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(54) **MISTUNED LAMINATE AIRFOIL**

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USPC 60/805

See application file for complete search history.

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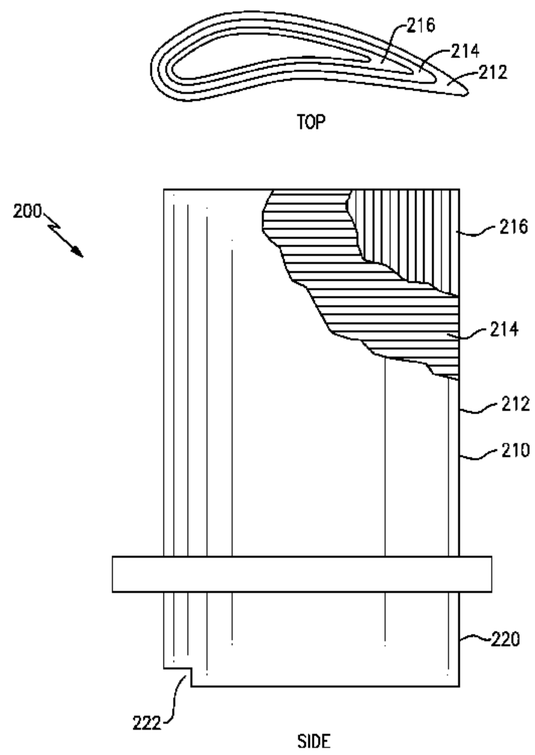
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(57) **ABSTRACT**

A gas turbine engine includes a fan mounting a first group of blades and a second group of blades. The first group of blades and the second group of blades share a profile shape. The first group of blades have a first laminate composition, and the second group of blades have a second laminate composition, distinct from the first laminate composition. A frequency of a vibratory mode of the first group of blades is offset from a frequency of a vibratory mode of the second group of blades.

20 Claims, 4 Drawing Sheets



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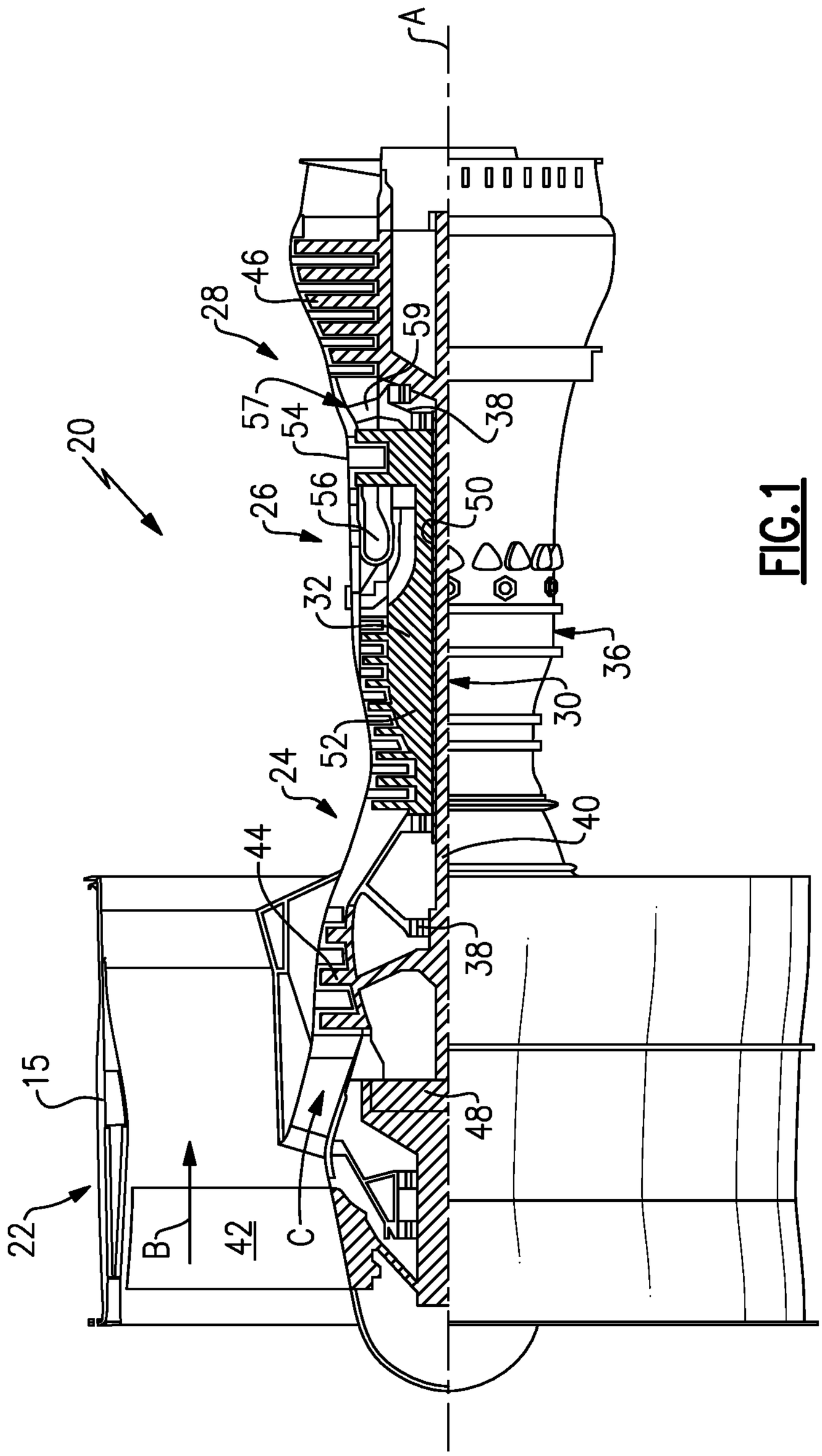


