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(54) TURBINE ROTOR BLADES HAVING MID-SPAN SHROUDS

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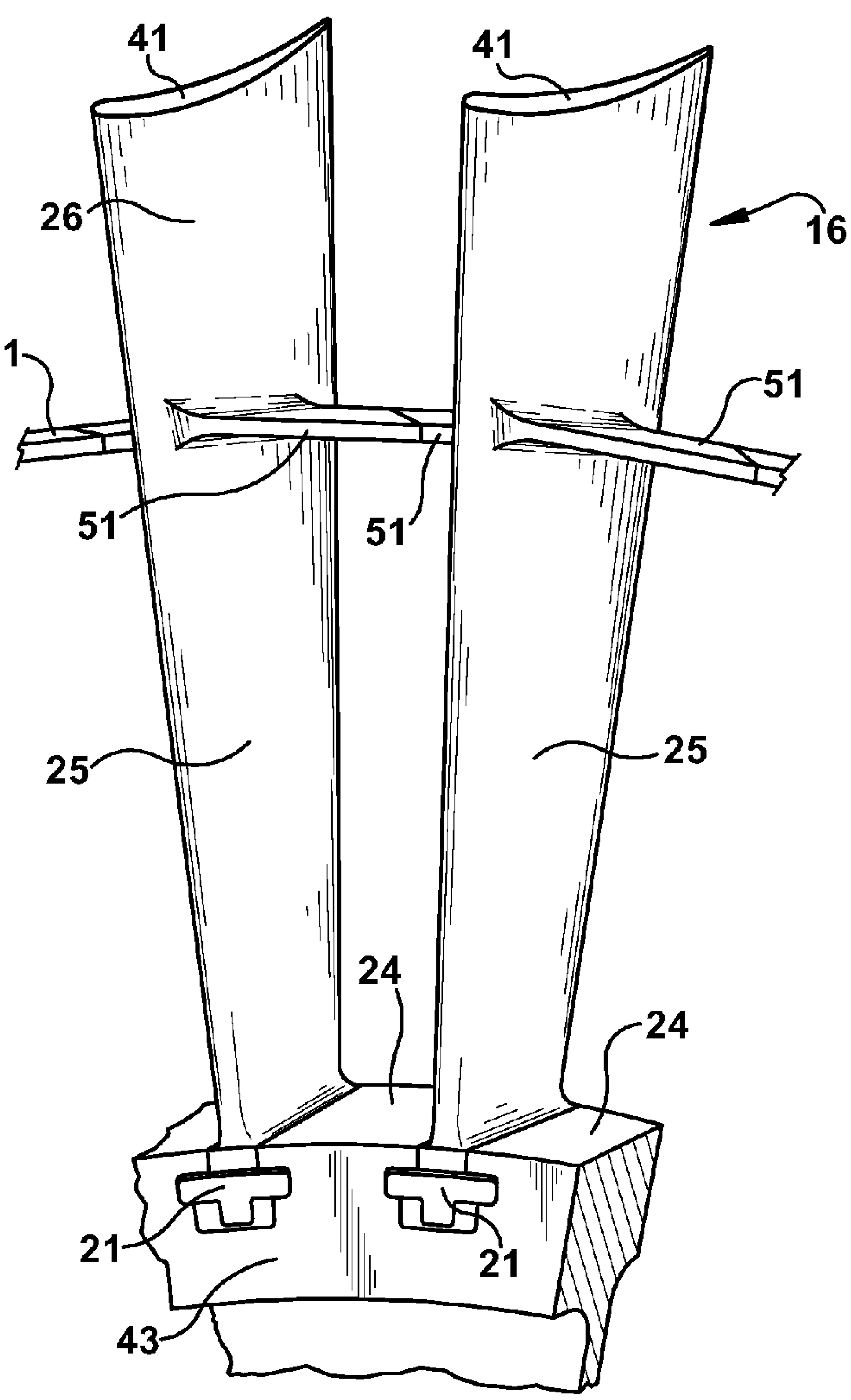
USPC .... **416/97 R**; 416/196 R

(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.



