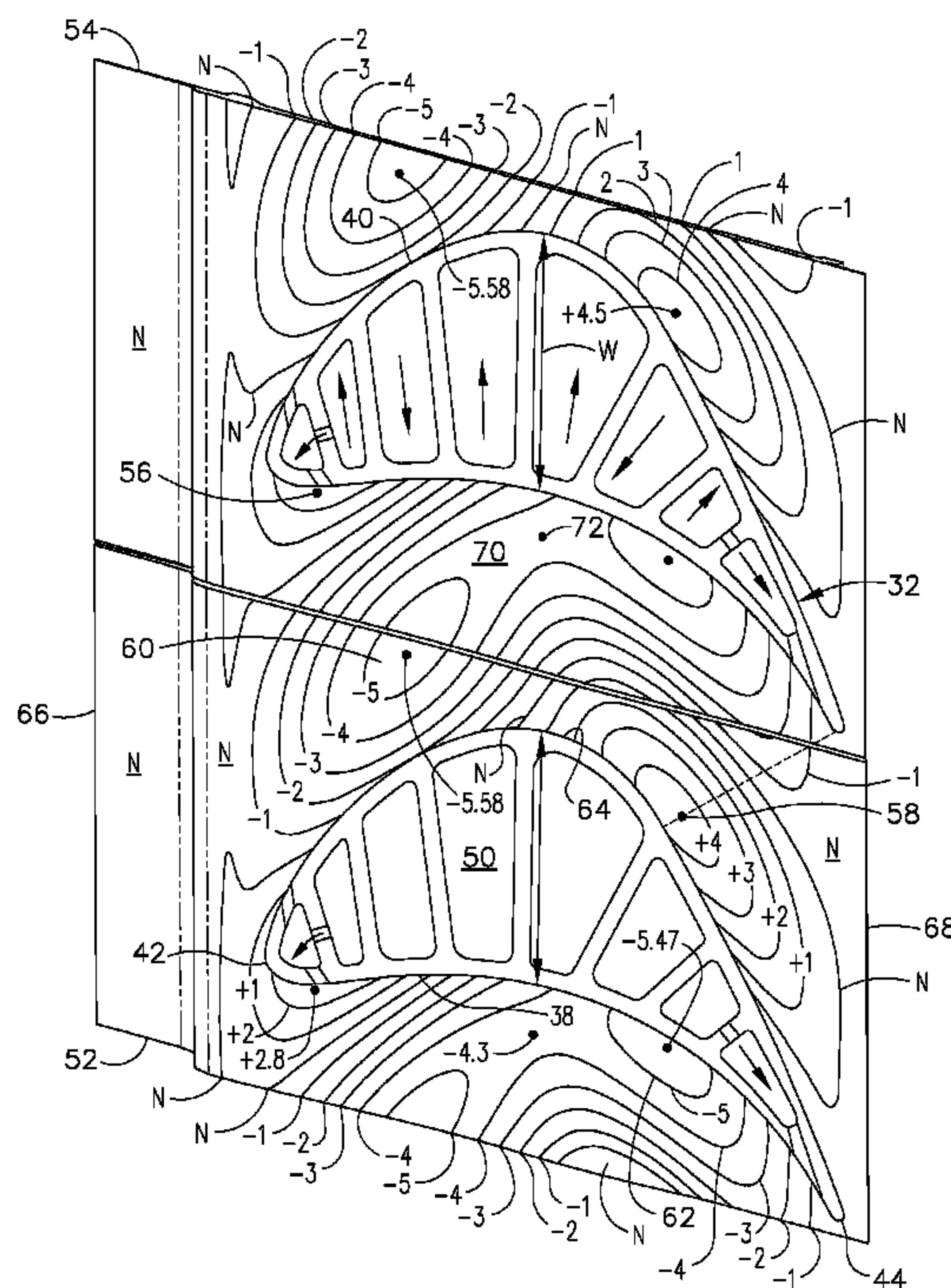




(86) Date de dépôt PCT/PCT Filing Date: 2010/06/15
 (87) Date publication PCT/PCT Publication Date: 2011/02/24
 (45) Date de délivrance/Issue Date: 2017/09/05
 (85) Entrée phase nationale/National Entry: 2012/02/16
 (86) N° demande PCT/PCT Application No.: US 2010/038630
 (87) N° publication PCT/PCT Publication No.: 2011/022111
 (30) Priorité/Priority: 2009/08/20 (US12/544,327)

(51) Cl.Int./Int.Cl. *F01D 5/22* (2006.01),
F01D 5/14 (2006.01)
 (72) Inventeurs/Inventors:
KUHNE, CRAIG MILLER, US;
BUBNICK, JOSEPH STEVEN, US;
KALB, ALISHA VACHHANI, US
 (73) Propriétaire/Owner:
GENERAL ELECTRIC COMPANY, US
 (74) Agent: CRAIG WILSON AND COMPANY

(54) Titre : AUBE DE TURBINE A PLATEAU DE FORME DOUBLE
 (54) Title: TURBINE BLADE WITH CONTOURED PLATFORM



(57) Abrégé/Abstract:

A turbine blade includes an airfoil and integral platform. The platform is biformally contoured in elevation to include bilaterally disposed elevated ridges and depressed troughs on opposite sides of the airfoil.

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau(43) International Publication Date
24 February 2011 (24.02.2011)(10) International Publication Number
WO 2011/022111 A3(51) International Patent Classification:
F01D 5/14 (2006.01)

45246 (US). KALB, Alisha, Vachhani [US/US]; 30 Merchant Street, M/D P30, Cincinnati, OH 45246 (US).

(21) International Application Number:
PCT/US2010/038630

(74) Agents: GNIBUS, Michael, M. et al.; General Electric Company, Global Patent Operation, 2 Corporate Drive, Suite 648, Shelton, CT 06484 (US).

(22) International Filing Date:
15 June 2010 (15.06.2010)

(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, 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, IS, JP, KE, KG, KM, 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, PE, PG, PH, PL, PT, RO, RS, RU, 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.

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
12/544,327 20 August 2009 (20.08.2009) US

(71) Applicant (for all designated States except US): GENERAL ELECTRIC COMPANY [US/US]; 1 River Road, Schenectady, NY 12345 (US).