FIG.1

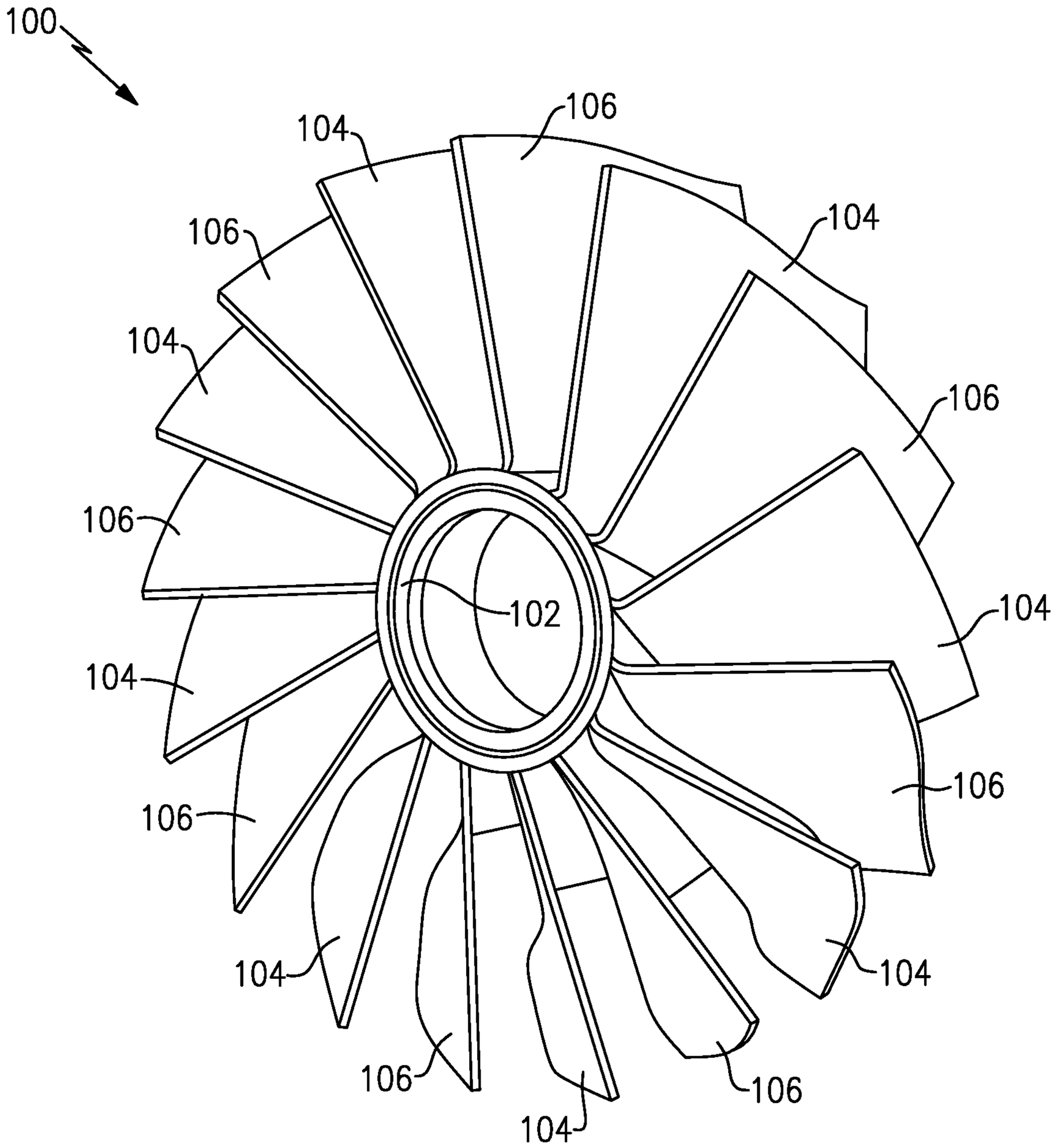
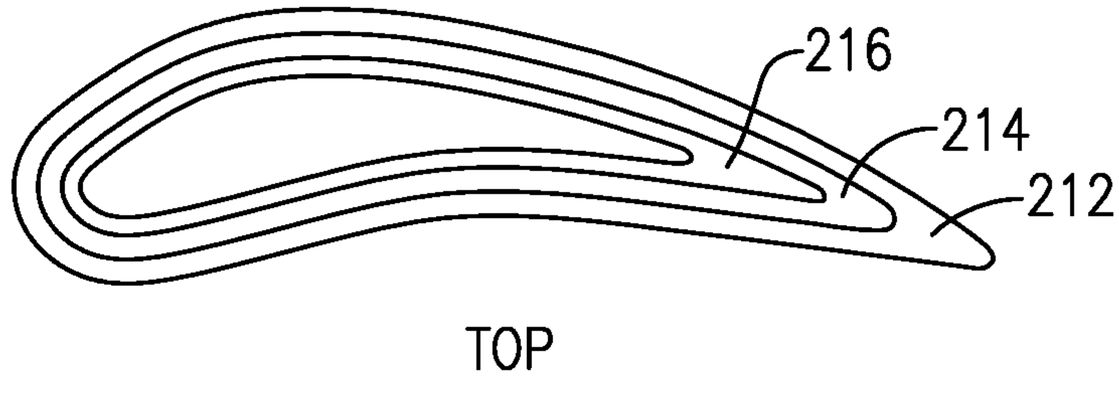

