



US010619492B2

(12) **United States Patent**  
**Vu et al.**

(10) **Patent No.:** **US 10,619,492 B2**

(45) **Date of Patent:** **Apr. 14, 2020**

(54) **VANE AIR INLET WITH FILLET**

(56) **References Cited**

(71) Applicant: **UNITED TECHNOLOGIES CORPORATION**, Farmington, CT (US)

U.S. PATENT DOCUMENTS

4,218,178 A \* 8/1980 Irwin ..... F01D 5/185  
415/114  
7,104,756 B2 9/2006 Harding et al.  
9,523,283 B2 12/2016 Uechi et al.  
2009/0162193 A1 \* 6/2009 Mariotti ..... F01D 5/143  
415/191  
2010/0310367 A1 12/2010 Devore et al.  
2012/0257954 A1 \* 10/2012 Chanteloup ..... F01D 5/187  
415/1

(72) Inventors: **Ky H. Vu**, East Hartford, CT (US);  
**Adam P. Generale**, Dobbs Ferry, NY (US); **Brandon L. Howard**, Vernon, CT (US)

(73) Assignee: **UNITED TECHNOLOGIES CORPORATION**, Farmington, CT (US)

(Continued)

FOREIGN PATENT DOCUMENTS

(\*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 91 days.

EP 1908921 4/2008  
EP 2418355 2/2012

(Continued)

(21) Appl. No.: **15/837,784**

OTHER PUBLICATIONS

(22) Filed: **Dec. 11, 2017**

European Patent Office, European Search Report dated Apr. 9, 2019 in Application No. 18198288.5.

(65) **Prior Publication Data**

US 2019/0178091 A1 Jun. 13, 2019

*Primary Examiner* — Michael Lebentritt

(74) *Attorney, Agent, or Firm* — Snell & Wilmer, L.L.P.

(51) **Int. Cl.**  
**F01D 5/18** (2006.01)  
**F01D 9/06** (2006.01)  
**F01D 9/04** (2006.01)

(57) **ABSTRACT**

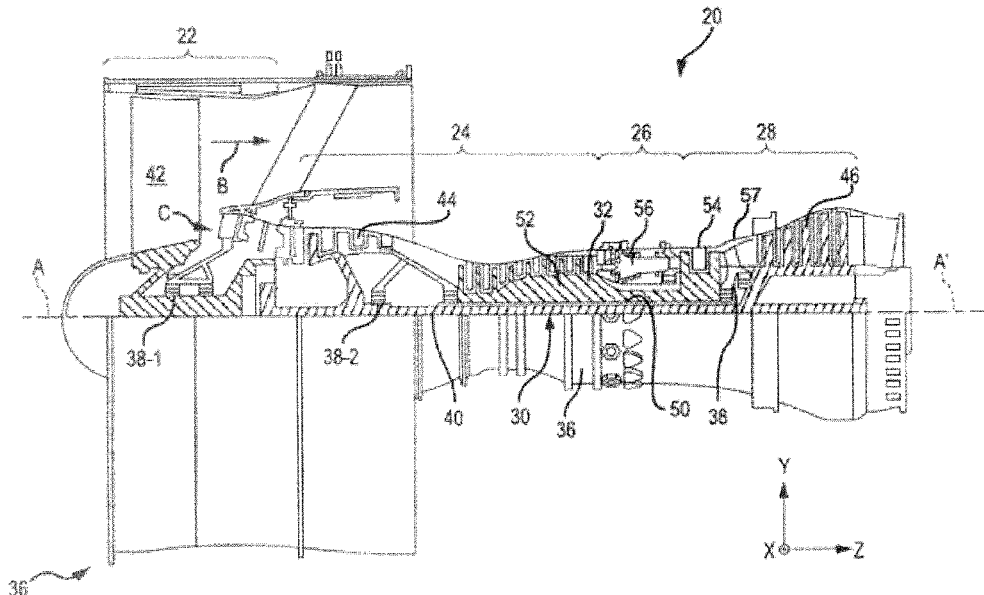
A vane for a gas turbine engine may comprise a vane platform and an airfoil extending radially from the vane platform. The airfoil may comprise an inlet defined, at least partially, by an internal surface of the airfoil. The internal surface may comprise a convex curve proximate the inlet. A transition between an external surface of the airfoil and a surface of the vane platform may comprise a concave curve. A radius of curvature of the convex curve of the internal surface may be concentric to a radius of curvature of the concave curve of the transition.

(52) **U.S. Cl.**  
CPC ..... **F01D 5/189** (2013.01); **F01D 5/187** (2013.01); **F01D 9/041** (2013.01); **F01D 9/065** (2013.01); **F05D 2240/81** (2013.01); **F05D 2250/51** (2013.01); **F05D 2250/711** (2013.01); **F05D 2260/201** (2013.01)

(58) **Field of Classification Search**  
None

See application file for complete search history.

**18 Claims, 4 Drawing Sheets**



(56)

**References Cited**

## U.S. PATENT DOCUMENTS

2013/0343873 A1\* 12/2013 Spangler ..... F01D 17/162  
415/115  
2014/0363302 A1\* 12/2014 Romanowski ..... F01D 5/143  
416/223 R  
2015/0110617 A1\* 4/2015 Stein ..... F01D 5/141  
415/208.1  
2015/0267549 A1 9/2015 Facchinetti et al.  
2015/0292343 A1\* 10/2015 Farah ..... F01D 9/044  
415/209.1  
2016/0194964 A1\* 7/2016 Vu ..... F01D 5/187  
60/722  
2016/0208631 A1\* 7/2016 Spangler ..... F01D 9/065  
2016/0222823 A1\* 8/2016 Vu ..... F01D 9/065  
2016/0237844 A1\* 8/2016 Holowczak ..... F01D 11/04  
2016/0245114 A1\* 8/2016 Wang ..... F01D 25/162  
2016/0258306 A1\* 9/2016 Spangler ..... F01D 9/065  
2017/0009587 A1\* 1/2017 Szymanski ..... F01D 5/141  
2017/0037732 A1\* 2/2017 Spangler ..... F01D 5/187  
2017/0089206 A1\* 3/2017 Quach ..... F01D 5/187  
2017/0130590 A1\* 5/2017 Spangler ..... F01D 5/18  
2017/0159450 A1\* 6/2017 Buhler ..... F01D 5/186  
2018/0223676 A1\* 8/2018 Spangler ..... F01D 5/189  
2018/0283195 A1\* 10/2018 Ortiz ..... F01D 9/065  
2018/0306036 A1\* 10/2018 Spangler ..... F01D 5/187  
2019/0071984 A1\* 3/2019 Leon ..... F01D 5/02

