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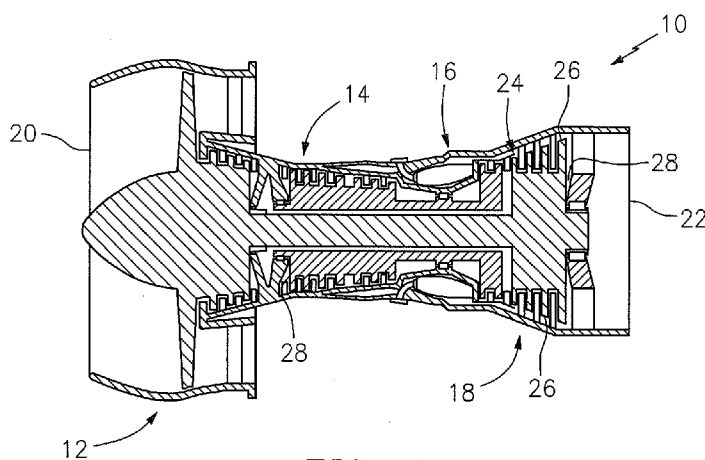


FIG. 1

(57) Abstract: A rotor blade for a gas turbine engine includes an airfoil and a cooling microcircuit. The airfoil includes a first side wall, a second side wall and a tip endwall, where the first side wall and the second side wall extend to and cooperate to form the tip endwall, defining a main cavity between the first side wall and the second side wall. The cooling microcircuit includes a microcircuit cavity, an inlet, a side wall outlet and a tip outlet. The microcircuit cavity is embedded within the first side wall, and the inlet extends from the main cavity to the microcircuit cavity. The side wall outlet extends from the microcircuit cavity to an exterior first side surface of the airfoil. The tip outlet extends from the microcircuit cavity to an exterior tip surface of the airfoil.



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ROTOR BLADE WITH ONE OR MORE SIDE WALL COOLING CIRCUITS

Applicant hereby claims priority to U.S. Patent Application No. 13/416,822 filed March 9, 2012, the disclosure of which is herein incorporated by reference.

[0001] This invention was made with government support under Contract No. F33615-03-D-2354-0009 awarded by the United States Air Force. The government may have certain rights in the invention.

BACKGROUND OF THE INVENTION

1. Technical Field

[0002] This disclosure relates generally to gas turbine engines and, more particularly, to a rotor blade for a gas turbine engine with one or more side wall cooling circuits.

2. Background Information

[0003] Turbine blades within a gas turbine engine are typically exposed to relatively high heat loads, which may cause oxidation, creep and/or thermal mechanical fatigue within material of the blades. Some turbine blades therefore include cooling passages to film cool exterior surfaces of the blade. The cooling passages typically extend from a main cavity, which is defined between a pressure side wall and a suction side wall, to an exterior surface of the blade. There is a need in the art, however, for improved blade cooling systems to mitigate ever increasing heat loads.

SUMMARY OF THE DISCLOSURE

[0004] According to a first aspect of the invention, a rotor blade for a gas turbine engine includes an airfoil and a cooling microcircuit. The airfoil includes a first (e.g., pressure or suction) side wall, a second (e.g., suction or pressure) side wall and a tip endwall, where the first side wall and the second side wall extend to and cooperate to form the tip endwall, defining a main cavity between the first side wall and the second side wall. The cooling microcircuit includes a microcircuit cavity, an inlet, a side wall outlet and a tip outlet. The microcircuit cavity is embedded within the first side wall, and the inlet extends from the main cavity to the microcircuit cavity. The side wall outlet extends from the microcircuit cavity to an exterior first

side surface of the airfoil. The tip outlet extends from the microcircuit cavity to an exterior tip surface of the airfoil.

[0005] In an embodiment, the first side wall is a pressure side wall, and the second side wall is a suction side wall. In another embodiment, the first side wall is the suction side wall, and the second side wall is the pressure side wall.

[0006] In an embodiment, the tip surface is a tip shelf that is recessed into the tip endwall. In one embodiment, the tip surface is continuous with the first side surface.

[0007] In an embodiment, at least a portion of the tip outlet extends to the tip surface along an axis that is angled relative to the first side surface.

[0008] In an embodiment, the microcircuit cavity includes a cavity length that extends radially through the first side wall. In one embodiment, the inlet is one of a plurality of inlets that extend from the main cavity to the microcircuit cavity, and the inlets are arranged radially along the cavity length. In another embodiment, the side wall outlet is one of a plurality of side wall outlets that extend from the microcircuit cavity to the first side surface, and the side wall outlets are arranged radially along the cavity length.