100
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104

FIG.2



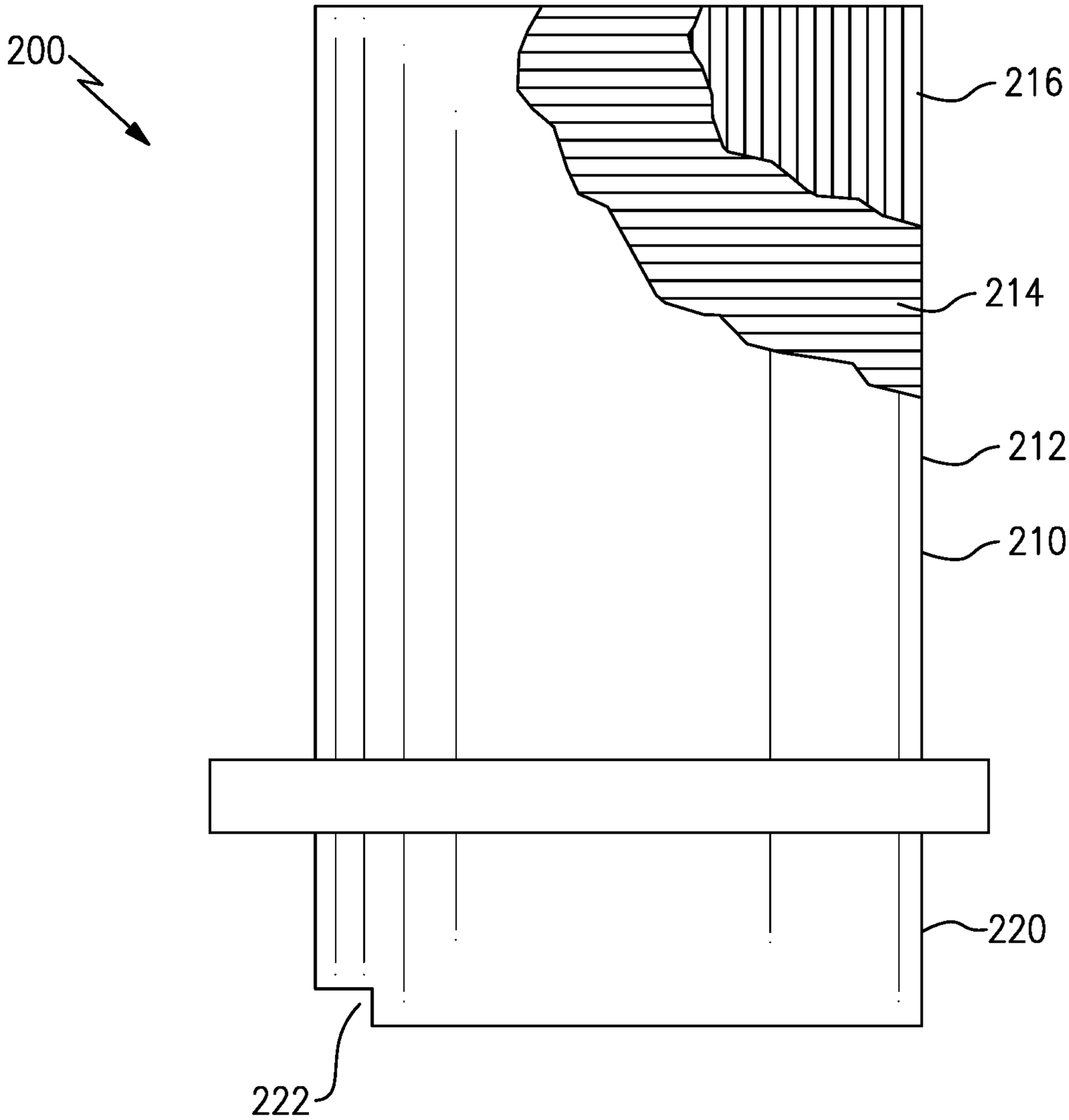
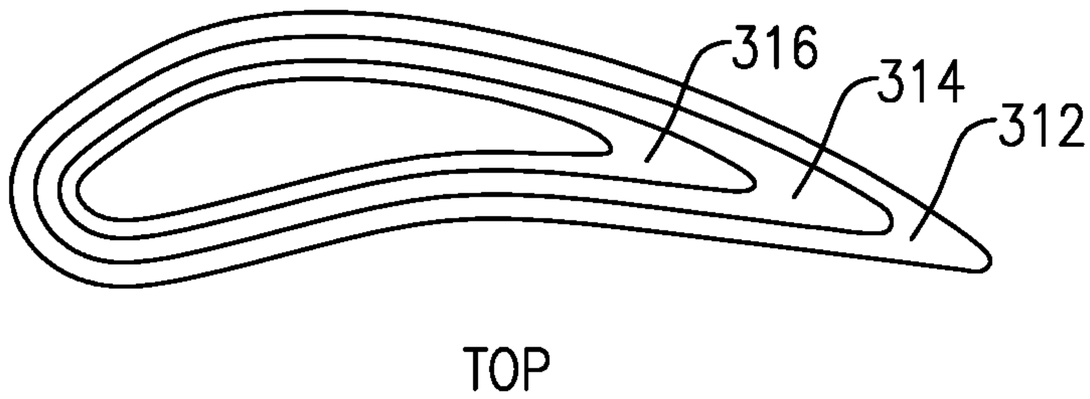