## FOREIGN PATENT DOCUMENTS

EP 2921650 9/2015  
EP 3047111 7/2016  
EP 3236010 10/2017

\* cited by examiner

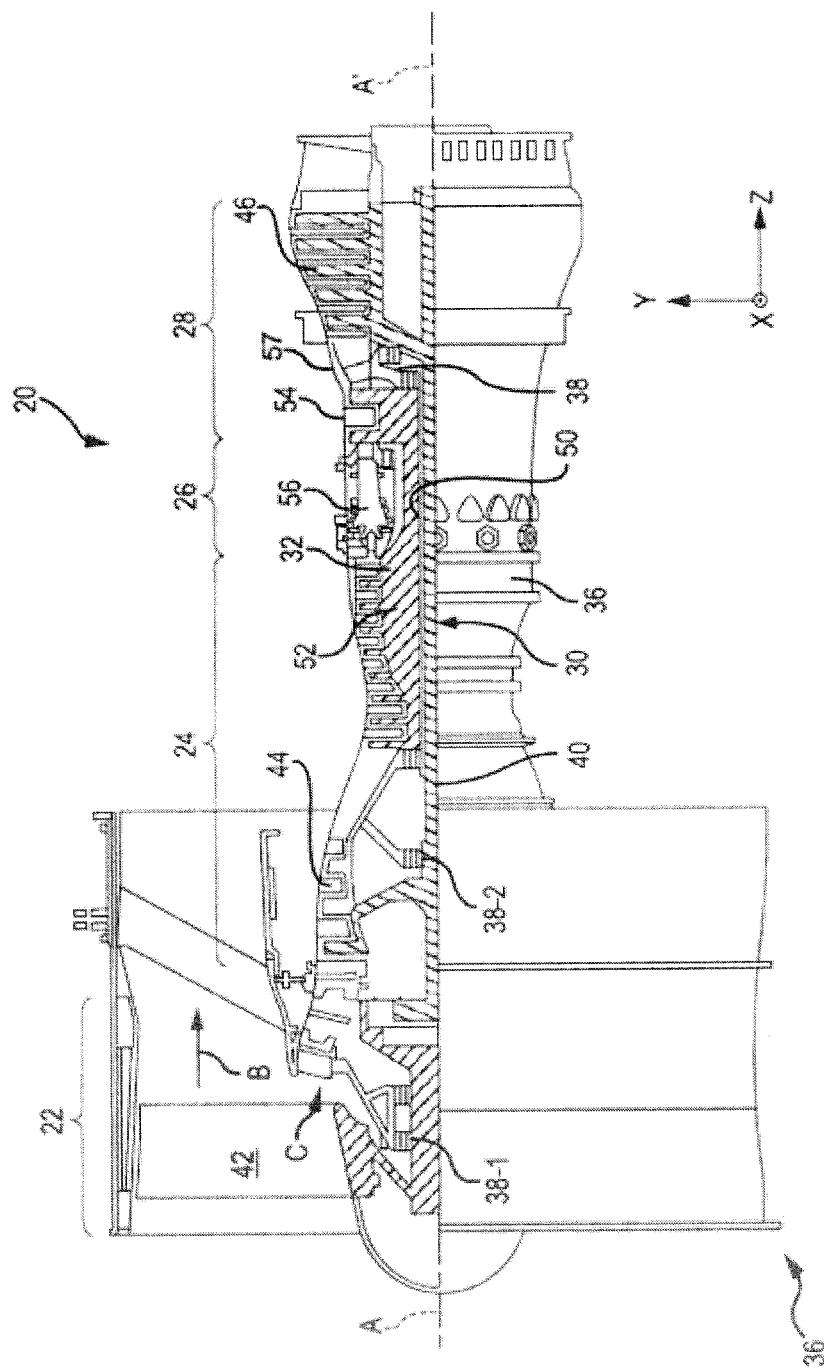
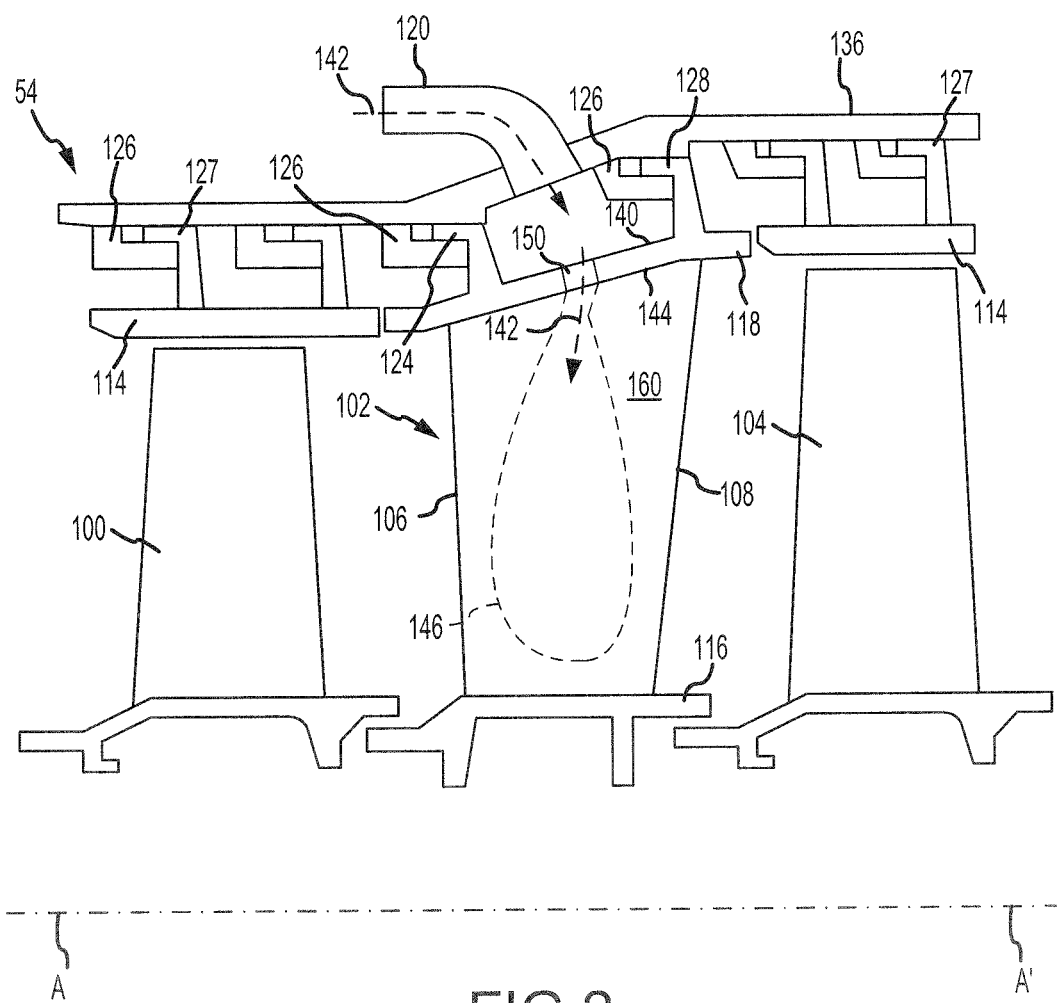


