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(57) **ABSTRACT**

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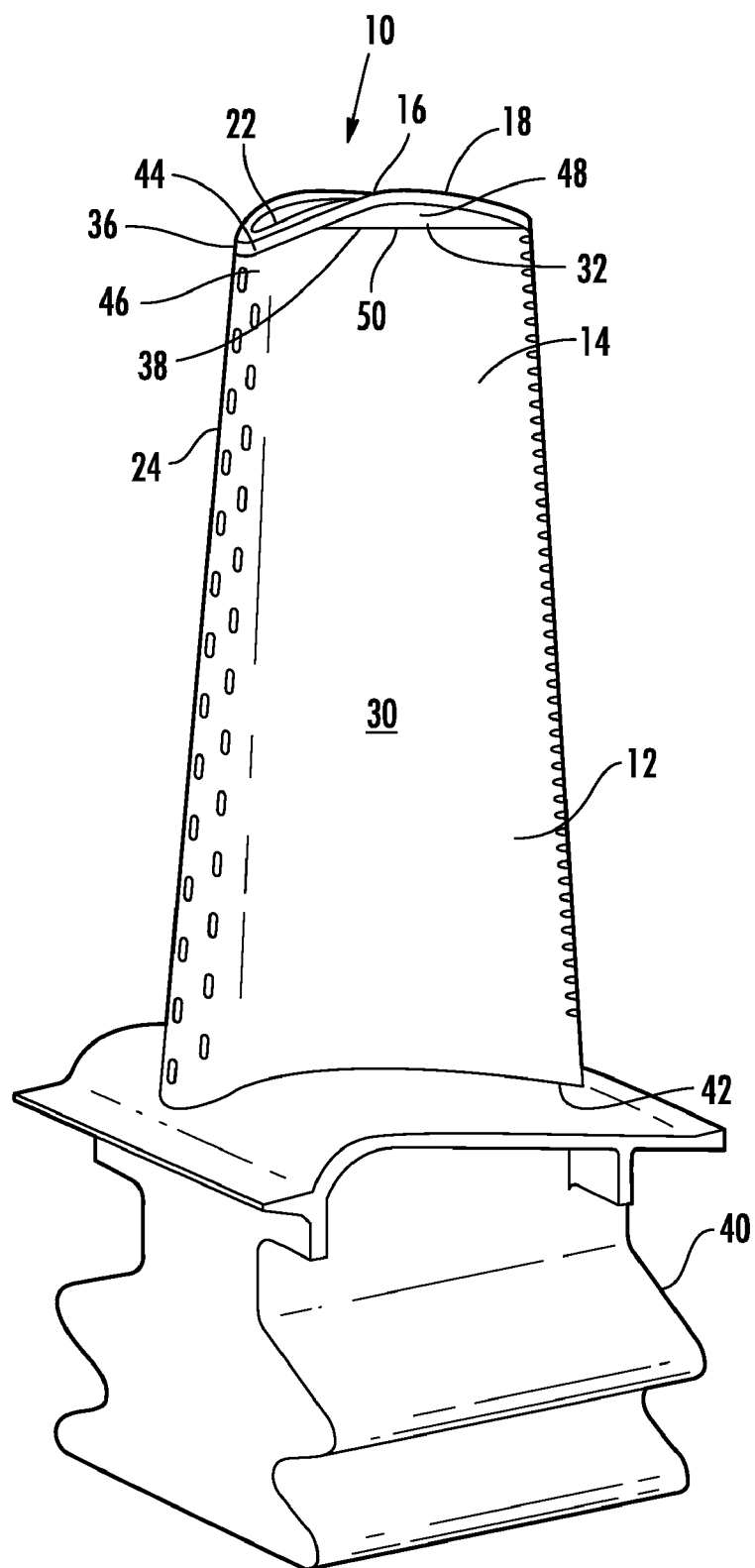
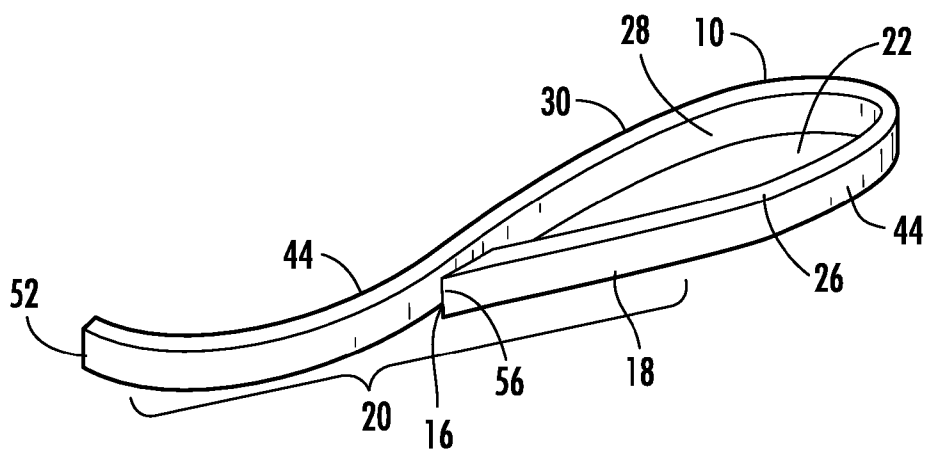
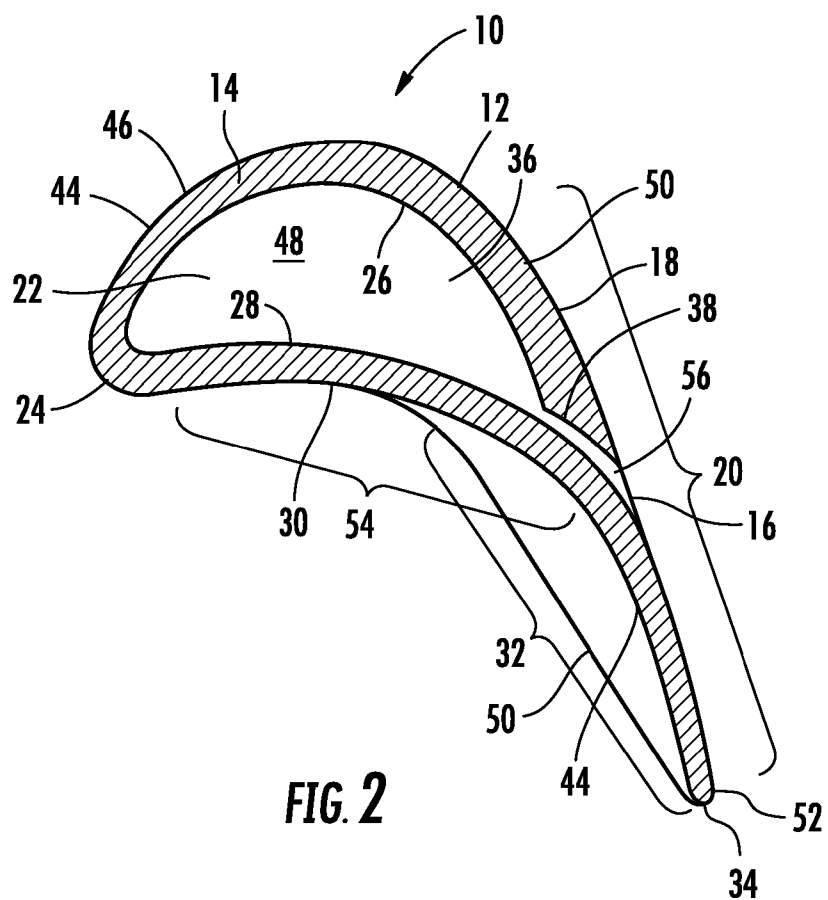


