

(19)



(11)

**EP 2 562 353 A2**

(12)

**EUROPEAN PATENT APPLICATION**

(43) Date of publication:

**27.02.2013 Bulletin 2013/09**

(51) Int Cl.:

**F01D 5/18 (2006.01)**

(21) Application number: **12180321.7**

(22) Date of filing: **13.08.2012**

(84) Designated Contracting States:

**AL AT BE BG CH CY CZ DE DK EE ES FI FR GB  
GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO  
PL PT RO RS SE SI SK SM TR**

Designated Extension States:

**BA ME**

(30) Priority: **24.08.2011 US 201113216403**

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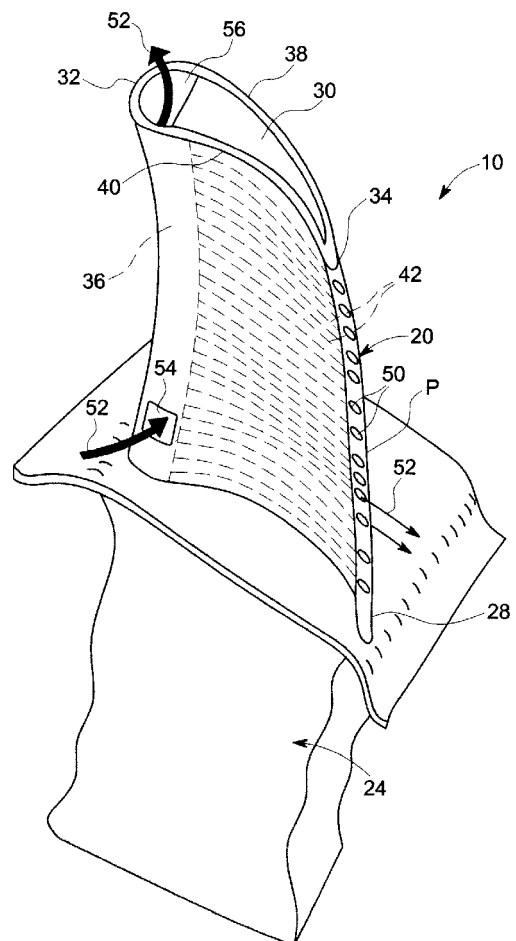
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(54) **Axially cooled airfoil**

(57) An airfoil is provided. The airfoil (10) includes an airfoil blade (20). The airfoil blade (20) has a trailing edge (34), a pressure sidewall (40) and a suction sidewall (38), where a portion of the airfoil blade (20) has a widest cross section when measured between the suction sidewall (38) and the pressure sidewall (40). A plenum (36) is located along the widest cross section. At least one passageway (42) extends in an axial direction from the plenum (36) and terminates at the trailing edge (34). The at least one passageway (42) is in fluid communication with and receives a flow from the plenum (36).



**FIG. 1**

## Description

### BACKGROUND OF THE INVENTION

**[0001]** The subject matter disclosed herein relates to an airfoil, and more specifically to an airfoil having at least one passageway extending in an axial direction from a plenum and terminating at a trailing edge.

**[0002]** Turbine engines include rotor blades that extend radially outwardly from a turbine rotor. The rotor blades include a shank and an airfoil. Hot gasses usually travel through a series of internal cooling passages or holes that are located within the airfoil. The cooling holes in the airfoil are typically oriented in a radial direction.

**[0003]** Orienting the cooling holes in the radial direction may create several concerns. For example, radially oriented coolant channels usually have warmer coolant located near the tip of the airfoil. Thus, tip damage due to overheating may occur. Radially oriented cooling holes also tend to provide less cooling at a leading edge of the airfoil, where heat load is typically high. Moreover, because the turbine rotor rotates during operation, cooling of the airfoil can become complex. This is because the rotary forces that are exerted on the airfoil as the turbine rotor operates are generally perpendicular to the orientation of the radially oriented cooling holes. This difference may lead to uneven cooling of the airfoil. Coriolis forces also act upon the airfoil and may negatively affect the cooling as well. The Coriolis force is proportional to the vector product of the velocity vector of the coolant flowing through the cooling holes and the angular velocity vector of the rotating airfoil. Thus, the Coriolis forces act upon the coolant located in the radially oriented cooling holes in a tangential direction. This redistributes coolant in the presence of Coriolis force, which results in non-uniform heat transfer of the airfoil.

**[0004]** One approach to improve airfoil cooling involves increasing the cooling flow by bleeding off more engine compressor air. However, this approach affects the efficiency of the turbine. Therefore, it would be desirable to provide an airfoil having an effective cooling system that would reduce the adverse effect of rotational and Coriolis forces.

### BRIEF DESCRIPTION OF THE INVENTION

**[0005]** According to one aspect of the invention, an airfoil is provided. The airfoil includes an airfoil blade. The airfoil blade has a trailing edge, a pressure sidewall and a suction sidewall, where a portion of the airfoil blade has a widest cross section when measured between the suction sidewall and the pressure sidewall. A plenum is located at the widest section of the airfoil. At least one passageway extends in an axial direction from the plenum and terminates at the trailing edge. At least one passageway is in fluid communication with and receives a flow from the plenum.

