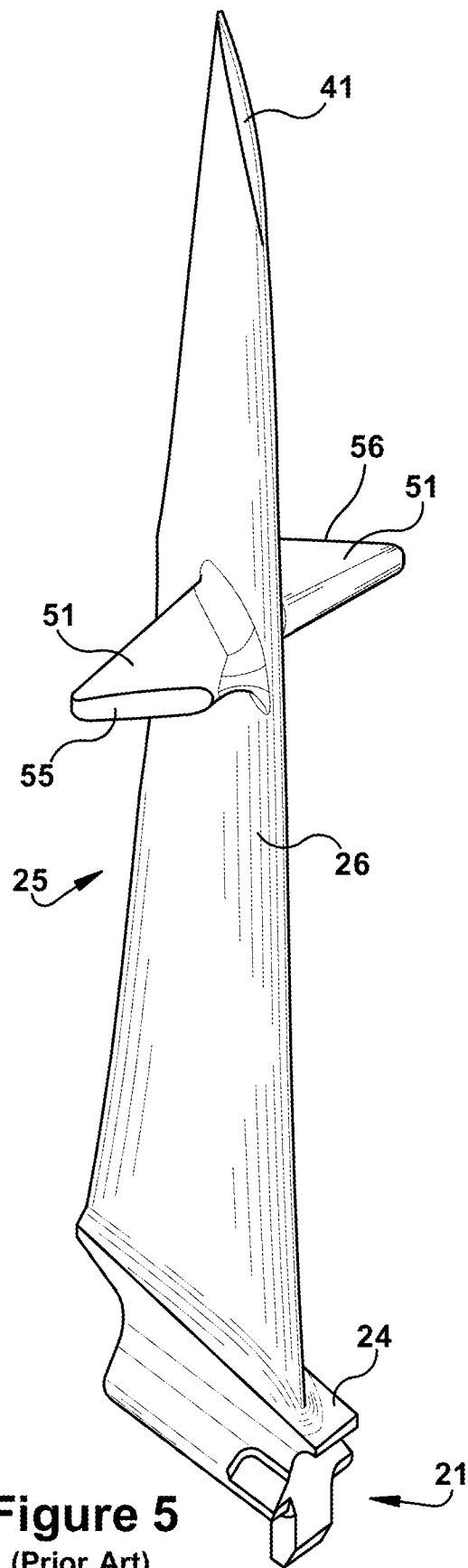


Figure 5
(Prior Art)

