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Inventor(s)	Xie; Ming et al.

Airfoil assembly having an airfoil and a spar

Abstract

An airfoil assembly for a turbine engine. The airfoil assembly has an airfoil, and a spa. The airfoil has a wall bounding an interior and defining an exterior surface. The wall extends between a leading edge and a trailing edge to define a chordwise direction, and between a root and a tip to define a spanwise direction. The spar includes a centerline axis, the spar extends into the interior of the airfoil.

Inventors: Xie; Ming (Beavercreek, OH), Boyer; Mitchell Harold (Cincinnati, OH), Davis; Tod Winton (Cincinnati, OH)

Applicant: GENERAL ELECTRIC COMPANY (Schenectady, NY)

Family ID: 1000008748167

Assignee: General Electric Company (Evendale, OH)

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Primary Examiner: Amick; Jacob M

Assistant Examiner: Brauch; Charles J

Attorney, Agent or Firm: McGarry Bair PC

Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS (1) This application is a continuation of U.S. patent application Ser. No. 18/304,708, filed Apr. 21, 2023, now U.S. Pat. No. 11,846,192, granted Dec. 19, 2023, which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

(1) The disclosure generally relates to an airfoil assembly, and more specifically to an airfoil assembly having an airfoil and a spar.

BACKGROUND

(2) Turbine engines, and particularly gas or combustion turbine engines, are rotary engines that extract energy from a flow of gases passing through a fan with a plurality of fan blades, then into the engine through a series of compressor stages, which include pairs of rotating blades and stationary vanes, through a combustor, and then through a series of turbine stages, which include pairs of rotating blades and stationary vanes. The blades are mounted to rotating disks, while the vanes are mounted to stator disks.

(3) During operation air is brought into the compressor section through the fan section where it is then pressurized in the compressor and mixed with fuel in the combustor for generating hot combustion gases which flow downstream through the turbine stages where the air is expanded and exhausted out an exhaust section. The expansion of the air in the turbine section is used to drive the rotating sections of the fan section and the compressor section. The drawing in of air, the pressurization of the air, and the expansion of the air is done, in part, through rotation of various rotating blades mounted to respective disks throughout the fan section, the compressor section and the turbine section, respectively. The rotation of the rotating blades imparts mechanical stresses along various portions of the blade; specifically, where the blade is mounted to the disk.

(4) In some turbine engines, a variable pitch airfoil can be included, which can be selectively rotated to adjust or otherwise tailor the flow of fluid over the variable pitch airfoil. The variable pitch airfoil is movable through use of a trunnion and a spar. The trunnion can rotate about a rotational axis, which in turn rotates the spar and the variable pitch airfoil. The trunnion is coupled to or otherwise formed with the spar, and the airfoil is coupled to or otherwise formed with the spar

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) A full and enabling disclosure of the present disclosure, including the best mode thereof, directed to one of ordinary skill in the art, is set forth in the specification, which makes reference to the appended figures, in which:

(2) FIG. 1 is a schematic cross-sectional view of a turbine engine.

(3) FIG. 2 is a schematic illustration of an airfoil assembly suitable for use within the turbine engine of FIG. 1, the airfoil assembly including an airfoil, a trunnion, and a spar.

(4) FIG. 3 is a schematic cross-sectional view of the airfoil assembly as seen from sectional line III-III of FIG. 2, further illustrating a furcated tail with a set of branches defining a set of intervening gaps, the airfoil assembly including a set of inserts receivable within the set of intervening gaps.

(5) FIG. 4 is a schematic, top-down view of the airfoil assembly as seen from sectional line IV-IV of FIG. 3.

(6) FIG. 5 is an exemplary method of forming the airfoil assembly of FIG. 2.

DETAILED DESCRIPTION

(7) Aspects of the disclosure herein are directed to an airfoil assembly for a turbine engine. The airfoil assembly includes an airfoil, a spar, and a trunnion. The spar couples the airfoil to the trunnion. The spar having a furcated tail with a set of branches defining a set of intervening gaps. The airfoil assembly further includes a set of inserts provided within the set of intervening gaps.

(8) For purposes of illustration, the present disclosure will be described with respect to an airfoil assembly for a turbine engine, specifically a fan blade of the turbine engine. It will be understood, however, that aspects of the disclosure described herein are not so limited and can have general applicability within other engines or within other portions of the turbine engine. For example, the disclosure can have applicability for an airfoil assembly in other engines or vehicles, and can be used to provide benefits in industrial, commercial, and residential applications.

(9) As used herein, the term “upstream” refers to a direction that is opposite the fluid flow direction, and the term “downstream” refers to a direction that is in the same direction as the fluid flow. The term “fore” or “forward” means in front of something and “aft” or “rearward” means behind something. For example, when used in terms of fluid flow, fore/forward can mean upstream and aft/rearward can mean downstream.

(10) Additionally, as used herein, the terms “radial” or “radially” refer to a direction away from a common center. For example, in the overall context of a turbine engine, radial refers to a direction along a ray extending between a center longitudinal axis of the engine and an outer engine circumference. Furthermore, as used herein, the term “set” or a “set” of elements can be any number of elements, including only one.