(72) Inventors; and

(75) Inventors/Applicants (for US only): KUHNE, Craig, Miller [US/US]; One Neumann Way, M/D G408, Cincinnati, OH 45215 (US). BUBNICK, Joseph, Steven [US/US]; 30 Merchant Street, M/D P20, Cincinnati, OH

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ,

[Continued on next page]

(54) Title: TURBINE BLADE WITH CONTOURED PLATFORM

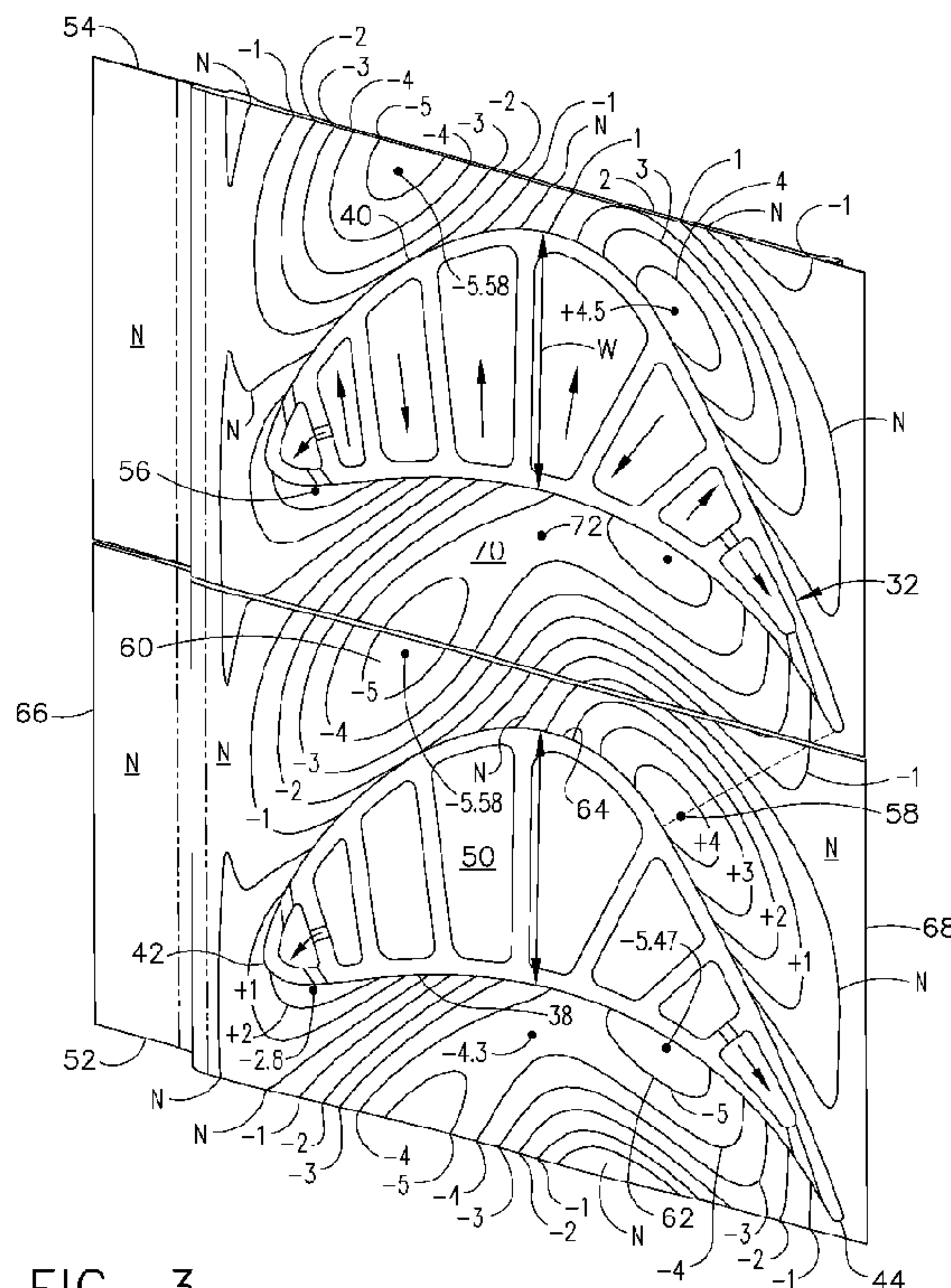


FIG. 3

(57) Abstract: A turbine blade includes an airfoil and integral platform. The platform is biformally contoured in elevation to include bilaterally disposed elevated ridges and depressed troughs on opposite sides of the airfoil.

WO 2011/022111 A3

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, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

- *with international search report (Art. 21(3))*
- *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

Declarations under Rule 4.17:

- *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*
- *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

(88) Date of publication of the international search report:

25 August 2011

237058

1

TURBINE BLADE WITH CONTOURED PLATFORM

2

3

BACKGROUND OF THE INVENTION

4

5 [0001] The present invention relates generally to gas turbine engines, and, more
6 specifically, to turbines therein.

7 [0002] In a gas turbine engine, air is pressurized in a compressor and mixed with fuel in
8 a combustor for generating hot combustion gases. Energy is extracted from the gases in
9 turbine stages which power the compressor and a shaft that typically drives a fan in an
10 aircraft turbofan engine application.

11 [0003] A high pressure turbine (HPT) directly follows the combustor and receives the
12 hottest gases therefrom from which energy is initially extracted. A low pressure turbine
13 (LPT) follows the HPT and extracts additional energy from the gases.

14 [0004] As energy is extracted from the gases in the various turbine stages, the velocity
15 and pressure distributions correspondingly vary, which in turn requires correspondingly
16 different aerodynamic profiles of the turbine stator vanes and rotor blades. The size of the
17 vanes and blades typically increases in the downstream direction for providing more
18 surface area to extract energy from the combustion gases as the pressure thereof decreases.

19 [0005] The velocity of the gases also decreases as energy is extracted and the flowpath
20 area increases, which in turn leads to changes in the span and thickness aspect ratios of the
21 vanes and blades and corresponding camber thereof.

22 [0006] Fundamental to turbine efficiency is the aerodynamic performance of the
23 individual turbine airfoils as the combustion gases are split along the leading edges thereof
24 for corresponding flow along the generally concave pressure side of the airfoil and the
25 generally convex suction side thereof. Differential pressure is effected between the

1 opposite airfoil sides, and aerodynamic contour or camber of the airfoil is optimized for
2 maximizing differential pressure without undesirable flow separation of the gases over the
3 suction side.

4 **[0007]** The turbine flowpath is defined circumferentially between adjacent airfoils as
5 well as radially between inner and outer flowpath surfaces. For the turbine nozzle, inner
6 and outer bands integral with the vanes bound the flow. And for the turbine blades,
7 radially inner platforms and radially outer shrouds bound the combustion gases.

8 **[0008]** A particular problem affecting turbine efficiency is the generation of undesirable
9 vortices as the combustion gases are split along the airfoil leading edges near a flow
10 boundary, such as the radially inner blade platforms. Two horseshoe vortices flow
11 downstream on opposite sides of each airfoil and create undesirable turbulence in the flow.

12 This turbulence can increase platform heating. And, migration of the vortices radially
13 outwardly can decrease turbine efficiency.

