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(54) **PILOT FUEL NOZZLE ASSEMBLY WITH MULTI-ANGLED VENTURI**

(71) Applicant: **General Electric Company**, Schenectady, NY (US)

(72) Inventors: **Hiranya Nath**, Bengaluru (IN); **Habeeb Kunnummal Manat**, Bengaluru (IN); **Hejie Li**, Mason, OH (US)

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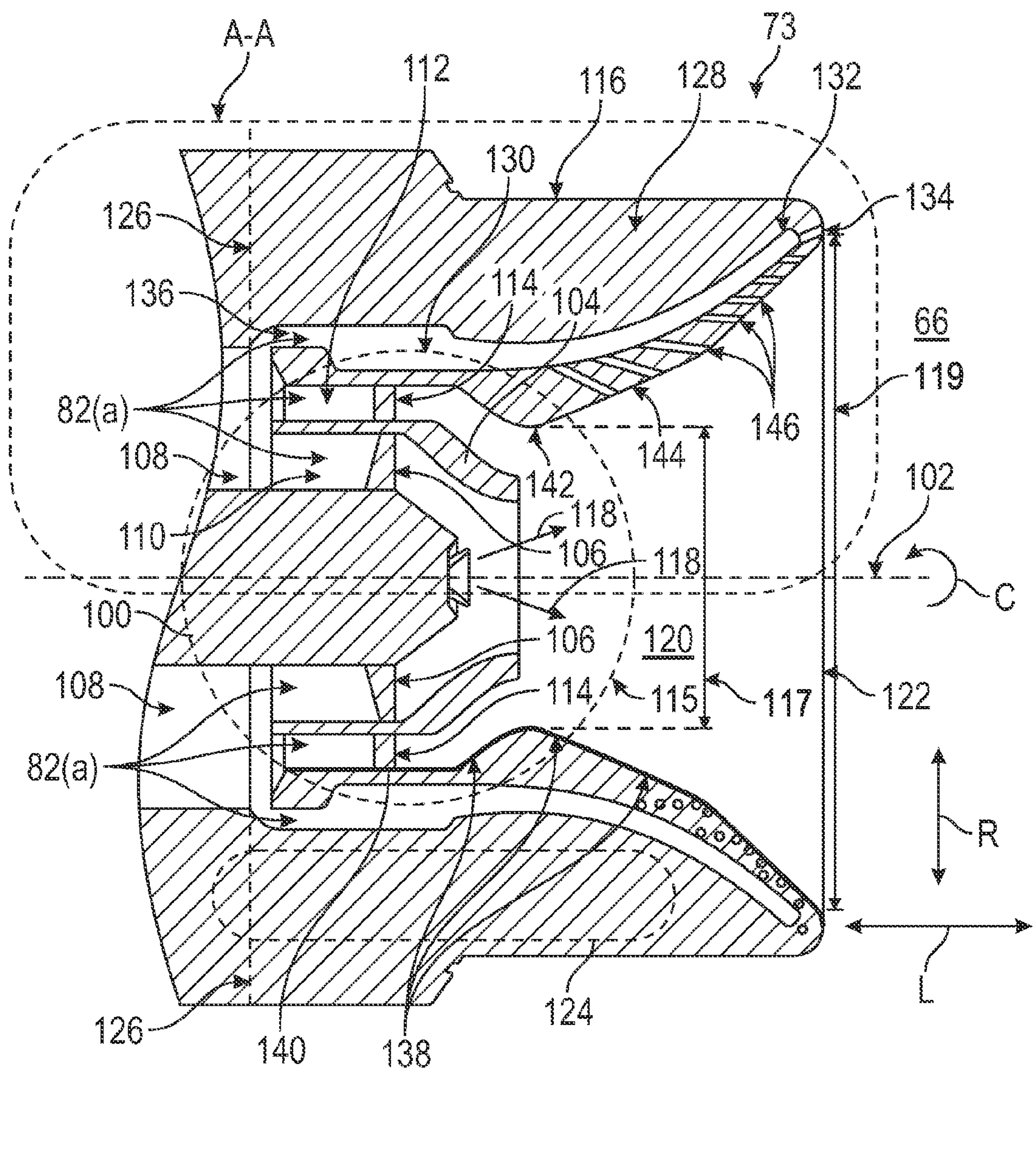
(57) **ABSTRACT**

A pilot fuel nozzle assembly includes a fuel nozzle, a swirler, and a vented pilot venturi. The vented pilot venturi has an annular wall with an oxidizer flow passage therein and a venturi expansion surface. The venturi expansion surface includes a plurality of conical surface segments extending circumferentially about the fuel nozzle centerline axis. At least two conical surface segments are joined together mechanically. One or more of the plurality of conical surface segments have a plurality of venturi oxidizer outlet ports extending through the venturi expansion surface. The plurality of venturi oxidizer outlet ports are circumferentially spaced about the fuel nozzle centerline axis.



