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MIXER ASSEMBLY WITH A CATALYTIC METAL COATING FOR A GAS TURBINE ENGINE

Abstract

A mixer assembly for a gas turbine engine. The mixer assembly includes a housing and a fuel injection port. The housing has a passage formed therein, and the housing includes a passage wall facing the passage. The fuel injection port is fluidly connected to a fuel source and is configured to inject a hydrocarbon fuel into the passage. At least a portion of the passage wall is a coated passage wall. The coated passage wall is (i) coated with a layer of a catalytic metal and (ii) located downstream of the fuel injection port.

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Background/Summary

TECHNICAL FIELD [0001] This application is a divisional of U.S. patent application Ser. No. 17/651,685 filed on Feb. 18, 2022, the contents of which are hereby incorporated by reference in their entirety.

TECHNICAL FIELD
[0002] The present disclosure relates to mixer assemblies, particularly mixer assemblies used in gas turbine engines, and, more particularly, mixer assembles with a catalytic metal coating for gas engine turbines.
BACKGROUND
[0003] Gas turbine engines include surfaces that contact hydrocarbon fluids, such as fuels and lubricating oils. Carbonaceous deposits (also known as coke) may form on these surfaces when exposed to the hydrocarbon fluids at elevated temperatures, resulting in carbon becoming attached to surfaces contacted by a fuel or oil and building up as deposits on those surfaces contacted by a fuel or oil.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0004] Features and advantages of the present disclosure will be apparent from the following description of various exemplary embodiments, as illustrated in the accompanying drawings, wherein like reference numbers generally indicate identical, functionally similar, and/or structurally similar elements.
[0005] FIG. **1** is a schematic perspective view of an aircraft having a gas turbine engine according to an embodiment of the present disclosure.
[0006] FIG. **2** is a schematic, cross-sectional view, taken along line **2-2** in FIG. **1**, of the gas turbine engine of the aircraft shown in FIG. **1**.
[0007] FIG. **3** is a schematic, cross-sectional view of a combustor of the gas turbine engine shown in FIG. **2** according to an embodiment of the present disclosure. FIG. **3** is a detail view showing detail **3** in FIG. **2**.
[0008] FIG. **4** is a schematic, cross-sectional view of a mixer assembly of the combustor in FIG. **3**. FIG. **4** is a detail view showing detail **4** in FIG. **3**.
[0009] FIG. **5** is a schematic, cross-sectional view of a combustor of the gas turbine engine shown in FIG. **2** according to another embodiment of the present disclosure. FIG. **5** is a detail view showing detail **3** in FIG. **2**.
[0010] FIG. **6** is a schematic, cross-sectional view of a mixer assembly of the combustor in FIG. **5**. FIG. **6** is a detail view showing detail **6** in FIG. **5**.
DETAILED DESCRIPTION
[0011] Features, advantages, and embodiments of the present disclosure are set forth or apparent from a consideration of the following detailed description, drawings, and claims. Moreover, it is to be understood that the following detailed description is exemplary and intended to provide further explanation without limiting the scope of the disclosure as claimed.
[0012] Various embodiments are discussed in detail below. While specific embodiments are discussed, this is done for illustration purposes only. A person skilled in the relevant art will

recognize that other components and configurations may be used without departing from the spirit and scope of the present disclosure.

[0013] As used herein, the terms “first,” “second,” and “third” may be used interchangeably to distinguish one component from another and are not intended to signify location or importance of the individual components.

[0014] The terms “forward” and “aft” refer to relative positions within a gas turbine engine or vehicle, and refer to the normal operational attitude of the gas turbine engine or vehicle. For example, with regard to a gas turbine engine, forward refers to a position closer to an engine inlet and aft refers to a position closer to an engine nozzle or exhaust.

[0015] The terms “upstream” and “downstream” refer to the relative direction with respect to fluid flow in a fluid pathway. For example, “upstream” refers to the direction from which the fluid flows, and “downstream” refers to the direction to which the fluid flows.

[0016] The terms “directly upstream” or “directly downstream,” when used to describe the relative placement of components in a fluid pathway, refer to components that are placed next to each other in the fluid pathway without any intervening components between them other than an appropriate fluid coupling, such as a pipe, tube, valve, or the like, to fluidly couple the components. Such components may be spaced apart from each other with intervening components that are not in the fluid pathway.

[0017] The terms “coupled,” “fixed,” “attached,” “connected,” and the like, refer to both direct coupling, fixing, attaching, or connecting as well as indirect coupling, fixing, attaching, or connecting through one or more intermediate components or features, unless otherwise specified herein.

[0018] The singular forms “a,” “an,” and “the” include plural references unless the context clearly dictates otherwise.

[0019] Approximating language, as used herein throughout the specification and claims, is applied to modify any quantitative representation that could permissibly vary without resulting in a change in the basic function to which it is related. Accordingly, a value modified by a term or terms, such as “about,” “approximately,” and “substantially” is not to be limited to the precise value specified. In at least some instances, the approximating language may correspond to the precision of an instrument for measuring the value, or the precision of the methods or machines for constructing or manufacturing the components and/or systems. For example, the approximating language may refer to being within a one, two, four, ten, fifteen, or twenty percent margin in either individual values, range(s) of values, and/or endpoints defining range(s) of values.

[0020] Here and throughout the specification and claims, range limitations are combined, and interchanged. Such ranges are identified and include all the sub-ranges contained therein unless context or language indicates otherwise. For example, all ranges disclosed herein are inclusive of the endpoints, and the endpoints are independently combinable with each other.

