US012385408B1

(12) **United States Patent**
Praisner et al.

(10) **Patent No.: US 12,385,408 B1**
(45) **Date of Patent: Aug. 12, 2025**

(54) **LIFE AND PERFORMANCE IMPROVEMENT TRENCHES**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **18/424,109**

(22) Filed: **Jan. 26, 2024**

(51) **Int. Cl.**
F01D 11/08 (2006.01)
F01D 11/24 (2006.01)
F04D 29/52 (2006.01)
F04D 29/68 (2006.01)

(52) **U.S. Cl.**
CPC ***F01D 11/08*** (2013.01); *F01D 11/24* (2013.01); *F04D 29/526* (2013.01); *F04D 29/681* (2013.01); *F04D 29/685* (2013.01); *F05D 2220/32* (2013.01); *F05D 2240/55* (2013.01)

(58) **Field of Classification Search**
CPC F01D 11/08; F01D 11/24; F04D 29/685; F04D 29/681; F04D 29/526; F05D 2240/11; F05D 2240/81
See application file for complete search history.

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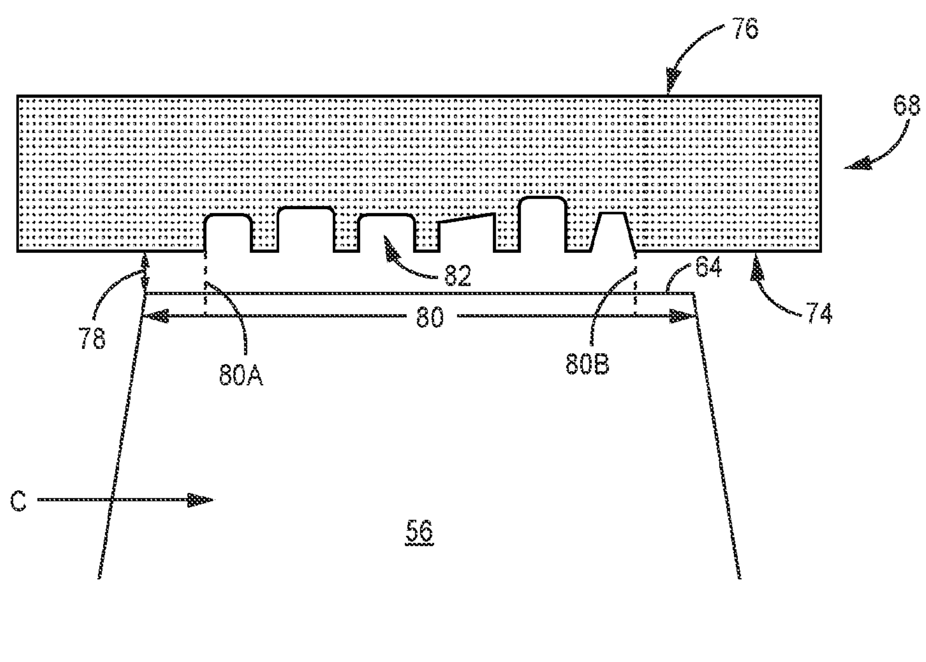
(57) **ABSTRACT**

A blade outer air seal assembly includes a plurality of seal segments circumferentially disposed about an array of blades rotatable about an axis, each of the plurality of seal segments having a radially inner surface facing a tip of each blade of the array of blades, the radially inner surface having an arrangement of trenches formed therein, and a radially outer surface opposite the radially inner surface. The arrangement of trenches is disposed between 30% and 80% of a chord of a blade of the array of blades as taken at the respective tip, and the arrangement of trenches is aperiodic in the axial direction.

