



(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
09.12.2009 Bulletin 2009/50

(51) Int Cl.:
F23R 3/04 (2006.01)

(21) Application number: **09251512.1**

(22) Date of filing: **08.06.2009**

(84) Designated Contracting States:
**AT BE BG CH CY CZ DE DK EE ES FI FR GB GR
HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL
PT RO SE SI SK TR**

(30) Priority: **06.06.2008 US 157115**

(71) Applicant: **United Technologies Corporation
Hartford, CT 06101 (US)**

(72) Inventors:
• **Strock, Christopher W.
Kennebunk, ME 04043 (US)**
• **Lutjen, Paul M.
Kennebunkport, ME 04046 (US)**

(74) Representative: **Tomlinson, Kerry John
Frank B. Dehn & Co.
St Bride's House
10 Salisbury Square
London EC4Y 8JD (GB)**

(54) **Counter-vortex, paired film cooling hole design**

(57) An apparatus for use in a gas turbine engine includes a wall (30) defining an exterior face (32), a first film cooling passage (36A) extending through the wall for providing film cooling to the exterior face of the wall, and a second film cooling passage (36B) extending through the wall adjacent to the first film cooling passage for providing film cooling to the exterior face of the wall.

The first film passage includes a first vortex-generating structure (40A) for inducing a vortex in a first rotational direction in a cooling fluid passing therethrough, and the second film passage includes a second vortex-generating structure (40B) for inducing a vortex in a second rotational direction in a cooling fluid passing therethrough. The first and second rotational directions are substantially opposite one another.

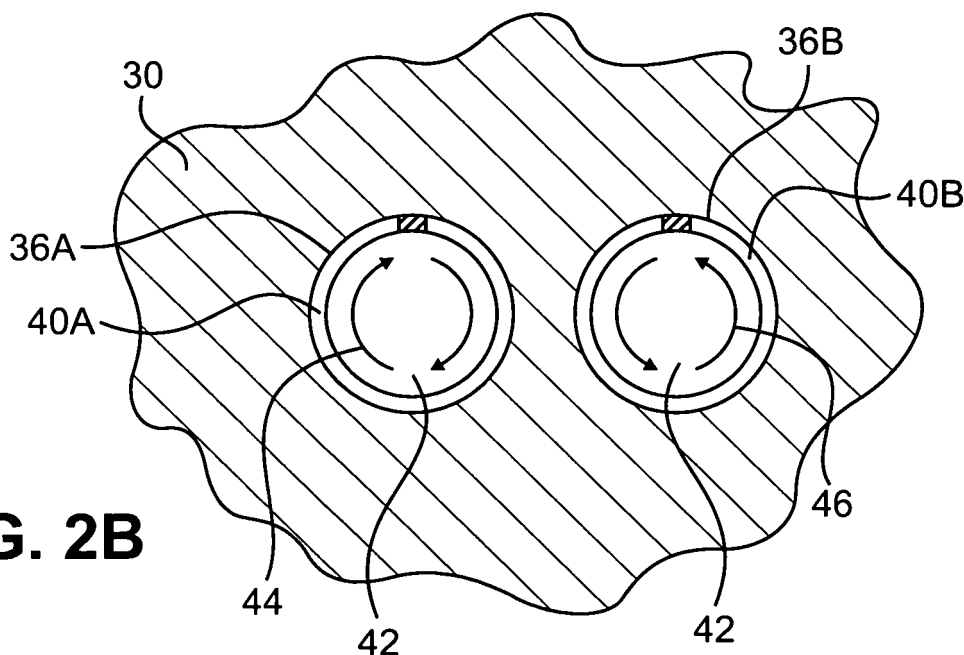


FIG. 2B

Description

BACKGROUND

[0001] The present invention relates to film cooling, and more particularly to structures and methods for providing vortex film cooling flows along gas turbine engine components.

[0002] Gas turbine engines utilize hot fluid flows in order to generate thrust or other usable power. Modern gas turbine engines have increased working fluid temperatures in order to increase engine operating efficiency. However, such high temperature fluids pose a risk of damage to engine components, such as turbine blades and vanes. High melting point superalloys and specialized coatings (e.g., thermal barrier coatings) have been used to help avoid thermally induced damage to engine components, but operating temperatures in modern gas turbine engines can still exceed superalloy melting points and coatings can become damaged or otherwise fail over time.

[0003] Cooling fluids have also been used to protect engine components, often in conjunction with the use of high temperature alloys and specialized coatings. One method of using cooling fluids is called impingement cooling, which involves directing a relatively cool fluid (e.g., compressor bleed air) against a surface of a component exposed to high temperatures in order to absorb thermal energy into the cooling fluid that is then carried away from the component to cool it. Impingement cooling is typically implemented with internal cooling passages. However, impingement cooling alone may not be sufficient to maintain suitable component temperatures in operation. An alternative method of using cooling fluids is called film cooling, which involves providing a flow of relatively cool fluid from film cooling holes in order to create a thermally insulative barrier between a surface of a component and a relatively hot fluid flow. Problems with film cooling include flow separation or "liftoff", where the film cooling flow lifts off the surface of the component desired to be cooled, undesirably allowing hot fluids to reach the surface of the component. Film cooling fluid liftoff can necessitate additional, more closely-spaced film cooling holes to achieve a given level of cooling. Cooling flows of any type can present efficiency loss for an engine. The more fluid that is redirected within an engine for cooling purposes, the less efficient the engine tends to be in producing thrust or another usable power output. Therefore, fewer and smaller cooling holes with less dense cooling hole patterns are desirable.

[0004] The present invention provides an alternative method and apparatus for film cooling gas turbine engine components.

