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Airfoil cooling circuit

Abstract

An airfoil for a gas turbine engine includes a first wall disposed in an interior cavity, the first wall extending in the spanwise direction from a base region to a tip wall and adjoining a pressure side wall and a suction side wall to form a first cooling channel; a second wall disposed in the interior cavity and extending in a chordwise direction from the first wall toward a trailing edge, the second wall adjoining the pressure side wall and the suction side wall to form a second cooling channel; a first hole through the first wall, the first hole connecting the first cooling channel to the second cooling channel; and a second hole though the second wall connecting the second cooling channel to a third cooling channel.

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Background/Summary

BACKGROUND

(1) The present disclosure relates generally to cooling components of gas turbine engines and more particularly to airfoil cooling circuits.

(2) Hollow airfoils of a turbine section of a gas turbine engine can require internal structures to achieve a desired cooling air flow while reducing stress concentrations. Improved cooling circuits and structures are needed to address both heat transfer and stress reduction.

SUMMARY

(3) In one aspect, an airfoil for a gas turbine engine includes a body defining and internal cavity, the body having a pressure side wall and a suction side wall, a tip wall extending in the chordwise direction between the pressure side wall and the suction side wall and defining a radially outer boundary of the internal cavity in the tip region, a first wall disposed in the interior cavity and extending in the spanwise direction to form a first cooling channel, a second wall disposed in the interior cavity and extending in the chordwise direction from the first wall toward the trailing edge to form a second cooling channel, a first hole through the first wall connecting the first cooling channel to the second cooling channel, and a second hole though the second wall connecting the second cooling channel to a third cooling channel. An area of the first hole is sized to provide all of a cooling fluid flow received in the second cooling channel and an area of the second hole is at least 80 percent of the area of the first hole.

(4) In another aspect, a turbine blade for use in a gas turbine engine includes a root portion comprising a plurality of cooling channels configured to receive a cooling fluid, a platform disposed adjacent to the root portion, and an airfoil disposed adjacent to the platform. The airfoil includes a pressure side wall and a suction side wall extending in a spanwise direction from a base region adjacent to the platform to a tip region and extending in a chordwise direction from a leading edge to a trailing edge, and a tip wall extending in the chordwise direction between the pressure side wall and the suction side wall. The airfoil further includes an internal cooling circuit formed by a plurality of walls and cross-over holes including: first, second, and third walls, and first and second crossover holes. The first wall is spaced from the leading edge and extends in the spanwise direction from the root to the tip wall and adjoins the pressure side wall, the suction side wall, and the tip wall to form a leading edge cooling channel. The second wall is spaced from the tip wall and extends in the chordwise direction from the first wall to the trailing edge. The second wall adjoining the pressure side wall, the suction side wall, and the first wall to form a tip flag cooling channel. The third wall is spaced from the first wall and extends in the spanwise direction from the root to the second wall. The third wall adjoins the pressure side wall, the suction side wall, the second wall to form a first cooling channel of a serpentine cooling circuit. The first crossover hole is through the first wall connecting the leading edge cooling channel to the tip flag cooling channel. The second crossover hole is though the second wall connecting the tip flag cooling channel to a second cooling channel of the serpentine cooling circuit. The third crossover hole is through the third wall connecting the first and second cooling channels of the serpentine cooling circuit.

(5) In yet another aspect, a method of providing internal cooling to airfoil in a gas turbine engine is disclosed. The airfoil has a pressure side wall and a suction side wall, the pressure side wall and the suction side wall extending in a spanwise direction from a base region to a tip region and in a chordwise direction from a leading edge to a trailing edge and defining and internal cooling circuit therebetween. The method includes conveying a cooling fluid in the spanwise direction from the base region to the tip through a leading edge channel, conveying the cooling fluid through a crossover hole in a leading edge partition wall to a tip flag channel, the tip flag channel defined between a tip wall and a tip partition wall and extending in a chordwise direction from the leading edge partition wall to the trailing edge, conveying the cooling fluid in the spanwise direction from the base region to the tip partition wall through a first channel of a serpentine cooling circuit, the

first channel disposed adjacent to the leading edge channel, conveying the cooling fluid from the tip flag channel through a crossover hole in the tip partition wall to a second channel of the serpentine cooling circuit, and conveying the cooling fluid from the first channel of the serpentine cooling circuit through a crossover hole in a first internal partition wall to the second channel of the serpentine cooling circuit.
(6) While the above-identified figures set forth one or more embodiments of the present disclosure, other embodiments are also contemplated, as noted in the discussion. In all cases, this disclosure presents the invention by way of representation and not limitation. It should be understood that numerous other modifications and embodiments can be devised by those skilled in the art, which fall within the scope and spirit of the principles of the invention. The figures may not be drawn to scale, and applications and embodiments of the present invention may include features and components not specifically shown in the drawings.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
(1) FIG. **1** is a quarter-sectional view of a gas turbine engine.
(2) FIG. **2** is a schematized cross-sectional view of a turbine section of the gas turbine engine of FIG. **1**.
(3) FIG. **3** is a schematized partial cutaway view of a simplified airfoil of the turbine section of FIG. **2**.
(4) FIG. **4** is a cross-sectional view of the airfoil of FIG. **3**
(5) While the above-identified figures set forth one or more embodiments of the present disclosure, other embodiments are also contemplated, as noted in the discussion. In all cases, this disclosure presents the invention by way of representation and not limitation. It should be understood that numerous other modifications and embodiments can be devised by those skilled in the art, which fall within the scope and spirit of the principles of the invention. The figures may not be drawn to scale, and applications and embodiments of the present invention may include features and components not specifically shown in the drawings.
DETAILED DESCRIPTION
(6) The present disclosure is directed to an airfoil cooling circuit arrangement with integral flow control features provided to improve flow distribution and thermal cooling performance. The disclosed airfoil cooling circuit has crossover supported cores or channels configured to eliminate dead end internal cavity walls in the tip region. The disclosed airfoil includes crossover holes to connect a leading edge channel to a tip flag channel, to connect channels of a serpentine circuit, and to connect the tip flag channel to the serpentine circuit. The disclosed airfoil provides increased wall thicknesses or wall area in regions of the airfoil that experience high metal temperatures and high thermal mechanical stress during operation.
(7) FIG. **1** is a quarter-sectional view of a gas turbine engine **20** that includes fan section **22**, compressor section **24**, combustor section **26** and turbine section **28**. Fan section **22** drives air along bypass flow path B while compressor section **24** draws air in along core flow path C where air is compressed and communicated to combustor section **26**. In combustor section **26**, air is mixed with fuel and ignited to generate a high pressure exhaust gas stream that expands through turbine section **28** where energy is extracted and utilized to drive fan section **22** and compressor section **24**.
(8) Although the disclosed non-limiting embodiment depicts a turbofan gas turbine engine, it should be understood that the concepts described herein are not limited to use with turbofans as the teachings may be applied to other types of turbine engines; for example a low-bypass turbine engine, or a turbine engine including a three-spool architecture in which three spools concentrically rotate about a common axis and where a low spool enables a low pressure turbine to drive a fan via

