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(54) **AXIALLY COOLED AIRFOIL**

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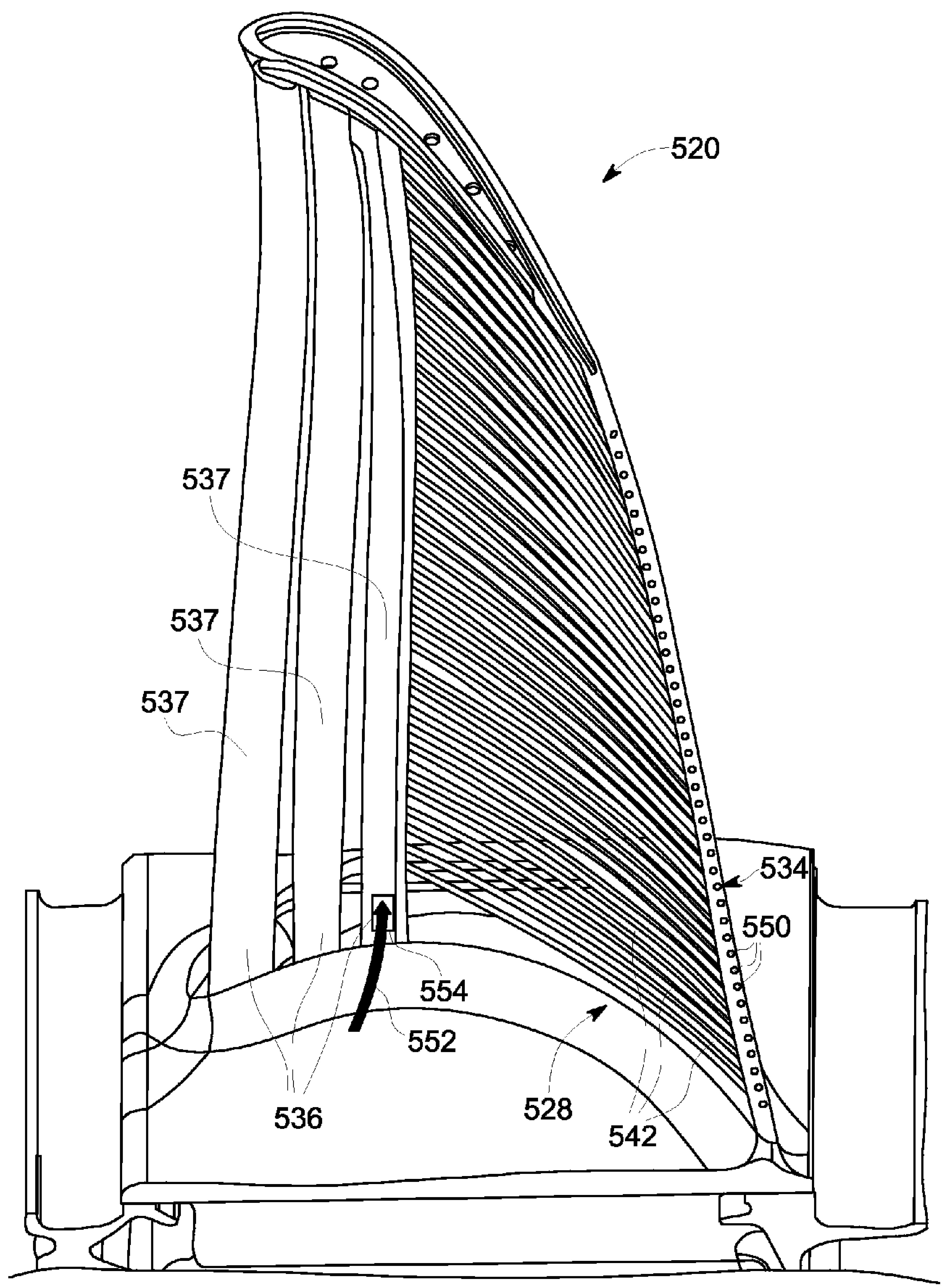
(57) **ABSTRACT**

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 along the widest cross section. At least one passageway extends in an axial direction from the plenum and terminates at the trailing edge. The at least one passageway is in fluid communication with and receives a flow from the plenum.