SUMMARY

[0005] An apparatus for use in a gas turbine engine includes a wall defining an exterior face, a first film cooling

passage extending through the wall for providing film cooling to the exterior face of the wall, and a second film cooling passage extending through the wall adjacent to the first film cooling passage for providing film cooling to the exterior face of the wall. The first film passage includes a first vortex-generating structure for inducing a vortex in a first rotational direction in a cooling fluid passing therethrough, and the second film passage includes a second vortex-generating structure for inducing a vortex in a second rotational direction in a cooling fluid passing therethrough. The first and second rotational directions are substantially opposite one another.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] FIG. 1 is a perspective view of an exemplary film cooled turbine blade.

[0007] FIG. 2A is a cross-sectional view of a portion of a film cooled gas turbine engine component.

[0008] FIGS. 2B-2E are cross-sectional views of portions of the film cooled gas turbine engine component taken along lines B-B, C-C, D-D and E-E, respectively, of FIG. 2A.

[0009] FIG. 3 is a schematic view of a pair of film cooling passages.

[0010] FIGS. 4A-4C are cross-sectional views of exemplary embodiments of vortex-generating structures.

[0011] FIG. 5 is a schematic view of another embodiment of a film cooling passage.

[0012] FIG. 6A is a cross-sectional view of a portion of another embodiment of a film cooled gas turbine engine component.

[0013] FIGS. 6B and 6C are cross-sectional views of a portion of the film cooled gas turbine engine component, taken along lines B-B and C-C, respectively, of FIG. 6A.

DETAILED DESCRIPTION

[0014] The present invention, in general, relates to structures and methods for generating a counter-rotating vortex film cooling flow along a surface of a component for a gas turbine engine exposed to hot gases, such as a turbine blade, vane, shroud, duct wall, etc. Such a film cooling flow can provide a thermally insulative barrier between the gas turbine engine component and the hot gases. According to the present invention, a pair of film cooling passages have closely-spaced outlets at an exterior surface (or face) of the component that is exposed to the hot gases. A vortex-generating structure is positioned within each film cooling passage of the pair to generate a vortex flow. The vortex flow generated within a first of the pair of film cooling passages rotates in a first rotational direction therein, prior to reaching an outlet, and the vortex flow generated within a second of the pair of film cooling passages rotates in a substantially opposite direction (i.e., counter-rotates with respect to the first rotational direction). In one embodiment of the present

invention, the vortex-generating structures can comprise helical ribs (or rifling), with the helical ribs of the first and second film cooling passages winding in opposite directions. Additional features and benefits of the present invention will be recognized in light of the description that follows.

[0015] FIG. 1 is a perspective view of an exemplary film cooled turbine blade 20 having an airfoil portion 22. Pairs of film cooling hole outlets 24 are positioned along exterior sidewall surfaces of the airfoil portion 22 (only one side of the airfoil portion 22 is visible in FIG. 1). The hole outlets 24 of each pair are located at substantially the same streamwise location along the airfoil portion 22. During operation, the pairs of film cooling hole outlets 24 eject a film cooling fluid (e.g., compressor bleed air) to provide a thermally insulative barrier along portions of the turbine blade 20 exposed to hot gases. The particular arrangement of the pairs of film cooling hole outlets 24 shown in FIG. 1 is merely exemplary, and nearly any desired arrangement of the pairs of film cooling hole outlets 24 is possible in alternative embodiments. It should also be noted that the turbine blade 20 is shown merely as one example of a gas turbine engine component that can be film cooled according to the present invention. The present invention is equally applicable to other types of gas turbine engine components, such as vanes, shrouds, duct walls, etc.

[0016] FIG. 2A is a cross-sectional view of a portion of a wall 30 of a film cooled gas turbine engine component. The wall 30 has an exterior surface 32 that is exposed to a hot gas flow 34. As shown in FIG. 2A, a substantially cylindrically shaped first film cooling passage 36A extends through the wall 30 to a first outlet 38A located at the exterior surface 32 of the wall 30, the first film cooling passage 36A being angled slightly toward a free stream direction of the hot gas flow 34. The first outlet 38A can be shaped similarly to a cross-sectional profile of an interior portion of the first film cooling passage 36A. A substantially helically-shaped vortex generating rib 40A is positioned along an interior surface of the first film cooling passage 36A, and can be formed using electro-discharge machining (EDM), stem drilling, casting, or other suitable processes. A film cooling fluid 42 passes through the first film cooling passage 36A and is ejected from the first outlet 38A, and then forms a thermally insulative barrier along the exterior surface 32 of the wall 30 that extends downstream from the first outlet 38A. Although only the first film cooling passage 36A is visible in FIG. 2A, a second film cooling passage 36B can be positioned adjacent to the first film cooling passage 36A and have a similar configuration. The first and second film cooling passages 36A and 36B respectively can be arranged substantially parallel to one another, angled toward one another (i.e., in a non-parallel arrangement), or have other configurations. Furthermore, the first and second film cooling passages 36A and 36B respectively can be connected to a common fluid supply manifold (not shown), or otherwise branched together opposite the first and second outlets

38A and 38B respectively.

[0017] FIG. 2B is a cross-sectional view of a portion of the wall 30 of the film cooled gas turbine engine component, taken along line B-B of FIG. 2A. The pair of first and second film cooling passages 36A and 36B respectively have a first and second substantially helically-shaped vortex-generating ribs 40A and 40B, respectively. The first vortex-generating rib 40A generates a vortex flow within the first film cooling passage 36A in generally a first rotational direction 44 (e.g., clockwise). The second vortex-generating rib 40B generates a vortex flow within the second film cooling passage 36B in generally a second rotational direction 46 (e.g., counter-clockwise). It should be noted that the cross-section of FIG. 2B is taken at a location within the wall 30, upstream from the first and second outlets 38A and 38B respectively of the film cooling passages 36A and 36B (see FIG. 2A), and vortex flows are present within the film cooling passages 36A and 36B upstream from the first and second outlets 38A and 38B respectively.

