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(54) **NEAR-WALL SERPENTINE COOLED TURBINE AIRFOIL**

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(57) **ABSTRACT**

Certain exemplary embodiments can provide a serpentine coolant flow path formed by inner walls in a cavity between pressure and suction side walls of a turbine airfoil and/or can be adapted to provide cooling matched to the heating topography of the airfoil, minimize differential thermal expansion, revive the coolant, and/or minimize the flow volume needed.

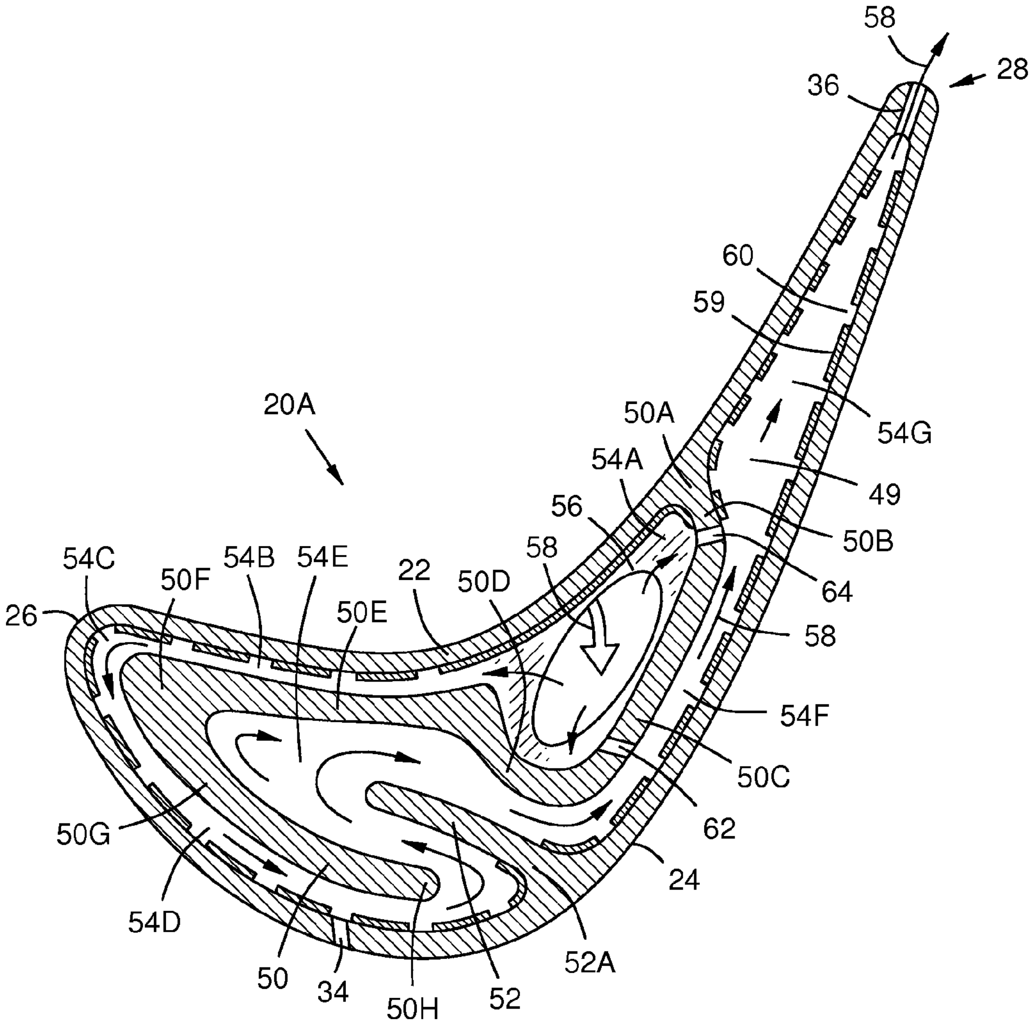


FIG 1
PRIOR ART

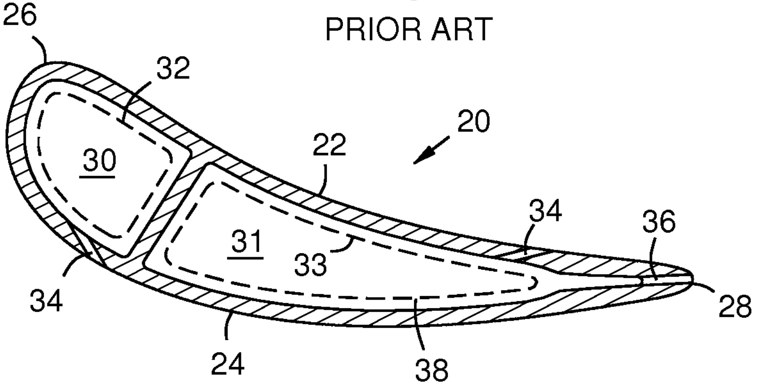
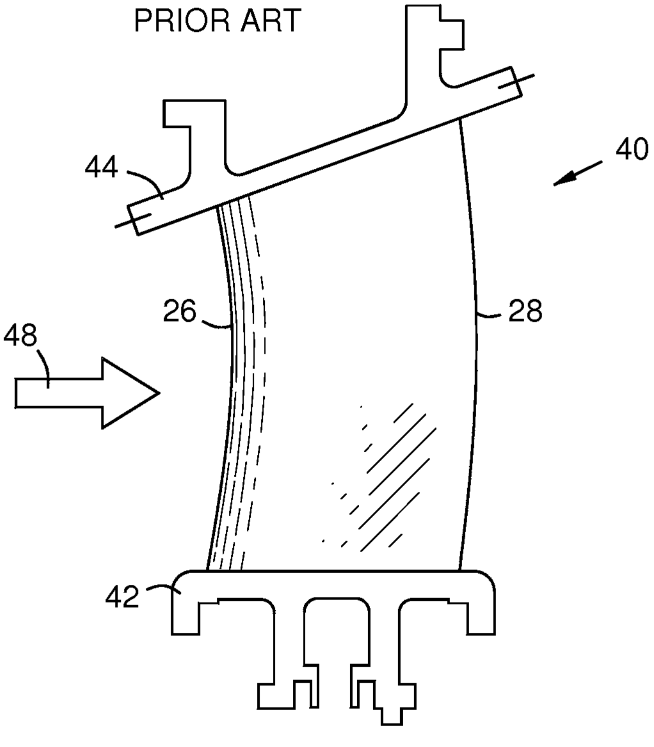