[0021] As noted above, coke deposition may occur on surfaces of a gas turbine engine that are exposed to hydrocarbon fluids, such as fuels and lubricating oils, at elevated temperatures. The fuel nozzle and swirler (collectively, a mixer assembly) used in a combustor for a gas turbine engine includes such surfaces. The fuel nozzle aft heat shield (FN-AHS) protects the fuel nozzle from hot combustion gases during engine operation. Surfaces of the FN-AHS and other surfaces of the mixer assembly are exposed to hydrocarbon fluids, such as fuel, and operation of the gas turbine engine, particularly, continuous operation at cruise for aircraft gas turbine engines, can result in significant build-up of coke and/or partially burned fuel deposits on exposed surfaces of the FN-AHS and the mixer assembly. Coke can build up in considerable thickness, and large pieces of coke can shed off these surfaces, becoming internal domestic objects that can cause significant damage to components downstream of the fuel nozzle (hot gas path components). Some of these components have thermal barrier coatings (TBCs). The resulting internal domestic object impact damage (DoD) results in spallation of the thermal barrier coating and, therefore, reduces the durability of

components such as combustors, nozzles, shrouds, and airfoils.
[0022] The embodiments discussed herein apply a coating of a catalytic metal to these surfaces of the mixer assembly and the fuel nozzle. Suitable catalytic metals include gold and the platinum group metals, such as, ruthenium, rhodium, palladium, osmium, iridium, and platinum. In some embodiments, palladium, platinum, and gold may be preferred catalytic metals. Without the catalytic metal coating, the coke bonds more strongly to the metallic components in the mixer assembly and the fuel nozzle, leading to the formation of larger coke particles that can shed or spall off during operation, as discussed above. As will be discussed further below, the catalytic metal prevents such build-up and spallation. Without intending to be bound to any theory, the catalytic metal coating promotes the formation of filamentary coke, rather than large granular coke. The filamentary coke does not bond to the catalytic metal surface of the mixer assembly and the fuel nozzle, and the filamentary coke can be easily removed during operation of the mixer assembly and the fuel nozzle in the combustor.
[0023] The mixer assembly discussed herein is particularly suitable for use in engines, such as a gas turbine engine used on an aircraft. FIG. **1** is a perspective view of an aircraft **10** that may implement various preferred embodiments. The aircraft **10** includes a fuselage **12**, wings **14** attached to the fuselage **12**, and an empennage **16**. The aircraft **10** also includes a propulsion system that produces a propulsive thrust required to propel the aircraft **10** in flight, during taxiing operations, and the like. The propulsion system for the aircraft **10** shown in FIG. **1** includes a pair of engines **100**. In this embodiment, each engine **100** is attached to one of the wings **14** by a pylon **18** in an under-wing configuration. Although the engines **100** are shown attached to the wing **14** in an under-wing configuration in FIG. **1**, in other embodiments, the engine **100** may have alternative configurations and be coupled to other portions of the aircraft **10**. For example, the engine **100** may additionally or alternatively include one or more aspects coupled to other parts of the aircraft **10**, such as, for example, the empennage **16**, and the fuselage **12**.
[0024] As will be described further below with reference to FIG. **2**, the engines **100** shown in FIG. **1** are gas turbine engines that are each capable of selectively generating a propulsive thrust for the aircraft **10**. The amount of propulsive thrust may be controlled at least in part based on a volume of fuel provided to the gas turbine engines **100** via a fuel system **150** (see FIG. **3**). An aviation turbine fuel in the embodiments discussed herein is a combustible hydrocarbon liquid fuel, such as a kerosene-type fuel, having a desired carbon number. The fuel is stored in a fuel tank **151** of the fuel system **150**. As shown in FIG. **1**, at least a portion of the fuel tank **151** is located in each wing **14** and a portion of the fuel tank **151** is located in the fuselage **12** between the wings **14**. The fuel tank **151**, however, may be located at other suitable locations in the fuselage **12** or the wing **14**. The fuel tank **151** may also be located entirely within the fuselage **12** or the wing **14**. The fuel tank **151** may also be separate tanks instead of a single, unitary body, such as, for example, two tanks each located within a corresponding wing **14**.
[0025] Although the aircraft **10** shown in FIG. **1** is an airplane, the embodiments described herein may also be applicable to other aircraft **10**, including, for example, helicopters and unmanned aerial vehicles (UAV). Preferably, the aircraft discussed herein are fixed-wing aircraft or rotor aircraft that generate lift by aerodynamic forces acting on, for example, a fixed wing (e.g., wing **14**) or a rotary wing (e.g., a rotor of a helicopter), and are heavier-than-air aircraft, as opposed to lighter-than-air aircraft (such as a dirigible). Further, although not depicted herein, in other embodiments, the gas turbine engine may be any other suitable type of gas turbine engine, such as an industrial gas turbine engine incorporated into a power generation system, a nautical gas turbine engine, etc.
[0026] FIG. **2** is a schematic, cross-sectional view of one of the engines **100** used in the propulsion system for the aircraft **10** shown in FIG. **1**. The cross-sectional view of FIG. **2** is taken along line **2-2** in FIG. **1**. For the embodiment depicted in FIG. **2**, the engine **100** is a high bypass turbofan engine. The engine **100** may also be referred to as a turbofan engine **100** herein. The turbofan engine **100** has an axial direction A (extending parallel to a longitudinal centerline **101**, shown for

reference in FIG. **2**), a radial direction R, and a circumferential direction. The circumferential direction (not depicted in FIG. **2**) extends in a direction rotating about the axial direction A. The turbofan engine **100** includes a fan section **102** and a turbomachine **104** disposed downstream from the fan section **102**.

[0027] The turbomachine **104** depicted in FIG. **2** includes a tubular outer casing **106** (also referred to as a housing or nacelle) that defines an inlet **108**. In this embodiment, the inlet **108** is annular. The outer casing **106** encases an engine core that includes, in a serial flow relationship, a compressor section including a booster or low-pressure (LP) compressor **110** and a high-pressure (HP) compressor **112**, a combustion section **114**, a turbine section including a high-pressure (HP) turbine **116** and a low-pressure (LP) turbine **118**, and a jet exhaust nozzle section **120**. The compressor section, the combustion section **114**, and the turbine section together define at least in part a core air flowpath **121** extending from the inlet **108** to the jet exhaust nozzle section **120**. The turbofan engine further includes one or more drive shafts. More specifically, the turbofan engine includes a high-pressure (HP) shaft or spool **122** drivingly connecting the HP turbine **116** to the HP compressor **112**, and a low-pressure (LP) shaft or spool **124** drivingly connecting the LP turbine **118** to the LP compressor **110**.