a gearbox, an intermediate spool that enables an intermediate pressure turbine to drive a first compressor of the compressor section, and a high spool that enables a high pressure turbine to drive a high pressure compressor of the compressor section.

(9) The example engine **20** generally includes low speed spool **30** and high speed spool **32** mounted for rotation about an engine central longitudinal axis A relative to an engine static structure **36** via several bearing systems **38**. It should be understood that various bearing systems **38** at various locations may alternatively or additionally be provided.

(10) Low speed spool **30** generally includes inner shaft **40** that connects fan **42** and low pressure (or first) compressor section **44** to low pressure (or first) turbine section **46**. Inner shaft **40** drives fan **42** through a speed change device, such as geared architecture **48**, to drive fan **42** at a lower speed than low speed spool **30**. High-speed spool **32** includes outer shaft **50** that interconnects high pressure (or second) compressor section **52** and high pressure (or second) turbine section **54**. Inner shaft **40** and outer shaft **50** are concentric and rotate via bearing systems **38** about engine central longitudinal axis A.

(11) Combustor **56** is arranged between high pressure compressor **52** and high pressure turbine **54**. In one example, high pressure turbine **54** includes at least two stages to provide a double stage high pressure turbine **54**. In another example, high pressure turbine **54** includes only a single stage. As used herein, a “high pressure” compressor or turbine experiences a higher pressure than a corresponding “low pressure” compressor or turbine.

(12) The example low pressure turbine **46** has a pressure ratio that is greater than about 5. The pressure ratio of the example low pressure turbine **46** is measured prior to an inlet of low pressure turbine **46** as related to the pressure measured at the outlet of low pressure turbine **46** prior to an exhaust nozzle.

(13) Mid-turbine frame **58** of engine static structure **36** is arranged generally between high pressure turbine **54** and low pressure turbine **46**. Mid-turbine frame **58** further supports bearing systems **38** in turbine section **28** as well as setting airflow entering low pressure turbine **46**.

(14) The core airflow C is compressed by low pressure compressor **44** then by high pressure compressor **52** mixed with fuel and ignited in combustor **56** to produce high speed exhaust gases that are then expanded through high pressure turbine **54** and low pressure turbine **46**. Mid-turbine frame **58** includes airfoils/vanes **60**, which are in the core airflow path and function as an inlet guide vane for low pressure turbine **46**. Utilizing vanes **60** of mid-turbine frame **58** as inlet guide vanes for low pressure turbine **46** decreases the length of low pressure turbine **46** without increasing the axial length of mid-turbine frame **58**. Reducing or eliminating the number of vanes in low pressure turbine **46** shortens the axial length of turbine section **28**. Thus, the compactness of gas turbine engine **20** is increased and a higher power density may be achieved.

(15) Each of the compressor section **24** and the turbine section **28** can include alternating rows of rotor assemblies and vane assemblies (shown schematically) that carry airfoils that extend into the core flow path C. To improve efficiency, static outer shroud seals (shown in FIG. **2**), such as a blade outer air seal (BOAS), can be located radially outward from rotor airfoils to reduce tip clearance and losses due to tip leakage.

(16) FIG. **2** is a schematized view of a portion of turbine section **28** that may employ various embodiments disclosed herein. Turbine section **28** includes alternating rows of rotor assemblies **62** and vane assemblies **64**. Rotor assemblies **62** include a plurality of rotor blades **66** that extend into core flow path C. Vane assembly **64** includes a plurality of stationary vanes **68** that extend into core flow path C. Turbine section **28** is housed within a case **70**, which can include multiple parts (e.g., turbine case, diffuser case, etc.). In various locations, components, such as seals, may be positioned between blades **66**, vanes **68**, and case **70**. For example, BOAS **72** are located radially outward from blade **66**. BOAS **72** can include BOAS supports that are configured to fixedly connect or attach BOAS **72** to case **70**. For example, case **70** can include a plurality of hooks **74** that engage with BOAS hooks **76** to secure the BOAS **72** between case **70** and a tip of blade **66**.