(11) Further yet, as used herein, the term “fluid” or iterations thereof can refer to any suitable fluid within the gas turbine engine at least a portion of the gas turbine engine is exposed to such as, but not limited to, combustion gases, ambient air, pressurized airflow, working airflow, or any combination thereof. It is yet further contemplated that the gas turbine engine can be other suitable turbine engine such as, but not limited to, a steam turbine engine or a supercritical carbon dioxide turbine engine. As a non-limiting example, the term “fluid” can refer to steam in a steam turbine engine, or to carbon dioxide in a supercritical carbon dioxide turbine engine.

(12) All directional references (e.g., radial, axial, proximal, distal, upper, lower, upward, downward, left, right, lateral, front, back, top, bottom, above, below, vertical, horizontal, clockwise, counterclockwise, upstream, downstream, forward, aft, etc.) are only used for identification purposes to aid the reader's understanding of the present disclosure, and do not create limitations, particularly as to the position, orientation, or use of aspects of the disclosure described herein. Connection references (e.g., attached, coupled, secured, fastened, connected, and joined) are to be construed broadly and can include intermediate members between a collection of elements and relative movement between elements unless otherwise indicated. As such, connection references do not necessarily infer that two elements are directly connected and in fixed relation to one another. The exemplary drawings are for purposes of illustration only and the dimensions, positions, order and relative sizes reflected in the drawings attached hereto can vary.

(13) The term “composite,” as used herein is, is indicative of a component having two or more materials. A composite can be a combination of at least two or more metallic, non-metallic, or a combination of metallic and non-metallic elements or materials. Examples of a composite material can be, but not limited to, a polymer matrix composite (PMC), a ceramic matrix composite (CMC), a metal matrix composite (MMC), carbon fibers, a polymeric resin, a thermoplastic resin, bismaleimide (BMI) materials, polyimide materials, an epoxy resin, glass fibers, and silicon matrix materials.

(14) As used herein, a “composite” component refers to a structure or a component including any

suitable composite material. Composite components, such as a composite airfoil, can include several layers or plies of composite material. The layers or plies can vary in stiffness, material, and dimension to achieve the desired composite component or composite portion of a component having a predetermined weight, size, stiffness, and strength.

(15) One or more layers of adhesive can be used in forming or coupling composite components. Adhesives can include resin and phenolics, wherein the adhesive can require curing at elevated temperatures or other hardening techniques.

(16) As used herein, PMC refers to a class of materials. By way of example, the PMC material is defined in part by a prepreg, which is a reinforcement material pre-impregnated with a polymer matrix material, such as thermoplastic resin. Non-limiting examples of processes for producing thermoplastic prepregs include hot melt pre-pregging in which the fiber reinforcement material is drawn through a molten bath of resin and powder pre-pregging in which a resin is deposited onto the fiber reinforcement material, by way of non-limiting example electrostatically, and then adhered to the fiber, by way of non-limiting example, in an oven or with the assistance of heated rollers. The prepregs can be in the form of unidirectional tapes or woven fabrics, which are then stacked on top of one another to create the number of stacked composite plies desired for the part.

(17) Multiple layers of prepreg are stacked to the proper thickness and orientation for the composite component and then the resin is cured and solidified to render a fiber reinforced composite part. Resins for matrix materials of PMCs can be generally classified as thermosets or thermoplastics. Thermoplastic resins are generally categorized as polymers that can be repeatedly softened and flowed when heated and hardened when sufficiently cooled due to physical rather than chemical changes. Notable example classes of thermoplastic resins include nylons, thermoplastic polyesters, polyaryletherketones, and polycarbonate resins. Specific example of high-performance thermoplastic resins that have been contemplated for use in aerospace applications include, polyetheretherketone (PEEK), polyetherketoneketone (PEKK), polyetherimide (PEI), polyaryletherketone (PAEK), and polyphenylene sulfide (PPS). In contrast, once fully cured into a hard rigid solid, thermoset resins do not undergo significant softening when heated, but instead thermally decompose when sufficiently heated. Notable examples of thermoset resins include epoxy, bismaleimide (BMI), and polyimide resins.

(18) Instead of using a prepreg, in another non-limiting example, with the use of thermoplastic polymers, it is possible to utilize a woven fabric. Woven fabric can include, but is not limited to, dry carbon fibers woven together with thermoplastic polymer fibers or filaments. Non-prepreg braided architectures can be made in a similar fashion. With this approach, it is possible to tailor the fiber volume of the part by dictating the relative concentrations of the thermoplastic fibers and reinforcement fibers that have been woven or braided together. Additionally, different types of reinforcement fibers can be braided or woven together in various concentrations to tailor the properties of the part. For example, glass fibers, carbon fibers, and thermoplastic fibers could all be woven together in various concentrations to tailor the properties of the part. The carbon fibers provide the strength of the system, the glass fibers can be incorporated to enhance the impact properties, which is a design characteristic for parts located near the inlet of the engine, and the thermoplastic fibers provide the binding for the reinforcement fibers.