[0028] The fan section **102** shown in FIG. **2** includes a fan **126** having a plurality of fan blades **128** coupled to a disk **130**. The plurality of fan blades **128** and the disk **130** are rotatable, together, about the longitudinal centerline (axis) **101** by the LP shaft **124**. The LP compressor **110** may also be directly driven by the LP shaft **124**, as depicted in FIG. **2**. The disk **130** is covered by a rotatable front hub **132** aerodynamically contoured to promote an airflow through the plurality of fan blades **128**. Further, an annular fan casing or outer nacelle **134** is provided, circumferentially surrounding the fan **126** and/or at least a portion of the turbomachine **104**. The nacelle **134** is supported relative to the turbomachine **104** by a plurality of circumferentially spaced outlet guide vanes **136**. A downstream section **138** of the nacelle **134** extends over an outer portion of the turbomachine **104** so as to define a bypass airflow passage **140** therebetween.

[0029] The turbofan engine **100** is operable with the fuel system **150** and receives a flow of fuel from the fuel system **150**. The fuel system **150** includes a fuel delivery assembly **153** providing the fuel flow from the fuel tank **151** to the turbofan engine **100**, and, more specifically, to a plurality of fuel injectors **200** that inject fuel into a combustion chamber **302** of a combustor **300** (see FIG. **3**, discussed further below) of the combustion section **114**. The components of the fuel system **150**, and, more specifically, the fuel tank **151**, is an example a fuel source that provides fuel to the fuel injectors **200**, as discussed in more detail below. The fuel delivery assembly **153** includes tubes, pipes, conduits, and the like, to fluidly connect the various components of the fuel system **150** to the engine **100**. The fuel tank **151** is configured to store the hydrocarbon fuel, and the hydrocarbon fuel is supplied from the fuel tank **151** to the fuel delivery assembly **153**. The fuel delivery assembly **153** is configured to carry the hydrocarbon fuel between the fuel tank **151** and the engine **100** and, thus, provides a flow path (fluid pathway) of the hydrocarbon fuel from the fuel tank **151** to the engine **100**.

[0030] The fuel system **150** includes at least one fuel pump fluidly connected to the fuel delivery assembly **153** to induce the flow of the fuel through the fuel delivery assembly **153** to the engine **100**. One such pump is a main fuel pump **155**. The main fuel pump **155** is a high-pressure pump that is the primary source of pressure rise in the fuel delivery assembly **153** between the fuel tank **151** and the engine **100**. The main fuel pump **155** may be configured to increase a pressure in the fuel delivery assembly **153** to a pressure greater than a pressure within a combustion chamber **302** of the combustor **300**.

[0031] The fuel system **150** also includes a fuel metering unit **157** in fluid communication with the fuel delivery assembly **153**. Any suitable fuel metering unit **157** may be used including, for example, a metering valve. The fuel metering unit **157** is positioned downstream of the main fuel pump **155** and upstream of a fuel manifold **159** configured to distribute fuel to the fuel injectors

200. The fuel system **150** is configured to provide the fuel to the fuel metering unit **157**, and the fuel metering unit **157** is configured to receive fuel from the fuel tank **151**. The fuel metering unit **157** is further configured to provide a flow of fuel to the engine **100** in a desired manner. More specifically, the fuel metering unit **157** is configured to meter the fuel and to provide a desired volume of fuel, at, for example, a desired flow rate, to the fuel manifold **159** of the engine **100**. The fuel manifold **159** is fluidly connected to the fuel injectors **200** and distributes (provides) the fuel received to the plurality of fuel injectors **200**, where the fuel is injected into the combustion chamber **302** and combusted. Adjusting the fuel metering unit **157** changes the volume of fuel provided to the combustion chamber **302** and, thus, changes the amount of propulsive thrust produced by the engine **100** to propel the aircraft **10**.

[0032] The turbofan engine **100** also includes various accessory systems to aid in the operation of the turbofan engine **100** and/or an aircraft, including the turbofan engine **100**. For example, the turbofan engine **100** may include a main lubrication system **162**, a compressor cooling air (CCA) system **164**, an active thermal clearance control (ATCC) system **166**, and a generator lubrication system **168**, each of which is depicted schematically in FIG. **2**. The main lubrication system **162** is configured to provide a lubricant to, for example, various bearings and gear meshes in the compressor section, the turbine section, the HP spool **122**, and the LP shaft **124**. The lubricant provided by the main lubrication system **162** may increase the useful life of such components and may remove a certain amount of heat from such components through the use of one or more heat exchangers. The compressor cooling air (CCA) system **164** provides air from one or both of the HP compressor **112** or the LP compressor **110** to one or both of the HP turbine **116** or the LP turbine **118**. The active thermal clearance control (ATCC) system **166** acts to minimize a clearance between tips of turbine blades and casing walls as casing temperatures vary during a flight mission. The generator lubrication system **168** provides lubrication to an electronic generator (not shown), as well as cooling/heat removal for the electronic generator. The electronic generator may provide electrical power to, for example, a startup electrical motor for the turbofan engine **100** and/or various other electronic components of the turbofan engine **100** and/or an aircraft including the turbofan engine **100**. The lubrication systems for the engine **100** (e.g., the main lubrication system **162** and the generator lubrication system **168**) may use hydrocarbon fluids, such as oil, for lubrication, in which the oil circulates through inner surfaces of oil scavenge lines.