[0018] FIG. 2C is a cross-sectional view of a portion of the wall 30 of the film cooled gas turbine engine component, taken along line C-C of FIG. 2A just downstream from the first and second outlets 38A and 38B respectively (not shown in FIG. 2C) along the exterior surface 32 of the wall 30 (relative to the hot gas flow 34). As shown in FIG. 2C, cooling fluid 42 from both the first and second film cooling passages 36A and 36B respectively (not shown in FIG. 2C) have mixed together to form a contiguous jet of the film cooling fluid 42 upon leaving the first and second outlets 38A and 38B, respectively (not shown in FIG. 2C). A boundary 48 is defined between the jet of the film cooling fluid 42 and the hot gas flow 34. The cooling fluid 42 passes along the exterior surface 32 of the wall 30, attached thereto, that is, the film cooling fluid 42 remains substantially in contact with the exterior surface 32 to form a barrier between the exterior surface 32 and the hot gas flow 34. The film cooling fluid 42 includes counter-rotating vortices defined by fluid rotating in the substantially opposite first and second rotational directions 44 and 46 respectively. The first and second rotational directions 44 and 46 respectively can be arranged to generally oppose a tendency of the hot gas flow 34 to move toward the exterior surface 32 of the wall 30, thereby reducing "liftoff" or "flow separation" that occur when a portion of the hot gas flow 34 extends between the film cooling fluid 42 and the exterior surface 32 of the wall 30. In the illustrated embodiment, the first and second rotational directions 44 and 46 respectively are arranged to flow generally toward the exterior surface 32 at a location where the vortexes adjoin each other, and generally away from the exterior surface 32 at lateral boundaries of the jet of the film cooling fluid 42.

[0019] FIG. 2D is a cross-sectional view of a portion of the wall 30 of the film cooled gas turbine engine component, taken along line D-D of FIG. 2A downstream from the cross-sectional view shown in FIG. 2C (relative to the hot gas flow 34). As shown in FIG. 2D, the counter-ro-

tating vortices defined by the film cooling fluid 42 rotating in the substantially opposite first and second rotational directions 44 and 46 respectively causes mixing with the hot gas flow 34 at or near the boundary 48, which can reduce momentum of the counter-rotating vortices of the film cooling fluid 42 and also reduce or disrupt momentum of the hot gas flow 34 in a direction toward the wall 30. This mixing can help reduce "liftoff" of the film cooling fluid 42, such that the film cooling fluid 42 remains substantially attached to the exterior surface 32 of the wall.

[0020] FIG. 2E is a cross-sectional view of a portion of the wall 30 of the film cooled gas turbine engine component, taken along line E-E of FIG. 2A downstream from the cross-sectional view of FIG. 2D. As shown in FIG. 2E, mixing of the film cooling fluid 42 with the hot gas flow 34 (not labeled in FIG. 2E) has formed a mixed fluid zone 48 around the original location of the boundary 48, which is no longer a distinct transition. The film cooling fluid 42 has lost essentially all rotational kinetic energy, meaning the counter-rotating vortices have substantially ceased to rotate. The film cooling fluid 42 still moves downstream along wall 30 substantially attached to the exterior surface 32. The film cooling fluid 42 will inevitably degrade as it continues downstream along the exterior surface 32 of the wall 30. However, the present invention can allow the film cooling fluid 42 to provide a relatively effective thermal barrier that is substantially attached to the exterior surface 32 for a relatively long distance along the wall 32 downstream from the first and second outlets 38A and 38B respectively.

[0021] FIG. 3 is a schematic view of the pair of first and second film cooling passages 36A and 36B respectively. The first and second film cooling passages 36A and 36B respectively define first and second central axes 50A and 50B, respectively. The first and second central axes 50A and 50B respectively are arranged substantially parallel to one another, and are closely spaced apart by a distance S. As used herein, the term "closely spaced" means spaced from each other on the order of a few diameters. For example, the spacing could be greater than one and up to ten diameters, or greater than one and up to three diameters. The first film cooling passage 36A has a radius R_A , and the second film cooling passage has a radius R_B . In one embodiment, the radii R_A and R_B can be substantially equal. The first vortex-generating structure 40A has a pitch P_A , and the second vortex-generating structure 40B has a pitch P_B . The pitches P_A and P_B can be substantially constant (as shown in FIG. 3) or variable along lengths of the first and second film cooling passages 36A and 36B, respectively.

[0022] The first and second vortex-generating structures 40A and 40B respectively can have nearly any desired cross-sectional shape (or profile). FIGS. 4A, 4B, and 4C are cross-sectional views of exemplary embodiments of vortex-generating structures 140A, 140B, and 140C, respectively, each defining a height H_t and a width W_t . The vortex-generating structure 140A shown in FIG. 4A has a substantially rectangular cross-sectional shape,

the vortex-generating structure 140B shown in FIG. 4B has a substantially triangular cross-sectional shape, and the vortex-generating structure 140C shown in FIG. 4C has a substantially arcuate cross-sectional shape. It should be understood that further cross-sectional shapes can be utilized in alternative embodiments.

[0023] The following are descriptions of particular dimensions and proportions for exemplary embodiments of the present invention. These embodiments are provided merely by way of example and not limitation. The first and second film cooling passages 36A and 36B and the first and second vortex-generating structures 40A and 40B can be described as having vortex generating structures with a pitch P that is a multiple of a radius R, where P represents either the pitch P_A or P_B and R represents the corresponding radius R_A or R_B . The pitch P can be in the range of approximately 1 to 10 times the radius R, or alternatively in the range of approximately 1.5 to 3 times the radius R.

