



- (51) **International Patent Classification:**
F01D 5/18 (2006.01)
- (21) **International Application Number:**
PCT/US2014/042615
- (22) **International Filing Date:**
17 June 2014 (17.06.2014)
- (25) **Filing Language:** English
- (26) **Publication Language:** English
- (71) **Applicant:** SIEMENS ENERGY, INC. [US/US]; 4400 Alafaya Trail, Orlando, Florida 32826-2399 (US).
- (72) **Inventors:** MARSH, Jan H.; 821 Bridgeway Boulevard, Orlando, Florida 32828 (US). MATTHEWS, Ralph W.; 1223 Twin Rivers Boulevard, Oviedo, Florida 32766 (US).
- (74) **Agent:** SWANSON, Erik C.; Siemens Corporation- Intellectual Property Dept., 170 Wood Avenue South, Iselin, New Jersey 08830 (US).
- (81) **Designated States** (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY,

BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

- (84) **Designated States** (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— with international search report (Art. 21(3))

- (54) **Title:** TURBINE AIRFOIL COOLING SYSTEM WITH LEADING EDGE IMPINGEMENT COOLING SYSTEM

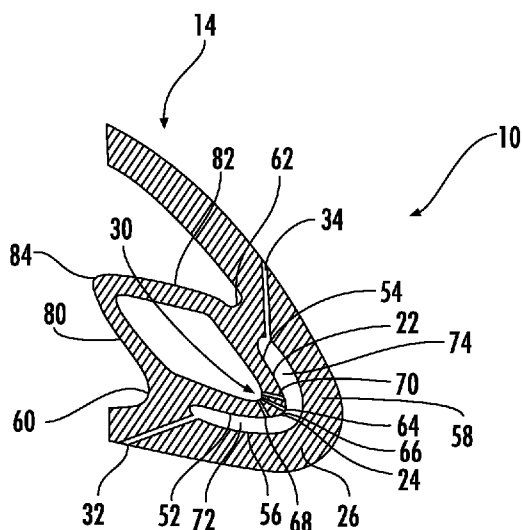


FIG. 4

(57) **Abstract:** A turbine airfoil (10) usable in a turbine engine and having an internal cooling system (14) with a leading edge impingement channel (16) for enhanced cooling of the leading edge (18) of the turbine airfoil (10) without a leading edge film cooling showerhead is disclosed. The internal cooling system (14) may include an leading edge cooling supply channel (20) formed from a leading edge wall (22) having a leading edge tip (24) that is advanced closer to an inner surface (26) of the leading edge (18) of the generally elongated, hollow airfoil (28) than other aspects of the leading edge cooling supply channel (20). The leading edge cooling supply channel (20) may include one or more leading edge impingement orifices (30) for directing cooling fluids to impinge on the inner surface (26) of the leading edge (18) of the airfoil (28). The impingement cooling fluid may be exhausted through one or more pressure side and suction side film cooling gill holes (32, 34) in the leading edge impingement channel (16).

TURBINE AIRFOIL COOLING SYSTEM WITH LEADING EDGE IMPINGEMENT COOLING SYSTEM

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

Development of this invention was supported in part by the United States Department of Energy, Advanced Turbine Development Program, Contract No. DE-FC26-05NT42644. Accordingly, the United States Government may have certain rights in this invention.

FIELD OF THE INVENTION

This invention is directed generally to turbine airfoils, and more particularly to leading edge cooling systems in hollow turbine airfoils of gas turbine engines.

BACKGROUND

Typically, gas turbine engines include a compressor for compressing air, a combustor for mixing the compressed air with fuel and igniting the mixture, and a turbine blade assembly for producing power. Combustors often operate at high temperatures that may exceed 2,500 degrees Fahrenheit. Typical turbine combustor configurations expose turbine blade assemblies to these high temperatures. As a result, turbine blades must be made of materials capable of withstanding such high temperatures. In addition, turbine blades often contain cooling systems for prolonging the life of the blades and reducing the likelihood of failure as a result of excessive temperatures.