[0033] It will be appreciated, however, that the turbofan engine **100** discussed herein is provided by way of example only. In other embodiments, any other suitable engine may be utilized with aspects of the present disclosure. For example, in other embodiments, the engine may be any other suitable gas turbine engine, such as a turboshaft engine, a turboprop engine, a turbojet engine, an unducted single fan engine, and the like. In such a manner, it will further be appreciated that, in other embodiments, the gas turbine engine may have other suitable configurations, such as other suitable numbers or arrangements of shafts, compressors, turbines, fans, etc. Further, although the turbofan engine **100** is shown as a direct drive, fixed-pitch turbofan engine **100**, in other embodiments, a gas turbine engine may be a geared gas turbine engine (i.e., including a gearbox between the fan **126** and shaft driving the fan, such as the LP shaft **124**), may be a variable pitch gas turbine engine (i.e., including a fan **126** having a plurality of fan blades **128** rotatable about their respective pitch axes), etc. Further, still, in alternative embodiments, aspects of the present disclosure may be incorporated into, or otherwise utilized with any other type of engine, such as reciprocating engines. Additionally, in still other exemplary embodiments, the exemplary turbofan engine **100** may include or be operably connected to any other suitable accessory systems. Additionally, or alternatively, the exemplary turbofan engine **100** may not include or be operably connected to one or more of the accessory systems **162**, **164**, **166**, **168**, discussed above.

[0034] FIG. **3** shows a combustor **300** of the combustion section **114** according to an embodiment of the present disclosure. FIG. **3** is a detail view showing detail **3** in FIG. **2**. The combustor **300** is an annular combustor that includes a combustion chamber **302** defined between an inner liner **304** and an outer liner **306**. Each of the inner liner **304** and outer liner **306** is annular about the longitudinal centerline **101** of the engine **100** (FIG. **2**). The combustor **300** also includes a combustor case **308** that is also annular about the longitudinal centerline **101** of the engine **100**. The combustor case **308** extends circumferentially around the inner liner **304** and the outer liner **306**, and the inner liner **304** and outer liner **306** are located radially inward of the combustor case **308**. The combustor **300** also includes a dome **310** mounted to a forward end of each of the inner liner **304** and the outer liner **306**. The dome **310** defines an upstream (or forward end) of the combustion chamber **302**.

[0035] A plurality of mixer assemblies **210** (only one is illustrated in FIG. **3**) are spaced around the dome **310**. The plurality of mixer assemblies **210** are circumferentially spaced about the longitudinal centerline **101** of the engine **100**. In the embodiment shown in FIG. **3**, each mixer assembly **210** is a twin annular premixing swirler (TAPS) that includes a main mixer **212** and a pilot mixer **214**. The pilot mixer **214** is supplied with fuel from the fuel injector **200** during the entire engine operating cycle, and the main mixer **212** is supplied with fuel from the fuel injector **200** only during increased power conditions of the engine operating cycle, such as take-off and climb, for example. The TAPS mixer assembly **210** is provided by way of example and the catalytic metal layer discussed herein may be applied to other mixer assembly designs and other combustor designs.

[0036] As noted above, the compressor section, including the HP compressor **112** (FIG. **2**), pressurizes air, and the combustor **300** receives an annular stream of this pressurized air from a discharge outlet (compressor discharge outlet **216**) of the HP compressor **112**. This air may be referred to as compressor discharge pressure air. A portion of the compressor discharge air flows into the mixer assembly **210**. Fuel is injected into the air in the mixer assembly **210** to mix with the air and to form a fuel-air mixture. The fuel-air mixture is provided to the combustion chamber **302** from the mixer assembly **210** for combustion. Ignition of the fuel-air mixture is accomplished by a suitable igniter **312**, and the resulting combustion gases flow in an axial direction toward and into an annular, first stage turbine nozzle **314**. The first stage turbine nozzle **314** is defined by an annular flow channel that includes a plurality of radially extending, circularly-spaced nozzle vanes **316** that turn the gases so that they flow angularly and impinge upon the first stage turbine blades (not shown) of a first turbine (not shown) of the HP turbine **116** (FIG. **2**).

[0037] The fuel injector **200** is fixed to the combustor case **308** by a nozzle mount. In this embodiment, the nozzle mount is a flange **202** that is integrally formed with a stem **204** of the fuel injector **200**. The flange **202** is fixed to the combustor case **308** and sealed to the combustor case **308**. The stem **204** includes a flow passage through which the hydrocarbon fuel flows, and the stem **204** extends radially inward from the flange **202**. The fuel injector **200** also includes a fuel nozzle tip **220** through which fuel is injected into the combustion chamber **302** as part of the mixer assembly **210**.

[0038] FIG. **4** shows the mixer assembly **210** of the combustor **300** shown in FIG. **3**. FIG. **4** is a detail view showing detail **4** in FIG. **3**, and, as FIG. **3** is a cross-sectional view, FIG. **4** is also a cross-sectional view of the mixer assembly **210**. The fuel nozzle tip **220** includes a fuel nozzle body **222** and an aft heat shield **224** attached to the fuel nozzle body **222**. The fuel nozzle body **222** is mounted to an inlet fairing **226**. The inlet fairing **226** is connected to or integral with the stem **204**. The fuel nozzle body **222** includes a main fuel nozzle **230** and a dual orifice pilot fuel injector tip **240** having a primary pilot fuel orifice **242** and a secondary pilot fuel orifice **244**. The primary pilot fuel orifice **242** and the secondary pilot fuel orifice **244** may be substantially concentric with each other and substantially centered in an annular pilot inlet **246**. The main fuel nozzle **230** surrounds the pilot inlet **246**, and the pilot inlet **246** is located between the main fuel nozzle **230** and the dual orifice pilot fuel injector tip **240**. In this embodiment, the fuel nozzle tip **220** is circular about an axis extending through the center of the primary pilot fuel orifice **242**. In the discussion below, various features of the fuel nozzle tip **220** may be discussed relative to this axis.