20 Claims, 4 Drawing Sheets



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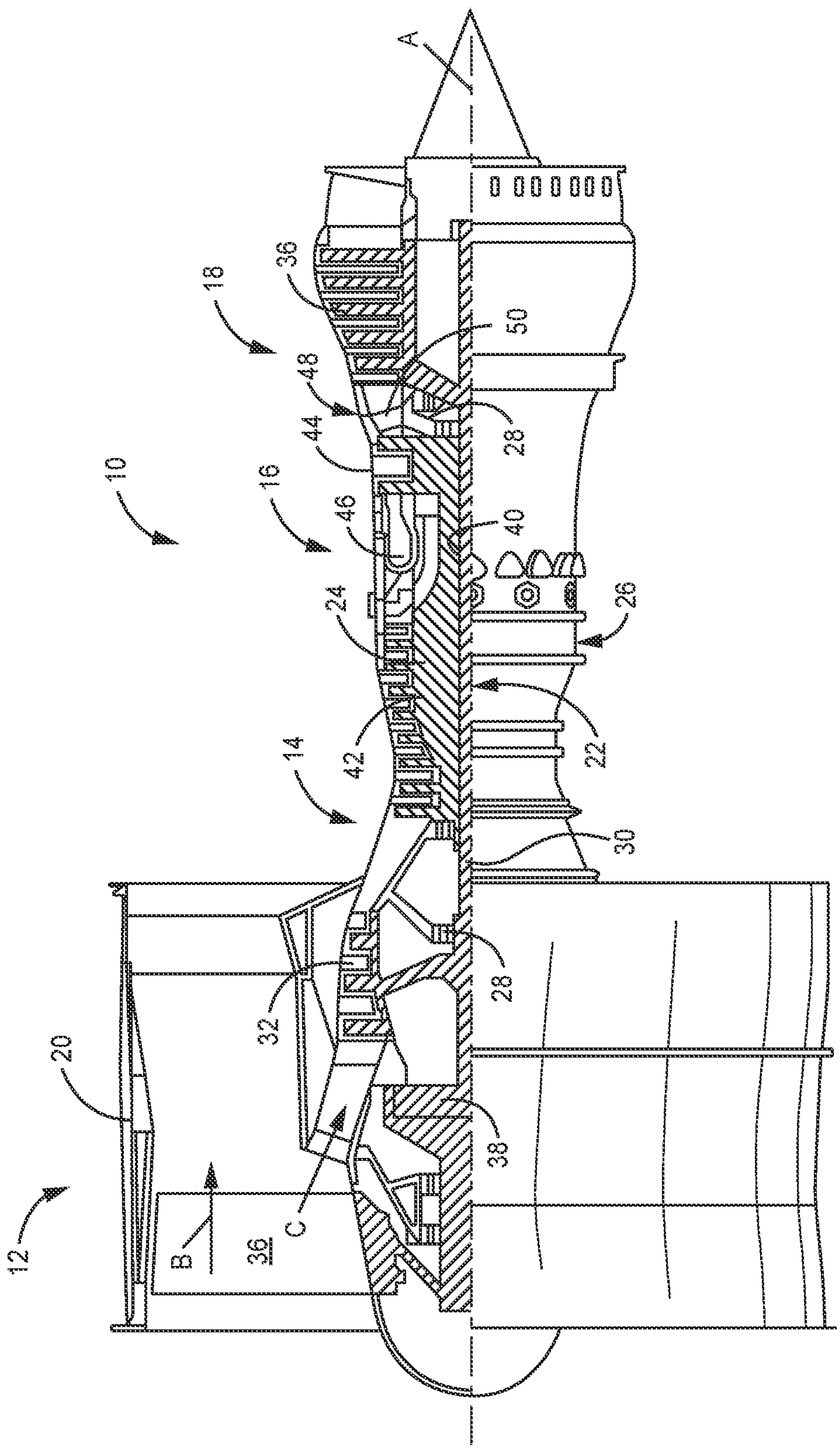