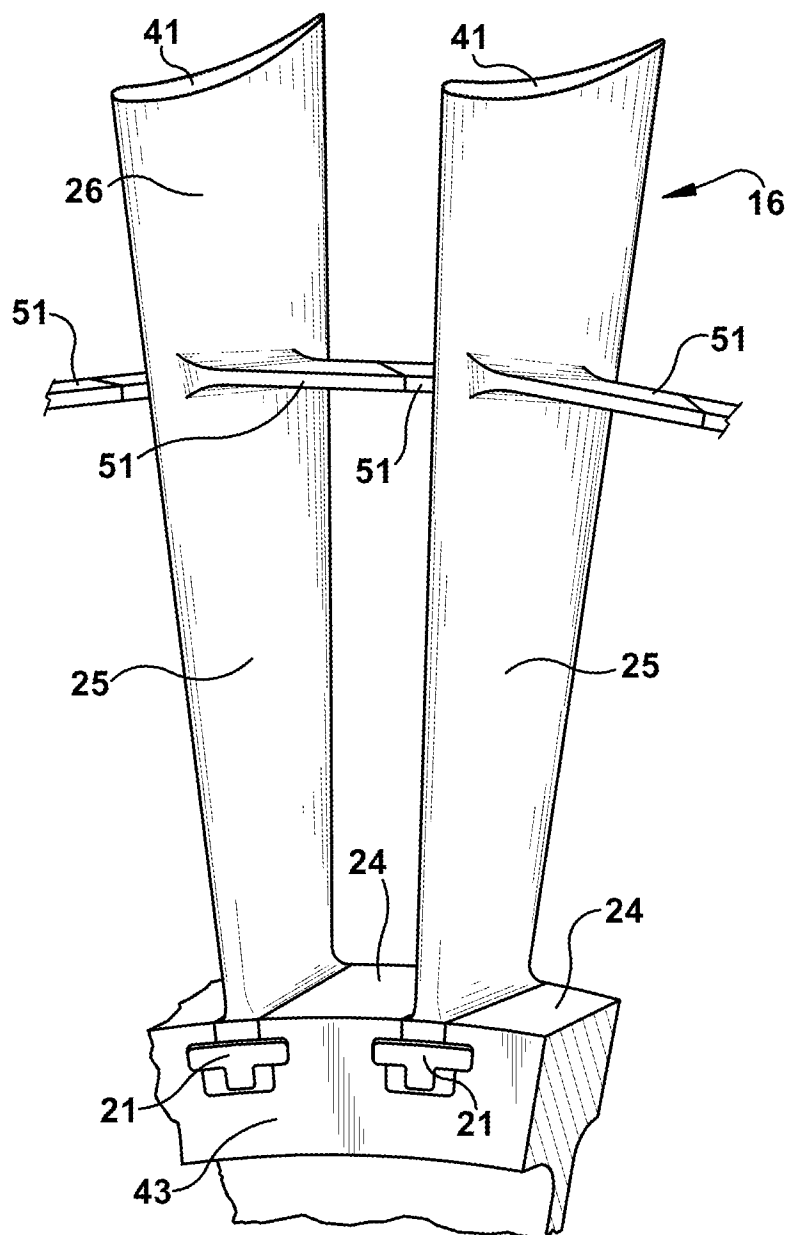


Figure 6

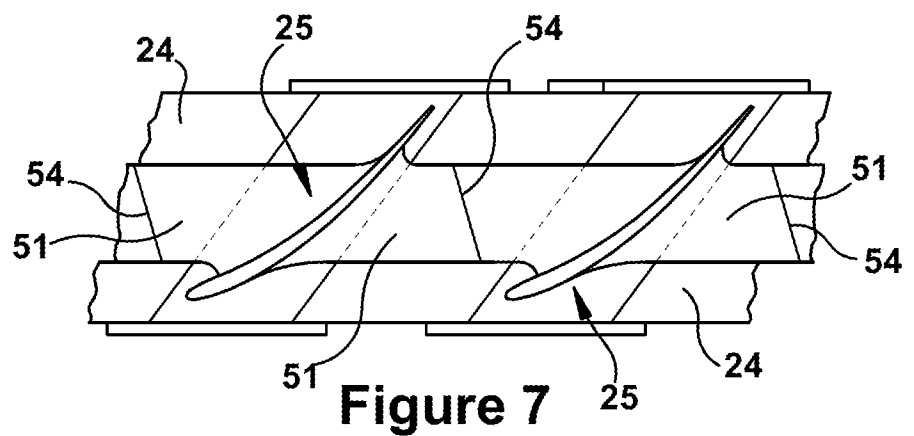