14 **[0009]** The outer and inner flowpath boundaries in the typical gas turbine engine may
15 vary in contour or axial profile, but are axisymmetrical with constant diameter or radius
16 from the axial centerline axis of the engine at each axial plane. The blade platforms, for
17 example, are therefore axisymmetric with uniform circumferential curvature from their
18 upstream forward ends to their downstream aft ends notwithstanding any axial inclination
19 or slope thereof.

20 **[0010]** In previous turbine developments, it is known to selectively contour the flowpath
21 boundaries to minimize the adverse affects of the horseshoe vortices. However, due to the
22 complex three dimensional (3D) configuration of the turbine stages and the
23 correspondingly complex 3D distributions of the velocity, pressure, and temperature of the
24 combustion gases contouring of the flowpath boundaries is equally complex and is directly
25 affected by the specific design of the specific turbine stage.

1 [0011] Accordingly, known flowpath contouring is highly specific to specific turbine
2 stages and is not readily transferable to different stages whose efficiency and performance
3 could instead be degraded.

4 [0012] Adding to the complexity of design and environment are the special flow fields
5 around the radially outer tips of the turbine blades which rotate at high speed inside a
6 surrounding stationary shroud during operation. Combustion gases which leak over the
7 airfoil tips in the required clearance between the tips and shroud perform little, if any,
8 useful work.

9 [0013] Modern turbine blade design typically incorporates squealer tip ribs which are
10 small radial extensions of the pressure and suction sides of the airfoil from leading to
11 trailing edge. The tip ribs are typically rectangular in cross section and spaced transversely
12 or circumferentially apart to define an open tip cavity atop the airfoil which has an integral
13 tip floor that encloses the typically hollow airfoil and the internal cooling circuit therein.

14 [0014] The small tip ribs provide sacrificial material in the event of a tip rub to protect
15 the tip floor and internal cooling circuit from undesirable damage. The tip ribs increase the
16 complexity of the combustion gas flow field introducing local secondary fields which
17 affect turbine efficiency, flow leakage, and tip cooling.

18 [0015] The primary flow direction of the combustion gases is in the axially downstream
19 direction in the flow passages defined between adjacent blades. The axial flow stream also
20 varies along the radial direction from root to tip of each airfoil, and is significantly affected
21 by the horseshoe vortices. And, these axial and radial flow variations are further
22 compounded over the airfoil tip where the combustion gases leak between the pressure and
23 suction sides of each airfoil.

24 [0016] Accordingly, it is desired to provide a turbine rotor blade having an improved
25 configuration for improving turbine performance and efficiency.

1

2

BRIEF DESCRIPTION OF THE INVENTION

3

4 **[0017]** A turbine blade includes an airfoil and integral platform. The platform is
5 biformally contoured in elevation to include bilaterally disposed elevated ridges and
6 depressed troughs on opposite sides of the airfoil.

7

8

BRIEF DESCRIPTION OF THE DRAWINGS

9

10 **[0018]** The invention, in accordance with preferred and exemplary embodiments,
11 together with further objects and advantages thereof, is more particularly described in the
12 following detailed description taken in conjunction with the accompanying drawings in
13 which:

14 **[0019]** Figure 1 is a schematic view of an exemplary turbofan gas turbine aircraft engine
15 including a single-stage HPT having a row of turbine rotor blades.

16 **[0020]** Figure 2 is an isometric view of two HPT blades illustrated in Figure 1 having
17 biformally contoured platforms for improving flow of the combustion gases thereover.

18 **[0021]** Figure 3 is a planiform sectional view of the two rotor blades illustrated in Figure
19 2 taken along line 3-3 with isoclines of common radial elevation and depression.

20 **[0022]** Figure 4 is top planiform view of the blades shown in Figure 2 taken along line
21 4-4 with representative transverse sections of the biformal platform contouring.

22

23

24

DETAILED DESCRIPTION OF THE INVENTION

25

1 [0023] Illustrated schematically in Figure 1 is an exemplary turbofan gas turbine engine
2 10 mounted to an aircraft wing (shown in part) for powering an aircraft in flight.

3 [0024] The engine 10 is axisymmetrical about a longitudinal or axial centerline axis, and
4 includes in serial flow communication a fan 12, compressor 14, and combustor 16
5 followed by a single-stage HPT. The HPT includes a nozzle 18 and a row of first stage
6 turbine rotor blades 20 extending radially outwardly from a supporting rotor disk 22.

7 [0025] The row of blades 20 is mounted inside a surrounding turbine shroud 24 with a
8 small radial clearance or tip gap G therebetween. And, a multistage LPT 26 follows the
9 single stage HPT.

10 [0026] During operation, air 28 enters the engine and is pressurized in the compressor
11 and mixed with fuel in the combustor. Hot combustion gases 30 then leave the combustor
12 to power the HPT and LPT which in turn power the compressor and fan.

13 [0027] The exemplary turbine blade 20 is typically cast from superalloy metal with an
14 airfoil 32, platform 34 at the root thereof, and a supporting dovetail 36 in an integral, one-
15 piece assembly.

16 [0028] The dovetail 36 may have any conventional form, such as the axial-entry dovetail
17 illustrated, which mounts the blade in a corresponding dovetail slot in the perimeter of the
18 supporting rotor disk 22. The disk 22 holds a full row of the blades spaced
19 circumferentially apart from each other to define interblade flow passages therebetween.

20 [0029] During operation, the combustion gases 30 are discharged from the combustor 16
21 downstream through the nozzle 18 and between the corresponding blades 20 which extract
22 energy therefrom for powering the supporting rotor disk. The individual platform 34
23 provides a radially inner boundary for the combustion gases and adjoins adjacent platforms
24 in the full row of turbine blades.

25 [0030] The airfoils 32 illustrated in Figures 1 and 2 include circumferentially or

1 transversely opposite pressure and suction sides 38,40 extending axially in chord between
2 opposite leading and trailing edges 42,44 and extend radially in span from the airfoil root
3 46 to terminate in a radially outer tip cap, or tip, 48. The airfoil pressure side 38 is
4 generally concave between the leading and trailing edges and complements the generally
5 convex airfoil suction side 40 between the leading and trailing edges.

6 **[0031]** The external surfaces of the pressure and suction sides 38,40 of the airfoil have
7 the typical crescent shape or profile conventionally configured for effecting corresponding
8 velocity and pressure distributions of the combustion gases thereover during operation for
9 maximizing energy extraction from the gases.

10 **[0032]** The airfoil 32 is typically hollow and includes an internal cooling circuit 50
11 which may have any conventional configuration, such as the illustrated two three-pass
12 serpentine circuits that terminate in corresponding impingement flow passages behind the
13 leading edge and in front of the trailing edge. The cooling circuit extends through the
14 platform and dovetail with corresponding inlets in the base of the dovetail for receiving
15 pressurized cooling air 28 from the compressor 14 in any conventional manner.