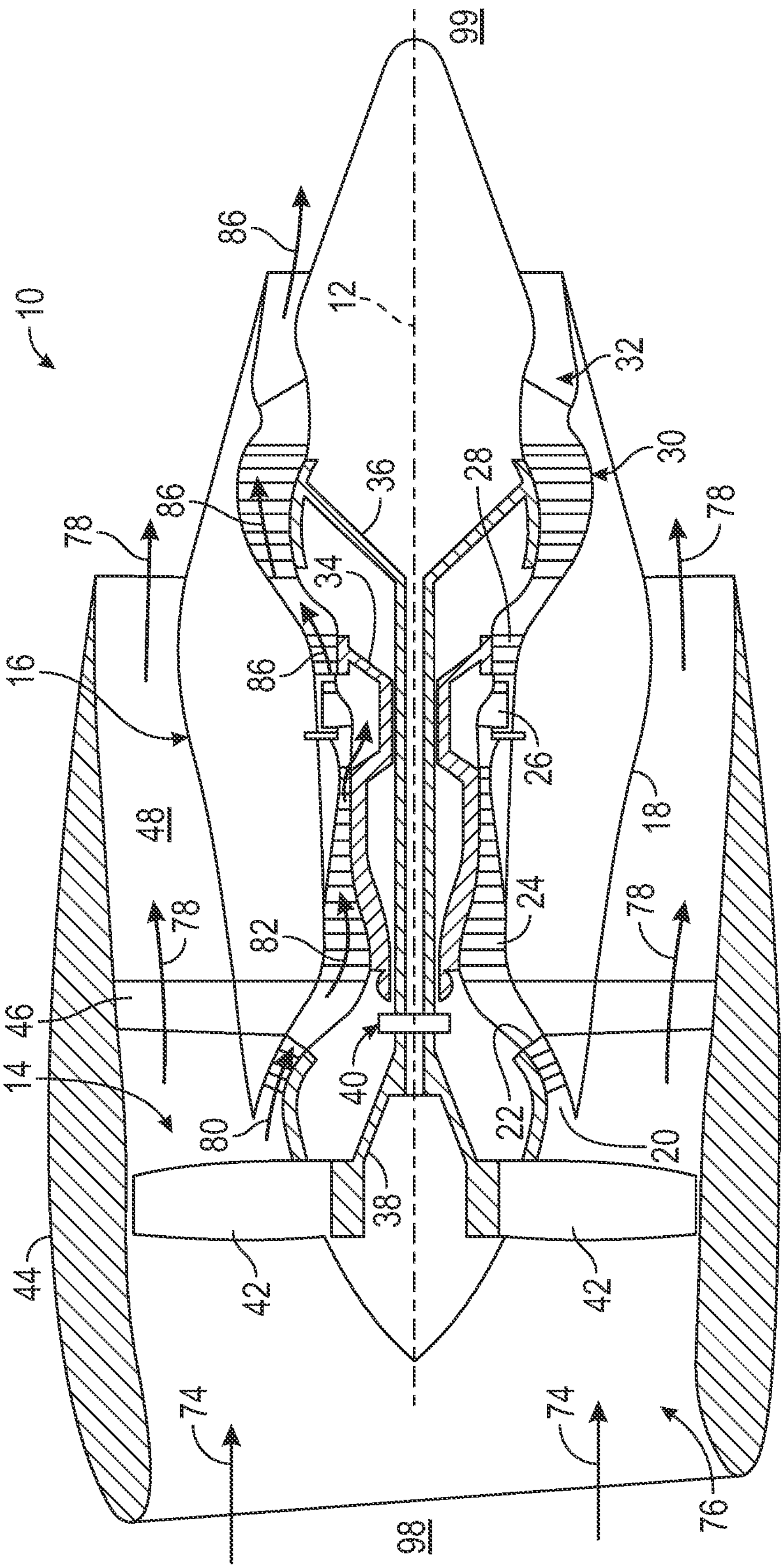

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FIG. 1

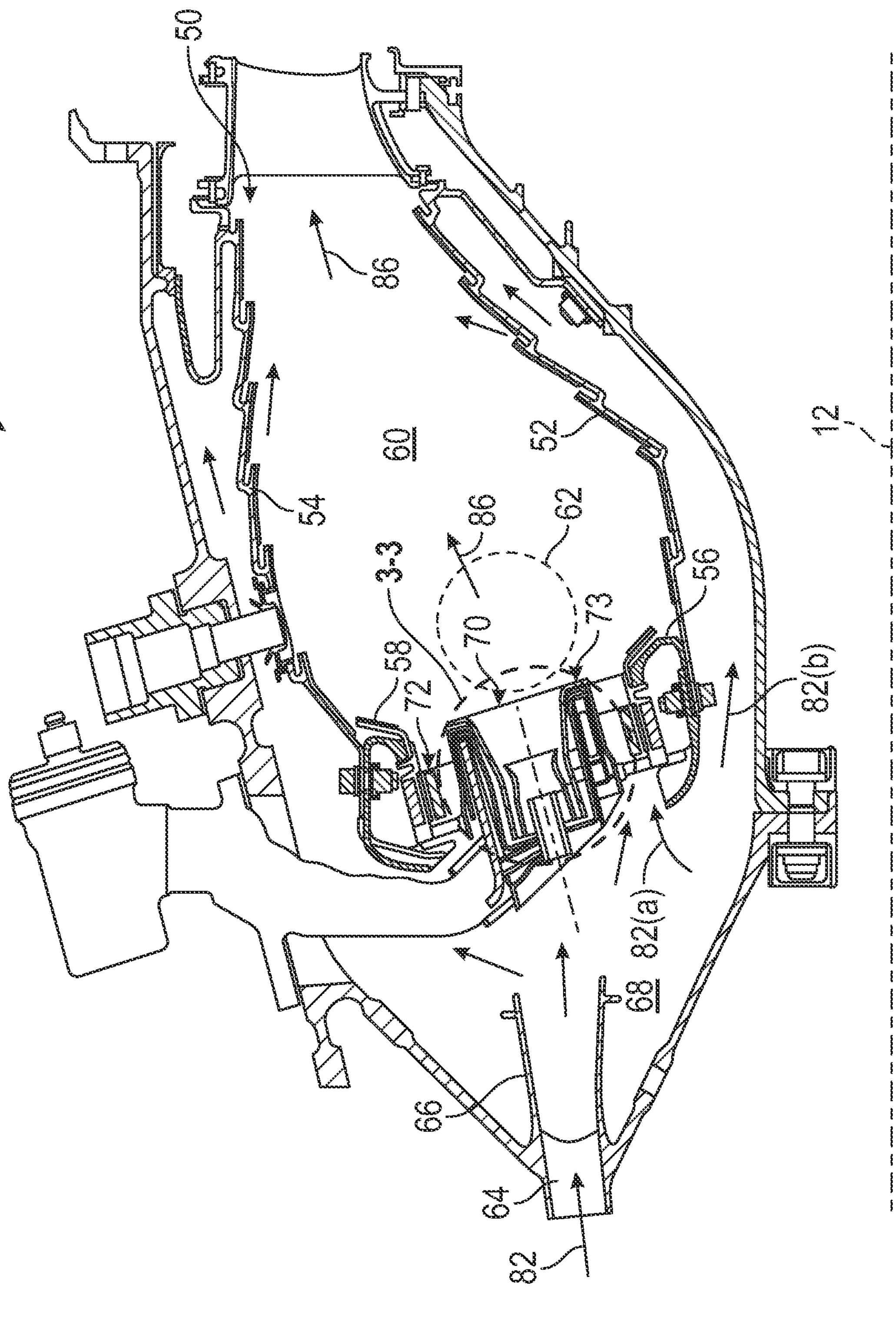

FIG. 2

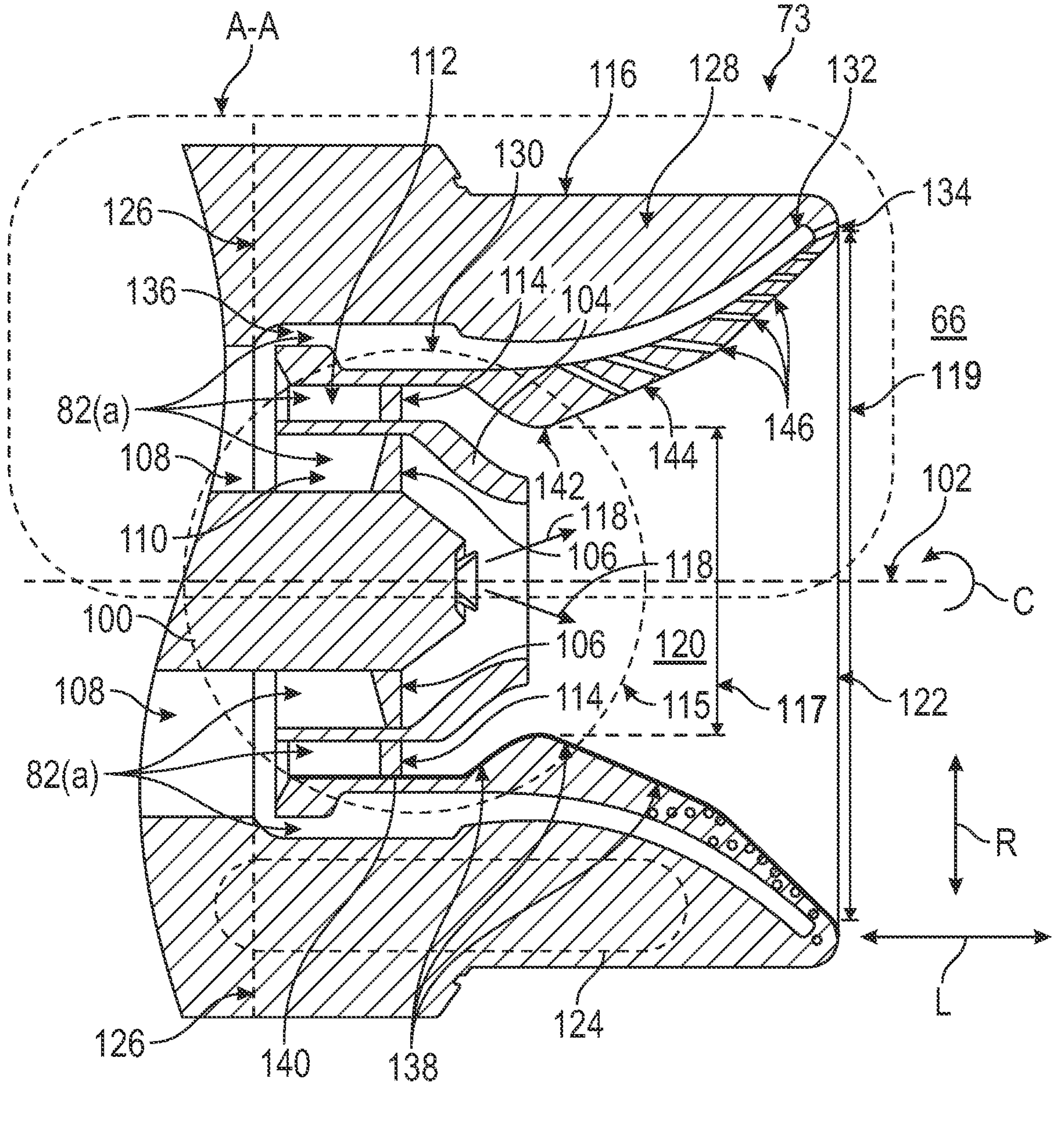
A-A
73
112
116
128
132
130
134
126
114
104
136
66
82(a)
119
146
108
144
142
102
110
118
106
C
118
100
120
106
108
114
115
117
122
82(a)
R
L
126
140
138
124

FIG. 3

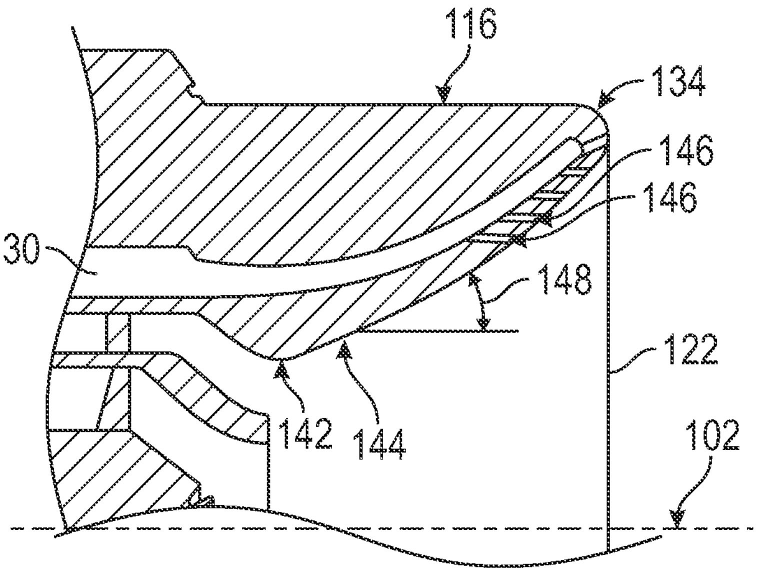
116
134
146
146
130
148
122
142
144
102

FIG. 4

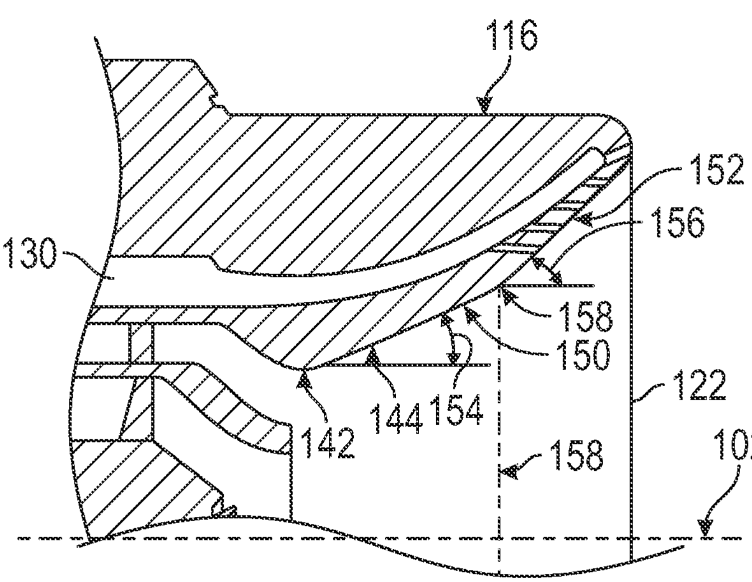
116
152
156
130
158
150
122
142
144
154
158
102

FIG. 5

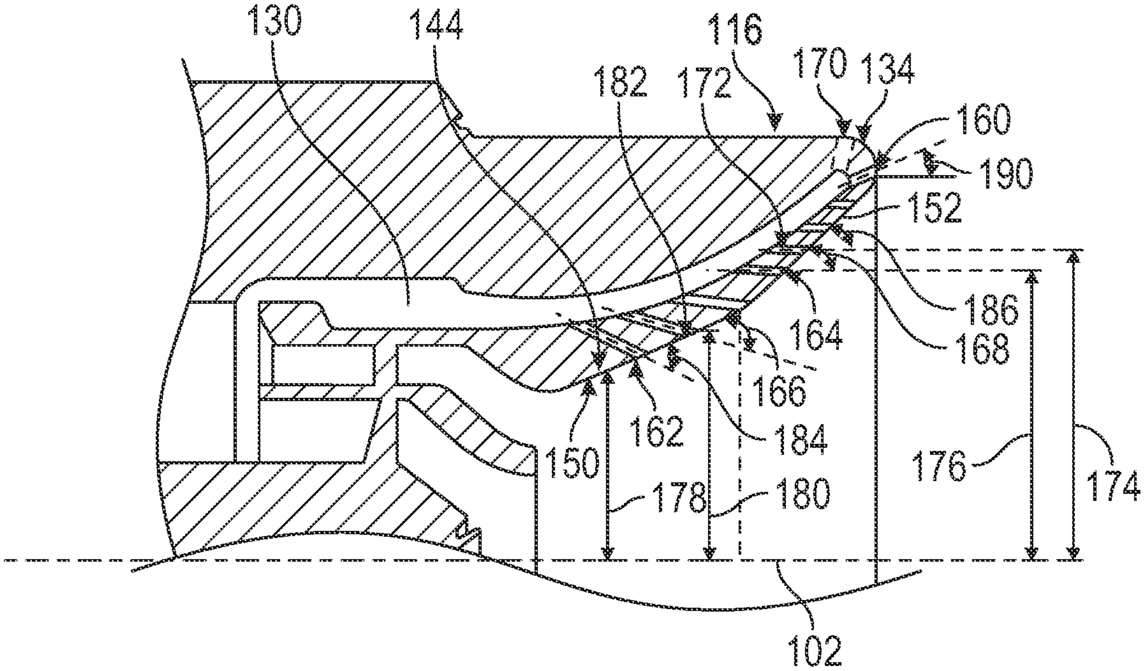
130
144
116
170
134
182
172
160
190
152
186
164
168
166
162
184
150
178
180
176
174
102

