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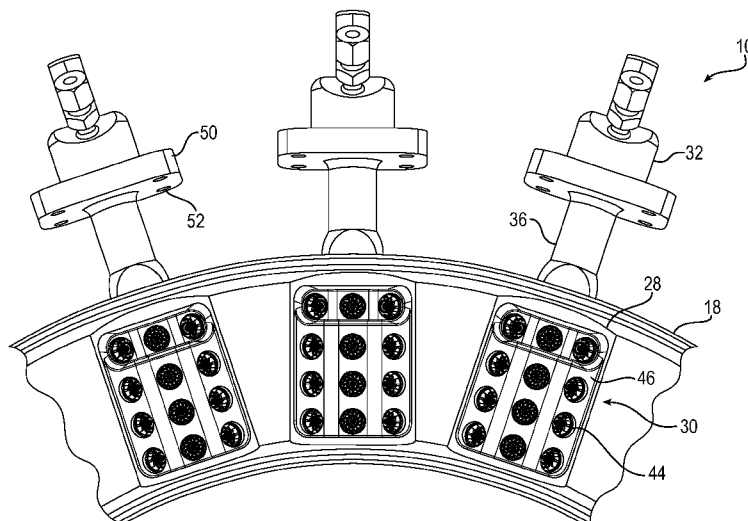


FIG. 1

(57) **Abstract:** An injector including a housing having a fluid channel for fluid and a plurality of injector modules fluidly connected to the fluid channel, where each injector module includes a spray cup having a plurality of radial air passages for directing air radially inwardly into the chamber, and a pressure swirl atomizer having a fluid passage for directing fluid in the axial direction and at least one air passage radially outwardly spaced from the fluid passage for directing air in the axial direction, wherein at least one of the injector modules is axially recessed relative to the other injector modules. By axially recessing at least one of the injector modules, a sheltered burning zone may be provided to enhance flame stability when injecting a mixture of air and fuel from the recessed module.

DIRECT INJECTION MULTIPOINT NOZZLE

Related Application Data

This application claims the benefit of U.S. Provisional Application No. 62/120,425
5 filed February 25, 2015, which is hereby incorporated herein by reference.

Field of Invention

The present invention relates generally to turbine engines, and more particularly to injectors for turbine engines having a plurality of direct injection multipoint nozzles.

Background

10 A turbine engine typically includes an outer casing extending radially from an air diffuser and a combustion chamber. The casing encloses a combustor for containment of burning fuel. The combustor includes a liner and a combustor dome, and an igniter is mounted to the casing and extends radially inwardly into the combustor for igniting fuel.

The turbine also typically includes one or more fuel injectors for directing fuel from a
15 manifold to the combustor. Fuel injectors also function to prepare the fuel for mixing with air prior to combustion. Each injector typically has an inlet fitting connected either directly or via tubing to the manifold, a tubular extension or stem connected at one end to the fitting, and one or more spray nozzles connected to the other end of the stem for directing the fuel into the combustion chambers. A fuel passage (e.g., a tube or cylindrical passage)
20 extends through the stem to supply the fuel from the inlet fitting to the nozzle. Appropriate valves and/or flow dividers can be provided to direct and control the flow of fuel through the nozzle. The fuel injectors are often placed in an evenly-spaced annular arrangement to dispense (spray) fuel in a uniform manner into the combustion chamber. Additional concentric and/or series combustion chambers each require their own arrangements of
25 nozzles that can be supported separately or on common stems. The fuel provided by the injectors is mixed with air and ignited, so that the expanding gases of combustion can, for example, move rapidly across and rotate turbine blades in a gas turbine engine to power an aircraft, or in other appropriate manners in other combustion applications.

Summary of Invention

30 The present invention provides an injector including a housing having a fluid channel for fluid and a plurality of injector modules fluidly connected to the fluid channel, where each injector module includes a spray cup having a plurality of radial air passages for directing air radially inwardly into the chamber, and a pressure swirl atomizer having a fluid passage for directing fluid in the axial direction and at least one air passage radially
35 outwardly spaced from the fluid passage for directing air in the axial direction, wherein at least one of the injector modules is axially recessed relative to the other injector modules.

By axially recessing at least one of the injector modules, a sheltered burning zone may be provided to enhance flame stability when injecting a mixture of air and fuel from the recessed module.

According to one aspect of the invention, an injector is provided that includes a
5 housing having a fluid channel for fluid and a plurality of injector modules fluidly connected to the fluid channel, each injector module including a spray cup having first and second axial ends, a chamber defined between the ends, and a plurality of radial air passages for directing air radially inwardly into the chamber, and a pressure swirl atomizer including a
10 body having a tip extending into the chamber, a fluid passage extending through the body for directing fluid in the axial direction into the chamber, and at least one air passage radially outwardly spaced from the fluid passage for directing air in the axial direction into the chamber, wherein at least one of the injector modules is axially recessed relative to the other injector modules.

The injector may further include a heatshield assembled to a downstream end of
15 each injector module, the heatshield including a body for protecting the injector modules from combustion heat and a plurality of apertures located so as to allow the fluid from a corresponding injector module to be dispensed from the spray cup,

The heatshield and recessed injector module may form a sheltered zone that shelters the fluid from the at least one axially recessed injector module from the other
20 injector modules.

The at least one axially recessed injector module may include at least two injector modules axially recessed relative to the other injector modules.

The at least two axially recessed injector modules may be angled relative to one another.

25 The plurality of injector modules may be spaced from one another in a direction perpendicular to the axial direction.

The plurality of apertures may be spaced along a length of the heatshield in a direction perpendicular to the axial direction.

30 The plurality of injector modules may be spaced from one another in the direction perpendicular to the axial direction along the length of the heatshield such that the injector modules float radially relative to an adjacent one of the plurality of injector modules.

The heatshield may include a plurality of segments each including a plurality of apertures spaced along a length of the segment in a direction perpendicular to the axial direction, wherein the segments are oriented in a side-by-side arrangement.

35 According to another aspect of the invention, an injector module includes a spray cup having first and second axial ends, a chamber defined between the ends, a plurality of

circumferentially spaced radial vanes extending in an axial direction from the first end to the second end, and a plurality of circumferentially spaced radial air passages formed between adjacent ones of the circumferentially spaced vanes for directing air radially inwardly into the chamber, and a pressure swirl atomizer including a body having a tip
5 extending into the chamber, a fluid passage extending through the body for directing fluid in the axial direction into the chamber through the tip, and at least one axial air passage radially outwardly spaced from the fluid passage for directing air in the axial direction into the chamber.

Each of the plurality of circumferentially spaced radial vanes may have a
10 longitudinal axis and is angled relative to the longitudinal axis.

