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(54) **ANGLED RADIAL FUEL/AIR DELIVERY SYSTEM FOR COMBUSTOR**

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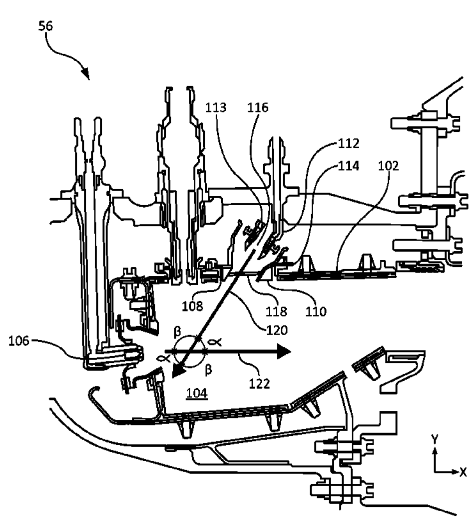
(57) **ABSTRACT**

A combustor is provided. The combustor may comprise an axial fuel delivery system, and a radial fuel delivery system aft of the axial fuel delivery system. The radial fuel delivery system may be configured to direct fuel at least partially towards the axial fuel delivery system. A radial fuel delivery system is also provided. The system may comprise a combustor including a combustor liner, a mixer coupled to the combustor liner, and a nozzle disposed within the mixer, wherein the mixer and the nozzle are configured to direct fuel in a direction at least partially forward.

14 Claims, 4 Drawing Sheets



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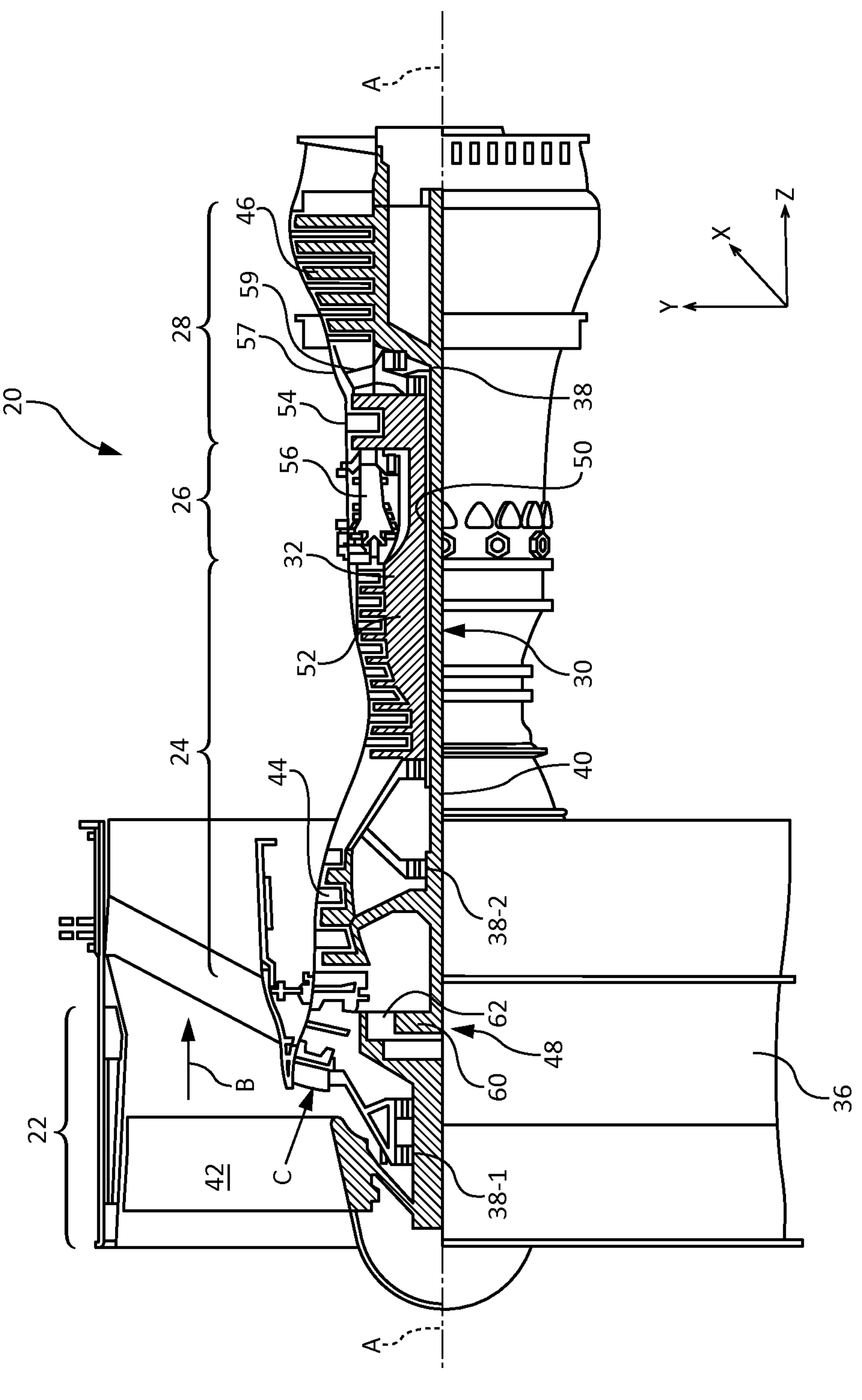
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FIG. 1