FIG. 1

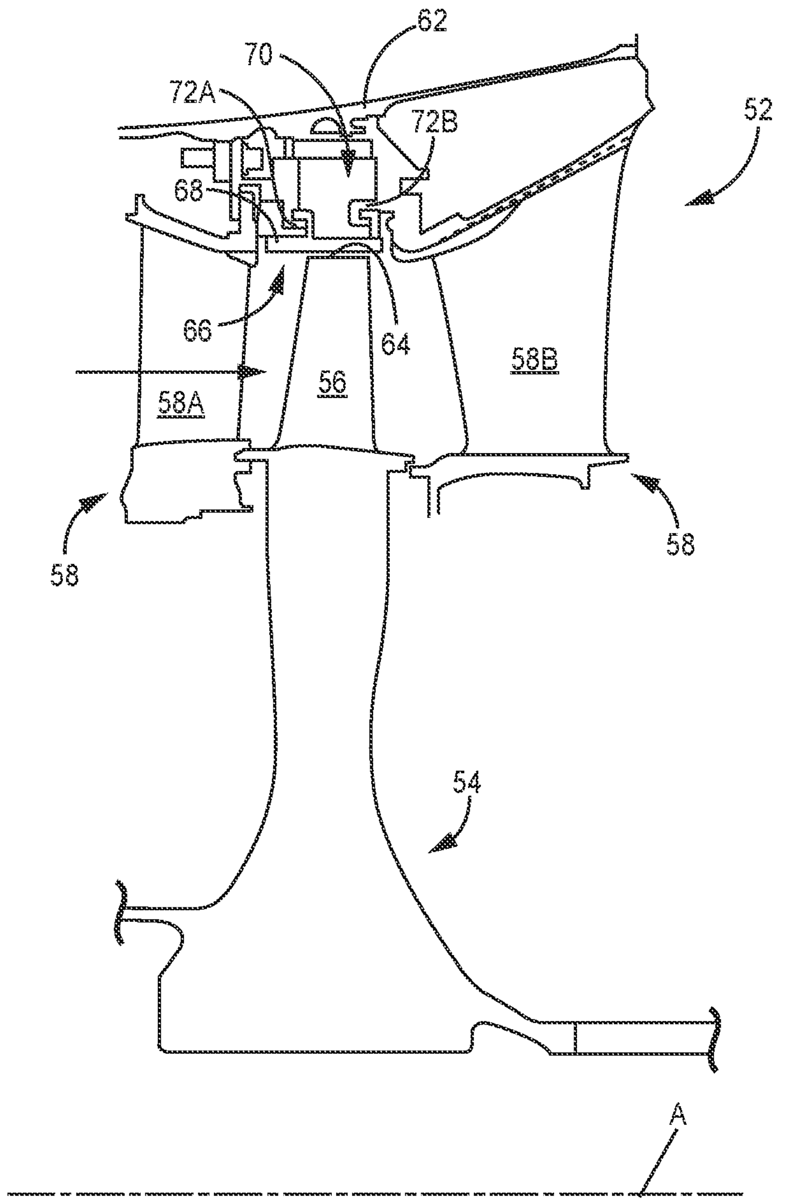

FIG. 2

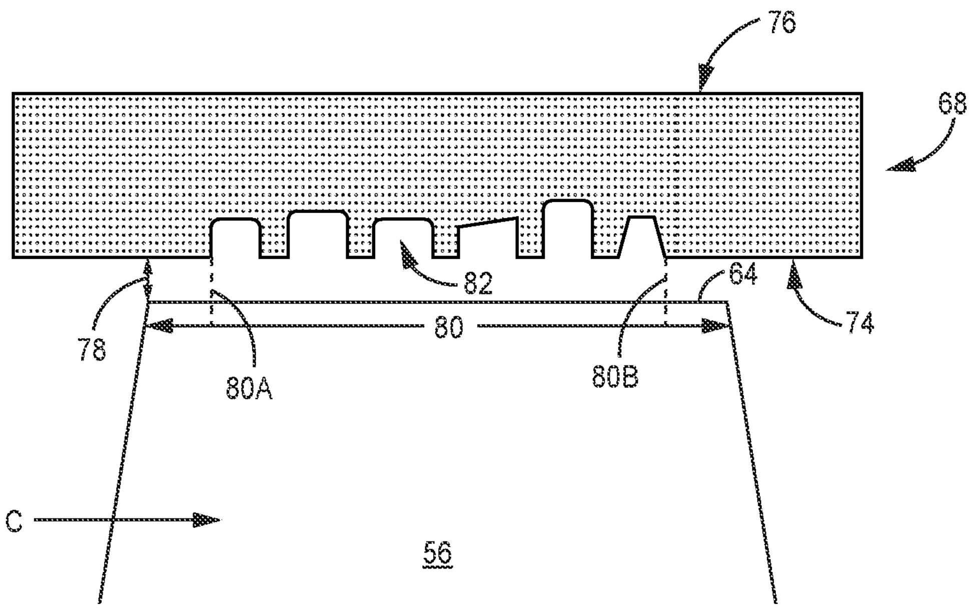

FIG. 3

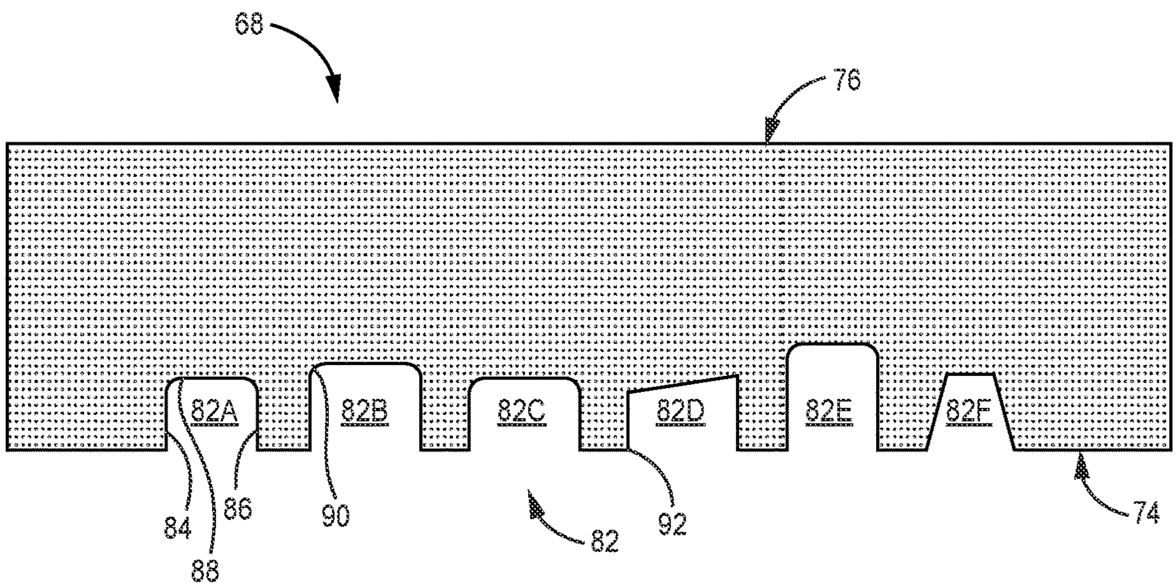

FIG. 4

LIFE AND PERFORMANCE IMPROVEMENT TRENCHES

STATEMENT OF GOVERNMENT INTEREST

This invention was made with government support under Contract No. 80NSSC21M0068 awarded by National Aeronautics and Space Administration. The government has certain rights in the invention.

BACKGROUND

The present disclosure relates generally to gas turbine engines and more particularly to sealing of rotor blades within gas turbine engines.

Gas turbine engines typically include a compressor section, a combustor section, and a turbine section. During operation, air is pressurized in the compressor section and is mixed with fuel and burned in the combustor section to generate hot combustion gases. The hot combustion gases are communicated through the turbine section, which extracts energy from the hot combustion gases to power the compressor section and other gas turbine engine loads.

The compressor and turbine sections of a gas turbine engine include alternating rows of rotating blades and stationary vanes. The turbine blades rotate and extract energy from the hot combustion gases that are communicated through the gas turbine engine. The turbine vanes prepare the airflow for the next set of blades. The vanes extend from platforms that may be contoured to manipulate flow.

An outer casing of an engine static structure may include one or more blade outer air seals (BOAS) that provide an outer radial flow path boundary for the hot combustion gases. The BOAS are arranged circumferentially adjacent to each other and meet at mate faces. The tips of rotating blades seal against radially inner faces of the BOAS. Complex BOAS geometries have been developed to enhance sealing interfaces between the BOAS and the blade tips. Cooling these complex geometries is often difficult.

SUMMARY

A blade outer air seal assembly includes a plurality of seal segments circumferentially disposed about an array of blades rotatable about an axis, each of the plurality of seal segments having a radially inner surface facing a tip of each blade of the array of blades, the radially inner surface having an arrangement of trenches formed therein, and a radially outer surface opposite the radially inner surface. The arrangement of trenches is disposed between 30% and 80% of a chord of a blade of the array of blades as taken at the respective tip, and the arrangement of trenches is aperiodic in the axial direction.