FIG. 1



TURBINE BLADE TIP

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0001] Development of this invention was supported in part by the United States Department of Energy, Advanced Turbine Development Program, Contract No. DE-FC26-05NT42644, H2 Advanced Hydrogen Turbine Development. Accordingly, the United States Government may have certain rights in this invention.

FIELD OF THE INVENTION

[0002] This invention is directed generally to turbine blades, and more particularly to airfoil tips for turbine blades.

BACKGROUND

[0003] Typically, gas turbine engines include a compressor for compressing air, a combustor for mixing the compressed air with fuel and igniting the mixture, and a turbine blade assembly for producing power. Combustors often operate at high temperatures that may exceed 2,500 degrees Fahrenheit. Typical turbine combustor configurations expose turbine blade assemblies to these high temperatures. As a result, turbine blades must be made of materials capable of withstanding such high temperatures.

[0004] Typically, turbine blades are formed from a root portion at one end and an elongated portion forming a blade that extends outwardly from a platform coupled to the root portion at an opposite end of the turbine blade. The blade is ordinarily composed of a tip opposite the root section, a leading edge, and a trailing edge. The tip of a turbine blade often has a tip feature to reduce the gap between ring segments and blades in the gas path of the turbine to reduce the flow of gases between the tip and outer ring segments. The tip features are often referred to as squealer tips and are frequently incorporated onto the tips of blades to help reduce pressure losses between turbine stages. These features are designed to minimize the gap between the blade tip and the ring segment.

SUMMARY OF THE INVENTION

[0005] A tip rail configured to reduce stress in the tip rail when formed from a single crystal alloy and attached to a turbine airfoil that is installed within a gas turbine engine is disclosed. The tip rail may be formed together with the turbine airfoil. The tip rail may include a gap in the tip rail in a portion located along a suction side of the airfoil at a mid-chord region. The gap reduces stress during use operation of a gas turbine engine in which the tip rail is attached to a turbine airfoil. The tip rail may be formed from at least one single crystal alloy oriented in a low modulus direction such that a gap exists at a location in the tip rail where the axis of orientation is positioned at a 45 degree angle to the outer surface of the suction side to reduce stress on the tip rail. The tip rail may form a leading edge region recess proximate to a leading edge between an inner edge of the tip rail on the suction side and an inner edge of the tip rail on the pressure side and may form a trailing edge region recess proximate to a trailing edge.

[0006] The tip rail may be attached to a tip of a turbine blade. The turbine blade may be formed from a generally elongated blade having a leading edge, a trailing edge, a pressure side extending from the leading edge to the trailing

edge, a suction side extending from the leading edge to the trailing edge and opposite to the pressure side, a tip at a first end, and a root coupled to the blade at an end generally opposite the first end for supporting the blade and for coupling the blade to a disc.

[0007] The tip rail may be coupled to the tip at the tip rail end. The tip rail may extend radially outward and may be configured such that an outer surface of the tip rail is generally aligned with an outer side surface of the turbine blade defining a cross-sectional profile of the turbine blade for a portion of the outer side surface of the turbine blade. The tip rail may be formed from one or more single crystal alloys oriented in a low modulus direction. A long line of the tip rail may be oriented in a low modulus direction such that a majority of the tip rail is positioned as close as possible to a 0 degree configuration or a 90 degree configuration. In at least one embodiment, the single crystal alloy may be oriented in a low modulus direction such that a gap exists at a location in the tip rail where the axis of orientation is positioned at a 45 degree angle to the outer surface of the suction side to reduce stress on the tip rail. Including a gap at a location of highest stress, greatly reduces stress within the tip rail.

[0008] A leading edge region recess may be formed proximate to the leading edge between an inner edge of the tip rail on the suction side and an inner edge of the tip rail on the pressure side and defined by an outer surface of the tip of the generally elongated blade. A trailing edge region recess may be formed proximate to the trailing edge between an outer surface of the tip rail and a tip edge at an intersection between the outer side surface and the outer surface of the tip such that at least a portion of the tip edge at the pressure side is exposed without the tip rail. The tip rail may include a gap located adjacent to the suction side of the generally elongated blade to limit the formation of stress in the tip rail along the suction side. The gap enables the tip rail to be formed from materials such as, but not limited to, one or more single crystal alloys.

