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(54) METHOD AND APPARATUS FOR REDUCING TURBINE BLADE TIP TEMPERATURES

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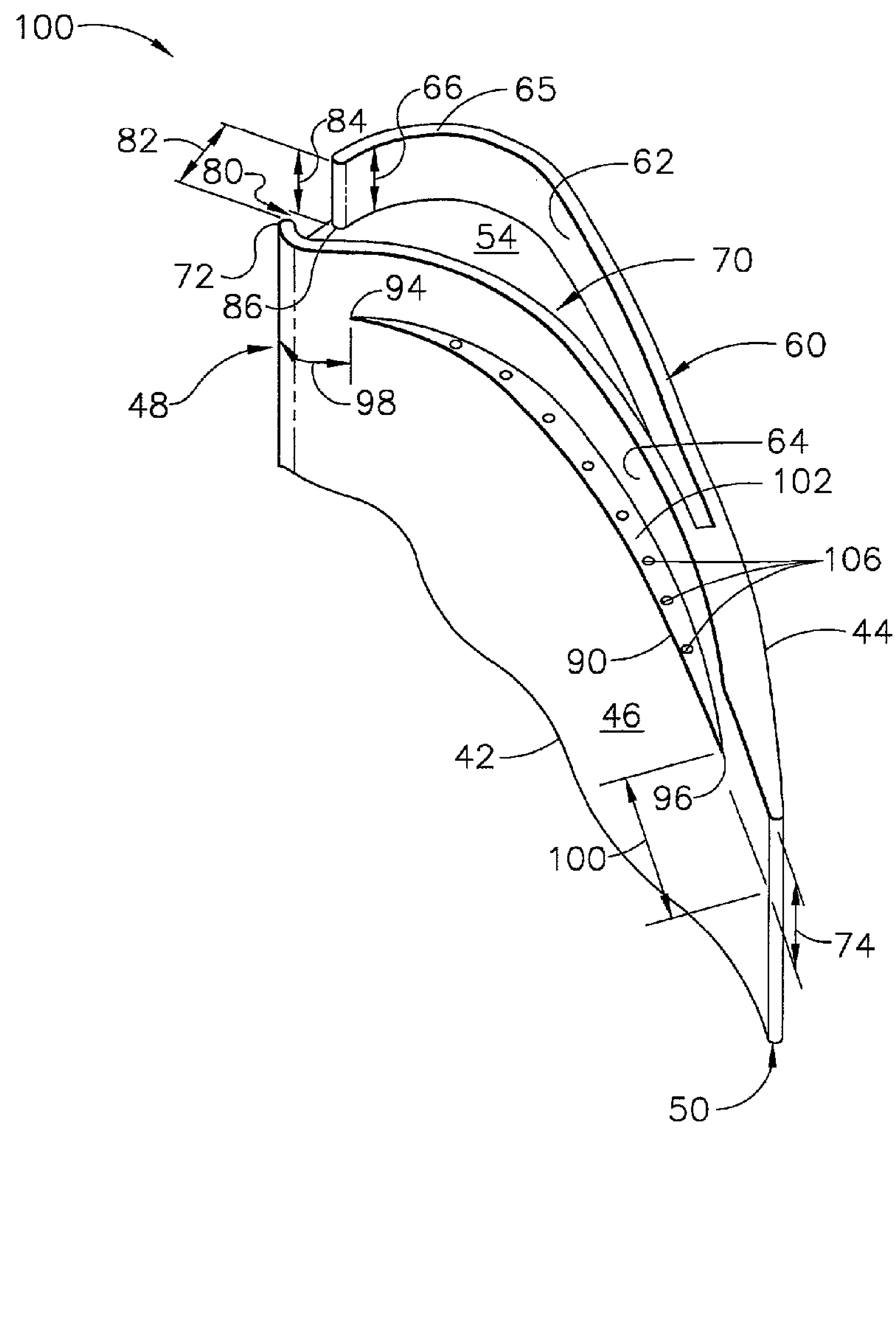
(57) **ABSTRACT**

A rotor blade for a gas turbine engine including a tip region that facilitates reducing operating temperatures of the rotor blade is described. The tip region includes a first tip wall and a second tip wall extending radially outward from a tip plate of an airfoil. The tip walls extend from adjacent a leading edge of the airfoil to connect at a trailing edge of the airfoil. A notch is defined between the first and second tip walls at the airfoil leading edge. At least a portion of the second tip wall is recessed to define a tip shelf.