The spray cup may further include an air blast shroud in the chamber that surrounds the at least one air passage and tip of the body.

The spray cup and pressure swirl atomizer may be monolithic.

The at least one axial air passage may include a plurality of circumferentially
15 spaced axial air passages.

The pressure swirl atomizer may include a plurality of circumferentially spaced axial vanes extending radially outwardly from the body, and wherein the air passages are formed between adjacent ones of the plurality of axial vanes.

Each of the plurality of axial vanes may have a longitudinal axis and is angled
20 relative to the longitudinal axis to swirl the air in the air passage.

The tip of the pressure swirl atomizer may be conical.

The spray cup may diverge from the first end to the second end.

The air from the radial air passages and the axial air passage may combine with the fluid from the fluid passage and is directed out of the spray cup through the second end.

25 The body may include an inner portion defining the fluid passage.

The body may include an outer portion surrounding the inner portion, and wherein a heatshield gap is provided between the inner and outer portions that heat shields the fluid in the fluid passage to isolate the fluid from air surrounding the outer portion.

The injector may further include a plug disposed within the inner portion, wherein
30 one or more swirl passages are defined between the plug and the inner portion to swirl the fluid flowing between the plug and the inner portion.

The one or more swirl passages is formed in the inner portion.

The injector may further include a radial strut between adjacent ones of the circumferentially spaced vanes for directing air in the respective radial air passage.

35 The injector may further include a plurality of radial struts, wherein the struts are respectively between adjacent ones of the circumferentially spaced vanes.

The radial strut may be a single radial strut extending around the spray cup.

The injector may further include a sheltering shroud extending axially from the second end of the spray cup.

According to another aspect of the invention, a plurality of injector modules are provided that are configured for fluid connection to a fluid channel, each injector module including a spray cup having first and second axial ends, a chamber defined between the ends, and a plurality of radial air passages for directing air radially inwardly into the chamber, and a pressure swirl atomizer including a body having a tip extending into the chamber, a fluid passage extending through the body for directing fluid in the axial direction into the chamber, and at least one air passage radially outwardly spaced from the fluid passage for directing air in the axial direction into the chamber, wherein at least one of the injector modules is axially recessed relative to the other injector modules so that fluid from the at least one axially recessed injector module is sheltered from the other injector modules.

The at least one axially recessed injector module may include at least two injector modules axially recessed relative to the other injector modules.

The at least two axially recessed injector modules may be angled relative to one another.

The plurality of injector modules may be spaced from one another in a direction perpendicular to the axial direction.

The foregoing and other features of the invention are hereinafter described in greater detail with reference to the accompanying drawings.

Brief Description of the Drawings

Fig. 1 is a front view of a portion of an exemplary combustor and a plurality of fuel injectors for a turbine engine.

Fig. 2 is a fragmentary cross-sectional view of a portion of the turbine engine illustrating a fuel injector in communication with the combustor.

Fig. 3 is a perspective view of the exemplary fuel injector according to the invention.

Fig. 4 is a front view of the exemplary fuel injector.

Fig. 5 is a fragmentary cross-sectional view of the exemplary fuel injector.

Fig. 6 is a side view of an exemplary injector module according to the invention.

Fig. 7 is a rear view of the exemplary injector module.

Fig. 8 is a front view of the exemplary injector module.

Fig. 9 is a cross-sectional view of the exemplary injector module.

Fig. 10 is a cross-sectional view of another exemplary injector module.

Fig. 11 is a cross-sectional view of still another exemplary injector module.

Fig. 12 is another cross-sectional view of the exemplary injector module of Fig. 11.
Fig. 13 is a fragmentary perspective view of another exemplary fuel injector.
Fig. 14 is another perspective view of the fuel injector of Fig. 13.
Fig. 15 is a fragmentary perspective view of yet another exemplary fuel injector.
5 Fig. 16 is a fragmentary perspective view of still another exemplary fuel injector.
Fig. 17 is a fragmentary perspective view of a further another exemplary fuel injector.
Fig. 18 is a fragmentary perspective view of another exemplary fuel injector.
Fig. 19 is a fragmentary perspective view of yet another exemplary fuel injector.
10 Fig. 20 is a fragmentary perspective view of still another exemplary fuel injector.
Fig. 21 is a fragmentary perspective view of a further another exemplary fuel injector.
Fig. 22 is a fragmentary perspective view of another exemplary fuel injector.

Detailed Description

15 The principles of the present invention have particular application to injectors for turbine engines and thus will be described below chiefly in this context. It will of course be appreciated, and also understood, that the principles of the invention may be useful in other applications where fluid, such as fuel, is mixed with air and distributed.

Referring now in detail to the drawings and initially to Figs. 1 and 2, a turbine
20 engine for an aircraft is illustrated generally at 10. The turbine engine 10 includes an outer casing 12 extending forwardly of an air diffuser 14. The casing 12 and diffuser 14 enclose a combustor 16 for containment of burning fuel. The combustor 16 includes at least one liner 18 configured to direct fuel into the combustor 16 and a combustor dome 20 at an upstream end of the liner 18. One or more igniters 22, such as a plurality of
25 circumferentially spaced igniters mounted to the casing 12 extend inwardly into the combustor 16 for igniting fuel.

A fuel injector, indicated generally at 30, is received within an aperture formed in the casing 12 and extends into the combustor 16. As shown in Fig. 1, a plurality of fuel injectors 30 are arranged circumferentially around the combustor 16. Each fuel injector 30
30 includes a valve housing 32 exterior of the casing 12, the valve housing having one or more ports 34 for receiving fluid, for example from a fuel manifold or line, and as shown multiple ports. A stem assembly 36 is supported by the valve housing 32 and includes an internal circuit fluidly connected to the one or more ports 34. The stem assembly 36 includes a housing 38, which serves as a heatshield and an injector body 40 (Fig. 3)
35 surrounded by the housing 38 that includes the internal circuit. Attached to the injector body 40 is a plurality of micro-mixing injector modules 44 (micro-mixing nozzles), each

injector module 44 having a fluid passage fluidly connected to the internal circuit. Attached to the injector modules 44 is a heatshield 46. The injector modules 44 and heatshields 46 extend into the combustor 16.

A plurality of radially-extending openings, such as rectangular openings, may be formed in the dome 20 in an evenly spaced-apart arrangement around the dome 20 and corresponding to locations of openings through which the stem 36 extends for the injector modules 44 and heatshields 46 to extend through. It will be appreciated that while a number of injectors 30 are shown in an evenly-spaced annular arrangement, the number and location, and spacing of the injectors 30 may vary depending upon the application.