[0009] In an embodiment, the rotor blade also includes a second microcircuit. The second microcircuit includes a second microcircuit cavity, a second inlet, a second side wall outlet, and a second tip outlet. The second microcircuit cavity is embedded within the first side wall. The second inlet extends from the main cavity to the second microcircuit cavity. The second side wall outlet extends from the second microcircuit cavity to the first side surface. The second tip outlet extends from the second microcircuit cavity to the tip surface.

[0010] In an embodiment, the rotor blade also includes a cooling passage that extends from the main cavity to one of the first side surface and the tip surface.

[0011] In an embodiment, the rotor blade also includes a protrusion that extends into the microcircuit cavity.

[0012] According to a second aspect of the invention, a turbine blade for a gas turbine engine includes an airfoil and a cooling microcircuit. The airfoil includes a first (e.g., pressure or suction) side wall, a second (e.g., suction or pressure) side wall and a tip endwall, where the first side wall and the second side wall extend to the tip endwall, forming a main cavity between first side wall and the second side wall. The cooling microcircuit includes a microcircuit cavity, an inlet, a side wall outlet and a tip outlet. The microcircuit cavity is configured within the first side

wall. The inlet directs cooling fluid from the main cavity into the microcircuit cavity. The side wall outlet directs a portion of the cooling fluid in the microcircuit cavity out of the airfoil to film cool an exterior first side surface of the airfoil. The tip outlet directs a portion of the cooling fluid in the microcircuit cavity out of the airfoil to film cool an exterior tip surface of the airfoil.

[0013] In an embodiment, the first side wall is a pressure side wall, and the second side wall is a suction side wall. In another embodiment, the first side wall is the suction side wall, and the second side wall is the pressure side wall.

[0014] In an embodiment, the tip surface is a tip shelf that is recessed into the tip endwall. In one embodiment, the tip surface is continuous with the first side surface.

[0015] In an embodiment, the tip outlet directs the cooling fluid out of the airfoil along an axis that is angled relative to the first side surface.

[0016] In an embodiment, the microcircuit cavity includes a cavity length that extends radially through the first side wall. The side wall outlet is one of a plurality of side wall outlets that direct a portion of the cooling air in the microcircuit cavity out of the airfoil to film cool the first side surface, and the side wall outlets are arranged radially along the cavity length.

[0017] In an embodiment, the turbine blade also includes a cooling passage that directs cooling fluid in the main cavity out of the airfoil to film cool one of the first side surface and the tip surface.

[0018] In an embodiment, the turbine blade also includes a protrusion that extends into the microcircuit cavity.

[0019] The foregoing features and the operation of the invention will become more apparent in light of the following description and the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] FIG. 1 is a cross-sectional illustration of a gas turbine engine;

[0021] FIG. 2 is a perspective illustration of a rotor blade;

[0022] FIG. 3 is a cross-sectional illustration of an outer radial section of an airfoil;

[0023] FIG. 4 is a schematic flow diagram of a plurality of cooling circuits for a rotor blade airfoil;

[0024] FIG. 5 is a side-sectional illustration of an outer radial section of a cooling circuit;

[0025] FIG. 6 is a cross-sectional illustration of an outer radial section of an airfoil;

[0026] FIG. 7 is a cross-sectional illustration of an outer radial section of an airfoil;
[0027] FIG. 8 is a cross-sectional illustration of an outer radial section of an airfoil; and
[0028] FIG. 9 is a schematic flow diagram of a plurality of cooling circuits for a rotor blade airfoil.

DETAILED DESCRIPTION OF THE INVENTION

[0029] FIG. 1 is a cross-sectional illustration of a gas turbine engine 10. The engine 10 includes a fan section 12, a compressor section 14, a combustor section 16 and a turbine section 18, which are sequentially arranged between an engine airflow inlet 20 and an engine airflow exhaust 22. The turbine section 18 includes one or more rotor stages 24. Each rotor stage 24 includes a plurality of rotor blades 26 arranged circumferentially around a rotor disc 28.

[0030] FIG. 2 is a perspective illustration of one of the rotor blades 26 (e.g., a high pressure turbine blade) included in the engine 10 illustrated in FIG. 1. The rotor blade 26 includes a platform 30 connected between a root 32 and a hollow airfoil 34, and one or more side wall cooling circuits 36, 38 and 40. The cooling circuits are known and often referred to in the art as “microcircuit cooling circuits”.