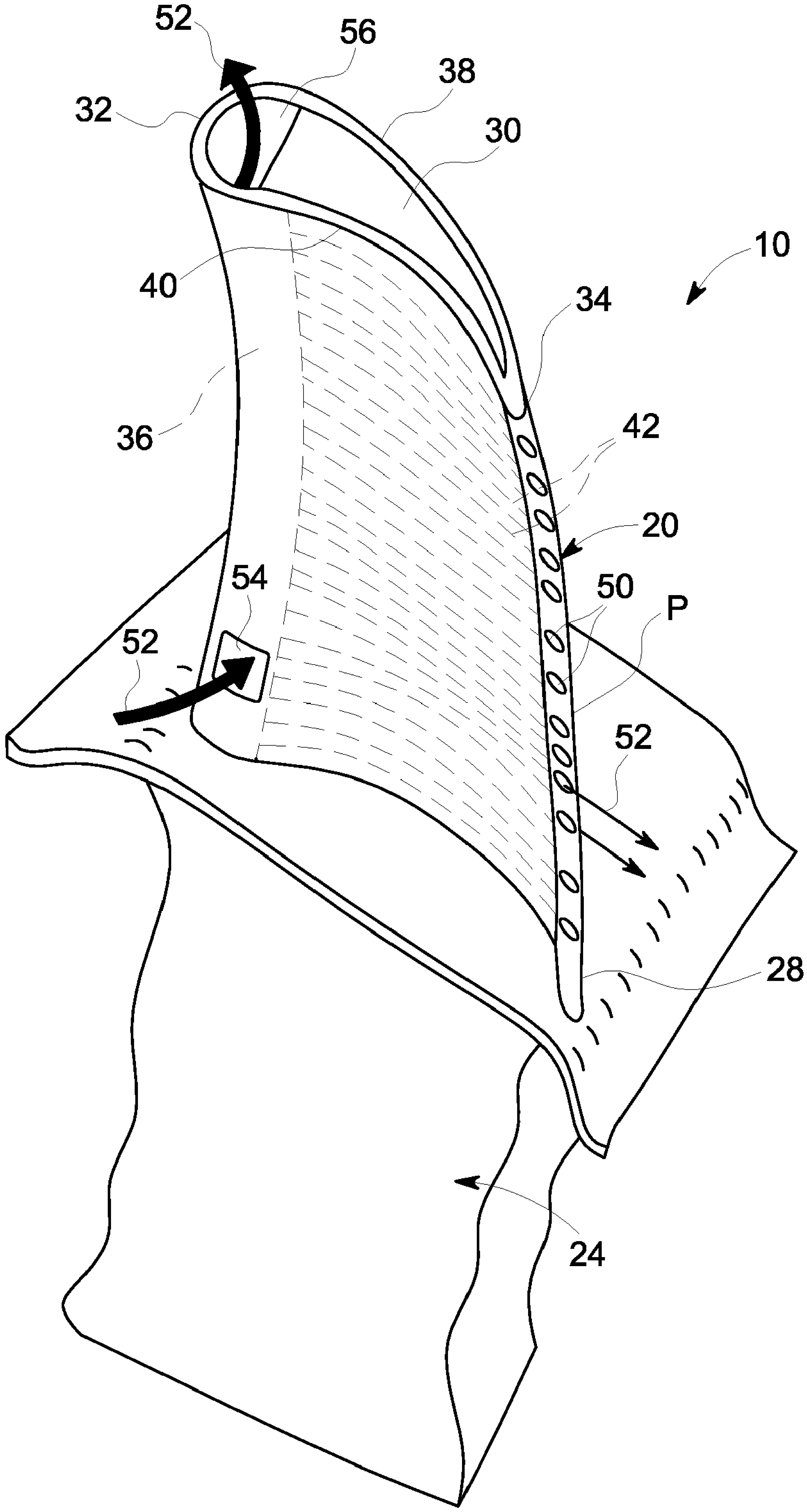


FIG. 1

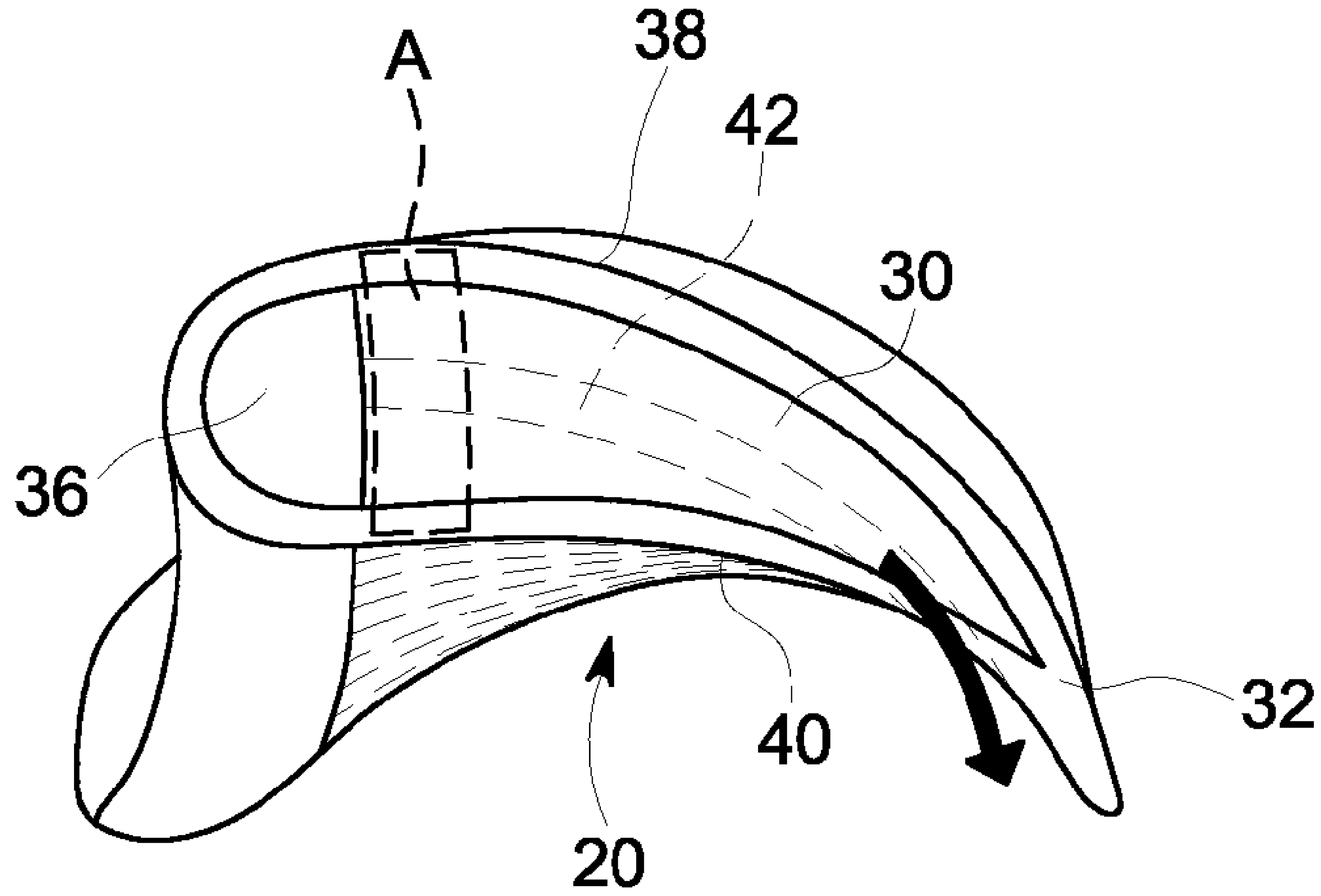


FIG. 2

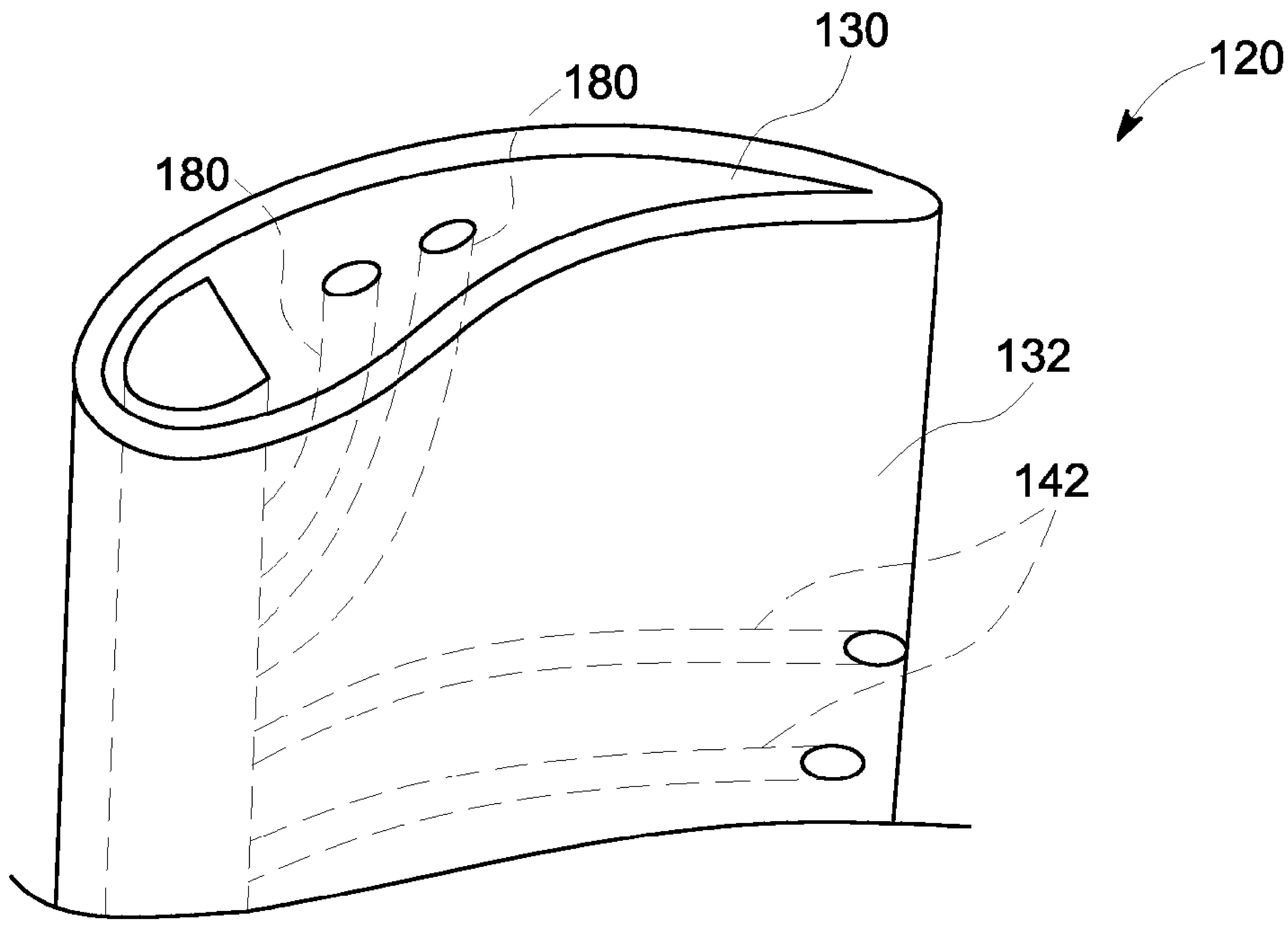


FIG. 3

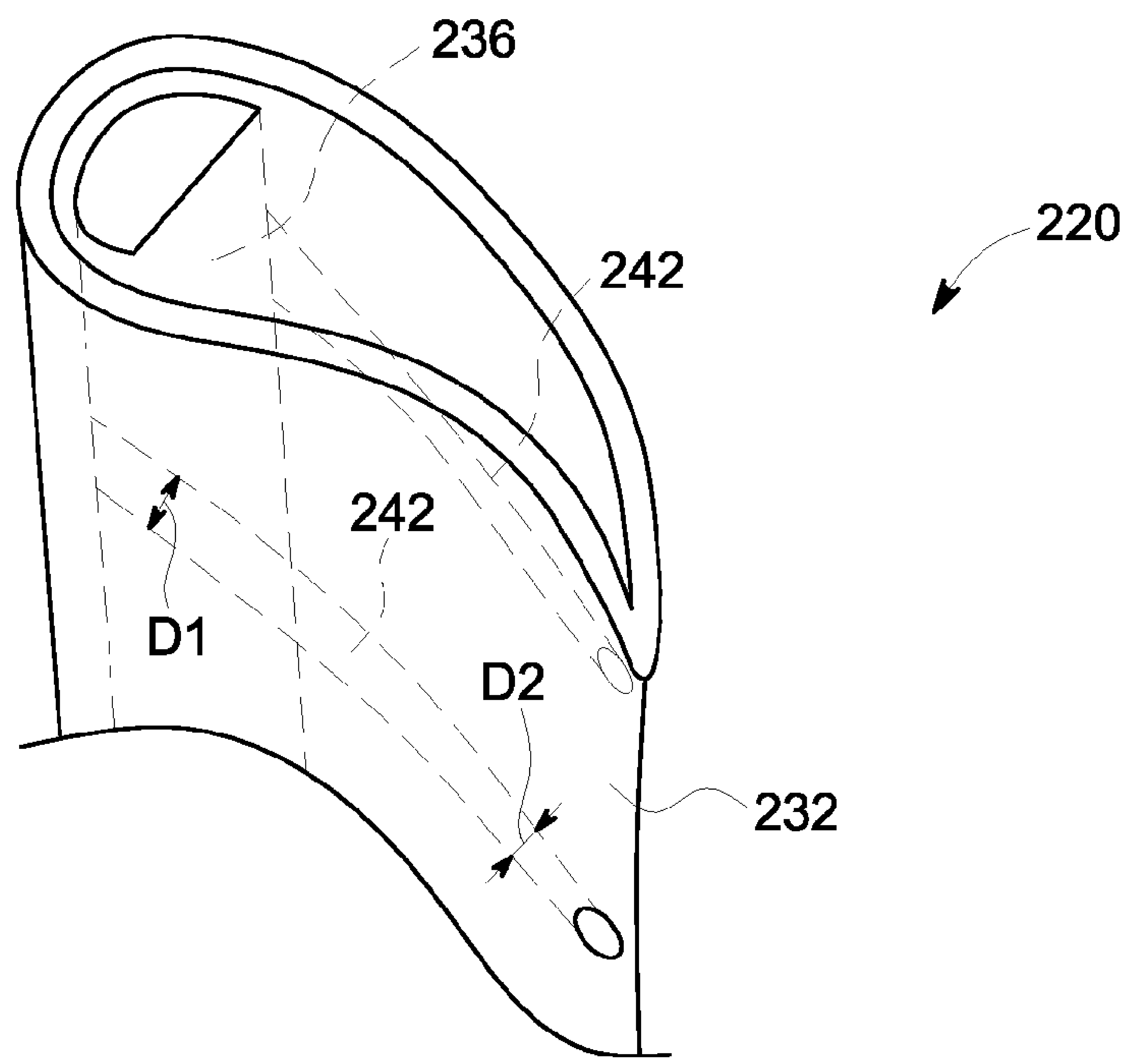


FIG. 4

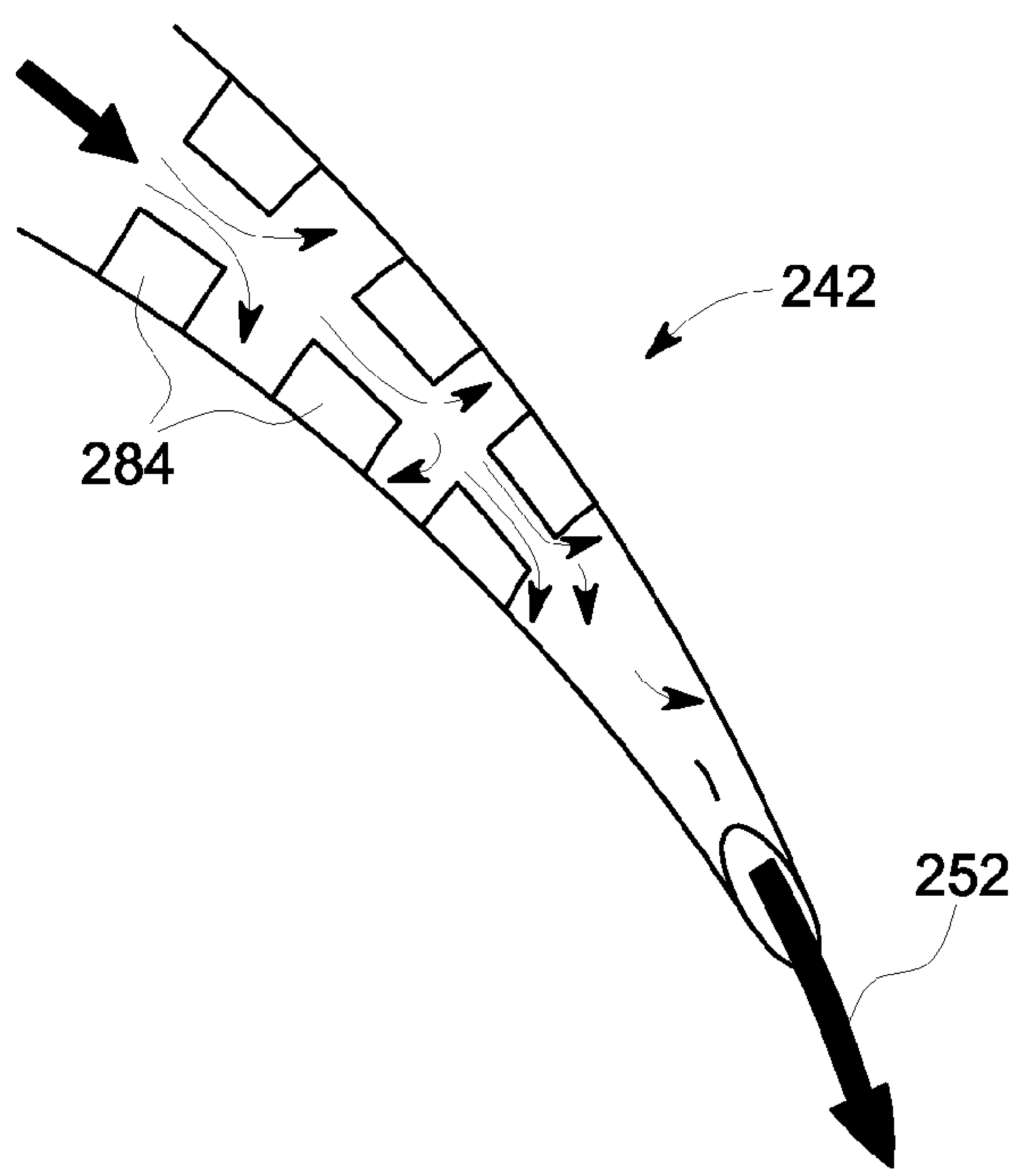


FIG. 5

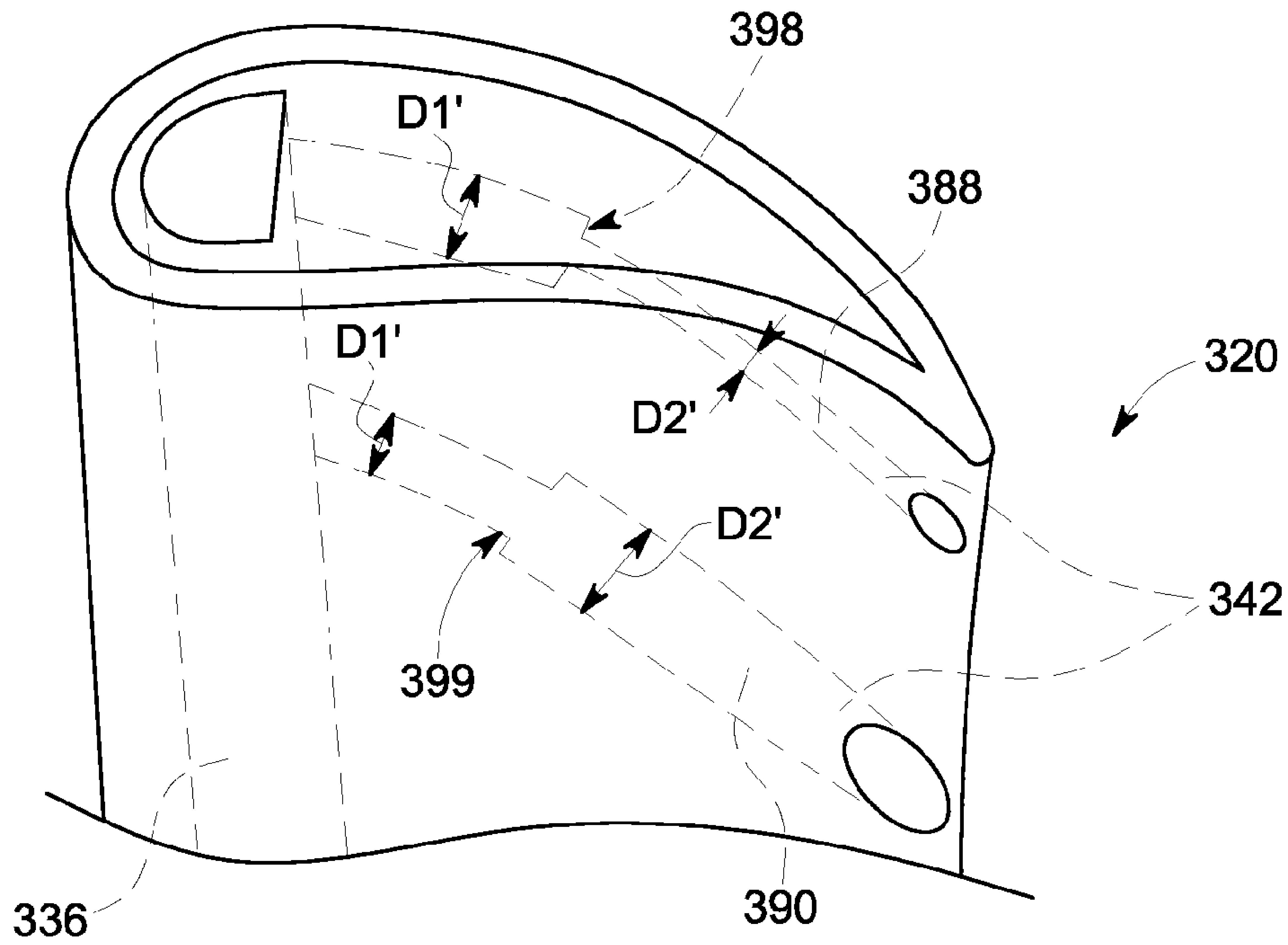

398
D1'
388
320
D1'
D2'
D2'
342
399
336
390

FIG. 6

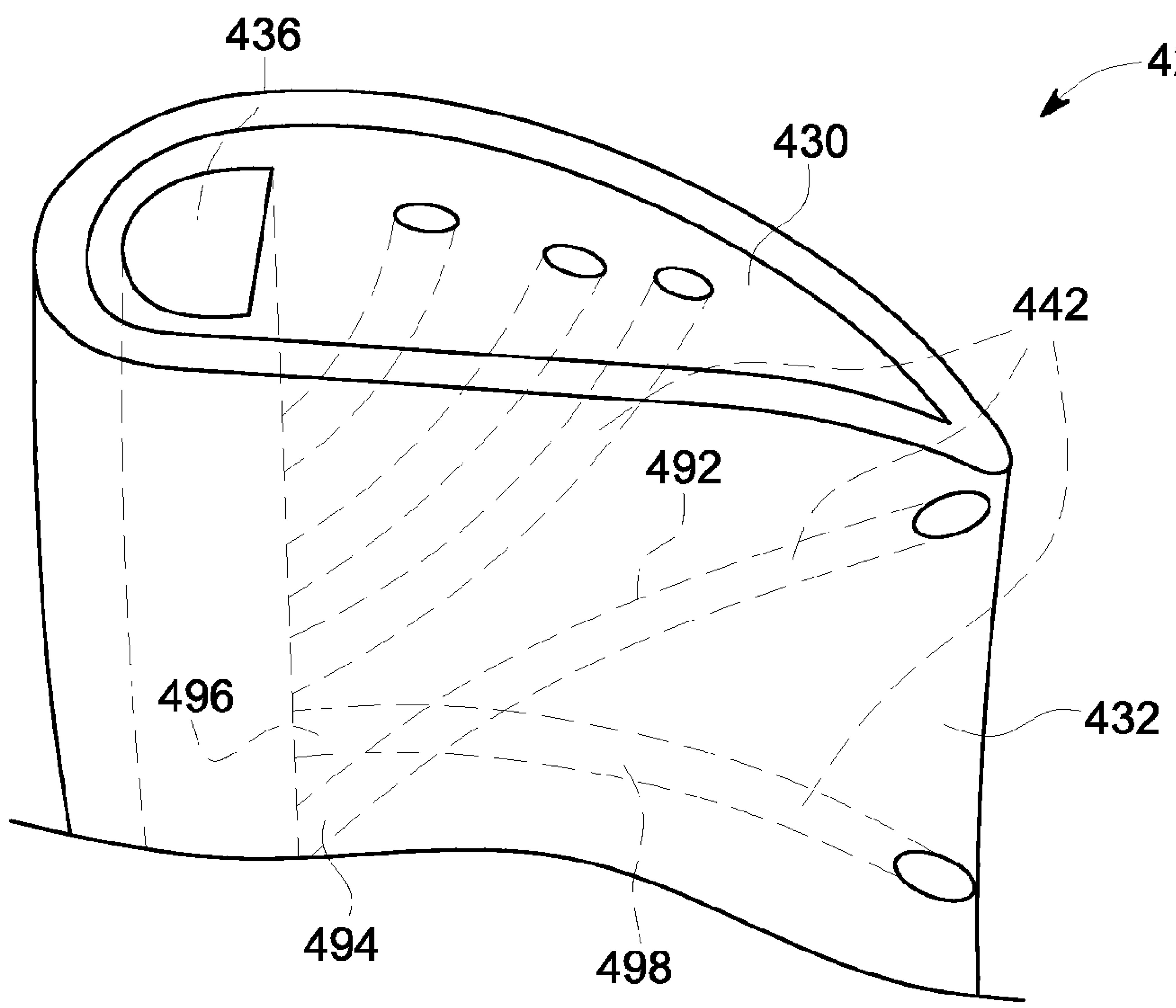

436
420
430
442
492
496
432
494
498

FIG. 7

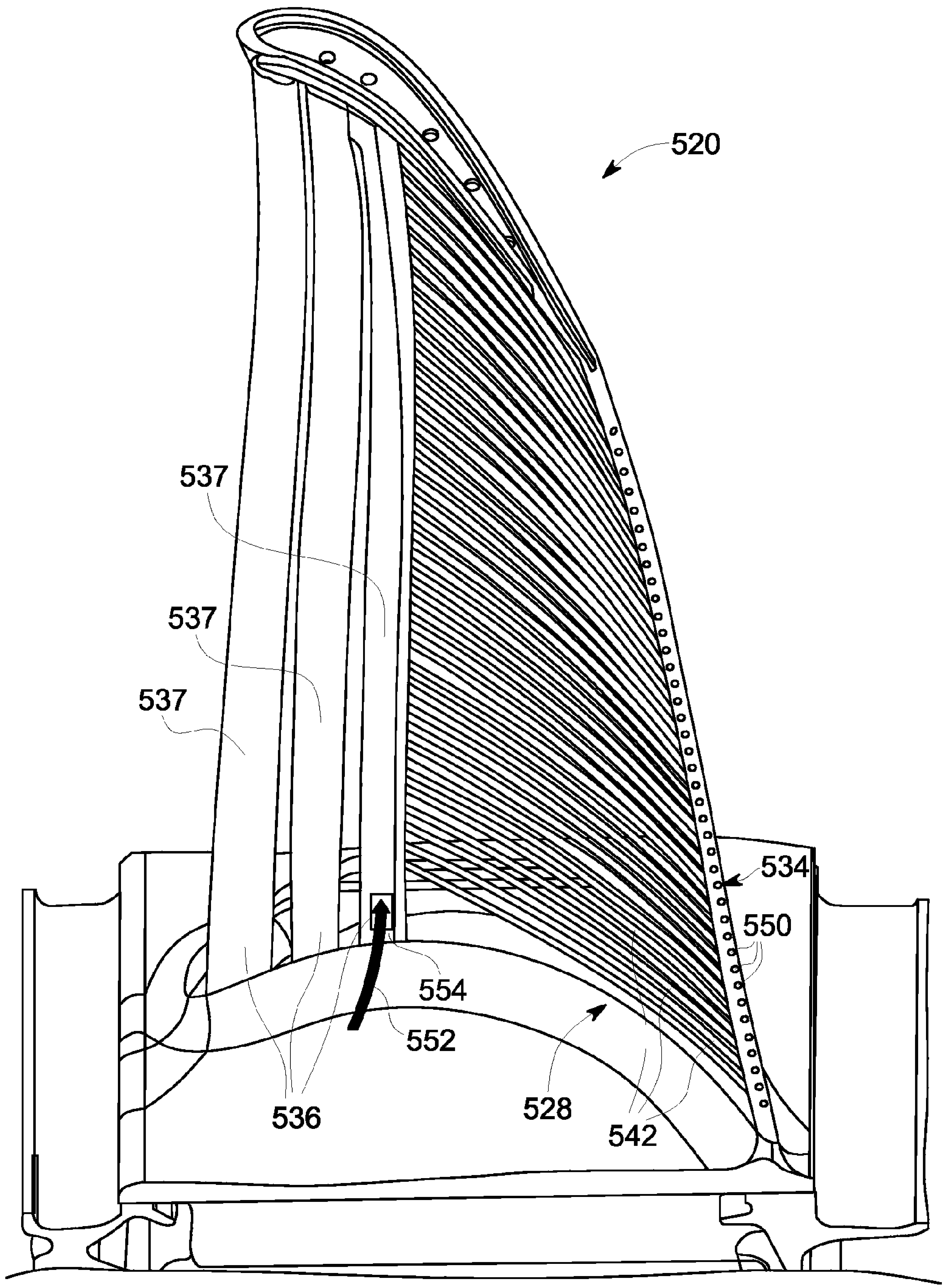


FIG. 8

AXIALLY COOLED AIRFOIL

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] The subject matter, which is regarded as the invention, is particularly pointed out and distinctly claimed in the claims at the conclusion of the specification. The foregoing and other features, and advantages of the invention are apparent from the following detailed description taken in conjunction with the accompanying drawings in which:

[0008] FIG. **1** is an illustration of an exemplary airfoil having an airfoil blade;

[0009] FIG. **2** is a top view of the airfoil shown in FIG. **1**;

[0010] FIG. **3** is an illustration of an alternative embodiment of the airfoil shown in FIG. **1**;

[0011] FIG. **4** is an illustration of another alternative embodiment of the airfoil shown in FIG. **1**;

[0012] FIG. **5** is a turbulated cooling passageway of the airfoil shown in FIG. **1**;

[0013] FIG. **6** is an illustration of yet another alternative embodiment of the airfoil shown in FIG. **1**;

[0014] FIG. **7** is an illustration of another alternative embodiment of the airfoil shown in FIG. **1**; and

[0015] FIG. **8** is an illustration of yet another alternative embodiment of the airfoil shown in FIG. **1**.

[0016] 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

[0017] 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**.

[0018] 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**.

[0019] 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**.

[0020] 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 acruate 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**.

[0021] 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.

[0022] 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.

[0023] 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**.

[0024] 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 D**1** 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 D**2**. The second diameter D**2** 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**.

[0025] 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 D**1'** 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 D**2'**. The second diameter D**2'** 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 D**1'** and the second diameter D**2'** 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 D**1'** is less than the second diameter D**2'** 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.