**[0006]** These and other advantages and features will

become more apparent from the following description taken in conjunction with the drawings.

### BRIEF DESCRIPTION OF THE DRAWING

**[0007]** Embodiments of the present invention will now be described, by way of example only, with reference to the accompanying drawings in which:

FIG. 1 is an illustration of an exemplary airfoil having an airfoil blade;

FIG. 2 is a top view of the airfoil shown in FIG. 1;

FIG. 3 is an illustration of an alternative embodiment of the airfoil shown in FIG. 1;

FIG. 4 is an illustration of another alternative embodiment of the airfoil shown in FIG. 1;

FIG. 5 is a turbulated cooling passageway of the airfoil shown in FIG. 1;

FIG. 6 is an illustration of yet another alternative embodiment of the airfoil shown in FIG. 1;

FIG. 7 is an illustration of another alternative embodiment of the airfoil shown in FIG. 1; and

FIG. 8 is an illustration of yet another alternative embodiment of the airfoil shown in FIG. 1.

**[0008]** The detailed description explains embodiments of the invention, together with advantages and features, by way of example with reference to the drawings.

### DETAILED DESCRIPTION OF THE INVENTION

**[0009]** FIG. 1 is an illustration of an exemplary airfoil indicated by reference number 10. In one embodiment, the airfoil 10 is employed in a rotor of a turbine engine (not shown). The airfoil 10 includes an airfoil blade 20 and a platform 24. The airfoil blade 20 projects outwardly from the platform 24. The airfoil blade 20 is attached or coupled to the platform 24 at a hub or root 28. The airfoil blade 20 extends outwardly and terminates at a tip portion 30. The airfoil blade 20 includes a leading edge 32 and a trailing edge 34, as well as a pressure sidewall 40 and a suction sidewall 38. A plenum 36 is located within the airfoil blade 20 and is shown in phantom line. In the exemplary embodiment as shown, the plenum 36 is located at the leading edge 30 of the airfoil blade 20, and may extend along a length of the airfoil blade 20 from the root 28 to the tip portion 30. However, it is understood that the plenum 36 may be located in other locations of the airfoil blade 20 as well. Specifically, in an alternative embodiment, the plenum 36 may be located at an area of the airfoil blade 20 having the widest cross section when

viewed from the tip portion 30. Specifically, referring to FIG. 2, an area A is denoted at the tip portion 30, and represents the portion of the airfoil blade 20 having the widest cross section when measured between the suction sidewall 38 and the pressure sidewall 40.

**[0010]** The plenum 36 is fluidly connected to and in communication with at least one cooling passageway 42. The cooling passageways 42 extend axially from the plenum 36 and terminate at the trailing edge 34 as a series of cooling holes 50. In the embodiment as shown in FIG. 1, a plurality of cooling passageways 42 are located between the root 28 and the tip portion 30 for providing cooling to the airfoil blade 20.

**[0011]** The plenum 36 is positioned to receive a cooling flow 52 through an aperture 54 located at the root 28 of the airfoil blade 20. The cooling flow 52 travels through the plenum 36 and to the cooling passageways 42. A portion of the cooling flow 52 may exit the airfoil blade 20 through an aperture 56 located at the tip portion 30. The remaining amount of the cooling flow 52 exits the cooling passageways 42 through the apertures 50 located at the trailing edge 34 of the airfoil blade 20.

**[0012]** In the exemplary embodiment as shown, the airfoil blade 20 includes a generally angled outer profile P. The cooling passageways 42 may also include a generally curved profile for accommodating the generally angled outer profile P of the airfoil blade 20. Turning now to FIG. 2, a top view of the airfoil blade 20 viewed from the tip portion 30 is illustrated. Referring now to both of FIGS. 1-2, the cooling passageways 42 include a generally arcuate or curved profile extending from the plenum 36 to the trailing edge 32. The generally curved profile of the cooling passageways 42 typically correspond with at least a portion of the generally angled outer profile P of the airfoil blade 20. The generally curved profile of the cooling passageways 42 may be manufactured using a variety of approaches. In one exemplary embodiment, the cooling passageways 42 are manufactured using a Shaped Tube Electrochemical Machining (STEM) process that facilitates a curved drilling process. However it is understood that other approaches may be used as well for creating the cooling passageways 42.

**[0013]** Conventional airfoil blades that are currently available typically have cooling holes oriented in the radial direction. Radially oriented coolant channels usually have warmer coolant located near the tip of the airfoil. Thus, tip damage due to overheating can occur. The cooling passageways 42 are oriented in the axial direction, which provides for more uniform cooling flow at the tip portion 30 of the airfoil blade 20. Moreover, the airfoil blade 20 may also provide increased cooling at the leading edge 32 when compared to a conventional airfoil blade having radially oriented cooling holes.