[0031] The airfoil 34 has an airfoil geometry that defines a concave pressure side surface 42, a convex suction side surface 44, a leading edge 46, a trailing edge 48 and a tip 50. The pressure side surface 42 and the suction side surface 44 extend axially between the leading edge 46 and the trailing edge 48. The pressure side surface 42 and the suction side surface 44 extend radially from the platform 30 to the tip 50. The tip 50 includes a first tip surface 52, and a second tip surface 54 that is contiguous with the pressure side surface 42.

[0032] Referring to FIGS. 2 and 3, the airfoil 34 includes a pressure side wall 56, a suction side wall 58 and a tip endwall 60. The pressure side wall 56 and the suction side wall 58 are connected together along the leading edge 46 and the trailing edge 48. The pressure side wall 56 and the suction side wall 58 extend radially from the platform 30 to the tip endwall 60 defining a main cavity 62 between the pressure side wall 56 and the suction side wall 58 (see FIG. 3). Referring to FIG. 2, the tip endwall 60 includes a leading edge segment 64, a trailing edge segment 66, an intermediate segment 68, and a tip shelf 70 that defines the second tip surface 54. The intermediate segment 68 extends axially between the leading edge segment 64 and the trailing edge segment 66. The tip shelf 70 is recessed radially into the intermediate

segment 68, and extends axially between the leading edge segment 64 and the trailing edge segment 66.

[0033] Referring to FIGS. 3 and 4, each of the cooling circuits 36, 38, 40 may include a microcircuit cavity 72, one or more inlets 74, one or more side wall outlets 76, and at least one tip outlet 78. The microcircuit cavity 72 may include a cavity length 80 that extends radially from a first cavity end 82 to a second cavity end 84. The first cavity end 82 is located proximate a base 85 of the airfoil 34. The second cavity end 84 is located proximate the tip 50. The microcircuit cavity 72 may be configured (e.g., embedded) within the pressure side wall 56. Each inlet 74 extends from the main cavity 62 to the microcircuit cavity 72.

[0034] Referring to FIGS. 3 and 4, the inlets 74 may be arranged radially along the cavity length 80.

[0035] Each side wall outlet 76 extends from the microcircuit cavity 72 to the pressure side surface 42. Referring to FIGS. 2 and 4, the side wall outlets 76 may be arranged radially along the cavity length 80.

[0036] Referring to FIG. 3, the tip outlet 78 extends from the second cavity end 84 to the second tip surface 54. In alternate embodiments, the tip outlet may extend from the second cavity end to the first tip surface where, for example, the airfoil does not include the tip shelf.

[0037] During engine operation, the main cavity 62 receives cooling fluid from a source; e.g., compressor air bled from the compressor stage 14 illustrated in FIG. 1. The inlets 74 for each respective cooling circuit 36, 38, 40 direct at least a portion of the cooling fluid from the main cavity 62 into the microcircuit cavity 72. The cooling fluid received from the inlets 74 flows through the microcircuit cavity 72 and convectively cools the pressure side wall 56. The side wall outlets 76 direct a first portion of the cooling fluid in the microcircuit cavity 72 out of the airfoil 34 to film cool the pressure side surface 42. The tip outlet 78 directs a second portion of the cooling fluid in the microcircuit cavity 72 out of the airfoil 34 to film cool the tip 50. The expelled second portion of the cooling fluid may also create a fluidic barrier that reduces migration of relatively hot gas path air (e.g., air flowing through the turbine section) over the tip 50. In addition, some of the expelled second portion of the cooling fluid may collect and provide a pocket of cooling fluid on the tip shelf 70 that protects the tip 50 from the hot gas path air.

[0038] FIG. 5 is a side-sectional illustration of a cooling circuit 88. In contrast to the cooling circuit illustrated in FIG. 3, the cooling circuit 88 includes one or more protrusions 90

and 92 (e.g., pedestals, vanes, etc.) that extend into/through the microcircuit cavity 72. The protrusions 90 and 92 may be configured to increase convective cooling within the pressure side wall 56, reduce stresses on the pressure side wall 56, or direct the cooling fluid through the microcircuit cavity 72 along one or more trajectories, etc. Additional examples of such protrusions are disclosed in U.S. Patent No. 6,932,571, which is hereby incorporated by reference in its entirety, and is commonly assigned to the assignee of the present invention.

[0039] FIG. 6 is a cross-sectional illustration of an airfoil 94 including a tip outlet 96. In contrast to the tip outlet 78 illustrated in FIG. 3, the tip outlet 96 includes a first tip outlet segment 98 and a second tip outlet segment 100. The first tip outlet segment 98 extends from the microcircuit cavity 72 to the second tip outlet segment 100. The second tip outlet segment 100 extends from the first tip outlet segment 98 along an axis 102 to the second tip surface 54, where the axis 102 is angled (e.g., acute or obtuse) relative to the second tip surface 54 and/or the pressure side surface 42.