FIG. 1



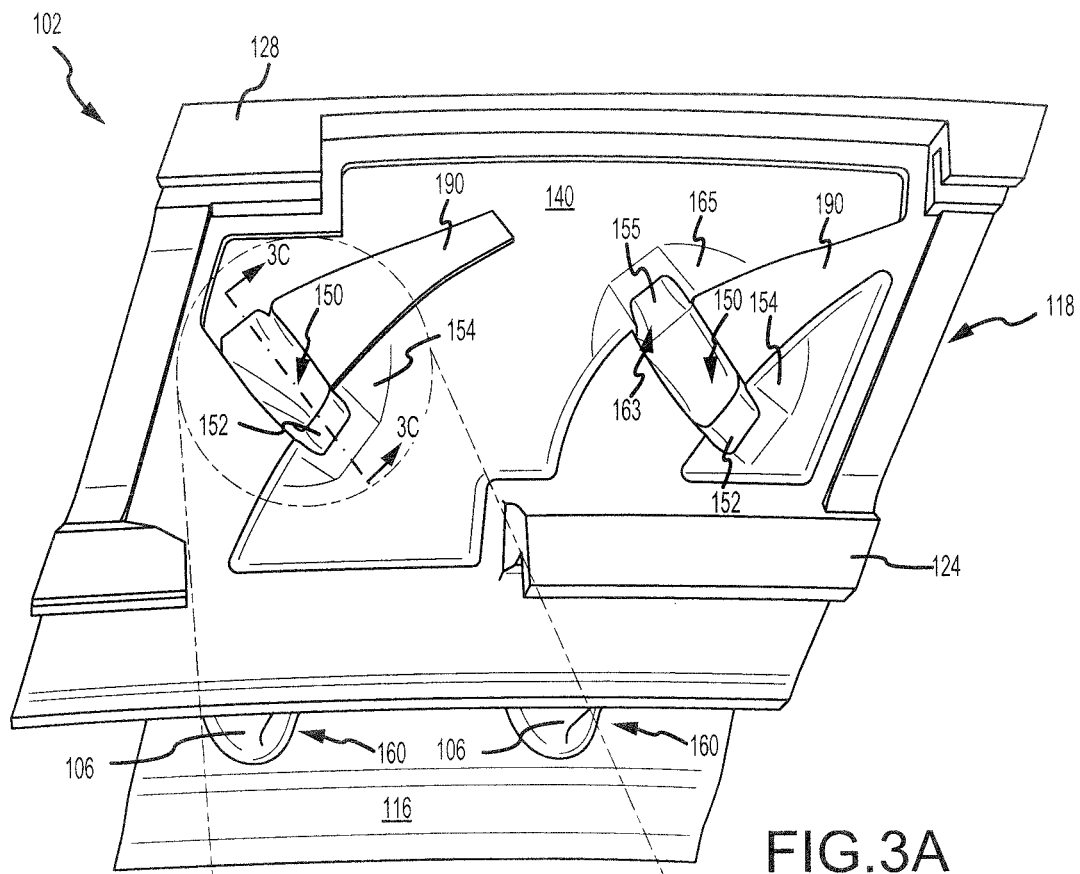


FIG. 3A

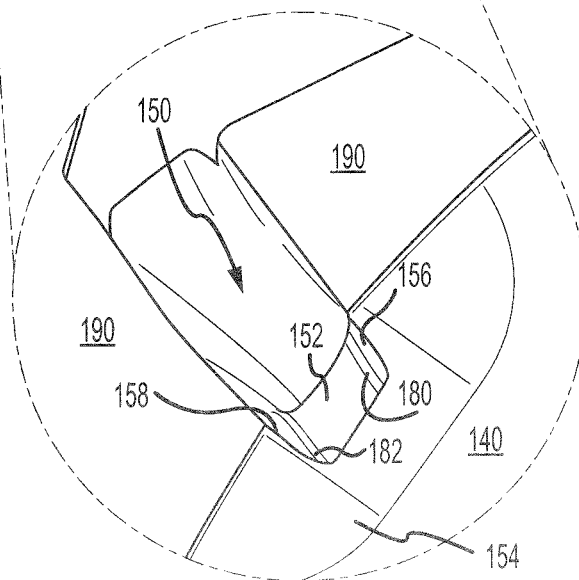


FIG. 3B

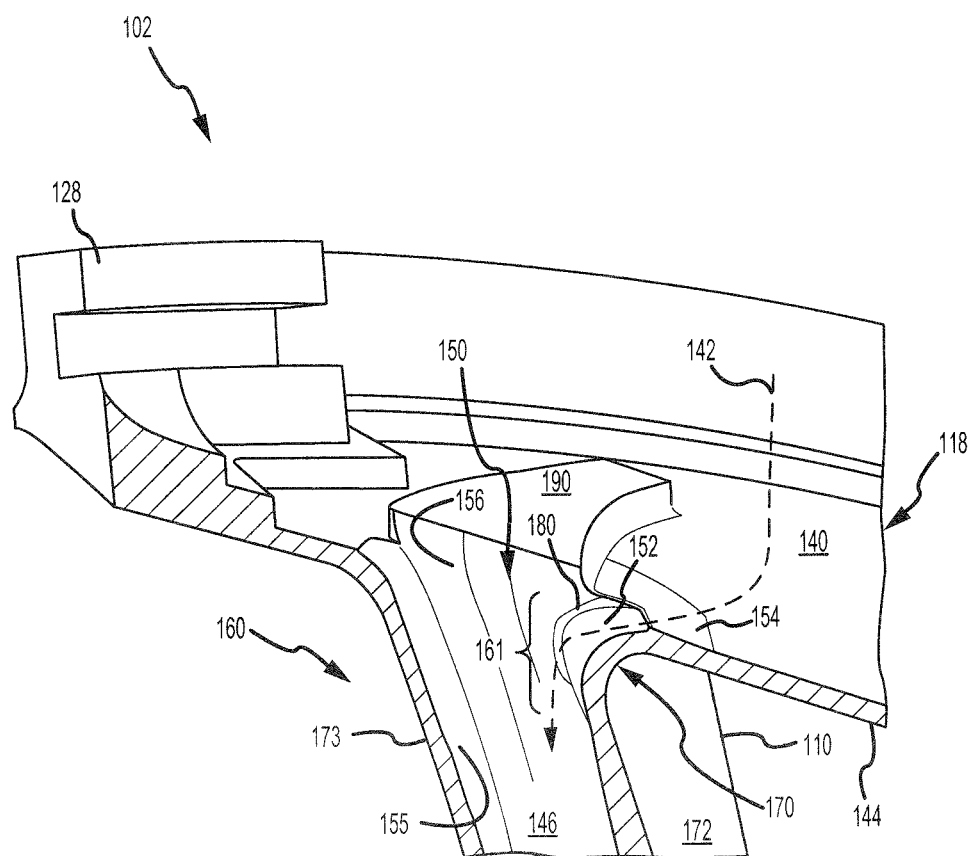


FIG.3C

1

**VANE AIR INLET WITH FILLET****STATEMENT OF GOVERNMENT INTEREST**

This disclosure was made with government support under Contract No. FA8626-16-C-2139 awarded by the United States Air Force. The government has certain rights in the disclosure.

**FIELD**

The present disclosure relates to cooling structures for gas turbine engines and, more specifically, to vane cooling structures.

**BACKGROUND**

A gas turbine engine typically includes a fan section, a compressor section, a combustor section, and a turbine section. The fan section may drive air along a bypass flowpath while the compressor section may drive air along a core flowpath. In general, during operation, air is pressurized in the compressor section and is mixed with fuel and burned in the combustor section to generate hot combustion gases. The hot combustion gases flow through the turbine section, which extracts energy from the hot combustion gases to power the compressor section and other gas turbine engine loads. Vanes in the turbine section may be fed cooling air from the bypass flowpath. The cooling air may flow along a platform of the vane and into an internal cavity of the vane airfoil. The geometry of the inlet can cause interrupted or recirculated of the cooling airflow. Additionally, the surfaces forming the inlet may experience increased thermal and mechanical stresses, particularly on a pressure side of the airfoil.

**SUMMARY**

A vane for a gas turbine engine is disclosed herein, in accordance with various embodiments. The vane may comprise a vane platform and an airfoil extending radially from the vane platform. The airfoil may comprise an inlet defined, at least partially, by an internal surface of the airfoil. The internal surface comprises a convex curve proximate the inlet. A ramp may be formed over a first surface of the vane platform.

In various embodiments, a transition between an external surface of the airfoil opposite the internal surface of the airfoil and a second surface of the vane platform opposite the first surface of the vane platform may comprise a concave curve. A radius of curvature of the convex curve of the internal surface may be concentric to a radius of curvature of the concave curve of the transition.