**[0014]** Rotary forces are exerted during operation of the turbine engine (not shown), which may lead to uneven cooling of conventional airfoil blades that have radially oriented cooling holes. Coriolis and rotational buoyancy forces also act upon the coolant located in the cooling

holes in tangential and radial directions. Radially oriented cooling holes are perpendicular to the direction in which the Coriolis forces act. In contrast, the cooling passageways 42 of the airfoil blade 20 are oriented in the axial direction that is generally parallel to the direction of rotation of the turbine engine. Therefore, adverse effects due to rotational and Coriolis forces may be reduced or substantially prevented in the airfoil blade 20 when compared to a conventional airfoil blade having radially oriented cooling holes.

**[0015]** FIG. 3 is an alternative embodiment of an airfoil blade 120. In the embodiment as shown, at least one cooling passageway 180 terminates at a tip portion 130 of the airfoil blade 120, while the remaining passageways 142 terminate at a leading edge 132 of the airfoil blade 120. That is, the cooling passageways 180 are generally oriented in part in a radial direction of the airfoil blade 120. Part of the cooling passageways may be in radial orientation of the airfoil blade 120 because it is desirable to have radial exit in the tip portion 130.

**[0016]** FIG. 4 is another alternative embodiment of an airfoil blade 220. In the embodiment as shown, the cooling passageways 242 are not generally radially aligned with one another and instead have a staggered configuration with respect to one another. Staggering the cooling passageways 242 may reduce the centrifugal tension that is exerted on the airfoil blade 220. FIG. 4 also illustrates the cooling passageways 242 having a tapered configuration, where the diameter of the cooling passageways 242 generally decrease as the cooling passageways 242 approach a trailing edge 232 of the airfoil blade 220. That is, a first diameter D1 of the cooling passageway 242, which is measured at a proximate end of the cooling passageway 242 with respect to a plenum 236, is greater than a second diameter D2. The second diameter D2 is measured at a distal end of the cooling passageway 242 with respect to the plenum 236. Turning now to FIG. 5, an enlarged view of a portion of one of the cooling passageways 242 is shown. The cooling passageway 242 includes a plurality of protrusions 284 which act as turbulators. That is, the protrusions 284 may create turbulence in the coolant flow 252 that exits the cooling passageway 242.

**[0017]** In yet another embodiment, which is shown in FIG. 6 an airfoil blade 320 is shown having a number of cooling passageways 342 with varying diameters. The cooling passageways 342 also include different configurations. That is, a portion of the cooling passageways 342 have a first configuration where a first diameter D1' of the cooling passageway 388, which is measured at a proximate end of the cooling passageway 342 with respect to a plenum 336, is greater than a second diameter D2'. The second diameter D2' is measured at a distal end of the cooling passageway 342 with respect to the plenum 336. The cooling passageways 388 have a stepped configuration. That is, the change in diameter between the first diameter D1' and the second diameter D2' does not change gradually, but rather changed by a

step 398 that is located in the cooling passageways 388. The remaining cooling passageways 390 also have a stepped configuration as well, and include a step 399. The first diameter D1' is less than the second diameter D2' in the remaining cooling passageways 390. This configuration may be used in an effort to enhance regional cooling of the airfoil blade 320. This arrangement may also be used for increasing the effectiveness of thermal management. This is because an increased diameter of a cooling passageway has slower coolant velocity, and thus results in a lower heat transfer coefficient. Therefore, the coolant located within this type of cooling passageway includes a cooling potential that may be preserved for locations that are located downstream in the cooling passageway.

**[0018]** In another embodiment of an airfoil 420, which is shown in FIG. 7, the cooling passageways 442 are arranged in a diagonal configuration. That is, at least one of the cooling passageways 442 is oriented to extend axially and crosses over another one of the cooling passageways 442. Specifically, at least one of the cooling passageways denoted by reference number 492 has a base portion 494 that is situated proximate to a plenum 436. The base portion 494 is situated below a base portion 496 of another cooling passageway that is denoted by reference number 498. The cooling passageway 492 extends axially in a direction towards a tip portion 430 of the airfoil blade 420, thereby crossing the other cooling passageway 498. The other cooling passageway 498 extends axially in a direction away from the tip portion 430 of the turbine airfoil 420. Thus, the cooling passageway 492 is oriented to extend axially and crosses the cooling passageway 498. In the embodiment as shown, a portion of the cooling passageways 442 also terminate at the tip portion 430 of the airfoil blade 420, while the remaining cooling passageways 492, 498 terminate at a leading edge 432 of the airfoil blade 120. Having at least a portion of the cooling passageways 442 arranged in the diagonal configuration as shown in FIG. 7 may generally prevent hot spots in the airfoil blade 420. Specifically, in the event a hot streak is present, the diagonal configuration may substantially reduce or substantially prevent hot spots on the airfoil blade 420. In other words, the diagonal configuration of the cooling passageways 442 do not generally follow hot-gas path streamlines if there are relatively strong temperature gradients across streamlines.