(17) Blades **66** include airfoil body **78** and platform **79**. Airfoil body includes pressure side wall **80**, suction side wall **82**, base region **84**, tip **86**, leading edge **88**, and trailing edge **90**. Pressure side wall **80** is disposed opposite suction side wall **82**. Pressure side wall **80** and suction side wall **82** each extend radially from base region **84** toward tip **86**. As used herein, the term "radial" refers to an orientation perpendicular to engine axis A. Pressure side wall **80** and suction side **82** each extend generally axially and/or tangentially (e.g., with respect to engine axis A) between leading edge **88** and trailing edge **90**. Each of base region **84** and tip **86** extend from leading edge **88** to trailing edge **90** at an innermost radial extent and an outermost radial extent of airfoil body **78**. Platform **79** joins airfoil body **78** at base region **84**. Platform **79** forms an inner diameter boundary of core airflow C. Blades **66** are joined to rotor disks **92**. Each blade **66** can include a root portion (not shown) received in rotor disk **92**.

(18) Vanes **68** include airfoil body **94**, inner diameter platform **96**, and outer diameter platform **98**. Airfoil body **94** includes pressure side wall **100**, suction side wall **102**, leading edge **104**, and trailing edge **106**. Airfoil **94** extends radially from inner diameter platform **96** to outer diameter platform **98**. Inner and outer diameter platforms **96**, **98** form inner and outer boundaries for core airflow C.

(19) Blades **66** and vanes **68** are hollow bodies with internal cavities. Internal cavities can include one or more cooling circuits defined by a plurality of cores or channels and flow passages configured to direct a cooling fluid. The channels can be separated by walls disposed in the internal cavity. Walls can extend, for example, radially or in a spanwise direction between base region **84** and tip **86** of blades **66**, joining pressure side wall **80** and suction side wall **82** to form radially extending channels. Walls can extend a full or partial radial span of airfoils **78** and **94**. Walls can additionally or alternatively extend axially or in a chordwise direction between leading edge **88** and trailing edge **90** of blade **66**, joining pressure side wall **80** and suction side wall **82** to form axially extending channels. Channels can be fluidly connected via turns or crossover holes through walls to form a cooling fluid flow path through blade **66** or vane **68**. Cooling fluid can be provided to the internal cavity of blades **66** via one or more openings in a base of blade **66** (e.g., through a root of the blade). A cooling fluid supply channel can extend through disk **92** and a root of blade **66** to convey cooling fluid to the internal cooling circuit. Cooling fluid can be separately provided to the internal cavity of vanes **68** via one or more openings in outer diameter platform **98**.

(20) FIG. **3** is a schematic partial cutaway view of one embodiment of blade **66** including an internal cooling circuit defined by plurality of cores or channels. Blade **66**, pressure side wall **80**, tip **86**, leading edge **88**, tip wall **110**, leading edge partition wall **112**, tip partition wall **114**, first internal partition wall **116**, second internal partition wall **118**, third internal partition wall **120**, leading edge channel **122**, tip flag channel **124**, first internal channel **126**, second internal channel **128**, third internal channel **130**, leading edge channel crossover hole **132**, tip holes **134**, tip channel crossover hole **136**, internal channel crossover hole **138**, trailing edge crossover holes **140**, and cooling flow Fc are shown. Suction side wall **82** is removed to show internal features. FIG. **3** is a schematic representation of an internal cooling circuit. The internal cooling circuit may include additional features not shown and/or alternative features or configurations as described herein. The features of FIG. **3** are not necessarily drawn to scale.

(21) FIG. **4** is a cross-sectional schematic view of blade **66**. FIG. **4** shows airfoil **78**, platform **79**, root portion **142**, tip **86**, leading edge **88**, trailing edge **90**, tip wall **110**, leading edge partition wall **112**, tip partition wall **114**, first internal partition wall **116**, second internal partition wall **118**, third internal partition wall **120**, leading edge channel **122**, tip flag channel **124**, first internal channel **126**, second internal channel **128**, third internal channel **130**, leading edge channel crossover hole **132**, tip holes **134**, tip channel crossover hole **136**, internal channel crossover hole **138**, trailing edge crossover holes **140**, inlets **144**, **146**, **148**, and **150**, curved surface **152**, trailing edge cavity **154**, and cooling flow Fc. FIG. **4** is a schematic representation of the internal cooling circuit. The internal cooling circuit may include additional features not shown and/or alternative features or

configurations as described herein. The features of FIG. **4** are not necessarily drawn to scale. FIGS. **3** and **4** are discussed together herein.

(22) Tip wall **110** extends from leading edge **88** to trailing edge **90** and from pressure side wall **80** to suction side wall **82** to define a radially outermost boundary of the internal cooling circuit of blade **66**. Tip wall **110** can include tip holes **134** connecting the internal cooling circuit to the exterior of blade **66** to exhaust cooling fluid from the internal cooling circuit. Tip holes **134** can be disposed adjacent leading edge **88** to exhaust the cooling fluid from leading edge channel **122**. Tip wall **110** can be radially recessed from tip **86** (i.e., a radially outermost extent of pressure side wall **80** and suction side wall **82**) to form a tip squealer pocket extending from leading edge **88** toward trailing edge **90**.

(23) Leading edge partition wall **112** extends radially or in a spanwise direction from root portion **142** to tip wall **110**. Leading edge partition wall **112** can extend substantially parallel to leading edge **88**. Leading edge partition wall **112** adjoins suction side wall **82**, pressure side wall **80**, and tip wall **110**. Leading edge partition wall **112** is axially spaced from leading edge **88**, such that leading edge **88**, leading edge partition wall **112**, pressure side wall **80**, and suction side wall **82** define a radially extending leading edge channel **122** through which a cooling fluid can be provided. Tip wall **110** defines a radially outermost boundary of leading edge channel **122**. Leading edge partition wall **112** includes leading edge channel crossover hole **132**. Leading edge channel crossover hole **132** is disposed adjacent to tip wall **110** and configured to convey cooling fluid from leading edge channel **122** to tip flag channel **124**. Leading edge crossover hole **132** is spaced from tip wall **110**, pressure side wall **80**, and suction side wall **82**. Leading edge channel crossover hole **132** can have a circular or non-circular shape. Leading edge channel crossover hole **132** can have a non-circular shape and incorporated by reference herein in its entirety.