FIG.3



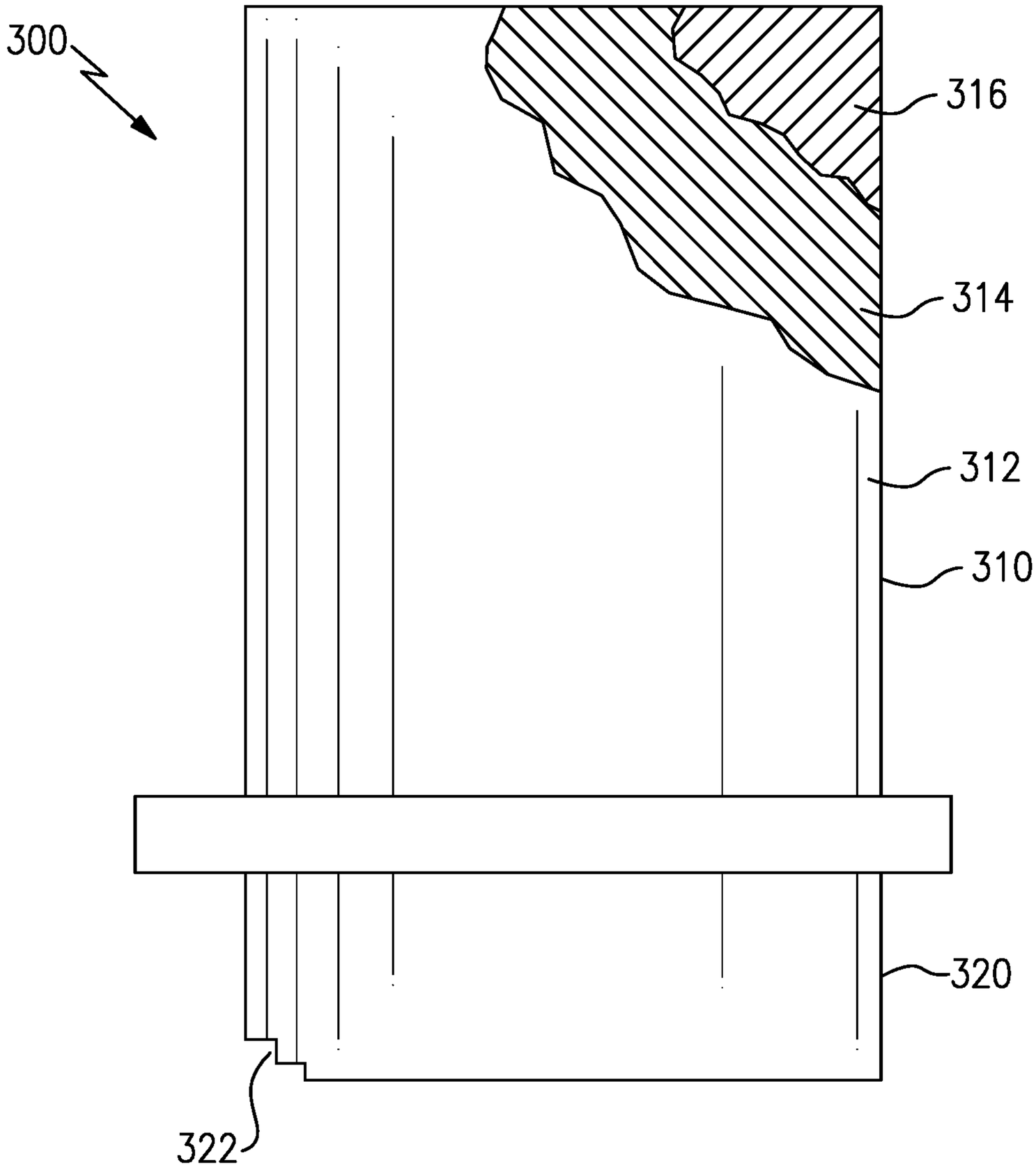


FIG.4

MISTUNED LAMINATE AIRFOIL

TECHNICAL FIELD

The present disclosure relates generally to airfoils for a gas powered turbine, and more specifically to mistuned airfoils.