**[0019]** In yet another embodiment of an airfoil blade 520, which is shown in FIG. 8, the airfoil 520 includes a serpentine passageway 536 instead of a plenum as shown in FIGS. 1-7. A cooling flow 552 enters the airfoil 520 through an aperture 554 located at a root 528 of the airfoil blade 520. In the embodiment as illustrated, the cooling flow 552 located within the serpentine passageway 536 flows at a relatively higher velocity when compared the cooling flow in the plenum shown in FIGS. 1-7. The coolant flow 552 flows within the vertical passages 537 of the serpentine passageway 536. A portion of the coolant flow 552 flows through the serpentine passageway

536, and a remaining portion of the coolant flow 552 flows from the serpentine passageway 536 and into the plurality of cooling passageways 542. The cooling passageways 542 extend axially from the serpentine passageway 536 and terminate at a trailing edge 534 as a series of cooling holes 550, where the cooling flow 552 exits the cooling holes 550. In the embodiment as shown in FIG. 8, the velocity of the coolant flow 552 is high enough such that the effects of the Coriolis forces that act upon the coolant located in the cooling passageways 542 are reduced when compared to the cooling passageways illustrated in FIGS. 1-7. The reduced Coriolis forces will in turn result in increased heat transfer coefficients. Higher heat transfer coefficients tend to cool areas of high heat load while reducing the effects of rotational forces in the cooling passageways 542.

**[0020]** While the invention has been described in detail in connection with only a limited number of embodiments, it should be readily understood that the invention is not limited to such disclosed embodiments. Rather, the invention can be modified to incorporate any number of variations, alterations, substitutions or equivalent arrangements not heretofore described, but which are commensurate with the spirit and scope of the invention. Additionally, while various embodiments of the invention have been described, it is to be understood that aspects of the invention may include only some of the described embodiments. Accordingly, the invention is not to be seen as limited by the foregoing description, but is only limited by the scope of the appended claims.

**[0021]** Various aspects and embodiments of the present invention are defined by the following numbered clauses:

1. An airfoil, comprising:

a platform;  
an airfoil blade, comprising:

a leading edge, a trailing edge, a root and a tip portion, the root of the airfoil blade being coupled to the platform;  
a plenum located along the leading edge;  
and  
a plurality of passageways located between the root portion and the tip portion, at least one of the plurality of passageways extending in an axial direction from the plenum and terminating at the trailing edge, and the plurality of passageways in fluid communication with and receiving a flow from the plenum.

2. The airfoil of clause 1, comprising at least one tip passageway that terminates at the tip portion of the airfoil blade.

3. The airfoil of clause 1, wherein at least one of the

plurality of passageways includes a generally curved profile.

4. The airfoil of clause 1, wherein the plurality of passageways have a staggered configuration with respect to one another.

5. The airfoil of clause 1, wherein at least one of the plurality of passageways has a tapered configuration, wherein a first diameter of the at least one of the plurality of passageways is measured at a proximate end with respect to the plenum and a second diameter is measured at a distal end with respect to the plenum, wherein the first diameter is greater than the second diameter.

6. The airfoil of clause 1, wherein the at least one of the plurality of passageways includes a plurality of protrusions that create a turbulence in the flow.

7. The airfoil of clause 1, wherein a portion of the plurality of passageways have a stepped configuration where a first diameter of the portion of the plurality of passageways is measured at a proximate end with respect to a plenum, and a second diameter is measured at a distal end with respect to the plenum, wherein the first diameter is greater than the second diameter and the first diameter to the second diameter changes by a step located in the plurality of passageways.

8. An airfoil, comprising:

a platform;

an airfoil blade, comprising:

a leading edge, a trailing edge, a root, and a tip portion, the root of the airfoil blade being coupled to the platform;

a serpentine passageway located along the leading edge;

a plurality of passageways located between the root portion and the tip portion, at least one of the plurality of passageways extending in an axial direction from the serpentine passageway and terminating at the trailing edge, at least one of the plurality of passageways including a generally curved profile, and the plurality of passageways in fluid communication with and receiving a flow from the serpentine passageway.

## Claims

1. An airfoil (10), comprising:

an airfoil blade (20) having a trailing edge (34),

a pressure sidewall (40) and a suction sidewall (38), a widest cross section of the airfoil blade (20) defined between the suction sidewall (38) and the pressure sidewall (40);

a plenum (36) located along the widest cross section; and

at least one passageway (42) extending in an axial direction from the plenum (36) and terminating at the trailing edge (34), the at least one passageway (42) in fluid communication with and receiving a flow from the plenum (36).

2. The airfoil (10) of claim 1, wherein the airfoil blade (20) includes a root (28) and a tip portion (30), wherein a plurality of passageways (42) are located between the root (28) portion and the tip portion (30).