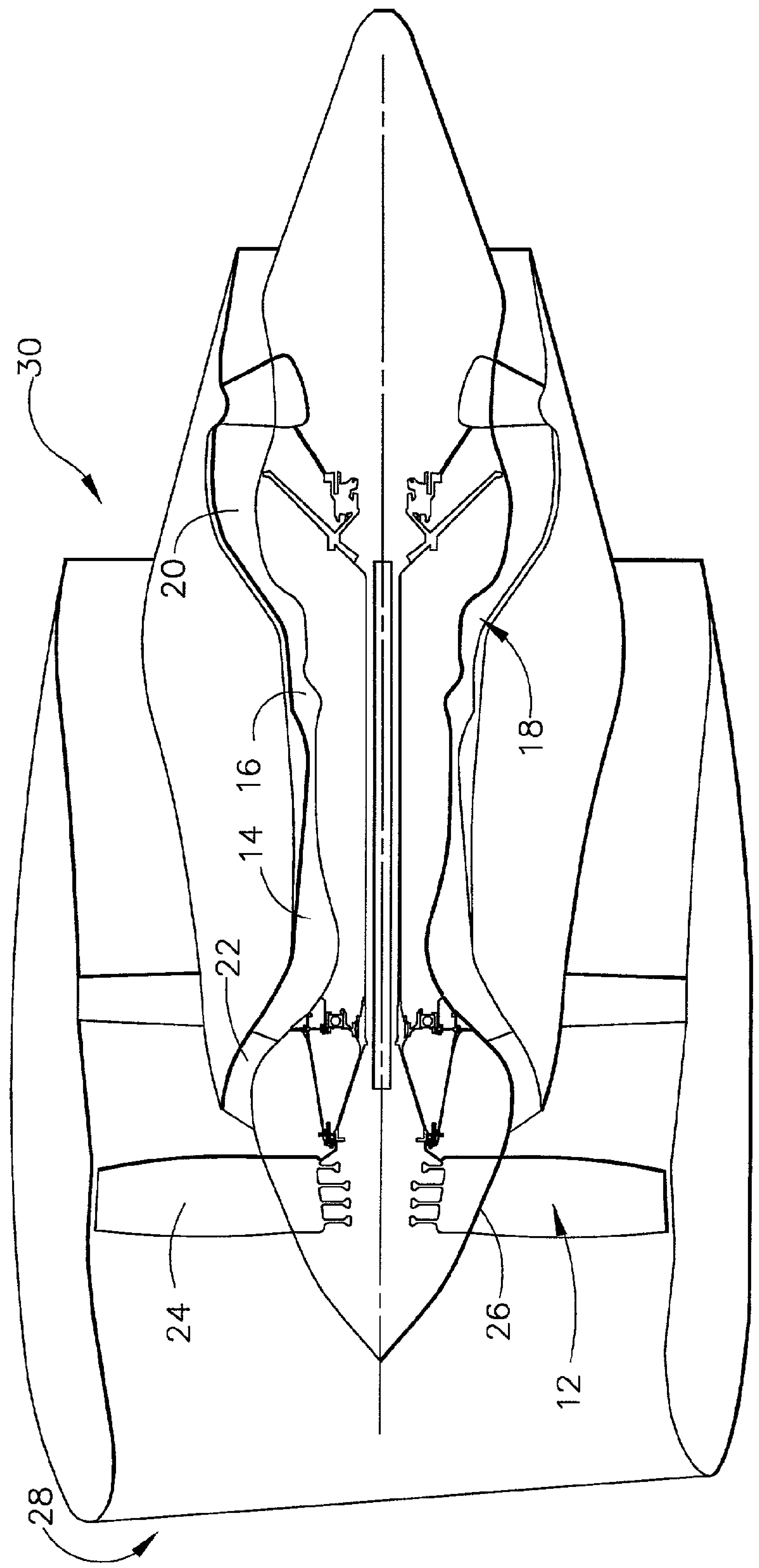



FIG. 1

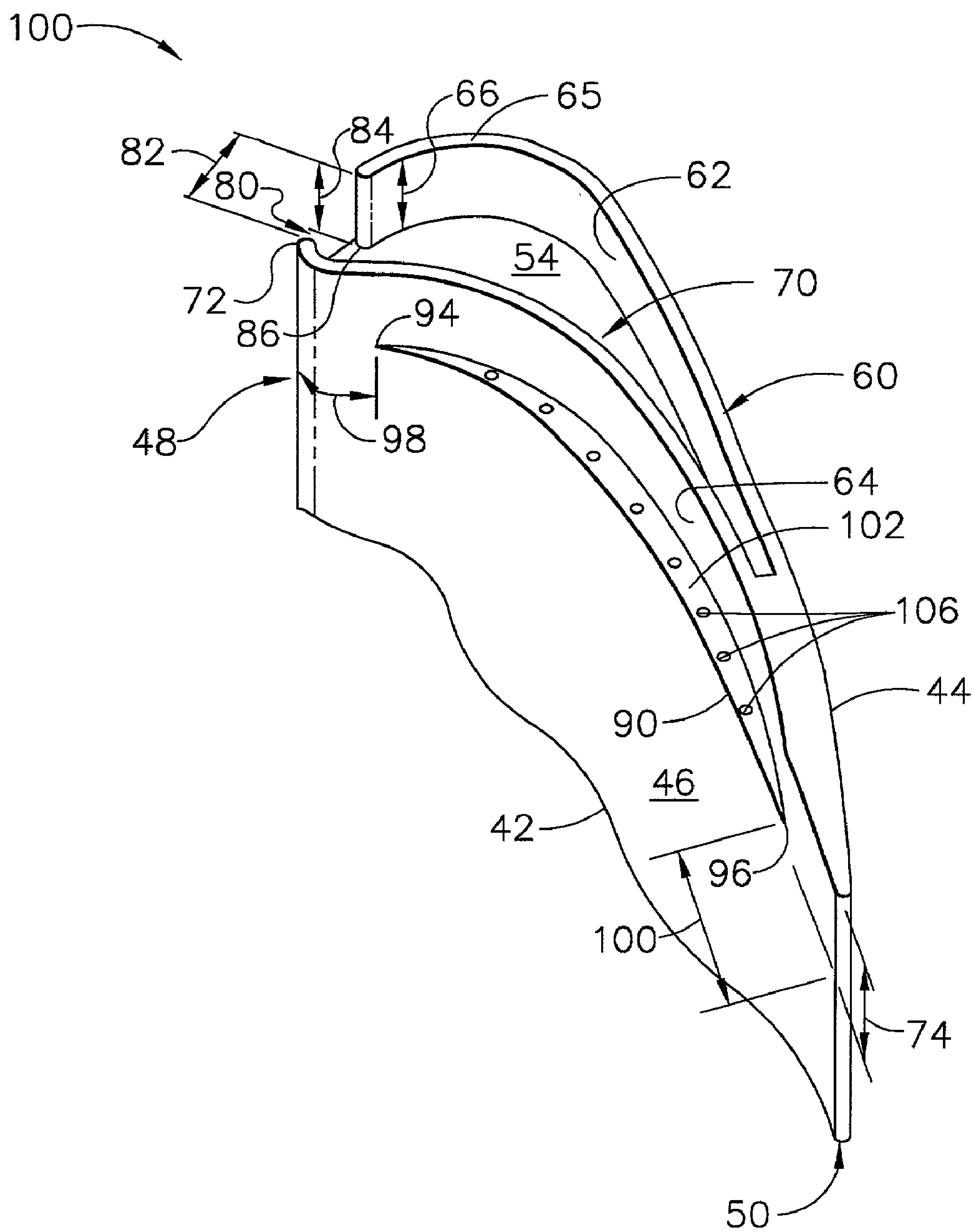

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FIG. 2

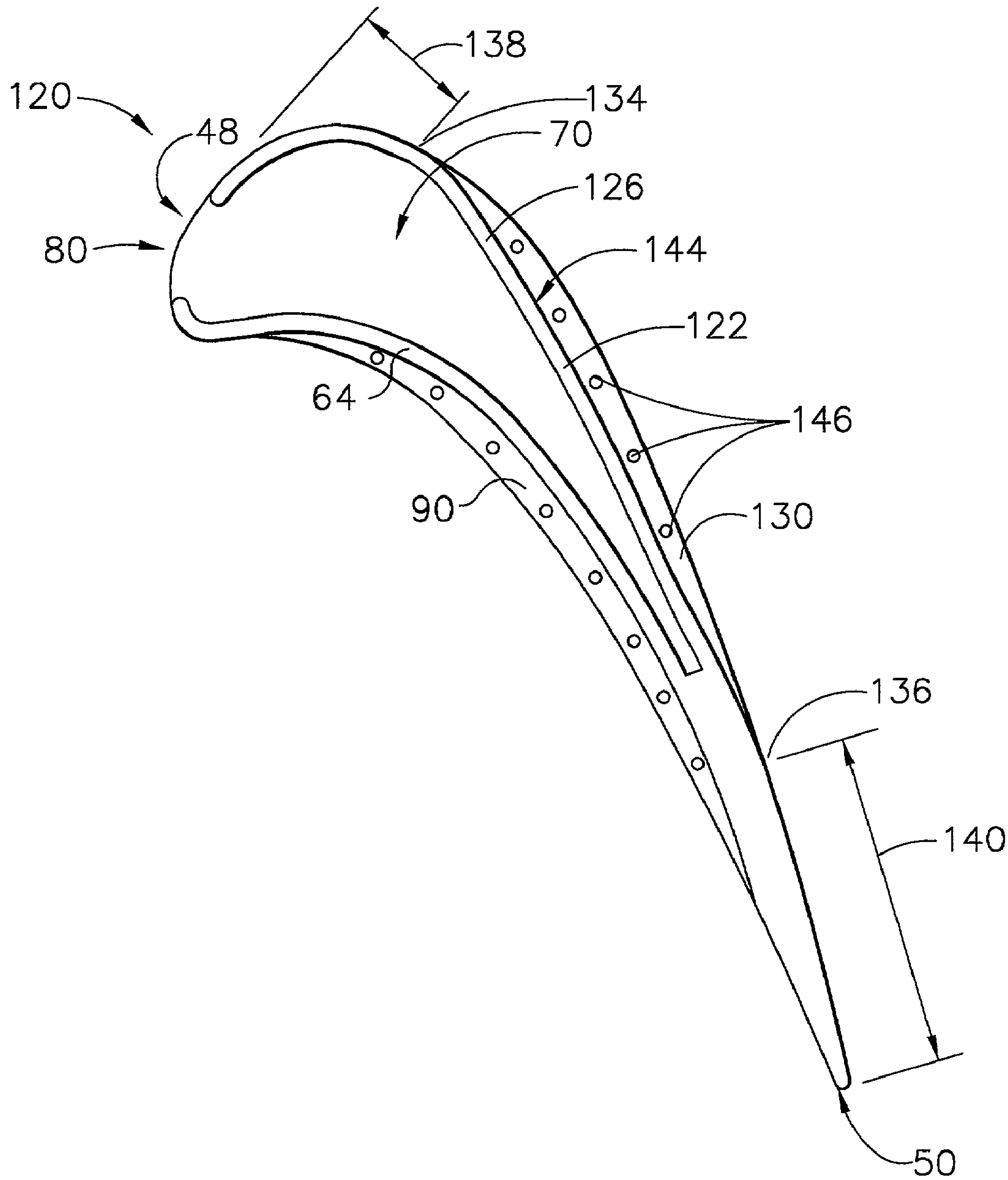


FIG. 3

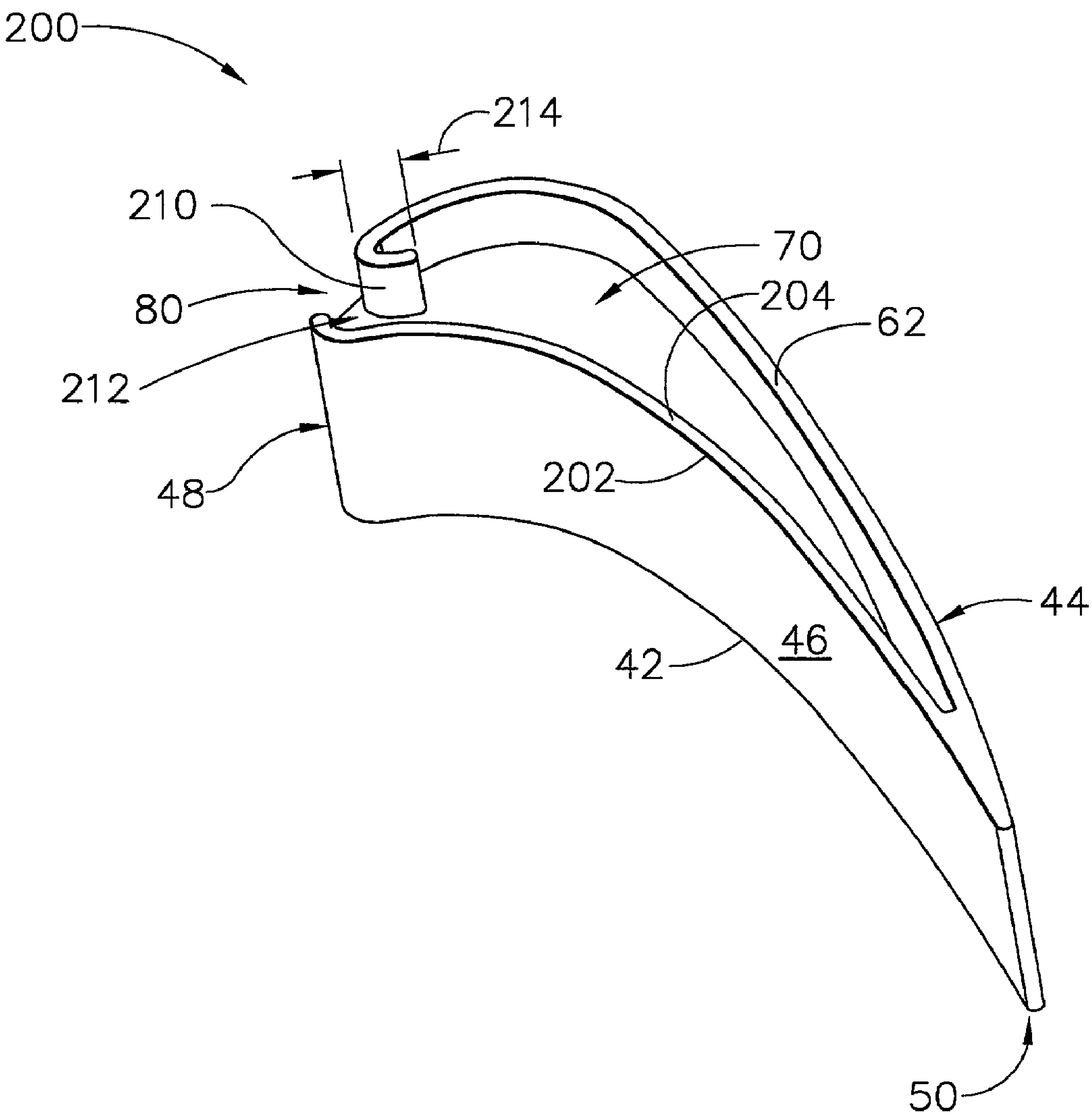


FIG. 4

# METHOD AND APPARATUS FOR REDUCING TURBINE BLADE TIP TEMPERATURES

## BACKGROUND OF THE INVENTION

[0001] This application relates generally to gas turbine engine rotor blades and, more particularly, to methods and apparatus for reducing rotor blade tip temperatures.

[0002] Gas turbine engine rotor blades typically include airfoils having leading and trailing edges, a pressure side, and a suction side. The pressure and suction sides connect at the airfoil leading and trailing edges, and span radially between the airfoil root and the tip. To facilitate reducing combustion gas leakage between the airfoil tips and stationary stator components, the airfoils include a tip region that extends radially outward from the airfoil tip.

[0003] The airfoil tip regions include a first tip wall extending from the airfoil leading edge to the trailing edge, and a second tip wall also extending from the airfoil leading edge to connect with the first tip wall at the airfoil trailing edge. The tip region prevents damage to the airfoil if the rotor blade rubs against the stator components.

[0004] During operation, combustion gases impacting the rotating rotor blades transfer heat into the blade airfoils and tip regions. Over time, continued operation in higher temperatures may cause the airfoil tip regions to thermally fatigue. To facilitate reducing operating temperatures of the airfoil tip regions, at least some known rotor blades include slots within the tip walls to permit combustion gases at a lower temperature to flow through the tip regions.