A gas turbine engine section includes a disk supporting an array of blades, the array of blades rotatable about an axis, a casing radially outward from the array of blades, and a blade outer air seal disposed between the casing and the array of blades. The blade outer air seal assembly includes a plurality of seal segments circumferentially disposed about an array of blades rotatable about an axis, each of the plurality of seal segments having a radially inner surface facing a tip of each blade of the array of blades, the radially inner surface having an arrangement of trenches formed therein, and a radially outer surface opposite the radially inner surface. The arrangement of trenches is disposed between 30% and 80% of a chord of a blade of the array of

blades as taken at the respective tip, and the arrangement of trenches is aperiodic in the axial direction.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a simplified cross-sectional illustration of an exemplary gas turbine engine.

FIG. **2** is a simplified cross-sectional illustration of a section of a gas turbine engine.

FIG. **3** is a simplified cross-sectional illustration of a blade and blade outer air seal segment from the section of FIG. **2**.

FIG. **4** is a simplified cross-sectional illustration showing the blade outer air seal segment in greater detail.

While the above-identified figures set forth one or more embodiments of the present disclosure, other embodiments are also contemplated, as noted in the discussion. In all cases, this disclosure presents the invention by way of representation and not limitation. It should be understood that numerous other modifications and embodiments can be devised by those skilled in the art, which fall within the scope and spirit of the principles of the invention. The figures may not be drawn to scale, and applications and embodiments of the present invention may include features and components not specifically shown in the drawings.

DETAILED DESCRIPTION

FIG. **1** is a simplified cross-sectional view of gas turbine engine **10**. Gas turbine engine **10** is disclosed herein as a two-spool turbofan that generally incorporates fan section **12**, a compressor section **14**, combustor section **16**, and turbine section **18**. Fan section **12** drives air along bypass flow path B in a bypass duct defined within housing **20**, such as a fan case or nacelle, and also drives air along core flow path C for compression and communication into combustor section **16** then expansion through turbine section **18**. Although depicted as a two-spool turbofan gas turbine engine in the disclosed non-limiting embodiment, it should be understood that the concepts described herein are not limited to use with two-spool turbofans as the teachings may be applied to other types of turbine engines including three-spool architectures.