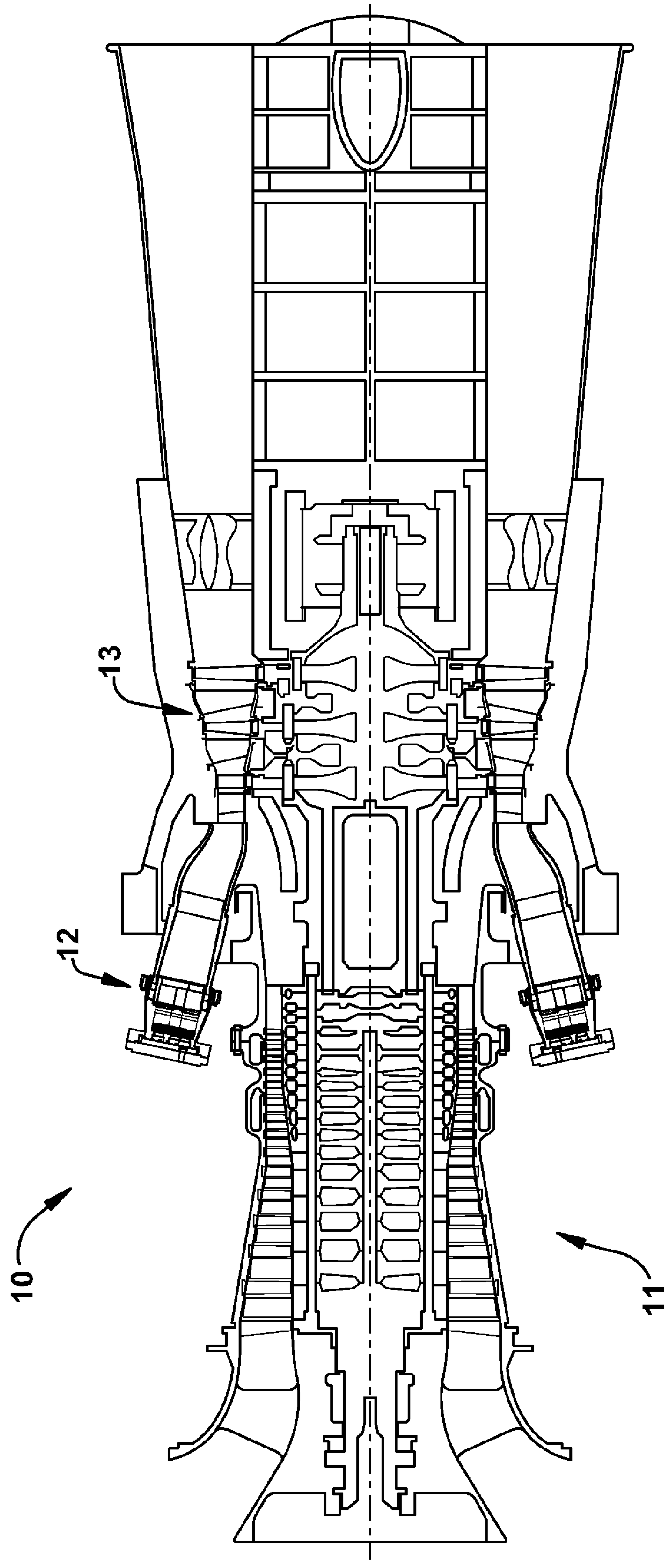


Figure1
(Prior Art)

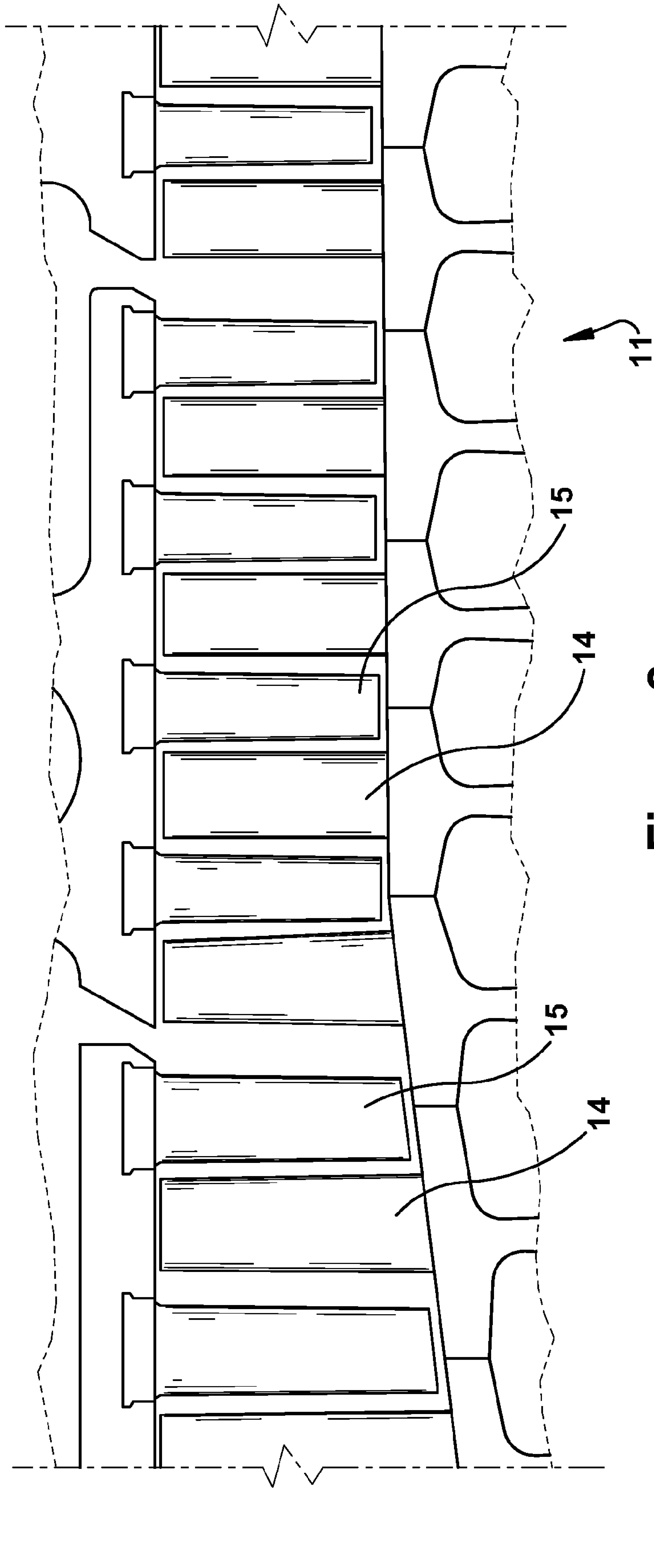


Figure 2
(Prior Art)