[0009] The gap in the tip rail may be positioned in a mid-chord region of the suction side between the leading and trailing edges. The tip rail may have a tip rail end in the midchord region of the suction side between the leading and trailing edges. The tip rail may extend about a tip edge of the tip around the leading edge and along a portion of the pressure side, crossing over to the suction side downstream of the tip rail end of the squealer tip reform, extending along at least a portion of a tip edge of the tip along the suction side, extending toward the trailing edge and terminating at a second end. The second end may terminate flush with the trailing edge.

[0010] The tip rail end of the tip rail may be nonorthogonal and nonparallel to a tip edge of the suction side of the generally elongated blade. The tip rail end of the tip rail may be aligned with a span of the tip rail that extends past the tip rail end. The tip rail may extend from the leading edge to the suction side near the tip rail end of the tip rail.

[0011] An advantage of this invention is that the span extending from the leading edge to the suction side and forming the trailing edge recess is positioned in a favorable manner such that less cooling of the tip rail will be required than conventional turbine blade tips.

[0012] Another advantage of this invention is that the gap positioned in the tip rail along the suction side eliminates the build up of stress in the tip rail at a location which is often the site of increased stress levels.

[0013] These and other embodiments are described in more detail below.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] The accompanying drawings, which are incorporated in and form a part of the specification, illustrate embodiments of the presently disclosed invention and, together with the description, disclose the principles of the invention.

[0015] FIG. 1 is a perspective view of a turbine blade with a tip rail attached thereto.

[0016] FIG. 2 is a top view of the tip rail in FIG. 1.

[0017] FIG. 3 is a perspective view of the tip rail of FIG. 1 displayed by itself.

DETAILED DESCRIPTION OF THE INVENTION

[0018] As shown in FIGS. 1-3, a tip rail 10 configured to reduce stress in the tip rail 10 when formed from a single crystal alloy and attached to a turbine airfoil 12 that is installed within a gas turbine engine is disclosed. The tip rail 10 may be formed with a generally elongated blade 14. The tip rail 10 may include a gap 16 in the tip rail 10 in a portion located along a suction side 18 of the airfoil 12 at a midchord region 20. The gap 16 reduces stress during use operation of a gas turbine engine in which the tip rail 10 is attached to a turbine airfoil 12. The tip rail 10 may be formed from at least one single crystal alloy oriented in a low modulus direction such that the gap 16 exists at a location in the tip rail 10 where the axis of orientation is positioned at a 45 degree angle to an outer surface 46 of the suction side 18 to reduce stress on the tip rail 10. The tip rail 10 may form a leading edge region recess 22 proximate to a leading edge 24 between an inner edge 26 of the tip rail 10 on the suction side 18 and an inner edge 28 of the tip rail 10 on the pressure side 30 and may form a trailing edge region recess 32 proximate to a trailing edge 34.

[0019] The tip rail 10 may be attached to a radially outward tip 36 of the turbine airfoil 12. The turbine airfoil 12 may be formed from a generally elongated blade 14 having a leading edge 24, a trailing edge 34, a pressure side 30 extending from the leading edge 24 to the trailing edge 34, a suction side 18 extending from the leading edge 24 to the trailing edge 34 and opposite to the pressure side 30, a tip 36 at a first end 38, and a root 40 coupled to the blade 14 at an end 42 generally opposite the first end 38 for supporting the blade 14 and for coupling the blade 14 to a disc. The pressure side 30 may be generally concave, and the suction side 18 may be generally convex.