The exemplary engine **10** generally includes low speed spool **22** and high-speed spool **24** mounted for rotation about an engine central longitudinal axis A relative to engine static structure **26** via several bearing systems **28**. It should be understood that various bearing systems **28** at various locations may alternatively or additionally be provided, and the location of bearing systems **28** may be varied as appropriate to the application.

Low speed spool **22** generally includes inner shaft **30** that interconnects, a first (or low) pressure compressor **32** and a first (or low) pressure turbine **34**. Inner shaft **30** is connected to fan **36** through a speed change mechanism, which in exemplary gas turbine engine **10** is illustrated as geared architecture (i.e., fan drive gear system) **38** to drive fan **36** at a lower speed than low speed spool **22**. High-speed spool **24** includes outer shaft **40** that interconnects a second (or high) pressure compressor **42** and a second (or high) pressure turbine **44**. Combustor **46** is arranged in the exemplary gas turbine **10** between high-pressure compressor **42** and high-pressure turbine **44**. Mid-turbine frame **48** of engine static structure **26** may be arranged generally between high-pressure turbine **44** and low-pressure turbine **34**. Mid-turbine frame **48** further supports bearing systems **28** in the turbine section **18**. Inner shaft **30** and outer shaft **40** are concentric and rotate via bearing systems **28** about the engine central longitudinal axis A which is collinear with their longitudinal axes.

The core airflow is compressed by low-pressure compressor **32** then high-pressure compressor **42**, mixed and burned with fuel in combustor **46**, then expanded through high-pressure turbine **44** and low-pressure turbine **34**. Mid-turbine frame **48** includes airfoils **50** which are in core airflow path C. Turbines **34**, **44** rotationally drive the respective low speed spool **22** and high-speed spool **24** in response to the expansion. It will be appreciated that each of the positions of fan section **12**, compressor section **14**, combustor section **16**, turbine section **18**, and fan drive gear system **38** may be varied. For example, fan drive gear system **38** may be located aft of low-pressure compressor **32**, aft of combustor section **16**, or even aft of turbine section **18**, and fan **36** may be positioned forward or aft of the location of fan drive gear system **38**.

Engine **10** in one example is a high bypass geared aircraft engine. In a further example, the engine bypass ratio is greater than about six (6), with an example embodiment being greater than about ten (10), and can be less than or equal to about 18.0, or more narrowly can be less than or equal to 16.0. The geared architecture of fan drive gear system **38** is an epicyclic gear train, such as a planetary gear system or other gear system, with a gear reduction ratio of greater than about 2.3. The gear reduction ratio may be less than or equal to 4.0. Low-pressure turbine **34** has a pressure ratio that is greater than about five. The low-pressure turbine pressure ratio can be less than or equal to 13.0, or more narrowly less than or equal to 12.0. In one disclosed embodiment, engine bypass ratio is greater than about ten (10:1), the diameter of fan **36** is significantly larger than that of low-pressure compressor **32**, and low-pressure turbine **34** has a pressure ratio that is greater than about five 5:1. The low-pressure turbine pressure ratio is pressure measured prior to an inlet of low-pressure turbine **34** as related to the pressure at the outlet of low-pressure turbine **34** prior to an exhaust nozzle. It should be understood, however, that the above parameters are only exemplary of one embodiment of a geared architecture engine and that the present invention is applicable to other gas turbine engines including direct drive turbofans.

A significant amount of thrust is provided by bypass flow B due to the high bypass ratio. Fan section **12** of engine **10** is designed for a particular flight condition, typically cruise at about 0.8 Mach and about 35,000 feet (10,668 meters). The flight condition of 0.8 Mach and 35,000 ft (10,668 meters), with engine **10** at its best fuel consumption—also known as "bucket cruise Thrust Specific Fuel Consumption ('TSFC')"—is the industry standard parameter of lbm of fuel being burned divided by lbf of thrust engine **10** produces at that minimum point. The engine parameters described above and those in this paragraph are measured at this condition unless otherwise specified. "Low fan pressure ratio" is the pressure ratio across the fan blade alone, without a Fan Exit Guide Vane ("FEGV") system. The low fan pressure ratio as disclosed herein according to one non-limiting embodiment is less than about 1.45, or more narrowly greater than or equal to 1.25. "Low corrected fan tip speed" is the actual fan tip speed in ft/sec divided by an industry standard temperature correction of $[(\text{Tram } ^\circ \text{R})/(518.7^\circ \text{R})]^{0.5}$. The "Low corrected fan tip speed" as disclosed herein according to one non-limiting embodiment is less than about 1150.0 ft/second (350.5 meters/second), and can be greater than or equal to 1000.0 ft/second (304.8 meters/second).