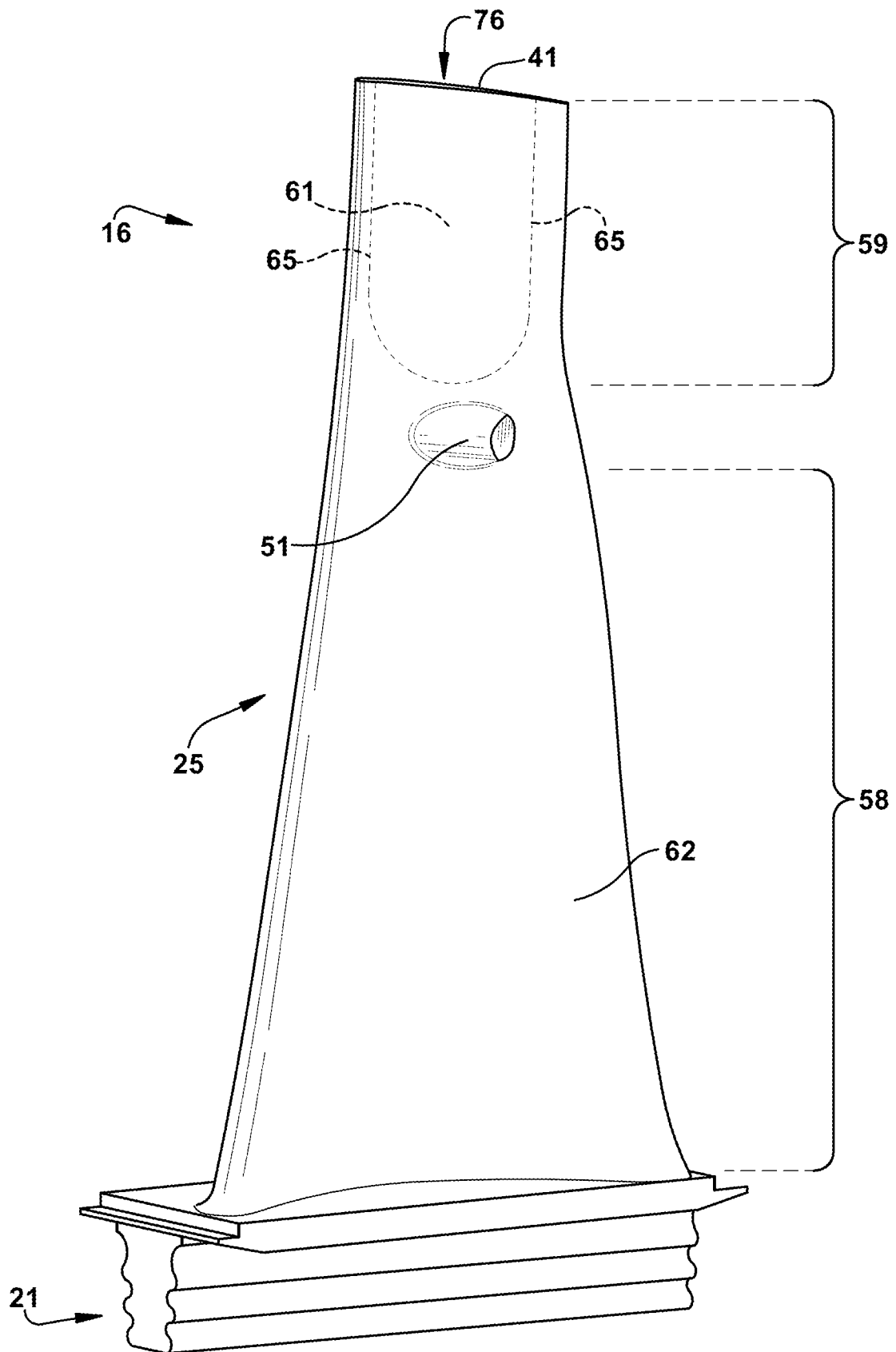
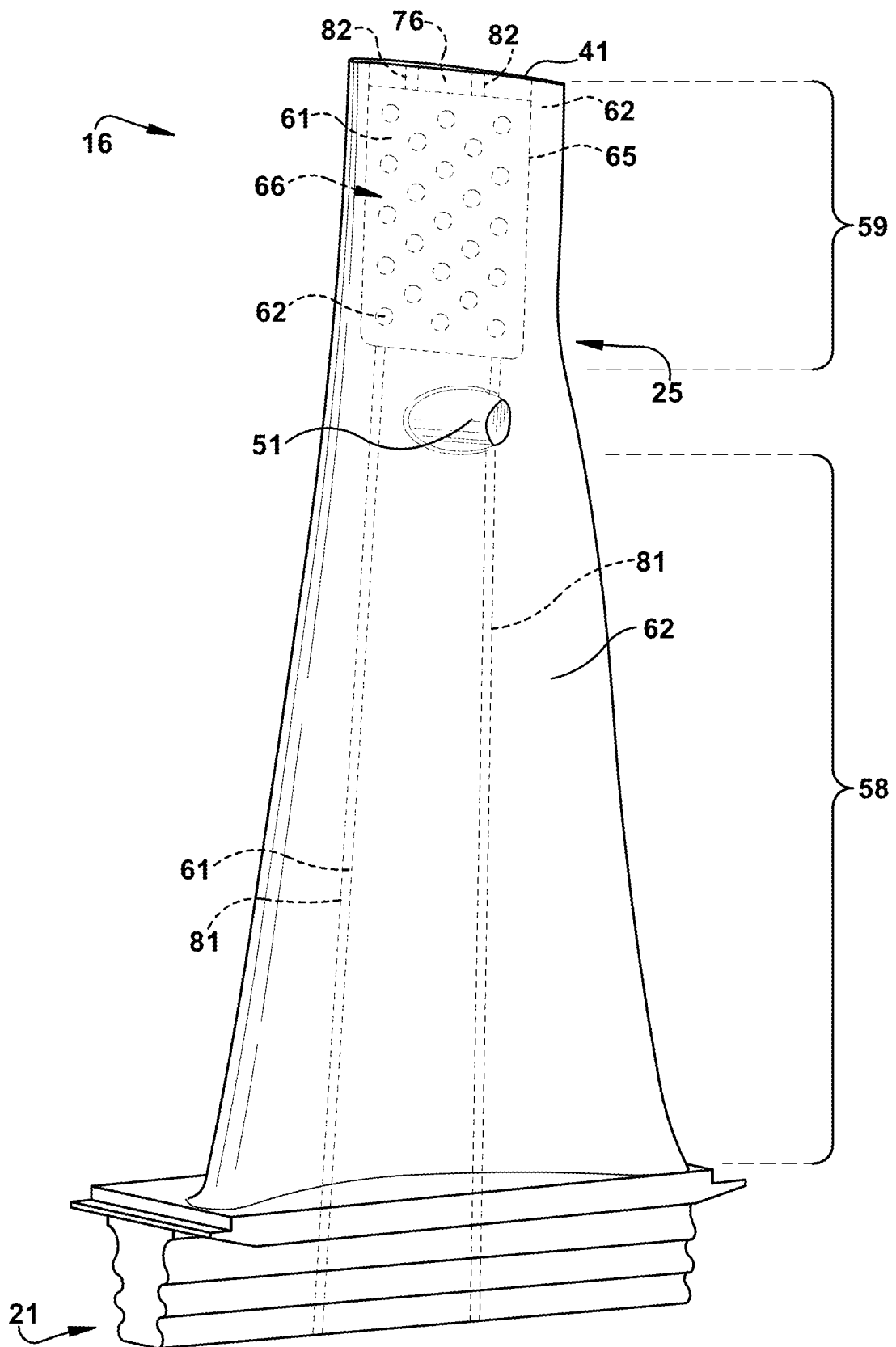