16 **[0033]** In this way, the blade is internally cooled from root to tip and between the leading
17 and trailing edges by the internal cooling air 28 which then may be discharged through the
18 thin airfoil sidewalls in various rows of film cooling holes of conventional size and
19 configuration.

20 **[0034]** Since the leading edge of the airfoil is typically subject to the hottest incoming
21 combustion gases, dedicated cooling thereof is provided in any suitable manner. And, the
22 thin trailing edge region of the airfoil typically includes a row of pressure side trailing edge
23 cooling slots for discharging a portion of the spent cooling air.

24 **[0035]** As described above, the turbine airfoils 32 shown in Figure 2 have precisely
25 configured 3D external profiles which correspondingly affect the velocity and pressure

1 distributions of the combustion gases 30 as they flow in the axial downstream direction
2 from leading to trailing edges 42,44 and between the root and tip. The blades are attached
3 to the perimeter of the supporting disk and rotate during operation, which generates
4 secondary flow fields in the combustion gases with radial migration of the combustion
5 gases along the span of the airfoil.

6 **[0036]** Furthermore, the relative pressure of the combustion gases on the pressure side 38
7 of the airfoil is higher than the pressure along the suction side 40 of the airfoil, and along
8 with the corresponding rotation of the blade during operation introduces further secondary
9 or tertiary affects in the combustion gas flow field as it flows radially up and over the
10 exposed airfoil tip 48 during operation.

11 **[0037]** The turbine rotor blade 20 described above may be conventional in configuration
12 and operation for use in a gas turbine engine, including for example the first stage of the
13 HPT. The otherwise conventional blade may then be specifically modified as described
14 hereinbelow for improving performance thereof, especially in new or derivative turbofan
15 engines.

16 **[0038]** As disclosed above in the Background section, the combustion gases 30 are split
17 as they flow over the leading edge of the airfoil along both opposite sides thereof into the
18 corresponding inter-airfoil flow passages. Horseshoe vortices are thusly created and
19 decrease turbine efficiency.

20 **[0039]** As initially shown in Figure 2, adjacent platforms 34 circumferentially or laterally
21 adjoin each other at corresponding straight splitlines 52,54 having conventional spline
22 seals (not shown) therebetween for maintaining a continuous circumferential inner
23 flowpath boundary for the hot combustion gases. The first splitline edge 52 is disposed on
24 the pressure side of the airfoil on the pressure side of the platform. And, the second
25 splitline edge 54 is disposed on the suction side of the airfoil on the suction side of the

1 platform.

2 [0040] In order to reduce the adverse affects of the horseshoe vortices, the outer surface
3 of the platform 34 is specifically contoured in 3D radial elevation R from the axial
4 centerline axis to include elevated ridges 56,58 and depressed troughs 60,62. This 3D
5 endwall contouring (EWC) is determined by numerical flow analysis for the specific
6 geometry of the turbine airfoil 32 in its operating environment in the turbofan engine for
7 minimizing pressure losses due to the horseshoe vortices.

8 [0041] Figures 2-4 illustrate two circumferentially adjacent turbine airfoils 32 extending
9 radially outwardly from atop their corresponding platforms 34. Isoclines of common
10 radial elevation or height H(+) and radial depression or depth D(-) are shown relative to a
11 nominal or reference elevation N which represents the axisymmetric or circular contour of
12 a conventional turbine blade platform as measured at each axial plane.

13 [0042] The specific EWC of the platform 34 includes elevated or positive portions (+)
14 and depressed or negative portions (-) determined by numerical flow analysis for
15 maximizing turbine efficiency. The exemplary isoclines have normalized maximum and
16 minimum values in height H and depth D relative to the reference land N, which has a zero
17 value corresponding with conventional axisymmetric contours devoid of ridges and
18 troughs.

19 [0043] In particular, each platform 34 is biformally contoured in radial elevation to
20 include bilaterally disposed elevated ridges 56,58 and depressed troughs 60,62 on opposite
21 sides of the airfoil, which ridges and troughs are complementary along the splitline edges
22 52,54 to uniformly repeat from platform to platform around the circumference of the blade
23 row.

24 [0044] A forward ridge 56 extends laterally between the pressure side 38 and the
25 splitline first edge 52.

1 [0045] An aft ridge 58 extends laterally between the suction side 40 and the splitline
2 second edge 54.

3 [0046] A forward trough 60 also extends laterally between the suction side 40 and the
4 splitline second edge 54.

5 [0047] And, an aft trough 62 extends laterally between the pressure side 38 and the
6 splitline first edge 52.

7 [0048] The biformal platform 34 is specifically contoured in elevation to include the
8 forward and aft elevated ridges 56,58 on opposite sides of the airfoil, and the forward and
9 aft depressed troughs 60,62 also on opposite sides of the airfoil in bilateral cooperation to
10 complement the EWC along the opposite pressure and suction sides.

11 [0049] Each platform has two opposite sides which adjoin each other in the
12 circumferential middle of the inter-blade flow passages, and the pressure-side platform of
13 one blade cooperates with the suction-side platform of the next blade to define the radially
14 inner flowpath boundary between adjacent blades.

15 [0050] Accordingly, the biformal EWC of each blade platform is identical for the row of
16 platforms, but must complement itself at each of the platform splitlines.

17 [0051] The airfoil 32 extends axially in chord between the axially opposite leading and
18 trailing edges 42,44, and the forward ridge 56 and the forward trough 60 are disposed
19 axially forward of the airfoil midchord, and the aft ridge 58 and the aft trough 62 are
20 disposed axially aft of the midchord.

21 [0052] The specific airfoil illustrated in Figure 3 has a hump 64 of maximum transverse
22 or circumferential width W located quite near or at the midchord thereof which
23 significantly affects its aerodynamic performance.

24 [0053] Correspondingly, the forward and aft ridges 56,58 and troughs 50,62 blend
25 axially in common at the hump 64 on both sides of the airfoil.