FIG. **2** illustrates portion **52** of a gas turbine engine, such as the gas turbine engine **10** of FIG. **1**. In this exemplary embodiment, portion **52** represents a portion of high-pressure turbine **44**. However, it should be understood that other portions of gas turbine engine **10** could benefit from the teachings of this disclosure, including but not limited to, compressor section **14** and low-pressure turbine **34**.

Portion **52** can include rotor disk **54** (only one shown) mounted to outer shaft **40** rotatable as a unit with respect to engine static structure **26**. Portion **52** can include alternating rows of rotating blades **56** (mounted to rotor disk **54**) and vanes **58**A and **58**B of vane assemblies **58** that are also supported within outer casing **62** of engine static structure **26**.

Each blade **56** of rotor disk **54** includes a tip **64** positioned at a radially outermost portion of a respective blade **56**. Blade tips **64** extend toward blade outer air seal (BOAS) assembly **66**. BOAS assembly **66** may find beneficial use in many industries including aerospace, industrial, electricity generation, naval propulsion, pumps for gas and oil transmission, aircraft propulsion, vehicle engines and stationery power plants. BOAS assembly **66** is disposed in an annulus radially between the outer casing **62** and blade tips **64**. BOAS assembly **66** generally includes a multitude of BOAS segments **68** (only one shown in FIG. **2**) arranged to form a full ring hoop assembly encircling associated blades **56** of a respective stage of portion **52**. Cavity **70** extends axially between the forward flange **72**A and the aft flange **72**B and radially between outer casing **62** and BOAS segments **68**. A secondary cooling airflow may be communicated into cavity **70** to provide a dedicated source of cooling airflow for cooling BOAS segments **68**. The secondary cooling airflow can be sourced from high-pressure compressor **42** or any other upstream portion of the gas turbine engine **10**.

FIG. **3** is a simplified cross-sectional illustration showing BOAS segment **68** and blade **56** near tip **64**. Segment **68** includes radially inner surface **74** facing tip **64**, and oppositely disposed radially outer surface **76**. A tip clearance gap **78** exists between tip **64** and radially inner surface **74**. Chord line **80** represents the chordal dimension of blade **56** proximate tip **64**.

As shown in FIG. **3**, multiple circumferentially extending trenches (or grooves) **82** are formed in radially inner surface **74** opposite tip **64**. In general, trenches **82** can help decrease leakage flow over tip **64** to improve engine efficiency and reduce heating of tip **64**, among other benefits. The forward (i.e., upstream)-most trench **82** can begin at approximately 30% chord, represented by chord position line **80**A, and the aft (i.e., downstream)-most trench **82** can terminate at approximately 80% chord, represented by chord position line **80**B. As such, trenches **82** are generally disposed between 30% to 80% chord, relative to chord line **80**. Moreover, in the embodiments discussed herein, there will generally be no trenches disposed at the leading edge of blade **56** (i.e., 0% to about 10% of chord line **80**), or at the trailing edge of blade **56** (i.e., about 90% to 100% of chord line **80**). The number of trenches **82** can be about four trenches to eight trenches, inclusive, in an exemplary embodiment, with six trenches **82** being shown in FIG. **3**. Further, trenches **82** are geometrically and/or dimensionally axially aperiodic (i.e., irregular, non-repeating, etc.), as is discussed in greater detail below with respect to FIG. **4**.

FIG. **4** is a simplified illustration of segment **68** showing trenches **82** in greater detail. In FIG. **4**, trenches **82** are individually labeled **82**A-**82**F, but will be collectively or generically referred to as trenches **82**. Each trench **82** can include an upstream surface **84**, a downstream surface **86** generally disposed along the y-axis (i.e., the radial direction), and an upper surface **88** generally disposed along the x-axis (i.e., the axial direction/axis A). As shown in FIG. **4**, surfaces **84**, **86**, and **88** are labeled only in forwardmost trench **82**A. Each trench **82** further has a width, defined by the distance between a respective upstream surface **84** and downstream surface **86**, and a height defined by the distance from a position flush with radially inner surface **74** of segment and a respective upper surface **88**. The width of a given trench **82** can be constant if upstream surface **84** and downstream surface **86** are parallel (e.g., trench **82**A), or varied if upstream surface **84** and downstream surface **86** are not parallel (e.g., trench **82**F). Similarly, the height of a given trench **82** can be constant if upper surface **88** is parallel with radially inner surface **74** of segment **68** (e.g., trench **82**A), or varied if upper surface **88** is not parallel to (i.e., angled with respect to) radially inner surface **74** (e.g., trench **82**D). As such, any of surfaces **84**, **86**, or **88** can be angled with respect to one another and/or radially inner surface **74** of segment **68**. This can include trenches **82** which are entirely angled/canted with respect to radially inner surface **74**. Any of surfaces **84**, **86**, **88**, can also be straight, curved/rounded, or combinations thereof. For example, trenches **82**A, **82**B, and **82**E have rounded upper corners **90** (one is labeled in trench **82**B) transitioning from respective upper surfaces **88** to respective upstream surfaces **84** and downstream surfaces **86**. Trench **82**C is an example with different upper corners **90**, that is, with one rounded upper corner **90** and one non-rounded upper corner **90**. Lower (i.e., radially inner) corners **92**, that is, corners formed at radially inner surface **74** of segment **68** will generally be straight/sharp (i.e., formed by two straight segments) and not rounded.