[0005] To facilitate minimizing thermal fatigue to the rotor blade tips, at least some known rotor blades include a shelf adjacent the tip region to facilitate reducing operating temperatures of the tip regions. The shelf is defined within the pressure side of the airfoil and disrupt combustion gas flow as the rotor blades rotate, thus enabling a film layer of cooling air to form against the pressure side of the airfoil. The film layer insulates the blade from the higher temperature combustion gases.

## BRIEF SUMMARY OF THE INVENTION

[0006] In an exemplary embodiment, a rotor blade for a gas turbine engine includes a tip region that facilitates reducing operating temperatures of the rotor blade, without sacrificing aerodynamic efficiency of the turbine engine. The tip region includes a first tip wall and a second tip wall that extend radially outward from an airfoil tip plate. The first tip wall extends from adjacent a leading edge of the airfoil to a trailing edge of the airfoil. The second tip wall also extends from adjacent the airfoil leading edge and connects with the first tip wall at the airfoil trailing edge to define an open-top tip cavity. At least a portion of the second tip wall is recessed to define a tip shelf. A notch extends from the tip plate and is defined between the first and second tip walls at the airfoil leading edge. The notch is in flow communication with the tip cavity.

[0007] During operation, as the rotor blades rotate, combustion gases at a higher temperature near each rotor blade leading edge migrate to the airfoil tip region. Because the tip walls extend from the airfoil, a tight clearance is defined between the rotor blade and stationary structural components that facilitates reducing combustion gas leakage therethrough. If rubbing occurs between the stationary structural components and the rotor blades, the tip walls contact the components and the airfoil remains intact. As the rotor blade rotates, combustion gases at lower temperatures near the leading edge flow through the notch and induce cooler gas temperatures into the tip cavity. The combustion gases on a pressure side of the rotor blade also flow over the tip region shelf and mix with film cooling air. As a result, the notch and shelf facilitate reducing operating temperatures of the rotor blade within the tip region, but without consuming additional cooling air, thus improving turbine efficiency.

## BRIEF DESCRIPTION OF THE DRAWINGS

[0008] **FIG. 1** is schematic illustration of a gas turbine engine;

[0009] **FIG. 2** is a partial perspective view of a rotor blade that may be used with the gas turbine engine shown in **FIG. 1**;

[0010] **FIG. 3** is a cross-sectional view of an alternative embodiment of the rotor blade shown in **FIG. 2**; and

[0011] **FIG. 4** is a partial perspective view of another alternative embodiment of a rotor blade that may be used with the gas turbine engine shown in **FIG. 1**.

## DETAILED DESCRIPTION OF THE INVENTION

[0012] **FIG. 1** is a schematic illustration of a gas turbine engine **10** including a fan assembly **12**, a high pressure compressor **14**, and a combustor **16**. Engine **10** also includes a high pressure turbine **18**, a low pressure turbine **20**, and a booster **22**. Fan assembly **12** includes an array of fan blades **24** extending radially outward from a rotor disc **26**. Engine **10** has an intake side **28** and an exhaust side **30**.

[0013] In operation, air flows through fan assembly **12** and compressed air is supplied to high pressure compressor **14**. The highly compressed air is delivered to combustor **16**. Airflow (not shown in **FIG. 1**) from combustor **16** drives turbines **18** and **20**, and turbine **20** drives fan assembly **12**.

[0014] **FIG. 2** is a partial perspective view of a rotor blade **40** that may be used with a gas turbine engine, such as gas turbine engine **10** (shown in **FIG. 1**). In one embodiment, a plurality of rotor blades **40** form a high pressure turbine rotor blade stage (not shown) of gas turbine engine **10**. Each rotor blade **40** includes a hollow airfoil **42** and an integral dovetail (not shown) used for mounting airfoil **42** to a rotor disk (not shown) in a known manner.

[0015] Airfoil **42** includes a first sidewall **44** and a second sidewall **46**. First sidewall **44** is convex and defines a suction side of airfoil **42**, and second sidewall **46** is concave and defines a pressure side of airfoil **42**. Sidewalls **44** and **46** are joined at a leading edge **48** and at an axially-spaced trailing edge **50** of airfoil **42** that is downstream from leading edge **48**.

[0016] First and second sidewalls **44** and **46**, respectively, extend longitudinally or radially outward to span from a blade root (not shown) positioned adjacent the dovetail to a tip plate **54** which defines a radially outer boundary of an internal cooling chamber (not shown). The cooling chamber is defined within airfoil **42** between sidewalls **44** and **46**. Internal cooling of airfoils **42** is known in the art. In one embodiment, the cooling chamber includes a serpentine passage cooled with compressor bleed air. In another embodiment, sidewalls **44** and **46** include a plurality of film cooling openings (not shown), extending therethrough to facilitate additional cooling of the cooling chamber. In yet another embodiment, airfoil **42** includes a plurality of trailing edge openings (not shown) used to discharge cooling air from the cooling chamber.

[**0017**] A tip region **60** of airfoil **42** is sometimes known as a squealer tip, and includes a first tip wall **62** and a second tip wall **64** formed integrally with airfoil **42**. First tip wall **62** extends from adjacent airfoil leading edge **48** along airfoil first sidewall **44** to airfoil trailing edge **50**. More specifically, first tip wall **62** extends from tip plate **54** to an outer edge **65** for a height **66**. First tip wall height **66** is substantially constant along first tip wall **62**.