BACKGROUND

Gas powered turbines generally include a compressor section that draws in and compresses air, a combustor section where the compressed air is mixed with a fuel and ignited, and a turbine section across which the resultant combustion products are expanded. The expansion of the combustion products drives the turbine to rotate, which in turn drives the compressor.

Within each of the compressor section and turbine section are multiple flowpath spanning rotor blades. Such blades typically include one or more airfoil shaped profiles, and are designed to interact with the flow of fluid through the primary fluid flowpath of the gas turbine engine either by being turned by the fluid flow, in the case of turbine blades, or by driving the fluid flow, in the case of compressor blades.

One impact of using airfoil shaped blades is that each blade has vibratory modes that can cause flutter and flow shedding, which can negatively impact the performance of the blade due to the resultant non-integral vibrations.

SUMMARY OF THE INVENTION

In one exemplary embodiment a fan for a gas turbine engine includes a fan mounting a first group of blades and a second group of blades, the first group of blades and the second group of blades sharing a profile shape, wherein the first group of blades have a first laminate composition, wherein the second group of blades have a second laminate composition, distinct from the first laminate composition, and wherein a frequency of a vibratory mode of the first group of blades is offset from a frequency of a vibratory mode of the second group of blades.

In another example of the above described fan for a gas turbine engine the first group of blades and the second group of blades are alternately arranged circumferentially around the fan.

In another example of any of the above described fans for a gas turbine engine each blade in the first group of blades is circumferentially adjacent a first blade of the second group of blades and a second blade of the second group of blades.

In another example of any of the above described fans for a gas turbine engine the frequency of the vibratory mode of the first group of blades is offset from the frequency of the vibratory mode of the second group of blades by at least 4%.

In another example of any of the above described fans for a gas turbine engine the frequency of the vibratory mode of the first group of blades is offset from the frequency of the vibratory mode of the second group of blades by at least 6%.

In another example of any of the above described fans for a gas turbine engine the first laminate composition is a first layup configuration, and wherein the second laminate composition is a second layup configuration distinct from the first layup configuration.

In another example of any of the above described fans for a gas turbine engine the first layup configuration includes at least one of a specific material layer orientation and a relative layer position, and wherein the second layup configuration includes at least one of a specific material layer orientation and a relative layer position.

In another example of any of the above described fans for a gas turbine engine the material layer orientation of the first layup configuration is distinct from the material layer orientation of the second layup configuration.

In another example of any of the above described fans for a gas turbine engine the relative layer position of the first layup configuration is distinct from the relative layer position of the second layup configuration.

In another example of any of the above described fans for a gas turbine engine each blade of the first group of blades, and each blade of the second group of blades is constructed at least partially of a polymer matrix composite.

In one exemplary embodiment a gas turbine engine includes a compressor section, a combustor fluidly connected to the compressor section, a turbine section fluidly connected to the combustor, a fan drivably connected to the turbine section, the fan including a first set of blades and a second set of blades, wherein each of the first set of blades and the second set of blades share a profile, the first set of blades having a first vibratory mode, and the second set of blades having a second vibratory mode distinct form the first vibratory mode.

In another example of the above described gas turbine engine the blades in the first set of blades are laminate blades having a first laminate composition and the blades in the second set of blades are laminate blades having a second laminate composition distinct from the first laminate composition.

In another example of any of the above described gas turbine engines the first laminate composition is a first layup configuration, and wherein the second laminate composition is a second layup configuration distinct from the first layup configuration.

In another example of any of the above described gas turbine engines the first layup configuration includes at least one of a specific material layer orientation and a relative layer position, and wherein the second layup configuration includes at least one of a specific material layer orientation and a relative layer position.

In another example of any of the above described gas turbine engines the material layer orientation of the first layup configuration is distinct from the material layer orientation of the second layup configuration.

In another example of any of the above described gas turbine engines the relative layer position of the first layup configuration is distinct from the relative layer position of the second layup configuration.

In another example of any of the above described gas turbine engines the first set of blades and the second set of blades are arranged in a circumferentially alternating configuration.

In another example of any of the above described gas turbine engines a vibratory mode of the first set of blades is offset from a vibratory mode of the second set of blades by at least 4%.

An exemplary method for creating a gas turbine engine fan includes installing a first set of blades and a second set of blades in circumferentially alternating positions about a rim, wherein set first set of blades and the second set of blades share a profile and have distinct vibratory modes.

In a further example of the above described exemplary method for creating a gas turbine engine fan installing the first set of blades and the second set of blades comprises

matching a keying feature with at least one of the first set of blades and the second set of blades with corresponding slots in the rim.

These and other features of the present invention can be best understood from the following specification and drawings, the following of which is a brief description.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** schematically illustrates an exemplary gas powered turbine.

FIG. **2** schematically illustrates a fan section of a gas turbine engine.

FIG. **3** schematically illustrates a top view and a side view of a first set of blades within the fan of FIG. **2**.

FIG. **4** schematically illustrates a top view and a side view of a second set of blades within the fan of FIG. **2**.