In various embodiments, the internal surface may comprise an internal pressure side surface of the airfoil, and the ramp may be located proximate a pressure side of the inlet. A transition between the internal pressure side surface of the airfoil and at least one of an internal leading edge surface of the airfoil or an internal trailing edge surface of the airfoil may comprise a concave curve. The internal leading edge surface of the airfoil or the internal trailing edge surface of the airfoil may extend to a radially raised surface of the vane platform.

In various embodiments, the internal surface may comprise an internal suction side surface of the airfoil, and the ramp may be located proximate a suction side of the inlet.

2

In various embodiments, the inlet may be in fluid communication with an internal cavity of the airfoil. The convex curve of the internal surface and the ramp may provide a smooth flowpath from a generally axial plane along the first surface of the vane platform to a generally radial plane of the internal cavity.

A gas turbine engine is also disclosed herein, in accordance with various embodiments. The gas turbine engine may comprise a combustor and a turbine aft of the combustor and including a vane. The vane may comprise a vane platform and an airfoil extending radially from the vane platform. The airfoil may comprise an inlet defined, at least partially, by an internal surface of the airfoil. The internal surface may comprise a convex curve proximate the vane platform. A ramp may be formed over a first surface of the vane platform.

In various embodiments, a transition between an external surface of the airfoil opposite the internal surface of the airfoil and a second surface of the vane platform opposite the first surface of the vane platform may comprise a concave curve. A radius of curvature of the convex curve of the internal surface may be concentric to a radius of curvature of the concave curve of the transition.

In various embodiments, the internal surface may comprise an internal pressure side surface of the airfoil. A first transition between the internal pressure side surface of the airfoil and an internal leading edge surface of the airfoil may comprise a first concave curve. A second transition between the internal pressure side surface of the airfoil and an internal trailing edge surface of the airfoil may comprise a second concave curve. In various embodiments, the inlet may be in fluid communication with an internal cavity of the airfoil. The convex curve of the internal surface may reduce stress at a pressure side of the inlet.