The injector 30 may be assembled to the combustor dome 20 using a grommet 28 to allow the relative position of the injector 30 and opening in the dome 20 to float while restricting leakage of air flow around the injector 30 into the combustor 16. This allows for an accommodation of manufacturing tolerances and changes in geometry during operation at elevated temperatures and pressures, for example. The grommet 28 and injector 30 may be assembled with a relatively close fit, and the grommet 28 interfaces the dome 20 with a relatively loose fit within the injector opening in the dome 20, while bottoming on the face of the dome. The relatively loose fit within the dome opening allows the position of the grommet 28 to float in the plane of contact. The pressure drop across the liner or other mechanical means act to bottom the grommet 28 against the dome 20 to maintain an axial seal, restricting air flow around the grommet 28 and into the combustor. A close sliding fit between the injector 30 and grommet 28 restrict air flow between the injector and grommet and into the combustor 16. The axial position of the grommet is fixed against the dome 20 and the sliding fit with the injector 30 may allow the injector to float in the axial direction. Alternatively, the heatshields 46 may interface with the dome 20 to provide an axial seal that is loaded with a pressure drop during operation to control air leakage

The heatshield 46 may be attached to a downstream end of each injector module 44 for protecting the injector modules 44 from combustion heat, such as by restricting air flow around the modules. The heatshield 46 may include a thermal barrier coating and may optionally have a plurality of cooling holes extending therethrough for relatively cool air to flow through to provide effusion cooling on a surface of the heatshield 46, and a plurality of openings 48 (Fig. 5) located so as to allow the fluid from a corresponding injector module 44 to be dispensed into the combustor 16. The injector modules 44 may be spaced so that the injector modules 44 can float radially relative to adjacent injector modules 44 along the heatshield to relieve thermal stress, and can expand at high temperatures thereby filling the gaps between the injector modules. The injector modules may also float axially, for example by growing axially due to heat and moving the

heatshield accordingly, and may also float in a transverse direction, for example by growing in the transverse direction due to heat.

The fuel injectors 30 each include a flat, radially extending injector mount or flange 50 adapted to be fixed and sealed to the outer surface of the outer casing 12 with appropriate fasteners received in openings 52. The valve housing 32 is integral with or fixed to the flange 50, such as by brazing or welding, and projects outwardly from the flange 50, and the stem assembly 36 is integral or fixed to the flange 50, such as by brazing or welding, and projects inwardly from the flange 50.

Turning now to Figs. 3-5 and as noted above, surrounding the injector body 40 is the housing or stem heatshield 38 that is spaced from the injector body 40 to provide an air gap. Attached to the downstream end of the injector body 40 are the plurality of injector modules 44, which are arranged in zones. As shown, the injector modules 44 are arranged in a first end linear zone 60, a center linear zone 62, a second end linear zone 64, and a sheltered zone 66. The first end linear zone 60, the center linear zone 62, and the second end linear zone 64 may be arranged at an angle relative to one another, such as a forty-five degree angle, to reduce interaction of the spray exiting the injector modules in one of the adjacent zones and to enhance flame stability. The central injector module 44a in the sheltered zone 66 may be aligned with the injector modules 44 in the center linear zone 62, and the first and second end injector modules 44b and 44c in the sheltered zone 66 may be aligned with the first end and second end zones 60 and 64, respectively.

The injector modules 44 may also be arranged in a plurality of stages. For example, the central injector module 44a in the sheltered zone 66 may be a first pilot stage, the first and second end injector modules 44b and 44c in the sheltered zone 66 may be a second pilot stage, and the first end linear zone 60, the center linear zone 62, and the second end linear zone 64 may be a main stage. The injector modules 44a-44c are axially recessed relative to the injector modules in zones 60, 62, and 64 such that the first and second pilot stages are recessed relative to the main stage to form a sheltered burning zone. Sheltering the flame produced by modules 44a-44c enhances flame stability when injecting the fluid-air mixture from the modules 44a-44c and not the modules in zones 60, 62 and 64, and prevents premature interaction of the flame from the modules 44a-44c with air from modules in zones 60, 62 and 64. The first pilot stage is positioned relative to the igniter to allow for ignition of fuel flowing through the first pilot stage. During low power operation, the second pilot stage can be used in addition to the first pilot stage, and for full power operation the main stage is used in addition to the first and second pilot stages. It should be appreciated that other staging schemes may be provided such as each of zones

60, 62 and 64 being a separate stage or each row of injector modules being a separate stage.

As shown in Fig. 5, the injector body 40 includes at least one flow passage, and in the illustrated embodiment a plurality of flow passages for receiving fuel from respective flow passages (not shown) in the stem 36. The flow passages in the stem are connected to a staging valve, for example in the valve housing 32, which is connected to the port 34 to receive fluid from the port. A first flow passage 70 of the plurality of flow passages serves as a pilot circuit typically for use during the entire engine operation, such as idle, low flow, etc. to maximum power. The first flow passage 70 directs the fluid to the injector module 44a in the sheltered zone 66. A second flow passage (not shown) of the plurality of flow passages serves as a second pilot circuit for use during low power operation and a third flow passage 72 of the plurality of flow passages serves as a main circuit for full power operation. The third flow passage 72 directs the fluid to the injector modules in zones 60, 62 and 64. It will be appreciated that the injector 30 may include any suitable number of pilot and main circuits that flow to any suitable arrangement of the injector modules. The pilot fuel passage(s) in the injector body may be configured such that the pilot fuel cools the main fuel circuits. It will also be appreciated that the injector may include any suitable number of valve housings, such as a first valve housing for the pilot circuit and a second valve housing for the main circuits.

Turning now to Figs. 6-9, the micro-mixing injector module 44 will be discussed in detail. The micro-mixing injector module 44 includes a spray cup 80 and an atomizer 82, such as a pressure swirl atomizer that may be unitarily formed in any suitable manner, such as by an additive manufacturing process such as casting or selective laser melting. By forming a one-piece injector module 44 in this manner, the spray cup effective area is increased and the module is lighter in weight. The spray cup 80 may be a straight cup, a converging cup, or a diverging cup in a direction of flow as shown.

The spray cup 80 has first and second axial ends 84 and 86, a chamber 88 defined between the ends 84 and 86, a plurality of circumferentially spaced radial vanes 90 extending in an axial direction from the first end 84 to the second end 86, and a plurality of circumferentially spaced radial air passages 92 formed between adjacent ones of the circumferentially spaced vanes 88 for directing air radially inwardly into the chamber. The plurality of circumferentially spaced radial air passages 92 provide for mixing of the fluid and axial air with radial air along the length of the spray cups 80. The radial vanes may be straight or angled to provide radial air flow that is swirling or non-swirling, respectively. To swirl the radial air, each of the plurality of circumferentially spaced radial vanes 90 has a longitudinal axis and may be angled relative to the longitudinal axis such that the vane

twists along the axial direction. The spray cup 80 may also include an air blast shroud 94 in the chamber 88 that surrounds the axial air passage and fluid passage of the pressure swirl atomizer 82 for controlling the interaction of the air and fluid to provide a directed air wash for controlling atomization.