DETAILED DESCRIPTION OF AN EMBODIMENT

FIG. **1** schematically illustrates a gas turbine engine **20**. The gas turbine engine **20** is disclosed herein as a two-spool turbofan that generally incorporates a fan section **22**, a compressor section **24**, a combustor section **26** and a turbine section **28**. Alternative engines might include an augmentor section (not shown) among other systems or features. The fan section **22** drives air along a bypass flow path B in a bypass duct defined within a nacelle **15**, while the compressor section **24** drives air along a core flow path C for compression and communication into the combustor section **26** then expansion through the turbine section **28**. 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.

While described herein in the context of an exemplary gas turbine engine, one of skill in the art, having the benefit of the following disclosure, will understand that the gaspath component, and associated cooling system, described herein can be utilized in any gas powered turbine, including a land based turbine, a marine turbine, a test rig, or any other gas powered turbine construction.

The exemplary engine **20** generally includes a low speed spool **30** and a high speed spool **32** mounted for rotation about an engine central longitudinal axis A relative to an engine static structure **36** via several bearing systems **38**. It should be understood that various bearing systems **38** at various locations may alternatively or additionally be provided, and the location of bearing systems **38** may be varied as appropriate to the application.

The low speed spool **30** generally includes an inner shaft **40** that interconnects a fan **42**, a first (or low) pressure compressor **44** and a first (or low) pressure turbine **46**. The inner shaft **40** is connected to the fan **42** through a speed change mechanism, which in exemplary gas turbine engine **20** is illustrated as a geared architecture **48** to drive the fan **42** at a lower speed than the low speed spool **30**. The high speed spool **32** includes an outer shaft **50** that interconnects a second (or high) pressure compressor **52** and a second (or high) pressure turbine **54**. A combustor **56** is arranged in exemplary gas turbine **20** between the high pressure compressor **52** and the high pressure turbine **54**. A mid-turbine frame **57** of the engine static structure **36** is arranged generally between the high pressure turbine **54** and the low pressure turbine **46**. The mid-turbine frame **57** further supports bearing systems **38** in the turbine section **28**. The inner shaft **40** and the outer shaft **50** are concentric and rotate via bearing systems **38** about the engine central longitudinal axis A which is collinear with their longitudinal axes.

The core airflow is compressed by the low pressure compressor **44** then the high pressure compressor **52**, mixed and burned with fuel in the combustor **56**, then expanded over the high pressure turbine **54** and low pressure turbine **46**. The mid-turbine frame **57** includes airfoils **59** which are in the core airflow path C. The turbines **46**, **54** rotationally drive the respective low speed spool **30** and high speed spool **32** in response to the expansion. It will be appreciated that each of the positions of the fan section **22**, compressor section **24**, combustor section **26**, turbine section **28**, and fan drive gear system **48** may be varied. For example, gear system **48** may be located aft of combustor section **26** or even aft of turbine section **28**, and fan section **22** may be positioned forward or aft of the location of gear system **48**.

The engine **20** in one example is a high-bypass geared aircraft engine. In a further example, the engine **20** bypass ratio is greater than about six (6), with an example embodiment being greater than about ten (10), the geared architecture **48** 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 and the low pressure turbine **46** has a pressure ratio that is greater than about five. In one disclosed embodiment, the engine **20** bypass ratio is greater than about ten (10:1), the fan diameter is significantly larger than that of the low pressure compressor **44**, and the low pressure turbine **46** has a pressure ratio that is greater than about five (5:1). Low pressure turbine **46** pressure ratio is pressure measured prior to inlet of low pressure turbine **46** as related to the pressure at the outlet of the low pressure turbine **46** prior to an exhaust nozzle. The geared architecture **48** may be an epicycle gear train, such as a planetary gear system or other gear system, with a gear reduction ratio of greater than about 2.3:1. 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 the bypass flow B due to the high bypass ratio. The fan section **22** of the engine **20** is designed for a particular flight condition—typically cruise at about 0.8 Mach and about 35,000 feet (10668 meters). The flight condition of 0.8 Mach and 35,000 ft (10668 m), with the engine 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 the engine produces at that minimum point. "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. "Low corrected fan tip speed" is the actual fan tip speed in ft/sec divided by an industry standard temperature correction of [(Tram ° R)/(518.7° R)]ˆ0.5. The "Low corrected fan tip speed" as disclosed herein according to one non-limiting embodiment is less than about 1150 ft/second (350.5 m/s).

One goal of gas turbine engine design, and specifically rotor and fan blade design, is to minimize non-integral vibrations caused by flutter and flow shedding. Tuning (intentionally designing the vibratory frequencies) of the gas turbine engine fan has been shown to reduce non-integral vibrations in the gas turbine engine.

One method of tuning the gas turbine engine fan involves varying the natural frequencies of individual fan blades. This variation is referred to herein as "mistuning the blades" A typical mistuned fan blade assembly includes alternating types of blades, with blades from a first blade set, and blades from a second blade set being arranged in a single rotor. The blades from the first blade set are designed with a first vibratory mode, and the blades in a second blade set are designed with a second vibratory mode, distinct from the first vibratory mode.

One approach to achieve this variation is by removing material from the blade edges. This method is commonly referred to as "clipping." Removing material from the blade edges changes the natural frequency of the blade, and, in so doing, may reduce the non-integral vibrations in the fan. This method typically involves modifying the blade edges after the blade is manufactured.