[**0018**] Second tip wall **64** extends from adjacent airfoil leading edge **48** along second sidewall **46** to connect with first tip wall **62** at airfoil trailing edge **50**. More specifically, second tip wall **64** is laterally spaced from first tip wall **62** such that an open-top tip cavity **70** is defined with tip walls **62** and **64**, and tip plate **54**. Second tip wall **64** also extends radially outward from tip plate **54** to an outer edge **72** for a height **74**. In the exemplary embodiment, second tip wall height **74** is equal first tip wall height **66**. Alternatively, second tip wall height **74** is not equal first tip wall height **66**.

[**0019**] A notch **80** is defined between first tip wall **62** and second tip wall **64** along airfoil leading edge **48**. More specifically, notch **80** has a width **82** extending between first and second tip walls **62** and **64**, and a height **84** measured between a bottom **86** of notch **80** defined by tip plate **54**, and first and second tip wall outer edges **65** and **72**, respectively.

[**0020**] In an alternative embodiment, notch **80** does not extend from tip plate **54**, but instead extends from first and second tip wall outer edges **65** and **72**, respectively, towards tip plate **54** for a distance (not shown) that is less than notch height **84**, and accordingly, notch bottom **86** is a distance (not shown) from tip plate **54**. In a further alternative embodiment, second tip wall **64** is not connected to first tip wall **62** at airfoil trailing edge **50**, and an opening (not shown) is defined between first tip wall **62** and second tip wall **64** at airfoil trailing edge **50**.

[**0021**] Notch **80** is in flow communication with open-top tip cavity **70** and permits combustion gas at a lower temperature to enter cavity **70** for lower heating purposes. In one embodiment, notch **80** also includes a guidewall (not shown in **FIG. 2**) used to channel flow entering open-top tip cavity **70** towards second tip wall **64**. More specifically, the guidewall extends from notch **80** towards airfoil trailing edge **50**.

[**0022**] Second tip wall **64** is recessed at least in part from airfoil second sidewall **46**. More specifically, second tip wall **64** is recessed from airfoil second sidewall **46** toward first tip wall **62** to define a radially outwardly facing first tip shelf **90** which extends generally between airfoil leading and trailing edges **48** and **50**. More specifically, shelf **90** includes a front edge **94** and an aft edge **96**. Front edge **94** and aft edge **96** each taper to be flush with second sidewall **46**. Shelf front edge **94** is a distance **98** downstream of airfoil leading edge **48**, and shelf aft edge **96** is a distance **100** upstream from airfoil trailing edge **50**.

[**0023**] Recessed second tip wall **64** and shelf **90** define a generally L-shaped trough **102** therebetween. In the exemplary embodiment, tip plate **54** is generally imperforate and only includes a plurality of openings **106** extending through tip plate **54** at tip shelf **90**. Openings **106** are spaced axially along shelf **90** and are in flow communication between trough **102** and the internal airfoil cooling chamber. In one embodiment, tip region **60** and airfoil **42** are coated with a thermal barrier coating.

[**0024**] During operation, squealer tip walls **62** and **64** are positioned in close proximity with a conventional stationary stator shroud (not shown), and define a tight clearance (not shown) therebetween that facilitates reducing combustion gas leakage therethrough. Tip walls **62** and **64** extend radially outward from airfoil **42**. Accordingly, if rubbing occurs between rotor blades **40** and the stator shroud, only tip walls **62** and **64** contact the shroud and airfoil **42** remains intact.

[**0025**] Because combustion gases assume a parabolic profile flowing through a turbine flowpath, combustion gases near turbine blade tip region leading edge **48** are at a lower temperature than gases near turbine blade tip region trailing edge **50**. As cooler combustion gases flow into notch **80**, a heat load of tip region **60** is reduced. More specifically, combustion gases flowing into notch **80** are at a higher pressure and reduced temperature than gases leaking from rotor blade pressure side **46** through the tip clearance to rotor blade suction side **44**. As a result, notch **80** facilitates reducing an operating temperatures within tip region **60**.

[**0026**] Furthermore, as combustion gases flow past airfoil first tip shelf **90**, trough **102** provides a discontinuity in airfoil pressure side **46** which causes the combustion gases to separate from airfoil second sidewall **46**, thus facilitating a decrease in heat transfer thereof. Additionally, trough **102** provides a region for cooling air to accumulate and form a film against sidewall **46**. First tip shelf openings **106** discharge cooling air from the airfoil internal cooling chamber to form a film cooling layer on tip region **60**. Because of blade rotation, combustion gases outside rotor blade **40** at leading edge **48** near a blade pitch line (not shown) will migrate in a radial flow toward airfoil tip region **60** near trailing edge **50** along second sidewall **46** such that leading edge tip operating temperatures are lower than trailing edge tip operating temperatures. First tip shelf **90** functions as a backward facing step in the migrated radial flow and provides a shield for the film of cooling air accumulated against sidewall **46**. As a result, shelf **90** facilitates improving cooling effectiveness of the film to lower operating temperatures of sidewall **46**.