5 The pressure swirl atomizer 82 has a body 100 having a first end 102 attached to the injector body 40, such as by brazing, and a second end 104 that forms a tip 106 extending into the chamber 88, a fluid passage 108 extending through the body 100 for directing fluid, such as fuel, in the axial direction into the chamber 88 through the tip 106, and at least one air passage 110 for directing air in the axial direction into the chamber 88.

10 The pressure swirl atomizer 82 has at the second end 104 a plurality of circumferentially spaced axial vanes 112 extending radially outwardly from the body 100. The at least one air passage 110, and in the illustrated embodiment a plurality of circumferentially spaced axial air passages 110 are formed between adjacent ones of the plurality of axial vanes 112. The axial vanes may be straight or angled to provide axial air flow that is swirling or

15 non-swirling, respectively. To swirl the axial air, each of the plurality of axial vanes 112 has a longitudinal axis and is angled relative to the longitudinal axis such that the axial vane twists along the axial direction.

 The body 100 includes an outer wall portion 120 radially outwardly spaced from an inner wall portion 122 substantially along the length of the body 100 to provide a heatshield

20 gap 124 that shields the fluid in the fluid passage 108 by thermally isolating the fluid from air, such as the air flowing around the outer wall portion 120 towards the air passages 110. Disposed within the inner wall portion 122 is a plug 126, which is coupled to the inner wall portion 122 in any suitable manner, such as by brazing. The plug 126 includes one or

25 more slots along its outer surface that form with the inner wall portion 122 flow passages, which may be swirling or non-swirling, for the fluid in the flow passage 108 to flow through to the tip 106.

 The outer wall portion 120 and inner wall portion 122 may be conical and may converge, and the inner wall portion 122 converges to form the tip 106. Fluid flowing through the slots in the plug 126 converges towards the center of the inner wall portion 122

30 to the tip 106 and is directed into the center of the spray cup 80. The distance the tip 106, and thus the fluid exit of the pressure swirl atomizer 82, extends into the chamber 88 may be varied based on application such that the fluid exit is recessed, flush, or protruding relative to an exit plane of the radial vanes 90 to control spray dispersion and combustion performance.

35 The micro-mixing injector modules 44 maintain lean combustion at high power conditions and may be straight, converging or diverging in a direction of flow, such as

straight injector modules having non-swirling axial through flow, diverging modules having non-swirling radial inflow, etc. The micro-mixing injector modules may include swirling air inlets providing swirling through flow, non-swirling air inlets providing non-swirling through flow, or a combination thereof, where the swirl can be both clockwise or counter clockwise about the flow direction.

The micro-mixing injector modules may be fabricated in any suitable manner, such as by an additive manufacturing process such as casting, direct metal deposition, selective laser melting, etc., macrolamination, a combination thereof, etc. The heatshield may be fabricated in any suitable manner, such as by macrolamination, rapid prototyping, casting, machining, a combination thereof, etc., may be formed by one or more components, and/or may be integral with the micro-mixing injector modules.

During operation of the injector 30, fuel flows from a fuel supply through the valve housing and depending on engine operation, flows through one or more of the flow passages in the stem 36 to the pilot and/or main circuits. The fuel flows through the flow passages in the stem 36 into the respective flow passages, such as 70 and 72 and into the respective fluid passages 108 in the pressure swirl atomizers 82. The fuel is then directed axially out of the tips 106 into the chambers 88. At the same time, air surrounding the injector 30 flows through the air passages 110 and is directed axially into the chambers 88, and the air flows through the radial air passages 92 radially inwardly into the chambers 128. The air from the air passages 92 and 110 mixes with the fuel in the chambers 88 and is directed out of the spray cups 80 at the second ends 86, through the openings 48 in the heatshields 46, and into the combustor 16.

By providing axial air flow and axial fuel flow into the chambers 88, the injector modules 44 provide improved atomization, enhanced combustion and increased effective area. By providing radial and axial air flow and axial fuel flow into the chambers 88, the fuel may be mixed to prevent local hot spots that lead to high NO_x emissions, and a stable flame may be maintained without autoignition and flashback. The axial air flow also prevents recirculation zones from forming at the first end of the spray cups 80, provides improved atomization, and enhanced combustion.

Turning now to Fig. 10, an exemplary embodiment of the micro-mixing injector module is shown at 144. The injector module 144 is substantially the same as the above-referenced injector module 44, and consequently the same reference numerals but indexed by 100 are used to denote structures corresponding to similar structures in the injector module. In addition, the foregoing description of the injector module 44 is equally applicable to the injector module 144 except as noted below. Moreover, it will be appreciated upon reading and understanding the specification that aspects of the injector

modules may be substituted for one another or used in conjunction with one another where applicable.

The micro-mixing injector module 144 includes a spray cup 180 and a pressure swirl atomizer 182 that may be unitarily formed. The spray cup 180 has a chamber 188 defined between the ends, a plurality of circumferentially spaced radial vanes 190 extending in an axial direction from the first end to the second end, and a plurality of circumferentially spaced radial air passages 192 formed between adjacent ones of the circumferentially spaced vanes 190 for directing air radially inwardly into the chamber. The spray cup 180 also includes a radial strut 230 between adjacent ones of the circumferentially spaced vanes 190 for directing air in the respective radial air passage 192. The radial strut 230 may be a single radial strut extending circumferentially around the spray cup 180 or a plurality of radial struts provided respectively between adjacent ones of the circumferentially spaced vanes 190. In an embodiment, the single strut or the plurality of struts may include multiple struts axially spaced from one another along the length of the spray cup 180 to tailor the flow along the axis of the spray cup. The struts may provide structural support to the vanes 190, and the vanes may have leading edges with angled lead-ins to allow for formation using additive manufacturing without sacrificial support material, thereby eliminating post-built machining and undesirable surface conditions in supported areas.

The pressure swirl atomizer 182 has a body 200 having a tip 206 extending into the chamber 188, a fluid passage 208 extending through the body 200 for directing fluid in the axial direction into the chamber 188 through the tip 206, and at least one air passage 210 for directing air in the axial direction into the chamber 188. The pressure swirl atomizer 182 has at the second end a plurality of circumferentially spaced axial vanes 212 extending radially outwardly from the body 200. A plug (not shown) may be provided that is coupled to an inner wall portion of the body 200.