- 1 [0054] Along the pressure side, the elevated forward ridge 56 blends axially with the
2 depressed aft trough 62 between the leading and trailing edges 42,44 as the platform
3 elevation correspondingly varies in height $H(+)$ and varies in depth $D(-)$ through the
4 nominal zero elevation N therebetween.
- 5 [0055] Along the suction side, the depressed forward trough 60 blends axially with the
6 elevated aft ridge 58 between the leading and trailing edges as the platform elevation
7 correspondingly varies in depth $D(-)$ and varies in height $H(+)$ through the nominal zero
8 elevation N therebetween.
- 9 [0056] Since the ridges and troughs have 3D surface coverage or area, they also blend
10 around their respective perimeters including directly adjacent to the opposite pressure and
11 suction sides of the airfoil at its root junction with the platform. Typically the airfoil root
12 46 comprises a small arcuate or concave fillet with the platform which is suitably sized to
13 blend with the variation in height and depth of the adjoining ridges and troughs.
- 14 [0057] The platform 34 illustrated in Figure 2 further includes axially opposite forward
15 and aft ends 66,68 which may be conventional in configuration.
- 16 [0058] The forward end 66 extends forwardly from the airfoil leading edges 42 in a
17 bullnose transition with a lower seal wing. And, the aft end 68 extends aft from the airfoil
18 trailing edges 44 in a short cantilevered extension.
- 19 [0059] The forward ridge 56 and forward trough 60 blend in common elevation N along
20 the platform forward end 66 before the airfoil leading edges and behind the bullnose, with
21 that forward end being axisymmetrical with constant radius R at each axial plane.
- 22 [0060] The aft ridge 58 and aft trough 62 correspondingly blend in common elevation N
23 with the platform aft end 68 behind the airfoil trailing edges, with that aft end being
24 axisymmetrical with constant radius R at each axial plane.
- 25 [0061] Correspondingly, the ridges and troughs also blend with each other along the

1 opposite splitline edges 52,54.

2 **[0062]** The forward ridge 56 and the aft trough 62 extend along the first splitline edge 52
3 and axially blend with each other in common elevation N near the leading edge 42, with
4 the forward ridge blending in common elevation N with the platform forward end 66, and
5 the aft trough blending in common elevation N with the platform aft end 68.

6 **[0063]** Correspondingly, the forward trough 60 and the aft ridge 58 extend along the
7 second splitline edge 54 and axially blend with each other in common elevation N near the
8 airfoil midchord or hump 64, with the forward trough blending in common elevation N
9 with the platform forward end 66, and the aft ridge blending in common elevation N with
10 the platform aft end 68.

11 **[0064]** The ridges 56,58 and troughs 60,62 extend along the corresponding splitline
12 edges 52,54 to complement each other from platform to platform, and thusly repeat in half-
13 patterns along the adjoining platforms, with the half-pattern along the splitline first edges
14 52 matching the opposite half-pattern along the second edges 54 in a combined full pattern
15 bounding each inter-blade flow passage across the platform splitlines.

16 **[0065]** As shown in Figure 3, the biformal EWC includes two distinct ridges 56,58
17 bilaterally disposed on opposite sides of the airfoil, as well as two distinct troughs 60,62
18 also disposed on opposite sides of the airfoil.

19 **[0066]** The aft trough 62 extends axially forwardly from the pressure side near the
20 trailing edge 44 to the splitline first edge 52 near the leading edge 42 to complement the
21 forward trough 60 along the splitline second edge 54.

22 **[0067]** The aft trough 62 joins the splitline first edge 52 in a commonly depressed saddle
23 70 rising laterally in depth or elevation to the forward ridge 56 on one side of the saddle
24 and the splitline first edge 52 on the opposite side of the saddle.

25 **[0068]** The saddle 70 is a continuous depression having an arcuate or kidney shape being

1 concave outwardly toward the first edge 52, and includes both the forward trough 60 from
2 one platform and the aft trough 62 from the next platform bridging the common splitline.

3 [0069] As shown in Figures 3 and 4, the saddle also has a locally depressed middle peak
4 72 and increases in depth D therefrom aft along the aft trough 62 and forward to the
5 splitline first edge 52.

6 [0070] Since the row of turbine blades adjoin circumferentially at the platforms, the
7 saddle on one platform complements the forward trough on the next adjacent platform
8 along the splitline edges. The saddle increases in depth D from its middle peak 72 both aft
9 to a local maximum depth in the aft trough, and forward to another local maximum depth
10 in the forward trough of the next adjacent platform.

11 [0071] Since the biformal EWC of the platform outer surface includes elevated ridges
12 and depressed troughs, the radial elevation varies between local maximums and local
13 minimums.

14 [0072] The forward and aft troughs 60,62 illustrated in Figures 3 and 4 are deeper in
15 depth D(-) than the forward and aft ridges 56,58 are high in height H(+).

16 [0073] The aft ridge 58 has a relative maximum height H of +4.5 and is higher than the
17 forward ridge 56 which has a smaller maximum height of +2.8.

18 [0074] The forward trough 60 has a maximum depth D of -5.58 and is slightly deeper
19 than the aft trough 62 which has a maximum depth D of -5.47.

20 [0075] The forward and aft ridges 56,58 have maximum elevations or heights disposed
21 similarly close and adjacent to the pressure and suction sides, respectively.

22 [0076] Correspondingly, the forward trough 60 has its maximum depth spaced laterally
23 from the suction side 40 and located closely adjacent to the splitline second edge 54. The
24 aft trough 62 has its maximum depth directly adjacent to the pressure side 38.

25 [0077] The maximum depths of the forward and aft troughs 60,62 are differently spaced

1 from the suction and pressure sides, respectively, due to the different aerodynamic
2 performance of those opposite airfoil sides. And, the different heights of the forward and
3 aft ridges 56,58 are also effected by the different aerodynamic performance of the airfoil
4 sides.

5 **[0078]** Computational flow analysis of the biformal EWC of the platforms 34 predicts
6 improved aerodynamic performance and turbine efficiency by reducing strength of the
7 horseshoe vortices and associated shear between the combustion gases and the platforms
8 during operation.

9 **[0079]** Secondary flows are also decreased by reducing the static pressure gradient
10 between adjacent airfoils in the inter-blade flow passages. Consistent with the decrease in
11 secondary flows is a reduction in total pressure loss as well as the mitigation of the transfer
12 of mass and momentum in the combustion gases from the predominate axially downstream
13 direction to the radial direction.

14 **[0080]** And therefore, further improvements may be obtained by specifically modifying
15 the airfoil tip 48. In particular, the tip 48 shown in Figure 1 includes a pressure-side first
16 rib 74 joined to a suction-side second rib 76 at the leading edge 42 and spaced transversely
17 apart at the opposite trailing edge 44 to define an aft outlet 78.

18 **[0081]** A tip baffle 80 extends chordally between the ribs 74,76 to define a first pocket
19 82 along the first rib 74 laterally open at the aft outlet 78, and also defining a laterally
20 closed second pocket 84 along the second rib 76.

21 **[0082]** The first and second squealer tip ribs 74,76 are radially integral extensions of the
22 airfoil pressure and suction sides, or sidewalls, and conform in profile or curvature
23 therewith. The airfoil tip includes a floor between the ribs 74,76 which bridges or spans
24 the opposite sidewalls to enclose the internal cooling circuit 50.

25 **[0083]** The tip baffle 80 bifurcates the airfoil tip 48 between the bounding ribs 74,76 to

1 define the first tip cavity or pocket 82 extending chordally along the first rib 74, and to also
2 define the corresponding second tip cavity or pocket 84 extending chordally along the
3 second rib 76.