Typically, turbine blades are formed from a root portion having a platform at one end and an elongated portion forming a blade that extends outwardly from the platform coupled to the root portion. The blade is ordinarily composed of a tip opposite the root section, a leading edge, and a trailing edge. The inner aspects of most turbine blades typically contain an intricate maze of cooling channels forming a cooling system. The cooling channels in a blade receive air from the compressor of the turbine engine and pass the air through the blade. The cooling channels often include multiple flow paths that are designed to maintain all aspects of the turbine

blade at a relatively uniform temperature. However, centrifugal forces and air flow at boundary layers often prevent some areas of the turbine blade from being adequately cooled, which results in the formation of localized hot spots. Localized hot spots, depending on their location, can reduce the useful life of a turbine blade and can damage a turbine blade to an extent necessitating replacement of the blade. Vanes likewise develop localized hot spots that can reduce the useful life of a turbine vane. Typically, the leading edge of turbine airfoils includes a plurality of film cooling holes forming a showerhead. While the showerhead of film cooling holes cools the leading edge, conventional showerhead configurations are often inefficient.

SUMMARY OF THE INVENTION

A turbine airfoil usable in a turbine engine and having an internal cooling system with a leading edge impingement channel for enhanced cooling of the leading edge of the turbine airfoil without a leading edge film cooling showerhead is disclosed. The internal cooling system may include an leading edge cooling supply channel formed from a leading edge wall having a leading edge tip that is advanced closer to an inner surface of the leading edge of the generally elongated, hollow airfoil than other aspects of the leading edge cooling supply channel. The leading edge cooling supply channel may include one or more leading edge impingement orifices for directing cooling fluids to impinge on the inner surface of the leading edge of the airfoil in the leading edge impingement channel. The impingement cooling fluid may be exhausted through one or more pressure side and suction side film cooling gill holes in the leading edge impingement channel that are aft of the leading edge of the airfoil.

In at least one embodiment, the turbine airfoil may be a turbine blade or vane. The turbine airfoil may be formed from a generally elongated, hollow airfoil having a leading edge, a trailing edge, a pressure side, a suction side, a tip at a first end, a root coupled to the airfoil at a second end generally opposite to the first end for supporting the airfoil and for coupling the airfoil to a disc, and an internal cooling system formed from at least one cavity in the elongated, hollow airfoil. The internal cooling system may include a leading edge cooling supply channel and a leading edge impingement channel positioned within the generally elongated, hollow airfoil

along the leading edge of the generally elongated, hollow airfoil. The leading edge cooling supply channel may be formed from a leading edge wall having a leading edge tip that is advanced closer to an inner surface of the leading edge of the generally elongated, hollow airfoil than other aspects of the leading edge cooling supply channel. In such a position, the leading edge cooling supply channel may send impingement fluids against the inner surface of the leading edge to cool the leading edge. The internal cooling system may also include one or more leading edge impingement orifices in the leading edge tip of the leading edge cooling supply channel for exhausting cooling fluids to impinge on the inner surface of the leading edge of the generally elongated, hollow airfoil in a leading edge impingement channel. The leading edge impingement orifice in the leading edge tip of the leading edge cooling supply channel may be formed from a plurality of leading edge impingement orifices aligned into one or more spanwise extending rows of leading edge impingement orifices.

The leading edge cooling supply channel may be formed from a first leading edge wall that extends spanwise and a second leading edge wall that extends spanwise and is coupled to the first leading edge wall forming the leading edge tip, whereby the first leading edge wall is nonorthogonal to the second leading edge wall. The first and second leading edge walls of the leading edge cooling supply channel may define a portion of the leading edge impingement channel formed from a pressure side section and a suction side section that is nonorthogonal to the pressure side section. In at least one embodiment, the pressure side section and the suction side section of the leading edge impingement channel may form a c-shaped cross-sectional leading edge impingement channel. The first leading edge wall may also be aligned with an outer wall forming the pressure side of the generally elongated hollow airfoil, and the second leading edge wall may be aligned with an outer wall forming the suction side of the generally elongated hollow airfoil. The leading edge cooling supply channel may be formed from a first aft edge wall that extends spanwise and a second aft edge wall that extends spanwise and is coupled to the first aft edge wall forming an aft edge tip, wherein the first aft edge wall is nonorthogonal to the second aft edge wall.