(19) In yet another non-limiting example, resin transfer molding (RTM) can be used to form at least a portion of a composite component. Generally, RTM includes the application of dry fibers to a mold or cavity. The dry fibers can include prepreg, braided material, woven material, or any combination thereof.

(20) Resin can be pumped into or otherwise provided to the mold or cavity to impregnate the dry fibers. The combination of the impregnated fibers and the resin are then cured and removed from the mold. When removed from the mold, the composite component can require post-curing processing.

(21) It is contemplated that RTM can be a vacuum assisted process. That is, the air from the cavity

or mold can be removed and replaced by the resin prior to heating or curing. It is further contemplated that the placement of the dry fibers can be manual or automated.

(22) The dry fibers can be contoured to shape the composite component or direct the resin. Optionally, additional layers or reinforcing layers of a material differing from the dry fiber can also be included or added prior to heating or curing.

(23) As used herein, CMC refers to a class of materials with reinforcing fibers in a ceramic matrix. Generally, the reinforcing fibers provide structural integrity to the ceramic matrix. Some examples of reinforcing fibers can include, but are not limited to, non-oxide silicon-based materials (e.g., silicon carbide, silicon nitride, or mixtures thereof), non-oxide carbon-based materials (e.g., carbon), oxide ceramics (e.g., silicon oxycarbides, silicon oxynitrides, aluminum oxide (Al_2O_3), silicon dioxide (SiO_2), aluminosilicates such as mullite, or mixtures thereof), or mixtures thereof.

(24) Some examples of ceramic matrix materials can include, but are not limited to, non-oxide silicon-based materials (e.g., silicon carbide, silicon nitride, or mixtures thereof), oxide ceramics (e.g., silicon oxycarbides, silicon oxynitrides, aluminum oxide (Al_2O_3), silicon dioxide (SiO_2), aluminosilicates, or mixtures thereof), or mixtures thereof. Optionally, ceramic particles (e.g., oxides of Si, Al, Zr, Y, and combinations thereof) and inorganic fillers (e.g., pyrophyllite, wollastonite, mica, talc, kyanite, and montmorillonite) can also be included within the ceramic matrix.

(25) Generally, particular CMCs can be referred to as their combination of type of fiber/type of matrix. For example, C/SiC for carbon-fiber-reinforced silicon carbide; SiC/SiC for silicon carbide-fiber-reinforced silicon carbide, SiC/SiN for silicon carbide fiber-reinforced silicon nitride; SiC/SiC—SiN for silicon carbide fiber-reinforced silicon carbide/silicon nitride matrix mixture, etc. In other examples, the CMCs can be comprised of a matrix and reinforcing fibers comprising oxide-based materials such as aluminum oxide (Al_2O_3), silicon dioxide (SiO_2), aluminosilicates, and mixtures thereof. Aluminosilicates can include crystalline materials such as mullite ($3\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$), as well as glassy aluminosilicates.

(26) “Preform” as used herein is a three-dimensional composite formed by a plurality of fibers including warp fibers and weft fibers. Additionally, at least one binder fibers that extends partially or fully through the preform in a direction perpendicular to both the warp and weft fibers. The at least one binder yarn can be integrated into the preform through weaving, stitching, or any appropriate manufacturing process.

(27) In certain non-limiting examples, the reinforcing fibers may be bundled and/or coated prior to inclusion within the matrix. For example, bundles of the fibers may be formed as a reinforced tape, such as a unidirectional reinforced tape. A plurality of the tapes may be laid up together to form a preform component. The bundles of fibers may be impregnated with a slurry composition prior to forming the preform or after formation of the preform. The preform may then undergo thermal processing, and subsequent chemical processing to arrive at a component formed of a CMC material having a desired chemical composition. For example, the preform may undergo a cure or burn-out to yield a high char residue in the preform, and subsequent melt-infiltration with silicon, or a cure or pyrolysis to yield a silicon carbide matrix in the preform, and subsequent chemical vapor infiltration with silicon carbide. Additional steps may be taken to improve densification of the preform, either before or after chemical vapor infiltration, by injecting it with a liquid resin or polymer followed by a thermal processing step to fill the voids with silicon carbide. CMC material as used herein may be formed using any known or hereinafter developed methods including but not limited to melt infiltration, chemical vapor infiltration, polymer impregnation pyrolysis (PIP), or any combination thereof.

(28) Such materials, along with certain monolithic ceramics (i.e., ceramic materials without a reinforcing material), are particularly suitable for higher temperature applications. Additionally, these ceramic materials are lightweight compared to superalloys, yet can still provide strength and

durability to the component made therefrom. Therefore, such materials are currently being considered for many gas turbine components used in higher temperature sections of gas turbine engines, such as airfoils (e.g., turbines, and vanes), combustors, shrouds and other like components, that would benefit from the lighter-weight and higher temperature capability these materials can offer.