4 **[0084]** The two ribs 74,76 are integrally joined together at the leading edge 42 of the
5 airfoil, but are not joined together at the trailing edge 44, and instead are spaced
6 transversely apart to define the aft outlet 78 for the first pocket 82.

7 **[0085]** Whereas the second pocket 84 is fully bound laterally by the tip baffle 80 and
8 corresponding portion of the second rib 76, and is therefore laterally closed, the first
9 pocket 82 is almost fully laterally bound by the first rib 74, tip baffle 80, and
10 corresponding portions of the second rib 76, but is specifically open at its aft outlet 78.

11 **[0086]** Computational Fluid Dynamics (CFD) analysis has been performed on this
12 exemplary tip embodiment to confirm performance improvements therefrom compared
13 with a reference design having a single tip cavity without the bifurcating tip baffle therein.

14 **[0087]** The introduction of the tip baffle may be used in specific designs for improving
15 turbine efficiency as well as reducing leakage of the combustion gases over the airfoil tip.

16 **[0088]** Turbine efficiency is based on the ability of the airfoil surfaces to extract energy
17 from the differential pressure in the combustion gases acting over the pressure and suction
18 sides of the airfoil from root to tip and between the leading and trailing edges. The
19 introduction of the tip baffle provides additional surface area at the blade tip against which
20 the tip flow may perform additional work on the blade. The tip baffle also provides an
21 additional seal like the two squealer tip ribs themselves for reducing tip flow leakage.

22 **[0089]** Tip leakage includes both axial and circumferential components in view of the
23 3D configuration of the airfoil tip. The combustion gases 30 engage the airfoil around its
24 leading edge both in axial and circumferential directions due to the oblique inlet angle
25 from the upstream turbine nozzle 18.

1 [0090] It is desired to place the tip baffle 80 so that it captures incident flow streamlines
2 over the forward portion of the second rib to funnel them inside the first tip pocket
3 bounded by the tip baffle itself. The leakage gases are funneled through the first pocket in
4 secondary flow fields that pressurize the first pocket while being guided aft along the tip
5 baffle itself. The so pressurized first pocket increases turbine efficiency by extracting
6 additional energy from the tip baffle itself, and also discourages further leakage over the
7 tip gap by the increased pressure therein.

8 [0091] Correspondingly, some of the leakage gases captured by the first pocket will flow
9 over the tip baffle into the second pocket and are further funneled in the aft direction
10 therein. The leakage gases from both pockets will then be discharged in large part over the
11 suction-side second rib in the downstream direction.

12 [0092] However, the introduction of the aft outlet 78 for the first pocket provides
13 additional advantages, including the partial recovery of tip gases back to the inter-blade
14 flow passages which terminate at the airfoil trailing edges. The aft outlet is located on the
15 pressure side of the airfoil, and tip leakage recovered therethrough is returned to the flow
16 passages upstream of the passage throats which are defined between the trailing edge
17 normal to the suction side of the next adjacent airfoil.

18 [0093] The bifurcated airfoil tip may be used in combination with the biformal platform
19 to collectively improve turbine efficiency, or they may be separately used as desired. Each
20 provides an additional design feature for controlling the flowfield of the combustion gases
21 as they flow downstream over the turbine blades from root to tip, and may be used to
22 advantage to improve performance of turbine blades.

23 [0094] While there have been described herein what are considered to be preferred and
24 exemplary embodiments of the present invention, other modifications of the invention
25 shall be apparent to those skilled in the art from the teachings herein, and it is, therefore,

237058

- 1 desired to be secured in the appended claims all such modifications as fall within the scope
- 2 of the invention.

237058

WHAT IS CLAIMED IS:

1. A turbine blade comprising:

an airfoil joined to a platform along laterally opposite pressure and suction sides, with said platform having corresponding laterally opposite first and second splitline edges; and

said platform is biformally contoured in elevation to include bilaterally disposed elevated ridges and depressed troughs on opposite sides of said airfoil, the elevated ridges and depressed troughs being complementary along said splitline edges;

wherein said airfoil extends axially in chord between opposite leading and trailing edges, and a forward ridge and a forward trough are disposed forward of the airfoil midchord, and an aft ridge and an aft trough are disposed aft of said midchord;

said forward ridge extends laterally between said pressure side and said splitline first edge; said forward trough extends laterally between said suction side and said splitline second edge;

said aft ridge extends laterally between said suction side and said splitline second edge;

said aft trough extends laterally between said pressure side and said splitline first edge; and

wherein said aft trough joins said splitline first edge in a commonly depressed saddle rising laterally in elevation to said forward ridge on one side and to said first splitline edge on an opposite side.

2. A blade according to claim 1 wherein:

said forward ridge blends axially with said aft trough adjacent said pressure side; and

said forward trough blends axially with said aft ridge adjacent said suction side.

3. A blade according to claim 2 wherein:

said platform further comprises axially opposite forward and aft ends;

said forward ridge and trough blend in common with said platform forward end before said leading edge; and

237058

said aft ridge and trough blend in common with said platform aft end behind said trailing edge.

4. A blade according to claim 3 wherein said forward and aft ridges have maximum heights adjacent said pressure and suction sides, respectively.

5. A blade according to claim 3 wherein said forward trough has a maximum depth spaced from said suction side, and said aft trough has a maximum depth adjacent said pressure side.

6. A blade according to claim 3 wherein said troughs are deeper than said ridges are high.

7. A row of turbine blades attached to a supporting disk and including at least first and second turbine blades each according to claim 1 adjoining circumferentially at their respective first and second platforms wherein said saddle on the first platform complements said forward trough on the second platform along said splitline edges; and

said saddle has a locally depressed peak and increases in depth therefrom aft to a maximum depth in said aft trough, and forward to another maximum depth in said forward trough of the second platform.

8. A blade according to claim 1 further comprising an airfoil tip having a pressure-side first rib joined to a suction-side second rib at said leading edge and spaced transversely apart at said opposite trailing edge to define an aft outlet, and a tip baffle extends chordally between said ribs to define a first pocket along said first rib laterally open at said aft outlet, and also defining a laterally closed second pocket along-said second rib.

9. A turbine blade comprising:

an airfoil integrally joined to a platform along laterally opposite pressure and suction sides extending longitudinally in span from said platform and axially in chord between opposite leading and trailing edge; and

237058

said platform being biformally contoured in elevation to include forward and aft elevated ridges and complementary forward and aft depressed troughs along said opposite pressure and suction sides;

wherein said forward and aft ridges are bilaterally disposed along said pressure and suction sides adjacent said leading edge and before said trailing edge, respectively; and said forward and aft troughs are bilaterally disposed along said suction and pressure sides behind said leading edge and before said trailing edge, respectively;

wherein said platform has laterally opposite first and second splitline edges along said pressure and suction sides, respectively; and said forward ridge and aft trough extend along said first splitline edge to complement said forward trough and aft ridge extending along said second splitline edge;

wherein said aft trough extends from said pressure side near said trailing edge to said splitline first edge near said leading edge to complement said forward trough along said splitline second edge; and

wherein said aft trough joins said splitline first edge in a commonly depressed saddle rising laterally in elevation to said forward ridge on one side and said first splitline edge on an opposite side.