The internal cooling system may include one or more pressure side film cooling gill holes extending from the pressure side section through an outer wall forming the pressure side of the generally elongated hollow airfoil. In at least one embodiment, the pressure side film cooling gill hole extending from the pressure side section through the outer wall forming the pressure side of the generally elongated hollow airfoil may be formed from a plurality of pressure side film cooling gill holes forming a spanwise extending linear row of pressure side film cooling gill holes. The internal cooling system may also include one or more suction side film cooling gill holes extending from the suction side section through an outer wall forming the suction side of the generally elongated hollow airfoil. In at least one embodiment, the suction side film cooling gill hole extending from the suction side section through the outer wall forming the suction side of the generally elongated hollow airfoil may be formed from a plurality of suction side film cooling gill holes forming a spanwise extending linear row of suction side film cooling gill holes.

The leading edge cooling supply channel may be offset from an outer wall forming the pressure side and an outer wall forming the suction side of the generally elongated hollow airfoil. In particular, the leading edge cooling supply channel may be supported by a pressure side rib extending between the outer wall forming the pressure side of the generally elongated hollow airfoil and the first leading edge wall of the leading edge cooling supply channel and may be supported by a suction side rib extending between the outer wall forming the suction side of the generally elongated hollow airfoil and the second leading edge wall of the leading edge cooling supply channel.

An advantage of the leading edge cooling supply channel with leading edge impingement orifices provides enhanced near wall impingement with higher heat transfer augmentation without film cooling at the leading edge of the airfoil, unlike most conventional systems.

Another advantage of the leading edge cooling supply channel is that the leading edge cooling supply channel provides an intermediate channel to feed near wall impingement at the leading edge.

Yet another advantage of the leading edge cooling supply channel is that the pressure side and suction side film cooling gill holes eject post impingement air away from the leading edge.

5 Another advantage of the leading edge cooling supply channel is that the ability to reduce the distance between the leading edge cooling supply channel and the leading edge is that there is more flexibility in designing interior aspects of the airfoil, such as enabling ribs to be widened within the airfoil and for internal passages to be added.

10 Still another advantage of the internal cooling system is that a better cooling distribution may be achieved through the combination of impingement array and film cooling gill holes that pull flow towards the edges of the impingement passage along the outer wall.

Another advantage of the internal cooling system is that the internal cooling system experiences higher back side convective cooling.

15 Yet another advantage of the internal cooling system is that there is no need, or a reduced need, for film cooling and thus, all showerhead holes have been removed leaving only film cooling gill holes.

20 Another advantage of the internal cooling system is that the turbine airfoil has increased resistance to thermal barrier coating spallation because of the lack of leading edge showerhead.

Still another advantage of the internal cooling system is that internal cooling system experiences increased component cooling efficiency.

25 Another advantage of the internal cooling system is that the internal cooling system experiences a reduction in cooling fluid flow due to less film cooling requirements as well as improved back side cooling due to better distribution and higher magnitude of cold side heat transfer coefficients.

These and other embodiments are described in more detail below.

BRIEF DESCRIPTION OF THE DRAWINGS

30 The accompanying drawings, which are incorporated in and form a part of the specification, illustrate embodiments of the presently disclosed invention and, together with the description, disclose the principles of the invention.

Figure 1 is a perspective view of a turbine airfoil having features according to the invention.

Figure 2 is a cross-sectional view of the turbine airfoil shown in Figure 1 taken along section line 2-2 in Figure 1.

5 Figure 3 is a schematic diagram of the internal cooling system within the turbine airfoil of Figure 2.

Figure 4 is a detail view of the leading edge impingement channel and the leading edge cooling supply channel shown at detail line 4-4 in Figure 2.

10 **DETAILED DESCRIPTION OF THE INVENTION**

As shown in Figures 1-4, a turbine airfoil 10 usable in a turbine engine and having an internal cooling system 14 with a leading edge impingement channel 16 for enhanced cooling of the leading edge 18 of the turbine airfoil 10 without a leading edge film cooling showerhead is disclosed. The internal cooling system 14 may
15 include an leading edge cooling supply channel 20 formed from a leading edge wall 22 having a leading edge tip 24 that is advanced closer to an inner surface 26 of the leading edge 18 of the generally elongated, hollow airfoil 28 than other aspects of the leading edge cooling supply channel 20. The leading edge cooling supply channel 20 may include one or more leading edge impingement orifices 30 for
20 directing cooling fluids to impinge on the inner surface 26 of the leading edge 18 of the airfoil 28 in the leading edge impingement channel 20. The impingement cooling fluid may be exhausted through one or more pressure side and suction side film cooling gill holes 32, 34 in the leading edge impingement channel 20 that are aft of the leading edge 18 of the airfoil 10.