A turbine for a gas turbine engine is disclosed herein, in accordance with various embodiments. The turbine may comprise an vane outer platform, a vane inner platform, and an airfoil extending between the vane outer platform and the vane inner platform. The airfoil may comprise an inlet defined, at least partially, by an internal pressure side surface of the airfoil. The internal pressure side surface may comprise a convex curve proximate the inlet.

In various embodiments, a transition between an external pressure side surface of the airfoil and a first surface of the vane outer platform may comprise a concave curve. A radius of curvature of the convex curve of the internal pressure side surface may be concentric to a radius of curvature of the concave curve of the transition. A ramp may extend between the internal pressure side surface of the airfoil and a second surface of the vane outer platform opposite the first surface of the vane outer platform. The convex curve of the internal pressure side surface may reduce stress along a pressure side of the inlet.

**BRIEF DESCRIPTION OF THE DRAWINGS**

The subject matter of the present disclosure is particularly pointed out and distinctly claimed in the concluding portion of the specification. A more complete understanding of the present disclosure, however, may best be obtained by referring to the detailed description and claims when considered in connection with the drawing figures, wherein like numerals denote like elements.

FIG. 1 illustrates a cross-sectional view of an exemplary gas turbine engine, in accordance with various embodiments;

3

FIG. 2 illustrates a schematic cross-section of a portion of a high pressure turbine section of the gas turbine engine of FIG. 1, in accordance with various embodiments;

FIG. 3A illustrates a radially inward looking perspective view of a vane, in accordance with various embodiments;

FIG. 3B illustrates an air inlet for an internal cavity vane, in accordance with various embodiments; and

FIG. 3C illustrates a cross-sectional view of a vane taken along the line 3C-3C in FIG. 3A, in accordance with various embodiments.

### DETAILED DESCRIPTION

The detailed description of various embodiments herein makes reference to the accompanying drawings, which show various embodiments by way of illustration. While these various embodiments are described in sufficient detail to enable those skilled in the art to practice the disclosure, it should be understood that other embodiments may be realized and that logical aerodynamic, thermodynamic, and mechanical changes may be made without departing from the spirit and scope of the disclosure. Thus, the detailed description herein is presented for purposes of illustration only and not of limitation. For example, the steps recited in any of the method or process descriptions may be executed in any order and are not necessarily limited to the order presented. Furthermore, any reference to singular includes plural embodiments, and any reference to more than one component or step may include a singular embodiment or step. Also, any reference to attached, fixed, connected, or the like may include permanent, removable, temporary, partial, full, and/or any other possible attachment option. Additionally, any reference to without contact (or similar phrases) may also include reduced contact or minimal contact.

Cross hatching lines may be used throughout the figures to denote different parts but not necessarily to denote the same or different materials. Throughout the present disclosure, like reference numbers denote like elements. Accordingly, elements with like element numbering may be shown in the figures, but may not necessarily be repeated herein for the sake of clarity.

As used herein, “aft” refers to the direction associated with the tail (e.g., the back end) of an aircraft, or generally, to the direction of exhaust of the gas turbine engine. As used herein, “forward” refers to the direction associated with the nose (e.g., the front end) of an aircraft, or generally, to the direction of flight or motion. As used herein, “proximate” refers to a direction inwards, or generally, towards the reference component.

A first component that is “radially outward” of a second component means that the first component is positioned at a greater distance away from the engine central longitudinal axis than the second component. A first component that is “radially inward” of a second component means that the first component is positioned closer to the engine central longitudinal axis than the second component. In the case of components that rotate circumferentially about the engine central longitudinal axis, a first component that is radially inward of a second component rotates through a circumferentially shorter path than the second component. The terminology “radially outward” and “radially inward” may also be used relative to references other than the engine central longitudinal axis.

In various embodiments and with reference to FIG. 1, a gas turbine engine 20 is provided. Gas turbine engine 20 may be a two-spool turbofan that generally incorporates a fan section 22, a compressor section 24, a combustor section

4

26, and a turbine section 28. Alternative engines may include, for example, an augmentor section among other systems or features. In operation, fan section 22 can drive fluid (e.g., air) along a bypass flow-path B while compressor section 24 can drive air along a core flow-path C for compression and communication into combustor section 26 then expansion through turbine section 28. Although depicted as a turbofan gas turbine engine 20 herein, 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 including multi-spool architectures, as well as industrial gas turbines.

Gas turbine engine 20 may generally comprise a low speed spool 30 and a high speed spool 32 mounted for rotation about an engine central longitudinal axis A-A' relative to an engine static structure 36 via several bearing systems 38, 38-1, and 38-2. Engine central longitudinal axis A-A' is oriented in the z direction on the provided x-y-z axes. It should be understood that various bearing systems 38 at various locations may alternatively or additionally be provided, including for example, bearing system 38, bearing system 38-1, and bearing system 38-2.

Low speed spool 30 may generally comprise an inner shaft 40 that interconnects a fan 42, a low pressure compressor 44, and a low pressure turbine 46. High speed spool 32 may comprise an outer shaft 50 that interconnects a high pressure compressor 52 and high pressure turbine 54. A combustor 56 may be located between high pressure compressor 52 and high pressure turbine 54. In various embodiments, engine static structure 36 may include a mid-turbine frame 57. The mid-turbine frame 57, if included, may be located generally between high pressure turbine 54 and low pressure turbine 46. Mid-turbine frame 57 may support one or more bearing systems 38 in turbine section 28. Inner shaft 40 and outer shaft 50 may be concentric and rotate via bearing systems 38 about the engine central longitudinal axis A-A', which is collinear with their longitudinal axes. As used herein, a “high pressure” compressor or turbine experiences a higher pressure than a corresponding “low pressure” compressor or turbine.

The core airflow C may be compressed by low pressure compressor 44 and high pressure compressor 52, mixed and burned with fuel in combustor 56, then expanded through the high pressure turbine 54 and low pressure turbine 46. Turbines 46, 54 rotationally drive the respective low speed spool 30 and high speed spool 32 in response to the expansion.