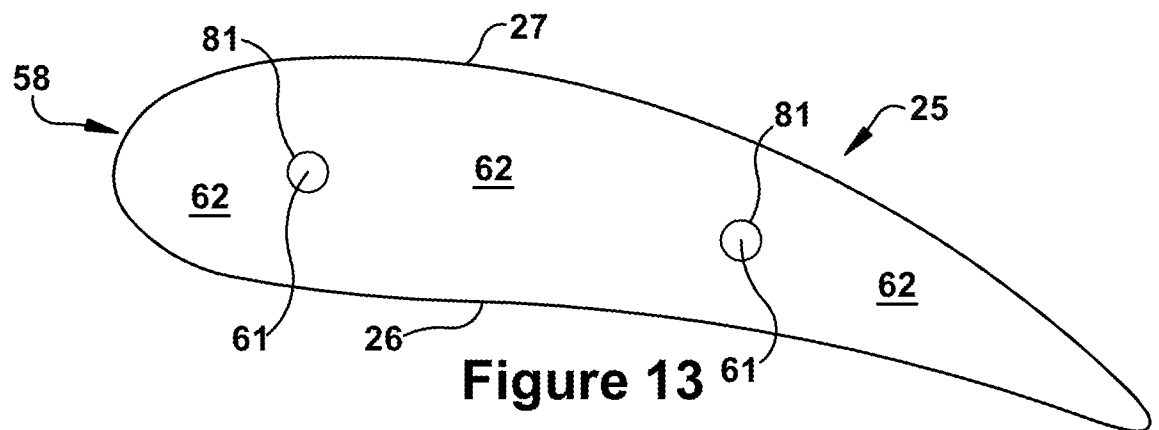
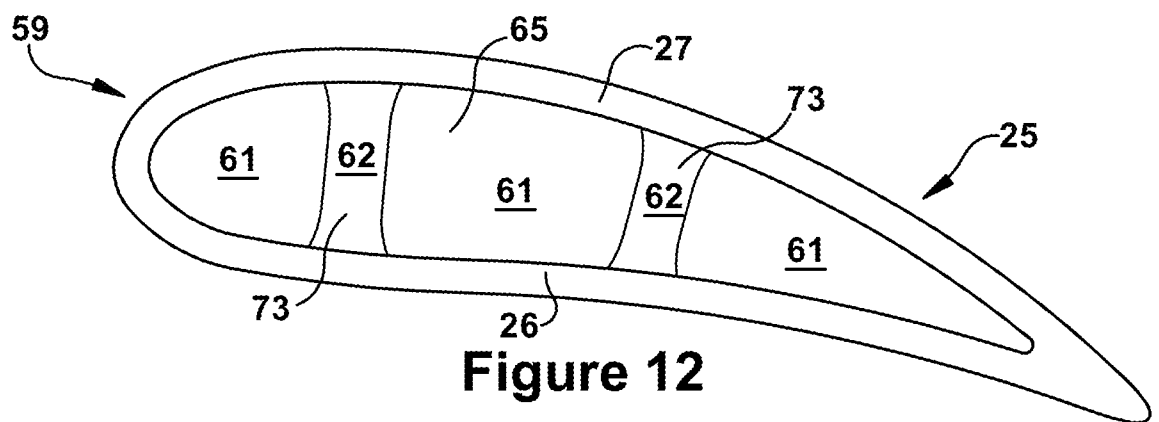