[0024] A ratio of the height of vortex-generating structure H_t over the diameter of the associated film cooling passage (i.e., two times the radius R_A or R_B) can be between approximately 0.05 and 0.5, or alternatively between approximately 0.1 and 0.3. A ratio of the width W_t over the height H_t of the vortex-generating structures 40A and 40B can be between approximately 0.5 and 4, or alternatively between approximately 0.5 and 1.5. The distance S between the axes 50A and 50B can be less than approximately ten times the radius R, or alternatively between approximately two to six times the radius R. Furthermore, a length of the first and second film cooling passages 36A and 36B respectively can be at least approximately three to ten times a hydraulic diameter at the respective first and second outlets 38A and 38B, or alternatively at least approximately 5 to ten times the hydraulic diameter at the respective first and second outlets 38A and 38B (where the hydraulic diameter is four times the area divided by the perimeter).

[0025] FIG. 5 is a schematic view of an alternative embodiment of a film cooling passage 36 of the present invention (applicable to either one of the pair of film cooling passages 36A or 36B). As shown in FIG. 5, the film cooling passage 36 includes two sets of helical vortex-generating ribs 46C and 46D that wind in the same direction, adjacent one another (the vortex-generating rib 46C is represented by a weighted line in FIG. 5, for illustrative purposes). In the illustrated embodiment, the rib 46C has a pitch P_1 and the rib 46D has a pitch P_2 . The pitches P_1 and P_2 can be substantially equal. The pitches P_1 and P_2 can be substantially constant (as shown in FIG. 3) or variable along lengths of the film cooling passage 36. In further embodiments, still more additional ribs can be provided.

[0026] The present invention provides numerous advantages. For example, while mixing of film cooling fluid jets with hot gas flows represents an efficiency loss, that loss is balanced against improved film cooling effectiveness per film cooling passage. This can permit a given

level of film cooling to be provided to a given component with a relatively small number of film cooling passages for a given film cooling fluid flow rate and/or increasing spacing between pairs of cooling hole outlets. Moreover, even with the presence of paired, closely spaced cooling hole outlets, the present invention can provide film cooling to a given surface area with a relatively low density of cooling holes and a relatively low total cooling hole area. Film cooling according to the present invention can help allow gas turbine engine components to operate in higher temperature environments with a relatively low risk of thermal damage.

[0027] FIGS. 6A, 6B and 6C illustrate an alternative embodiment of the present invention, configured to produce a different effect from the previously described embodiments.

FIG. 6A is a cross-sectional view of another embodiment of a portion of a wall 30 of the film cooled gas turbine engine component. FIG. 6B is a cross sectional view of a portion of the film cooled gas turbine engine component 30, taken along line B-B of FIG. 6A. In this embodiment, the first film cooling passage 36A has a first helical vortex-generating rib 40C, which winds in an opposite direction with respect to the first vortex-generating rib 40A of previously-described embodiments, and a second helical vortex-generating rib 40D, which winds in an opposite direction with respect to the second vortex-generating rib 40B of previously-described embodiments (vortex-generating ribs 40A and 40B are not shown in FIG. 6B). In this configuration, the film cooling fluid 42 rotates in the second rotational direction 46 (e.g., counter-clockwise) within the first film cooling passage 36A, and the film cooling fluid 42 rotates in the first rotational direction 44 (e.g., clockwise) within the second film cooling passage 36B.

[0028] FIG. 6C is a cross sectional view of a portion of the film cooled gas turbine engine component 30, taken along line C-C of FIG. 6A (i.e., downstream from an outlet of the film cooling passage 36A). In the illustrated embodiment, the first and second rotational directions 44 and 46 are arranged to flow generally away from the exterior surface 32 at a location where the vortexes adjoin each other, and generally toward the exterior surface 32 at lateral boundaries of the jet of the film cooling fluid 42. This configuration would essentially encourage liftoff of the fluid 42 from the exterior surface 32 (i.e., the entrainment of the hot gas flow 34 between the exterior surface 32 and the cooling fluid 42), which may be desirable for fluidic injection applications, etc.

[0029] Although the present invention has been described with reference to preferred embodiments, workers skilled in the art will recognize that changes may be made in form and detail without departing from the scope of the invention, which is defined by the claims and their equivalents. For instance, the particular angle of film cooling passages relative to a film cooled surface can vary as desired for particular applications. Moreover, a cross-sectional area of film cooling passages of the

present invention can vary over their length (e.g., with substantially conical film cooling passages).

5 Claims

1. An apparatus for use in a gas turbine engine, the apparatus comprising:

a wall defining an exterior face;
a first film cooling passage extending through the wall for providing film cooling to the exterior face of the wall, wherein the first film passage includes a first vortex-generating structure for inducing a vortex in a first rotational direction in a cooling fluid passing therethrough; and
a second film cooling passage extending through the wall adjacent to the first film cooling passage for providing film cooling to the exterior face of the wall, wherein the second film passage includes a second vortex-generating structure for inducing a vortex in a second rotational direction in a cooling fluid passing therethrough, and wherein the first and second rotational directions are substantially opposite one another.

2. The apparatus of claim 1, wherein the first vortex-generating structure comprises a first helical rib disposed along an interior surface of the first film cooling passage.

3. The apparatus of claim 2, wherein the second vortex-generating structure comprises a second helical rib disposed along an interior surface of the second film cooling passage, and wherein the first and second helical ribs of the first and second vortex-generating structures wind about respective central axes in opposite directions.

4. The apparatus of claim 1, 2 or 3 wherein the first and second vortex-generating structures are configured as mirror images of one another.

5. The apparatus of claim 1, 2, 3 or 4 wherein the first and second film cooling passages have respective first and second outlets closely spaced from each other along the exterior face of the wall.