(29) The term “metallic” as used herein is indicative of a material that includes metal such as, but not limited to, titanium, iron, aluminum, stainless steel, and nickel alloys. A metallic material or alloy can be a combination of at least two or more elements or materials, where at least one is a metal.

(30) FIG. 1 is a schematic cross-sectional diagram of a turbine engine 10 for an aircraft. The turbine engine 10 has a generally longitudinally extending axis or centerline 12 extending forward 14 to aft 16. The turbine engine 10 includes, in downstream serial flow relationship, a fan section 18 including a fan 20, a compressor section 22 including a booster or low pressure (LP) compressor 24 and a high pressure (HP) compressor 26, a combustion section 28 including a combustor 30, a turbine section 32 including an HP turbine 34, and an LP turbine 36, and an exhaust section 38.

(31) The fan section 18 includes a fan casing 40 surrounding the fan 20. The fan 20 includes a plurality of fan blades 42 disposed radially about the engine centerline 12. The HP compressor 26, the combustor 30, and the HP turbine 34 form an engine core 44 of the turbine engine 10, which generates combustion gases. The engine core 44 is surrounded by a core casing 46, which can be coupled with the fan casing 40.

(32) An HP shaft or spool 48 disposed coaxially about the engine centerline 12 of the turbine engine 10 drivingly connects the HP turbine 34 to the HP compressor 26. An LP shaft or spool 50, which is disposed coaxially about the engine centerline 12 of the turbine engine 10 within the larger diameter annular HP spool 48, drivingly connects the LP turbine 36 to the LP compressor 24 and fan 20. The spools 48, 50 are rotatable about the engine centerline and couple to a plurality of rotatable elements, which can collectively define a rotor 51.

(33) The LP compressor 24 and the HP compressor 26 respectively include a plurality of compressor stages 52, 54, in which a set of compressor blades 56, 58 rotate relative to a corresponding set of static compressor vanes 60, 62 to compress or pressurize the stream of fluid passing through the stage. In a single compressor stage 52, 54, multiple compressor blades 56, 58 can be provided in a ring and can extend radially outward relative to the engine centerline 12, from a blade platform to a blade tip, while the corresponding static compressor vanes 60, 62 are positioned upstream of and adjacent to the rotating compressor blades 56, 58. It is noted that the number of blades, vanes, and compressor stages shown in FIG. 1 were selected for illustrative purposes only, and that other numbers are possible.

(34) The compressor blades 56, 58 for a stage of the compressor can be mounted to (or integral to) a disk 61, which is mounted to the corresponding one of the HP and LP spools 48, 50. The static compressor vanes 60, 62 for a stage of the compressor can be mounted to the core casing 46 in a circumferential arrangement.

(35) The HP turbine 34 and the LP turbine 36 respectively include a plurality of turbine stages 64, 66, in which a set of turbine blades 68, 70 are rotated relative to a corresponding set of static turbine vanes 72, 74, also referred to as a nozzle, to extract energy from the stream of fluid passing through the stage. In a single turbine stage 64, 66, multiple turbine blades 68, 70 can be provided in a ring and can extend radially outward relative to the engine centerline 12 while the corresponding static turbine vanes 72, 74 are positioned upstream of and adjacent to the rotating turbine blades 68, 70. It is noted that the number of blades, vanes, and turbine stages shown in FIG. 1 were selected for illustrative purposes only, and that other numbers are possible.

(36) The turbine blades 68, 70 for a stage of the turbine can be mounted to a disk 71, which is mounted to the corresponding one of the HP and LP spools 48, 50. The turbine vanes 72, 74 for a stage of the compressor can be mounted to the core casing 46 in a circumferential arrangement.

(37) Complementary to the rotor portion, the stationary portions of the turbine engine **10**, such as the static vanes **60, 62, 72, 74** among the compressor and turbine sections **22, 32** are also referred to individually or collectively as a stator **63**. As such, the stator **63** can refer to the combination of non-rotating elements throughout the turbine engine **10**.

(38) In operation, the airflow exiting the fan section **18** is split such that a portion of the airflow is channeled into the LP compressor **24**, which then supplies a pressurized airflow **76** to the HP compressor **26**, which further pressurizes the air. The pressurized airflow **76** from the HP compressor **26** is mixed with fuel in the combustor **30** and ignited, thereby generating combustion gases. Some work is extracted from these gases by the HP turbine **34**, which drives the HP compressor **26**. The combustion gases are discharged into the LP turbine **36**, which extracts additional work to drive the LP compressor **24**, and the exhaust gas is ultimately discharged from the turbine engine **10** via the exhaust section **38**. The driving of the LP turbine **36** drives the LP spool **50** to rotate the fan **20** and the LP compressor **24**.

(39) A portion of the pressurized airflow **76** can be drawn from the compressor section **22** as bleed air **77**. The bleed air **77** can be drawn from the pressurized airflow **76** and provided to engine components requiring cooling. The temperature of pressurized airflow **76** entering the combustor **30** is significantly increased above the bleed air temperature. The bleed air **77** may be used to reduce the temperature of the core components downstream of the combustor **30**. The bleed air **77** can also be utilized by other systems.