Turning now to Figs. 11 and 12, an exemplary embodiment of the micro-mixing injector module is shown at 244. The injector module 244 is substantially the same as the above-referenced injector module 44, and consequently the same reference numerals but indexed by 200 are used to denote structures corresponding to similar structures in the injector module. In addition, the foregoing description of the injector module 44 is equally applicable to the injector module 244 except as noted below. Moreover, it will be appreciated upon reading and understanding the specification that aspects of the injector modules may be substituted for one another or used in conjunction with one another where applicable.

The micro-mixing injector module 244 includes a spray cup 280 and a pressure swirl atomizer 282 that may be unitarily formed. The spray cup 280 has a chamber 288 defined between the ends, a plurality of circumferentially spaced radial vanes 290 extending in an axial direction from the first end to the second end, and a plurality of circumferentially spaced radial air passages 292 formed between adjacent ones of the circumferentially spaced vanes 290 for directing air radially inwardly into the chamber. The spray cup 180 also includes a sheltering shroud 332 extending from the second end of the spray cup 280 into which air could be metered through angled holes or slots to provide an air wash across the surface. The sheltering shroud 332 may be divergent extending from the second end, and the sheltering shroud 332 allows for the module 244 to be recessed relative to adjacent cups without having a recessed heatshield.

The pressure swirl atomizer 282 has a body 300 having a tip 306 extending into the chamber 288, a fluid passage 308 extending through the body 200 for directing fluid in the axial direction into the chamber 288 through the tip 306, and at least one air passage 310 for directing air in the axial direction into the chamber 288. The pressure swirl atomizer 282 has at the second end a plurality of circumferentially spaced axial vanes 312 extending radially outwardly from the body 300. The body 300 includes an outer wall portion 320 radially outwardly spaced from an inner wall portion 322 substantially along the length of the body 300. One or more swirl passages 334 are formed in the inner wall portion 322, and a plug 326 (Fig. 12) without slots may be provided that is coupled to the inner wall portion 322.

Turning now to Fig. 13, an exemplary embodiment of the fuel injector is shown at 430. The fuel injector 430 is substantially the same as the above-referenced fuel injector 30, and consequently the same reference numerals but indexed by 400 are used to denote structures corresponding to similar structures in the fuel injectors. In addition, the foregoing description of the fuel injector 30 is equally applicable to the fuel injector 430 except as noted below. Moreover, it will be appreciated upon reading and understanding the specification that aspects of the fuel injectors may be substituted for one another or used in conjunction with one another where applicable.

The fuel injector 430 includes a valve housing, a stem assembly that includes a housing 438 and injector body 440, and a plurality of micro-mixing injector modules 444. The injector modules 444 include a sheltering shroud 532 similar to the injector modules 244 that has a downstream portion that replaces the heatshield. The downstream portions of the shrouds 532 are interleaved with the downstream portion of adjacent modules 444 to allow the modules 444 to grow axially compared to adjacent modules due to thermal gradients across the injector 430. For example, the relative growth of a module 444

serving as a pilot compared to adjacent modules may open an air leakage gap to cool the front surfaces near the burning zone.

Turning now to Fig. 14, the fuel injector 430 may optionally include a heatshield 446. The exit of the modules 444 may provide a metered air flow to cool the backside of the heatshield 446 and supply effusion cooling holes.

Turning now to Figs. 15-18, exemplary embodiments of the fuel injector are shown at 630, 730, 830, and 930 respectively. The fuel injectors 630, 730, 830, and 930 are substantially the same as the above-referenced fuel injector 30, and consequently the same reference numerals but indexed by 600, 700, 800, and 900 respectively are used to denote structures corresponding to similar structures in the fuel injectors. In addition, the foregoing description of the fuel injector 30 is equally applicable to the fuel injectors 630, 730, 830, and 930 except as noted below. Moreover, it will be appreciated upon reading and understanding the specification that aspects of the fuel injectors may be substituted for one another or used in conjunction with one another where applicable.

As shown, multiple injection surfaces may be formed at varying orientations relative to the combustion volume downstream of the injector to form other burning zone arrangements. The injection surfaces can be designed to enhance flame stability when operating at lower power conditions and staged such that lean combustion is maintained at high power conditions. The injectors include fewer injector modules than the injector 30 and may be used, for example, in an application with reduced flow requirements, such as in small engines.

Referring now to Fig. 15, the injector modules 644 may be arranged in zones, such as a first zone 660 and a sheltered zone 666. To provide sheltering for multiple stages, such as an additional low power stage, such as a first pilot stage and a second pilot stage, multiple injector modules 644 are provided in the sheltered zone 666.

Referring now to Fig. 16, the injector modules 744 may be arranged in zones, such as a first zone 760 and a sheltered zone 766. To isolate the pilot stage(s) from the primary stage(s), the pilot injector modules 744 are provided in the zone 760 and the primary injector modules 744 are provided in the sheltered zone 766.

Referring now to Fig. 17, the injector modules 844 may be arranged in zones, such as a first zone 860 and a sheltered zone 866. The single injector module 844 in the sheltered zone 866 is sheltered relative to the other injector modules 844 to shelter the pilot reaction from un-fueled cups during ignition.

Referring now to Fig. 18, the injector modules 944 may be arranged in zones, such as a first zone 960, a second zone 962, and a sheltered zone 966. The single injector module 944 in the first zone 960 operates for the pilot stage and is surrounded by the

recessed injector modules 944 in the sheltered zone 966 that operate for a second stage. The injector modules 944 below the sheltered zone 966 in the zone 962 operate for a third stage. The second and third stages may be brought online in any order.

Turning now to Figs. 19-22, exemplary embodiments of the fuel injector are shown at 1030, 1130, 1230, and 1330 respectively. The fuel injectors 1030, 1130, 1230, and 1330 are substantially the same as the above-referenced fuel injector 30, and consequently the same reference numerals but indexed by 1000, 1100, 1200, and 1300 respectively are used to denote structures corresponding to similar structures in the fuel injectors. In addition, the foregoing description of the fuel injector 30 is equally applicable to the fuel injectors 1030, 1130, 1230, and 1330 except as noted below. Moreover, it will be appreciated upon reading and understanding the specification that aspects of the fuel injectors may be substituted for one another or used in conjunction with one another where applicable.

The injector modules 1030, 1130, 1230 and 1330 illustrate various numbers of zones and angular separation of the zones and stages. A sheltered zone may be provided in any of the injector modules 1030, 1130, 1230 and 1330 and/or angular separation between zones may be provided to isolate injector modules.