FIG 2
PRIOR ART



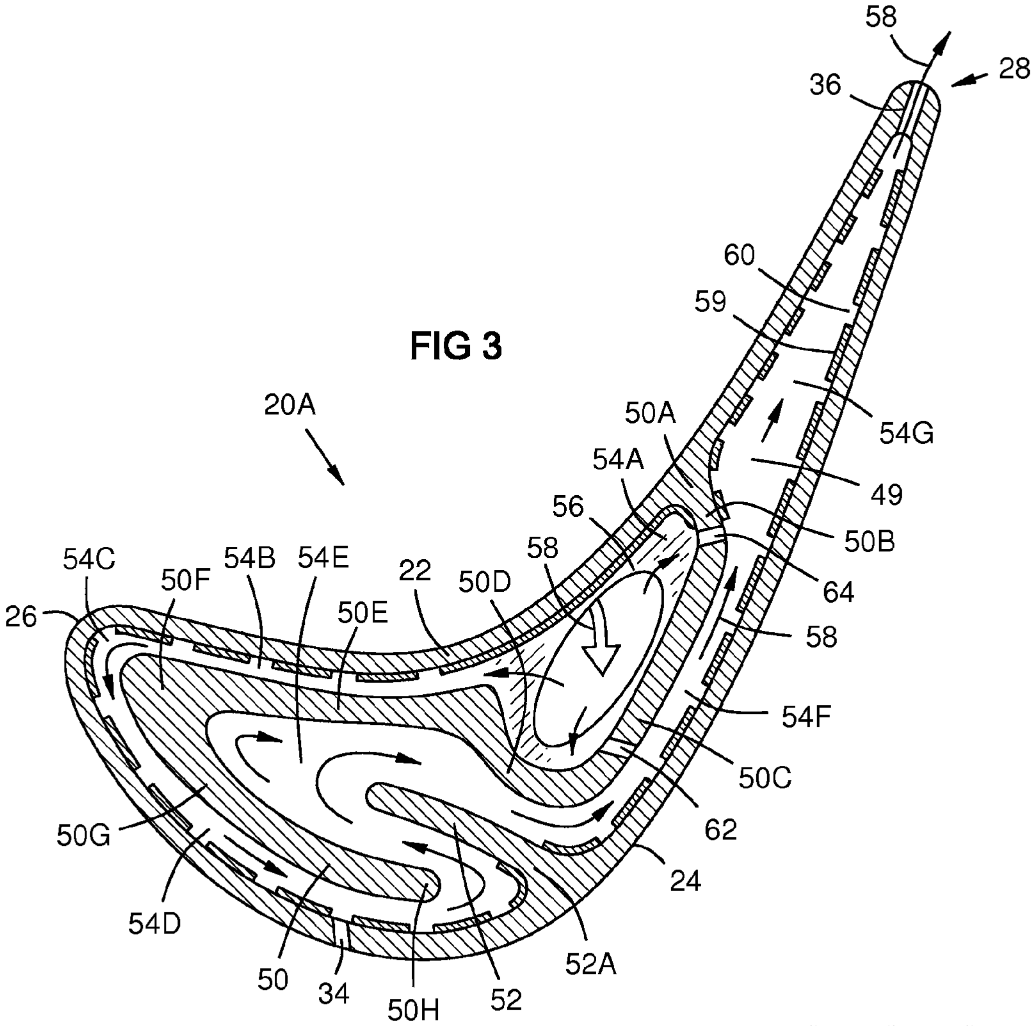

58
28
36
60
59
54G
50A
20A
54A
49
56
50B
58
64
54C
50F
54B
54E
22
50D
58
26
50E
54F
50C
62
50G
24
54D
52A
50
34
50H
52

FIG 3

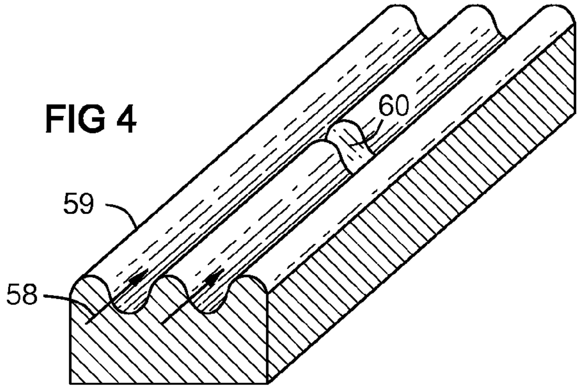

60
59
58

FIG 4

FIG 5

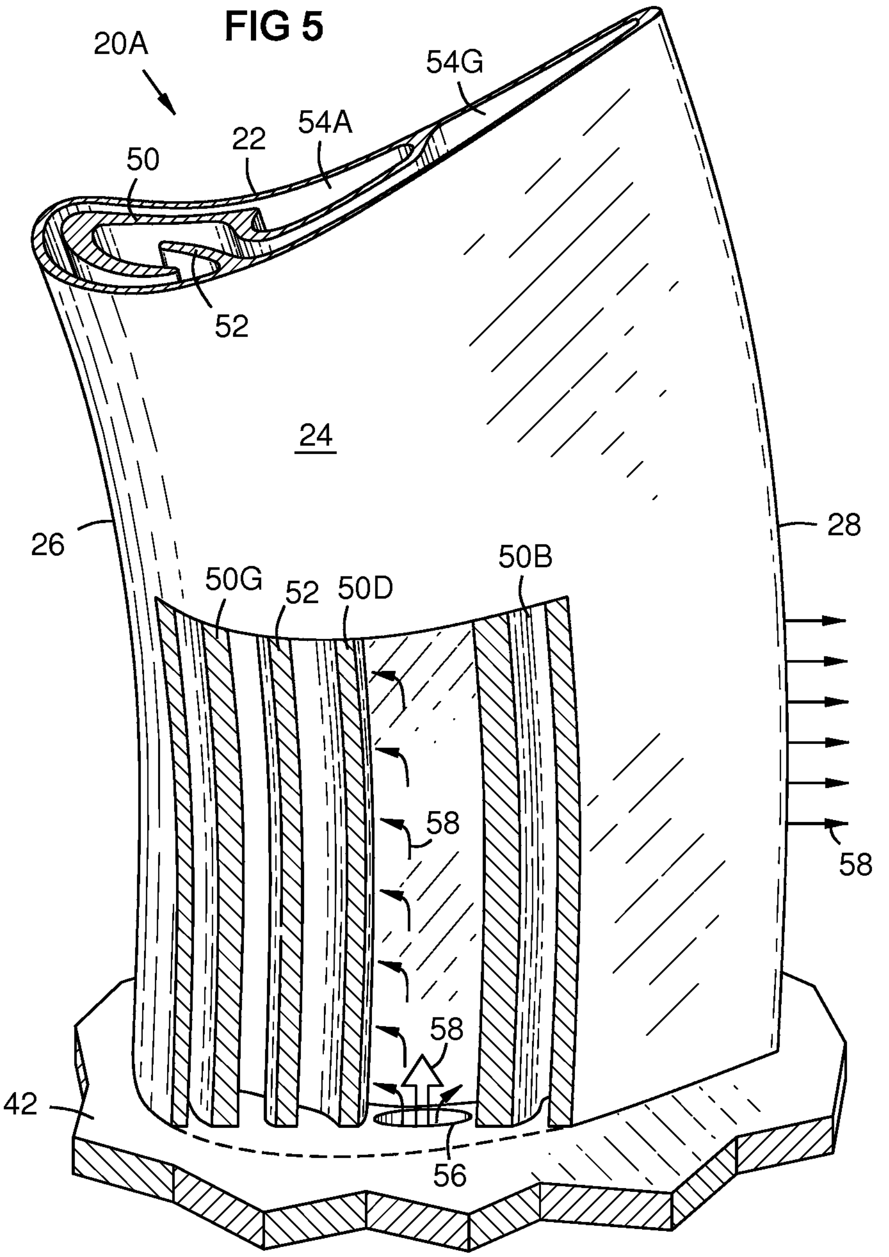