3. The airfoil (10) of claim 2, wherein the root (28) is coupled to a platform (24) of the airfoil (10).

4. The airfoil (10) of claim 2 or 3, comprising at least one tip passageway (180) that terminates at the tip portion (130) of the airfoil blade (120).

5. The airfoil (10) of any of claims 1 to 4, wherein the at least one passageway (42) includes a generally curved profile.

6. The airfoil (10) of any of claims 1 to 5, comprising a plurality of passageways (242) that have a staggered configuration with respect to one another.

7. The airfoil (10) of any of claims 1 to 6, wherein the at least one passageway (242) has a tapered configuration, wherein a first diameter (D1) of the at least one passageway (242) is measured at a proximate end of the at least one passageway (242) with respect to the plenum (236) and a second diameter (D2) is measured at a distal end of the at least one passageway (242) with respect to the plenum (236), wherein the first diameter (D1) is greater than the second diameter (D2).

8. The airfoil (10) of any preceding claim, wherein the at least one passageway (242) includes a plurality of protrusions (284) that create a turbulence in the flow located in the at least one passageway (242).

9. The airfoil (10) of any preceding claim, wherein the at least one passageway (342) is a plurality of passageways (388), a portion of the plurality of passageways (388) having a stepped configuration where a first diameter (D1') of the portion of the plurality of passageways (388) is measured at a proximate end of the plurality of passageways (388) with respect to a plenum (336), and a second diameter (D2') is measured at a distal end of the plurality of passageways (388) with respect to the plenum (336), wherein

the first diameter (D1') is greater than the second diameter (D2') and the first diameter (D1') to the second diameter (D2') changes by a step (398) located in the plurality of passageways (388).

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10. The airfoil (10) of claim 9, wherein a remaining portion of the plurality of passageways (390) have the first diameter (D1') being less than the second diameter (D2').

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11. The airfoil of any preceding claim, wherein the at least one passageway (342) is a plurality of passageways, wherein least one of the passageways (342) is oriented to extend diagonally and cross over another one of the passageways (342).

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12. The airfoil of any preceding claim, wherein the plenum (336) is located along a leading edge (32) of the airfoil (10).

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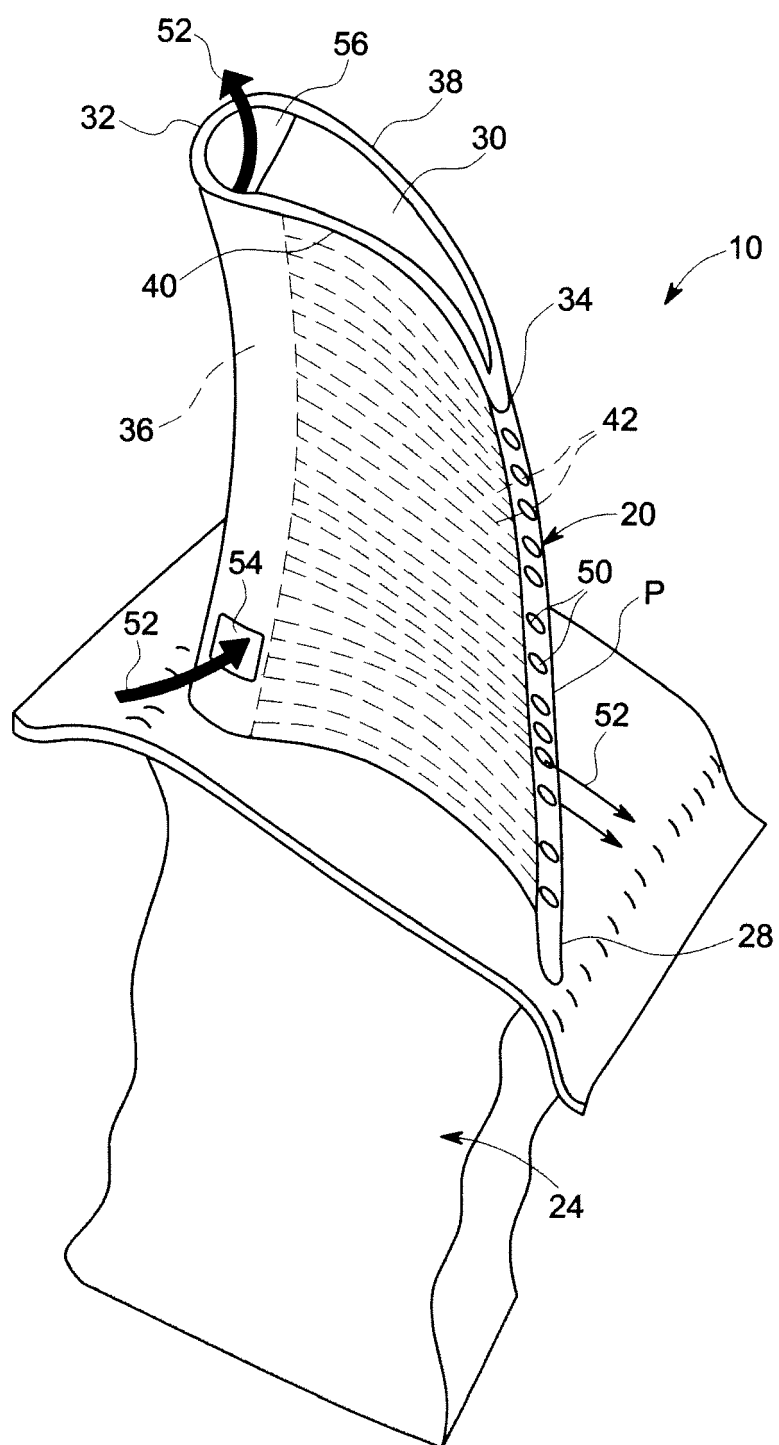