[**0027**] **FIG. 3** is a cross-sectional view of an alternative embodiment of a rotor blade **120** that may be used with a gas turbine engine, such as gas turbine engine **10** (shown in **FIG. 1**). Rotor blade **120** is substantially similar to rotor blade **40** shown in **FIG. 2**, and components in rotor blade **120** that are identical to components of rotor blade **40** are identified in **FIG. 3** using the same reference numerals used in **FIG. 2**. Accordingly, rotor blade **120** includes airfoil **42** (shown in **FIG. 2**), sidewalls **44** and **46** (shown in **FIG. 2**) extending between leading and trailing edges **48** and **50**, respectively, and notch **80**. Furthermore, rotor blade **120** includes second tip wall **64** and first tip shelf **90**. Additionally, rotor blade **120** includes a first tip wall **122**. Notch **80** is defined between first and second tip walls **122** and **64**, respectively.

[**0028**] First tip wall **122** extends from adjacent airfoil leading edge **48** along first sidewall **44** to connect with second tip wall **64** at airfoil trailing edge **50**. More specifically, first tip wall **122** is laterally spaced from second tip wall **64** to define opentop tip cavity **70**. First tip wall **122** also extends a height (not shown) radially outward from tip plate **54** to an outer edge **126**. In the exemplary embodiment, the first tip wall height is equal second tip wall height **74**. Alternatively, the first tip wall height is not equal second tip wall height **74**.

**[0029]** First tip wall **122** is recessed at least in part from airfoil first sidewall **44**. More specifically, first tip wall **122** is recessed from airfoil first sidewall **44** toward second tip wall **64** to define a radially ouwardly facing second tip shelf **130** which extends generally between airfoil leading and trailing edges **48** and **50**. More specifically, shelf **130** includes a front edge **134** and an aft edge **136**. Front edge **134** and aft edge **136** each taper to be flush with first sidewall **44**. Shelf front edge **134** is a distance **138** downstream of airfoil leading edge **48**, and shelf aft edge **136** is a distance **140** upstream from airfoil trailing edge **50**.

**[0030]** Recessed first tip wall **122** and second tip shelf **130** define therebetween a generally L-shaped trough **144**. In the exemplary embodiment, tip plate **54** is generally imperforate and includes plurality of openings **106** extending through tip plate **54** at first tip shelf **90**, and a plurality of openings **146** extending through tip plate **54** at second tip shelf **130**. Openings **146** are spaced axially along second tip shelf **130** and are in flow communication between trough **144** and the internal airfoil cooling chamber. In one embodiment, tip region **62** and airfoil **42** are coated with a thermal barrier coating.

**[0031]** During operation, squealer tip walls **122** and **64** are positioned in close proximity with a conventional stationary stator shroud (not shown), and define a tight clearance (not shown) therebetween to facilitate reducing combustion gas leakage therethrough. Tip wall **122** functions in an identical manner as tip wall **62** described above, and extends radially outward from airfoil **42**. Accordingly, if rubbing occurs between rotor blades **40** and the stator shroud, only tip walls **122** and **64** contact the shroud and airfoil **42** remains intact.

**[0032]** Furthermore, as rotor blades **40** rotate and combustion gases flow past airfoil tip shelves **90** and **130**, troughs **102** and **144**, respectively provide a discontinuity in airfoil pressure side **46** and airfoil suction side **44**, respectively, which causes the combustion gases to separate from airfoil sidewalls **46** and **44**, respectively, thus facilitating a decrease in heat transfer thereof Trough **144** functions similarly with trough **102** to facilitate film cooling circulation..

**[0033]** **FIG. 4** is a partial perspective view of an alternative embodiment of a rotor blade **200** that may be used with a gas turbine engine, such as gas turbine engine **10** (shown in **FIG. 1**). Rotor blade **200** is substantially similar to rotor blade **40** shown in **FIG. 2**, and components in rotor blade **200** that are identical to components of rotor blade **40** are identified in **FIG. 4** using the same reference numerals used in **FIG. 2**. Accordingly, rotor blade **200** includes airfoil **42**, sidewalls **44** and **46** extending between leading and trailing edges **48** and **50**, respectively, and notch **80**. Furthermore, rotor blade **200** includes first tip wall **62**, notch **80**, and a second tip wall **202**. Notch **80** is defined between first and second tip walls **62** and **202**, respectively.

**[0034]** Second tip wall **202** extends from adjacent airfoil leading edge **48** along airfoil first sidewall **44** to airfoil trailing edge **50**. More specifically, second tip wall **202** extends from tip plate **54** to an outer edge **204** for a height (not shown). The second tip wall height is substantially constant along second tip wall **202**. Second tip wall **202** is laterally spaced from first tip wall **62** to define open-top tip cavity **70** in the exemplary embodiment, the second tip wall height is equal first tip wall height **66**. Alternatively, the second tip wall height is not equal first tip wall height **66**.

**[0035]** Notch **80** includes a guidewall **210** extending from first tip wall **62** towards airfoil trailing edge. More specifically, guidewall **210** curves to extend from first tip wall **62** to define a curved entrance **212** for notch **80**. Guidewall **210** has a length **214** that is selected to channel airflow entering open-top tip cavity **70** towards second tip wall **202**.