[0040] FIG. 7 is a cross-sectional illustration of an airfoil 104. In contrast to the airfoil 34 illustrated in FIG. 3, the airfoil 104 includes one or more cooling passages 106, 108 and 110 that provide additional film cooling to the tip 50. The cooling passages may include a first cooling passage 106, a second cooling passage 108 and a third cooling passage 110. The first cooling passage 106 extends from the main cavity 62 to the second tip surface 54. The second and the third cooling passages 108 and 110 extend from the main cavity 62 to the first tip surface 52. The present invention, however, is of course not limited to the aforesaid cooling passage configurations. It is also contemplated that an airfoil may include a combination of the tip outlets illustrated in FIGS. 3, 6 and/or 7.

[0041] FIG. 8 is a cross-sectional illustration of an airfoil 112. In contrast to the airfoil 34 illustrated in FIG. 3, the airfoil 112 includes at least one suction side wall cooling circuit 114. The cooling circuit 114 may be configured in a similar manner as described above with respect to, for example, the cooling circuits 36, 38, 40 and/or 88. In the embodiment illustrated in FIG. 8, for example, the cooling circuit 114 includes a microcircuit cavity 116, at least one inlet 118, at least one side wall outlet 120, and at least one tip outlet 122. The microcircuit cavity 116 is embedded within the suction side wall 58. The inlet 118 extends from the main cavity 62 to the microcircuit cavity 116. The side wall outlet 120 extends from the microcircuit cavity 116 to the suction side surface 44. The tip outlet 122 extends from the microcircuit cavity 116 to the tip

surface 52. In alternative embodiments, however, the tip outlet may extend from the microcircuit cavity to, for example, a tip shelf surface contiguous with the suction side surface.

[0042] FIG. 9 is a schematic flow diagram of a plurality of cooling circuits for an airfoil 124. In contrast to the airfoil 34 illustrated in FIG. 4, one or more of the cooling circuits 36, 38 and 40 may be interconnected within the side wall.

[0043] In some embodiments, one or more of the side wall outlets may have a rectangular cross-sectional geometry that flares outwards as the outlets extend from the main cavity to the pressure (and/or suction) side surface as illustrated, for example, in FIGS. 2 and 5. In some embodiments, the tip outlet may have a rectangular cross-sectional geometry that flares outwards as the outlet extends from the main cavity to the second tip surface as illustrated, for example, in FIGS. 2 and 5. One of ordinary skill will appreciate that the outlet geometry of the side wall outlets and/or the tip outlets may take various alternate shapes in order to provide the desired cooling.

[0044] In some embodiments, one or more of the cooling circuits may extend radially inwards from the airfoil into, for example, the blade root.

[0045] The cooling circuits, cooling passages and/or cavities described above may be formed utilizing, for example, one or more of the following methods: drilling, electrical discharge machining, electrical chemical machining, laser machining, water jet machining, and casting. The present invention, however, is of course not limited to any particular formation methods.

[0046] While various embodiments of the present invention have been disclosed, it will be apparent to those of ordinary skill in the art that many more embodiments and implementations are possible within the scope of the invention. For example, the present invention as described herein includes several aspects and embodiments that include particular features. Although these features may be described individually, it is within the scope of the present invention that some or all of these features may be combined within any one of the aspects and remain within the scope of the invention. Accordingly, the present invention is not to be restricted except in light of the attached claims and their equivalents.

What is claimed is:

1. A rotor blade for a gas turbine engine, comprising:
an airfoil comprising a first side wall, a second side wall and a tip endwall, wherein the first side wall and the second side wall extend to and cooperate to form the tip endwall defining a main cavity between the first side wall and the second side wall; and
a cooling microcircuit comprising
a microcircuit cavity embedded within the first side wall;
an inlet extending from the main cavity to the microcircuit cavity;
a side wall outlet extending from the microcircuit cavity to an exterior first side surface of the airfoil; and
a tip outlet extending from the microcircuit cavity to an exterior tip surface of the airfoil.
2. The rotor blade of claim 1, wherein the first side wall comprises a pressure side wall, and the second side wall comprises a suction side wall.
3. The rotor blade of claim 1, wherein the first side wall comprises a suction side wall, and the second side wall comprises a pressure side wall.
4. The rotor blade of claim 1, further comprising a tip shelf recessed into the tip endwall, wherein the tip shelf comprises the tip surface.
5. The rotor blade of claim 4, wherein the tip surface is continuous with the first side surface.
6. The rotor blade of claim 1, wherein at least a portion of the tip outlet extends to the tip surface along an axis that is angled relative to the first side surface.
7. The rotor blade of claim 1, wherein the microcircuit cavity comprises a cavity length that extends radially through the first side wall, the inlet is one of a plurality of inlets that extend

from the main cavity to the microcircuit cavity, and the inlets are arranged radially along the cavity length.