FIG. 6

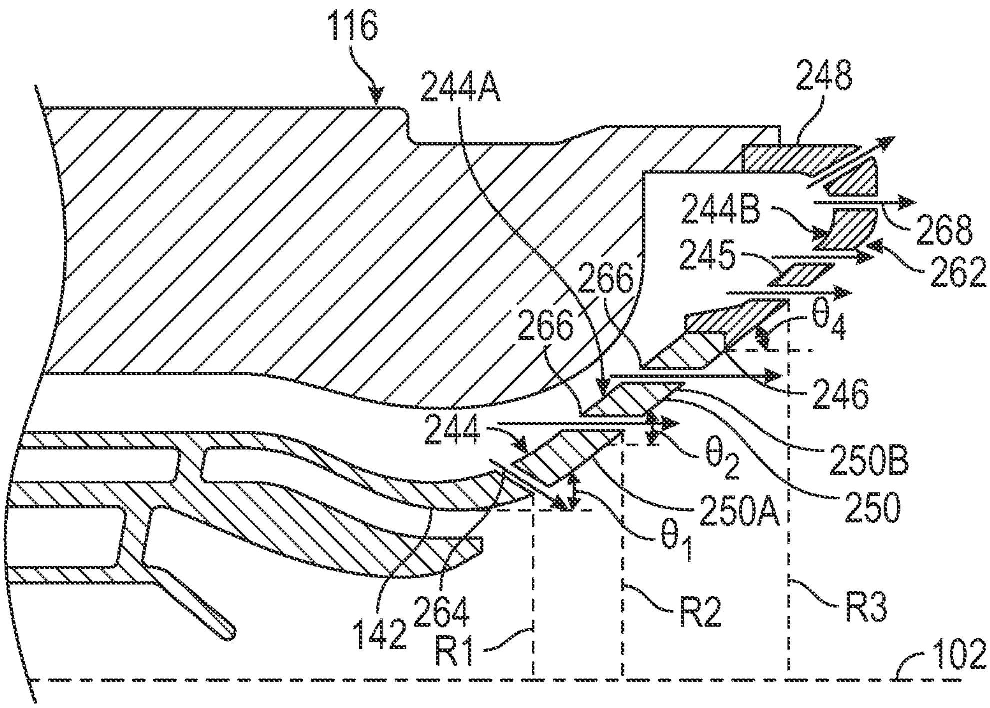
116
244A
248
244B
268
245
262
266
266
θ_4
246
244
θ_2
250B
250A
250
θ_1
142
264
R1
R2
R3
102

FIG. 7

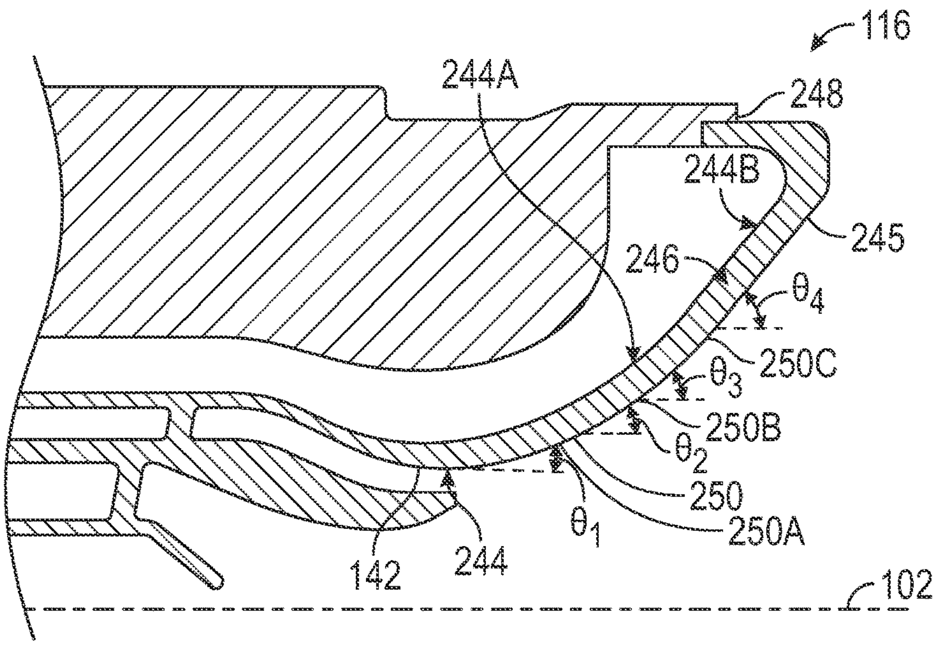
116
244A
248
244B
245
246
θ_4
250C
θ_3
250B
θ_2
250
250A
θ_1
142
244
102

FIG. 8

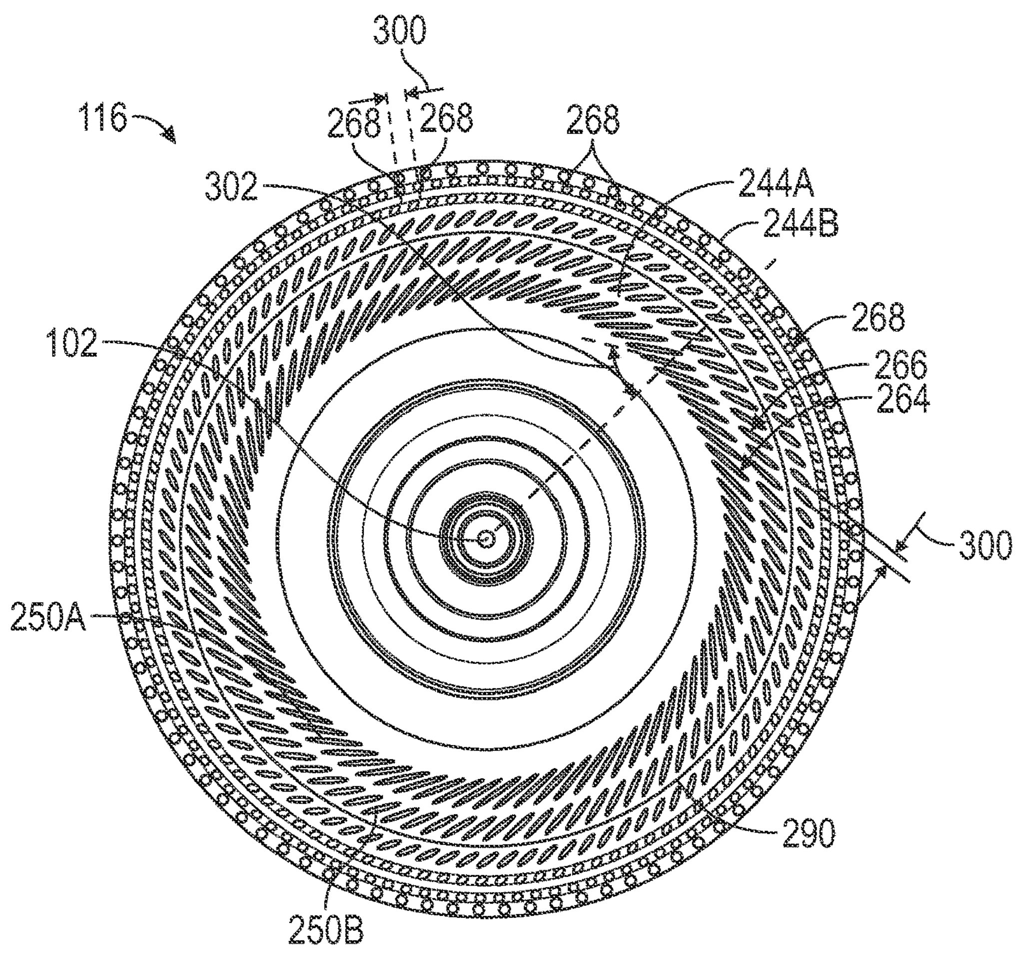
300
116
268
268
268
302
244A
244B
268
102
266
264
300
250A
290
250B

FIG. 9

PILOT FUEL NOZZLE ASSEMBLY WITH MULTI-ANGLED VENTURI

TECHNICAL FIELD

[0001] The present disclosure relates to a venturi of a pilot fuel nozzle assembly for a combustor of a gas turbine engine.

BACKGROUND

[0002] Some combustors in use are known as TAPS (Twin Annular Pre-mixing Swirler) combustors. TAPS combustors include a pre-mixer/swirler fuel nozzle assembly in which air and fuel are mixed. The TAPS pre-mixer/swirler fuel nozzle assembly includes both a pilot swirler and a main pre-mixer. The pilot swirler includes a venturi into which a fuel and air mixture is injected by a pilot fuel nozzle and surrounding air swirlers. The fuel and air mixture exits the venturi into a combustion chamber, where the fuel and air mixture is ignited and burned. At the outlet end of the venturi, a heat shield is generally provided to protect the fuel nozzle assembly. An aft surface of the heat shield facing the combustion chamber is subject to high temperatures from the burning fuel and air mixture exiting the venturi.

BRIEF DESCRIPTION OF THE DRAWINGS

[0003] The foregoing and other features and advantages will be apparent from the following, more particular, 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.

[0004] FIG. **1** is a schematic partial cross-sectional side view of an exemplary high by-pass turbofan jet engine, according to an embodiment of the present disclosure.

[0005] FIG. **2** is a partial cross-sectional side view of an exemplary combustion section, according to an embodiment of the present disclosure.

[0006] FIG. **3** is a partial cross-sectional side view of an exemplary pilot fuel nozzle assembly, according to an embodiment of the present disclosure.

[0007] FIG. **4** is a partial cross-sectional side of a portion of the fuel nozzle in FIG. **3** showing a venturi expansion surface of a vented pilot venturi of the pilot fuel nozzle assembly having a generally curved profile shape, according to an embodiment of the present disclosure.

[0008] FIG. **5** is a partial cross-sectional side detail view of a portion of the fuel nozzle in FIG. **3** showing a venturi expansion surface of the vented pilot venturi of the pilot fuel nozzle assembly that is a double-angled surface, according to another embodiment of the present disclosure.

[0009] FIG. **6** is a partial cross-sectional side detail view of a portion of the fuel nozzle in FIG. **3**, taken at detail A-A in FIG. **3** showing an arrangement of oxidizer outlet ports shown in FIG. **3**, according to another embodiment of the present disclosure.

[0010] FIG. **7** is a cross-sectional side detail view of a portion of a fuel nozzle showing a venturi expansion surface of a vented pilot venturi of the pilot fuel nozzle assembly, according to another embodiment of the present disclosure.

[0011] FIG. **8** is a cross-sectional side detail view of a portion of a fuel nozzle showing a venturi expansion surface of the vented pilot venturi of the pilot fuel nozzle assembly, according to yet another embodiment of the present disclosure.

[0012] FIG. **9** is an aft, forward-looking view of a pilot fuel nozzle assembly, according to an embodiment of the present disclosure.

DETAILED DESCRIPTION

[0013] 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, the following detailed description is exemplary and intended to provide further explanation without limiting the scope of the disclosure as claimed.

[0014] 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 present disclosure.

[0015] 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.

[0016] 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.

[0017] The singular forms "a," "an," and "the" include plural references unless the context clearly dictates otherwise.

[0018] As used herein, the terms "axial" and "axially" refer to directions and orientations that extend substantially parallel to a centerline of the turbine engine. Moreover, the terms "radial" and "radially" refer to directions and orientations that extend substantially perpendicular to the centerline of the turbine engine. In addition, as used herein, the terms "circumferential" and "circumferentially" refer to directions and orientations that extend arcuately about the centerline of the turbine engine.

[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 the 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] TAPS combustors are known to include a fuel nozzle assembly that has a pilot swirler that includes a splitter and a venturi. The pilot swirler ejects a fuel and air mixture into the venturi, which then flows into a combustion chamber, where the fuel and air mixture is ignited and burned. At the outlet end of the venturi, a heat shield is generally provided to protect the fuel nozzle assembly. The heat shield conventionally includes a flange in which cooling air is provided to the forward surface to cool the flange, and some of the cooling air is also provided to the aft surface.

[0022] The present disclosure discusses a fuel nozzle architecture with a vented venturi feature. More specifically, the present disclosure provides for a vented venturi as part of the pilot fuel nozzle assembly, where the arrangement of the vented venturi reduces high temperatures on the venturi surface. According to the present disclosure, the vented venturi has an air flow passage within a venturi wall and a plurality of rows of oxidizer outlet ports that extend through the wall of the venturi from the air flow passage to the inner surface of the venturi. The flow of an oxidizer within the air flow passage and through the oxidizer outlet ports provides cooling air to the inner surface of the venturi, and also to an outer end portion of the venturi. The oxidizer outlet ports are circumferentially spaced in a circumferential direction about a circumference of the venturi inner surface, and about the circumference of the outlet end of the venturi.