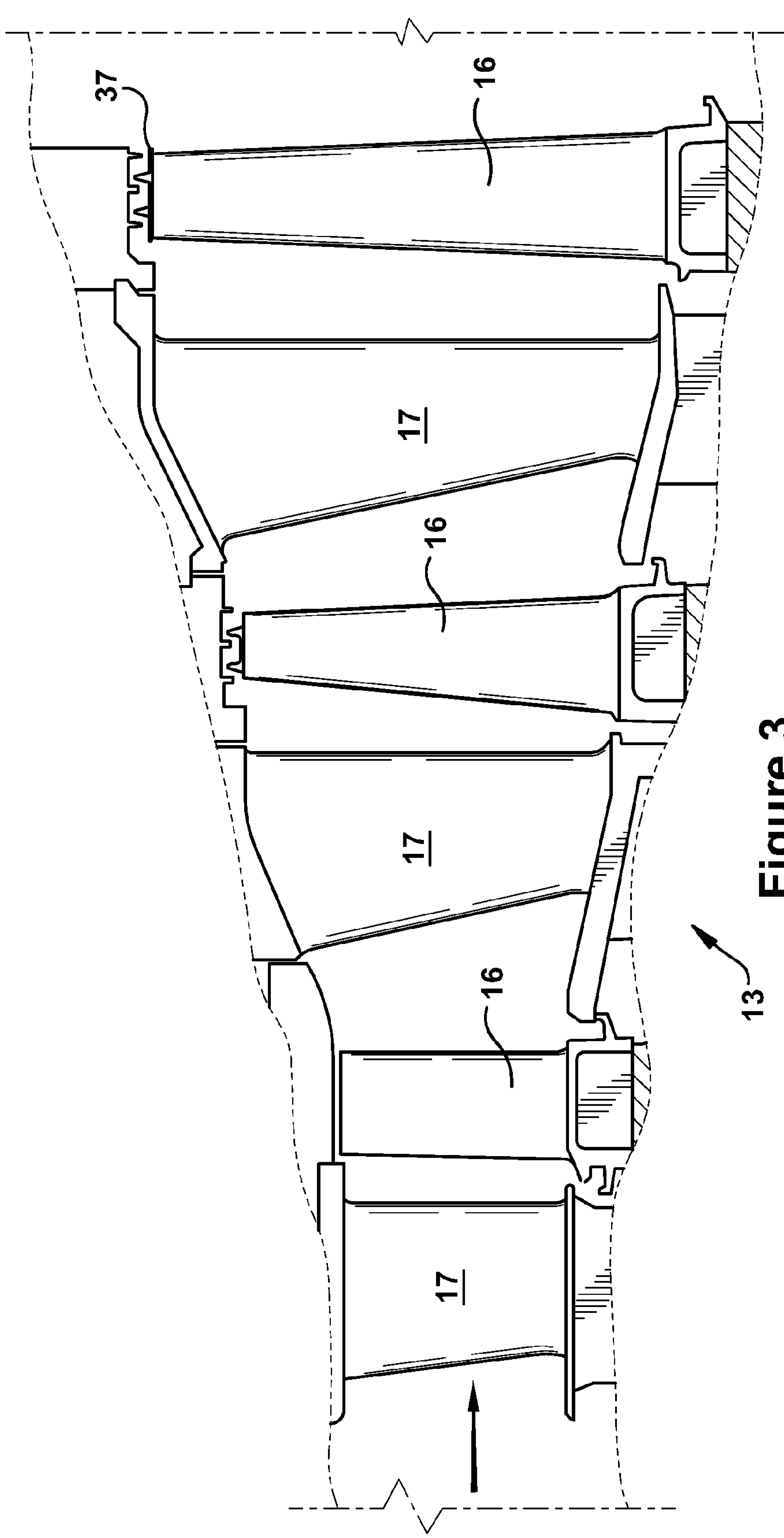


Figure 3
(Prior Art)

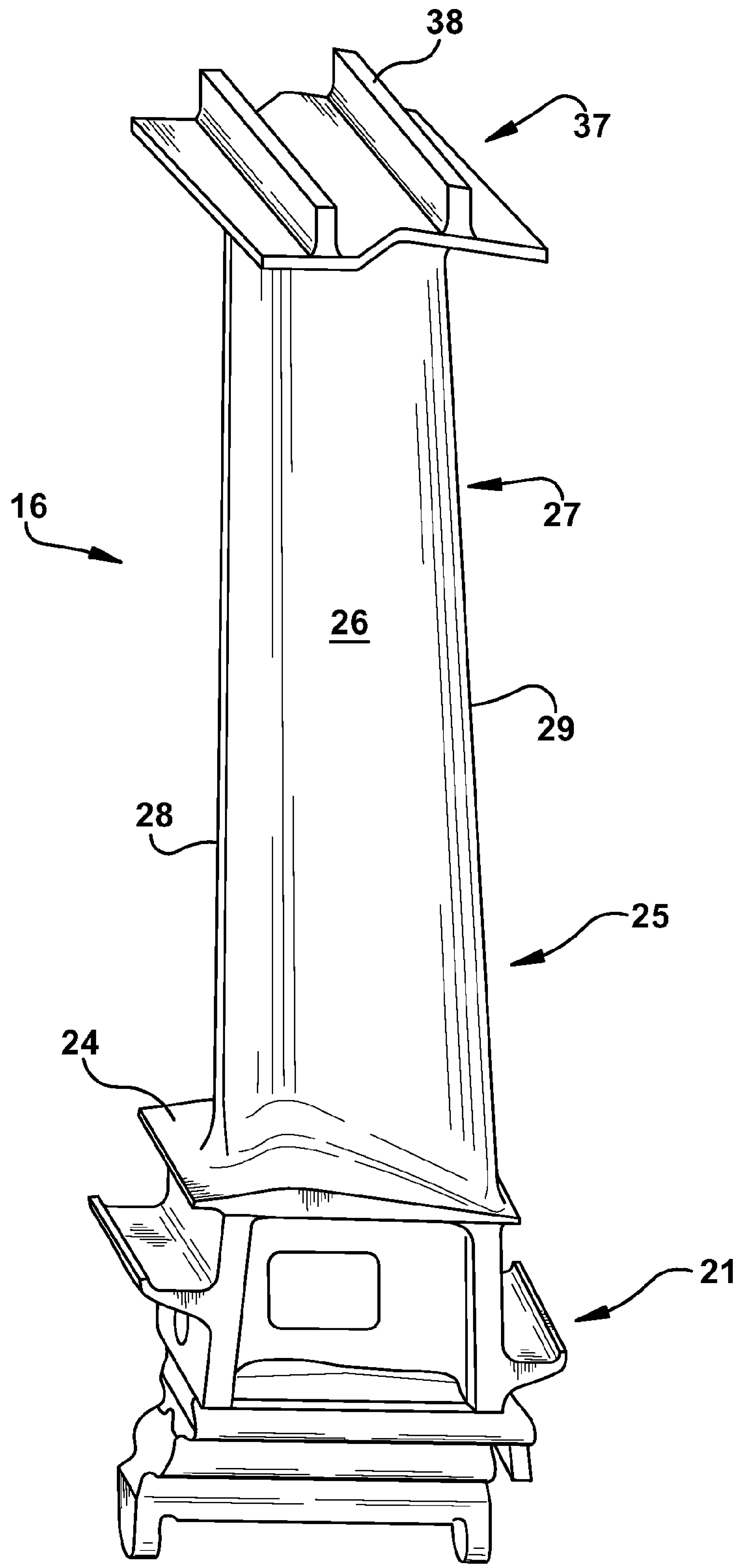


Figure 4
(Prior Art)