8. The rotor blade of claim 1, wherein the microcircuit cavity comprises a cavity length that extends radially through the first side wall, the side wall outlet is one of a plurality of side wall outlets that extend from the microcircuit cavity to the first side surface, and the side wall outlets are arranged radially along the cavity length.

9. The rotor blade of claim 1, further comprising a second microcircuit comprising
a second microcircuit cavity embedded within the first side wall;
a second inlet extending from the main cavity to the second microcircuit cavity;
a second side wall outlet extending from the second microcircuit cavity to the first side surface; and
a second tip outlet extending from the second microcircuit cavity to the tip surface.

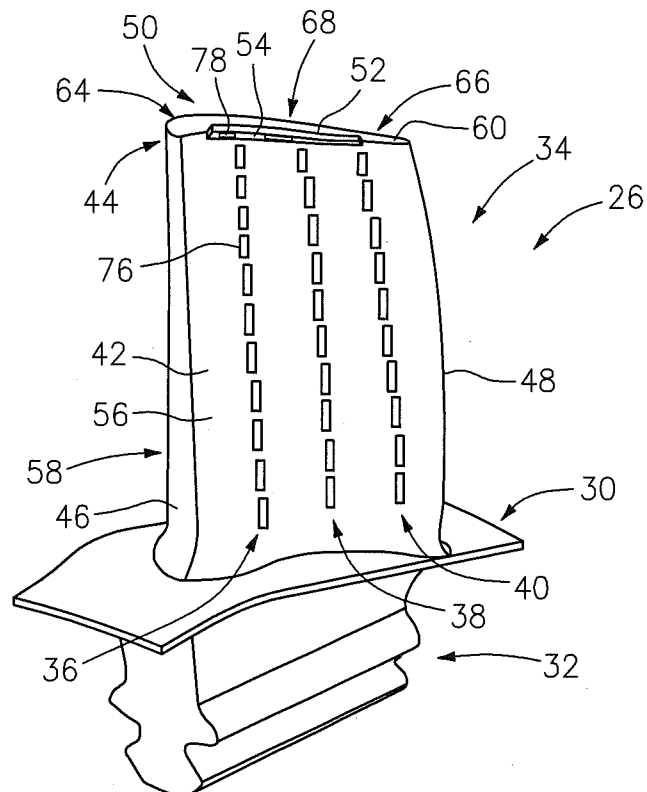
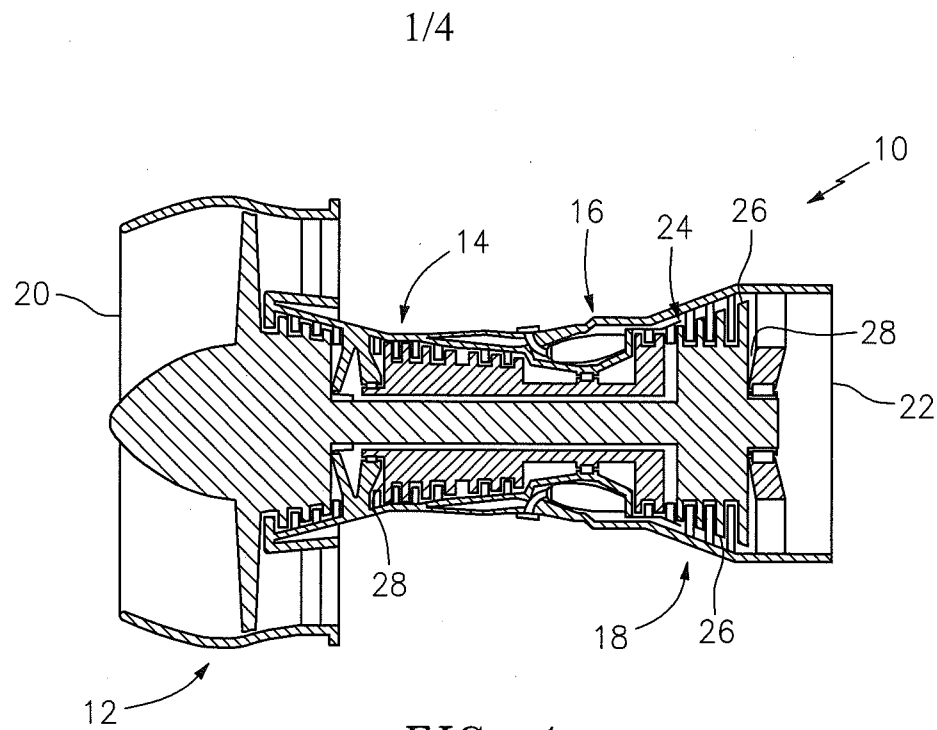
10. The rotor blade of claim 1, further comprising a cooling passage extending from the main cavity to one of the first side surface and the tip surface.