(40) A remaining portion of the airflow, referred to as a bypass airflow **78**, bypasses the LP compressor **24** and engine core **44** and exits the turbine engine **10** through a stationary vane row, and more particularly an outlet guide vane assembly **80**, comprising a plurality of airfoil guide vanes **82**, at a fan exhaust side **84**. More specifically, a circumferential row of radially extending airfoil guide vanes **82** are utilized adjacent the fan section **18** to exert some directional control of the bypass airflow **78**.

(41) Some of the air supplied by the fan **20** can bypass the engine core **44** and be used for cooling of portions, especially hot portions, of the turbine engine **10**, and/or used to cool or power other aspects of the aircraft. In the context of a turbine engine, the hot portions of the engine are normally downstream of the combustor **30**, especially the turbine section **32**, with the HP turbine **34** being the hottest portion as it is directly downstream of the combustion section **28**. Other sources of cooling fluid can be, but are not limited to, fluid discharged from the LP compressor **24** or the HP compressor **26**.

(42) FIG. **2** is schematic illustration of an airfoil assembly **130** suitable for use within the turbine engine **10** of FIG. **1**. The airfoil assembly **130** can include an airfoil **132** that is any suitable airfoil of the turbine engine **10**. As a non-limiting example, the airfoil **132** can be a blade of the plurality of fan blades **42**, or a blade from the compressor blades **56, 58** or the turbine blades **68, 70**. It is contemplated that the airfoil **132** can be a blade, vane, airfoil, or other component of any turbine engine, such as, but not limited to, a gas turbine engine, a turboprop engine, a turboshaft engine, a ducted turbofan engine, an unducted turbofan engine or an open rotor turbine engine.

(43) The airfoil **132** can include a wall **138** bounding an interior **148**. The wall **138** can extend between a leading edge **144** and a trailing edge **146** to define a chordwise direction (C). The wall **138** can further extend between a root **140** and a tip **142** to define a spanwise direction (S). The wall **138** can be a composite wall made of one or more layers of composite material. The one or more layers of material can be applied during the same stage or different stages of the manufacturing of the airfoil **132**.

(44) By way of non-limiting example, wall **138** can include at least a polymer matrix composite (PMC) portion or a polymeric portion. The polymer matrix composite can include, but is not limited to, a matrix of thermoset (epoxies, phenolics) or thermoplastic (polycarbonate, polyvinylchloride, nylon, acrylics) and embedded glass, carbon, steel, or Kevlar fibers.

(45) The airfoil assembly **130** can further include a spar **136** and a trunnion **134**. The spar **136** can

extend into the interior **148**. The spar **136** can extend from the root **140**. The spar **136** can be operably coupled to the trunnion **134**. The spar **136** can be any suitable material such as, but not limited to, a composite material. The spar **136** can be a metal composite. The trunnion **134** can include any suitable material such as, but no limited to, a metallic material or a composite material. It will be appreciated that the term composite material can further include metals but with a composite architecture (e.g., a metal matrix composite). In the case of a composite material, the spar **136** and/or the trunnion **134** can be any suitable composite material such as a 2D or 3D composite, a laminate skin, a woven or a braided composite, or any other suitable composite. The spar **136** can further include a composite material with a bonding agent impregnated into the composite material. The spar **136** can then be cured to bond the composite material together.

(46) The airfoil **132** has a span length (L) measured along the spanwise direction S from the root **140** at 0% the span length (L) to the tip **142** at 100% the span length (L). An entirety of the spar **136** can be located below 20% of the span length (L). Alternatively, the spar **136** can extend past 20% of the span length (L).

(47) During operation of the airfoil assembly **130**, the trunnion **134** can rotate about a pitch axis (Pax) in a rotational direction (Rd). As the spar **136** couples the trunnion **134** to the airfoil **132**, rotation of the trunnion **134** in the rotational direction (Rd) causes the airfoil **132** to rotate about the pitch axis (Pax). This rotation can be used to control the pitch of the airfoil assembly **130** such that the airfoil assembly **130** is defined as a variable pitch airfoil assembly. The pitch of the airfoil assembly **130** can be varied based on the operation or intended operation of the turbine engine (e.g., the turbine engine **10** of FIG. **1**) that the airfoil assembly **130** is provided on.

(48) FIG. **3** is a schematic cross-sectional view of the airfoil assembly **130** as seen from sectional line III-III of FIG. **2**. The airfoil **132** (FIG. **2**) has been removed from the airfoil assembly **130** for illustrative purposes.

(49) The trunnion **134** includes a wall **163** with an interior surface **162** at least a partially defining a flared socket **164** interior **148** of the trunnion **134**. The flared socket **164** extends between an open top **170** and a bottom **168**. The spar **136** extends through the open top **170** and into the interior **148**. The bottom **168** can be an open bottom or a sealed/closed off bottom. The flared socket **164** can take any suitable shape with at least one flared cross section, as illustrated.