[0039] Fuel is provided through the stem **204** to the main fuel nozzle **230**. The main fuel nozzle **230** includes an annular main fuel passage **232** disposed in an annular main fuel ring **234**. The main fuel nozzle **230** includes a circular array of main fuel injection orifices **236** or an annular array of main fuel injection orifices **236** extending radially outward from the annular main fuel passage **232** and through the wall of the annular main fuel ring **234**. The main fuel nozzle **230** and the annular main fuel ring **234** are spaced radially outward of the primary pilot fuel orifice **242** and the secondary pilot fuel orifice **244**. The main fuel nozzle **230** injects fuel in a radially outward direction through the circular array of main fuel injection orifices **236**.

[0040] Fuel is also provided through the stem **204** to the primary pilot fuel orifice **242** and the secondary pilot fuel orifice **244**. The secondary pilot fuel orifice **244** is radially located directly adjacent to the primary pilot fuel orifice **242** and surrounds the primary pilot fuel orifice **242**. The pilot mixer **214** includes an inner pilot swirler **251**, an outer pilot swirler **253**, and a swirler splitter **255** positioned between the inner pilot swirler **251** and the outer pilot swirler **253**. The inner pilot swirler **251** is located radially outward of the dual orifice pilot fuel injector tip **240** and adjacent to the dual orifice pilot fuel injector tip **240**. The outer pilot swirler **253** is located radially outward of the inner pilot swirler **251**. The swirler splitter **255** extends downstream of the dual orifice pilot fuel injector tip **240** and a first venturi **260** is formed in a downstream portion **257** of the swirler splitter **255**. The first venturi **260** includes a converging section **262**, a diverging section **264**, and a throat **266** between the converging section **262** and the diverging section **264**. The throat **266** is located downstream of the primary pilot fuel orifice **242** and the secondary pilot fuel orifice **244**. The swirler splitter **255** and, more specifically, the downstream portion **257** of the swirler splitter **255** forms a housing for the first venturi **260**. The inner pilot swirler **251** and the outer pilot swirler **253** are generally oriented parallel to a centerline of the dual orifice pilot fuel injector tip **240**. The inner pilot swirler **251** and the outer pilot swirler **253** include a plurality of swirling vanes **259** for causing air traveling therethrough to swirl.

[0041] A portion of the compressor discharge air flows into the mixer assembly pilot inlet **246** and, then, into the inner pilot swirler **251** and the outer pilot swirler **253**. As noted above, fuel and air are provided to the pilot mixer **214** at all times during the engine operating cycle so that a primary combustion zone is produced within a central portion of the combustion chamber **302**. The primary pilot fuel orifice **242** is circular, and the secondary pilot fuel orifice **244** is annular. Each of the primary pilot fuel orifice **242** and the secondary pilot fuel orifice **244** injects fuel in a generally downstream direction and into the compressed air flowing through the inner pilot swirler **251**. The primary pilot fuel orifice **242** and the secondary pilot fuel orifice **244** are examples of a fuel injection port that is fluidly connected to a fuel source and configured to inject a hydrocarbon fuel into the mixer assembly. This fuel and air mixture flows through the first venturi **260** and exits through a circular outlet **268**. The outlet **268** is downstream of the diverging section **264**.

[0042] The pilot mixer **214** is supported by an annular pilot housing **270**. The pilot housing **270** includes a conical wall section **272** circumscribing a conical pilot mixing chamber **274** that is in flow communication with, and downstream from, the pilot mixer **214**, and more specifically, the outlet **268**. The pilot mixing chamber **274** is also fluidly connected to the primary pilot fuel orifice **242** and the secondary pilot fuel orifice and downstream of the primary pilot fuel orifice **242** and the secondary pilot fuel orifice **244**. The pilot mixing chamber **274** is a passage of the fuel injector **200** and, more specifically, the fuel nozzle tip **220**. As the fuel nozzle tip **220** is also a portion of the mixer assembly **210**, the pilot mixing chamber **274** also is a passage of the mixer assembly **210**. The conical wall section **272** of the pilot housing **270** is thus a passage wall that includes a passage wall surface **276** facing the pilot mixing chamber **274** (passage). In this embodiment, the conical wall section **272** is part of a second venturi **280** formed by the pilot housing **270**. The second venturi **280** includes a converging section **282**, a diverging section **284**, and a throat **286** between the converging section **282** and the diverging section **284**. The diverging section **284** is provided by the conical wall section **272**, which extends downstream from the throat **286** and continues with diverging surfaces **228** of the aft heat shield **224**. The diverging surfaces **228** of this embodiment form a conical wall section of the aft heat shield **224** that is coplanar with the wall surface **276** of the conical wall section **272**. Diverging section **284** has an upstream end, which, in this embodiment, is the throat **286** and a downstream end, which, in this embodiment, is an outlet **278** of the pilot mixing chamber **274**. As can be seen in FIG. **4**, the cross-sectional area of the second venturi **280** at the outlet **278** (the downstream end) is greater than the cross-sectional area of the second venturi **280** at the throat **286** (the upstream end).

[0043] Air flows through the outer pilot swirler **253** through the converging section **282** toward the throat **286**. This air is mixed with the fuel-air mixture from the outlet **268** and through the throat **286** to the diverging section **284** and the aft heat shield **224**. The pilot mixing chamber **274** and, more specifically, the wall surface **276** of the conical wall section **272** are exposed to hydrocarbon fuel as the fuel-air mixture flows through the pilot mixing chamber **274**, through the outlet **278** of the pilot mixing chamber **274**, and into the combustion chamber **302**. Being adjacent to the combustion chamber **302** and adjacent to the primary combustion zone, the fuel, the conical wall section **272**, and aft heat shield **224** are exposed to high temperatures. For example, the conical wall section **272** and the aft heat shield **224** may be at temperatures from six hundred degrees Fahrenheit to one thousand one hundred degrees Fahrenheit. The pilot housing **270** and the aft heat shield **224** are made from materials suitable for use in these high temperature environments including, for example, stainless steel, corrosion-resistant alloys of nickel and chromium, and high-strength nickel-base alloys. The pilot housing **270** and aft heat shield **224** may thus be formed from a metal alloy chosen from the group consisting of iron-based alloys, nickel-based alloys, and chromium-based alloys. Exposed surfaces of these materials at these temperatures, and, more particularly, the wall surface **276** may thus be susceptible to a significant build-up of coke and/or partially burned fuel deposits. The coke forming on such materials may be strongly bound to these metallic components of the fuel nozzle tip **220** leading to the formation of a thick layer of coke with large particles. As noted above, coke can build up in considerable thickness on these surfaces and large pieces of coke can shed off, becoming internal domestic objects that can cause significant damage to components downstream of the fuel nozzle (hot gas path components).