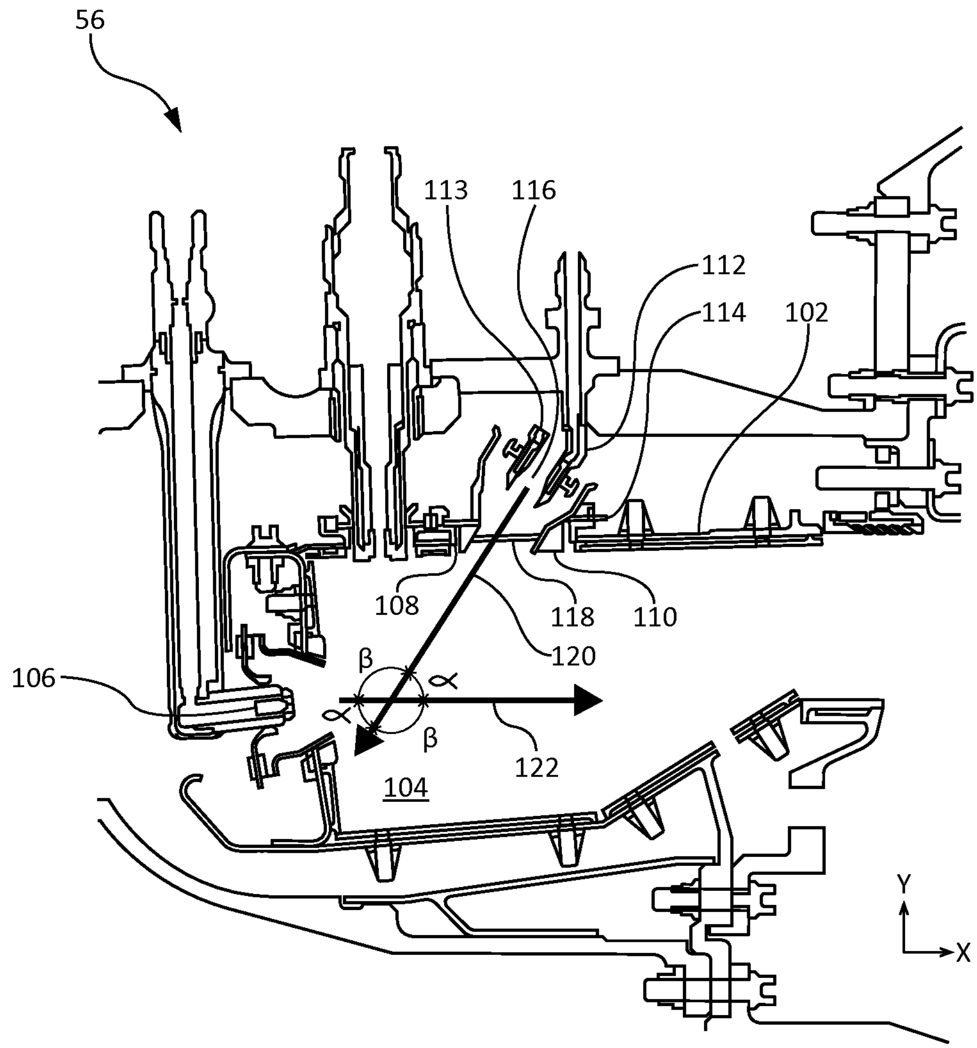

FIG. 2

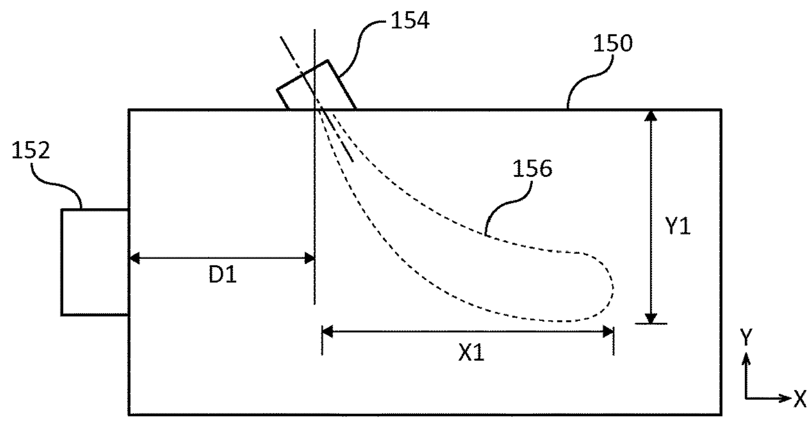

FIG. 3A

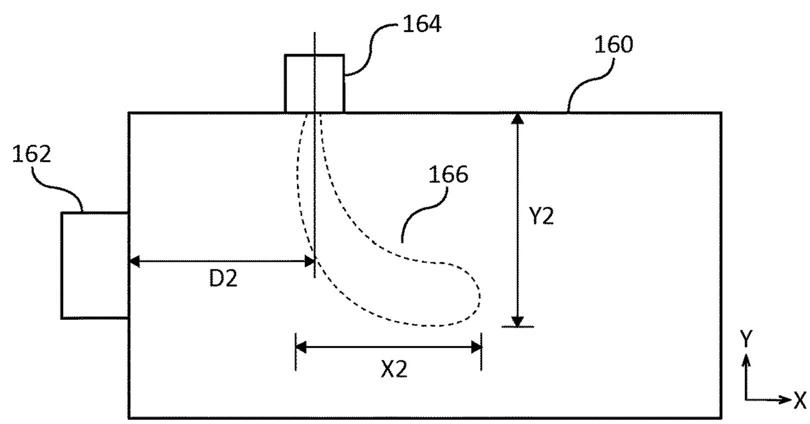

FIG. 3B

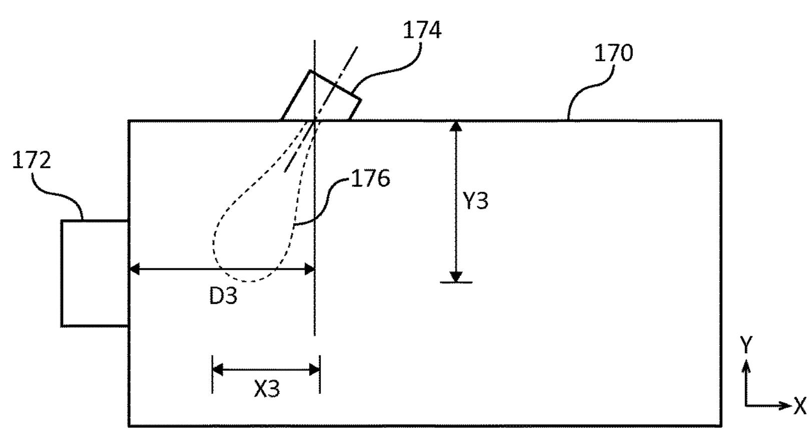

FIG. 3C

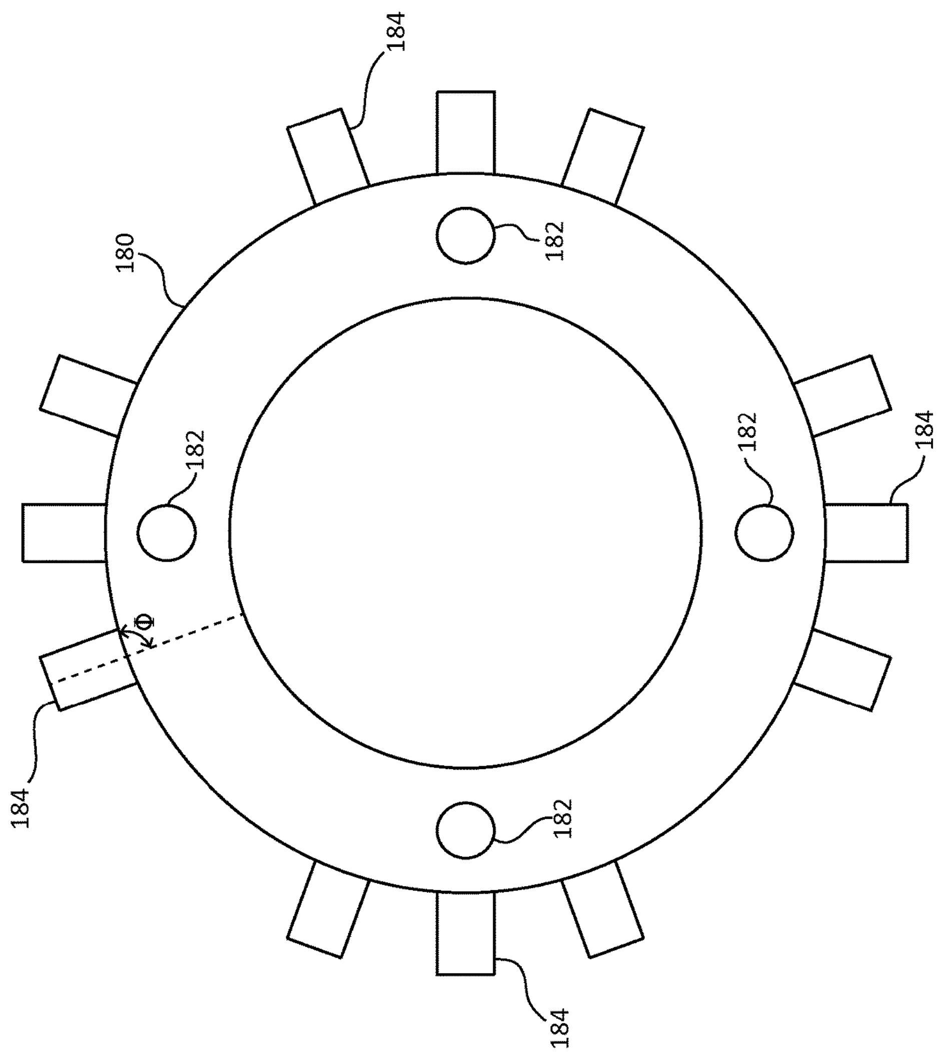

FIG. 4

ANGLED RADIAL FUEL/AIR DELIVERY SYSTEM FOR COMBUSTOR

GOVERNMENT LICENSE RIGHTS

This disclosure was made with government support under contract No. NNC13TA45T awarded by National Aeronautics and Space Administration (NASA). The government has certain rights in the disclosure.