(50) The spar extends along a centerline axis **150** and terminates at a first end **160** within the flared socket **164**. The spar **136** includes a furcated tail **152** with a set of branches. As a non-limiting example, the set of branches include a first branch **154**, a second branch **156**, a third branch **174**, and a fourth branch **176** that define a set of intervening gaps **158**. The set of intervening gaps **158** extends axially into the spar **136**. The set of intervening gaps **158** can extend any suitable distance into the spar **136**. As a non-limiting example, the set of intervening gaps **158** can extend to an apex (e.g., a tip of each gap) that coincides with a location where the flared socket **164** begins to flare radially outward from the centerline axis **150**. It is contemplated that a central intervening gap (e.g., a gap radially nearest the centerline axis **150**) can extend axially farther than the other intervening gaps of the set of intervening gaps **158**. The spar **136** can be symmetric or asymmetric about the centerline axis **150**.

(51) A set of inserts **172** are received within the set of intervening gaps **158**. Each insert of the set of inserts **172** corresponds to a single intervening gap of the set of intervening gaps **158**. The set of inserts **172** are shown as removed from the set of intervening gaps **158** for illustrative purposes only. The set of inserts **172** can include any suitable material such as, but not limited to, a composite material or a metallic material. As a non-limiting example, the set of inserts **172** can be the same or different material as the spar **136**.

(52) The set of inserts **172** are used to retain the spar **136** within the flared socket **164**. This is done by using the set of inserts **172** to push the spar **136** radially outwards against the interior surface **162** such that the spar **136**, is held in frictional contact with the trunnion **134**. It will be further appreciated that the spar **136** can be retained within the trunnion **134** through any other suitable

method such as, but not limited to, co-cured, adhesion, welding, bonding, fastening, or the like.

(53) FIG. 4 is a schematic, top-down view of the airfoil assembly as seen from sectional line IV-IV of FIG. 3. As illustrated, the spar **136** can be polygonal (e.g., non-circular). As a non-limiting example, the spar **136** can each include a rectangular cross section when cut along a horizontal plane that is perpendicular to the centerline axis **150**. The open top **170** can have a corresponding cross section to the spar **136**. As a non-limiting example, the open top **170** can have a rectangular cross section when viewed along the horizontal plane. The rectangular cross section can be provided along an entirety of the flared socket **164**. Alternatively, the cross section of the open top **170** can differ from the cross-section of the spar **136**. Alternatively, the open top **170** can have any suitable non-rectangular cross section such as a circular cross section.

(54) FIG. 5 is an exemplary method **182** of forming the airfoil assembly **130** of FIG. 3. Reference will be made FIGS. 2-5 by relating the method **182** to the physical aspects of the airfoil assembly outlined in FIGS. 2-4.

(55) The method **182** can begin by furcating the spar **136** to produce the furcated tail **152**, at **184**. This can be done by physically cutting or machining the spar **136** or by forming the spar **136** to include the furcated tail **152**. The spar **136**, specifically at least the furcated tail **152**, can be inserted into the trunnion **134**, and more specifically, into the flared socket **164** of the trunnion **134**, at **186**. The spar **136** can be inserted through the open top **170**. This can require bending or compressing the spar **136** radially inward towards the centerline axis **150** to ensure that the furcated tail **152** can fit through the open top **170**. Once inserted, the furcated tail **152** can splay outwards and contact the interior surface **162**. The set of inserts **172** can be placed within the trunnion **134**, specifically within the set of intervening gaps **158**, at **188**. This can be done by inserting the set of inserts **172** through the bottom **168** of the trunnion **134**. The spar **136**, and the set of inserts **172** can then be cured together, at **190**, such that the spar **136** and the set of inserts **172** form a unitary body.

(56) It will be understood that the method **182** is flexible and the method **182** is illustrated merely for illustrative purposes. For example, the sequence of steps depicted is for illustrative purposes only, and is not meant to limit the method **182** in any way, as it is understood that the steps can proceed in a different logical order or additional or intervening steps can be included without detracting from embodiments of the invention. By way of non-limiting example, the curing step, at **190**, can further including curing the trunnion **134**, the spar **136**, and the set of inserts **172** together such that the trunnion **134**, the spar **136**, and the set of inserts **172** form a unitary body.

(57) The method **182** can further include forming the spar **136** as a 3D woven preform spar prior to or in tandem with furcating the spar **136**, at **184**. The method **182** can further include placing the spar **136** into the interior **148** of the airfoil **132**. The spar **136** can be placed into the interior **148** of the airfoil **132** either before or after the steps described in the method **182**. The method **182** can further include providing the airfoil assembly **130** within a portion of the turbine engine **10** (FIG. 1).

(58) It is contemplated that the use of the 3D woven preform spar as opposed to a 2D spar can result in a turbine engine with increased efficiency. For example, the 2D spar can rely on hand laid plies or a combination of multiple woven or prefabricated preforms into one composite assembly. Hand layup or assembly of 2D preforms increases the labor and costs required to build the composite assembly. Assembly of 2D preforms also comes with assembly and positioning challenges. Moreover, a composite assembly formed from 2D plies or multiple preforms will be more likely to have limited interlaminar loading capability. Conversely, a 3D preform (e.g., the 3D woven preform spar) that is formed from a single woven preform, the complex and time-consuming process of combining multiple preforms, such as with the 2D spar, is not needed.