FIG 6

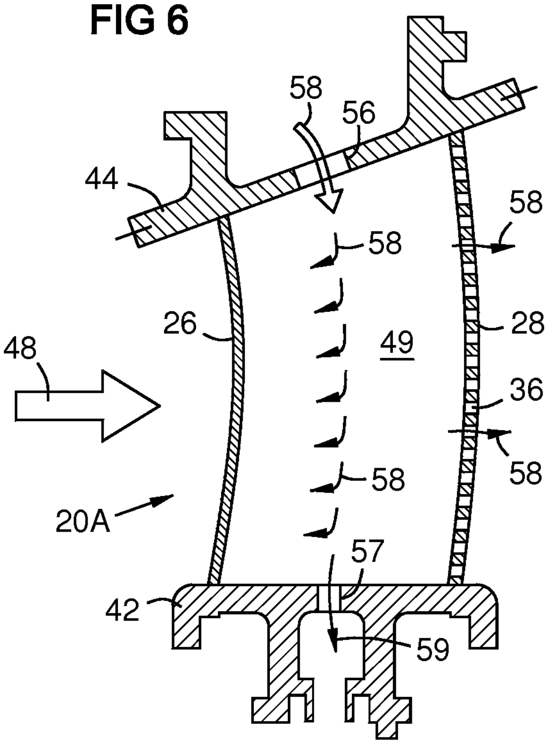
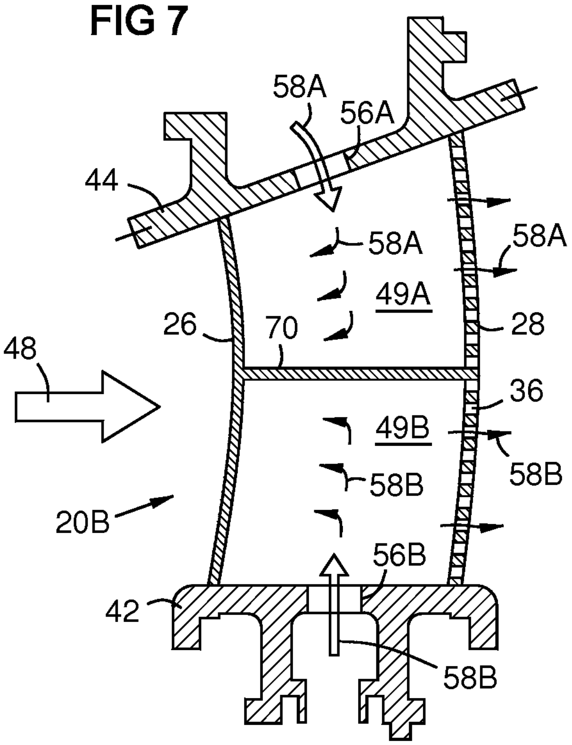

58
56
44
58
58
26
28
48
49
36
58
58
20A
57
42
59

FIG 7


58A
56A
44
58A
58A
49A
26
70
28
48
36
49B
58B
58B
20B
56B
42
58B

NEAR-WALL SERPENTINE COOLED TURBINE AIRFOIL

STATEMENT REGARDING FEDERALLY SPONSORED DEVELOPMENT

[0001] Development for this invention was supported in part by Contract Number DE-FC26-05NT42644, awarded by the United States Department of Energy. Accordingly, the United States Government may have certain rights in this invention.