FIG. 1

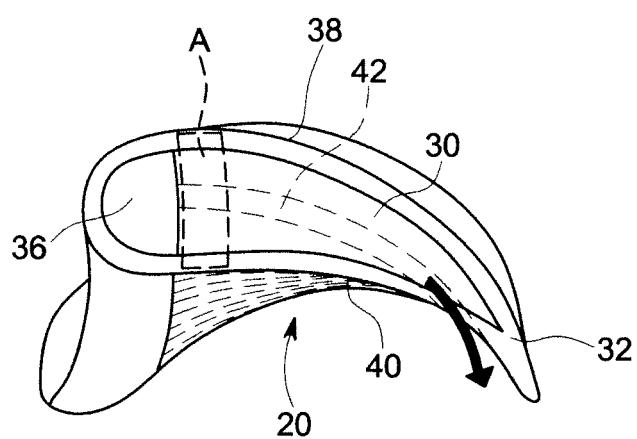


FIG. 2

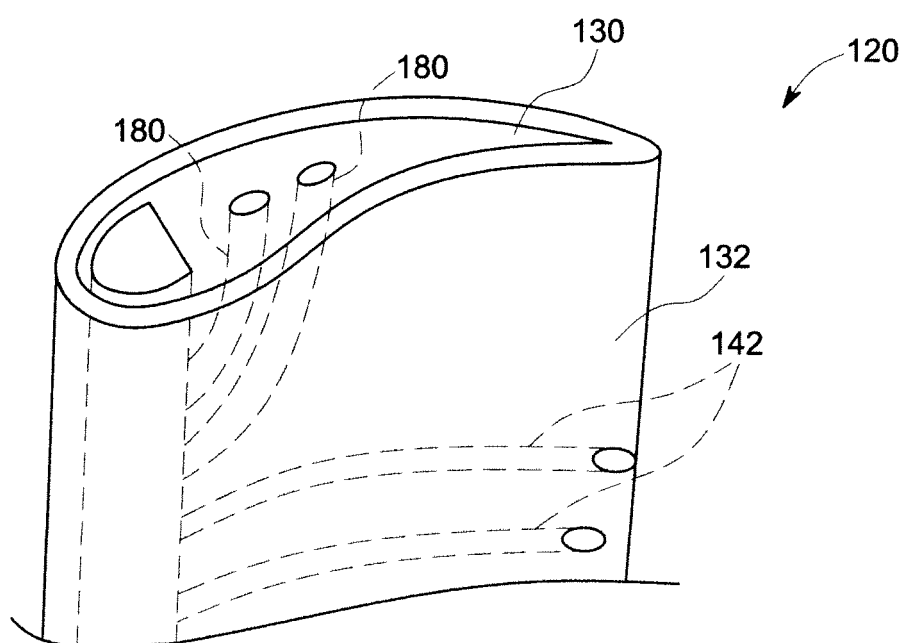


FIG. 3