[0023] To address the vulnerability of the aft heat shield of the fuel nozzle assembly to oxidation that reduces the durability of the fuel nozzle assembly, the heat shield area is minimized and the shape and the design of the wall of the venturi is tailored to reduce wall gas temperature while retaining the overall flow structure. The venturi can be made of a single part or can be made of a number of segments that are joined together and arranged at various angles. The venturi has a plurality of holes. One or more segments of the venturi is provided with a row of cooling holes. One or more segments of the venturi may not have cooling holes.

[0024] Referring now to the drawings, FIG. **1** is a schematic partial cross-sectional side view of an exemplary high by-pass turbofan jet engine **10**, herein referred to as "engine **10**," according to an embodiment of the present disclosure. Although further described below with reference to a turbofan engine, the present disclosure is also applicable to turbomachinery in general, including turbojet, turboprop, and turboshaft gas turbine engines, including marine and industrial turbine engines and auxiliary power units. As shown in FIG. **1**, engine **10** has a longitudinal centerline axis **12** that extends therethrough from an upstream end **98** to a downstream end **99** for reference purposes. In general, engine **10** may include a fan assembly **14** and a turbo-engine **16** disposed downstream from the fan assembly **14**.

[0025] The turbo-engine **16** may generally include a substantially tubular outer casing **18** that defines an annular inlet **20**. The outer casing **18** encases or at least partially forms, in serial flow relationship, a compressor section having a booster or a low pressure (LP) compressor **22**, a high pressure (HP) compressor **24**, a combustion section **26**, a turbine section including a high pressure (HP) turbine **28**, a low pressure (LP) turbine **30**, and a jet exhaust nozzle section **32**. A high pressure (HP) rotor shaft **34** drivingly connects the HP turbine **28** to the HP compressor **24**. A low pressure (LP) rotor shaft **36** drivingly connects the LP turbine **30** to the LP compressor **22**. The LP rotor shaft **36** may also be connected to a fan shaft **38** of the fan assembly **14**. In particular embodiments, as shown in FIG. **1**, the LP rotor shaft **36** may be connected to the fan shaft **38** by way of a reduction gear **40**, such as in an indirect-drive or a geared-drive configuration. In other embodiments, although not illustrated, the engine **10** may further include an intermediate pressure (IP) compressor and a turbine rotatable with an intermediate pressure shaft (not shown).

[0026] As shown in FIG. **1**, the fan assembly **14** includes a plurality of fan blades **42** that are coupled to and that extend radially outwardly from the fan shaft **38**. An annular fan casing or a nacelle **44** circumferentially surrounds the fan assembly **14** and/or at least a portion of the turbo engine **16**. In one embodiment, the nacelle **44** may be supported relative to the turbo-engine **16** by a plurality of circumferentially spaced outlet guide vanes or struts **46**. Moreover, at least a portion of the nacelle **44** may extend over an outer portion of the turbo-engine **16** so as to define a bypass airflow passage **48** therebetween.

[0027] FIG. **2** is a partial cross-sectional side view of an exemplary combustion section **26** of the turbo-engine **16** shown in FIG. **1**, according to an embodiment of the present disclosure. The combustion section **26** in FIG. **2** is depicted as an exemplary Twin Annular Pre-mixing Swirler (TAPS) type combustor section. The present disclosure can be implemented in other combustor types, so the TAPS combustion section is merely exemplary. As shown in FIG. **2**, the combustion section **26** may generally include a combustor assembly **50** (e.g., an annular type combustor assembly) having an annular inner liner **52**, an annular outer liner **54**, a bulkhead wall **56**, and a dome assembly **58**, together defining a combustion chamber **60**. The combustion chamber **60** may more specifically define a region defining a primary combustion zone **62** at which initial chemical reaction of a fuel-oxidizer mixture and/or recirculation of combustion gases **86** may occur before flowing further downstream, where mixture and/or recirculation of combustion products and air may occur before flowing to the HP turbine **28** and the LP turbine **30**. The combustor assembly **50** also includes a pilot fuel nozzle assembly **70** that has a pilot fuel nozzle portion **73** and a main pre-mixer portion **72**. As will be described below, the pilot fuel nozzle portion **73** includes a pilot fuel nozzle and pilot air swirlers that produce a swirled pilot fuel and air mixture that is ejected into a pilot venturi, and then into the combustion chamber **60**, where the swirled pilot fuel and air mixture is burned to produce combustion gases **86**. The pilot fuel nozzle portion **73** generally operates at all operating conditions of the engine **10**. The main pre-mixer portion **72** has main fuel nozzles and main air swirlers that produce a main fuel and air mixture that is ejected into the combustion chamber **60**, where the main fuel and air mixture is also ignited and burned. The main pre-mixer portion **72** generally operates at higher power operations of the engine **10** (e.g., during a take-off phase or a cruising phase).

[0028] During operation of the engine **10**, as shown in FIGS. **1** and **2** collectively, a volume of air, as indicated schematically by arrows **74**, enters the engine **10** from upstream end **98** through an associated inlet **76** of the nacelle **44** and/or fan assembly **14**. As the inlet air **74** passes across the fan blades **42**, a portion of the air as indicated schematically by arrows **78** is directed or routed into the bypass airflow passage **48**, while another portion of the air, as indicated schematically by arrow **80**, is directed or routed into the LP compressor **22**. Air portion **80** is progressively compressed as it flows through the LP compressor **22** and

HP compressor **24** towards the combustion section **26**. As shown in FIG. **2**, the now compressed air, as indicated schematically by arrow **82**, flows across a compressor exit guide vane (CEGV) **64** and through a pre-diffuser **66** into a diffuser cavity **68** of the combustion section **26**.

[0029] The compressed air **82** pressurizes the diffuser cavity **68**. A first portion of the compressed air **82**, as indicated schematically by arrows **82**(*a*), flows from the diffuser cavity **68** into the pilot fuel nozzle assembly **70**, where the first portion of the compressed air **82** is premixed with fuel and ejected from pilot fuel nozzle assembly **70** and burned, thus generating combustion gases, as indicated schematically by arrows **86**, within the primary combustion zone **62** of the combustor assembly **50**. Typically, the LP compressor **22** and HP compressor **24** provide more compressed air to the diffuser cavity **84** than is needed for combustion. Therefore, a second portion of the compressed air **82**, as indicated schematically by arrows **82**(*b*), may be used for various purposes other than combustion.

[0030] Referring back to FIGS. **1** and **2** collectively, the combustion gases **86** generated in the combustion chamber **60** flow from the combustor assembly **50** into the HP turbine **28**, thus causing the HP rotor shaft **34** to rotate, thereby supporting operation of the HP compressor **24**. As shown in FIG. **1**, the combustion gases **86** are then routed through the LP turbine **30**, thus causing the LP rotor shaft **36** to rotate, thereby supporting operation of the LP compressor **22** and/or rotation of the fan shaft **38**. The combustion gases **86** are then exhausted through the jet exhaust nozzle section **32** of the turbo-engine **16** to provide propulsive at downstream end **99**.

[0031] FIG. **3** is a partial cross-sectional side view of an exemplary pilot fuel nozzle portion **73**, taken at detail **3-3** in FIG. **2**, according to an embodiment of the present disclosure. In FIG. **2**, the pilot fuel nozzle assembly **70** includes both the pilot fuel nozzle portion **73** and the main pre-mixer portion **72** attached thereto. The main pre-mixer portion **72** is not depicted in FIG. **3** and only the pilot fuel nozzle portion **73** is depicted therein. The pilot fuel nozzle portion **73** includes a pilot oxidizer inlet **108** and a pilot fuel nozzle **100** aligned along a longitudinal centerline axis **102** (venturi centerline axis). In FIG. **3**, the pilot fuel nozzle **100** is merely shown as a general representation of a pilot fuel nozzle and internal component parts, such as a fuel line, etc., that are known to be part of a pilot fuel nozzle in a TAPS-type pilot fuel nozzle, are not shown in FIG. **3**, for the sake of clarity.

[0032] The pilot fuel nozzle **100** is surrounded by a pilot splitter **104**, which is separated from the pilot fuel nozzle **100** by a pilot inner air passage **110**. Positioned within the pilot inner air passage **110** are inner air passage swirl vanes **106**. Surrounding the pilot splitter **104** is a vented pilot venturi **116**, which will be described in more detail in the following paragraphs. A pilot outer air passage **112** is formed between the pilot splitter **104** and the vented pilot venturi **116**, with outer air passage swirl vanes **114** disposed within the pilot outer air passage **112**. In operation, air **82**(*a*) enters the pilot oxidizer inlet **108**, and the flow of the air **82**(*a*) is separated by the pilot splitter **104** between the pilot inner air passage **110** and the pilot outer air passage **112**. A swirl is induced into the air **82**(*a*) flowing through the pilot inner air passage **110** and the pilot outer air passage **112** by the inner air passage swirl vanes **106** and the outer air passage swirl vanes **114**. Thus, the pilot splitter **104**, the inner air passage swirl vanes **106**, and the outer air passage swirl vanes **114**, function as a pilot oxidizer swirler **115** (indicated by a dotted circle in FIG. **3**). The swirled airflow mixes with fuel **118** (shown as arrows) ejected from the pilot fuel nozzle **100** in an open cavity portion **120** of the vented pilot venturi **116** to produce a swirled fuel and air mixture (not shown). The swirled fuel and air mixture is generally swirled circumferentially (C) about the open cavity portion **120** (i.e., swirled in a pilot swirl direction). The swirled fuel and air mixture within the open cavity portion **120** flows toward an outlet **122** of the vented pilot venturi **116**, where the swirled fuel and air mixture is ignited and burned within the combustion chamber **60**.

[0033] The vented pilot venturi **116** will now be described in more detail. The vented pilot venturi **116**, depicted in the drawings, omits some elements that may be included as part of the pilot fuel nozzle assembly **70** that are not necessary for an understanding of the vented pilot venturi **116**. In particular, while the cross section of FIG. **3** depicts a generally solid area around the outer portion of the venturi (e.g., area **124**), the area **124** may include elements such as a main fuel circuit and a main air flow passage that form a part of the main pre-mixer portion **72**. Such main fuel circuits and main air flow passages that form part of TAPS-type pre-mixer are known to those skilled in the art.

[0034] In FIG. **3**, the vented pilot venturi **116** is seen to be formed of a generally annular wall **128** that extends, in the longitudinal direction (L), along the longitudinal centerline axis **102** from an inlet end **126** to the outlet **122**. The vented pilot venturi **116** also extends circumferentially about the longitudinal centerline axis **102**. The annular wall **128** includes an oxidizer flow passage **130** within the annular wall **128**. The oxidizer flow passage **130** extends from the inlet end **126** of the vented pilot venturi **116** to an outlet end **132** of the vented pilot venturi **116** adjacent to the outlet **122**. That is, the oxidizer flow passage **130** terminates within the annular wall **128** prior to the outlet **122** near a rounded outlet tip portion **134**. The oxidizer flow passage **130** is in fluid communication with the pilot oxidizer inlet **108**. That is, the inlet end of the vented pilot venturi **116** includes a flow passage inlet **136** in which the air **82**(*a*) from the pilot oxidizer inlet **108** can enter the oxidizer flow passage **130**.