(24) Tip partition wall **114** extends axially or in a chordwise direction from leading edge partition wall **112** to trailing edge **90**. Tip partition wall **114** is radially spaced from tip wall **110**. Tip partition wall **114** can extend substantially parallel to tip wall **110**. Tip partition wall **114** adjoins pressure side wall **80**, suction side wall **82** and leading edge partition wall **112**. Tip partition wall **114**, together with tip wall **110**, leading edge partition wall **112**, and pressure and suction side walls **80**, **82** form tip flag channel **124** through which cooling fluid can be provided. Tip flag channel **124** is open at trailing edge **90** to exhaust cooling fluid. Tip partition wall **114** includes tip channel crossover hole **136**. Tip channel crossover hole **136** is disposed to convey cooling fluid from tip flag channel **124** to second internal channel **128** of the internal cooling circuit provided between first and second internal partition walls **116** and **118**. Tip channel crossover hole **136** is spaced from pressure side wall **80**, suction side wall **82**, first internal partition wall **116**, and second internal partition wall **118**.

(25) First internal partition wall **116**, second internal partition wall **118**, and third internal partition wall **120** extend radially or in a spanwise direction from tip partition wall **114** toward root **142**. First and second partition walls **116** and **118** can extend substantially parallel to leading edge partition wall **112**. Third internal partition wall **120** can extend substantially parallel to trailing edge **90**. First, second, and third partition walls **116**, **118**, and **120** adjoin tip partition wall **114**, pressure side wall **80**, and suction side wall **82**. Together, first internal partition wall **116**, second internal partition wall **118**, and third internal partition wall **120** can form a serpentine cooling circuit in blade **66** through which cooling fluid can be provided.

(26) Together, first internal partition wall **116**, leading edge partition wall **112**, tip partition wall **114**, and pressure and suction side walls **80**, **82** define first internal channel **126**. First internal channel **126** is immediately aft of leading edge channel **122**. As used herein, “aft” refers to an axial location with respect to engine axis A and a direction of core airflow C through engine **20**. Leading edge partition wall **112** extends in the spanwise direction from root **142** to tip wall **110** thereby separating a cooling flow Fc through leading edge channel **122** from a cooling flow Fc through first internal channel **126** along the span of blade **66**. First internal partition wall **116** extends in the

spanwise direction from root **142** to tip partition wall **114**. Leading edge channel **122** and first internal channel **126** separately extend through root portion **142**, opening at a base of root portion **142** at inlets **144** and **146**, respectively. Inlets **144** and **146** are configured to receive a cooling fluid. Cooling fluid is separately fed to leading edge channel **122** and first internal channel **126** from inlets **144** and **146** in root portion **142**.

(27) Together, second internal partition wall **118**, tip partition wall **114**, first internal partition wall **116**, and pressure and suction side walls **80**, **82** define second internal channel **128** in the body portion of airfoil **78**. Second internal channel **128** is disposed immediately aft of first internal channel **126**. As previously discussed, first internal partition wall **116** extends from tip partition wall **114** through root portion **142**, thereby separating first internal channel **126** from second internal channel **128** along the span of blade **66**. First and second internal channels **126** and **128** are fluidly connected by internal channel crossover hole **138**. Internal channel crossover hole **138** is disposed in first internal partition wall **116**. Internal channel crossover hole **138** is disposed adjacent to tip partition wall **114**. Internal crossover hole **138** is spaced from tip partition wall **114**, pressure side wall **80**, and suction side wall **82**. Internal channel crossover hole **138** can have a circular or non-circular shape. As noted above with respect to leading edge channel crossover hole **132**, internal channel crossover hole **138** can have a non-circular shape.

(28) Second internal partition wall **118** extends in the spanwise direction from tip partition wall **114** toward root portion **142**. Together, second internal partition wall **118**, tip partition wall **114**, third internal partition wall **120**, and pressure and suction side walls **80**, **82** define third internal channel **130**. Second internal partition wall **118** extends a partial length of the internal cavity of blade **66** such that second internal channel **128** and third internal channel **130** are fluidly connected at an innermost radial extent. First internal partition wall **116** can have curved surface **152** that extends axially to define a radially innermost boundary of second internal channel **128**. Curved surface **152** of first internal partition wall **116** is disposed radially inward of second internal partition wall **118** to form a cooling channel therebetween, which opens to third internal channel **130**. Curved surface **152** is configured to direct flow of cooling fluid from second internal passage **128** to third internal passage **130**.

(29) Root portion **142** includes inlets **148** and **150** disposed aft of inlet **146**. Inlets **148** and **150** are configured to convey a cooling fluid to internal channel **130** and trailing edge **90**. Inlets **148** and **150** can convey cooling fluid through separate inlet channels, which combine in root portion **142** before opening to third internal channel **130** and trailing edge **90**.