FIELD OF INVENTION

The present disclosure relates to combustion systems for gas turbine engines, and, more specifically, to an angled radial fuel/air mixture delivery system for a combustor.

BACKGROUND

Gas turbine engines may comprise a compressor for pressurizing an air supply, a combustor for burning a fuel, and a turbine for converting the energy from combustion into mechanical energy. The combustor may have an inner liner and an outer liner that define a combustion chamber. A fuel injector would typically introduce fuel into the front section of the combustor. As the fuel burns, nitrogen oxide (NOx) and other emissions may be produced. Such emissions are subject to administrative regulation. To reduce NOx emission and improve pattern factor, a fuel staged lean burn combustor may be used. For example, axially staged combustors may include pilot fuel injectors and radial main mixers. The pilot fuel injectors introduce fuel into the front section of the combustor, while the radial main mixers located downstream of the pilot injectors deliver fuel/air mixture radially at an angle into the combustor.

When injected normally into the combustor, the main flame generated by the main radial mixer may have a very long flame length. As a result, the main flame may either extend to the combustor exit or be quenched by the opposite side liner. As shorter combustor lengths typically provide better performance, long flame lengths corresponding to greater combustor lengths may decrease performance. Similarly, quenching the main flame on the opposite side liner may result in a poor burn. Poor mixing will result in poor pattern factor.

SUMMARY

A fuel staged combustor may comprise an axial fuel delivery system, and a radial fuel delivery system aft of the axial fuel delivery system. The radial fuel delivery system may be configured to direct a mixture of fuel and air at least partially towards the axial fuel delivery system.

In various embodiments, the axial fuel delivery system may be configured to deliver fuel in a gas flow path. The radial fuel delivery system may be configured to direct a mixture of fuel and air into the combustor at an angle between 5 degrees and 85 degrees relative to a gas flow path. The radial fuel delivery system may be configured to direct a mixture of fuel and air into the combustor at an angle between 15 degrees and 75 degrees relative to the normal of gas flow path. A liner may have the radial fuel delivery system extending at least partially though the liner. The radial fuel delivery system may comprise a mixer disposed in a cavity defined by a combustor liner. The combustor may comprise a plurality of axial fuel delivery systems with one to three radial fuel delivery systems for each axial fuel delivery system.

A gas turbine engine may comprise a compressor, a combustor aft of the compressor, and an axial fuel delivery system in the combustor. A radial fuel delivery system may be downstream of the axial fuel delivery system in the combustor, and the radial fuel delivery system may be configured to direct fuel at least partially in an upstream direction.

In various embodiments, the axial fuel delivery system may be configured to deliver fuel in a gas flow path. The radial fuel delivery system may be configured to direct fuel into the combustor at an angle between 5 degrees and 85 degrees relative to the gas flow path. The radial fuel delivery system may be configured to direct fuel into the combustor at an angle between 15 degrees and 75 degrees relative to the gas flow path. The combustor may further comprise a liner with the radial fuel delivery system extending at least partially though the liner. The radial fuel delivery system may comprise a mixer disposed in a cavity defined by a combustor liner. The combustor may further comprise a plurality of axial fuel delivery systems with one to three radial fuel delivery systems for each axial fuel delivery system.

A radial fuel delivery system may comprise a combustor including a combustor liner, a mixer coupled to the combustor liner, and a nozzle disposed within the mixer, wherein the mixer and the nozzle are configured to direct fuel at least partially in an upstream direction.

In various embodiments, the mixer and the nozzle are configured to deliver a mixture of fuel and air at a negative angle relative to a gas flow path. The radial fuel delivery system may be configured to direct a mixture of fuel and air into the combustor at an angle between 5 degrees and 85 degrees relative to a gas flow path. The radial fuel delivery system may also be configured to direct a mixture of fuel and air into the combustor at an angle between 15 degrees and 75 degrees relative to the normal of a gas flow path. The mixer may be disposed at least partially through the combustor liner. The mixer may be configured to deliver a mixture of fuel and air mixture at an angle relative to the combustor liner.

The foregoing features and elements may be combined in various combinations without exclusivity, unless expressly indicated otherwise. These features and elements as well as the operation thereof will become more apparent in light of the following description and the accompanying drawings. It should be understood, however, the following description and drawings are intended to be exemplary in nature and non-limiting.

BRIEF DESCRIPTION OF THE DRAWINGS

The subject matter of the present disclosure is particularly pointed out and distinctly claimed in the concluding portion of the specification. A more complete understanding of the present disclosure, however, may best be obtained by referring to the detailed description and claims when considered in connection with the figures, wherein like numerals denote like elements.