[0044] To prevent the build-up of coke and the issues discussed above, at least a portion of the surfaces of the second venturi **280**, including, for example, the wall surface **276** and the aft heat shield **224** may be coated with a layer of a catalytic metal (referred to herein as a catalytic metal layer **288**) to inhibit coke deposition and build-up. As noted above, the pilot mixing chamber **274** is passage, and, in embodiments discussed herein, a portion of the passage wall is a coated passage wall that is coated with a layer of a catalytic metal (the catalytic metal layer **288**). coated passage wall is located downstream of the fuel injection port (the primary pilot fuel orifice **242** and the secondary pilot fuel orifice **244**, in this embodiment). As noted above, air flows through the pilot mixing chamber **274** (passage) and is introduced by an air inlet. In these embodiments, the air inlet is upstream of the coated passage wall. More specifically, air is introduced into the pilot mixing chamber **274** (passage) by the pilot inlet **246**, through the inner pilot swirler **251** and the outer pilot swirler **253**. The air flowing through the inner pilot swirler **251** is also introduced to the pilot mixing chamber **274** via outlet **268**.

[0045] Suitable catalytic metals include the platinum group metals, and the catalytic metal may be a metal selected from the group consisting of ruthenium, rhodium, palladium, osmium, iridium, and platinum. Of this group, palladium and platinum may be preferred catalytic metals. Gold may also be a suitable metal, and, in some embodiments, the catalytic metal may be one of palladium, platinum, or gold. Without intending to be bound to any theory, these catalytic metals promote the formation of fine scale (less than one hundred microns in size) filaments of coke, rather than large grains of coke (greater than two hundred microns in size). These filaments of coke are lightly bound (do not from a strong bond) to the catalytic metal layer **288** and the filamentary coke can be easily removed by normal operation of the fuel nozzle without damage to downstream components.

[0046] Exposed surfaces of the underlying (base) material of the pilot housing **270**, and, more specifically, the conical wall section **272** or the aft heat shield **224**, promote the formation of thick, large grains of coke, and the catalytic metal layer **288** of this embodiment is applied as a continuous layer on the wall surface **276** to avoid discontinuities that would expose the base material. Only a thin layer of the catalytic metal is needed to promote the filamentary coke formation. As these catalytic metals may be expensive, the thickness of the catalytic metal layer **288** is preferably minimized. The catalytic metal layer **288** may have a thickness of, preferably, less than fifty microns, and, more preferably, less than twenty-five microns. In some embodiments, the thickness of the catalytic metal layer **288** may be from five microns to ten microns.
[0047] For aerodynamic purposes related to the flow of the fuel-air mixture through the pilot mixing chamber **274**, the catalytic metal layer **288** preferably has a very smooth surface finish. A smooth surface finish also helps to prevent coke from sticking to the second venturi **280**. In some embodiments, the catalytic metal layer **288** may have a surface finish (a surface roughness, Ra) from twenty microinches to one hundred fifty microinches and, in other embodiments, from eighty microinches to one hundred fifty microinches.
[0048] The catalytic metal layer **288** may be applied using any suitable method that produces a continuous metal layer with the thicknesses and surface finishes discussed above. The components discussed herein, such as the diverging section **284** of the second venturi **280** and the diverging surfaces **228** of the aft heat shield **224**, can be preferably coated using a line-of-sight process, such as electroplating, for example, as opposed to other processes, such as chemical vapor deposition. When electroplating is used, the electroplating process may be carried out using the equipment, capabilities, and experience found at a commercial plating shop within the aerospace industry. The electroplating may be performed using the following conditions for the bath. The catalytic metal layer **288** can be plated from an electrolytic plating bath containing the catalytic metal salts in either the (II) or (IV) oxidation state. The temperature of the bath during coating may be from seventy-five to eighty-five degrees Celsius. The current density may be from six to ten amperes per square foot (Amp/ft.sup.2 or asf). The pH of the bath, measured at room temperature, may be from eleven to thirteen. The conductivity of the solution, measured at room temperature, may be from eight and a half milliSiemens per centimeter (mS/cm) to twelve milliSiemens per centimeter (mS/cm). The solution may be stirred at a stir rate of sixty to three hundred revolutions per minute (rpm). Depending upon the desired thickness, electroplating may be performed for one to three hours.
[0049] In the preceding discussion, the combustor **300** and the mixer assembly **210** were configured to use a twin annular premixing swirler (TAPS), but the catalytic metal layer **288** discussed herein may be applied to other mixer assembly designs and other combustor designs. Another example of a combustor **400** is shown in FIG. **5**. FIG. **5** is a detail view showing detail **3** in FIG. **2** for a rich burn combustor design, and, as FIG. **2** is a cross-sectional view, FIG. **5** is also a cross-sectional view of the combustor **400**. FIG. **6** shows a mixer assembly **410** of the combustor **400** shown in FIG. **5**. FIG. **6** is a detail view showing detail **6** in FIG. **5**, and, as FIG. **5** is a cross-sectional view, FIG. **6** is also a cross-sectional view of the mixer assembly **410**. The combustor **400** and the mixer assembly **410** of this embodiment include the same or similar components as the combustor **300** and the mixer assembly **210** discussed above. Components in this embodiment that are the same or similar to those discussed above are identified with the same reference numeral and a detailed description of these components is omitted.
[0050] The combustor **400** of this embodiment shows a rich burn combustor. A plurality of mixer assemblies **410** (only one is illustrated) are spaced around the dome **310**. As shown in FIG. **6**, the mixer assembly **410** of this embodiment includes an inner swirler **412** and an outer swirler **414** through which compressed air flows. Fuel is injected into the mixer assembly **410** by a fuel injection port **402**. The fuel injection port **402** injects fuel in a generally downstream direction and into the compressed air flowing through the inner swirler **412**. The fuel is injected into a mixing