FIELD OF THE INVENTION

[0002] This invention relates to coolant flow channels in turbine airfoils, and particularly in curved vanes.

BACKGROUND OF THE INVENTION

[0003] Stationary guide vanes and rotating turbine blades in gas turbines often have internal cooling channels. Cooling effectiveness is important in order to minimize thermal stress on these airfoils. Cooling efficiency is important in order to minimize the volume of air diverted from the compressor for cooling.

[0004] Film cooling provides a film of cooling air on outer surfaces of an airfoil via holes in the airfoil surface from internal cooling channels. Film cooling can be inefficient, because so many holes are needed that a high volume of cooling air is required. Thus, film cooling has been used selectively in combination with other techniques.

[0005] Impingement cooling is a technique in which perforated cooling tubes are inserted into span-wise channels in an airfoil to create impingement jets against the inner surfaces of the airfoil. A disadvantage is that warmer post-impingement air moves along the inner surfaces of the airfoil and interferes with the impingement jets. Impingement tubes require a nearly straight airfoil for insertion, but some turbine airfoils have a curved span for aerodynamic efficiency.

[0006] Another technique uses serpentine cooling channels that go from one end of the airfoil to the other and back. Air in such channels is much cooler at the beginning of the flow sequence, so it can cool the airfoil unevenly.

[0007] The present invention provides high efficiency, a cooling rate topography that matches the heating topography of an airfoil, coolant revival at mid-flow, and reduction of differential thermal expansion. It does not require impingement tube inserts, and can be formed in curved airfoils. Thus, it overcomes all of the above-mentioned disadvantages.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] The invention is explained in the following description in view of the drawings that show:

[0009] FIG. **1** is a transverse sectional view of a prior art turbine vane with impingement cooling inserts.

[0010] FIG. **2** is a side view of a prior art curved gas turbine vane.

[0011] FIG. **3** is a transverse sectional view of a turbine airfoil showing aspects of the invention.

[0012] FIG. **4** is a perspective view of a portion of an airfoil wall with corrugations.

[0013] FIG. **5** is a perspective cutaway sectional view of a curved vane and part of an inner platform showing aspects of the invention.

[0014] FIG. **6** is a sectional side view of a curved turbine vane between inner and outer platforms, showing aspects of the invention.

[0015] FIG. **7** is a sectional side view of a curved turbine vane between inner and outer platforms with a transverse partition providing radially inner and outer cooling circuits.

DETAILED DESCRIPTION OF THE INVENTION

[0016] FIG. **1** is a transverse sectional view of a prior art turbine vane **20** with a pressure side wall **22**, a suction side wall **24**, a leading edge **26**, a trailing edge **28**, internal cooling channels **30**, **31**, impingement cooling baffles **32**, **33**, film cooling holes **34**, and coolant exit holes **36**. The impingement cooling baffles are thin-walled tubes inserted into the cooling channels **30**, **31**. They are spaced apart from the channel walls. Cooling air enters an end of each impingement baffle **32**, **33**, and flows span-wise within the vane. It exits impingement holes **38**, and impinges on the walls **22**, **24**.

[0017] FIG. **2** shows a side view of a prior art curved turbine vane **40** that spans between radially inner and outer platforms **42**, **44**. The platforms are mounted in a circular array of adjacent platforms, forming inner and outer shrouds that define an annular flow path between them for a working gas **48** that passes over the vanes.