[0020] The tip rail 10 may be coupled to the tip 36 at the first end 38. The tip rail 10 may be formed from one or more single crystal alloys oriented in a low modulus direction. A long line of the tip rail 10 may be oriented in a low modulus direction such that a majority of the tip rail 10 is positioned a close a possible to a 0 degree configuration or a 90 degree configuration. In at least one embodiment, the single crystal alloy may be oriented in a low modulus direction such that a gap 16 exists at a location in the tip rail 10 where the axis of orientation is positioned at a 45 degree angle to the outer surface 46 of the suction side 18 to reduce stress on the tip rail 10. Including a gap 16 at a location of highest stress, greatly reduces stress within the tip rail 10. The tip rail 10 may include a gap 16 located adjacent to the suction side 18 of the generally elongated blade 14 to limit the formation of stress in the tip rail 10 along the suction side 18. The tip rail 10 may be

formed from one or more single crystal alloys oriented such that an axis of orientation is positioned to reduce stress on the tip rail 10.

[0021] The tip rail 10 may be formed from one or more single crystal alloys, such as, but not limited to, PWA1483, PWA1484, CMSX-3, CMSX-4, ReneN5, and CMSX 486. The tip rail 10 may be formed with a thickness such that the thickness is reduced to minimize uncooled structure protruding into the hot gas path. In addition, the tip rail 10 may be formed with a thickness such that the thickness is reduced to minimize the mass of the tip rail 10 in the event that the tip rail 10 were to separate from the blade tip 36 and become a projectile in the turbine engine. Furthermore, it is desirable to have some degree of thickness to retain dimensional accuracy. Thus, the tip rail 10 may have a thickness of between about 1.0 millimeter and 3.0 millimeter. In one embodiment, the tip rail 10 may have a thickness of about 2.0 millimeter. The tip rail 10 may be formed together with the tip 36 of the turbine airfoil 12 in a single casting.

[0022] The tip rail 10 may be configured such that an outer surface 44 of the tip rail 10 is generally aligned with an outer side surface 46 of the turbine airfoil 12 defining a cross-sectional profile of the turbine airfoil 12. In particular, the tip rail 10 may be configured such that the outer surface 44 of the tip rail 10 does not extend beyond the outer side surface 46 of the turbine airfoil 12. As shown in FIG. 2, the tip rail 10 may be configured to follow at least a portion of the outline of the turbine airfoil 12 to which the tip rail 10 is attached. The tip rail 10 may be configured such that a leading edge region recess 22 may be formed proximate to the leading edge 24 between an inner edge 26 of the tip rail 10 on the suction side 18 and an inner edge 28 of the tip rail 10 on the pressure side 30 and defined by an outer surface 48 of the tip 48 of the generally elongated blade 14. The tip rail 10 may also be configured to include a trailing edge region recess 32 proximate to the trailing edge 34 between an outer surface 44 of the tip rail 10 and a tip edge 50 at an intersection between the outer side surface 46 and the outer surface 48 of the tip 36 such that at least a portion of the tip edge 50 at the pressure side 30 is exposed without the tip rail 10.

[0023] In addition, the tip rail 10 may only extend for a portion of the distance around the perimeter of the turbine airfoil tip 36. In particular, the tip rail 10 may include a gap 16 located adjacent to the suction side 18 of the generally elongated blade 14 to limit the formation of stress in the tip rail 10 along the suction side 18. The gap 16 may be positioned in a midchord region 20 of the suction side 18 between the leading and trailing edges 24, 34.

[0024] In at least one embodiment, as shown in FIG. 2, the tip rail 10 may have a tip rail end 56 in the midchord region 20 of the suction side 18 between the leading and trailing edges 24, 34. The tip rail 10 may extend around the perimeter of the tip 36 along the suction side 18, the leading edge 24 and partially along the pressure side 30, crossing over to the suction side 18 and terminating at the trailing edge 50. Thus, a portion of the tip edge 50 at the perimeter of the tip 36 is exposed and is not covered by the tip rail 10. More specifically, the tip rail 10 may extend about a tip edge 50 of the tip 36 around the leading edge 24 and along a portion of the pressure side 30, crossing over to the suction side 18 downstream of the tip rail end 56 of the tip rail 10, extending along at least a portion of a tip edge 50 of the tip 36 along the suction side 18, extending toward the trailing edge 34 and terminating at a second end 52. The tip rail end 56 of the tip rail 10 may be

nonorthogonal and nonparallel to a tip edge **50** of the suction side **18** of the generally elongated blade **14**. The tip rail end **56** of the tip rail **10** may be aligned with a span **54** of the tip rail **10** that extends past the tip rail end **56**. The tip rail **10** may extend from the leading edge **24** and the suction side **18** near the tip rail end **56** of the tip rail **10**.