chamber **404** that mixes the fuel with the compressed air to form a fuel-air mixture. As with the pilot mixing chamber **274** discussed above, the mixing chamber **404** of this embodiment is a passage of the fuel injector **200** with a wall section **406** that includes a passage wall surface **408** facing the mixing chamber **404** (passage). In this embodiment, wall section **406** is part of a venturi **420** that includes a converging section **422**, a diverging section **424**, and a throat **426** between the converging section **422** and the diverging section **424**. In this embodiment, the catalytic metal layer **288** is formed on the surfaces of the venturi **420**. The fuel-air mixture exits through an outlet **428** of the mixing chamber **404** and is combined with air flowing through the outer swirler **414** at a position upstream of the diverging surfaces **228** of the aft heat shield **224**. In this embodiment, catalytic metal layer **288** is also formed on the diverging surfaces **228** of the aft heat shield **224**.

[0051] Our testing confirmed the effectiveness of applying the catalytic metal to exposed surfaces of the fuel nozzle tip **220** in the manner discussed in the embodiments above. One such test was an engine-simulative combustion test. In this test, we applied a layer of platinum as the catalytic metal layer **288** to the diverging section **284** of the second venturi **280** in a twin annular premixing swirler (TAPS) to form a coated venturi (See FIG. **4**). We applied the platinum to the diverging section **284** using electroplating under conditions discussed above. We compared the coated venturi to a fuel nozzle tip **220**, operated under similar conditions, without the coated venturi (non-coated venturi). We ran the engine-simulative combustion test for a duration of about two hours with a controlled ramp up after ignition, a hold at condition for about forty-five minutes, a controlled cool down, and flameout. We measured the starting temperature at the inlet at four hundred degrees Fahrenheit, increasing to about one thousand degrees in the space of fifty minutes. We held the temperature constant at about one thousand degrees for forty-five minutes, and then began the cool down and flameout, allowing the temperature to decrease to two hundred degrees two hours after the initial measurement. During the test, we maintained a relatively constant fuel flow rate of about two hundred pounds mass per hour. During cool down and flameout, we first increased the fuel flow rate to about two hundred thirty pounds mass per hour for a half hour, before flaming out by cutting fuel flow to the fuel nozzle. The inlet pressure was measured at about ninety pounds per square inch absolute at the start of the cycle and was gradually increased to one hundred eighty pounds per square inch absolute for the forty-five-minute hold. During cool down, about an hour into the test, the inlet pressure linearly decreased to about one hundred sixty pounds per square inch absolute at the end when the fuel flow was stopped.

[0052] Each of the coated venturi and the non-coated venturi showed coke deposition. We performed an adhesion test by applying a piece of transparent office tape, such as Scotch® Magic™ Tape, with the adhesive side on the coke of each venturi. We then peeled off the tape and observed the coke adhered to the tape. More coke was removed from the platinum coated venturi than the non-coated venturi, and the morphology of the coke was different between the two. The coke from the platinum coated venturi displayed a filamentary morphology and was of a finer scale than the coke from the non-coated venturi. As demonstrated by this test, catalytic metal coating, such as the platinum catalytic coating, on the venturi can effectively reduce coke buildup during engine operation.

[0053] Further aspects of the present disclosure are provided by the subject matter of the following clauses.

[0054] A mixer assembly for a gas turbine engine includes a housing and a fuel injection port. The housing includes a passage formed therein and a passage wall facing the passage. The fuel injection port is fluidly connected to a fuel source and configured to inject a hydrocarbon fuel into the passage. At least a portion of the passage wall is a coated passage wall. The coated passage wall is (i) coated with a layer of a catalytic metal and (ii) located downstream of the fuel injection port.

[0055] The mixer assembly of the preceding clause, wherein the layer of the catalytic metal of the coated passage wall has a surface roughness. The surface roughness is from twenty microinches to one hundred fifty microinches.

[0056] The mixer assembly of any of the preceding clauses, wherein the catalytic metal is a metal selected from the group consisting of ruthenium, rhodium, palladium, osmium, iridium, and platinum.
[0057] The mixer assembly of any of the preceding clauses, wherein the catalytic metal is one of palladium, platinum, or gold.
[0058] The mixer assembly of any of the preceding clauses, wherein the layer of the catalytic metal has a thickness that is less than twenty-five microns.
[0059] The mixer assembly of any of the preceding clauses, wherein the layer of the catalytic metal has a thickness that is from five microns to ten microns.
[0060] The mixer assembly of any of the preceding clauses, wherein the layer of the catalytic metal is an electroplated layer.
[0061] The mixer assembly of any of the preceding clauses, wherein the passage wall is formed from a metal alloy chosen from the group consisting of iron-based alloys, nickel-based alloys, and chromium-based alloys.
[0062] The mixer assembly of any of the preceding clauses, wherein the passage includes a conical section. A passage wall of the conical section of the passage is the coated passage wall.
[0063] The mixer assembly of any of the preceding clauses, wherein the conical section has an upstream end and a downstream end. The passage has a cross-sectional area at each of the upstream end and the downstream end. The cross-sectional area of the passage at the downstream end of the conical section is greater than the cross-sectional area of the passage at the upstream end of the conical section.
[0064] The mixer assembly of any of the preceding clauses, further comprising an air inlet configured to introduce air to flow through the air inlet into the passage. The air inlet is upstream of the coated passage wall.
[0065] The mixer assembly of any of the preceding clauses, wherein the passage is a venturi including a converging section, a diverging section, and a throat. The coated passage wall includes the passage wall of the diverging section.
[0066] The mixer assembly of any of the preceding clauses, wherein the coated passage wall includes the passage wall of the converging section.
[0067] The mixer assembly of any of the preceding clauses, further comprising a pilot fuel injector tip and a pilot swirler. The pilot fuel injector tip includes a least one pilot fuel orifice. The fuel injection port is the pilot fuel orifice. The pilot swirler is located radially outward of the pilot fuel injector tip and adjacent to the pilot fuel injector tip. Air is configured to flow through the pilot swirler and to mix with fuel from the pilot fuel orifice as a fuel-air mixture. The pilot swirler has an outlet configured to discharge the fuel-air mixture into the passage.
[0068] The mixer assembly of any of the preceding clauses, further comprising an array of main fuel injection orifices configured to inject fuel in a radially outward direction. The main fuel injection orifices are located radially outward from the passage.
[0069] The mixer assembly of any of the preceding clauses, wherein the passage is a venturi including a converging section, a diverging section, and a throat. The coated passage wall includes a passage wall of the diverging section, and the outlet of the pilot swirler is located upstream of the diverging section.
[0070] The mixer assembly of any of the preceding clauses, wherein the pilot swirler is formed by a housing. The housing is shaped as a venturi.
[0071] A gas turbine engine includes a combustor including a combustion chamber, and the mixer assembly of any of the preceding clauses. The mixer assembly is configured to inject a mixture of air and hydrocarbon fuel into the combustion chamber.
[0072] The gas turbine engine of the preceding clause, wherein the combustor is configured to combust the mixture of air and the hydrocarbon fuel to generate combustion products, and wherein the gas turbine engine further comprises at least one component coated with a thermal barrier