FIG. **1** illustrates an exemplary gas turbine engine, in accordance with various embodiments;

FIG. **2** illustrates a combustor of a gas turbine engine including a radial main mixer at an angle relative to the combustor and gas flow, in accordance with various embodiments;

FIG. **3A** illustrates a combustor with a radial main mixer angled in a direction of gas flow, in accordance with various embodiments;

FIG. 3B illustrates a combustor with a radial main mixer angled perpendicular to a direction of gas flow, in accordance with various embodiments;

FIG. 3C illustrates a combustor with a radial main mixer angled in a negative direction, in accordance with various embodiments; and

FIG. 4 illustrates an annular combustor with an axial fuel delivery system circumferentially distributed about the combustor, in accordance with various embodiments.

DETAILED DESCRIPTION

The detailed description of exemplary embodiments herein makes reference to the accompanying drawings, which show exemplary embodiments by way of illustration. While these exemplary embodiments are described in sufficient detail to enable those skilled in the art to practice the exemplary embodiments of the disclosure, it should be understood that other embodiments may be realized and that logical changes and adaptations in design and construction may be made in accordance with this disclosure and the teachings herein. Thus, the detailed description herein is presented for purposes of illustration only and not limitation. The scope of the disclosure is defined by the appended claims. For example, the steps recited in any of the method or process descriptions may be executed in any order and are not necessarily limited to the order presented.

Furthermore, any reference to singular includes plural embodiments, and any reference to more than one component or step may include a singular embodiment or step. Also, any reference to attached, fixed, connected or the like may include permanent, removable, temporary, partial, full and/or any other possible attachment option. Additionally, any reference to without contact (or similar phrases) may also include reduced contact or minimal contact. Surface shading lines may be used throughout the figures to denote different parts but not necessarily to denote the same or different materials.

As used herein, “aft” refers to the direction associated with the tail (e.g., the back end) of an aircraft, or generally, to the direction of exhaust of the gas turbine. As used herein, “forward” refers to the direction associated with the nose (e.g., the front end) of an aircraft, or generally, to the direction of flight or motion.

As used herein, “distal” refers to the direction radially outward, or generally, away from the axis of rotation of a turbine engine. As used herein, “proximal” refers to a direction radially inward, or generally, towards the axis of rotation of a turbine engine.

In various embodiments and with reference to FIG. **1**, a gas turbine engine **20** is provided. Gas turbine engine **20** may be a two-spool turbofan that generally incorporates a fan section **22**, a compressor section **24**, a combustor section **26** and a turbine section **28**. Alternative engines may include, for example, an augmentor section among other systems or features. In operation, fan section **22** can drive coolant (e.g., air) along a bypass flow-path B while compressor section **24** can drive coolant along a core flow-path C for compression and communication into combustor section **26** then expansion through turbine section **28**. Although depicted as a turbofan gas turbine engine **20** herein, it should be understood that the concepts described herein are not limited to use with turbofans as the teachings may be applied to other types of turbine engines including three-spool architectures.

Gas turbine engine **20** may generally comprise a low speed spool **30** and a high speed spool **32** mounted for rotation about an engine central longitudinal axis A-A' relative to an engine static structure **36** via several bearing systems **38**, **38-1**, and **38-2**. It should be understood that various bearing systems **38** at various locations may alternatively or additionally be provided, including for example, bearing system **38**, bearing system **38-1**, and bearing system **38-2**.

Low speed spool **30** may generally comprise an inner shaft **40** that interconnects a fan **42**, a low-pressure compressor **44** and a low-pressure turbine **46**. Inner shaft **40** may be connected to fan **42** through a geared architecture **48** that can drive fan **42** at a lower speed than low speed spool **30**. Geared architecture **48** may comprise a gear assembly **60** enclosed within a gear housing **62**. Gear assembly **60** couples inner shaft **40** to a rotating fan structure. High speed spool **32** may comprise an outer shaft **50** that interconnects a high-pressure compressor **52** and high-pressure turbine **54**. A combustor **56** may be located between high-pressure compressor **52** and high-pressure turbine **54**. Mid-turbine frame **57** may support one or more bearing systems **38** in turbine section **28**. Inner shaft **40** and outer shaft **50** may be concentric and rotate via bearing systems **38** about the engine central longitudinal axis A-A', which is collinear with their longitudinal axes. As used herein, a “high-pressure” compressor or turbine experiences a higher pressure than a corresponding “low-pressure” compressor or turbine.

The core airflow C may be compressed by low-pressure compressor **44** then high-pressure compressor **52**, mixed and burned with fuel in combustor **56**, then expanded over high-pressure turbine **54** and low-pressure turbine **46**. Mid-turbine frame **57** includes airfoils **59**, which are in the core airflow path. Airfoils **59** may be formed integrally into a full-ring, mid-turbine-frame stator and retained by a retention pin. Turbines **46**, **54** rotationally drive the respective low speed spool **30** and high speed spool **32** in response to the expansion.