(30) Third internal partition wall **120** extends in the spanwise direction from tip partition wall **114** toward root portion **142**. Third internal partition wall **120** can include a plurality of trailing edge crossover holes **140** configured to convey cooling fluid to trailing edge cavity **154** or exhaust cooling fluid from the internal cooling circuit through trailing edge **90**. Trailing edge cavity **154** is disposed aft of third internal channel **130** and extends in the spanwise direction from tip partition wall **114** to base portion **84** (shown in FIG. **2**) adjacent platform **79**. Trailing edge cavity **154** is open to trailing edge **90** to exhaust the cooling fluid from blade **66**.

(31) Cooling fluid can be provided to the internal cooling circuit of blade **66** through inlets **144**, **146**, **148**, and **150** in root portion **142**. Inlet **146** may or may not be metered, and inlets **148** and **150** may be open, metered, or blocked. Cooling flow Fc can be separately received in each of leading edge channel **122** and first internal channel **126** via inlets **144** and **146**, respectively. Cooling flow Fc is conveyed in a radial or spanwise direction toward tip wall **110**. Cooling fluid Fc from leading edge channel **122** is conveyed to tip flag channel **124** via leading edge channel crossover hole **132**. A portion of cooling flow Fc through leading edge channel **122** is exhausted through tip holes **134**. Cooling flow Fc moves in an axial or chordwise direction in tip flag channel **124**. A portion of cooling flow Fc from tip flag channel **124** can be conveyed to second internal channel **128** through tip channel crossover hole **136**. Tip channel crossover hole **136** can be sized to convey a majority of cooling flow Fc received from leading edge channel **122** to second internal channel **128**. A

portion of cooling flow Fc can be conveyed through tip flag channel to trailing edge **90** for convective cooling of a tip region of airfoil **78**. Cooling fluid Fc is exhausted through trailing edge **90**.

(32) Cooling flow Fc supplied to first internal channel **126** via inlet **146** is conveyed in a radial direction toward tip partition wall **114**. Cooling flow Fc in first internal channel **126** is conveyed to second internal channel **128** via internal channel crossover hole **138** near tip partition wall **114**. Cooling flow Fc in second internal channel **128** received from tip flag channel **124** and first internal channel **126** is conveyed in a radial direction toward base region **84** (shown in FIG. **2**) of airfoil **78**. Cooling flow Fc turns at an innermost radial extent of second internal partition wall **118** and curved surface **152** of first internal partition wall **116** and is directed radially outward toward tip partition wall **114** in third internal channel **130**. Cooling flow Fc in third internal channel **130** is conveyed to trailing edge cavity **154** via trailing edge crossover holes **140** and out of trailing edge **90**. Third internal channel **130** may additionally receive cooling flow Fc from inlets **148** and **150** in root portion **142**. Cooling flow Fc is directed from inlets **148** and **150** radially outward toward tip partition wall **114**. Curved surface **152** of first internal partition wall **116** can be configured to direct cooling flow Fc toward third internal channel **130** and trailing edge cavity **154**.

(33) Leading edge partition wall **112** extends fully to tip wall **110** to provide internal cooling of tip **86** at leading edge **88**. This region can experience high thermal loads and mechanical stress during operation. As illustrated in FIG. **3**, a portion of cooling flow Fc is back pressured by leading edge partition wall **112** above and around leading edge channel crossover hole **132**, providing back pressure and cooling in the region of tip **86** and promoting the flow of cooling fluid to the outside corner of leading edge cooling channel **122** and improved convective heat transfer in this region of the tip. Leading edge channel crossover hole **132** can provide an improvement over prior art turns formed by a curved internal wall forming both the radially extending leading edge cooling channel and the axial extending tip flag channel, which can fail to provide adequate cooling of the outside corner of the channel formed by the leading edge and tip wall. The additional cooling provided by extending leading edge partition wall **112** to tip wall **110** can reduce a local thermal mechanical strain in this region. Additionally, mechanical stresses associated with dead-ended internal walls (walls that are discontinued with an end separated from an adjacent channel wall) are reduced by extending leading edge partition wall **112** to tip wall **110** and utilizing leading edge channel crossover hole **132** to convey cooling fluid Fc to tip flag channel **124**. The extension of leading edge partition wall **112** to tip wall **110** allows mechanical stresses to be distributed all the way to tip wall **110**.

(34) Leading edge channel crossover hole **132** has an area sized to provide a desired cooling flow Fc to tip flag channel **124**. Leading edge channel crossover hole **132** is sized to convey substantially all or the majority of cooling fluid in leading edge channel **122** to tip flag channel **124**. Leading edge channel crossover hole **132** is smaller than a forward most area of tip flag channel **124** to provide back pressure cooling in the tip region at leading edge **88**. Leading edge channel crossover hole **132** has a minimum size defined by a desired pressure drop across leading edge channel crossover hole **132**. As used herein, “substantially all” refers to cooling fluid Fc not used for film cooling of external surfaces or tip cooling (i.e., via tip holes **134**). As shown in FIG. **3**, a portion of cooling flow Fc is exhausted from leading edge channel **122** through tip holes **134**. A small portion of cooling flow Fc can also be used for film cooling in the region of leading edge **88**, exiting leading edge channel **122** through film cooling holes (not shown). Leading edge channel crossover hole **132** can be disposed closer to tip wall **110** than to tip partition wall **114** to cool tip wall **110** adjacent to leading edge partition wall **112** in tip flag channel **124**. Leading edge channel crossover hole **132** is spaced radially inward of tip wall **110** a distance selected to provide effective back pressure and cooling in the tip region at leading edge **88** and improved convective heat transfer in this region of airfoil **78**. Leading edge channel crossover hole **134** can be disposed closer to pressure side wall **80** than to suction side wall **82**. During operation of blade **66**, higher

mechanical stress can be observed at suction side wall **82** of blade **66** adjacent to leading edge partition wall **112**. Leading edge channel crossover hole **132** can be disposed closer to pressure side wall **80** to provide additional leading edge partition wall thickness in a region adjacent to suction side wall **82**. Leading edge channel crossover hole **132** is sized to supply all of cooling fluid Fc received in tip channel **124**.