Low pressure compressor 44, high pressure compressor 52, low pressure turbine 46, and high pressure turbine 54 may comprise one or more stages or sets of rotating blades and one or more stages or sets of stationary (i.e., non-rotating) vanes axially interspersed with the rotating blade stages.

FIG. 2 shows a portion of high pressure turbine 54, in accordance with various embodiments. High pressure turbine 54 may include a first rotating member or blade 100, a non-rotating member or vane 102, and a second rotating member or blade 104. Blades 100 and 104 may each be configured to rotate about engine central longitudinal axis A-A', in response to receiving a flow of fluid (e.g., air) from combustor section 26 (FIG. 1). Power from the flow may be converted to mechanical power, or torque, by blades 100 and 104. Blades 100 and 104 may be disposed radially inward of annular blade outer air seals (BOAS) 114.

Vane 102 may be coupled to an engine casing structure 136 or other support structure of high pressure turbine 54. Engine casing structure 136 may form a portion of engine



5

static structure **36** (FIG. 1). Vane **102** may help direct the flow of fluid between blade **100** and blade **104**. Vane **102** may comprise a static structure that does not rotate relative to engine central longitudinal axis A-A'. Although the present disclosure is directed the geometry for a cooling inlet for a vane in high pressure turbine **54**, one skilled in the art will realize that the cooling inlet geometry disclosed herein may be equally applicable to vanes in low pressure turbine **46**, high pressure compressor **52**, low pressure compressor **44**, and/or other vanes of gas turbine engine **20** (FIG. 1).

Engine casing structure **136** may include case hooks **126**. BOAS **114** may be coupled to engine casing structure **136** by BOAS hooks **127** engaging case hooks **126**. Vane **102** may be coupled to engine casing structure **136** by forward vane hooks **124** and aft vane hooks **128** engaging case hooks **126**.

Vane **102** includes an airfoil **160** that extends between a vane inner platform **116** and a vane outer platform **118**. Hot combustion gas from combustor section **26** (FIG. 1) may flow between vane inner platform **116** and vane outer platform **118**. Vane **102** may be a stationary vane or a variable vane and could be cantilevered. Airfoil **160** comprises a leading edge **106** and a trailing edge **108**. Airfoil **160** further comprises a generally concave pressure side and a generally convex suction side extending between leading edge **106** and trailing edge **108**.

Cooling fluid **142**, such as bleed air from bypass flow-path B, may be introduced to vane **102** through a turbine cooling air (TCA) pipe **120** at a radially outer diameter of vane **102**. TCA pipe **120** may provide cooling fluid **142** to vane outer platform **118** and airfoil **160**. In various embodiments, the cooling fluid **142** from TCA pipe **120** may mix with cooling fluid from an upstream source, for example, with fluid flowing aft across BOAS **114** (e.g., between BOAS **114** and engine casing structure **136**).

With reference to FIG. 3A, a radially inward looking view of vane **102** is illustrated, in accordance with various embodiments. With combined reference to FIG. 2 and FIG. 3A, vane outer platform **118** comprises a radially outward facing surface **140** and a radially inward facing surface **144**. Airfoil **160** extends radially from radially inward facing surface **144** of vane outer platform **118**. Vane **102** may further comprise an inlet **150** configured to provide cooling fluid **142** to airfoil **160**.

FIG. 3B illustrates an inlet **150**, in accordance with various embodiments. With combined reference to FIGS. 2 and 3B, inlet **150** may be in fluid communication with an internal cavity **146** of airfoil **160**. Cooling fluid **142** may flow into internal cavity **146** of airfoil **160** via inlet **150**. For example, cooling fluid **142** from flow from TCA pipe **120**, along surface **140** of vane outer platform **118**, through inlet **150**, and into internal cavity **146**.

FIG. 3C illustrates a cross-section view of vane **102** taken on the line 3C-3C in FIG. 3A. With combined reference to FIGS. 3B and 3C, inlet **150** may be defined, at least partially, by an internal pressure side surface **152** of airfoil **160**. Internal pressure side surface **152** is oriented away from (i.e., opposite) an external pressure side surface **172** of airfoil **160**. Internal pressure side surface **152** may be oriented toward an internal suction side surface **155** of airfoil **160**. Internal suction side surface is oriented away from (i.e., opposite) an external suction side surface **173** of airfoil **160**. Internal suction side surface **155** may also define a portion of inlet **150**. Internal pressure side surface **152** may extend to surface **140** of vane outer platform **118**. In various embodiments, internal pressure side surface **152** may extend to a ramp **154** formed over surface **140** of vane outer platform **118**. In this regard, a portion of internal pressure

6

side surface **152** may be raised radially with respect to surface **140** of vane outer platform **118**. Ramp **154** may comprise a sloped surface extending from surface **140** of vane outer platform **118** to inlet **150** (e.g., to internal pressure side surface **152**). The slope of ramp **154** may allow the cooling fluid **142** traveling along surface **140** to travel (i.e., flow) smoothly into inlet **150**. Ramp **154** may be located proximate a pressure side of inlet **150**. The pressure side of inlet **150** corresponds to the portion of the inlet (e.g., portion **161** of internal pressure side surface **152**) located proximate the pressure side of airfoil **160**.

A portion **161** of internal pressure side surface **152** proximate vane outer platform **118** may be curved. Stated differently, the portion **161** of internal pressure side surface **152** defining inlet **150** may be curved. For example, portion **161** of internal pressure side surface **152** may comprise a convex curve. In this regard, portion **161** (i.e., the convex curve) may extend between a generally axially oriented portion of internal pressure side surface **152**, located proximate surface **140** and/or ramp **154**, and a generally radially oriented portion of internal pressure side surface **152**, located proximate internal cavity **146**. The convex curve of internal pressure side surface **152** may give inlet **150** a bell-mouth shape proximate the pressure side of airfoil **160**. Stated differently, a fillet may be formed by internal pressure side surface **152** at a transition from the generally axial plane of vane outer platform **118** to the generally radial plane of airfoil **160**.