6. An apparatus for use in a gas turbine engine, the apparatus comprising:

a wall defining an exterior face;
a pair of closely spaced film cooling passages extending through the wall for providing film cooling to the exterior face of the wall, the pair comprising:

a first film cooling passage extending to a

- first outlet on the exterior face of the wall, wherein the first film passage includes a first helically-shaped vortex-generating structure disposed along an interior surface of the first film cooling passage for inducing a vortex in a first rotational direction in a cooling fluid passing therethrough; and a second film cooling passage extending to a second outlet on the exterior face of the wall, wherein the second film passage includes a second helically-shaped vortex-generating structure disposed along an interior surface of the second film cooling passage for inducing a vortex in a second rotational direction in a cooling fluid passing therethrough.
7. The apparatus of claim 6, wherein the first and second rotational directions are substantially opposite one another.
8. The apparatus of claim 10, wherein the first and second vortex-generating structures are configured as substantially mirror images of each other.
9. The apparatus of any preceding claim, wherein the first and second rotational directions are arranged to flow generally toward the exterior face of the wall at a location where the vortices adjoin each other.
10. The apparatus of any preceding claim, wherein the first and second film cooling passages define respective first and second central axes, wherein the first film cooling passage defines a first diameter, and wherein the first and second central axes are spaced from each other by a distance less than or equal to approximately ten times the first diameter.
11. The apparatus of any preceding claim, wherein the first and second film cooling passages are both substantially cylindrically-shaped.
12. The apparatus of any preceding claim, wherein the first and second film cooling passages extend substantially parallel to each other through the wall.
13. A method of film cooling a gas turbine engine component exposed to a hot fluid stream, the method comprising:
- directing a cooling fluid into a first film cooling passage of the component;
 passing the cooling fluid over at least one first vortex-generating structure to rotate a portion of the cooling fluid within the first film cooling passage in a first rotational direction;
 directing a cooling fluid into a second film cooling passage of the component;
 passing the cooling fluid over at least one second vortex-generating structure to rotate a portion of the cooling fluid within the second film cooling passage in a second rotational direction that counter-rotates with respect to the first rotational direction;
 ejecting the cooling fluid rotating in the first rotational direction out of a first outlet in fluid communication with the first film cooling passage;
 ejecting the cooling fluid rotating in the second rotational direction out of a second outlet in fluid communication with the second film cooling passage, wherein the counter-rotating cooling fluid ejected from the first and second outlets forms a contiguous cooling film jet; and
 passing the counter-rotating cooling film jet along an exterior surface of the component to provide film cooling therealong.
14. The method of claim 13, wherein the counter-rotation of the film cooling jet concentrates mixing with the hot fluid stream at a region spaced away from the exterior surface of the component.