Gas turbine engine **20** may be, for example, a high-bypass ratio geared aircraft engine. In various embodiments, the bypass ratio of gas turbine engine **20** may be greater than about six (6). In various embodiments, the bypass ratio of gas turbine engine **20** may be greater than ten (10). In various embodiments, geared architecture **48** may be an epicyclic gear train, such as a star gear system (sun gear in meshing engagement with a plurality of star gears supported by a carrier and in meshing engagement with a ring gear) or other gear system. Geared architecture **48** may have a gear reduction ratio of greater than about 2.3 and low-pressure turbine **46** may have a pressure ratio that is greater than about five (5). In various embodiments, the bypass ratio of gas turbine engine **20** is greater than about ten (10:1). In various embodiments, the diameter of fan **42** may be significantly larger than that of the low-pressure compressor **44**. Low-pressure turbine **46** pressure ratio may be measured prior to inlet of low-pressure turbine **46** as related to the pressure at the outlet of low-pressure turbine **46** prior to an exhaust nozzle. It should be understood, however, that the above parameters are exemplary of various embodiments of a suitable geared architecture engine and that the present disclosure contemplates other turbine engines including direct drive turbofans.

Combustor **56** may include both radial and axial fuel delivery systems, as discussed in further detail below. The radial fuel delivery systems may be angled relative to the axial gas flow through combustor **56**. Angling the radial duel delivery systems of combustor **56** may impact the completeness of the fuel burn and thus emissions. Angling the radial fuel delivery system may also impact the length of ignited gasses ejected from the radial fuel delivery system.

With reference to FIG. **2**, a combustor **56** having an axial fuel delivery system **106** at a forward location of the combustor and a radial fuel delivery system **112** aft of axial fuel delivery system **106** according to various embodiments. A xy axis is provided for ease of description. Radial fuel delivery system **112** delivers fuel into combustion chamber **104** in an at least partially radial direction (i.e., the y direction). Radial fuel delivery system **112** has nozzle **113** in cavity **116** defined by bluff body **118** and mixer **110**. Mixer **110** mixes the fuel delivered by radial fuel delivery system **112** with air and provides a stable burn pattern. Mixer **110** comprises a bluff body **118** extending from inner walls of mixer **110**, as described in further detail below. Mixer **110** may rest in opening **108** defined by combustor liner **102**. Mixer **110** may be secured to combustor **56** by tabs **114**.

In various embodiments, radial fuel delivery system **112** may deliver fuel into combustor **56** in direction **120**. Fuel delivery direction **120** is the direction that fuel is traveling when leaving nozzle **113** and/or mixer **110**. Fuel delivery direction **120** may have a radial component (i.e., in the y direction) and an axial component (i.e., in the x direction). Gas flow direction **122** is the direction of compressed gas in core flowpath C (of FIG. **1**) entering combustor **56**. Fuel delivered by axial fuel delivery system **106** may also move in gas flow direction **122**.

In various embodiments, fuel delivery direction **120** may be selected relative to a gas flow direction **122**. The angle between the gas flow direction **122** and fuel delivery direction **120** may be described as negative, neutral, or positive. Radial fuel delivery system **112** is at a "negative angle" when gas flow direction **122** and fuel delivery direction **120** are oriented with angle α being acute (i.e., less than 90°) and angle β being obtuse (i.e., greater than 90°). In that regard, radial fuel delivery system **112** at a negative angle directs a fuel/air mixture at least partially upstream or in a direction opposite gas flow direction **122**. Radial fuel delivery system **112** is at a "positive angle" when gas flow direction **122** and fuel delivery direction **120** are oriented with angle α being obtuse (i.e., greater than 90°) and angle β being acute (i.e., less than 90°). Radial fuel delivery system **112** is at a "neutral angle" when both angles α and β are approximately 90°.

In various embodiments, a radial fuel delivery system **112** oriented so that fuel delivery direction **120** is oriented relative to gas flow direction **122** with angle α being between 5° and 85° or between 15° and 75°. Orienting radial fuel delivery system **112** at a negative angle (e.g., with angle α between 5° and 85°) tends to provide shortened flame length and improved burn completion relative to radial fuel delivery system **112** oriented at positive and/or neutral angles, as described in further detail below.

With reference to FIG. **3**A, a combustor **150** is shown with axial fuel delivery system **152** oriented at a positive angle, in accordance with various embodiments. Radial fuel delivery system **154** may be aft of axial fuel delivery system **152** and separated from axial fuel delivery system **152** by a distance D_1. Gas in combustor **150** may flow generally in an aft direction (i.e., a direction along the x axis). Radial fuel delivery system may deliver fuel into combustor **150** at an angle relative to gas flow direction defined by the x axis. Radial fuel delivery system **154** may also deliver fuel at an angle relative to a radial direction (i.e., a direction along the y axis). Axial fuel delivery system **152** oriented at a positive angle may produce flame **156** with large X_1 (width) and Y_1 (height) dimensions relative to an axial fuel delivery system oriented at a negative angle, as described in further detail below.