11. The rotor blade of claim 1, further comprising a protrusion extending into the microcircuit cavity.

12. A turbine blade for a gas turbine engine, comprising:
a hollow airfoil comprising a first side wall, a second side wall and a tip endwall, wherein the first side wall and the second side wall extend to the tip endwall forming a main cavity between the first side wall and the second side wall; and
a plurality of cooling microcircuits, each comprising
a microcircuit cavity configured within the first side wall;
an inlet that directs cooling fluid from the main cavity into the microcircuit cavity;
a side wall outlet that directs a portion of the cooling fluid in the microcircuit cavity out of the airfoil to film cool an exterior first side surface of the airfoil; and

a tip outlet that directs a portion of the cooling fluid in the microcircuit cavity out of the airfoil to film cool an exterior tip surface of the airfoil.

13. The turbine blade of claim 12, wherein the first side wall comprises a pressure side wall, and the second side wall comprises a suction side wall.
14. The turbine blade of claim 12, wherein the first side wall comprises a suction side wall, and the second side wall comprises a pressure side wall.
15. The turbine blade of claim 12, further comprising a tip shelf recessed into the tip endwall, wherein the tip shelf comprises the tip surface.
16. The turbine blade of claim 15, wherein the tip surface is contiguous with the first side surface.
17. The turbine blade of claim 12, wherein the tip outlet directs the cooling fluid out of the airfoil along an axis that is angled relative to the first side surface.
18. The turbine blade of claim 12, wherein the microcircuit cavity comprises a cavity length that extends radially through the first side wall, the side wall outlet is one of a plurality of side wall outlets that direct a portion of the cooling air in the microcircuit cavity out of the airfoil to film cool the first side surface, and the side wall outlets are arranged radially along the cavity length.
19. The rotor blade of claim 12, further comprising a cooling passage that directs cooling fluid in the main cavity out of the airfoil to film cool one of the first side surface and the tip surface.
20. The rotor blade of claim 12, further comprising a protrusion extending into the microcircuit cavity.