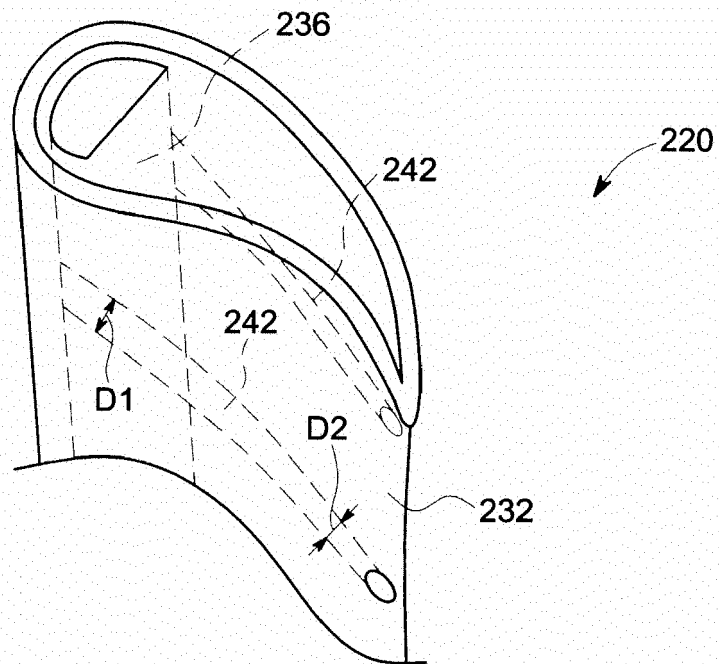


FIG. 4

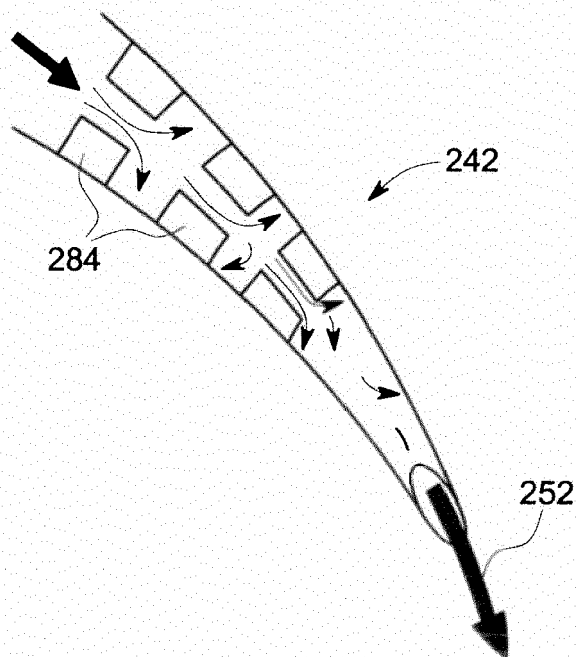


FIG. 5

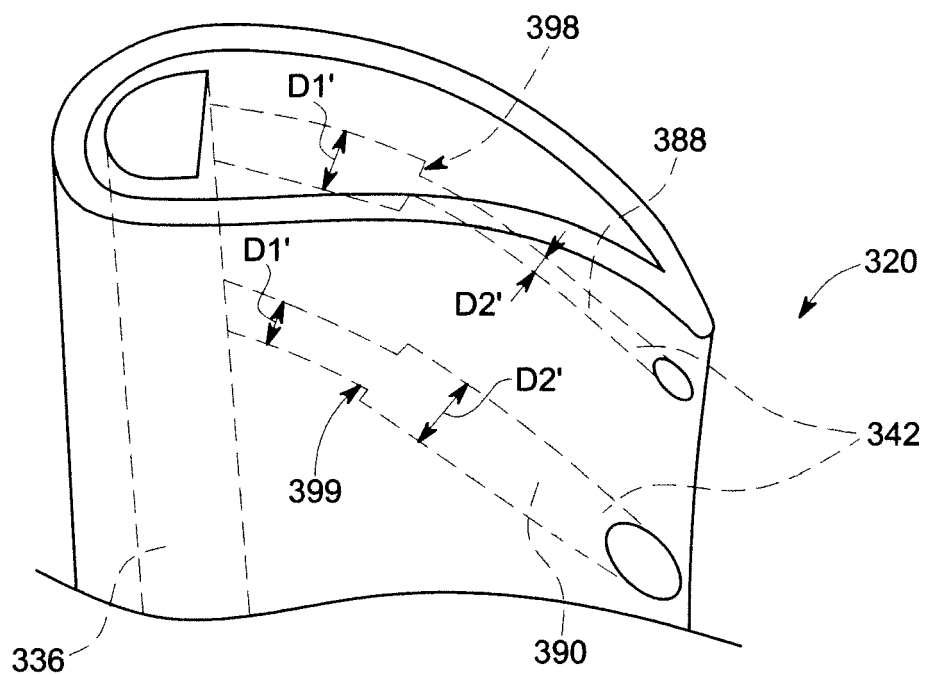