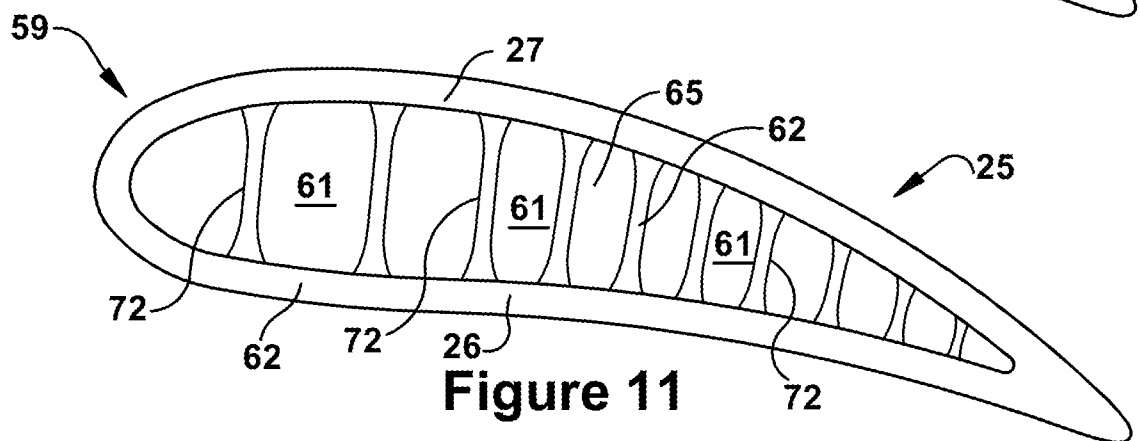
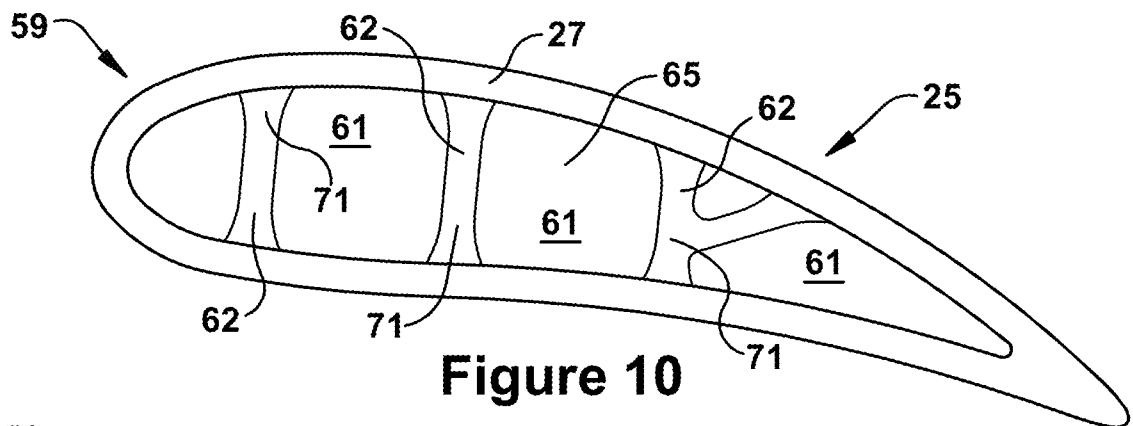