2/4

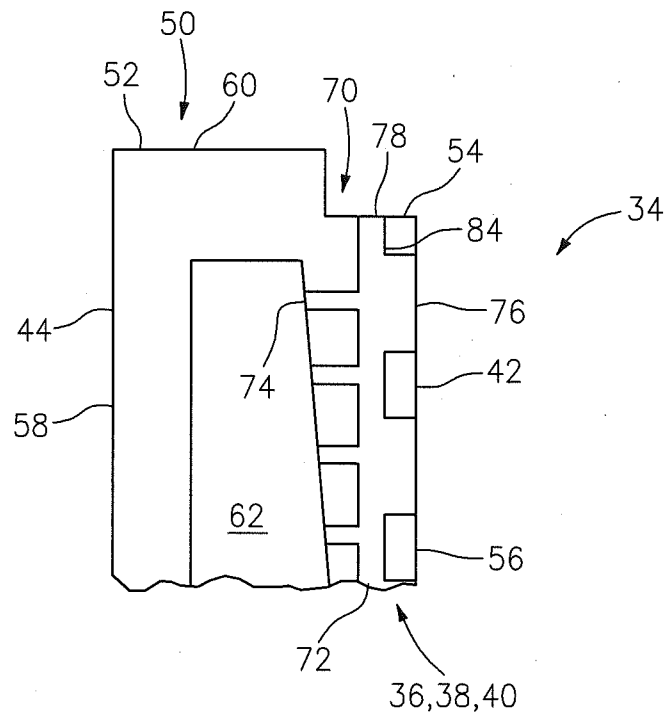


FIG. 3

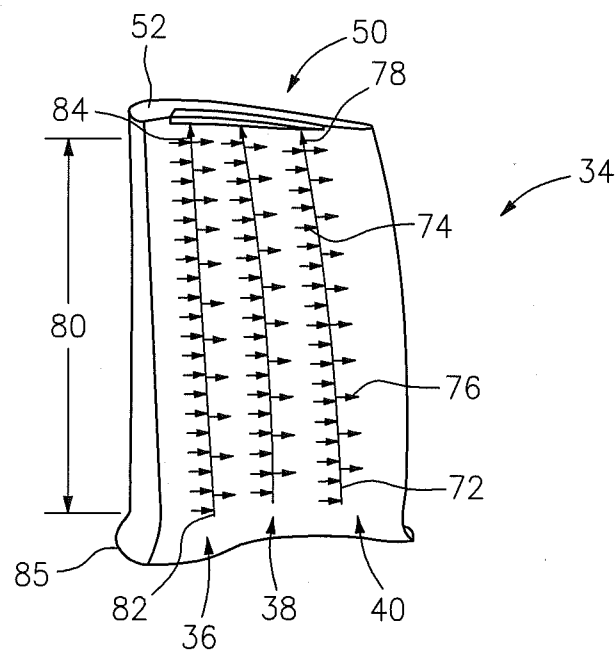


FIG. 4

3/4

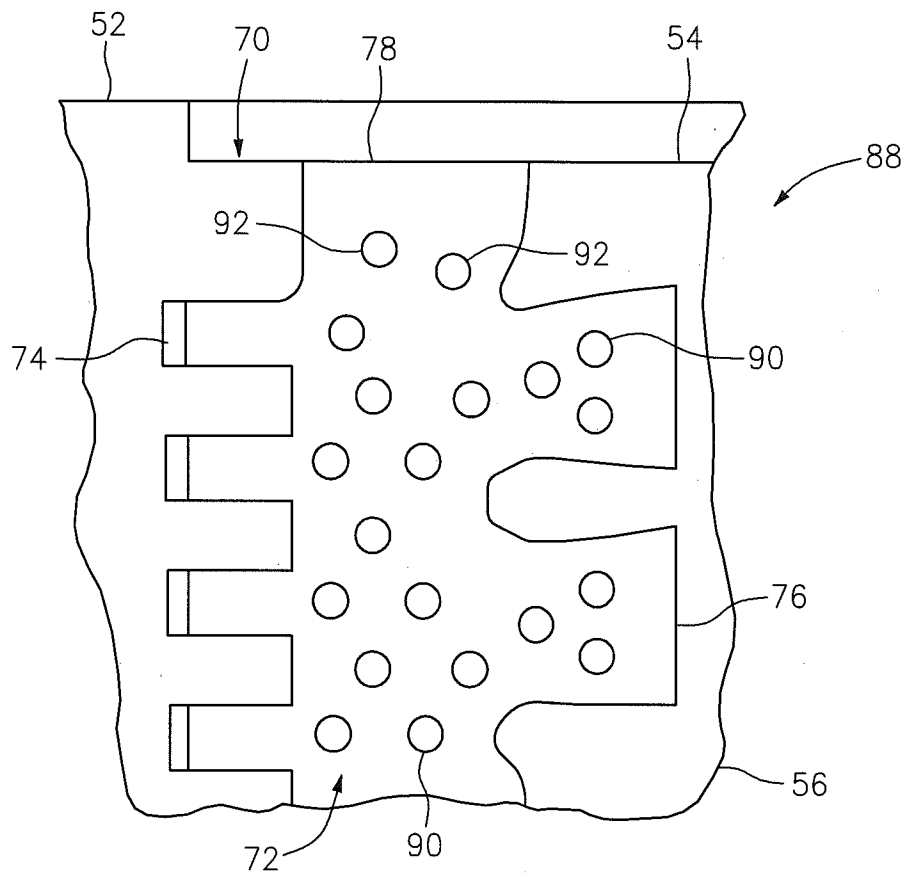


FIG. 5

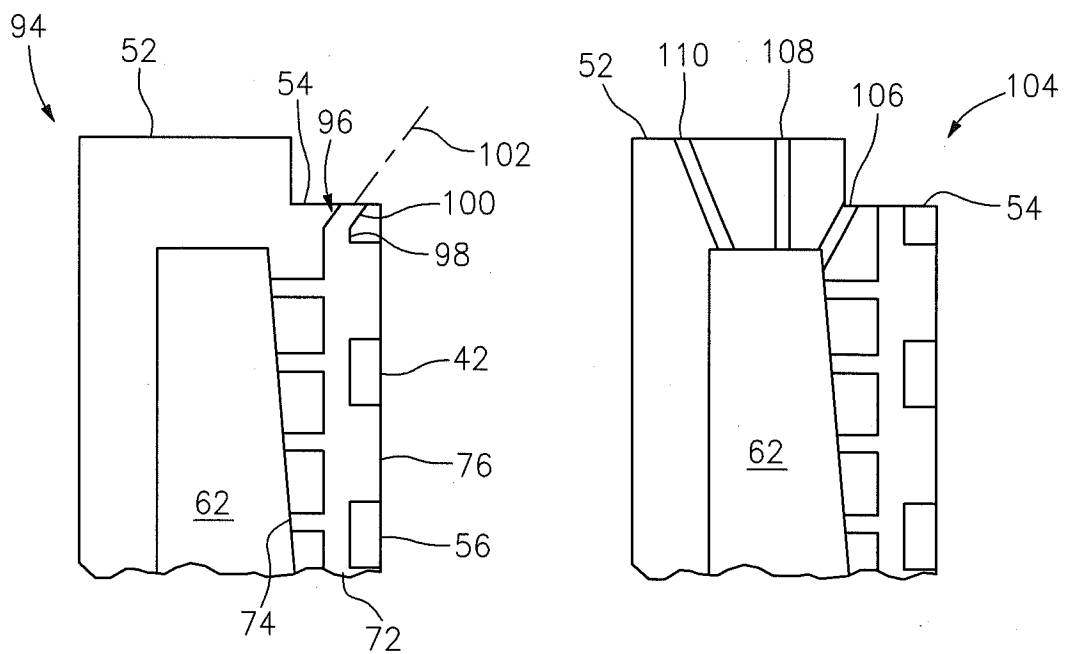