10. A blade according to claim 9 wherein:

said forward ridge blends axially with said aft trough along said pressure side; and

said forward trough blends axially with said aft ridge along said suction side.

11. A blade according to claim 10 wherein:

said platform further comprises axially opposite forward and aft ends;

said forward ridge and trough blend in common with said platform forward end before said leading edge; and

said aft ridge and trough blend in common with said platform aft end behind said trailing edge.

237058

12. A blade according to claim 10 wherein:
said airfoil has a hump of maximum transverse width near the midchord thereof; and
said forward and aft ridges and troughs blend axially in common at said hump.

13. A blade according to claim 10 wherein said troughs are deeper than said ridges are high.

14. A blade according to claim 10 wherein said aft ridge is higher than said forward ridge.

15. A blade according to claim 10 wherein said forward trough is deeper than said aft trough.

16. A blade according to claim 10 wherein said forward and aft ridges have maximum heights disposed similarly close to said pressure and suction sides, respectively.

17. A blade according to claim 10 wherein said forward and aft troughs have maximum depths differently spaced from said suction and pressure sides, respectively.

18. A blade according to claim 9 wherein said saddle has a locally depressed peak and increases in depth therefrom aft along said aft trough and forward to said splitline first edge.

19. A blade according to claim 9 further comprising an airfoil tip having a pressure-side first rib joined to a suction-side second rib at said leading edge and spaced transversely apart at said opposite trailing edge to define an aft outlet, and a tip baffle extends chordally between said ribs to define a first pocket along said first rib laterally open at said aft outlet, and also defining a laterally closed second pocket along-said second rib.