Another method of tuning the gas turbine engine fan involves having fan blades with different thicknesses on the same rotor. Typically, this method uses fan blades on the rotor alternating between blades of different external profiles. Thus, both "thick" and "thin" blades are used and both "thick" and "thin" blades are manufactured.

Both of these approaches, "clipping" and "thick—thin," have undesirable aerodynamic consequences as a result of the blades in each set having distinct aerodynamic profiles from the blades in the other set.

With continued reference to FIG. **1**, FIG. **2** schematically illustrates a fan **100** for a fan section of a gas turbine engine, such as the engine **20** of FIG. **1**. The fan **100** includes a rim **102**, and multiple fan blades **104**, **106** protruding radially outward from the rim **102**. The fan blades **104**, **106** are divided into a first set of fan blades **104**, and a second set of fan blades **106**. The fan blades **104**, **106** are arranged circumferentially with alternating blades form each set. In other words, each blade **104** in the first set is circumferentially adjacent to two blades **106** in the second set.

All of the fan blades **104**, **106** in the fan **100** have identical blade profiles. In some examples, the fan blades **104**, **106** include identical geometries for the entire blade **104**, **106**. In alternative examples the fan blades **104**, **106** include identical blade geometries, with one or more distinctions in a root geometry connecting the blade **104**, **106** to the rim **102**. By way of example, the distinctions in the root geometry can be a keying feature configured to prevent incorrect installation of a blade **104** from the first set of blades **104** in a slot designated for a blade **106** in the second set of blades **106**, and vice versa.

Each of the blades **104**, **106** is constructed of a laminated composite, such as a polymer matrix composite (PMC). As is understood in the art, PMC's, as well as other laminated composites, are constructed of multiple laminated layers. The orientations and the relative positions of the layers affect the structural qualities of the object being constructed. By way of example, altering the direction (orientation) of the layers or the positions of the layers relative to each other will alter the strength and stiffness of the blade, without altering the completed geometry of the blade **104**, **106**. The specific construction, relative position of, and orientation of, the multiple layers in the laminate is referred to as the "layup" of the laminate construction.

As a further effect of utilizing distinct laminate compositions between the blades **104**, **106** the vibratory modes of the blades **104**, **106** are distinct. The resultant vibratory modes of the laminate composition of any given blade **104**, **106** can be determined empirically or theoretically according to known methods in the art, with the specific vibratory modes depending on the geometry of the blade **104**, **106** and the laminate composition.

In the example of FIG. **2**, the first set of blades **104** is designed with a first vibratory mode, and the second set of blades **106** is designed with a second vibratory mode. In some examples, the first and second set of blades **104**, **106** have vibratory modes where the frequencies are offset by at least 4%, and the laminate compositions are chosen accordingly. In further examples, the blades **104**, **106** are designed with vibratory modes where the frequencies are offset by at least 6%. By intentionally creating an offset of 6% or more, the variability due to manufacturing issues, and tolerances, can be accounted for and the frequencies of the vibratory modes are ensured to be offset by at least 4% in a final production. The magnitude of the offset required to account for the above described variability depends on the specific engine parameter, manufacturing parameters, and the like, and can be determined by one of skill in the art having the benefit of this disclosure.

With continued reference to FIGS. **1** and **2**, FIG. **3** schematically illustrates a top view and a side view of an exemplary blade **200** that can be used as a blade **104**, **106** in the example fan **100** of FIG. **2**. The thickness and orientation of the layers illustrated in the example of FIG. **3** are exaggerated for explanatory effect, and one of skill in the art having the benefit of this disclosure will recognize that alternative orientations and thicknesses can be utilized to achieve similar results. Similarly, FIG. **4** schematically illustrates a top view and a side view of an exemplary blade **300** that can be used as a blade **104**, **106** in the example fan **100** of FIG. **2**.

Each of the blades **200**, **300** includes a blade portion **210**, **310** protruding radially outward from a root **220**, **320**. The root **220**, **320** interfaces with, and connects the blade **200**, **300** to the rim **102** (shown in FIG. **2**). Each blade portion **210**, **310** is constructed of multiple layers **212**, **214**, **216**, **312**, **314**, **316**. While illustrated as including three layers **212**, **214**, **216**, **312**, **314**, **316**, one of skill in the art, having the benefit of this disclosure, will understand that each blade **200**, **300** will be constructed of substantially more layers than the three illustrated layers **212**, **214**, **216**, **312**, **314**, **316**.

In this example, each layer is made from unidirectional tape material, illustrated as parallel lines, with the orientation of the tape layers affecting the material properties of the blade portion **210**, **310**. As can be seen, the internal tape layers **214**, **216** of the blade **200** of FIG. **3** have a first orientation, whereas the internal tape layers **314**, **316** of the blade **300** of FIG. **4** have a second orientation, distinct from the first orientation. Further differentiating the layup of the blades **200**, **300** in some examples is the spacing between the layers, the layer material, and/or the positioning of similarly aligned layers within a single blade **200**, **300**. In such examples, the thickness of corresponding layers and the relative position of corresponding layers within the structure (e.g. the innermost layer vs. the outermost layer), are varied giving rise to distinct vibratory mode frequencies.