The fillet (i.e., curve) formed by internal pressure side surface **152** may provide a smooth flowpath between vane outer platform **118** and airfoil **160** such that cooling fluid **142** flowing along surface **140** may flow more easily into inlet **150** and internal cavity **146**. The curve of internal pressure side surface **152** may allow cooling fluid **142** to cover (e.g., form a film or blanket over) internal pressure side surface **152** more completely. Stated differently, the curve of internal pressure side surface **152** may tend to reduce occurrences of cooling gaps (i.e., areas not contacted by cooling fluid **142**) along internal pressure side surface **152**, particularly, proximate to vane outer platform **118**. In this regard, the curve of internal pressure side surface **152** may reduce stress along inlet **150**, and, in particular, along the portion of inlet **150** proximate the pressure side of airfoil **160**. The geometry of inlet **150** may also serve to reduce pressure loss for the internal fluid circuit (e.g., internal cavity **146**) and to maintain attachment (i.e., contact) of cooling fluid **142** along the internal walls of airfoil **160**, particularly, along the portions of the internal walls where cooling flow **142** transitions from a generally axially oriented flow direction across the vane platform to a generally radially oriented flow direction into inlet **150** and internal cavity **146**. Cooling flow **142** maintaining contact with the internal walls of airfoil **160** tends to create a more uniform temperature and heat transfer and/or cooling along airfoil **160**. Stated differently, cooling flow **142** maintaining contact with the internal walls of airfoil **160** tends to avoid hot zones (i.e., areas not contacted cooling flow **142**), which can increase thermal stresses experienced by vane **102**.

A transition **170** between external pressure side surface **172** of airfoil **160** and radially inward facing surface **144** of vane outer platform **118** may be generally curved. For example, transition **170** may comprise a concave curve. In various embodiments, a radius of curvature of the convex curve formed by portion **161** of internal pressure side surface **152** may be concentric to a radius of curvature of the concave curve formed by transition **170**. Stated differently,

a geometry of the convex curve may complement the geometry of the concave curve.

Inlet **150** may be further defined by a portion of an internal trailing edge surface **156** of airfoil **160** proximate to vane outer platform **118**. Inlet **150** also may be defined by a portion of an internal leading edge surface **158** of airfoil **160** proximate to vane outer platform **118**. Internal trailing edge surface **156** may be located proximate trailing edge **108** of airfoil **160** as compared to internal leading edge surface **158**. Internal leading edge surface **158** may be oriented generally toward internal trailing edge surface **156**. In various embodiments, internal trailing edge surface **156** and internal leading edge surface **158** may extend beyond surface **140** in a radial direction. For example, in various embodiments, vane outer platform **118** may comprise a raised surface **190**. Raised surface **190** may be a greater radial distance from engine central longitudinal axis A-A' as compared to surface **140** of vane outer platform **118**. In various embodiments, the location of raised surface **190** may correspond a location of airfoil **160**, and internal trailing edge surface **156** and/or internal leading edge surface **158** may extend to raised surface **190**.

A transition **180** between internal trailing edge surface **156** and internal pressure side surface **152** and proximate vane outer platform **118** (e.g., along portion **161** of internal pressure side surface **152**) may be curved. For example, transition **180** may comprise a concave curve. Stated differently, transition **180** may form a fillet between internal trailing edge surface **156** and internal pressure side surface **152**. A transition **182** between internal leading edge surface **158** and internal pressure side surface **152** and proximate vane outer platform **118** (e.g., along portion **161** of internal pressure side surface **152**) may be curved. For example, transition **182** may comprise a concave curve. Stated differently, transition **182** may form fillet between internal leading edge surface **158** and internal pressure side surface **152**. In various embodiments, the fillets formed by transitions **180** and **182** may be formed along portion **161** of internal pressure side surface **152**. Transitions **180** and **182** may be configured such that internal trailing edge surface **156**, internal pressure side surface **152**, and internal leading edge surface **158** to form a generally U (or "half pipe") shaped surface at inlet **150**. In various embodiments, ramp **154** may be configured to surround the portion of inlet **150** proximate the pressure side of airfoil **160**. For example, ramp **154** may extend to the radially raised portion of internal pressure side surface **152** and to the radially raised portions of internal trailing edge surface **156** and internal leading edge surface **158** that are proximate internal pressure side surface **152**. Ramp **154** may allow the cooling fluid **142** traveling along surface **140** to travel (i.e., flow) smoothly into inlet **150**.

In various embodiments, the suction side of inlet **150** (i.e., the portion of inlet **150** defined by internal suction side surface **155** and the portions of internal trailing edge surface **156** and internal leading edge surface **158** that are proximate internal suction side surface **155**) may comprise a geometry similar to the pressure side of inlet **150**. For example, with combined reference to FIGS. 3A and 3C, internal suction side surface **155** may extend radially beyond surface **140** and form a convex curve (i.e., fillet) **163** having a radius of curvature that is concentric to the radius of curvature of the transition between radially inward facing surface **144** and external suction side surface **173**. In various embodiments, internal suction side surface **155** may extend to a ramp **165**, similar to ramp **154**, surrounding the portion of inlet **150** proximate the suction side of airfoil **160**. In various embodi-

ments, internal trailing edge surface **156**, internal suction side surface **155**, and internal leading edge surface **158** may form a generally U (or "half pipe") shaped surface at inlet **150**. In various embodiments, cooling fluid may be supplied to vane **102** at vane inner platform **116**, and inlet **150** may be located through vane inner platform **116**.

Benefits, other advantages, and solutions to problems have been described herein with regard to specific embodiments. Furthermore, the connecting lines shown in the various figures contained herein are intended to represent exemplary functional relationships and/or physical couplings between the various elements. It should be noted that many alternative or additional functional relationships or physical connections may be present in a practical system. However, the benefits, advantages, solutions to problems, and any elements that may cause any benefit, advantage, or solution to occur or become more pronounced are not to be construed as critical, required, or essential features or elements of the inventions. The scope of the inventions is accordingly to be limited by nothing other than the appended claims, in which reference to an element in the singular is not intended to mean "one and only one" unless explicitly so stated, but rather "one or more." Moreover, where a phrase similar to "at least one of A, B, or C" is used in the claims, it is intended that the phrase be interpreted to mean that A alone may be present in an embodiment, B alone may be present in an embodiment, C alone may be present in an embodiment, or that any combination of the elements A, B and C may be present in a single embodiment; for example, A and B, A and C, B and C, or A and B and C. Different cross-hatching is used throughout the figures to denote different parts but not necessarily to denote the same or different materials.