**[0036]** The above-described rotor blade is cost-effective and highly reliable. The rotor blade includes a leading edge notch defined between leading edges of first and second tip walls. The tip walls connect at a trailing edge of the rotor blade and define a tip cavity. In the exemplary embodiment, one of the tip walls is recessed to define a tip shelf. During operation, as the rotor blade rotates, the tip walls prevent the rotor blade from rubbing against stationary structural members. As combustion gases flow past the rotor blade, the rotor blade notch facilitates lowering heating of the tip cavity without increasing cooling air requirements and sacrificing aerodynamic efficiency of the rotor blade. Furthermore, the tip shelf disrupts combustion gases flowing past the airfoil to facilitate a cooling layer being formed against the shelf. As a result, cooler operating temperatures within the rotor blade facilitate extending a useful life of the rotor blades in a cost-effective and reliable manner.

**[0037]** While the invention has been described in terms of various specific embodiments, those skilled in the art will recognize that the invention can be practiced with modification within the spirit and scope of the claims.

What is claimed is:

**1**. A method for fabricating a rotor blade for a gas turbine engine to facilitate reducing operating temperatures of a tip portion of the rotor blade, the rotor blade including a leading edge, a trailing edge, a first sidewall, and a second sidewall, the first and second sidewalls connected axially at the leading and trailing edges, and extending radially between a rotor blade root to a rotor blade tip plate, said method comprising the steps of:

forming a first tip wall extending from the rotor blade tip plate along the first sidewall; and

forming a second tip wall extending from the rotor blade tip plate along the second sidewall such that the second tip wall connects with the first tip wall at the rotor blade trailing edge, and such that a notch is defined between the first and second tip walls along the rotor blade leading edge.

**2**. A method in accordance with claim 1 further comprising the step of forming a guide wall extending from the rotor blade notch aftward towards the rotor blade trailing edge such that flow entering the notch is directed with the guide wall towards the first sidewall.

**3**. A method in accordance with claim 1 wherein said step of forming a first tip wall further comprises the step of recessing at least a portion of the first tip wall with respect to the rotor blade first sidewall such that a first tip shelf is defined.

**4**. A method in accordance with claim 3 wherein said step of forming a second tip wall further comprises the step of recessing at least a portion of the second tip wall with respect to the rotor blade second sidewall such that a second tip shelf is defined.

**5**. A method in accordance with claim 1 wherein said step of forming a second tip wall further comprises the step of forming the second tip wall such that a notch extends from the tip plate and is defined between the first and second tip walls.

**6**. An airfoil for a gas turbine engine, said airfoil comprising:

a leading edge;

a trailing edge;

a tip plate;

a first sidewall extending in radial span between an airfoil root and said tip plate;

a second sidewall connected to said first sidewall at said leading edge and said trailing edge, said second sidewall extending in radial span between the airfoil root and said tip plate;

a first tip wall extending radially outward from said tip plate along said first sidewall;

a second tip wall extending radially outward from said tip plate along said second sidewall, said first tip wall connected to said second tip wall at said trailing edge; and

a notch extending between said first tip wall and said second tip wall along said airfoil leading edge.

**7**. An airfoil in accordance with claim 6 wherein said notch comprises a guide wall extending from said notch towards said airfoil trailing edge.

**8**. An airfoil in accordance with claim 7 wherein said guide wall configured to channel flow entering said notch towards said first tip wall.

**9**. An airfoil in accordance with claim 6 wherein said first tip wall recessed at least partially from said first sidewall to define a first tip shelf.

**10**. An airfoil in accordance with claim 9 wherein said second tip wall recessed at least partially from said second sidewall to define a second tip shelf.

**11**. An airfoil in accordance with claim 6 wherein said first tip wall and said second tip wall are substantially equal in height.

**12**. An airfoil in accordance with claim 6 wherein said first tip wall extends a first distance from said tip plate, said second tip wall extends a second distance from said tip plate.

**13**. An airfoil in accordance with claim 12 wherein said notch extends from said tip plate at least one of said first distance or said second distance.

**14**. A gas turbine engine comprising a plurality of rotor blades, each said rotor blade comprising an airfoil comprising a leading edge, a trailing edge, a first sidewall, a second sidewall, a first tip wall, a second tip wall, and a notch, said airfoil first and second sidewalls connected axially at said leading and trailing edges, said first and second sidewalls extending radially from a blade root to said tip plate, said first tip wall extending radially outward from said tip plate along said first sidewall, said second tip wall extending radially outward from said tip plate along said second sidewall, said notch along said airfoil leading edge between said first tip wall and said second tip wall, said notch extending from said tip plate.

**15**. A gas turbine engine in accordance with claim 14 wherein said rotor blade airfoil first sidewall is concave, said rotor blade airfoil second sidewall is convex.

**16**. A gas turbine engine in accordance with claim 15 wherein said rotor blade airfoil notch comprises a guide wall extending from said notch towards said rotor blade trailing edge, said guide wall configured to channel flow entering said notch towards said first tip wall.

**17**. A gas turbine engine in accordance with claim 15 wherein said rotor blade first tip wall at least partially recessed with respect to said rotor blade first sidewall to define a first tip shelf

**18**. A gas turbine engine in accordance with claim 17 wherein said rotor blade second tip wall at least partially recessed with respect to said rotor blade second sidewall to define a second tip shelf

**19**. A gas turbine engine wherein said rotor blade notch extends radially outward from said rotor blade tip plate.

**20**. A gas turbine engine wherein said rotor blade first tip wall and said rotor blade second tip wall have approximately equal heights.

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