Referring now to Fig. 19, the injector modules 1044 may be arranged in zones separated in circumferential and radial directions relative to a centerline of the combustor, such as a sheltered zone 1066 and one or more main zones, such as five main zones 1060, 1061, 1062, 1063, and 1064. The number of zones and angular separation may be used for highly resolved control of distribution injection points.

Similarly, referring to Fig. 20, the injector modules 1144 may be arranged in zones separated in circumferential and radial directions relative to a centerline of the combustor, such as six zones 1160, 1161, 1162, 1163, 1164, and 1165. The number of zones and angular separation may be used for highly resolved control of distribution injection points.

Referring now to Fig. 21, the injector modules 1244 may be arranged in zones, such as a sheltered zone 1266, a first zone 1260 on a front of the injector, and second and third zones 1262 and 1264 perpendicular to the first zone. When the injector is used in an annular combustor, the arrangement controls the interaction between adjacent injectors.

Referring now to Fig. 22, the injector modules 1344 may be arranged in zones separated in circumferential and radial directions relative to a centerline of the combustor and oriented with radial and circumferential inclination, such as zones 1360, 1361, 1362, 1363, 1364, 1365, and 1366. The injector 1330 may be used in a combustor with a round interface.

Although the invention has been shown and described with respect to a certain embodiment or embodiments, it is obvious that equivalent alterations and modifications will occur to others skilled in the art upon the reading and understanding of this specification and the annexed drawings. In particular regard to the various functions performed by the
5 above described elements (components, assemblies, devices, compositions, etc.), the terms (including a reference to a "means") used to describe such elements are intended to correspond, unless otherwise indicated, to any element which performs the specified function of the described element (i.e., that is functionally equivalent), even though not structurally equivalent to the disclosed structure which performs the function in the herein
10 illustrated exemplary embodiment or embodiments of the invention. In addition, while a particular feature of the invention may have been described above with respect to only one or more of several illustrated embodiments, such feature may be combined with one or more other features of the other embodiments, as may be desired and advantageous for any given or particular application.

Claims

1 1. An injector including:
2 a housing having a fluid channel for fluid; and
3 a plurality of injector modules fluidly connected to the fluid channel, each injector
4 module including:
5 a spray cup having first and second axial ends, a chamber defined between
6 the ends, and a plurality of radial air passages for directing air radially inwardly into
7 the chamber; and
8 an atomizer including a body having a tip extending into the chamber, a fluid
9 passage extending through the body for directing fluid in the axial direction into the
10 chamber, and at least one air passage radially outwardly spaced from the fluid
11 passage for directing air in the axial direction into the chamber,
12 wherein at least one of the injector modules is axially recessed relative to the other
13 injector modules.

1 2. The injector according to claim 1, further including a heatshield assembled
2 to a downstream end of each injector module, the heatshield including a body for protecting
3 the injector modules from combustion heat and a plurality of apertures located so as to
4 allow the fluid from a corresponding injector module to be dispensed from the spray cup,
5 the heatshield and recessed injector module optionally forming a sheltered zone that
6 shelters the fluid from the at least one axially recessed injector module from the other
7 injector modules, the heatshield preferably including a plurality of segments each including
8 a plurality of apertures spaced along a length of the segment in a direction perpendicular to
9 the axial direction, with the segments preferably being oriented in a side-by-side
10 arrangement.

1 3. The injector according to any preceding claim, wherein the at least one
2 axially recessed injector module includes at least two injector modules axially recessed
3 relative to the other injector modules, the at least two axially recessed injector modules
4 preferably being angled relative to one another, and/or preferably spaced from one another
5 in a direction perpendicular to the axial direction, and/or preferably spaced along a length
6 of the heatshield in a direction perpendicular to the axial direction, and/or preferably
7 spaced from one another in the direction perpendicular to the axial direction along the
8 length of the heatshield such that the injector modules float radially relative to an adjacent
9 one of the plurality of injector modules.

1 4. The injector according to any preceding claim, wherein each spray cup
2 preferably is monolithic with the atomizer, and includes a plurality of circumferentially
3 spaced radial vanes extending in the axial direction from the first end to the second end,
4 and wherein the plurality of radial air passages are formed between adjacent ones of the
5 plurality of circumferentially spaced radial vanes, and each of the plurality of
6 circumferentially spaced radial vanes preferably has a longitudinal axis and is angled
7 relative to the longitudinal axis, and the spray cup preferably includes an air blast shroud in
8 the chamber that surrounds the at least one air passage and tip of the body.

1 5. The injector according to any preceding claim, wherein the at least one air
2 passage includes a plurality of circumferentially spaced air passages, and preferably the
3 atomizer includes a plurality of circumferentially spaced axial vanes extending radially
4 outwardly from the body, and wherein the air passages preferably are formed between
5 adjacent ones of the plurality of axial vanes, and preferably each of the plurality of axial
6 vanes has a longitudinal axis and is angled relative to the longitudinal axis to swirl the air in
7 the air passage.

1 6. The injector according to any preceding claim, wherein body includes an
2 inner portion defining the fluid passage and a plug disposed within the inner portion,
3 wherein one or more swirl passages are defined between the plug and the inner portion to
4 swirl the fluid flowing between the plug and the inner portion, the one or more swirl
5 passages preferably being formed in the inner portion.

1 7. The injector according to any preceding claim, further including at least one
2 and preferably a plurality of radial struts between adjacent ones of the circumferentially
3 spaced vanes for directing air in the respective radial air passage, wherein the struts
4 preferably are respectively between adjacent ones of the circumferentially spaced vanes,
5 or where the radial strut is a single radial strut extending around the spray cup.

1 8. An injector module including:
2 a spray cup having first and second axial ends, a chamber defined between the
3 ends, a plurality of circumferentially spaced radial vanes extending in an axial direction
4 from the first end to the second end, and a plurality of circumferentially spaced radial air
5 passages formed between adjacent ones of the circumferentially spaced vanes for
6 directing air radially inwardly into the chamber; and

7 a pressure swirl atomizer including a body having a tip extending into the chamber,
8 a fluid passage extending through the body for directing fluid in the axial direction into the
9 chamber through the tip, and at least one axial air passage radially outwardly spaced from
10 the fluid passage for directing air in the axial direction into the chamber.

1 9. The injector or injector module according to claim 8, wherein each of the
2 plurality of circumferentially spaced radial vanes has a longitudinal axis and is angled
3 relative to the longitudinal axis, and the spray cup preferably includes an air blast shroud in
4 the chamber that surrounds the at least one air passage and tip of the body, and wherein
5 the spray cup and pressure swirl atomizer preferably are monolithic.