(59) Benefits associated with the present disclosure include an airfoil assembly with a decreased burden of manufacture when compared to a conventional airfoil assembly. For example, the conventional airfoil assembly including a spar and trunnion requires additional structure to ensure that the airfoil of the conventional airfoil assembly is coupled to the trunnion. For example, the

conventional airfoil assembly utilizes a laminated spar provided within a flared socket of a trunnion. Positioning the laminated spar within the flared socket such that the laminated spar is retained within the flared socket, however, requires a time-intensive and labor-intensive method of isolating certain portions of the laminated spar to couple the laminated spar to the trunnion. The conventional airfoil assembly can further require that the spar is physically coupled to or formed with the trunnion, which in turn can make assembling and disassembling (e.g., during maintenance) difficult. The airfoil assembly, as described herein, however, includes the spar, and the set of inserts that are cured together after assembly. This configuration of the airfoil assembly greatly reduces the complexity of the airfoil assembly with respect to the conventional airfoil assembly, which in turn greatly reduces the burden of manufacture.

(60) For example, to the extent not already described, the different features and structures of the various embodiments can be used in combination, or in substitution with each other as desired. That one feature is not illustrated in all of the embodiments is not meant to be construed that it cannot be so illustrated, but is done for brevity of description. Thus, the various features of the different embodiments can be mixed and matched as desired to form new embodiments, whether or not the new embodiments are expressly described. All combinations or permutations of features described herein are covered by this disclosure.

(61) This written description uses examples to describe aspects of the disclosure described herein, including the best mode, and also to enable any person skilled in the art to practice aspects of the disclosure, including making and using any devices or systems and performing any incorporated methods. The patentable scope of aspects of the disclosure is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal languages of the claims.

(62) Further aspects are provided by the subject matter of the following clauses:

(63) An airfoil assembly for a turbine engine, the airfoil assembly comprising an airfoil comprising a wall bounding an interior and defining an exterior surface, the wall extending between a leading edge and a trailing edge to define a chordwise direction, and between a root and a tip to define a spanwise direction, a trunnion having a flared socket with an open top, a spar including a 3-dimensional preform, the spar extending from the flared socket, through the open top of the flared socket, and into the interior of the airfoil, the spar having a furcated tail with a set of branches defining a set of intervening gaps, with each gap of the set of intervening gaps being formed between adjacent branches of the set of branches, and set of inserts, with each insert of the set of inserts being received within a respective intervening gap of the set of intervening gaps, with the set of inserts being co-cured with the spar to define a unitary body.

(64) A turbine engine comprising an airfoil assembly having an airfoil comprising a wall bounding an interior and defining an exterior surface, the wall extending between a leading edge and a trailing edge to define a chordwise direction, and between a root and a tip to define a spanwise direction, a trunnion having a flared socket with an open top, a spar including a 3-dimensional preform, the spar extending from the flared socket, through the open top of the flared socket, and into the interior of the airfoil, the spar having a furcated tail with a set of branches defining a set of intervening gaps, with each gap of the set of intervening gaps being formed between adjacent branches of the set of branches, and a set of inserts, with each insert of the set of inserts being received within a respective intervening gap of the set of intervening gaps, with the set of inserts being co-cured with the spar to define a unitary body.

(65) A method of forming an airfoil assembly for a turbine engine, the airfoil assembly having a trunnion having a flared socket with an open top, and a spar, the method comprising furcating the spar such that the spar includes a furcated tail having a set of branches, with the set of branches defining a set of intervening gaps, with each gap of the set of intervening gaps being formed

between adjacent branches of the set of branches, inserting at least the furcated tail of the spar into the trunnion, inserting a set of inserts into the set of intervening gaps, with each insert of the set of inserts corresponding to a respective intervening gap of the set of intervening gaps, and curing the spar and the set of inserts such that the spar and the set of inserts form a unitary body

(66) The airfoil assembly of any preceding clause, wherein the spar extends along a centerline axis and the furcated tail is symmetric about the centerline axis.

(67) The airfoil assembly of any preceding clause, wherein the spar includes a composite material.

(68) The airfoil assembly of any preceding clause, wherein the airfoil includes a composite material.

(69) The airfoil assembly of any preceding clause, wherein the set of intervening gaps includes three or more intervening gaps.

(70) The airfoil assembly of any preceding clause, wherein the spar extends along a centerline axis in the spanwise direction, and the flared socket includes a rectangular cross-sectional area when viewed along a horizontal plane that is perpendicular to the centerline axis.

(71) The airfoil assembly of any preceding clause, wherein the spar includes a rectangular cross-sectional area when viewed along the horizontal plane.

(72) The airfoil assembly of any preceding clause, wherein the set of inserts include a metallic material or a composite material.

(73) The airfoil assembly of any preceding clause, wherein the set of inserts, the spar, and the trunnion are co-cured with each other to form a unitary body.