As noted above, trenches **82** can be aperiodically arranged in the axial direction. In general, each trench will be different from at least a neighboring (i.e., the immediate upstream or downstream) trench **82** in cross-sectional geometry (defined by the x-y plane) or in at least one dimension (i.e., width or height). For example, trench **82**A and trench **82**B have substantially similar cross-sectional geometries defined, in part, by rounded upper corners **90**, but can have different dimensions (e.g., heights). Other trenches **82** can differ in both cross-sectional geometry and dimensions (e.g., trenches **82**E and **82**F).

For a given segment **68**, the aperiodic arrangement can be determined using software-based optimization based on such factors as blade stage (e.g., first or second) and/or engine section (e.g., turbine or compressor). Such modeling can also determine the optimal number of trenches (e.g., four to eight) and position of trenches (e.g., from 30% to 80% along chord line **80**). It has been observed through such modeling that relatively wider trenches **82** can be preferable at the mid-chord region from about 40% to 60% of chord line **80**. It has further been observed that rounded upper corners **90** and non-rounded lower corners **92** are preferable.

The disclosed aperiodic trenches can be used with a variety of BOAS segments and blades, including those formed form metallics or reinforced composites (e.g., ceramic matrix composites), in turbine or compressor sections, with various tip clearances, and even with blades having squealer tips. The disclosed aperiodic trenches have applications in both commercial and military turbines.

Discussion of Possible Embodiments

The following are non-exclusive descriptions of possible embodiments of the present invention.

A blade outer air seal assembly includes a plurality of seal segments circumferentially disposed about an array of blades rotatable about an axis, each of the plurality of seal segments having a radially inner surface facing a tip of each blade of the array of blades, the radially inner surface having an arrangement of trenches formed therein, and a radially outer surface opposite the radially inner surface. The arrangement of trenches is disposed between 30% and 80% of a chord of a blade of the array of blades as taken at the respective tip, and the arrangement of trenches is aperiodic in the axial direction.

The assembly of the preceding paragraph can optionally include, additionally and/or alternatively, any one or more of the following features, configurations and/or additional components:

In the above assembly, the arrangement of trenches can include four trenches to eight trenches.

In any of the above assemblies, each trench of the arrangement of trenches can have a width defined by an upstream surface and a downstream surface.

In any of the above assemblies, for a first trench of the arrangement of trenches, the width can be constant, and for a second trench of the arrangement of trenches, the width can be varied.

In any of the above assemblies, each trench of the arrangement of trenches can have a height defined by an upper surface and the radially inner surface of a respective seal segment.

In any of the above assemblies, for a first trench of the arrangement of trenches, the height can be constant, and for a second trench of the arrangement of trenches, the height can be varied.

In any of the above assemblies, each trench of the arrangement of trenches can have a pair of upper corners and a pair of lower corners.

In any of the above assemblies, for a first trench the arrangement of trenches, one corner of the pair of upper corners can be rounded.

In any of the above assemblies, for a second trench the arrangement of trenches, both corners of the pair of upper corners can be rounded.

In any of the above assemblies, each corner of the pair of lower corners can be straight.

In any of the above assemblies, the array of blades can be located in a turbine section of the gas turbine engine.

A gas turbine engine section includes a disk supporting an array of blades, the array of blades rotatable about an axis, a casing radially outward from the array of blades, and a blade outer air seal disposed between the casing and the array of blades. The blade outer air seal assembly includes a plurality of seal segments circumferentially disposed about an array of blades rotatable about an axis, each of the plurality of seal segments having a radially inner surface facing a tip of each blade of the array of blades, the radially inner surface having an arrangement of trenches formed therein, and a radially outer surface opposite the radially inner surface. The arrangement of trenches is disposed between 30% and 80% of a chord of a blade of the array of blades as taken at the respective tip, and the arrangement of trenches is aperiodic in the axial direction.

The section of the preceding paragraph can optionally include, additionally and/or alternatively, any one or more of the following features, configurations and/or additional components:

In the above section, the arrangement of trenches can include four trenches to eight trenches.

In any of the above sections, each trench of the arrangement of trenches can have a width defined by an upstream surface and a downstream surface.