25 In at least one embodiment, as shown in Figure 1, the turbine airfoil 10 may be a turbine blade or vane. The turbine airfoil 10 may be formed from a generally elongated, hollow airfoil 28 having a leading edge 18, a trailing edge 36, a pressure side 48, a suction side 50, a tip 38 at a first end 40, a root 42 coupled to the airfoil 10 at a second end 44 generally opposite to the first end 40 for supporting the airfoil 10
30 and for coupling the airfoil 10 to a disc, and a cooling system 14 formed from at least one cavity 46 in the elongated, hollow airfoil 28. The internal cooling system 14 may include a leading edge cooling supply channel 20 and a leading edge impingement

channel 16 positioned within the generally elongated, hollow airfoil 28 along the leading edge 18 of the generally elongated, hollow airfoil 28, as shown in Figures 2-4. The leading edge cooling supply channel 20 may be formed from a leading edge wall 22 having a leading edge tip 24 that is advanced closer to the inner surface 26 of the leading edge 18 of the generally elongated, hollow airfoil 28 than other aspects of the leading edge cooling supply channel 20.

The leading edge cooling supply channel 20 may be formed from a first leading edge wall 52 that extends spanwise and a second leading edge wall 54 that extends spanwise and is coupled to the first leading edge wall 52 forming the leading edge tip 24. The first leading edge wall 52 may be nonorthogonal to the second leading edge wall 54. In at least one embodiment, as shown in Figures 2 and 4, the first leading edge wall 52 may be aligned with an outer wall 56 forming the pressure side 48 of the generally elongated hollow airfoil 28. The second leading edge wall 54 may be aligned with an outer wall 58 forming the suction side 50 of the generally elongated hollow airfoil 28. The leading edge cooling supply channel 20 may be offset from the outer wall 56 forming the pressure side 48 and the outer wall 58 forming the suction side 50 of the generally elongated hollow airfoil 28. The leading edge cooling supply channel 20 may be supported by a pressure side rib 60 extending between the outer wall 56 forming the pressure side 48 of the generally elongated hollow airfoil 28 and the first leading edge wall 52 of the leading edge cooling supply channel 20. The leading edge cooling supply channel 20 may also be supported by a suction side rib 62 extending between the outer wall 58 forming the suction side 50 of the generally elongated hollow airfoil 28 and the second leading edge wall 54 of the leading edge cooling supply channel 20. The leading edge cooling supply channel 20 may also be formed from a first aft edge wall 80 that extends spanwise and a second aft edge wall 82 that extends spanwise and is coupled to the first aft edge wall 80 forming an aft edge tip 84. The first aft edge wall 80 may be nonorthogonal to the second aft edge wall 82.

The internal cooling system 14 may include one or more leading edge impingement orifices 30 in the leading edge tip 24 of the leading edge cooling supply channel 20 for exhausting cooling fluids to impinge on the inner surface 26 of the leading edge 18 of the generally elongated, hollow airfoil 28 in a leading edge

impingement channel 16. In at least one embodiment, the internal cooling system 14 may include a plurality of leading edge impingement orifices 30 aligned into a spanwise extending row of leading edge impingement orifices 30. In at least one embodiment, there may be multiple spanwise extending rows of leading edge
5 impingement orifices 30, such as, but not limited to, a first spanwise extending row 64 at a stagnation line 66, a second spanwise extending row 68 on the pressure side 48 of the stagnation line 66 and a third spanwise extending row 70 on the suction side 50 of the stagnation line 66. The leading edge impingement orifices 30 may have any appropriate sized opening and cross-sectional area and shape.

10 The first and second leading edge walls 52, 54 of the leading edge cooling supply channel 20 may define a portion of the leading edge impingement channel 16 formed from a pressure side section 72 and a suction side section 74 that is nonorthogonal to the pressure side section 72. The pressure side section 72 and the suction side section 74 of the leading edge impingement channel 16 may form a c-
15 shaped cross-sectional leading edge impingement channel 16. The internal cooling system 14 may also include one or more pressure side film cooling gill holes 32 extending from the pressure side section 72 through the outer wall 56 forming the pressure side 48 of the generally elongated hollow airfoil 28. In at least one embodiment, the internal cooling system 14 may also include a plurality of pressure
20 side film cooling gill holes 32 forming a spanwise extending linear row of pressure side film cooling gill holes 32. The internal cooling system 14 may also include one or more suction side film cooling gill holes 34 extending from the suction side section 74 through the outer wall 58 forming the suction side 50 of the generally elongated hollow airfoil 28. In at least one embodiment, the internal cooling system 14 may
25 also include a plurality of suction side film cooling gill holes 34 forming a spanwise extending linear row of suction side film cooling gill holes 34. The inlets of the pressure and suction side film cooling gill holes 32, 34 may be aft of the leading edge tip 24 of the leading edge cooling supply channel 20.