[0035] The annular wall **128** further defines an inner venturi surface **138** that extends from the inlet end **126** of the venturi to the outlet **122** of the venturi, and the inner venturi surface **138** defines, at least in part, the open cavity portion **120** through the vented pilot venturi **116**. The inner venturi surface **138** (depicted in bold for emphasis in FIG. **3**) extends circumferentially about the longitudinal centerline axis **102**. The inner venturi surface **138** can generally be seen to include an upstream portion **140** that forms an outer surface of the pilot outer air passage **112**, a throat area **142**, and a venturi expansion surface **144** downstream of the throat area **142**. Thus, the throat area **142** is disposed between the inlet end **126** of the vented pilot venturi **116** and the outlet **122** of the vented pilot venturi **116**. The throat area **142** can be seen to have a first diameter **117** less than a remaining portion of the venturi expansion surface **144** downstream of the throat area. That is, the venturi expansion surface **144** can be seen to be an expansion flow surface portion that expands in diameter as the inner venturi surface **138** progresses from the throat area **142** to the outlet **122**. Accordingly, the venturi expansion surface **144**, from the throat area **142** to the outlet **122** of the vented pilot venturi **116**, includes the first diameter **117** at the throat area and a second diameter **119** at the outlet **122**, where the second diameter **119** at the outlet **122** is greater than the first diameter **117** at the throat area **142**.

[0036] The annular wall **128** further defines a plurality of oxidizer outlet ports **146**. The oxidizer outlet ports **146** extend from the oxidizer flow passage **130** through the venturi expansion surface **144**. Thus, the oxidizer outlet ports **146** are holes that allow the air **82**(*a*) flowing through the oxidizer flow passage **130** in the annular wall to flow through the holes and into the open cavity portion **120**. The oxidizer outlet ports **146** will be described in more detail below, but the plurality of oxidizer outlet ports **146** can be circumferentially spaced in the circumferential direction (C) about the longitudinal centerline axis **102**.

[0037] FIG. **4** shows the venturi expansion surface **144** as having a generally curved profile shape extending from the throat area **142** to the outlet **122**. Alternatively, the venturi expansion surface **144** may be generally a conical-shaped portion (i.e., a conical-shaped surface) extending from the throat area **142** to the outlet **122**. A half-angle **148** of the venturi expansion surface **144** (e.g., a single conical-shaped venturi expansion surface) may have a range from fifteen degrees to forty degrees. Of course, the present disclosure is not limited to the foregoing range and other half-angles may be implemented instead.

[0038] FIG. **5** depicts a venturi expansion surface **144** that is a double-angled surface, according to an embodiment of the present disclosure. That is, a first conical surface segment **150** of the venturi expansion surface **144** may be a generally conical-shaped surface that extends from the throat area **142** to a breakpoint **158** along the first conical surface segment **150**. The first conical surface segment **150** may have a first conical half-angle **154**. A second conical surface segment **152** of the venturi expansion surface **144** may also be a generally conical-shaped surface that extends from the breakpoint **158** to the outlet **122**. The second conical surface segment **152** may have a second conical half-angle **156**. In one aspect, the first conical half-angle may range from fifteen to thirty degrees, while the second conical half-angle may range from thirty to forty degrees. In another aspect, the first conical half-angle may range from thirty to forty degrees, while the second conical half-angle may range from fifteen to thirty degrees. Of course, the present disclosure is not limited to the foregoing ranges and other half-angles could be implemented instead. In addition, the expansion surface of the present disclosure is not limited to only two conical surfaces, and other arrangements may be implemented instead. For example, the first conical surface segment **150** may be implemented to the breakpoint **158**, and a curved surface implemented downstream of the breakpoint. Alternatively, a curved surface may be implemented in place of the first conical surface segment **150** to the breakpoint **158**, and then the second conical surface segment **152** may be included from the breakpoint **158** to the outlet **122**. In addition, the present disclosure is not limited to dividing the venturi expansion surface **144** into two portions, but more than two portions could be implemented. For example, three conical surface portions could be implemented, where two separate breakpoints would be present between the conical surfaces.

[0039] FIG. **6** is an enlarged view taken at detail A-A in FIG. **3**, depicting an arrangement of the oxidizer outlet ports **146** shown in FIG. **3**. FIG. **6** shows the double-angled venturi expansion surface **144** having the arrangement of the oxidizer outlet ports **146**. Thus, the arrangement of the oxidizer outlet ports **146** with respect to the double-angled expansion surface will be described. The first conical surface segment **150** is seen to include oxidizer outlet ports **162** and **182** (corresponding to the oxidizer outlet ports **146** of FIG. **3**). Each of the oxidizer outlet ports **162** and **182** extends from the oxidizer flow passage **130** through the first conical surface segment **150**. In the vented venturi of the present disclosure, a plurality of the oxidizer outlet ports **162** are arranged about the circumference of the first conical surface segment **150**, and a plurality of the oxidizer outlet ports **182** are arranged about the circumference of the first conical surface segment **150**. The plurality of oxidizer outlet ports **162** arranged about the circumference of the first conical surface segment **150** may be referred to as a first row of oxidizer outlet ports, and the plurality of oxidizer outlet ports **182** arranged about the circumference of the first conical surface segment **150** can be referred to as a second row of oxidizer outlet ports. Collectively, the first row of oxidizer outlet ports **162** and the second row of oxidizer outlet ports **182** may be referred to as a first group of oxidizer outlet ports. In FIG. **6**, the first row of oxidizer outlet ports **162** can be arranged at a radial distance **178** from the longitudinal centerline axis **102**, while the second row of oxidizer outlet ports **182** can be seen to be arranged at a radial distance **180** different from the radial distance **178**.

[0040] The oxidizer outlet port **162** can be aligned at an angle **184** with respect to the first conical surface segment **150**, in the longitudinal direction (L). The oxidizer outlet port **182** can be aligned at an angle **166** with respect to the first conical surface segment **150**, in the longitudinal direction (L). The angles **184** and **166** may be the same, or they may be different from one another. In some aspects of the present disclosure, the angles **184** and **166** may have a range from twelve degrees to thirty degrees. Of course, the present disclosure is not limited to the foregoing range and the angles **184** and **166** may be arranged at other angles instead.

[0041] The second conical surface segment **152** is seen to include oxidizer outlet ports **164** and **172** (again, corresponding to the oxidizer outlet ports **146** of FIG. **3**). Each of the oxidizer outlet ports **164** and **172** extends from the oxidizer flow passage **130** through the second conical surface segment **152**. In the vented venturi of the present disclosure, a plurality of the oxidizer outlet ports **164** are arranged about the circumference of the second conical surface segment **152**, and a plurality of the oxidizer outlet ports **172** are arranged about the circumference of the second conical surface segment **152**. The plurality of oxidizer outlet ports **164** arranged about the circumference of the second conical surface segment **152** may be referred to as a third row of oxidizer outlet ports, and the plurality of oxidizer outlet ports **172** arranged about the circumference of the second conical surface segment **152** may be referred to as a fourth row of oxidizer outlet ports. Collectively, the third row of oxidizer outlet ports **164** and the fourth row of oxidizer outlet ports **172** may be referred to as a second group of oxidizer outlet ports. In FIG. **6**, the third row of oxidizer outlet ports **164** can be seen to be arranged at a radial distance **176** from the longitudinal centerline axis **102**, while the fourth row of oxidizer outlet ports **172** can be seen to be arranged at a radial distance **174** different from the radial distance **176**.

[0042] The oxidizer outlet port **164** can be aligned at an angle **168** with respect to the second conical surface segment

152, in the longitudinal direction (L). The oxidizer outlet port 172 is seen to be aligned at an angle 186 with respect to the second conical surface segment 152, in the longitudinal direction (L). The angles 168 and 186 may be the same, or may be different from one another. In some aspects of the present disclosure, the angles 168 and 186 may have a range from twelve degrees to thirty degrees. Of course, the present disclosure is not limited to the foregoing range and other angles may be implemented instead.

[0043] In FIG. 6, the rounded outlet tip portion 134 is seen to include a tip oxidizer outlet port 160. The tip oxidizer outlet port 160 extends from the oxidizer flow passage 130 through the rounded outlet tip portion 134. The tip oxidizer outlet port 160 is seen to be aligned at an angle 190 with respect to the longitudinal centerline axis 102, where the angle 190 extends radially outward and aft. Similar to the oxidizer outlet ports 164, 172, the angle 190 of the tip oxidizer outlet port may range from twelve to thirty degrees. Of course, the present disclosure is not limited to a tip oxidizer outlet port 160 at the rounded outlet tip portion 134, and, as shown in FIG. 6, a second tip oxidizer outlet port 170 may be included. Additional tip oxidizer outlet ports may also be included, depending on the cooling effect to be achieved. Of course, the present disclosure is not limited to the foregoing range and the angle 190 may be arranged at other angles instead.

[0044] FIGS. 7 and 8 show a venturi expansion surface 244 of the vented pilot venturi 116, according to another embodiment of the present disclosure. As shown in FIG. 7 and FIG. 8, the venturi expansion surface 244 has a first venturi expansion surface portion 244A and a second venturi expansion surface portion 244B. The first venturi expansion surface portion 244A extends from the throat area 142 to a breakpoint 246 (e.g., a joint point) along the venturi expansion surface 244. The second venturi expansion surface portion 244B extends from the breakpoint 246 to a tip portion 248 of the vented pilot venturi 116. The first venturi expansion surface portion 244A is mechanically joined (e.g., soldered, brazed, welded, or linked) to the second venturi expansion surface portion 244B at the breakpoint 246. For example, as shown in FIG. 7, the second venturi expansion surface portion 244B has a square edge at the breakpoint 246 for mating with a corresponding square edge of the first venturi expansion surface portion 244A. The tip portion 248 of the vented pilot venturi is located radially outward rom the longitudinal centerline axis 102 than the breakpoint 246. The first venturi expansion surface portion 244A is located at a first radial distance to the longitudinal centerline axis 102 and the second venturi expansion surface portion 244B is located at a second radial distance to the longitudinal centerline axis 102 greater than the first radial distance. The second venturi expansion surface portion 244B is formed from a single segment made from a unitary material that is selected to withstand combustion temperatures. The first venturi expansion surface portion 244A is formed from one or more surface segments. As shown in FIG. 7 and FIG. 8, the first venturi expansion surface portion 244A has a plurality of conical surface segments 250. The plurality of conical surface segments 250 form circumferential conical annular surfaces around the longitudinal centerline axis 102. FIG. 7 illustrates at least two of the plurality of conical surface segments 250 joined mechanically together in series. The term "in series" is used herein to mean that an end of one conical surface segment is connected to an adjacent or next conical surface segment, which, in turn, is connected to yet another adjacent or a next conical surface segment, etc. In an embodiment, the plurality of conical surface segments 250 are separate pieces joined together using any joining technique. An example of joining technique includes soldering, brazing, or welding the plurality of conical surface segments 250. Another example of joining technique includes adhesive bonding or chemical joining. In an embodiment, the plurality of conical surface segments 250 can be made from a same material or different materials. In another embodiment, at least two of the plurality of conical surface segments 250 can be made as a single unitary piece of a same material. In an embodiment, as will be described in further detail in the following paragraphs, the plurality of conical surface segments 250 are angled relative to each other and relative to the longitudinal centerline axis 102. Any number of conical surface segments 250 can be used. When the number of conical surface segments 250 is relatively high, for example, greater than ten, the first venturi expansion surface portion 244A can be said to be continuously varying in shape, and edges between the conical surface segments are smoothed.