With reference to FIG. **3**B, a combustor **160** is shown with axial fuel delivery system **162** oriented at a neutral angle (i.e., a right angle), in accordance with various embodiments. Radial fuel delivery system **164** may be aft of axial fuel delivery system **162** and separated from axial fuel delivery system **162** by a distance D_2. Gas in combustor **160** may flow generally in an aft direction (i.e., a direction along the x axis). Radial fuel delivery system may deliver fuel into combustor **160** perpendicular to gas flow direction defined by the x axis. Radial fuel delivery system **164** may also deliver fuel perpendicular to a radial direction (i.e., a direction along the y axis). Axial fuel delivery system **162** oriented at a positive angle may produce flame **166** with large X_2 (width) and Y_2 (height) dimensions relative to an axial fuel delivery system oriented at a negative angle, as described in further detail below.

With reference to FIG. **3**C, a combustor **170** is shown with axial fuel delivery system **172** oriented at a negative angle, in accordance with various embodiments. Radial fuel delivery system **174** may be aft of axial fuel delivery system **172** and separated from axial fuel delivery system **172** by a distance D_1. Gas in combustor **170** may flow generally in an aft direction (i.e., a direction along the x axis). Radial fuel delivery system **172** may deliver fuel into combustor **170** at an angle relative to the direction of the gas flow in combustor **170** defined by the x axis as depicted. In that regard, radial fuel delivery system **172** may delivery a fuel mixture in at least a partially upstream direction relative to the flow of gas in combustor **170** (i.e., moving at least partially forward towards axial fuel delivery system **172** as depicted). Radial fuel delivery system **174** may also deliver fuel at an angle relative to a radial direction (i.e., a direction along the y axis). Axial fuel delivery system **172** oriented at a positive angle may produce flame **176** with small X_1 (width) and Y_1 (height) dimensions relative to an axial fuel delivery system oriented at a positive or neutral angle, as described above.

With reference to FIG. **4**, an annular combustor **180** is shown as viewed from forward to aft with axial fuel delivery systems **182** and radial fuel delivery systems **184**. Annular combustor **180** may have multiple radial fuel delivery systems **184** for each axial fuel delivery system **182**. Axial fuel delivery systems **182** may serve as pilot lights. The combustion supported by axial fuel delivery system **182** may ignite fuel mixture exiting radial fuel delivery system **184**. In various embodiments, annular combustor **180** may include one or more radial fuel delivery systems **184** for each axial fuel delivery system **182** (e.g., one to three radial fuel delivery systems **184** for each axial fuel delivery system **182**). Each radial fuel delivery system **184** may be oriented at radial angle ϕ relative to a radial direction. Radial fuel delivery system **184** may be oriented at a negative axial angle α (as shown in FIG. **2**) with a radial angle ϕ (in a circumferential direction) between −90° and 90°. Radial fuel delivery system **184** oriented at a negative axial angle α may tend to provide improved fuel burn and a short flame length for any radial angle ϕ.

Benefits and other advantages have been described herein with regard to specific embodiments. Furthermore, the connecting lines shown in the various figures contained herein are intended to represent exemplary functional relationships and/or physical couplings between the various elements. It should be noted that many alternative or additional functional relationships or physical connections may be present in a practical system. However, the benefits, advantages, and any elements that may cause any benefit or advantage to occur or become more pronounced are not to be construed as critical, required, or essential features or elements of the disclosure. The scope of the disclosure is accordingly to be limited by nothing other than the appended claims, in which reference to an element in the singular is not intended to mean "one and only one" unless explicitly so stated, but rather "one or more." Moreover, where a phrase similar to "at least one of A, B, or C" is used in the claims, it is intended that the phrase be interpreted to mean that A alone may be present in an embodiment, B alone may be present in an embodiment, C alone may be present in an embodiment, or that any combination of the elements A, B and C may be present in a single embodiment; for example, A and B, A and C, B and C, or A and B and C.

Systems, methods and apparatus are provided herein. In the detailed description herein, references to "various embodiments", "one embodiment", "an embodiment", "an example embodiment", etc., indicate that the embodiment described may include a particular feature, structure, or characteristic, but every embodiment may not necessarily include the particular feature, structure, or characteristic. Moreover, such phrases are not necessarily referring to the same embodiment. Further, when a particular feature, structure, or characteristic is described in connection with an embodiment, it is submitted that it is within the knowledge of one skilled in the art to affect such feature, structure, or characteristic in connection with other embodiments whether or not explicitly described. After reading the description, it will be apparent to one skilled in the relevant art(s) how to implement the disclosure in alternative embodiments.

Furthermore, no element, component, or method step in the present disclosure is intended to be dedicated to the public regardless of whether the element, component, or method step is explicitly recited in the claims. No claim element herein is to be construed under the provisions of 35 U.S.C. 112(f), unless the element is expressly recited using the phrase "means for." As used herein, the terms "comprises", "comprising", or any other variation thereof, are intended to cover a non-exclusive inclusion, such that a process, method, article, or apparatus that comprises a list of elements does not include only those elements but may include other elements not expressly listed or inherent to such process, method, article, or apparatus.