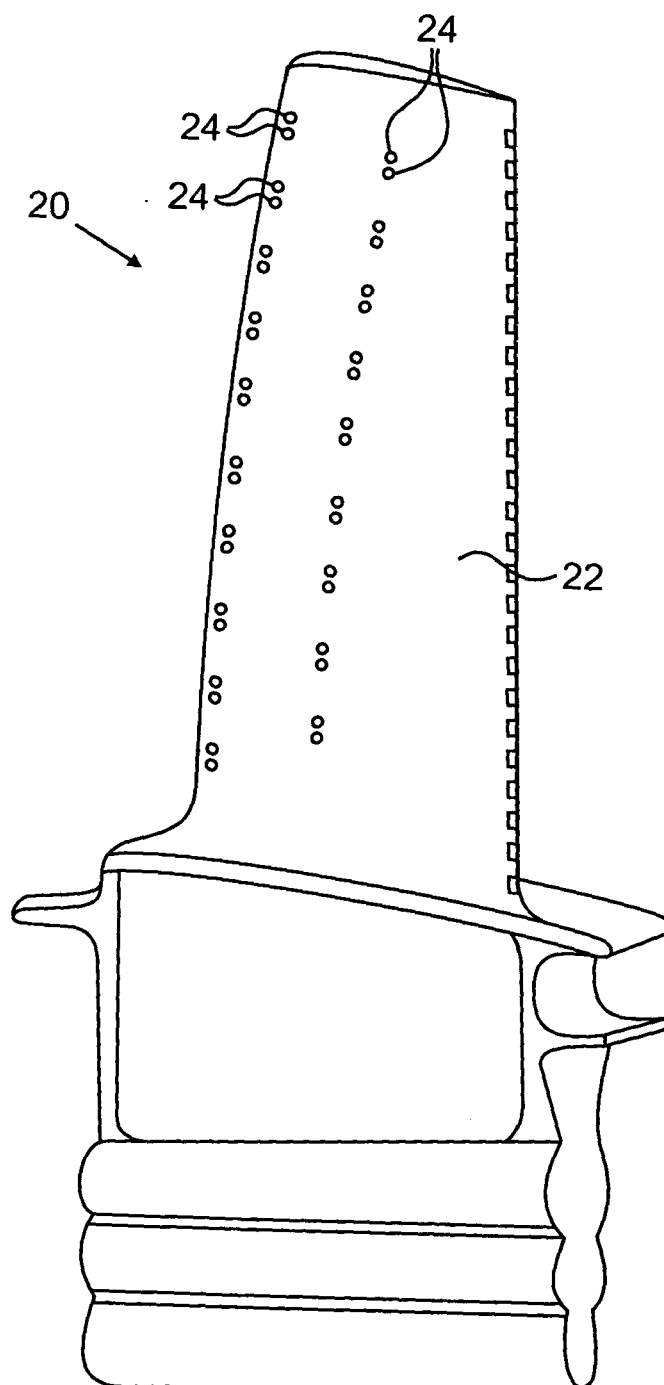


FIG. 1

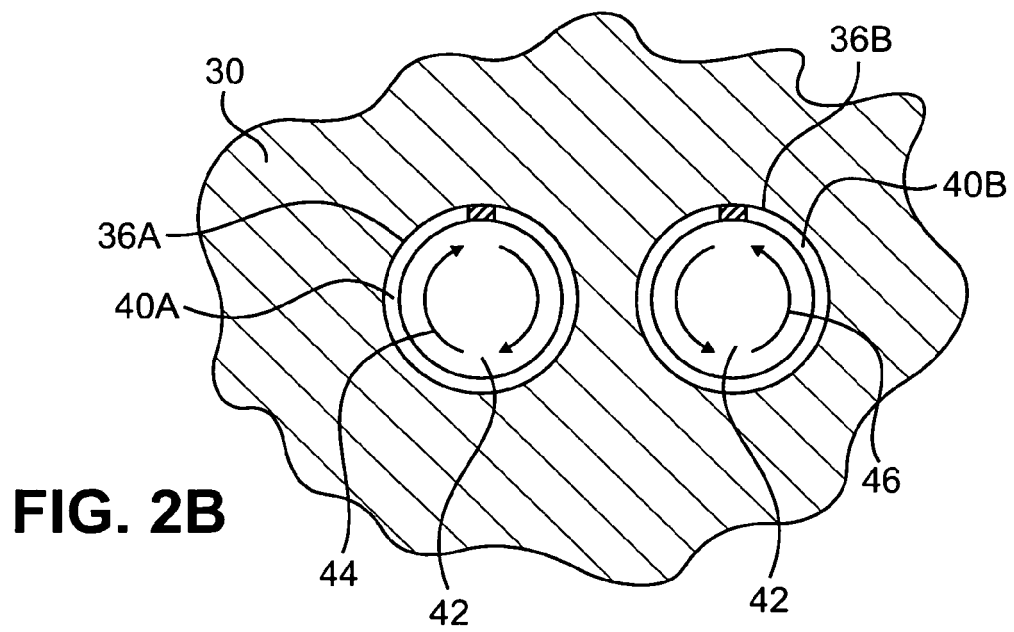
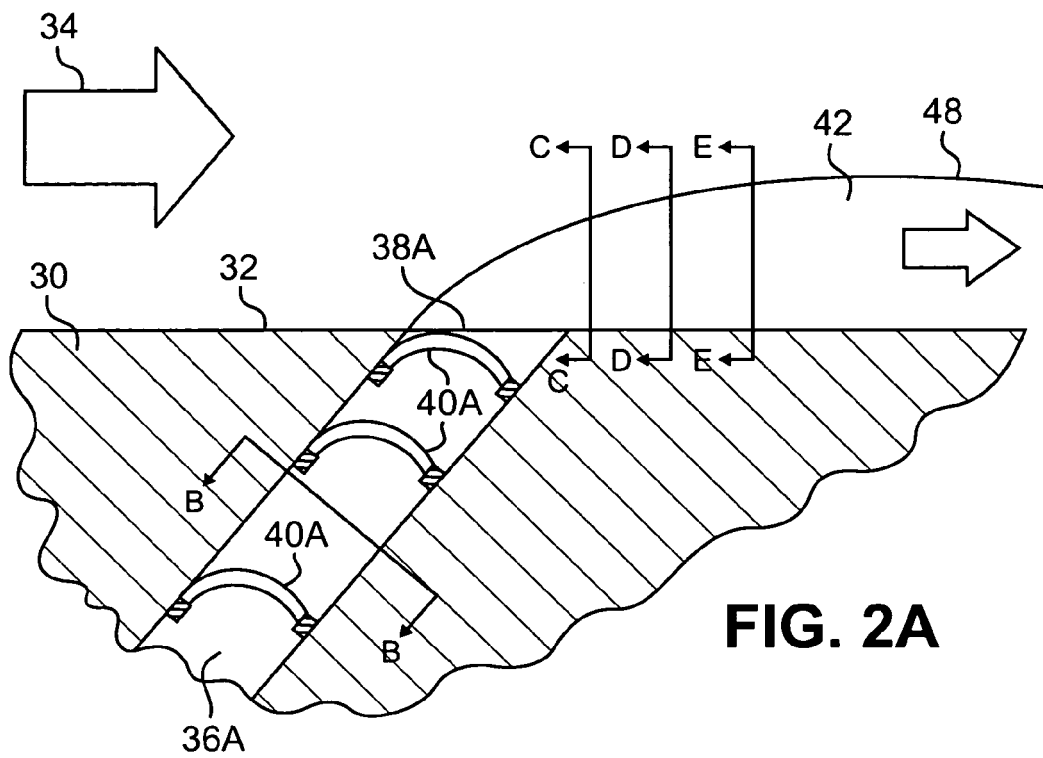