[0026] 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.

[0027] 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.

[0028] 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.

1. An airfoil, comprising:

an airfoil blade having a trailing edge, a pressure sidewall and a suction sidewall, a widest cross section of the airfoil blade defined between the suction sidewall and the pressure sidewall;

a plenum located along the widest cross section; and

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

2. The airfoil of claim **1**, wherein the airfoil blade includes a root and a tip portion, wherein a plurality of passageways are located between the root portion and the tip portion.

3. The airfoil of claim **2**, wherein the root is coupled to a platform of the airfoil.

4. The airfoil of claim **2**, comprising at least one tip passageway that terminates at the tip portion of the airfoil blade.

5. The airfoil of claim **1**, wherein the at least one passageway includes a generally curved profile.

6. The airfoil of claim **1**, comprising a plurality of passageways that have a staggered configuration with respect to one another.

7. The airfoil of claim **1**, wherein the at least one passageway has a tapered configuration, wherein a first diameter of the at least one passageway is measured at a proximate end of the at least one passageway with respect to the plenum and a second diameter is measured at a distal end of the at least one passageway with respect to the plenum, wherein the first diameter is greater than the second diameter.

8. The airfoil of claim **1**, wherein the at least one passageway includes a plurality of protrusions that create a turbulence in the flow located in the at least one passageway.