FIG. 6

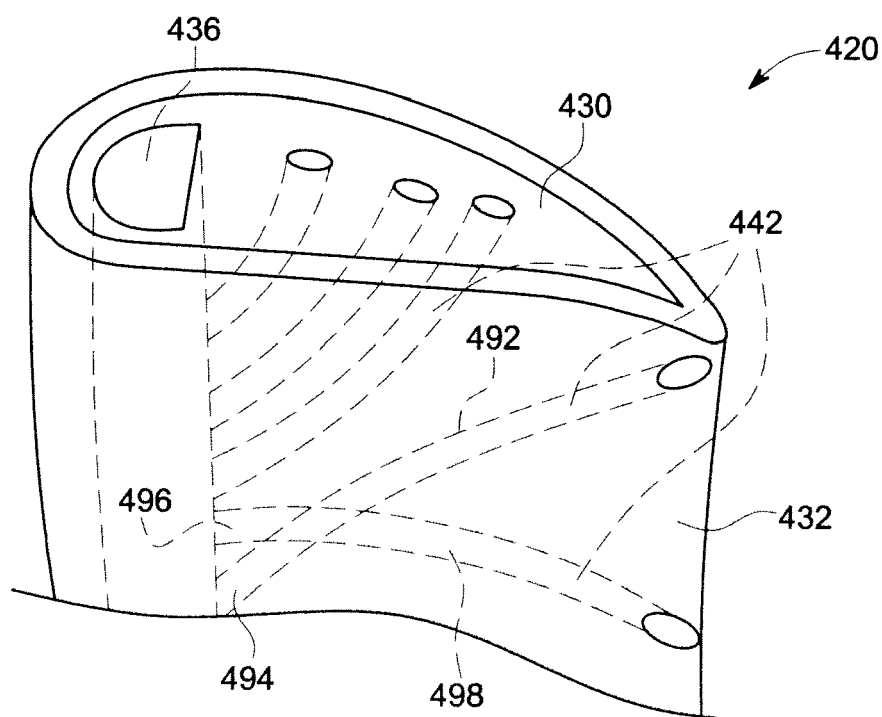


FIG. 7

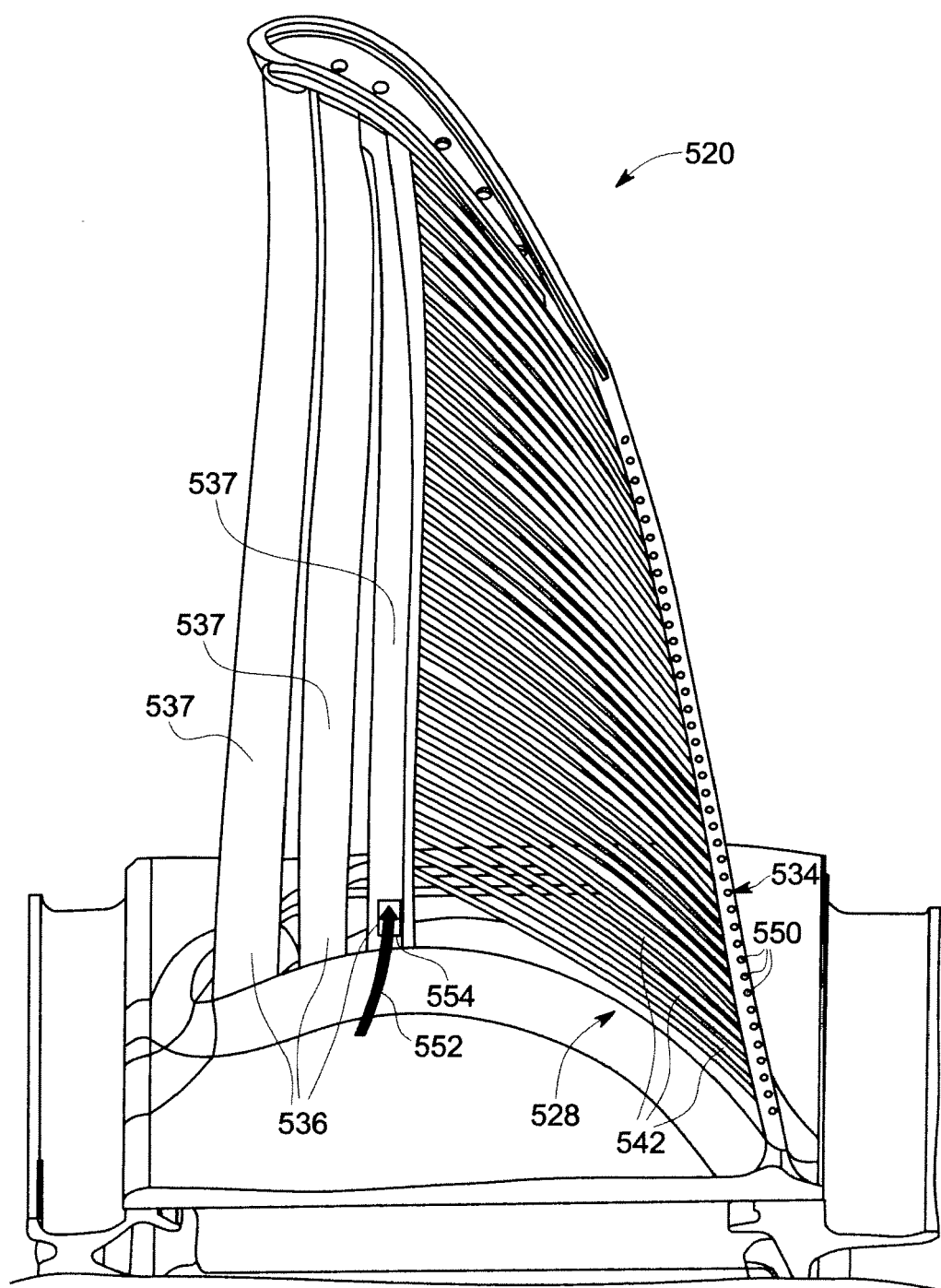


FIG. 8