In some examples, the blades **200**, **300** include distinct keying features **222**, **322** within the root **220**, **320**. The keying feature **222**, **322** ensures that any given blade **200**, **300** can only be inserted in a slot for that particular blade set, thereby minimizing manufacturing and maintenance errors and complexity.

In some examples, the root **220**, **320** is constructed of the same laminate as the blade portion **210**, **310**, and the entire blade **200**, **300** structure is a single integral structure. In alternative examples, the root **220**, **320** can be a distinct

structure that the blade portion **210**, **310** is built onto. In such examples, the layup variation between the first set of blades **200** and the second set of blades **300** applies only to the blade portion **210**, **310**, and the roots **220**, **320** can have the same structure.

While illustrated in FIGS. **3** and **4** as including no internal features for simplicity, one of skill in the art will understand that in some examples the blades **200**, **300** can include internal cavities, or other internal structures according to known designs without impacting the layup based mistuning described herein.

It is further understood that any of the above described concepts can be used alone or in combination with any or all of the other above described concepts. Although an embodiment of this invention has been disclosed, a worker of ordinary skill in this art would recognize that certain modifications would come within the scope of this invention. For that reason, the following claims should be studied to determine the true scope and content of this invention.

The invention claimed is:

1. A fan for a gas turbine engine comprising:

the fan mounting a first group of blades and a second group of blades;

said first group of blades and said second group of blades sharing a profile shape;

wherein said first group of blades have a first laminate composition;

wherein said second group of blades have a second laminate composition, distinct from the first laminate composition, and said first group of blades and said second group of blades each include a corresponding root shape distinct from the corresponding root shape of the other of said first group of blades and said second group of blades, wherein each of the corresponding root shapes has a same layup structure as each other of the corresponding root shapes; and

wherein a frequency of a vibratory mode of the first group of blades is offset from a frequency of a vibratory mode of the second group of blades.

2. The fan of claim **1**, wherein said first group of blades and said second group of blades are alternately arranged circumferentially around said fan.

3. The fan of claim **2**, wherein each blade in said first group of blades is circumferentially adjacent a first blade of said second group of blades and a second blade of said second group of blades.

4. The fan of claim **1**, wherein the frequency of the vibratory mode of the first group of blades is offset from the frequency of the vibratory mode of the second group of blades by at least 4%.

5. The fan of claim **4**, wherein the frequency of the vibratory mode of the first group of blades is offset from the frequency of the vibratory mode of the second group of blades by at least 6%.

6. The fan of claim **1**, wherein the first laminate composition is a first layup configuration, and wherein the second laminate composition is a second layup configuration distinct from the first layup configuration.

7. The fan of claim **6**, wherein the first layup configuration includes at least one of a specific material layer orientation and a relative layer position, and wherein the second layup configuration includes at least one of a specific material layer orientation and a relative layer position.

8. The fan of claim **7**, wherein the material layer orientation of the first layup configuration is distinct from the material layer orientation of the second layup configuration.

9. The fan of claim **7**, wherein the relative layer position of the first layup configuration is distinct from the relative layer position of the second layup configuration.

10. The fan of claim **1**, wherein each blade of said first group of blades, and each blade of said second group of blades is constructed at least partially of a polymer matrix composite.

11. The fan of claim **1**, wherein the distinct root shapes of one of said first group of blades and said second group of blades includes a keying feature.

12. The fan of claim **1**, wherein each blade structure is a single integral structure including a corresponding blade root.

13. A gas turbine engine comprising:

a compressor section;

a combustor fluidly connected to the compressor section;

a turbine section fluidly connected to the combustor;

a fan drivably connected to said turbine section, the fan including a first set of blades and a second set of blades, wherein each of said first set of blades and said second set of blades share a profile;

the first set of blades having a first vibratory mode; and

the second set of blades having a second vibratory mode distinct from the first vibratory mode; and

wherein said first set of blades and said second set of blades each include a corresponding root shape distinct from the corresponding root shape of the other of said first set of blades and said second set of blades, and each of the corresponding root shapes has a same layup structure as each other of the corresponding root shapes.

14. The gas turbine engine of claim **13**, wherein the blades in the first set of blades are laminate blades having a first laminate composition and the blades in the second set of blades are laminate blades having a second laminate composition distinct from the first laminate composition.

15. The gas turbine engine of claim **14**, wherein the first laminate composition is a first layup configuration, and wherein the second laminate composition is a second layup configuration distinct from the first layup configuration.

16. The gas turbine engine of claim **15**, wherein the first layup configuration includes at least one of a specific material layer orientation and a relative layer position, and wherein the second layup configuration includes at least one of a specific material layer orientation and a relative layer position.

17. The gas turbine engine of claim **16**, wherein the material layer orientation of the first layup configuration is distinct from the material layer orientation of the second layup configuration.

18. The gas turbine engine of claim **16**, wherein the relative layer position of the first layup configuration is distinct from the relative layer position of the second layup configuration.

19. The gas turbine engine of claim **14**, wherein said first set of blades and said second set of blades are arranged in a circumferentially alternating configuration.

20. The gas turbine engine of claim **14**, wherein a vibratory mode of the first set of blades is offset from a vibratory mode of the second set of blades by at least 4%.

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