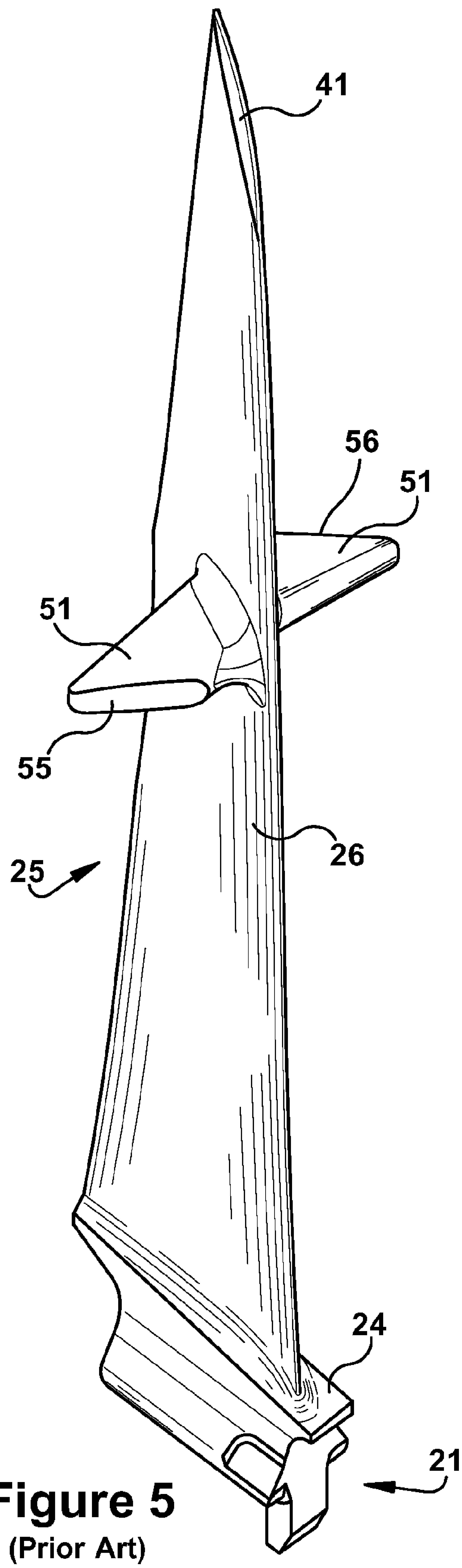


Figure 5
(Prior Art)