(35) Internal channel crossover hole **138** is disposed adjacent to tip partition wall **114**. Internal channel crossover hole **138** can be spaced from tip partition wall to provide back pressure cooling of the outermost radial extent of first internal channel **126** provided by cooling flow impinging first internal partition wall **116** above internal channel crossover hole **138**. Internal channel crossover hole **138** can provide an improvement over designs incorporating a dead end first partition wall (i.e., partition wall that does not fully extend to tip partition wall **114**). By extending first internal partition wall **112** to tip partition wall **114** and utilizing internal channel crossover hole **138** to convey cooling fluid Fc to second internal channel **128**, mechanical stresses can be distributed across first partition wall **112** to tip partition wall **114** and promote cooling flow Fc filling of first internal channel **126** at tip partition wall **114**. Back pressure of cooling flow Fc provided by first internal partition wall **116** can fill first internal channel **126** in the corner formed between leading edge partition wall **112** and tip partition wall **114**. Internal channel crossover hole **138** can be centered on first internal partition wall **116** between pressure side wall **80** and suction side wall **82** absent increased mechanical stress on suction side wall **82** adjacent to internal channel crossover hole **138**. Centering internal channel **138** can improve ease of manufacturing. Internal channel crossover hole **138** has an area sized to provide a desired cooling flow Fc to second internal channel **128**. Internal channel crossover hole **138** is sized to convey substantially all cooling fluid received in first internal channel **126** via inlet **146** to second internal channel **128**.

(36) Tip channel crossover hole **136** is disposed between first internal partition wall **116** and second internal partition wall **118**. Tip channel crossover hole **136** is spaced from first internal partition wall **116**, second internal partition wall **118**, pressure side wall **80**, and suction side wall **82** to provide an increased wall thickness along pressure and suction side walls **80**, **82** adjacent to tip channel crossover hole **136** and between first and second internal partition walls **116**, **118** and tip channel crossover hole **136**. Mechanical stresses associated with dead-ended internal walls are reduced by extending tip partition wall **114** from leading edge partition wall **112** to trailing edge **90** and utilizing tip channel crossover hole **136** to convey cooling fluid Fc to second internal channel **128**. The full extension of tip partition wall **114** from leading edge partition wall **112** to trailing edge **90** can provide improved stress distribution over dead-ended partition wall designs.

(37) Tip channel crossover hole **136** can be sized to cause preferential cooling flow Fc from leading edge channel **122** to second internal channel **128** while maintaining some cooling flow Fc to trailing edge **90**. Tip channel crossover hole **136** and internal channel crossover hole **138** can be configured to convey substantially all of cooling flow Fc traveling through trailing edge crossover holes **140** and out of trailing edge **90**. Cooling flow Fc through tip channel crossover hole **136** can be dependent on an outlet area of tip flag channel **124** and an outlet area of trailing edge channel **154** and can be roughly proportional to an outlet area of tip flag channel **124** and an outlet area of trailing edge channel **154** when inlets **148** and **150** are blocked. Tip channel crossover hole **136** can have an area similar to an area of leading edge channel crossover hole **132** to provide preferentially cooling flow to second internal channel **128**. For example, tip channel crossover hole **136** can have an area that is at least 80 percent of an area of leading edge channel crossover hole **132**.

(38) The shape, size, and location of leading edge channel crossover hole **132**, tip channel crossover hole **136**, and internal channel crossover hole **138** can be selected to provide effective flow-through cooling with minimal pressure losses, provide back pressure cooling in leading edge channel **122** and second internal channel **128**, and minimize the effects of thermal mechanical stress concentrations. Leading edge channel crossover hole **132**, tip channel crossover hole **136**, and internal channel crossover hole **138** can be shaped to provide increased wall material in areas

of high mechanical stress without reducing an area required to achieve a desired cooling fluid flow. The disclosed crossover supported tip flag and serpentine core can improve airfoil cooling while reducing stress.

DISCUSSION OF POSSIBLE EMBODIMENTS

(39) The following are non-exclusive descriptions of possible embodiments of the present invention.

(40) An airfoil for a gas turbine engine includes a body defining and internal cavity, the body having a pressure side wall and a suction side wall, a tip wall extending in the chordwise direction between the pressure side wall and the suction side wall and defining a radially outer boundary of the internal cavity in the tip region, a first wall disposed in the interior cavity and extending in the spanwise direction to form a first cooling channel, a second wall disposed in the interior cavity and extending in the chordwise direction from the first wall toward the trailing edge to form a second cooling channel, a first hole through the first wall connecting the first cooling channel to the second cooling channel, and a second hole though the second wall connecting the second cooling channel to a third cooling channel. An area of the first hole is sized to provide all of a cooling fluid flow received in the second cooling channel and an area of the second hole is at least 80 percent of the area of the first hole.

(41) The airfoil of the preceding paragraph can optionally include, additionally and/or alternatively, any one or more of the following features, configurations and/or additional components:

(42) In an embodiment of the airfoil of the preceding paragraphs, the first cooling channel can be disposed adjacent to the leading edge.

(43) In an embodiment of the airfoil of any of the preceding paragraphs, the first hole can be spaced from the pressure side wall, the suction side wall, the tip wall, and the second wall.

(44) In an embodiment of the airfoil of any of the preceding paragraphs, the first hole can be disposed closer to the pressure side wall than the suction side wall.