[0025] The tip rail **10** may be formed with a method of manufacturing a tip rail **10** for a turbine airfoil **12**. The method may include forming a tip rail **10** having a footprint less than a cross-sectional area of a tip **36** of a turbine airfoil **12** to which the tip rail **10** is configured to be attached. The method of forming the tip rail **10** may include forming the tip rail **10** with a thickness between about 1.0 millimeter and about 3.0 millimeter. In particular, the tip rail **10** may include forming the tip rail **10** with a thickness of about 2.0 millimeter. In one embodiment, the tip rail **10** may be 2.0 millimeters tall and 2.0 millimeters wide, and possibly up to 5.0 millimeters wide.

[0026] The foregoing is provided for purposes of illustrating, explaining, and describing embodiments of this invention. Modifications and adaptations to these embodiments will be apparent to those skilled in the art and may be made without departing from the scope or spirit of this invention.

I claim:

1. A turbine blade, comprising:
 - a generally elongated blade having a leading edge, a trailing edge, a pressure side extending from the leading edge to the trailing edge, a suction side extending from the leading edge to the trailing edge and opposite to the pressure side, a tip at a first end, and a root coupled to the blade at an end generally opposite the first end for supporting the blade and for coupling the blade to a disc;
 - a tip rail coupled to the tip at the first end, extending radially outward and configured such that an outer surface of the tip rail is generally aligned with an outer side surface of the turbine blade defining a cross-sectional profile of the turbine blade for a portion of the outer side surface of the turbine blade, wherein a leading edge region recess is formed proximate to the leading edge between an inner edge of the tip rail on the suction side and an inner edge of the tip rail on the pressure side and defined by an outer surface of the tip of the generally elongated blade, and a trailing edge region recess is formed proximate to the trailing edge between an outer surface of the tip rail and a tip edge at an intersection between the outer side surface and the outer surface of the tip such that at least a portion of the tip edge at the pressure side is exposed without the tip rail;
 - wherein the tip rail is formed from a single crystal orientation; and
 - wherein the tip rail includes a gap located adjacent to the suction side of the generally elongated blade to limit the formation of stress in the tip rail along the suction side.
2. The turbine blade of claim 1, wherein the tip rail is formed from at least one single crystal alloy oriented such that an axis of orientation is positioned to reduce stress on the tip rail.
3. The turbine blade of claim 2, wherein the tip rail is formed from at least one single crystal alloy oriented in a low modulus direction such that the gap exists at a location in the tip rail where the axis of orientation is positioned at a 45 degree angle to the outer side surface of the suction side to reduce stress on the tip rail.
4. The turbine blade of claim 1, wherein the tip rail has a tip rail end in the midchord region of the suction side between the

leading and trailing edges and the tip rail extends about a tip edge of the tip around the leading edge and along a portion of the pressure side, crossing over to the suction side downstream of the tip rail end of the squealer tip reform, extending along at least a portion of a tip edge of the tip along the suction side, extending toward the trailing edge and terminating at a second end.

5. The turbine blade of claim 4, wherein the tip rail end of the tip rail is nonorthogonal and nonparallel to a tip edge of the suction side of the generally elongated blade.

6. The turbine blade of claim 5, wherein the tip rail end of the tip rail is aligned with a span of the tip rail that extends past the tip rail end.

7. The turbine blade of claim 6, wherein the tip rail extends from the leading edge to the suction side near the tip rail end of the tip rail.