In any of the above sections, for a first trench of the arrangement of trenches, the width can be constant, and for a second trench of the arrangement of trenches, the width can be varied.

In any of the above sections, each trench of the arrangement of trenches can have a height defined by an upper surface and the radially inner surface of a respective seal segment.

In any of the above sections, for a first trench of the arrangement of trenches, the height can be constant, and for a second trench of the arrangement of trenches, the height can be varied.

In any of the above sections, each trench of the arrangement of trenches can have a pair of upper corners and a pair of lower corners.

In any of the above sections, for a first trench the arrangement of trenches, one corner of the pair of upper corners can be rounded.

In any of the above sections, the array of blades can be located in a turbine section of the gas turbine engine.

While the invention has been described with reference to an exemplary embodiment(s), it will be understood by those skilled in the art that various changes may be made, and equivalents may be substituted, for elements thereof, without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment(s) disclosed, but that the invention will include all embodiments falling within the scope of the appended claims.

The invention claimed is:

1. A blade outer air seal assembly comprising:
- a plurality of seal segments circumferentially disposed about an array of blades rotatable about an axis, each of the plurality of seal segments comprising:
  - a radially inner surface facing a tip of each blade of the array of blades, the radially inner surface having an arrangement of trenches formed therein; and
  - a radially outer surface opposite the radially inner surface,
  - wherein the arrangement of trenches is disposed between 30% and 80% of a chord of a blade of the array of blades as taken at the respective tip; and
  - wherein the arrangement of trenches is aperiodic in the axial direction, wherein trenches disposed between 40% to 60% of the chord of the blade are wider than trenches disposed outside thereof.

2. The assembly of claim **1**, wherein the arrangement of trenches comprises four trenches to eight trenches.

3. The assembly of claim **2**, wherein each trench of the arrangement of trenches has a width defined by an upstream surface and a downstream surface.

4. The assembly of claim **3**, wherein for a first trench of the arrangement of trenches, the width is constant, and wherein for a second trench of the arrangement of trenches, the width is varied.

5. The assembly of claim **3**, wherein each trench of the arrangement of trenches has a height defined by an upper surface and the radially inner surface of a respective seal segment.

6. The assembly of claim **5**, wherein for a first trench of the arrangement of trenches, the height is constant, and wherein for a second trench of the arrangement of trenches, the height is varied.

7. The assembly of claim **5**, wherein each trench of the arrangement of trenches has a pair of upper corners and a pair of lower corners.

8. The assembly of claim **7**, wherein for a first trench of the arrangement of trenches, one corner of the pair of upper corners is rounded.

9. The assembly of claim **8**, wherein for a second trench of the arrangement of trenches, both corners of the pair of upper corners are rounded.

10. The assembly of claim **7**, wherein each corner of the pair of lower corners is straight.

11. The assembly of claim **1**, wherein the array of blades is located in a turbine section of the gas turbine engine.

12. A gas turbine engine section comprising:
- a disk supporting an array of blades, the array of blades rotatable about an axis;
- a casing radially outward from the array of blades; and
- a blade outer air seal assembly disposed between the casing and the array of blades, the blade outer air seal assembly comprising:
  - a plurality of seal segments circumferentially disposed about the array of blades, each of the plurality of seal segments comprising:
    - a radially inner surface facing a tip of each blade of the array of blades, the radially inner surface having an arrangement of trenches formed therein; and
    - a radially outer surface opposite the radially inner surface,
  - wherein the arrangement of trenches is disposed between 30% and 80% of a chord of a blade of the array of blades as taken at the respective tip; and
  - wherein the arrangement of trenches is aperiodic in the axial direction, wherein trenches disposed between 40% to 60% of the chord of the blade are wider than trenches disposed outside thereof.

13. The section of claim **12**, wherein the arrangement of trenches comprises four trenches to eight trenches.

14. The section of claim **13**, wherein each trench of the arrangement of trenches has a width defined by an upstream surface and a downstream surface.

15. The section of claim **14**, wherein for a first trench of the arrangement of trenches, the width is constant, and wherein for a second trench of the arrangement of trenches, the width is varied.

16. The section of claim **14**, wherein each trench of the arrangement of trenches has a height defined by an upper surface and the radially inner surface of a respective seal segment.

17. The section of claim **16**, wherein for a first trench of the arrangement of trenches, the height is constant, and wherein for a second trench of the arrangement of trenches, the height is varied.

18. The section of claim **16**, wherein each trench of the arrangement of trenches has a pair of upper corners and a pair of lower corners.

19. The section of claim **18**, wherein for a first trench of the arrangement of trenches, one corner of the pair of upper corners is rounded.

20. The section of claim **12**, wherein the array of blades is located in a turbine section of the gas turbine engine.

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