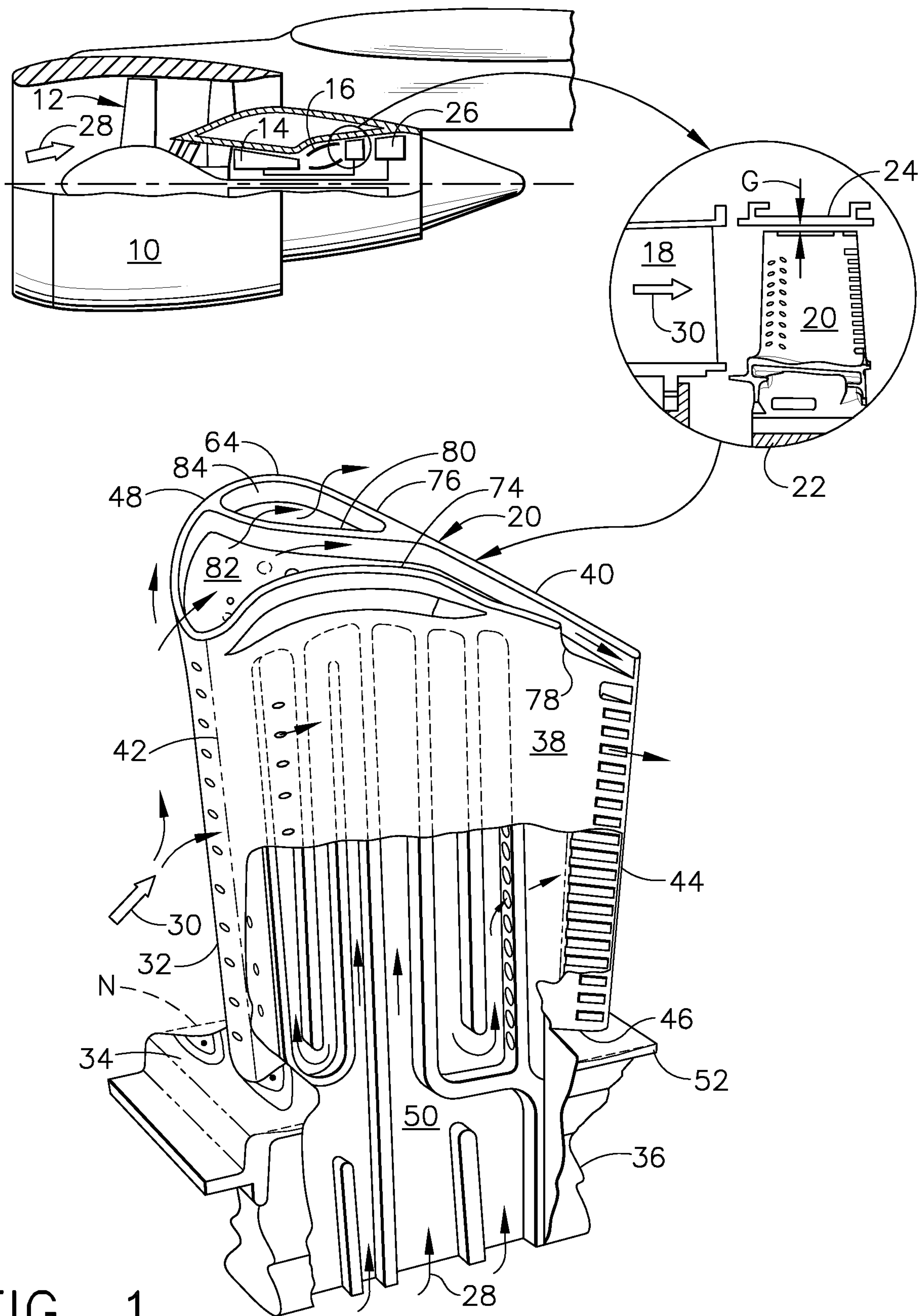


FIG. 1

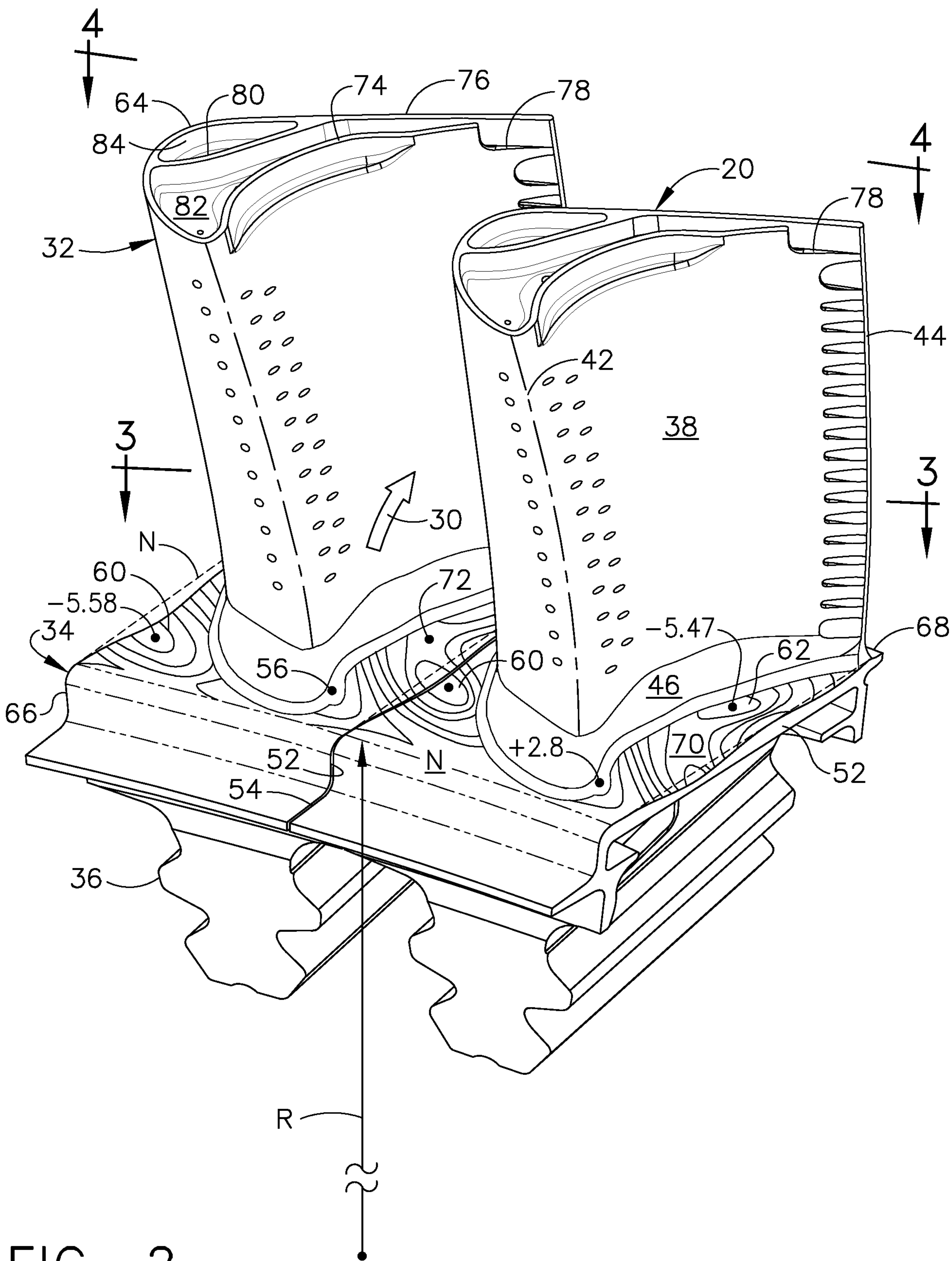


FIG. 2

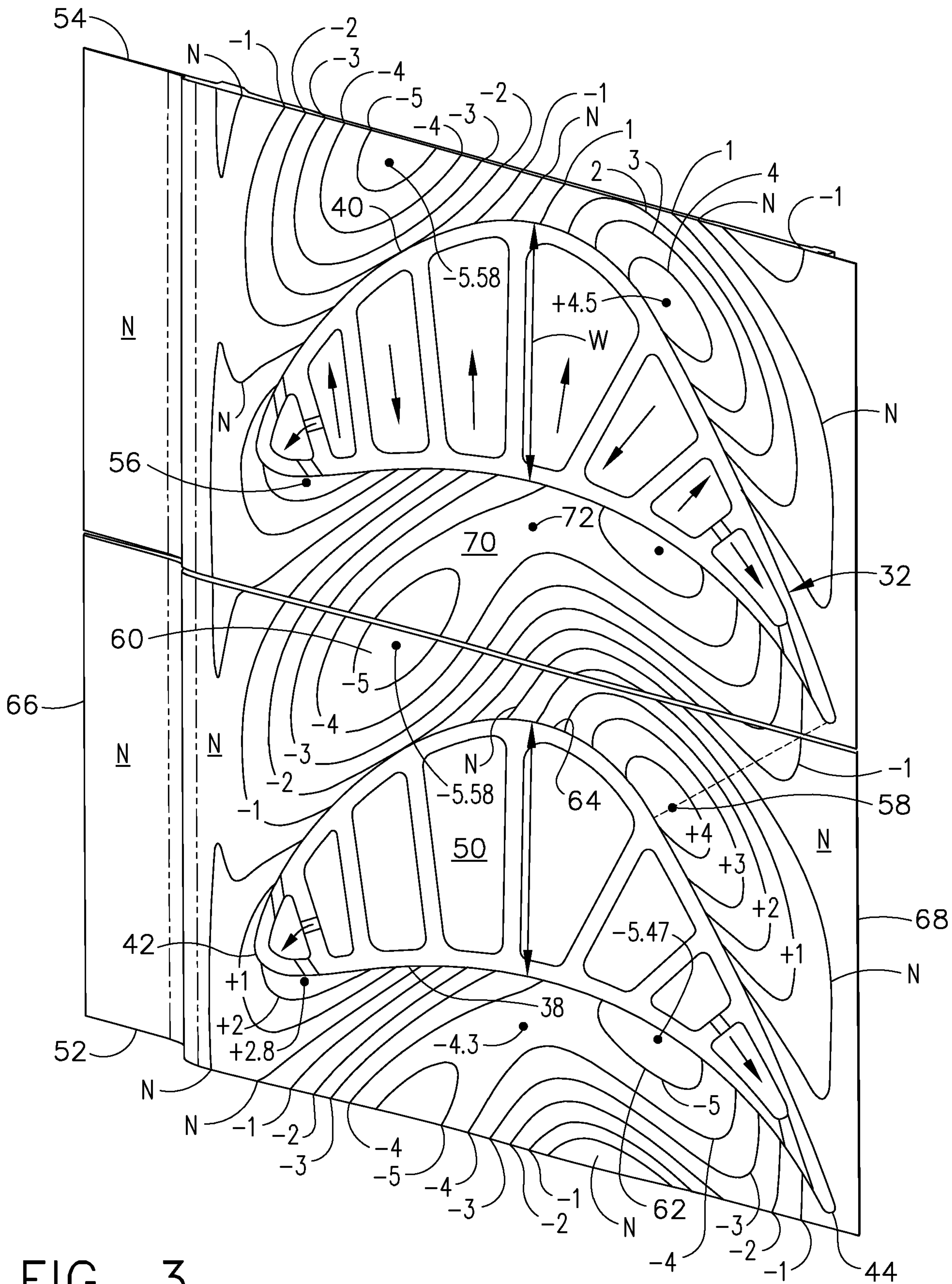


FIG. 3