8. A turbine blade, comprising:

- a generally elongated blade having a leading edge, a trailing edge, a pressure side extending from the leading edge to the trailing edge, a suction side extending from the leading edge to the trailing edge and opposite to the pressure side, a tip at a first end, and a root coupled to the blade at an end generally opposite the first end for supporting the blade and for coupling the blade to a disc;

- a tip rail coupled to the tip at the first end, extending radially outward and configured such that an outer surface of the tip rail is generally aligned with an outer side surface of the turbine blade defining a cross-sectional profile of the turbine blade for a portion of the outer side surface of the turbine blade, wherein a leading edge region recess is formed proximate to the leading edge between an inner edge of the tip rail on the suction side and an inner edge of the tip rail on the pressure side and defined by an outer surface of the tip of the generally elongated blade, and a trailing edge region recess is formed proximate to the trailing edge between an outer surface of the tip rail and a tip edge at an intersection between the outer side surface and the outer surface of the tip such that at least a portion of the tip edge at the pressure side is exposed without the tip rail;

- wherein the tip rail includes a gap located adjacent to the suction side of the generally elongated blade to limit the formation of stress in the tip rail along the suction side;

- wherein the gap in the tip rail is positioned in a midchord region of the suction side between the leading and trailing edges; and

- wherein the tip rail is formed from at least one single crystal alloy oriented in a low modulus direction such that a gap exists at a location in the tip rail where the axis of orientation is positioned at a 45 degree angle to the outer surface of the suction side to reduce stress on the tip rail.

9. The turbine blade of claim 8, wherein the tip rail has a tip rail end in the midchord region of the suction side between the leading and trailing edges and the tip rail extends about a tip edge of the tip around the leading edge and along a portion of the pressure side, crossing over to the suction side downstream of the tip rail end of the squealer tip reform, extending along at least a portion of a tip edge of the tip along the suction side, extending toward the trailing edge and terminating at a second end.

10. The turbine blade of claim 9, wherein the tip rail end of the tip rail is nonorthogonal and nonparallel to a tip edge of the suction side of the generally elongated blade.

11. The turbine blade of claim **10**, wherein the tip rail end of the tip rail is aligned with a span of the tip rail that extends past the tip rail end.

12. The turbine blade of claim **11**, wherein the tip rail extends from the leading edge to the suction side near the tip rail end of the tip rail.

13. A component for a turbine blade, comprising:

a tip rail configured to be coupled to a tip of a gas turbine airfoil;

wherein the tip rail extends radially outward and is configured such that an outer surface of the tip rail is generally aligned with an outer side surface of the turbine blade defining a cross-sectional profile of the turbine blade for a portion of the outer side surface of the turbine blade, wherein a leading edge region recess is formed between an inner edge of the tip rail on a suction side of the airfoil and an inner edge of the tip rail on a pressure side of the airfoil, and a trailing edge region recess is formed proximate to a trailing edge between an outer surface of the tip rail and a tip edge at an intersection between the outer side surface and the outer surface of the tip of the airfoil such that at least a portion of the tip edge at the pressure side is exposed without the tip rail;

wherein the tip rail includes a gap located adjacent to the suction side of the airfoil to limit the formation of stress in the tip rail along the suction side;

wherein the gap in the tip rail is positioned in a midchord region of the suction side between the leading and trailing edges; and

wherein the tip rail is formed from at least one single crystal alloy oriented in a low modulus direction such that a gap exists at a location in the tip rail where the axis of orientation is positioned at a 45 degree angle to the outer surface of the suction side to reduce stress on the tip rail.

14. The component of claim **13**, wherein the tip rail has a tip rail end in the midchord region of the suction side between the leading and trailing edges and the tip rail extends about a tip edge of the tip around the leading edge and along a portion of the pressure side, crossing over to the suction side downstream of the tip rail end of the squealer tip reform, extending along at least a portion of a tip edge of the tip along the suction side, extending toward the trailing edge and terminating at a second end.

15. The component of claim **14**, wherein the tip rail end of the tip rail is nonorthogonal and nonparallel to a tip edge of the suction side of the airfoil.

16. The component of claim **15**, wherein the tip rail end of the tip rail is aligned with a span of the tip rail that extends past the tip rail end.

17. The component of claim **16**, wherein the tip rail extends from the leading edge to the suction side near the tip rail end of the tip rail.

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