What is claimed is:

1. An annular combustor, comprising:

a combustor liner defining a combustion chamber;

an axial fuel delivery system located forward the combustion chamber, wherein the axial fuel delivery system delivers a first fuel into the combustion chamber in a gas flow direction, wherein the gas flow direction is a direction of compressed gas traveling axially through the combustion chamber; and

a radial fuel delivery system aft of the axial fuel delivery system, the radial fuel delivery system comprising:

a mixer comprising a bluff body, wherein a mouth of the mixer is coupled to an opening in the combustor liner, and wherein the bluff body extends from an inner wall of the mixer and spans the mouth of the mixer, and

a nozzle in a cavity defined by the bluff body and the mixer, wherein the nozzle delivers a second fuel into the cavity to form a mixture of the second fuel and air in the cavity, and wherein the nozzle is oriented at an angle of between 5 degrees and 85 degrees relative to the gas flow direction and directs the second fuel into the combustion chamber at least partially in an upstream direction relative to the gas flow direction, and wherein the first fuel and the second fuel are ignited in the combustion chamber,

wherein the radial fuel delivery system extends at least partially though the combustor liner, and wherein the radial fuel delivery system is configured to direct the mixture of the second fuel and air over the bluff body to increase a mixing of the second fuel and air upon entering the combustion chamber.

2. The annular combustor of claim **1**, wherein the radial fuel delivery system is configured to direct the mixture of the second fuel and air into the combustion chamber at an axial angle between 5 degrees and 85 degrees relative to the combustor liner.

3. The annular combustor of claim **1**, wherein the radial fuel delivery system is configured to direct the mixture of the second fuel and air into the combustion chamber at an axial angle between 15 degrees and 75 degrees relative to the combustor liner.

4. The annular combustor of claim **1**, further comprising a plurality of axial fuel delivery systems having between one and three radial fuel delivery systems for each axial fuel delivery system.

5. A gas turbine engine, comprising:

a compressor;

an annular combustor aft of the compressor, the annular combustor comprising a combustor liner disposed radially outward of a combustion chamber;

an axial fuel delivery system located forward the combustion chamber, wherein the axial fuel delivery system delivers a first fuel into the combustion chamber in a gas flow direction, and wherein the gas flow direction is a direction of compressed gas traveling axially through the annular combustor; and

a radial fuel delivery system downstream of the axial fuel delivery system, the radial fuel delivery system comprising:

a mixer comprising a bluff body, wherein a mouth of the mixer is coupled to an opening in the combustor liner, and wherein the bluff body spans the mouth of the mixer, and

a nozzle in a cavity defined by the mixer, wherein the nozzle delivers a second fuel into the cavity, and wherein the nozzle is oriented at an angle of between 5 degrees and 85 degrees relative to the gas flow direction, and wherein the radial fuel delivery system is configured to direct the second fuel into the combustion chamber at least partially in an upstream direction, and wherein the first fuel and the second fuel are ignited in the combustion chamber,

wherein the radial fuel delivery system extends at least partially through the combustor liner, and wherein the radial fuel delivery system is configured to direct a mixture of the second fuel and air over the bluff body to increase a mixing of the second fuel and air upon entering the combustion chamber.

6. The gas turbine engine of claim **5**, wherein the radial fuel delivery system is configured to direct the second fuel into the combustion chamber at an angle between 5 degrees and 85 degrees relative to the combustor liner.

7. The gas turbine engine of claim **5**, wherein the radial fuel delivery system is configured to direct the second fuel into the combustion chamber at an angle between 15 degrees and 75 degrees relative to the combustor liner.

8. The gas turbine engine of claim **5**, wherein the annular combustor further comprises a plurality of axial fuel delivery systems having at least one to three radial fuel delivery systems for each axial fuel delivery system.

9. A radial fuel delivery system, comprising:

an annular combustor comprising a combustor liner defining a combustion chamber;

a mixer coupled to the combustor liner, the mixer comprising a bluff body, wherein a mouth of the mixer is located in an opening in the combustor liner, and wherein the bluff body extends from an inner wall of the mixer and spans the mouth of the mixer; and

a nozzle disposed within a cavity defined by the mixer, wherein the mixer and the nozzle are configured to direct fuel into the combustion chamber at least partially in an upstream direction relative to an axial gas flow through the combustion chamber, wherein the fuel is ignited in the combustion chamber, and wherein at least one of the nozzle or the inner wall of the mixer is oriented at an angle of between 5 degrees and 85 degrees relative to the combustor liner,

wherein the mixer and the nozzle are configured to direct a mixture of the fuel and air over the bluff body to increase a mixing of the fuel and air upon entering the combustion chamber.

10. The radial fuel delivery system of claim **9**, wherein the mixer and the nozzle are configured to deliver the mixture of the fuel and air into the combustion chamber at a negative angle relative to the axial gas flow through the combustion chamber.

11. The radial fuel delivery system of claim **9**, wherein the radial fuel delivery system is configured to direct the mixture of the fuel and air into the combustion chamber at an angle between 5 degrees and 85 degrees relative to the axial gas flow through the combustion chamber.

12. The radial fuel delivery system of claim **9**, wherein the radial fuel delivery system is configured to direct the mixture of the fuel and air into the combustion chamber at an angle between 15 degrees and 75 degrees relative to the axial gas flow through the combustion chamber.

13. The radial fuel delivery system of claim **9**, wherein the mixer is disposed at least partially through the combustor liner.

14. The radial fuel delivery system of claim **9**, wherein the nozzle is oriented at an acute angle relative to the combustor liner.

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