FIG. 2C

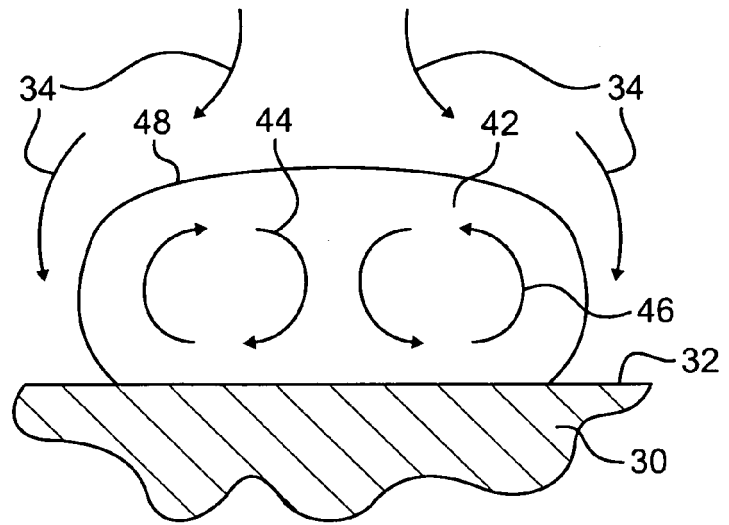


FIG. 2D

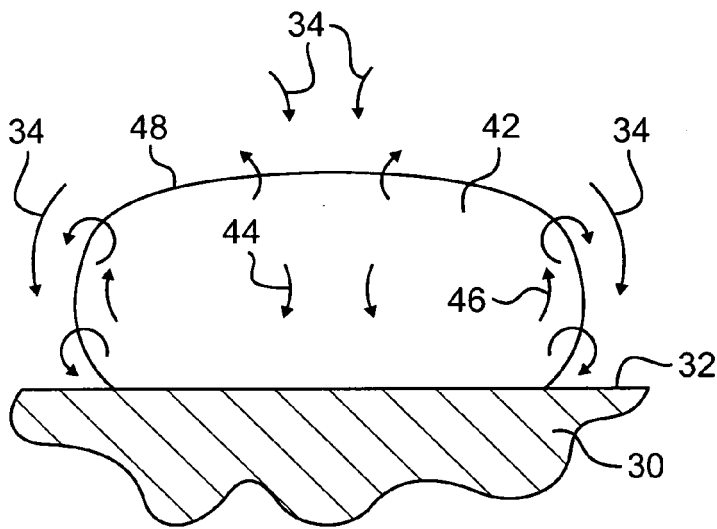
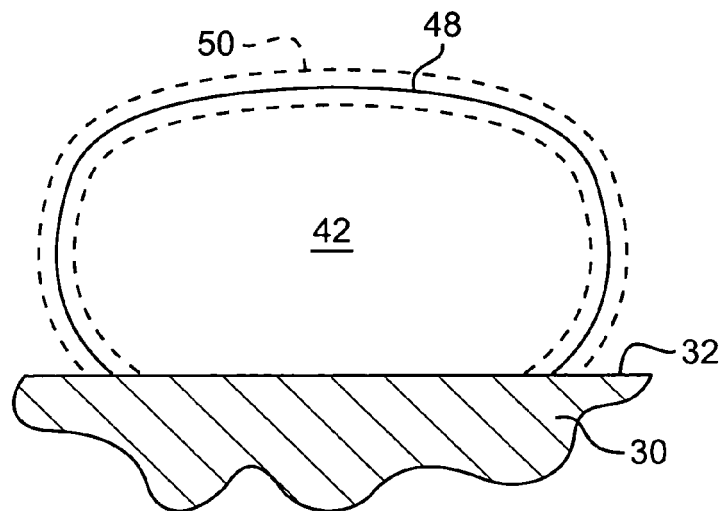


FIG. 2E



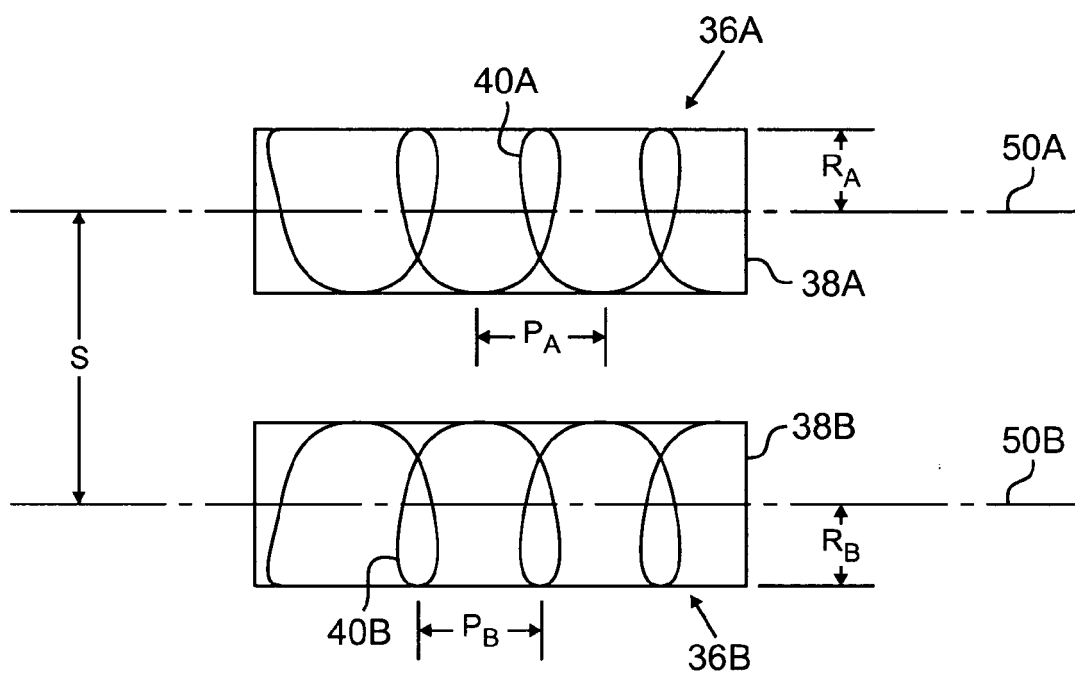
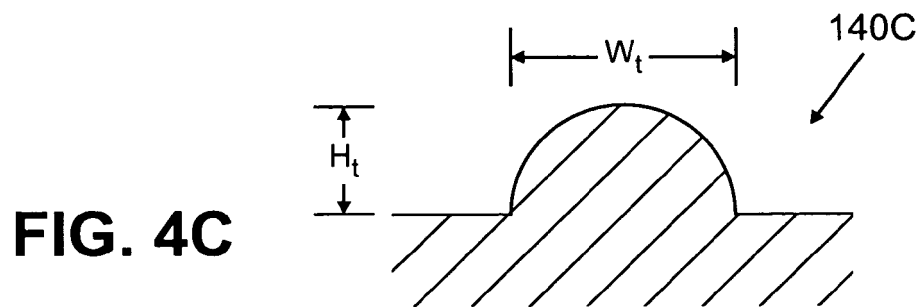
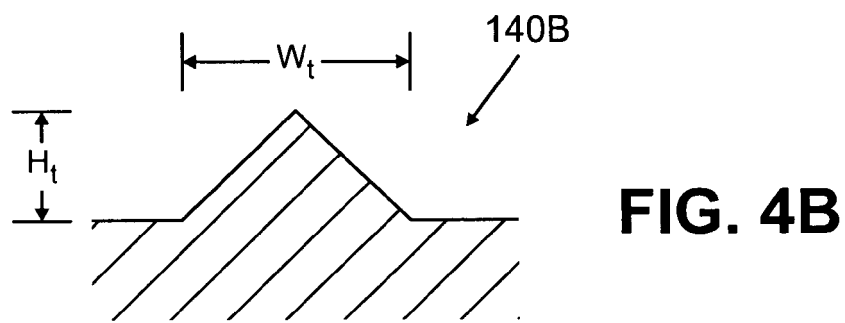
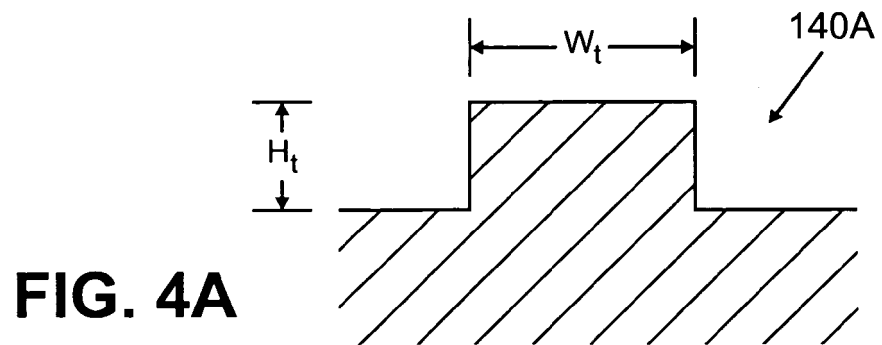