[0045] FIG. 7 shows the first venturi expansion surface portion 244A having two surface segments, a first conical surface segment 250A and a second conical surface segment 250B. For example, the two conical surface segments 250A and 250B are discussed herein for the sake of explanation and illustration. However, any number of conical surface segments can be used. The first conical surface segment 250A defines a first conical half-angle θ_1 relative to the longitudinal centerline axis 102. The second conical surface segment 250B defines a second conical half-angle θ_2 relative to the longitudinal centerline axis 102. The first conical surface segment 250A and the second conical surface segment 250B are joined together such that an end of the first conical surface segment is connected to an end of the second conical surface segment.

[0046] FIG. 8 shows the first venturi expansion surface portion 244A having three surface segments, a first conical surface segment 250A, a second conical surface segment 250B, and a third conical surface segment 250C. The first conical surface segment 250A defines a first conical half-angle θ_1 relative to the longitudinal centerline axis 102. The second conical surface segment 250B defines a second conical half-angle θ_2 relative to the longitudinal centerline axis 102. The third conical surface segment 250C defines a third conical half-angle θ_3 relative to the longitudinal centerline axis 102. Although two and three surface segments are depicted in FIGS. 7 and 8, respectively, the first conical surface segment 250A can have one, two, or more surface segments. The first conical half-angle θ_1 can be between about 150 and 40°. The second conical half-angle θ_2 can be between about 20° and 40°. The third conical half-angle θ_3 can be between about 30° and 40°.

[0047] As shown in FIG. 7 and FIG. 8, the second venturi expansion surface portion 244B has a single conical surface segment 245 that forms a fourth conical half-angle θ_4 relative to the longitudinal centerline axis 102 and the single conical surface segment 245 is formed as a unitary piece (e.g., made of a single material) that is selected to withstand combustion temperatures. The fourth conical half-angle θ_4 can be between about 40° and 50°. However, the present disclosure is not limited to the foregoing ranges and other half-angles could be implemented instead. In an embodiment, as illustrated in FIG. **7**, the single conical surface segment **245** of the second venturi expansion surface portion **244**B is mechanically joined with the second conical surface segment **250**B of the first venturi expansion surface portion **244**A. For example, as shown in FIG. **7**, an edge of the single conical surface segment **245** is mechanically joined (mated, soldered, brazed, etc.) with an edge of the second conical surface segment **250**B. In an embodiment, as shown in FIG. **7**, the single conical surface segment **245** of the second venturi expansion surface portion **244**B has two ends. One edge is connected to the tip portion **248** of the vented pilot venturi **116** and an opposite edge is connected to an edge of the second conical surface segment **250**B. In an embodiment, as depicted in FIG. **7**, the single conical surface segment **245** of the second venturi expansion surface portion **244**B can have a polygonal cross-sectional shape that is selected to allow for an increased number of rows of oxidizer outlet ports or holes in the single conical surface segment **245** of the second venturi expansion surface portion **244**B. Although the second venturi expansion surface portion **244**B is shown having a single conical surface segment **245**, the second venturi expansion surface portion **244**B can also have a plurality of conical surface segments.

[0048] In an embodiment, the first conical half-angle θ_1 is less than the second conical half-angle θ_2, the second conical half-angle θ_2 is less than the third conical half-angle θ_3, and the third conical half-angle θ_3 is less than the fourth conical half-angle θ_4 (i.e., $\theta_1<\theta_2<\theta_3<\theta_4$). In another embodiment, the first conical half-angle θ_1 is less than the second conical half-angle θ_2, the second conical half-angle θ_2 is less than the third conical half-angle θ_3, and the third conical half-angle θ_3 is greater than the fourth conical half-angle θ_4 (i.e., $\theta_1<\theta_2<\theta_3>\theta_4$). In another embodiment, the first conical half-angle θ_1 is less than the second conical half-angle θ_2, the second conical half-angle θ_2 that is greater than the third conical half-angle θ_3, and the third conical half-angle θ_3 is less than the fourth conical half-angle θ_4 (i.e., $\theta_1<\theta_2>\theta_3<\theta_4$). In another embodiment, the first conical half-angle θ_1 is less than the second conical half-angle θ_2, the second conical half-angle θ_2 is greater than the third conical half-angle θ_3, and the third conical half-angle θ_3 is greater than the fourth conical half-angle θ_4 (i.e., $\theta_1<\theta_2<\theta_3>\theta_4$). The angles of the segments can be advantageously selected to have a desired flow structure or to control the boundary layer of gas flow that is conducive to have an optimal lower gas temperatures on the venturi surfaces. In addition, the angles can be selected so as to provide a desired pilot aero volume and recirculation zone for improved flame stability.

[0049] As shown in FIGS. **7** and **8**, the plurality of conical surface segments **250** are shown to be flat or linear. However, any one or more of the plurality of conical surface segments **250** can have a curved surface. For example, while the first conical surface segment **250**A may be flat, the second conical surface segment **250**B can have a curved surface.

[0050] As shown in FIG. **7**, the vented pilot venturi **116** has a plurality of oxidizer outlet ports **262** that are distributed on the venturi expansion surface **244**. The plurality of oxidizer outlet ports **262** can be provided on the first venturi expansion surface portion **244**A and/or the second venturi expansion surface portion **244**B of the venturi expansion surface **244**. Alternatively, in another embodiment, any of the first venturi expansion surface portion **244**A and/or the second venturi expansion surface **244**B may not be provided with oxidizer outlet ports. In an embodiment, at least one row of oxidizer outlet ports **262** is provided through each segment (e.g., first venturi expansion surface portion **244**A and the second venturi expansion surface portion **244**B), or that one or more segments (e.g., the first venturi expansion surface portion **244**A or the second venturi expansion surface portion **244**B) may not have oxidizer outlet ports **262**. The plurality of oxidizer outlet ports **262** provided on the venturi expansion surface **244** are not shown in FIG. **8** for clarity purposes only so as to more clearly show the first conical half-angle θ_1, the second conical half-angle θ_2, and the third conical half-angle θ_3 of the plurality of conical surface segments **250**, and the fourth conical half-angle θ_4 of the single conical surface segment **245** of the second venturi expansion surface portion **244**B.

[0051] In the embodiment shown in FIG. **7**, a first plurality of oxidizer outlet ports **264** are arranged about the circumference of the first conical surface segment **250**A, and a second plurality of oxidizer outlet ports **266** are arranged about the circumference of the second conical surface segment **250**B. The first plurality of oxidizer outlet ports **264**, arranged about the circumference of the first conical surface segment **250**A, may be referred to as a first row of oxidizer outlet ports, and the second plurality of oxidizer outlet ports **266**, arranged about the circumference of the second conical surface segment **250**B may be referred to as a second row of oxidizer outlet ports. The first plurality of oxidizer outlet ports **264** can be arranged at a radial distance R**1** from the longitudinal centerline axis **102**, while the second plurality of oxidizer outlet ports **266** can be arranged at a radial distance R**2** different from the radial distance R**1** (e.g., radial distance R**2** is greater than radial distance R**1**).

[0052] In an embodiment, a third plurality of oxidizer outlet ports **268** can be provided on the second venturi expansion surface portion **244**B. As shown in FIG. **7**, the third plurality of oxidizer outlet ports **268** are arranged about the circumference of the second venturi expansion surface portion **244**B as a plurality of third rows of oxidizer outlet ports. The third plurality of oxidizer outlet ports **268** can be arranged at a radial distance R**3** from the longitudinal centerline axis **102** that is greater than the radial distance R**2** and the radial distance R**1**. In an embodiment, a number of rows of the third plurality of oxidizer outlet ports **268** provided on the second venturi expansion surface portion **244**B (for example, four, as shown in FIG. **7**) is greater than a number of rows of the first plurality of oxidizer outlet ports **264** arranged about the circumference of the first conical surface segment **250**A (for example, one row, as shown in FIG. **7**) and a number of rows of the second plurality of oxidizer outlet ports **266** arranged about the circumference of the second conical surface segment **250**B (for example, two rows, as shown in FIG. **7**) as the second venturi expansion surface portion **244**B is subject to higher temperatures than the first conical surface segment **250**A. In an embodiment, because the venturi surface area increases with an increase in radius ($2 \cdot \pi \cdot r$) in an axial direction, the number of outlet ports is increased to achieve effective cooling of the venturi walls.

[0053] While the forgoing description was made with reference to one row of the first plurality of oxidizer outlet ports **264** about the circumference of the first conical surface segment **250**A, and two rows of the second plurality of oxidizer outlet ports **266** about the circumference of the second conical surface segment **250**B, for a total of three rows, the present disclosure is not limited to the three rows of the oxidizer outlet ports. More specifically, the number of rows of the oxidizer outlet ports may range from one row to ten rows of the oxidizer outlet ports. Similarly, the third plurality of oxidizer outlet ports **268** are arranged about the circumference of the second venturi expansion surface portion **244**B as a plurality of third rows of oxidizer outlet ports that can be two rows or more (for example, four rows, as depicted in FIG. **7**). The number of rows, however, is not limited to the foregoing and the number of rows can be selected based on a desired cooling effect to be achieved. In addition, one or more of the plurality of conical surface segments **250** (e.g., the first conical surface segment **250**A and/or the second conical surface segment **250**B) may also not have any oxidizer outlet ports.

[0054] FIG. **9** is an aft, forward-looking view of a pilot fuel nozzle assembly, according to an aspect of the present disclosure. As shown in FIG. **9**, the third plurality of oxidizer outlet ports **268** are spaced circumferentially about the circumference of the second venturi expansion surface portion **244**B. The circumferential spacing **300** of the third plurality of oxidizer outlet ports **268** may be based on the size of the third plurality of oxidizer outlet ports **268**. For example, the circumferential spacing **300** may be at least from twice an average diameter of the third plurality of oxidizer outlet ports **268**, or up to six times the average diameter of the third plurality of oxidizer outlet ports **268**. Here, the average diameter of the third plurality of oxidizer outlet ports **268** may be from 0.02 inches to 0.038 inches (or, roughly, 0.50 mm to 0.965 mm). The foregoing spacing and outlet port diameter size may also be applicable to the first plurality of oxidizer outlet ports **264** and the second plurality of oxidizer outlet ports **266**. The spacing between the first plurality of oxidizer outlet ports **264**, the second plurality of oxidizer outlet ports **266**, or the third plurality of oxidizer outlet ports **268** can be the same or different. The circumferential spacing **300** between the first plurality of oxidizer outlet ports **264**, between the second plurality of oxidizer outlet ports **266**, or between the third plurality of oxidizer outlet ports **268** can be at least twice the average diameter, or up to six times an average diameter of an oxidizer outlet port. Of course, the spacing and the size of the outlet ports are not limited to the foregoing, and other spacing or port sizes may be implemented instead, depending on the cooling effect to be achieved. An interface edge **290** between the first venturi expansion surface portion **244**A and the second venturi expansion surface portion **244**B is shown in FIG. **9** as a circumferential line. The interface edge **290** corresponds to the breakpoint **246** (e.g., a joint point) shown in FIG. **7**.