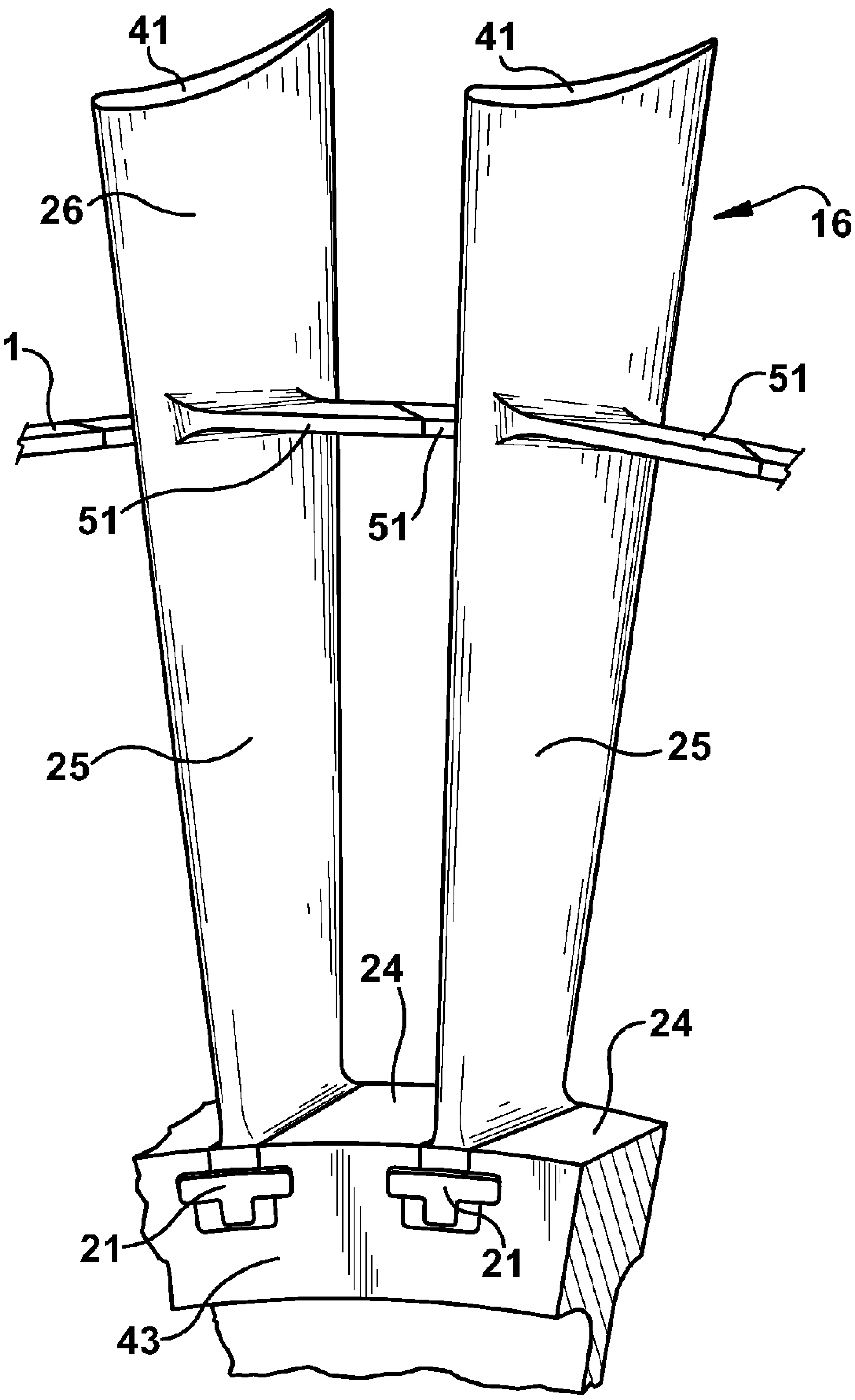


Figure 6

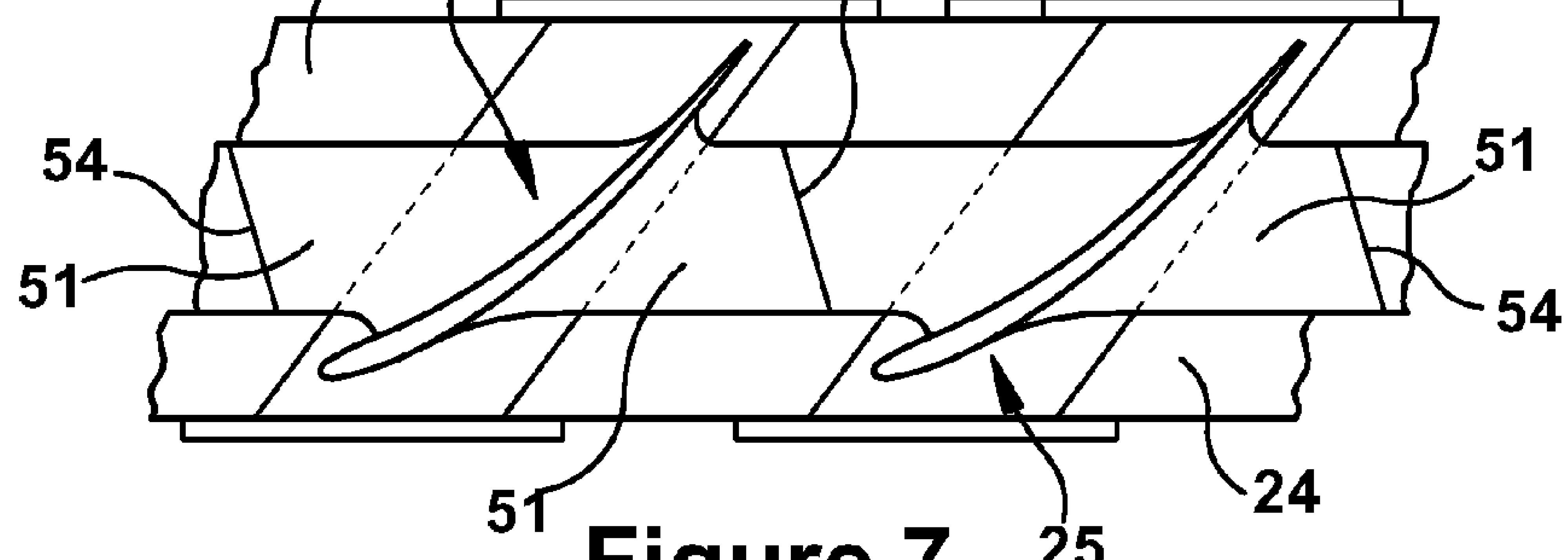


Figure 7

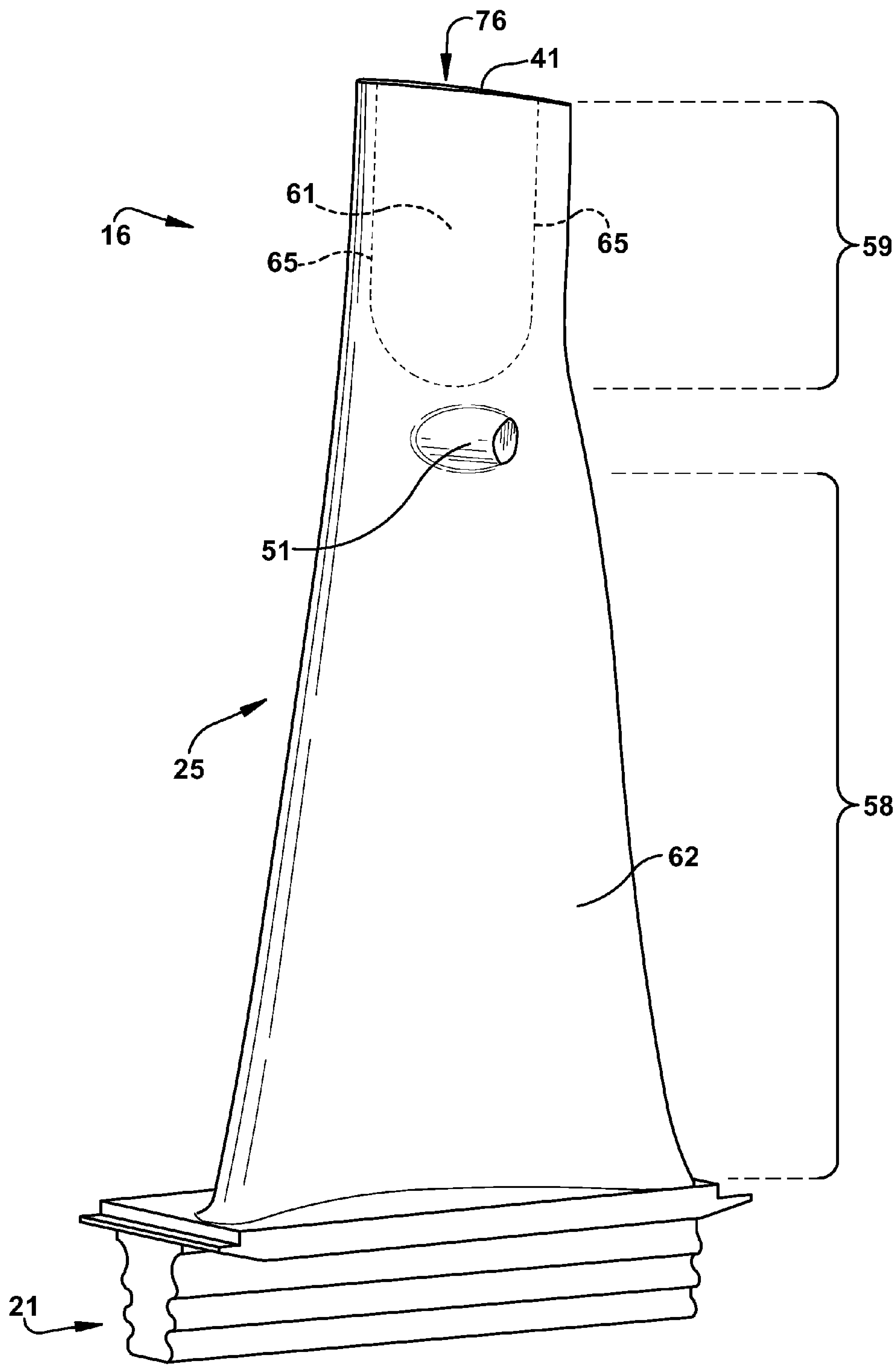


Figure 8

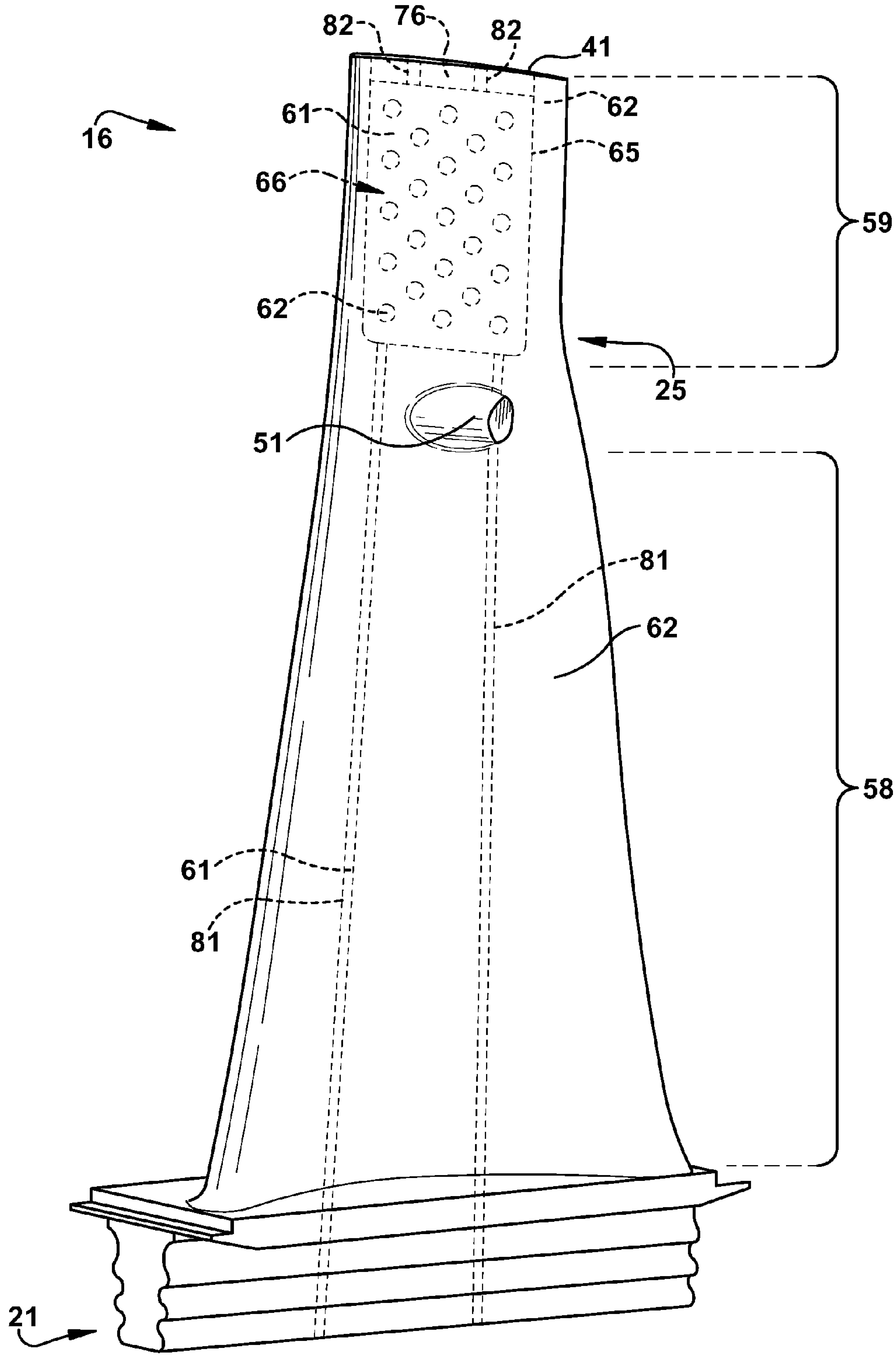


Figure 9

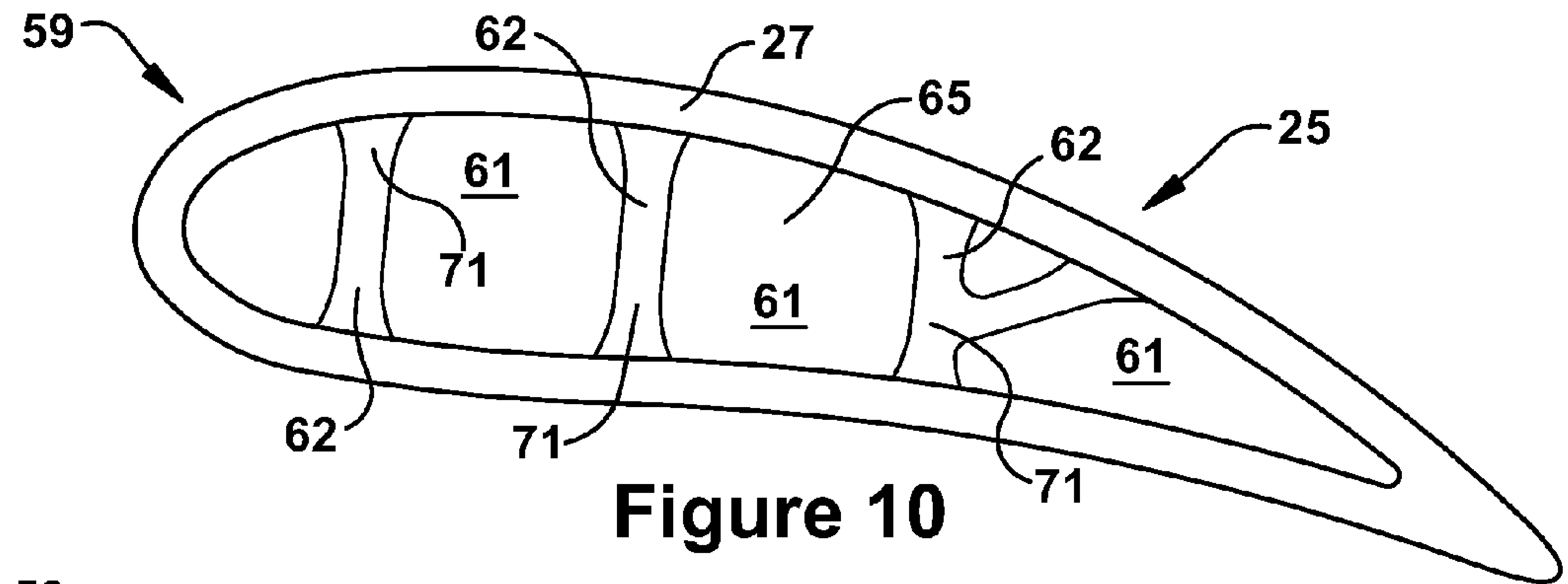


Figure 10

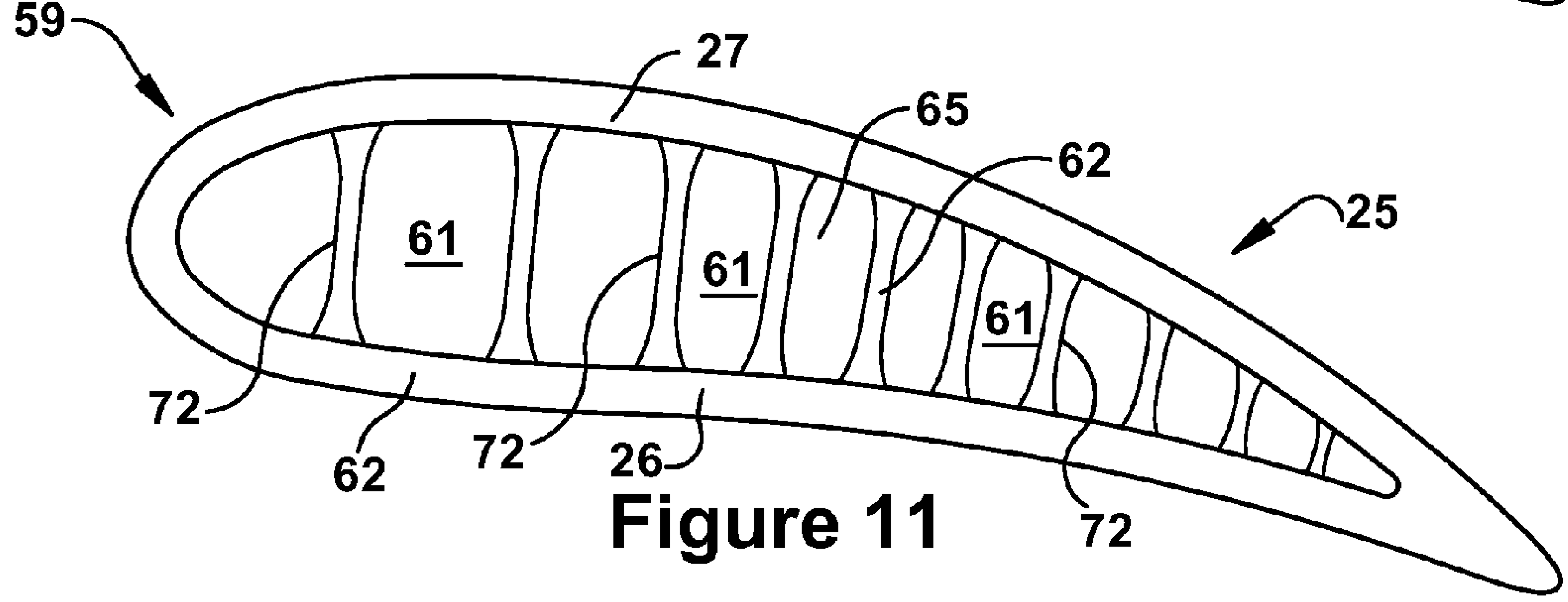


Figure 11

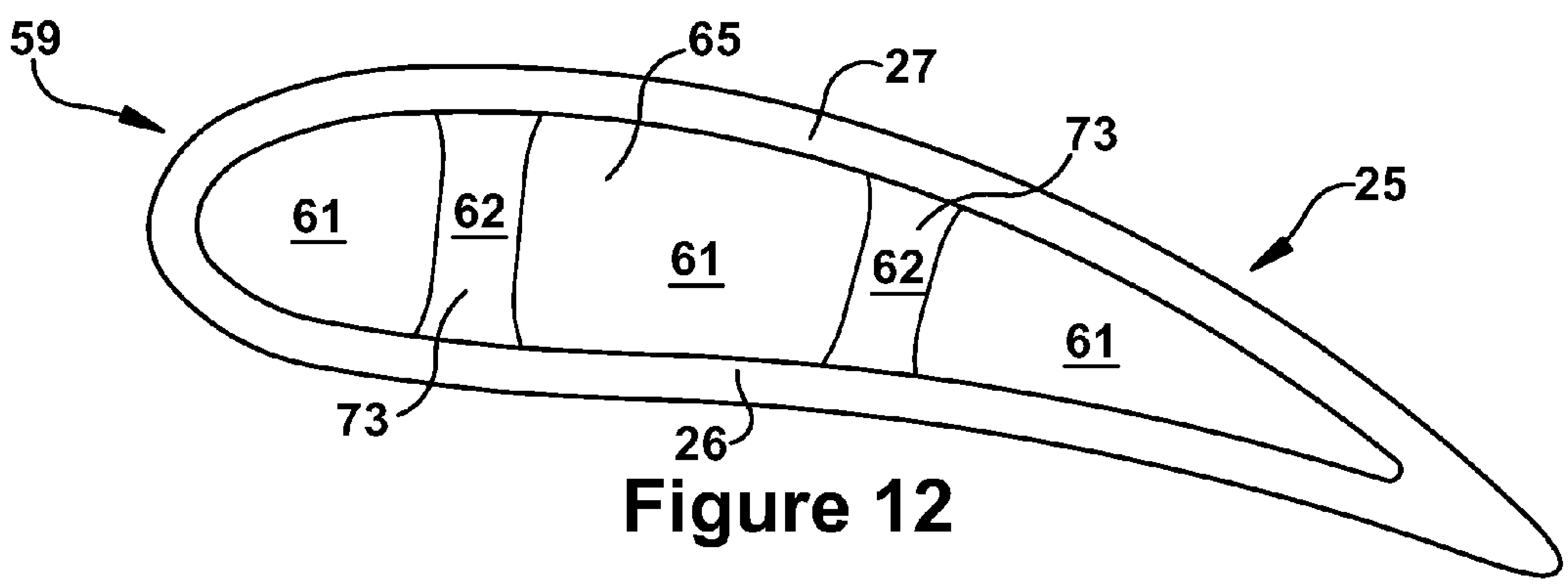


Figure 12

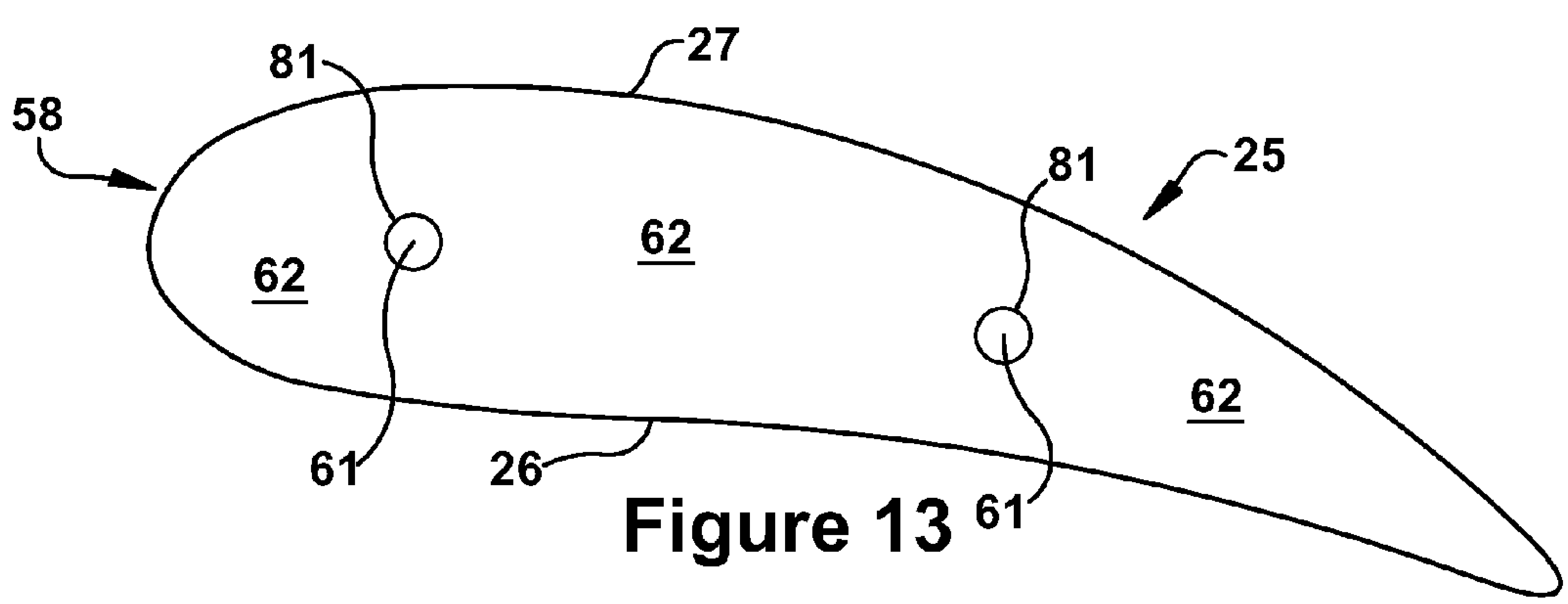


Figure 13

TURBINE ROTOR BLADES HAVING MID-SPAN SHROUDS

BACKGROUND OF THE INVENTION

[0001] 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.

[0002] 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.

[0003] 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 improves 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.

[0004] 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.

[0005] 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

[0006] 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.

[0007] 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

[0008] 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:

[0009] FIG. **1** is a schematic representation of an exemplary combustion turbine engine in which embodiments of the present application may be used;

[0010] FIG. **2** is a sectional view of the compressor in the combustion turbine engine of FIG. **1**;

[0011] FIG. **3** is a sectional view of the turbine in the combustion turbine engine of FIG. **1**;

[0012] FIG. **4** is a perspective view of an exemplary turbine rotor blade having a tip shroud of conventional design;