Figure 7

**Figure 8**

**Figure 9**



INTERNATIONAL SEARCH REPORT

International application No
PCT/US2013/076778

A. CLASSIFICATION OF SUBJECT MATTER
INV. F01D5/18 F01D5/22
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)
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)

EP0-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	US 2011/194943 A1 (MAYER CLINTON A [US] ET AL) 11 August 2011 (2011-08-11) abstract; figures 2,3,7,8 -----	1-22
X	US 2012/027616 A1 (MERRILL GARY B [US] ET AL) 2 February 2012 (2012-02-02) paragraphs [0002], [0016]; figures 1-3 -----	1-22
X	EP 2 236 755 A2 (GEN ELECTRIC [US]) 6 October 2010 (2010-10-06) figures 2,6,6A -----	1,22
X	EP 2 412 926 A2 (UNITED TECHNOLOGIES CORP [US]) 1 February 2012 (2012-02-01) abstract; figure 2 -----	1-22
X	US 5 813 827 A (NORDLUND RAYMOND SCOTT [US] ET AL) 29 September 1998 (1998-09-29) abstract; figures 1,2,4 -----	1-22

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

☒ See patent family annex.

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Date of the actual completion of the international search

29 April 2014

Date of mailing of the international search report

09/05/2014

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2013/076778

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2011194943 A1	11-08-2011	NONE	
US 2012027616 A1	02-02-2012	NONE	
EP 2236755 A2	06-10-2010	EP 2236755 A2	06-10-2010
		JP 2010230005 A	14-10-2010
		RU 2010111039 A	27-09-2011
		US 2010247315 A1	30-09-2010
EP 2412926 A2	01-02-2012	EP 2412926 A2	01-02-2012
		US 2012020805 A1	26-01-2012
US 5813827 A	29-09-1998	CN 1228135 A	08-09-1999
		DE 69820572 D1	29-01-2004
		DE 69820572 T2	16-12-2004
		EP 0918923 A1	02-06-1999
		JP 4175669 B2	05-11-2008
		JP 2002511123 A	09-04-2002
		KR 20000016687 A	25-03-2000
		US 5813827 A	29-09-1998
		WO 9846860 A1	22-10-1998