FIG. 3



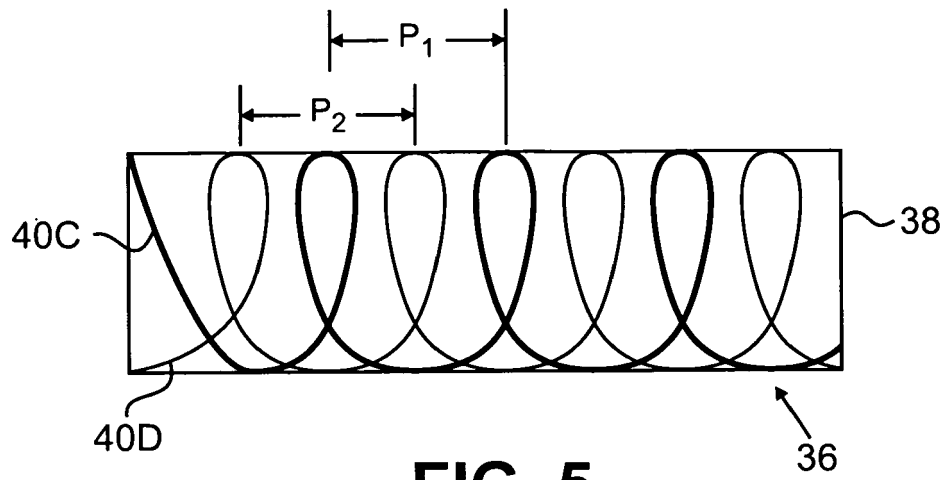


FIG. 5

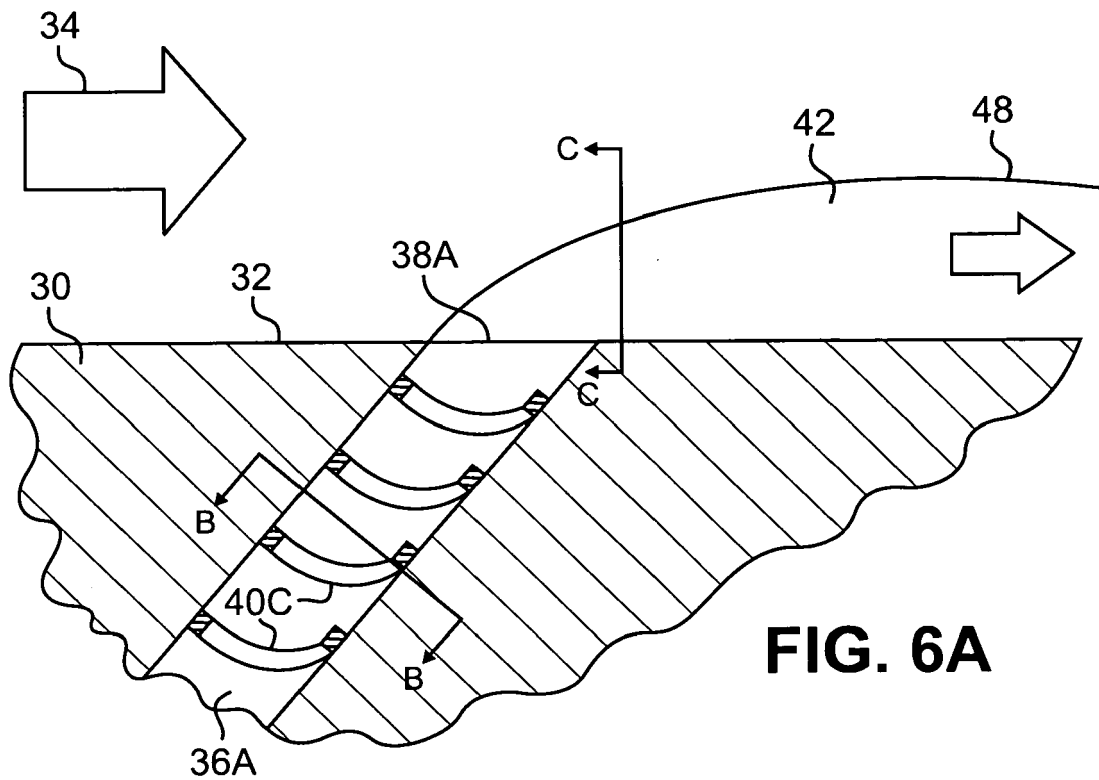


FIG. 6A