[0018] FIG. **3** shows a transverse section of an airfoil with a pressure side wall **22** and a suction side wall **24** connected to each other at a leading edge **26** and a trailing edge **28**. Within the airfoil is a cavity **49** with a first inner wall **50** and a second inner wall **52**, defining a continuous serpentine cooling flow path with a sequence of segments as follows:

[0019] a) a cooling inlet channel **54**A that extends span-wise along at least a portion of the pressure side wall **22**;

[0020] b) a forward pressure side near-wall channel **54**B along a forward portion of the pressure side wall;

[0021] c) a leading edge near-wall channel **54**C;

[0022] d) a forward suction side near-wall channel **54**D along a forward portion of the suction side wall;

[0023] e) a loop channel **54**E routed forward toward the leading edge **26** then back, between the first and second inner walls **50**, **52**;

[0024] f) an intermediate suction side near-wall channel **54**F along an intermediate portion of the suction side wall **24**; and

[0025] g) an aft channel **54**G between the pressure and suction side walls **22**, **24** aft of the cooling inlet channel **54**A. Some or all of the coolant flow **58** may exit the airfoil via holes **36** in the trailing edge **28**.

[0026] Herein, the term "radial" means in a direction of the airfoil span from root to tip and perpendicular in relation to the turbine rotational axis when the airfoil is installed in a turbine. "Transverse section" means a section through the airfoil taken on a plane normal to the airfoil span. "Chord line" is a line connecting the leading and trailing edge in a given transverse section of the airfoil. "Span-wise" means oriented substantially in a direction of a line or curve connecting the midpoints of all chord lines of an airfoil. "Span-wise" may be the same or approximately the same as "radial" for a straight airfoil. However, it curves in airfoils that curve along their span as in FIG. **2**. "Forward" and "aft" mean toward the leading or trailing edge respectively within a transverse section of the airfoil. The span-wise cooling inlet channel **54**A, as seen in the transverse section, may be located adjacent to the pressure side wall at position between 30% and 70% of a chord length from the leading edge of the airfoil.

The first inner wall **50** may have a first end **50**A that is joined to an inner surface of the pressure side wall **22** at a position between 50% and 75% of a chord length from the leading edge. Coolant refreshment holes **62**, **64** may be provided in the first inner wall **50** between the cooling inlet channel **54**A and the intermediate suction side channel **54**F and/or between the cooling inlet channel **54**A and the aft channel **54**G. Film cooling holes **34** may be provided, for example in the suction side wall upstream of the coolant refreshment holes.

[0027] The cooling flow path **54**A-G may be narrowed along hotter portions of the airfoil outer walls **22**, **24**, **26**, **28**, to locally increase the cooling flow speed via the Bernoulli principle, and thus locally increase cooling. This provides the designer with a mechanism to fine tune the cooling topography on the airfoil outer walls in the design phase to match the heating topography of the airfoil.

[0028] FIG. **4** shows corrugations **59**, which may be provided on the inner surfaces of the pressure and suction side walls **22**, **24** to increase their surface area for the coolant flow **58**. The corrugations may be aligned with the flow **58**, to minimize resistance. Periodic gaps **60** or other discontinuities in the corrugations may be provided to restart the boundary layer to mix cooler air into a newly formed boundary layer.

[0029] FIG. **5** is a perspective sectional view of a curved vane **20**A and part of an inner platform **42**. A cutaway provides an inner view of parts of the inner walls **50** and **52**. The radially inner and outer ends of the airfoil outer walls **22**, **24**, **26**, **28** and inner walls **50**, **52**, may be integral with the respective platform **42**, **44**, or attached thereto. The inner walls **50**, **52** extend span-wise along at least a portion of the span of the airfoil, as if they were extruded span-wise from the transverse section of FIG. **3**. However, casting may be used for fabrication. One or both ends of the cooling inlet channel **54**A may be supplied with coolant through an inlet **56**.

[0030] FIG. **6** is a sectional side view of a curved turbine vane **20**A with a cavity **49** between inner and outer platforms **42**, **44**. For clarity, the inner walls **50** and **52** are not shown. Cooling air **58** from the turbine compressor may enter the cavity **49** through one or more inlets **56** in the outer platform **44**. The coolant follows a serpentine path as previously shown, and may exit the vane via trailing edge exit holes **36**. Part of the coolant **58** may exit a metering hole **57** in the inner platform **42**, to supply a plenum and channels that cool the inner shroud. Alternately, the coolant **58** may enter the inner **42** platform as shown in FIG. **5**. In this case, part of the coolant may exit a metering hole in the outer platform. Alternately, the coolant **58** may enter both the inner and outer platforms **42**, **44**.