1 10. The injector or injector module according to any preceding claim, wherein
2 the at least one axial air passage includes a plurality of circumferentially spaced axial air
3 passages, and wherein the pressure swirl atomizer preferably includes a plurality of
4 circumferentially spaced axial vanes extending radially outwardly from the body, and
5 wherein the air passages preferably are formed between adjacent ones of the plurality of
6 axial vanes.

1 11. The injector or injector module according to claim 9 or 10, wherein each of
2 the plurality of axial vanes has a longitudinal axis and is angled relative to the longitudinal
3 axis to swirl the air in the air passage.

1 12. The injector or injector module according to any preceding claim, wherein
2 the tip of the pressure swirl atomizer is conical, or wherein the spray cup diverges from the
3 first end to the second end.

1 13. The injector or injector module according to any preceding claim, wherein
2 the air from the radial air passages and the axial air passage combines with the fluid from
3 the fluid passage and is directed out of the spray cup through the second end.

1 14. The injector or injector module according to any preceding claim, wherein
2 the body includes an inner portion defining the fluid passage, the body preferably including
3 an outer portion surrounding the inner portion, and wherein a heatshield gap preferably is
4 provided between the inner and outer portions that heat shields the fluid in the fluid
5 passage to isolate the fluid from air surrounding the outer portion, and preferably a plug is
6 disposed within the inner portion, and wherein one or more swirl passages preferably are

7 defined between the plug and the inner portion to swirl the fluid flowing between the plug
8 and the inner portion, and the one or more swirl passages preferably is formed in the inner
9 portion.

1 15. The injector or injector module according to any preceding claim, further
2 including a radial strut between adjacent ones of the circumferentially spaced vanes for
3 directing air in the respective radial air passage, or a plurality of radial struts, wherein the
4 struts are respectively between adjacent ones of the circumferentially spaced vanes, or the
5 radial strut is a single radial strut extending around the spray cup.

1 16. The injector or injector according to any preceding claim, further including a
2 sheltering shroud extending axially from the second end of the spray cup.

1 17. A plurality of injector modules according to any of claims 8-16, wherein the
2 plurality of injector modules are spaced from one another in a direction perpendicular to the
3 axial direction such that the injector modules float radially relative to an adjacent one of the
4 plurality of injector modules.

1 18. A plurality of injector modules configured for fluid connection to a fluid
2 channel, each injector module including:

3 a spray cup having first and second axial ends, a chamber defined between the
4 ends, and a plurality of radial air passages for directing air radially inwardly into the
5 chamber; and

6 a pressure swirl atomizer including a body having a tip extending into the chamber,
7 a fluid passage extending through the body for directing fluid in the axial direction into the
8 chamber, and at least one air passage radially outwardly spaced from the fluid passage for
9 directing air in the axial direction into the chamber,

10 wherein at least one of the injector modules is axially recessed relative to the other
11 injector modules so that fluid from the at least one axially recessed injector module is
12 sheltered from the other injector modules.

1 19. The injector modules according to claim 18, wherein the at least one axially
2 recessed injector module includes at least two injector modules axially recessed relative to
3 the other injector modules, and the at least two axially recessed injector modules
4 preferably are angled relative to one another, and/or the plurality of injector modules
5 preferably are spaced from one another in a direction perpendicular to the axial direction.