FIG. 6

FIG. 7

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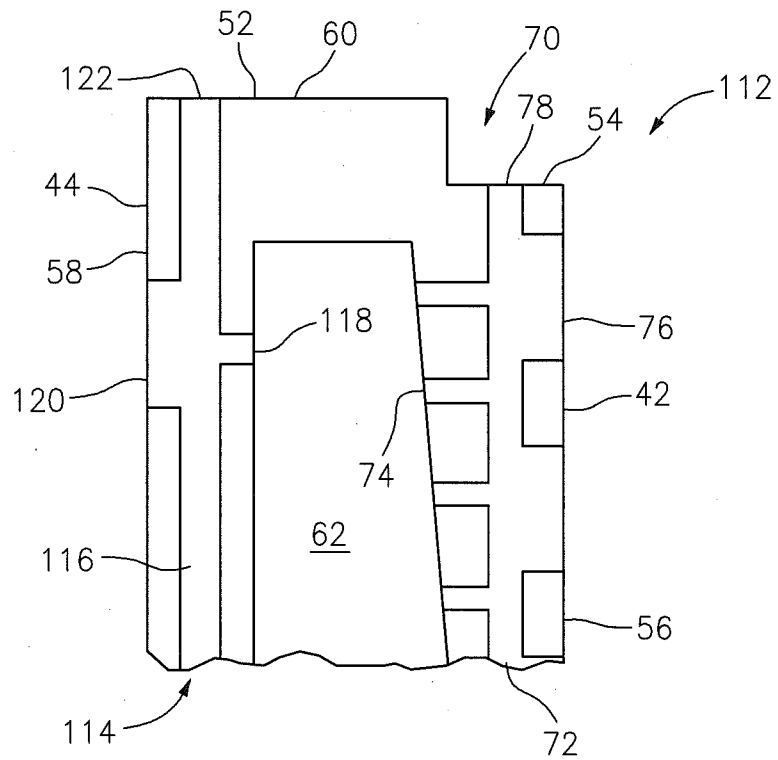


FIG. 8

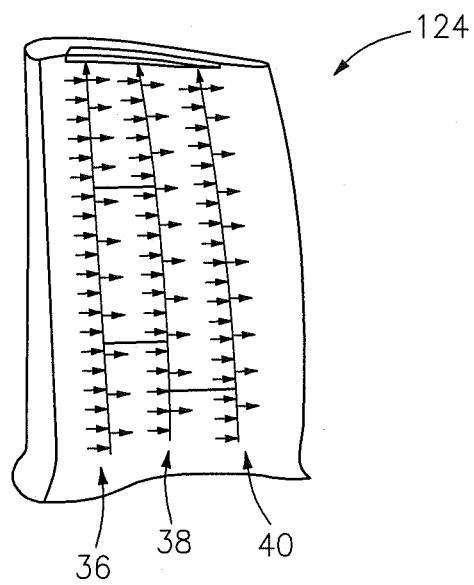


FIG. 9