(45) An embodiment of the airfoil of any of the preceding paragraphs can further include a third wall spaced from the first wall and a fourth wall spaced from the third wall. The third and fourth walls can extend in a spanwise direction and adjoin the pressure side wall, the suction side wall, and the tip wall to form a third cooling channel between the third and fourth walls and a fourth cooling channel between the first and third walls.

(46) In an embodiment of the airfoil of any of the preceding paragraphs, the third and fourth cooling channels can form a portion of a serpentine cooling circuit.

(47) In an embodiment of the airfoil of any of the preceding paragraphs, the second hole can be spaced from the pressure side wall, the suction side wall, the third wall, and the fourth wall

(48) An embodiment of the airfoil of any of the preceding paragraphs can further include a third hole through the third wall connecting the fourth channel and the third channel of the serpentine circuit. The third hole can be disposed adjacent to the second wall.

(49) In an embodiment of the airfoil of any of the preceding paragraphs, the third hole can be spaced from the pressure side wall, the suction side wall, and the second wall, and wherein the third hole can be sized to direct substantially all cooling flow from the fourth channel to the third channel.

(50) An embodiment of the airfoil of any of the preceding paragraphs can further include a fifth wall disposed between the fourth wall and the trailing edge, the fifth wall extending in a spanwise direction and adjoining the pressure side wall, the suction side wall, and the second wall to form a fifth cooling channel. The fourth cooling channel can be open to the fifth cooling channel in the base region.

(51) In an embodiment of the airfoil of any of the preceding paragraphs, the second hole and the third hole can be configured to provide all of the cooling fluid received in the fifth cooling channel.

(52) In an embodiment of the airfoil of any of the preceding paragraphs, the second hole can be centered between the pressure side wall and the suction side wall.

(53) A turbine blade for use in a gas turbine engine includes a root portion comprising a plurality of cooling channels configured to receive a cooling fluid, a platform disposed adjacent to the root portion, and an airfoil disposed adjacent to the platform. The airfoil includes a pressure side wall and a suction side wall extending in a spanwise direction from a base region adjacent to the platform to a tip region and extending in a chordwise direction from a leading edge to a trailing edge, and a tip wall extending in the chordwise direction between the pressure side wall and the suction side wall. The airfoil further includes an internal cooling circuit formed by a plurality of walls and cross-over holes including: first, second, and third walls, and first and second crossover holes. The first wall is spaced from the leading edge and extends in the spanwise direction from the root to the tip wall and adjoins the pressure side wall, the suction side wall, and the tip wall to form a leading edge cooling channel. The second wall is spaced from the tip wall and extends in the chordwise direction from the first wall to the trailing edge. The second wall adjoining the pressure side wall, the suction side wall, and the first wall to form a tip flag cooling channel. The third wall is spaced from the first wall and extends in the spanwise direction from the root to the second wall. The third wall adjoins the pressure side wall, the suction side wall, the second wall to form a first cooling channel of a serpentine cooling circuit. The first crossover hole is through the first wall connecting the leading edge cooling channel to the tip flag cooling channel. The second crossover hole is though the second wall connecting the tip flag cooling channel to a second cooling channel of the serpentine cooling circuit. The third crossover hole is through the third wall connecting the first and second cooling channels of the serpentine cooling circuit.
(54) The turbine blade of the preceding paragraph can optionally include, additionally and/or alternatively, any one or more of the following features, configurations and/or additional components:
(55) In an embodiment of the turbine blade of the preceding paragraphs, the third crossover hole can be disposed adjacent to the second wall.
(56) In an embodiment of the turbine blade of any of the preceding paragraphs, the first crossover hole can be disposed closer to the tip wall than to the second wall.
(57) In an embodiment of the turbine blade of any of the preceding paragraphs, the first cross-over hole can be disposed closer to the pressure side wall than the suction side wall.
(58) An embodiment of the turbine blade of any of the preceding paragraphs can further include a fourth wall spaced from the third wall extending in the spanwise direction from the second wall toward the root and adjoining the pressure side wall, the suction side wall, and the second wall to form the second cooling channel of the serpentine cooling circuit. The second crossover hole can be spaced from the third wall, the fourth wall, the pressure side wall, and the suction side wall.
(59) A method of providing internal cooling to airfoil in a gas turbine engine is disclosed. The airfoil has a pressure side wall and a suction side wall, the pressure side wall and the suction side wall extending in a spanwise direction from a base region to a tip region and in a chordwise direction from a leading edge to a trailing edge and defining and internal cooling circuit therebetween. The method includes conveying a cooling fluid in the spanwise direction from the base region to the tip through a leading edge channel, conveying the cooling fluid through a crossover hole in a leading edge partition wall to a tip flag channel, the tip flag channel defined between a tip wall and a tip partition wall and extending in a chordwise direction from the leading edge partition wall to the trailing edge, conveying the cooling fluid in the spanwise direction from the base region to the tip partition wall through a first channel of a serpentine cooling circuit, the first channel disposed adjacent to the leading edge channel, conveying the cooling fluid from the tip flag channel through a crossover hole in the tip partition wall to a second channel of the serpentine cooling circuit, and conveying the cooling fluid from the first channel of the serpentine cooling circuit through a crossover hole in a first internal partition wall to the second channel of the serpentine cooling circuit.
(60) The method of the preceding paragraph can optionally include, additionally and/or

alternatively, any one or more of the following features, configurations additional components, and/or steps:
(61) In an embodiment of the method of the preceding paragraphs, the first crossover hole can be disposed closer to the pressure side wall than the suction side wall.
(62) While the invention has been described with reference to an exemplary embodiment(s), it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment(s) disclosed, but that the invention will include all embodiments falling within the scope of the appended claims.