coating downstream of the combustor and configured to receive the combustion products.
[0073] The gas turbine engine of any of the preceding clauses, wherein the mixer assembly includes a heat shield adjacent to the combustion chamber. At least a portion of the heat shield is coated with a layer of the catalytic metal.
[0074] Although the foregoing description is directed to the preferred embodiments, other variations and modifications will be apparent to those skilled in the art and may be made without departing from the spirit or scope of the disclosure. Moreover, features described in connection with one embodiment may be used in conjunction with other embodiments, even if not explicitly stated above.

Claims

1. A mixer assembly for a gas turbine engine, the mixer assembly comprising: a housing including a passage formed therein and a passage wall facing the passage; and a fuel injection port fluidly connected to a fuel source and configured to inject a hydrocarbon fuel into the passage, wherein at least a portion of the passage wall is a coated passage wall, the coated passage wall being (i) coated with a layer of a catalytic metal and (ii) located downstream of the fuel injection port.
2. The mixer assembly of claim 1, wherein the layer of the catalytic metal of the coated passage wall has a surface roughness, the surface roughness being from twenty microinches to one hundred fifty microinches.
3. The mixer assembly of claim 1, wherein the catalytic metal is a metal selected from the group consisting of ruthenium, rhodium, palladium, osmium, iridium, and platinum.
4. The mixer assembly of claim 1, wherein the catalytic metal is one of palladium, platinum, or gold.
5. The mixer assembly of claim 1, wherein the layer of the catalytic metal has a thickness that is less than twenty-five microns.
6. The mixer assembly of claim 1, wherein the layer of the catalytic metal has a thickness that is from five microns to ten microns.
7. The mixer assembly of claim 1, wherein the layer of the catalytic metal is an electroplated layer.
8. The mixer assembly of claim 1, wherein the passage wall is formed from a metal alloy chosen from the group consisting of iron-based alloys, nickel-based alloys, and chromium-based alloys.
9. The mixer assembly of claim 1, wherein the passage includes a conical section, a passage wall of the conical section of the passage being the coated passage wall.
10. The mixer assembly of claim 9, wherein the conical section has an upstream end and a downstream end, the passage having a cross-sectional area at each of the upstream end and the downstream end, the cross-sectional area of the passage at the downstream end of the conical section being greater than the cross-sectional area of the passage at the upstream end of the conical section.
11. The mixer assembly of claim 1, further comprising an air inlet configured to introduce air to flow through the air inlet into the passage, the air inlet being upstream of the coated passage wall.
12. The mixer assembly of claim 11, wherein the passage is a venturi including a converging section, a diverging section, and a throat, the coated passage wall including the passage wall of the diverging section.
13. The mixer assembly of claim 12, wherein the coated passage wall further includes the passage wall of the converging section.
14. The mixer assembly of claim 1, further comprising: a pilot fuel injector tip including a least one pilot fuel orifice, the fuel injection port being the pilot fuel orifice; and a pilot swirler is located radially outward of the pilot fuel injector tip and adjacent to the pilot fuel injector tip, air being configured to flow through the pilot swirler and to mix with fuel from the pilot fuel orifice as a fuel-air mixture, the pilot swirler having an outlet configured to discharge the fuel-air mixture into

the passage.

15. The mixer assembly of claim 14, further comprising an array of main fuel injection orifices configured to inject fuel in a radially outward direction, the main fuel injection orifices being located radially outward from the passage.

16. The mixer assembly of claim 14, wherein the passage is a venturi including a converging section, a diverging section, and a throat, the coated passage wall including a passage wall of the diverging section, and the outlet of the pilot swirler being located upstream of the diverging section.

17. The mixer assembly of claim 16, wherein the pilot swirler is formed by a housing, the housing being shaped as a venturi.

18. A gas turbine engine comprising: a combustor including a combustion chamber; and the mixer assembly of claim 1 configured to inject a mixture of air and hydrocarbon fuel into the combustion chamber.

19. The gas turbine engine of claim 18, wherein the combustor is configured to combust the mixture of air and the hydrocarbon fuel to generate combustion products, and wherein the gas turbine engine further comprises at least one component coated with a thermal barrier coating downstream of the combustor and configured to receive the combustion products.

20. The gas turbine engine of claim 18, wherein the mixer assembly includes a heat shield adjacent to the combustion chamber, at least a portion of the heat shield being coated with a layer of the catalytic metal.