30 In another embodiment, the internal cooling system 14 may include the leading edge impingement orifices 30 but may not exhaust cooling fluids through the leading edge 18 of the airfoil 10. Rather, the cooling fluids may be exhausted through the radially inner or outer ends 40, 44 of the leading edge impingement

channel 16. This configuration may develop significant cross flow near the tip 38 or elsewhere, which may degrade the effectiveness of the leading edge impingement orifices 30. However, the reduced distance between the leading edge tip 24 housing the leading edge impingement orifices 30 and the inner surface 26 of the leading edge 18 of the airfoil 10 should lower the negative impact versus conventional configurations.

During use, cooling fluids, such as, but not limited to, air, may be supplied to the internal cooling system 14. The cooling fluids may enter the leading edge cooling supply channel 20 and flow spanwise throughout the leading edge cooling supply channel 20. The cooling fluids may flow through the leading edge impingement orifices 30 and may impinge on the inner surface 26 of the leading edge 18. The cooling fluids may increase in temperature due to convection and may flow along the inner surface forming the pressure and suction sides 48, 50. The cooling fluids may be exhausted from the leading edge impingement channel 16 through the pressure side and suction side film cooling gill holes 32, 34.

The foregoing is provided for purposes of illustrating, explaining, and describing embodiments of this invention. Modifications and adaptations to these embodiments will be apparent to those skilled in the art and may be made without departing from the scope or spirit of this invention.

CLAIMS

We claim:

1. A turbine airfoil (10) for use in a gas turbine engine, comprising:
a generally elongated, hollow airfoil (28) having a leading edge (18), a trailing edge (36), a pressure side (48), a suction side (50), a first end (40), a second end (44) generally opposite to the first end (40) for supporting the airfoil (28), and an internal cooling system (14) formed from at least one cavity (46) in the elongated, hollow airfoil (28);
the internal cooling system (14) including a leading edge cooling supply channel (20) and a leading edge impingement channel (16) positioned within the generally elongated, hollow airfoil (28) along the leading edge (18) of the generally elongated, hollow airfoil (28);
wherein the leading edge cooling supply channel (20) is formed from a leading edge wall (22) having a leading edge tip (24) that is advanced closer to an inner surface (26) of the leading edge (18) of the generally elongated, hollow airfoil (28) than other aspects of the leading edge cooling supply channel (20); and
at least one leading edge impingement orifice (30) in the leading edge tip (24) of the leading edge cooling supply channel (20) for exhausting cooling fluids to impinge on the inner surface (26) of the leading edge (18) of the generally elongated, hollow airfoil (28) in a leading edge impingement channel (16).
2. The turbine airfoil (10) of claim 1, wherein the leading edge cooling supply channel (20) is formed from a first leading edge wall (52) that extends spanwise and a second leading edge wall (54) that extends spanwise and is coupled to the first leading edge wall (52) forming the leading edge tip (24), wherein the first leading edge wall (52) is nonorthogonal to the second leading edge wall (54).
3. The turbine airfoil (10) of claim 2, wherein the first and second leading edge walls (52, 54) of the leading edge cooling supply channel (20) define a portion of the leading edge impingement channel (16) formed from a pressure side section

(72) and a suction side section (74) that is nonorthogonal to the pressure side section (72).

4. The turbine airfoil (10) of claim 3, wherein the pressure side section (72) and the suction side section (74) of the leading edge impingement channel (16) form a c-shaped cross-sectional leading edge impingement channel (16).

5. The turbine airfoil (10) of claim 3, further comprising at least one pressure side film cooling gill hole (32) extending from the pressure side section (72) through an outer wall (56) forming the pressure side (48) of the generally elongated hollow airfoil (28).