[0055] The first plurality of oxidizer outlet ports **264** that are arranged about the circumference of the first conical surface segment **250**A, and/or the second plurality of oxidizer outlet ports **266** that are arranged about the circumference of the second conical surface segment **250**B may also be arranged at an angle with respect to the circumferential direction (C) so as to provide a swirl of the air within the venturi. For example, the first plurality of oxidizer outlet ports **264** and/or the second plurality of oxidizer outlet ports **266** may be arranged at a co-swirl circumferential angle **302** so as to provide air flow in a co-swirl direction with respect to the pilot swirl direction. In one aspect, the co-swirl circumferential angle **302** may range from zero to sixty degrees. Of course, the co-swirl circumferential angle **302** is not limited to the foregoing range and other angles may be implemented instead, based on a desired swirl effect. In addition, while FIG. **9** depicts a single co-swirl circumferential angle **302** for the row of oxidizer outlet ports closest to the longitudinal centerline axis **102**, the oxidizer outlet ports arranged in rows outward of the inner-most row may also be angled in the co-swirl direction.

[0056] The vented venturi described above provides for additional cooling of the outlet end of the venturi. The air flowing through the outlet ports is used for cooling the venturi walls. Air flowing through the outlet ports is not intended for mixing with fuel-air mixture coming out from the pilot. The vented venturi can be made of a single part or can be made of a number of segments that are joined together and arranged at various segment angles. Each segment may have a plurality of oxidizer outlet ports. One or more segments of the venturi is provided with a row of cooling oxidizer outlet ports. One or more segments of the venturi may also not have cooling oxidizer outlet ports. In an embodiment, the vented venturi can have an overall greater divergence angle to generate a larger recirculation zone for pilot flame stability. A divergence angle corresponds to the overall increase in angle from an inlet end of the venturi to an exit end of the venturi. A higher venturi angle results in a pilot flame being in closer proximity to a main flame encircling the main flame and, thus, promoting flame stability at fuel staged modes. With a higher discharge angle of venturi, the fuel-air mixture emanating from the pilot (i.e., pilot fuel-air mixture) comes in greater proximity to the main fuel-air mixer. The pilot fuel-air mixture and the main fuel-air mixture interact closely and thus improves flame stability.

[0057] While the foregoing description relates generally to a gas turbine engine, the gas turbine engine may be implemented in various environments. For example, the engine may be implemented in an aircraft, but may also be implemented in non-aircraft applications such as power generating stations, marine applications, or oil and gas production applications. Thus, the present disclosure is not limited to use in aircraft.

[0058] Further aspects are provided by the subject matter of the following clauses.

[0059] A pilot fuel nozzle assembly for a combustor of a gas turbine engine, the pilot fuel nozzle assembly including a pilot fuel nozzle defined about a fuel nozzle centerline axis, a pilot oxidizer inlet disposed near the pilot fuel nozzle, a pilot splitter arranged radially outward of the pilot fuel nozzle to define a pilot inner air passage between the pilot fuel nozzle and the pilot splitter, the pilot inner air passage being in fluid communication with the pilot oxidizer inlet, and a vented pilot venturi disposed radially outward of the pilot splitter and in fluid communication with the pilot oxidizer inlet to define a pilot outer air passage between the pilot splitter and the vented pilot venturi, the vented pilot venturi including, an annular wall extending circumferentially about the fuel nozzle centerline axis, and extending in a longitudinal direction along the fuel nozzle centerline axis from an inlet end of the vented pilot venturi to an outlet of the vented pilot venturi, the annular wall including an oxidizer flow passage within the annular wall, the oxidizer flow passage extending from the inlet end of the vented pilot venturi to an outlet end of the vented pilot venturi adjacent to the outlet, and the oxidizer flow passage being in fluid communication with the pilot oxidizer inlet. The annular wall defines an inner venturi surface defining an open cavity through the vented pilot venturi, the inner venturi surface including a throat area disposed between the inlet end of the vented pilot venturi and the outlet of the vented pilot venturi, the throat area having a diameter less than a remaining portion of the inner venturi surface downstream of the throat area, and a venturi expansion surface disposed, in the longitudinal direction, from the throat area to the outlet of the vented pilot venturi, the venturi expansion surface having a first diameter at the throat area and a second diameter at the outlet, the second diameter being greater than the first diameter. The venturi expansion surface comprises a plurality of conical surface segments extending circumferentially about the fuel nozzle centerline axis, and at least two conical surface segments are joined together mechanically, and one or more of the plurality of conical surface segments have a plurality of venturi oxidizer outlet ports extending from the oxidizer flow passage through the venturi expansion surface, and the plurality of venturi oxidizer outlet ports are circumferentially spaced about the fuel nozzle centerline axis.

[0060] The pilot fuel nozzle assembly of the preceding clause, wherein the plurality of conical surface segments are separate segment pieces that are joined together.

[0061] The pilot fuel nozzle assembly of any preceding clause, wherein the plurality of conical surface segments are made from a same material.

[0062] The pilot fuel nozzle assembly of any preceding clause, wherein two or more of the plurality of conical surface segments are made as a single unitary piece of a same material.

[0063] The pilot fuel nozzle assembly of any preceding clause, wherein the plurality of conical surface segments are angled relative to each other and angled relative to the fuel nozzle centerline axis.

[0064] The Pilot Fuel Nozzle Assembly of any Preceding Clause, Wherein One or More of the Plurality of Conical Surface Segments are Flat or Curved.

[0065] The pilot fuel nozzle assembly of any preceding clause, wherein each of the plurality of the plurality of venturi oxidizer outlet ports being arranged at an angle extending radially outward with respect to the fuel nozzle centerline axis.

[0066] The pilot fuel nozzle assembly of any preceding clause, wherein the plurality of venturi oxidizer outlet ports are arranged in a row circumferentially about the venturi expansion surface, and wherein a spacing, circumferentially, between each of the venturi oxidizer outlet ports in the row being in a range from twice an average diameter of the venturi oxidizer outlet ports to six times the average diameter of the venturi oxidizer outlet ports.

[0067] The pilot fuel nozzle assembly of any preceding clause, wherein the plurality of venturi oxidizer outlet ports are arranged at a co-swirl circumferential angle with respect to a circumferential direction about the fuel nozzle centerline axis, the co-swirl circumferential angle being in a range from zero degrees to sixty degrees, and the co-swirl circumferential angle being in a same direction as a pilot swirl direction of a pilot oxidizer swirler.

[0068] The pilot fuel nozzle assembly of any preceding clause, wherein the venturi expansion surface comprises a first venturi expansion surface portion and a second venturi expansion surface portion, wherein the first venturi expansion surface portion comprises a first conical surface segment and a second conical surface segment, the second conical surface segment being connected to the first conical surface segment, and the second venturi expansion surface portion comprises a single conical surface segment, wherein a first plurality of oxidizer outlet ports are arranged about a circumference of the first conical surface segment as a first row of oxidizer outlet ports, and a second plurality of oxidizer outlet ports are arranged about the circumference of the second conical surface segment as a second row of oxidizer outlet ports, wherein a third plurality of oxidizer outlet ports are arranged on the single conical surface segment of the second venturi expansion surface portion as a plurality of third row of oxidizer outlet ports, and wherein a number of rows of the third plurality of oxidizer outlet ports being greater than a number of rows of the first plurality of oxidizer outlet ports and greater than a number of rows of the second plurality of oxidizer outlet ports.

[0069] The pilot fuel nozzle assembly of any preceding clause, wherein the venturi expansion surface has a first venturi expansion surface portion and a second venturi expansion surface portion, the first venturi expansion surface portion extends from the throat area to a breakpoint along the venturi expansion surface, and the second venturi expansion surface portion extends from the breakpoint to a tip portion of the vented pilot venturi.

[0070] The pilot fuel nozzle assembly of any preceding clause, wherein the second venturi expansion surface portion has a single conical surface segment formed from a unitary material that being selected to withstand combustion temperatures.

[0071] The pilot fuel nozzle assembly of any preceding clause, wherein the first venturi expansion surface portion comprises a first conical surface segment, a second conical surface segment, and a third conical surface segment, the third conical surface segment being connected to the second conical surface segment and the second conical surface segment being connected to the first conical surface segment.

[0072] The pilot fuel nozzle assembly of any preceding clause, wherein the first conical surface segment defines a first conical half-angle θ_1 relative to the fuel nozzle centerline axis, the second conical surface segment defines a second conical half-angle θ_2 relative to the fuel nozzle centerline axis, and the third conical surface segment defines a third conical half-angle θ_3 relative to the fuel nozzle centerline axis.

[0073] The pilot fuel nozzle assembly of any preceding clause, wherein the second venturi expansion surface portion has a single conical surface segment that defines a fourth conical half-angle θ_4 relative to the fuel nozzle centerline axis, wherein the first conical half-angle θ_1 being less than the second conical half-angle θ_2, the second conical half-angle θ_2 being less than the third conical half-angle θ_3, and the third conical half-angle θ_3 being less than the fourth conical half-angle θ_4.

[0074] The pilot fuel nozzle assembly of any preceding clause, wherein the second venturi expansion surface portion has a single conical surface segment that defines a fourth conical half-angle θ_4 relative to the fuel nozzle centerline axis, wherein the first conical half-angle θ_1 being less than the second conical half-angle θ_2, the second conical half-angle θ_2 being less than the third conical half-angle θ_3, and the third conical half-angle θ**3** being greater than the fourth conical half-angle θ_4.

[0075] The pilot fuel nozzle assembly of any preceding clause, wherein the second venturi expansion surface portion has a single conical surface segment that defines a fourth conical half-angle θ_4 relative to the fuel nozzle centerline axis, wherein the first conical half-angle θ_1 being less than the second conical half-angle θ_2, the second conical half-angle θ_2 being greater than the third conical half-angle θ_3, and the third conical half-angle θ_3 being less than the fourth conical half-angle θ_4.

[0076] The pilot fuel nozzle assembly of any preceding clause, wherein the second venturi expansion surface portion has a single conical surface segment that defines a fourth conical half-angle θ_4 relative to the fuel nozzle centerline axis, wherein the first conical half-angle θ_1 being less than the second conical half-angle θ_2, the second conical half-angle θ_2 being greater than the third conical half-angle θ_3, and the third conical half-angle θ_3 being greater than the fourth conical half-angle θ_4.

[0077] The pilot fuel nozzle assembly of any preceding clause, wherein the second venturi expansion surface portion has a single conical surface segment that defines a fourth conical half-angle θ_4 relative to the fuel nozzle centerline axis, wherein the first conical half-angle θ_1 being between 15° and 40°, the second conical half-angle θ_2 being between 20° and 40°, the third conical half-angle θ_3 being between 30° and 40°, and the fourth conical half-angle being between about 400 and 50°.

[0078] A turbine engine comprises a combustor having a pilot fuel nozzle assembly, the pilot fuel nozzle assembly including, a pilot fuel nozzle defined about a fuel nozzle centerline axis, a pilot oxidizer inlet disposed near the pilot fuel nozzle, a pilot splitter arranged radially outward of the pilot fuel nozzle to define a pilot inner air passage between the pilot fuel nozzle and the pilot splitter, the pilot inner air passage being in fluid communication with the pilot oxidizer inlet, and a vented pilot venturi disposed radially outward of the pilot splitter and in fluid communication with the pilot oxidizer inlet to define a pilot outer air passage between the pilot splitter and the vented pilot venturi, the vented pilot venturi including, an annular wall extending circumferentially about the fuel nozzle centerline axis, and extending in a longitudinal direction along the fuel nozzle centerline axis from an inlet end of the vented pilot venturi to an outlet of the vented pilot venturi, the annular wall including an oxidizer flow passage within the annular wall, the oxidizer flow passage extending from the inlet end of the vented pilot venturi to an outlet end of the vented pilot venturi adjacent to the outlet, and the oxidizer flow passage being in fluid communication with the pilot oxidizer inlet. The annular wall defines an inner venturi surface defining an open cavity through the vented pilot venturi, the inner venturi surface including, a throat area disposed between the inlet end of the vented pilot venturi and the outlet of the vented pilot venturi, the throat area having a diameter less than a remaining portion of the inner venturi surface downstream of the throat area, and a venturi expansion surface disposed, in the longitudinal direction, from the throat area to the outlet of the vented pilot venturi, the venturi expansion surface having a first diameter at the throat area and a second diameter at the outlet, the second diameter being greater than the first diameter. The venturi expansion surface comprises a plurality of conical surface segments extending circumferentially about the fuel nozzle centerline axis, and at least two conical surface segments are joined together mechanically, and one or more of the plurality of conical surface segments have a plurality of venturi oxidizer outlet ports extending from the oxidizer flow passage through the venturi expansion surface, and the plurality of venturi oxidizer outlet ports are circumferentially spaced about the fuel nozzle centerline axis.