9. The airfoil of claim **1**, wherein the at least one passageway is a plurality of passageways, a portion of the plurality of passageways having a stepped configuration where a first diameter of the portion of the plurality of passageways is measured at a proximate end of the plurality of passageways with respect to a plenum, and a second diameter is measured at a distal end of the plurality of passageways 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.

10. The airfoil of claim **9**, wherein a remaining portion of the plurality of passageways have the first diameter being less than the second diameter.

11. The airfoil of claim **1**, wherein the at least one passageway is a plurality of passageways, wherein least one of the passageways is oriented to extend diagonally and cross over another one of the passageways.

12. The airfoil of claim **1**, wherein the plenum is located along a leading edge of the airfoil.

13. 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.

14. The airfoil of claim **13**, comprising at least one tip passageway that terminates at the tip portion of the airfoil blade.

15. The airfoil of claim **13**, wherein at least one of the plurality of passageways includes a generally curved profile.

16. The airfoil of claim **13**, wherein the plurality of passageways have a staggered configuration with respect to one another.

17. The airfoil of claim **13**, 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.

18. The airfoil of claim **13**, wherein the at least one of the plurality of passageways includes a plurality of protrusions that create a turbulence in the flow.

19. The airfoil of claim **13**, 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.

20. 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.

* * * * *