6. The turbine airfoil (10) of claim 5, wherein the at least one pressure side film cooling gill hole (32) extending from the pressure side section (72) through the outer wall (56) forming the pressure side (48) of the generally elongated hollow airfoil (28) comprises a plurality of pressure side film cooling gill holes (32) forming at least one spanwise extending linear row of pressure side film cooling gill holes (32).

7. The turbine airfoil (10) of claim 3, further comprising at least one suction side film cooling gill hole (34) extending from the suction side section (74) through an outer wall (58) forming the suction side (50) of the generally elongated hollow airfoil (28).

8. The turbine airfoil (10) of claim 7, wherein the at least one suction side film cooling gill hole (34) extending from the suction side section (74) through the outer wall (58) forming the suction side (50) of the generally elongated hollow airfoil (28) comprises a plurality of suction side film cooling gill holes (34) forming at least one spanwise extending linear row of suction side film cooling gill holes (34).

9. The turbine airfoil (10) of claim 2, wherein the first leading edge wall (52) is aligned with an outer wall forming the pressure side (48) of the generally elongated hollow airfoil (28), and the second leading edge wall (54) is aligned with

an outer wall forming the suction side (50) of the generally elongated hollow airfoil (28).

10. The turbine airfoil (10) of claim 2, wherein the leading edge cooling supply channel (20) is formed from a first aft edge wall (80) that extends spanwise and a second aft edge wall (82) that extends spanwise and is coupled to the first aft edge wall (80) forming an aft edge tip (84), wherein the first aft edge wall (80) is nonorthogonal to the second aft edge wall (82).

11. The turbine airfoil (10) of claim 10, wherein the leading edge cooling supply channel (20) is offset from an outer wall (56) forming the pressure side (48) and an outer wall (58) forming the suction side (50) of the generally elongated hollow airfoil (28).

12. The turbine airfoil (10) of claim 11, wherein the leading edge cooling supply channel (20) is supported by a pressure side rib (60) extending between the outer wall (56) forming the pressure side (48) of the generally elongated hollow airfoil (28) and the first leading edge wall (52) of the leading edge cooling supply channel (20) and is supported by a suction side rib (62) extending between the outer wall (58) forming the suction side (50) of the generally elongated hollow airfoil (28) and the second leading edge wall (54) of the leading edge cooling supply channel (20).

13. The turbine airfoil (10) of claim 1, wherein the at least one leading edge impingement orifice (30) in the leading edge tip (24) of the leading edge cooling supply channel (20) is formed from a plurality of leading edge impingement orifices (30) aligned into a spanwise extending row of leading edge impingement orifices (30).