Systems, methods and apparatus are provided herein. In the detailed description herein, references to "one embodiment", "an embodiment", "various embodiments", etc., indicate that the embodiment described may include a particular feature, structure, or characteristic, but every embodiment may not necessarily include the particular feature, structure, or characteristic. Moreover, such phrases are not necessarily referring to the same embodiment. Further, when a particular feature, structure, or characteristic is described in connection with an embodiment, it is submitted that it is within the knowledge of one skilled in the art to affect such feature, structure, or characteristic in connection with other embodiments whether or not explicitly described. After reading the description, it will be apparent to one skilled in the relevant art(s) how to implement the disclosure in alternative embodiments.

Furthermore, no element, component, or method step in the present disclosure is intended to be dedicated to the public regardless of whether the element, component, or method step is explicitly recited in the claims. No claim element is intended to invoke 35 U.S.C. 112(t) unless the element is expressly recited using the phrase "means for." As used herein, the terms "comprises," "comprising," or any other variation thereof, are intended to cover a non-exclusive inclusion, such that a process, method, article, or apparatus that comprises a list of elements does not include only those elements but may include other elements not expressly listed or inherent to such process, method, article, or apparatus.

The invention claimed is:

1. A vane for gas turbine engine, comprising:  
a vane platform;

an airfoil extending radially from the vane platform, the airfoil comprising an inlet defined, at least partially, by an internal pressure side surface of the airfoil, wherein

9

the internal pressure side surface comprises a convex curve proximate the inlet, wherein a first transition between the internal pressure side surface of the airfoil and an internal leading edge surface of the airfoil comprises a first concave curve and a second transition between the internal pressure side surface of the airfoil and an internal trailing edge surface of the airfoil comprises a second concave curve, and wherein the first transition and the second transition are configured such that the internal trailing edge surface, the internal pressure side surface, and the internal leading edge surface to form a U shaped surface at the inlet; and a ramp formed over a first surface of the vane platform.

2. The vane of claim 1, wherein a third transition between an external surface of the airfoil opposite the internal pressure side surface of the airfoil and a second surface of the vane platform opposite the first surface of the vane platform comprises a concave curve.

3. The vane of claim 2, wherein a radius of curvature of the convex curve of the internal pressure side surface is concentric to a radius of curvature of the concave curve of the third transition.

4. The vane of claim 1, wherein the ramp is located proximate a pressure side of the inlet.

5. The vane of claim 1, wherein the at least one of the internal leading edge surface of the airfoil or the internal trailing edge surface of the airfoil extends to a radially raised surface of the vane platform.

6. The vane of claim 1, wherein the ramp is located proximate a suction side of the inlet.

7. The vane of claim 1, wherein the inlet is in fluid communication with an internal cavity of the airfoil, and wherein the convex curve of the internal pressure side surface and the ramp provide a smooth flowpath from a generally axial plane along the first surface of the vane platform to a generally radial plane of the internal cavity.

8. A gas turbine engine, comprising:  
 a combustor; and  
 a turbine aft of the combustor and including a vane, the vane comprising:  
 a vane platform,  
 an airfoil extending radially from the vane platform, the airfoil comprising an inlet defined, at least partially, by an internal surface of the airfoil, wherein the internal surface comprises a convex curve proximate the vane platform, wherein a first transition between the internal surface of the airfoil and an internal leading edge surface of the airfoil comprises a first concave curve and a second transition between the internal surface of the airfoil and an internal trailing edge surface of the airfoil comprises a second concave curve, and wherein the first transition and the second transition are configured such that the internal trailing edge surface, the internal surface, and the internal leading edge surface to form a U shaped surface at the inlet, and  
 a ramp formed over a first surface of the vane platform.

10

9. The gas turbine engine of claim 8, wherein a third transition between an external surface of the airfoil opposite the internal surface of the airfoil and a second surface of the vane platform opposite the first surface of the vane platform comprises a concave curve.

10. The gas turbine engine of claim 9, wherein a radius of curvature of the convex curve of the internal surface is concentric to a radius of curvature of the concave curve of the third transition.

11. The gas turbine engine of claim 8, wherein the internal surface comprises an internal pressure side surface of the airfoil.

12. The gas turbine engine of claim 8, wherein the inlet is in fluid communication with an internal cavity of the airfoil.

13. The gas turbine engine of claim 12, wherein the convex curve of the internal surface reduces stress at a pressure side of the inlet.

14. A turbine for a gas turbine engine, comprising:

an vane outer platform;

a vane inner platform; and

an airfoil extending between the vane outer platform and the vane inner platform, the airfoil comprising an inlet defined, at least partially, by an internal pressure side surface of the airfoil, wherein the internal pressure side surface comprises a convex curve proximate the inlet, wherein a first transition between the internal pressure side surface of the airfoil and an internal leading edge surface of the airfoil comprises a first concave curve and a second transition between the internal pressure side surface of the airfoil and an internal trailing edge surface of the airfoil comprises a second concave curve, and wherein the first transition and the second transition are configured such that the internal trailing edge surface, the internal pressure side surface, and the internal leading edge surface to form a U shaped surface at the inlet.

15. The turbine of claim 14, wherein a third transition between an external pressure side surface of the airfoil and a first surface of the vane outer platform comprises a concave curve.

16. The turbine of claim 15, wherein a radius of curvature of the convex curve of the internal pressure side surface is concentric to a radius of curvature of the concave curve of the third transition.

17. The turbine of claim 16, further comprising a ramp extending between the internal pressure side surface of the airfoil and a second surface of the vane outer platform opposite the first surface of the vane outer platform.

18. The turbine of claim 14, wherein the convex curve of the internal pressure side surface reduces stress along a pressure side of the inlet.

\* \* \* \* \*