[0031] FIG. **7** shows a sectional side view of a curved turbine vane **20**B with two cavities **49**A and **49**B separated by a transverse partition **70**. Two coolant flows **58**A, **58**B from the turbine compressor may enter the respective cavities **49**A, **49**B through one or more respective inlets **56**A **56**B. The two coolant flows **58**A, **58**B may be differently metered by the respective inlet opening sizes or by other means in order to customize the flow volumes in the cavities **49**A, **49**B to different requirements for the radially outer and inner portions of the vane.

[0032] Fabrication of the airfoils **20**A, **20**B including the inner walls **50**, **52** may be done by any known process including an advanced casting technique described in U.S. Pat. No. 7,141,812 of Mikro Systems Incorporated. The airfoil may be cast separately from the platforms, and joined thereto, or the airfoil and platforms may be cast integrally as one part. If they are cast integrally, the inner walls **50**, **52** only need to be attached to the pressure and suction side walls **22**, **24** at one end of each inner wall **50**A, **52**A as shown in FIG. **3**. The radial ends of the inner walls **50**, **52** may be integral with, or attached to, the platforms **42**, **44**. Additional attachment points (not shown) between the inner walls **50**, **52** and the outer walls **22**, **24**, **26**, **28** may be provided if needed for structural strength or vibration damping. The corrugations **59** may be cast integrally with the pressure and suction side walls **22**, **24**.

[0033] Benefits of the invention can be seen by following the coolant flow in FIG. **3**. First, the coolant enters the cooling inlet channel **54**A, then it spreads over a front portion of the pressure side wall **22**. This is where the airfoil is hottest, and where the coolant flow **58** is coolest. Next, the coolant turns around behind the leading edge **26** and flows back along a front portion of the suction side wall **24**. Now the coolant has gained heat, and has lost some of its cooling capacity. However, as it flows around the loop circuit **54**E, it is cooled by the inner wall segments **50**E, **50**D. This revives the cooling capacity of the flow **58**. It also warms the inner wall segments **50**E, **50**D, which reduces the temperature disparity between these otherwise cool inner wall segments and the hot pressure side wall **22**, reducing stress from differential thermal expansion. Furthermore, the speed of the flow across the surface to be cooled may be increased because the cross-sectional area of the flow path is reduced in this region compared to channel **54**A. The revived coolant then follows intermediate and aft channels **54**F, **54**G. The coolant may be further revived by refreshment holes **62**, **64**, as previously described. However, these holes may not be needed. Corrugations **59** may be provided as previously described, and may be aligned with the flow **58**, thus providing increased surface area with minimal friction. The coolant flow boundary layer may be restarted periodically via the gaps **60**. These features make optimum use of the coolant, and minimize the flow volume needed.

[0034] While various embodiments of the present invention have been shown and described herein, it will be obvious that such embodiments are provided by way of example only. Numerous variations, changes and substitutions may be made without departing from the invention herein. Accordingly, it is intended that the invention be limited only by the spirit and scope of the appended claims.

What is claimed is:

1. A turbine airfoil comprising:

a pressure side wall and a suction side wall connected to each other along leading and trailing edges;

a cavity disposed between the pressure and suction side walls;

a continuous serpentine cooling flow path formed by first and second inner walls in the cavity;

wherein:

the continuous serpentine cooling flow path routes a coolant flow in the following sequence as seen in a transverse section of the airfoil:

a) a cooling inlet channel that extends span-wise along at least a portion of the pressure side wall;

b) a forward pressure side near-wall channel along a forward portion of the pressure side wall;

c) a leading edge near-wall channel;

d) a forward suction side near-wall channel along a forward portion of the suction side wall; and

e) a loop channel routed between the first and second inner walls;

the cooling inlet channel, as seen in the transverse section, is adjacent to the pressure side wall at position between 30% and 70% of a chord length from the leading edge of the airfoil;

the first inner wall comprises a first end joined to an inner surface of the pressure side wall at a position between 50% and 75% of a chord length from the leading edge; and

the first inner wall extends span-wise along at least a portion of the airfoil.

2. The turbine airfoil of claim **1**, wherein the continuous serpentine cooling flow path routes the coolant flow through an intermediate suction side near-wall channel along an intermediate portion of the suction side wall.

3. The turbine airfoil of claim **1**, wherein the continuous serpentine cooling flow path routes the coolant flow through an aft channel that is aft of the cooling inlet channel between the pressure and suction side walls.