[0013] FIG. **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;

[0014] FIG. **6** is a perspective view of turbine rotor blades having mid-span shrouds as in FIG. **5** in an installed condition;

[0015] FIG. **7** is a top view of turbine rotor blades having mid-span shrouds as in FIG. **5** in an installed condition;

[0016] FIG. **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;

[0017] FIG. **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;

[0018] FIG. **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;

[0019] FIG. **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;

[0020] FIG. **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

[0021] FIG. **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

[0022] 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.

[0023] 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.

[0024] By way of background, referring now to the figures, FIGS. **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. FIG. **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 FIG. **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**.

[0025] FIG. **2** illustrates a view of an exemplary multi-staged axial compressor **11** that may be used in the combustion turbine engine of FIG. **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 FIG. **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**.

[0026] FIG. **3** illustrates a partial view of an exemplary turbine section or turbine **13** that may be used in the combustion turbine engine of FIG. **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 FIG. **3**. Each additional stage may include a row of turbine stator blades **17** followed by a row of turbine rotor blades **16**.

[0027] 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.

[0028] FIG. **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 FIG. **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**.

[0029] FIG. **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 FIG. **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 slowing. 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 FIG. **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.

[0030] FIG. **6** is a perspective view of rotor blades **16** having mid-span shrouds **51** as they might be arranged in an installed condition. FIG. **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.

[0031] FIG. **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. FIG. **9** is a similar view illustrating an alternative embodiment for the internal structure. As used herein and as depicted on FIGS. **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 FIGS. **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 FIG. **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 FIG. **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**.

[0032] 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**.

[0033] 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**.

[0034] As to other characteristics of the mid-span shroud **51** of the present invention, the mid-span shroud **51** may 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 FIGS. **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**.

[0035] As mentioned, the hollow region **61** of the outboard region **59** may include a hollow chamber **65**. As illustrated via the dotted lines of FIGS. **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 FIG. **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**.

[0036] According to the present invention, FIGS. **10** through **12** illustrate several possible embodiments for the configuration of the connectors **66** formed within the chamber **65** of the outboard region **59**. FIG. **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 FIG. **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 FIG. **10**. In another alternative, as illustrated in FIG. **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.

[0037] FIG. **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 FIG. **13**, for example, might be a cross-sectional view of the inboard region of FIG. **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.

[0038] 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%.

[0039] 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**.

[0040] 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 FIG. **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 FIG. **8**, that opens to the hollow chamber **65** of the airfoil **25**.

[0041] It will 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.

[0042] 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.

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%.

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