1/2

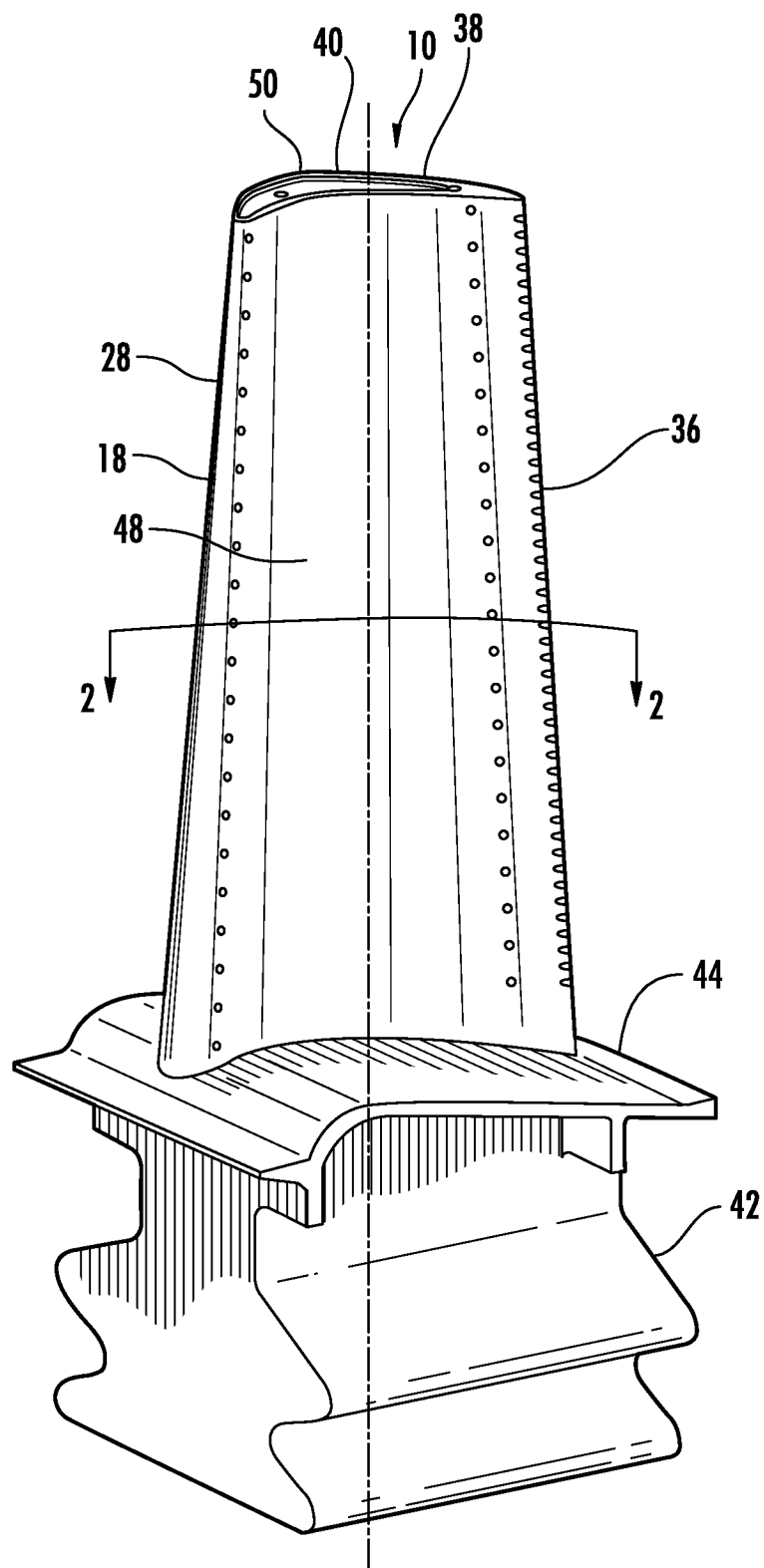
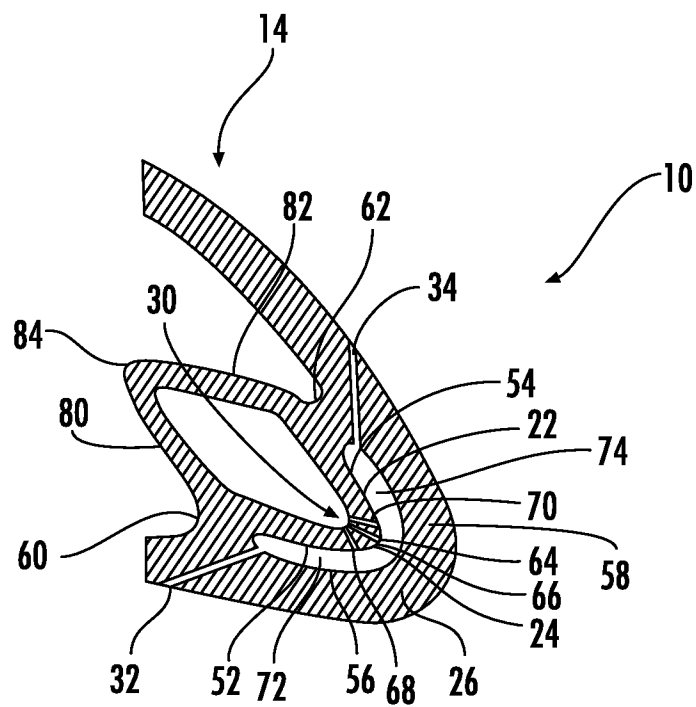
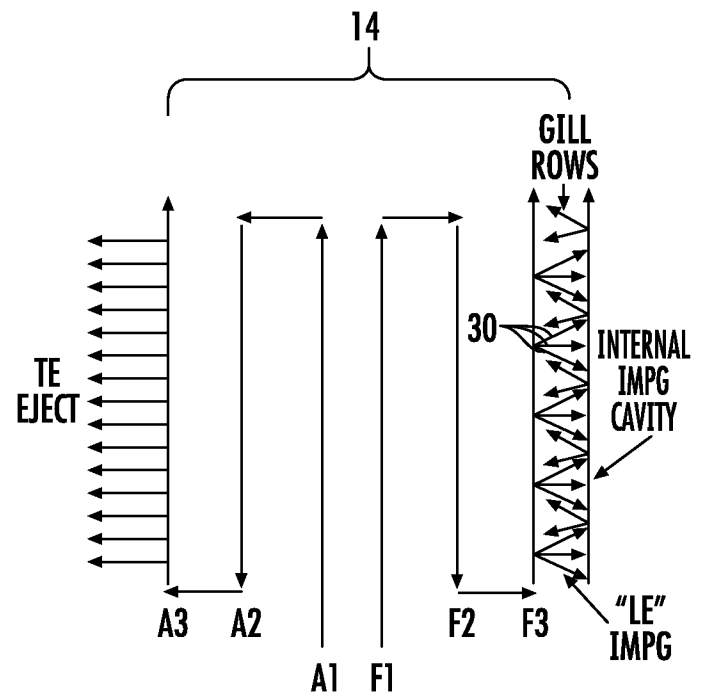
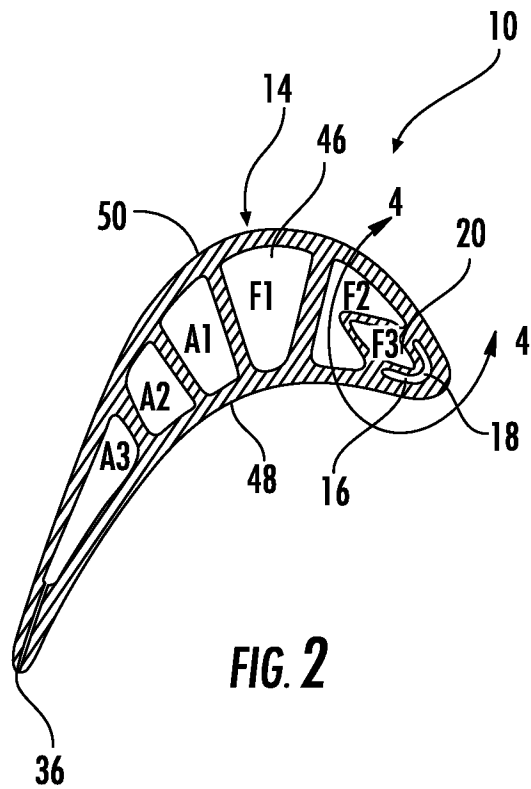