4. The turbine airfoil of claim **1**, wherein the continuous serpentine cooling flow path extends span-wise along a full span of the airfoil.

5. The turbine airfoil of claim **1**, wherein the cavity is partitioned by a transverse partition into two continuous serpentine cooling flow path routes each according to claim **1** with respective coolant inlets.

6. The turbine airfoil of claim **1**, further comprising corrugations on an inner surface of at least one of the pressure and suction side walls, wherein the corrugations are aligned with a coolant flow direction, and the corrugations comprise periodic gaps.

7. The turbine airfoil of claim **1**, further comprising a coolant refreshment hole in the first inner wall between the cooling inlet channel and the intermediate suction side near-wall channel or between the cooling inlet channel and the aft channel, and further comprising a film cooling hole in the suction side wall upstream of the coolant refreshment hole.

8. The turbine airfoil of claim **1**, wherein the cooling flow path narrows at a portion of the airfoil to locally increase a coolant flow speed.

9. The turbine airfoil of claim **1**, further comprising corrugations formed on an inner surface of at least one of the pressure side wall and the suction side wall.

10. A turbine airfoil comprising:

a pressure side wall and a suction side wall connected to each other along leading and trailing edges;

a cavity disposed between the pressure and suction side walls;

first and second inner walls within the cavity forming a continuous serpentine cooling flow path as seen in a transverse section of the airfoil;

wherein:

the first inner wall comprises a first end that joins an inner surface of the pressure side wall, thence extends toward the suction side wall, thence extends forward beside the suction side wall, thence extends toward the pressure side wall, thence extends forward beside the pressure side wall, thence turns behind the leading edge, thence extends aft beside the suction side wall, thence terminates in a second end;

the second inner wall comprises a first end that joins an inner surface of the suction side wall aft of the second end of the first inner wall and extending away from the suction side wall, thus defining a loop forward and back in the cooling flow path around the second inner wall and between the first and second inner walls; and

the continuous serpentine cooling flow path passes forward along an inner surface of the pressure side wall, thence around an inner surface of the leading edge, thence aft along the inner surface of the suction side wall, thence forward and back around the loop, thence along the suction side wall, thence into a channel between the pressure side and suction side walls aft of the first end of the first inner wall.

11. The turbine airfoil of claim **10**, further comprising a coolant inlet opening into a span-wise cooling air inlet channel between the first inner wall and the pressure side wall, adjacent to and forward of a first end of the first inner wall.

12. The turbine airfoil of claim **10**, wherein the first end of the first inner wall joins the inner surface of the pressure side wall at a position that is between 50% and 75% of a chord length from the leading edge.

13. The turbine airfoil of claim **10**, wherein the continuous serpentine cooling flow path extends along a full span of the airfoil.

14. The turbine airfoil of claim **10**, wherein the cavity is partitioned by a transverse partition into two continuous serpentine cooling flow paths each having respective coolant inlets.

15. The turbine airfoil of claim **10**, further comprising corrugations on inner surfaces of the pressure side wall and/or the suction side wall, wherein the corrugations are aligned with a coolant flow direction substantially transversely to a span of the airfoil, and the corrugations comprise periodic gaps.

16. The turbine airfoil of claim **10**, further comprising a coolant refreshment hole in the first inner wall between the cooling inlet channel and a subsequent portion of the serpentine cooling flow path.

17. The turbine airfoil of claim **10**, wherein the cooling flow path narrows at a portion of the airfoil to locally increase a coolant flow speed.

18. The turbine airfoil of claim **10**, wherein the first and second inner walls are connected to, or are integral with, radially inner and outer platforms at each respective end of the airfoil.

19. A turbine airfoil comprising a continuous serpentine cooling flow path in a cavity between pressure and suction side walls of a turbine airfoil, the serpentine cooling flow path comprising a flow sequence comprising an inlet at an end of the airfoil, a span-wise channel, a forward pressure side wall channel that turns behind a leading edge of the airfoil, a forward suction side wall channel along a forward part of the suction side wall, a loop channel that connects the forward pressure side wall channel and the forward suction side wall channel, an intermediate suction side wall channel along an intermediate part of the suction side wall, an aft channel between the pressure and suction side walls, and a refreshment flow path from the span-wise channel to the intermediate suction side wall channel or to the aft channel.

20. The turbine airfoil of claim **19**, further comprising a coolant exit hole in a trailing edge of the airfoil.

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