(74) The airfoil assembly of any preceding clause, wherein the turbine engine includes a fan section, a compressor section, a combustion section and a turbine section in serial flow arrangement with the airfoil assembly being provided within one of the fan section, the compressor section, or the turbine section of the turbine engine.

(75) The method of any preceding clause, further comprising furcating the tail such that the tail is symmetric about a centerline axis extending along the spar.

(76) The method of any preceding clause, further comprising curing the spar, the trunnion, and the set of inserts such that the spar, the trunnion and the set of inserts form a unitary body.

(77) The method of any preceding clause, further comprising inserting the spar through the open top.

(78) The method of any preceding clause, further comprising inserting the set of inserts through an open bottom, opposite the open top, of the flared socket.

(79) The method of any preceding clause, further comprising forming the spar with a composite material.

(80) The method of any preceding clause, further comprising forming the spar as a 3-dimensional preform.

(81) The method of any preceding clause, further comprising providing the spar within an interior of an airfoil assembly having a wall bounding an interior and defining an exterior surface extending between a leading edge and a trailing edge to define a chordwise direction, and between a root and a tip to define a spanwise direction.

(82) The method of any preceding clause, further comprising providing the airfoil assembly within a fan section, a compressor section or a turbine section of the turbine engine.

Claims

1. An airfoil assembly for a turbine engine, the airfoil assembly comprising: an airfoil comprising a wall bounding an interior and defining an exterior surface, the wall extending between a leading edge and a trailing edge to define a chordwise direction, and between a root and a tip to define a spanwise direction; and a spar including a centerline axis, the spar extending into the interior of the airfoil, the spar having a furcated tail with a set of branches defining a set of intervening gaps, with

each gap of the set of intervening gaps being formed between adjacent branches of the set of branches.

2. The airfoil assembly of claim 1, wherein the furcated tail is symmetric about the centerline axis.

3. The airfoil assembly of claim 1, wherein the spar includes a composite material.

4. The airfoil assembly of claim 1, wherein the airfoil includes a composite material.

5. The airfoil assembly of claim 1, wherein the set of intervening gaps includes three or more intervening gaps.

6. The airfoil assembly of claim 1, further comprising a trunnion having a flared socket with an open top, with the furcated tail being provided within the flared socket.

7. The airfoil assembly of claim 6, wherein the flared socket includes a rectangular cross-sectional area when viewed along a plane that is perpendicular to the centerline axis and intersects the trunnion at the open top.

8. The airfoil assembly of claim 7, wherein the spar includes a rectangular cross-sectional area when viewed along the plane.

9. The airfoil assembly of claim 6, wherein the trunnion is co-cured with the spar to define a unitary body.

10. The airfoil assembly of claim 1, further comprising a set of inserts receivable within the set of intervening gaps.

11. The airfoil assembly of claim 10, wherein the set of inserts include at least one of a metallic material or a composite material.

12. The airfoil assembly of claim 11, wherein the set of inserts include a first composite material and the spar includes a second composite material, with the first composite material and the second composite material being co-cured together after the set of inserts are received within the set of intervening gaps.

13. The airfoil assembly of claim 1, wherein the spar includes a 3-dimensional preform.

14. An unducted turbine engine comprising a fan section including the airfoil assembly of claim 1.

15. An airfoil assembly for a turbine engine, the airfoil assembly comprising: an airfoil comprising a wall bounding an interior and defining an exterior surface, the wall extending between a leading edge and a trailing edge to define a chordwise direction, and between a root and a tip to define a spanwise direction; a trunnion having an interior surface defining a flared socket, the flared socket having an open top, the interior surface extending continuously from and defining a perimeter of the open top; and a spar including a centerline axis, the spar extending from the flared socket, through the open top of the flared socket, and into the interior of the airfoil, the spar including a portion being splayed radially outward, with respect to the centerline axis, within the flared socket and directly contacting the interior surface of the trunnion.

16. The airfoil assembly of claim 15, wherein the flared socket includes a rectangular cross-sectional area when viewed along a plane that is perpendicular to the centerline axis and intersects the trunnion at the open top.

17. An airfoil assembly for a turbine engine, the airfoil assembly comprising: an airfoil comprising a wall bounding an interior and defining an exterior surface, the wall extending between a leading edge and a trailing edge to define a chordwise direction, and between a root and a tip to define a spanwise direction; a spar including a centerline axis, the spar extending into the interior of the airfoil, and a set of inserts, with each insert of the set of inserts being received within a respective portion of the spar, with the set of inserts being co-cured with the spar to define a unitary body.

18. The airfoil assembly of claim 17, wherein the spar includes a furcated tail defining a set of intervening gaps, with the set of inserts being provided within the set of intervening gaps.

19. The airfoil assembly of claim 17, wherein the spar includes a first composite material, and the set of inserts comprise at least one of a second composite material, or a metallic material.

20. The airfoil assembly of claim 15, wherein the open top confronts root of the airfoil and is located along an axial termination of the trunnion, with respect to the centerline axis.