[0079] Although the foregoing description is directed to the preferred embodiments of the present disclosure, other variations and modifications will be apparent to those skilled in the art and may be made without departing from the present disclosure. Moreover, features described in connection with one embodiment of the present disclosure may be used in conjunction with other embodiments, even if not explicitly stated above.

We claim:

1. A pilot fuel nozzle assembly for a combustor of a gas turbine engine, the pilot fuel nozzle assembly comprising:

a pilot fuel nozzle defined about a fuel nozzle centerline axis;

a pilot oxidizer inlet disposed near the pilot fuel nozzle;

a pilot splitter arranged radially outward of the pilot fuel nozzle to define a pilot inner air passage between the pilot fuel nozzle and the pilot splitter, the pilot inner air passage being in fluid communication with the pilot oxidizer inlet; and

a vented pilot venturi disposed radially outward of the pilot splitter and in fluid communication with the pilot oxidizer inlet to define a pilot outer air passage between the pilot splitter and the vented pilot venturi, the vented pilot venturi comprising, an annular wall extending circumferentially about the fuel nozzle centerline axis, and extending in a longitudinal direction along the fuel nozzle centerline axis from an inlet end of the vented pilot venturi to an outlet of the vented pilot venturi, the annular wall comprising an oxidizer flow passage within the annular wall, the oxidizer flow passage extending from the inlet end of the vented pilot venturi to an outlet end of the vented pilot venturi adjacent to the outlet, and the oxidizer flow passage being in fluid communication with the pilot oxidizer inlet,

wherein the annular wall defines an inner venturi surface defining an open cavity through the vented pilot venturi, the inner venturi surface comprising:

(a) a throat area disposed between the inlet end of the vented pilot venturi and the outlet of the vented pilot venturi, the throat area having a diameter less than a remaining portion of the inner venturi surface downstream of the throat area; and

(b) a venturi expansion surface disposed, in the longitudinal direction, from the throat area to the outlet of the vented pilot venturi, the venturi expansion surface having a first diameter at the throat area and a second diameter at the outlet, the second diameter being greater than the first diameter,

wherein the venturi expansion surface comprises a plurality of conical surface segments extending circumferentially about the fuel nozzle centerline axis, and at least two conical surface segments of the plurality of conical surface segments are joined together mechanically, and one or more of the plurality of conical surface segments have a plurality of venturi oxidizer outlet ports extending from the oxidizer flow passage through the venturi expansion surface, and the plurality of venturi oxidizer outlet ports are circumferentially spaced about the fuel nozzle centerline axis.

2. The pilot fuel nozzle assembly according to claim **1**, wherein the plurality of conical surface segments are separate segment pieces that are joined together.

3. The pilot fuel nozzle assembly according to claim **1**, wherein the plurality of conical surface segments are made from a same material.

4. The pilot fuel nozzle assembly according to claim **1**, wherein two or more of the plurality of conical surface segments are made as a single unitary piece of a same material.

5. The pilot fuel nozzle assembly according to claim **1**, wherein the plurality of conical surface segments are angled relative to each other and angled relative to the fuel nozzle centerline axis.

6. The pilot fuel nozzle assembly according to claim **1**, wherein one or more of the plurality of conical surface segments are flat or curved.

7. The pilot fuel nozzle assembly according to claim **1**, wherein each of the plurality of venturi oxidizer outlet ports is arranged at an angle extending radially outward with respect to the fuel nozzle centerline axis.

8. The pilot fuel nozzle assembly according to claim **1**, wherein the plurality of venturi oxidizer outlet ports are arranged in a row circumferentially about the venturi expansion surface, and wherein a spacing, circumferentially, between each of the venturi oxidizer outlet ports in the row is in a range from twice a diameter of the venturi oxidizer outlet ports to six times the diameter of the venturi oxidizer outlet ports.

9. The pilot fuel nozzle assembly according to claim **1**, wherein the plurality of venturi oxidizer outlet ports are arranged at a co-swirl circumferential angle with respect to a circumferential direction about the fuel nozzle centerline axis, the co-swirl circumferential angle being in a range from zero degrees to sixty degrees, and the co-swirl circumferential angle being in a same direction as a pilot swirl direction of a pilot oxidizer swirler.

10. The pilot fuel nozzle assembly according to claim **1**, wherein the venturi expansion surface comprises a first venturi expansion surface portion and a second venturi expansion surface portion, wherein the first venturi expansion surface portion comprises a first conical surface segment and a second conical surface segment, the second conical surface segment being connected to the first conical surface segment, and the second venturi expansion surface portion comprises a single conical surface segment,

wherein a first plurality of oxidizer outlet ports are arranged about a circumference of the first conical surface segment as a first row of oxidizer outlet ports, and a second plurality of oxidizer outlet ports are arranged about a circumference of the second conical surface segment as a second row of oxidizer outlet ports,

wherein a third plurality of oxidizer outlet ports are arranged on the single conical surface segment of the second venturi expansion surface portion as a plurality of third row of oxidizer outlet ports, and

wherein a number of rows of the third plurality of oxidizer outlet ports is greater than a number of rows of the first plurality of oxidizer outlet ports and greater than a number of rows of the second plurality of oxidizer outlet ports.

11. The pilot fuel nozzle assembly according to claim **1**, wherein the venturi expansion surface has a first venturi expansion surface portion and a second venturi expansion surface portion, the first venturi expansion surface portion extends from the throat area to a breakpoint along the venturi expansion surface, and the second venturi expansion surface portion extends from the breakpoint to a tip portion of the vented pilot venturi.

12. The pilot fuel nozzle assembly according to claim **11**, wherein the second venturi expansion surface portion has a single conical surface segment formed from a unitary material that is selected to withstand combustion temperatures.

13. The pilot fuel nozzle assembly according to claim **11**, wherein the first venturi expansion surface portion comprises a first conical surface segment, a second conical surface segment, and a third conical surface segment, the third conical surface segment being connected to the second conical surface segment and the second conical surface segment being connected to the first conical surface segment.

14. The pilot fuel nozzle assembly according to claim **13**, wherein the first conical surface segment defines a first conical half-angle θ_1 relative to the fuel nozzle centerline axis, the second conical surface segment defines a second conical half-angle θ_2 relative to the fuel nozzle centerline axis, and the third conical surface segment defines a third conical half-angle θ_3 relative to the fuel nozzle centerline axis.

15. The pilot fuel nozzle assembly according to claim **14**, wherein the second venturi expansion surface portion has a single conical surface segment that defines a fourth conical half-angle θ_4 relative to the fuel nozzle centerline axis, wherein the first conical half-angle θ_1 is less than the second conical half-angle θ_2, the second conical half-angle θ_2 is less than the third conical half-angle θ_3, and the third conical half-angle θ_3 is less than the fourth conical half-angle θ_4.

16. The pilot fuel nozzle assembly according to claim **14**, wherein the second venturi expansion surface portion has a single conical surface segment that defines a fourth conical half-angle θ_4 relative to the fuel nozzle centerline axis, wherein the first conical half-angle θ_1 is less than the second conical half-angle θ_2, the second conical half-angle θ_2 is less than the third conical half-angle θ_3, and the third conical half-angle θ_3 is greater than the fourth conical half-angle θ_4.

17. The pilot fuel nozzle assembly according to claim **14**, wherein the second venturi expansion surface portion has a single conical surface segment that defines a fourth conical half-angle θ_4 relative to the fuel nozzle centerline axis, wherein the first conical half-angle θ_1 is less than the second conical half-angle θ_2, the second conical half-angle θ_2 is greater than the third conical half-angle θ_3, and the third conical half-angle θ_3 is less than the fourth conical half-angle θ_4.

18. The pilot fuel nozzle assembly according to claim **14**, wherein the second venturi expansion surface portion has a single conical surface segment that defines a fourth conical half-angle θ_4 relative to the fuel nozzle centerline axis, wherein the first conical half-angle θ_1 is less than the second conical half-angle θ_2, the second conical half-angle θ_2 is greater than the third conical half-angle θ_3, and the third conical half-angle θ_3 is greater than the fourth conical half-angle θ_4.

19. The pilot fuel nozzle assembly according to claim **14**, wherein the second venturi expansion surface portion has a single conical surface segment that defines a fourth conical half-angle θ_4 relative to the fuel nozzle centerline axis, wherein the first conical half-angle θ_1 is between 15° and 40°, the second conical half-angle θ_2 is between 20° and 40°, the third conical half-angle θ_3 is between 30° and 40°, and the fourth conical half-angle θ_4 is between 400 and 500.

20. A turbine engine comprising:

a combustor having a pilot fuel nozzle assembly, the pilot fuel nozzle assembly comprising:

a pilot fuel nozzle defined about a fuel nozzle centerline axis;

a pilot oxidizer inlet disposed near the pilot fuel nozzle;

a pilot splitter arranged radially outward of the pilot fuel nozzle to define a pilot inner air passage between the pilot fuel nozzle and the pilot splitter, the pilot inner air passage being in fluid communication with the pilot oxidizer inlet; and

a vented pilot venturi disposed radially outward of the pilot splitter and in fluid communication with the pilot oxidizer inlet to define a pilot outer air passage between the pilot splitter and the vented pilot venturi, the vented pilot venturi comprising, an annular wall extending circumferentially about the fuel nozzle centerline axis, and extending in a longitudinal direction along the fuel nozzle centerline axis from an inlet end of the vented pilot venturi to an outlet of the vented pilot venturi, the annular wall comprising an oxidizer flow passage within the annular wall, the oxidizer flow passage extending from the inlet end of the vented pilot venturi to an outlet end of the vented pilot venturi adjacent to the outlet, and the oxidizer flow passage being in fluid communication with the pilot oxidizer inlet,

wherein the annular wall defines an inner venturi surface defining an open cavity through the vented pilot venturi, the inner venturi surface comprising:

(a) a throat area disposed between the inlet end of the vented pilot venturi and the outlet of the vented pilot venturi, the throat area having a diameter less than a remaining portion of the inner venturi surface downstream of the throat area; and

(b) a venturi expansion surface disposed, in the longitudinal direction, from the throat area to the outlet of the vented pilot venturi, the venturi expansion surface having a first diameter at the throat area and a second diameter at the outlet, the second diameter being greater than the first diameter,

wherein the venturi expansion surface comprises a plurality of conical surface segments extending circumferentially about the fuel nozzle centerline axis, and at least two conical surface segments are joined together mechanically, and one or more of the plurality of conical surface segments have a plurality of venturi oxidizer outlet ports extending from the oxidizer flow passage through the venturi expansion surface, and the plurality of venturi oxidizer outlet ports are circumferentially spaced about the fuel nozzle centerline axis.

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