Claims

1. An airfoil for a gas turbine engine, the airfoil comprising: a body defining an internal cavity, the body having a pressure side wall and a suction side wall, the pressure side wall and the suction side wall extending in a spanwise direction from a base region to a tip region and in a chordwise direction from a leading edge to a trailing edge; a tip wall extending in the chordwise direction between the pressure side wall and the suction side wall and defining a radially outer boundary of the internal cavity in the tip region; a first wall disposed in the interior cavity, the first wall extending in the spanwise direction from the base region to the tip wall and adjoining the pressure side wall and the suction side wall to form a first cooling channel; a second wall disposed in the interior cavity and extending in the chordwise direction from the first wall toward the trailing edge, the second wall adjoining the pressure side wall and the suction side wall to form a second cooling channel; a first hole through the first wall, the first hole connecting the first cooling channel to the second cooling channel, wherein all of a cooling fluid flow in the second cooling channel is received from the first hole; and a second hole though the second wall connecting the second cooling channel to a third cooling channel, wherein an area of the second hole is at least 80 percent of the area of the first hole.
2. The airfoil of claim 1, wherein the first cooling channel is disposed adjacent to the leading edge.
3. The airfoil of claim 2, wherein the first hole is spaced from the pressure side wall, the suction side wall, the tip wall, and the second wall.
4. The airfoil of claim 3, wherein the first hole is disposed closer to the pressure side wall than the suction side wall.
5. The airfoil of claim 3 and further comprising: a third wall spaced from the first wall; and a fourth wall spaced from the third wall; wherein the third and fourth walls extend in the spanwise direction and adjoin the pressure side wall, the suction side wall, and the second wall; wherein the third cooling channel is formed between the third and fourth walls; and wherein a fourth cooling channel is formed between the first and third walls.
6. The airfoil of claim 5, wherein the third and fourth cooling channels form a portion of a serpentine cooling circuit.
7. The airfoil of claim 6, wherein the second hole is spaced from the pressure side wall, the suction side wall, the third wall, and the fourth wall.
8. The airfoil of claim 5 and further comprising a third hole through the third wall connecting the fourth channel and the third channel of the serpentine circuit, wherein the third hole is disposed adjacent to the second wall.
9. The airfoil of claim 8, wherein the third hole is spaced from the pressure side wall, the suction side wall, and the second wall, and wherein the third hole is sized to direct substantially all cooling flow from the fourth channel to the third channel.
10. The airfoil of claim 9 and further comprising a fifth wall disposed between the fourth wall and

the trailing edge, the fifth wall extending in the spanwise direction and adjoining the pressure side wall, the suction side wall, and the second wall to form a fifth cooling channel, wherein the fourth cooling channel is open to the fifth cooling channel in the base region.

11. The airfoil of claim 9, wherein the second hole and the third hole are configured to provide all of the cooling fluid received in the fifth cooling channel.

12. The airfoil of claim 11, wherein the second hole is centered between the pressure side wall and the suction side wall.

13. An airfoil for a gas turbine engine, the airfoil comprising: a body defining an internal cavity, the body having a pressure side wall and a suction side wall, the pressure side wall and the suction side wall extending in a spanwise direction from a base region to a tip region and in a chordwise direction from a leading edge to a trailing edge; a tip wall extending in the chordwise direction between the pressure side wall and the suction side wall and defining a radially outer boundary of the internal cavity in the tip region; a first wall disposed in the interior cavity, the first wall extending in the spanwise direction from the base region to the tip wall and adjoining the pressure side wall and the suction side wall to form a first cooling channel; a second wall disposed in the interior cavity and extending in the chordwise direction from the first wall toward the trailing edge, the second wall adjoining the pressure side wall and the suction side wall to form a second cooling channel; a third wall spaced from the first wall, the third wall extending in a spanwise direction and adjoining the pressure side wall, the suction side wall, and the second wall; a fourth wall spaced from the third wall, the fourth wall extending in a spanwise direction and adjoining the pressure side wall, the suction side wall, and the second wall, wherein a third cooling channel is formed between the third and fourth walls and a fourth cooling channel is formed between the first and third walls, the third and fourth cooling channels forming a portion of a serpentine cooling circuit; a first hole through the first wall, the first hole connecting the first cooling channel to the second cooling channel, wherein an area of the first hole is sized to provide all of a cooling fluid flow received in the second cooling channel; a second hole though the second wall connecting the second cooling channel to a third cooling channel, wherein an area of the second hole is at least 80 percent of the area of the first hole; and a third hole through the third wall connecting the fourth channel and the third channel of the serpentine circuit, wherein the third hole is disposed adjacent to the second wall.

14. The airfoil of claim 13, wherein the first cooling channel is disposed adjacent to the leading edge.

15. The airfoil of claim 13, wherein the first hole is spaced from the pressure side wall, the suction side wall, the tip wall, and the second wall.

16. The airfoil of claim 13, wherein the first hole is disposed closer to the pressure side wall than the suction side wall.

17. The airfoil of claim 13, wherein the second hole is spaced from the pressure side wall, the suction side wall, the third wall, and the fourth wall.

18. The airfoil of claim 13, wherein the third hole is spaced from the pressure side wall, the suction side wall, and the second wall.

19. The airfoil of claim 13 and further comprising a fifth wall disposed between the fourth wall and the trailing edge, the fifth wall extending in the spanwise direction and adjoining the pressure side wall, the suction side wall, and the second wall to form a fifth cooling channel, wherein the fourth cooling channel is open to the fifth cooling channel in the base region.

20. The airfoil of claim 19, wherein the second hole and the third hole are configured to provide all of the cooling fluid received in the fifth cooling channel.