FIG. 1



INTERNATIONAL SEARCH REPORT

International application No
PCT/US2014/042615

A. CLASSIFICATION OF SUBJECT MATTER INV. F01D5/18 ADD.		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED		
Minimum documentation searched (classification system followed by classification symbols) F01D		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO-Internal, WPI Data		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2013/280091 A1 (PROPHETER-HINCKLEY TRACY A [US] ET AL) 24 October 2013 (2013-10-24) abstract paragraph [0048] paragraph [0056] figure 8	1-13
X	----- EP 1 380 724 A2 (MITSUBISHI HEAVY IND LTD [JP]) 14 January 2004 (2004-01-14) abstract paragraph [0004] - paragraph [0006] figures	1-9,13
X	----- DE 196 17 556 A1 (ASEA BROWN BOVERI [CH]) 6 November 1997 (1997-11-06) abstract column 1, line 38 - line 47 figures 1,2,5 -----	1-6,13
☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents : "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search 10 March 2015	Date of mailing of the international search report 23/03/2015	
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Mielimonka, Ingo	

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2014/042615

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2013280091	A1	24-10-2013	EP 2841701 A1 04-03-2015
			US 2013280091 A1 24-10-2013
			WO 2013163037 A1 31-10-2013
EP 1380724	A2	14-01-2004	CA 2432685 A1 11-01-2004
			CN 1477292 A 25-02-2004
			EP 1380724 A2 14-01-2004
			JP 4070621 B2 02-04-2008
			JP 2004044572 A 12-02-2004
			US 2004009066 A1 15-01-2004
DE 19617556	A1	06-11-1997	CN 1170079 A 14-01-1998
			DE 19617556 A1 06-11-1997
			EP 0806546 A1 12-11-1997
			JP H1037701 A 10-02-1998
			US 5827045 A 27-10-1998