1

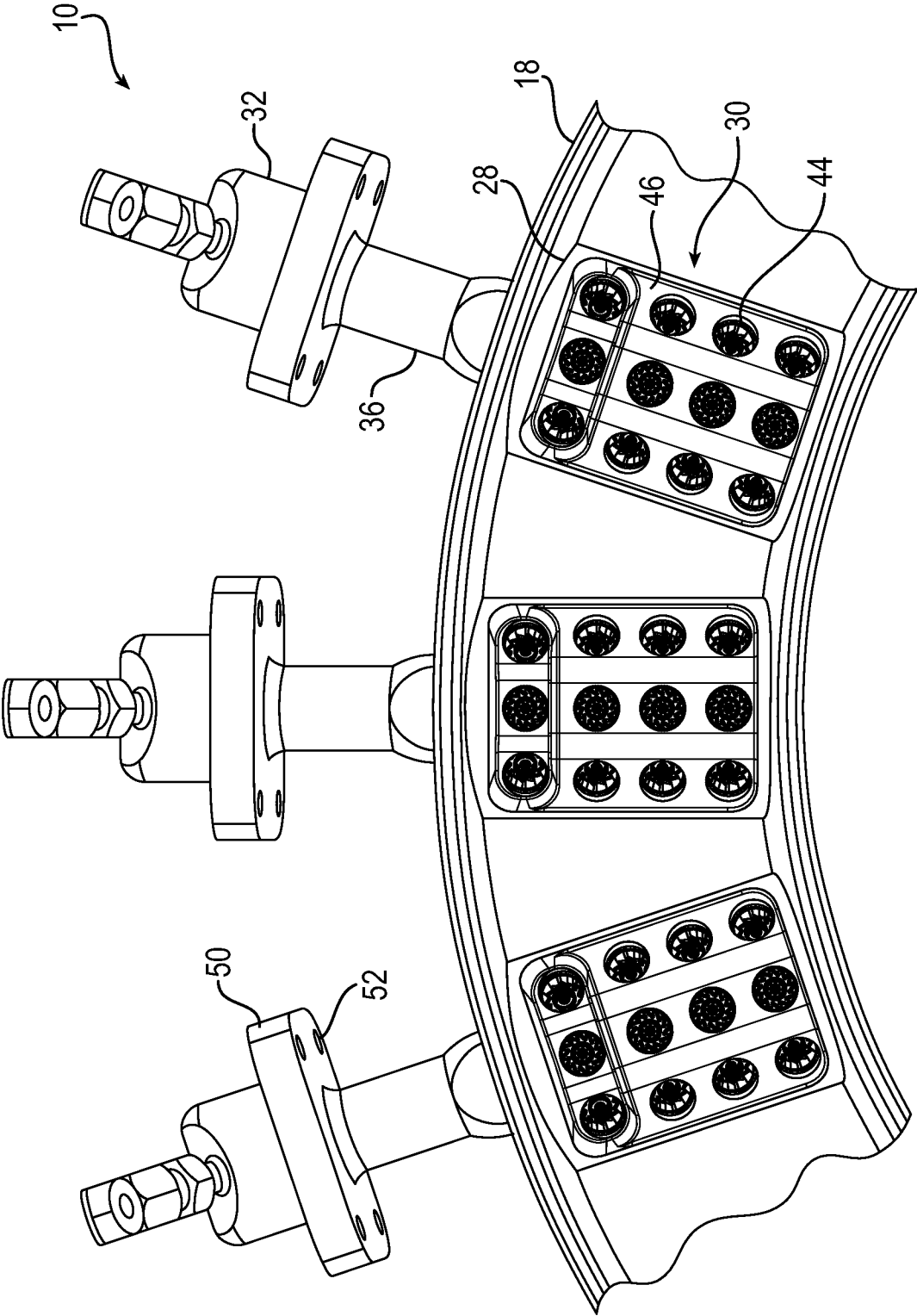


FIG. 1

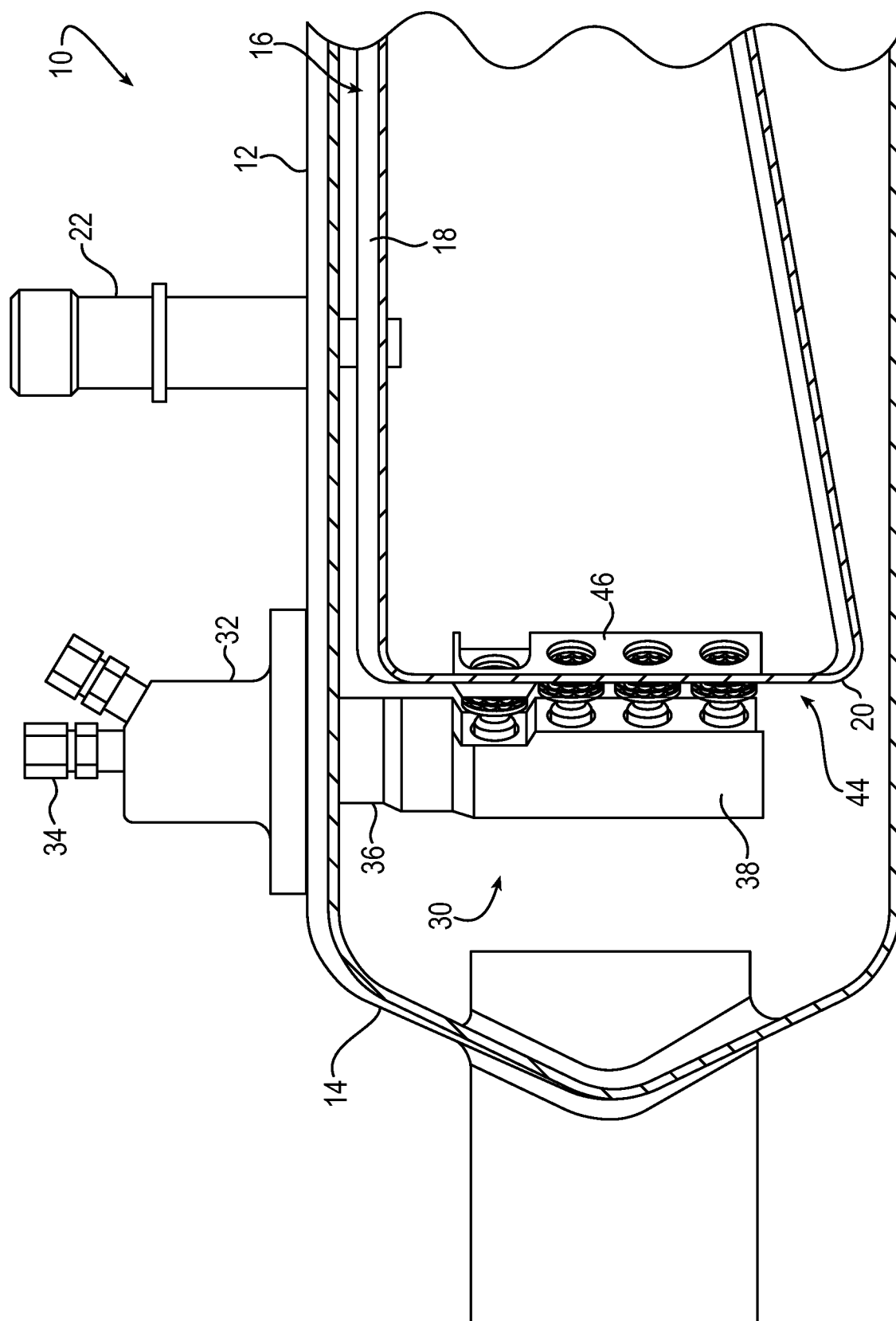


FIG. 2

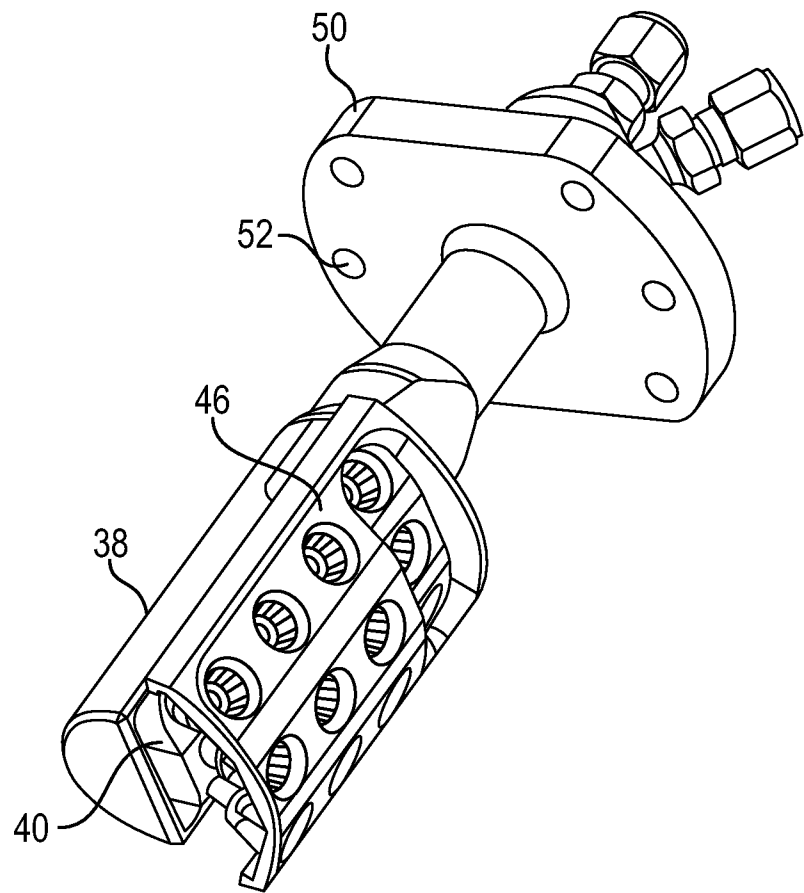


FIG. 3

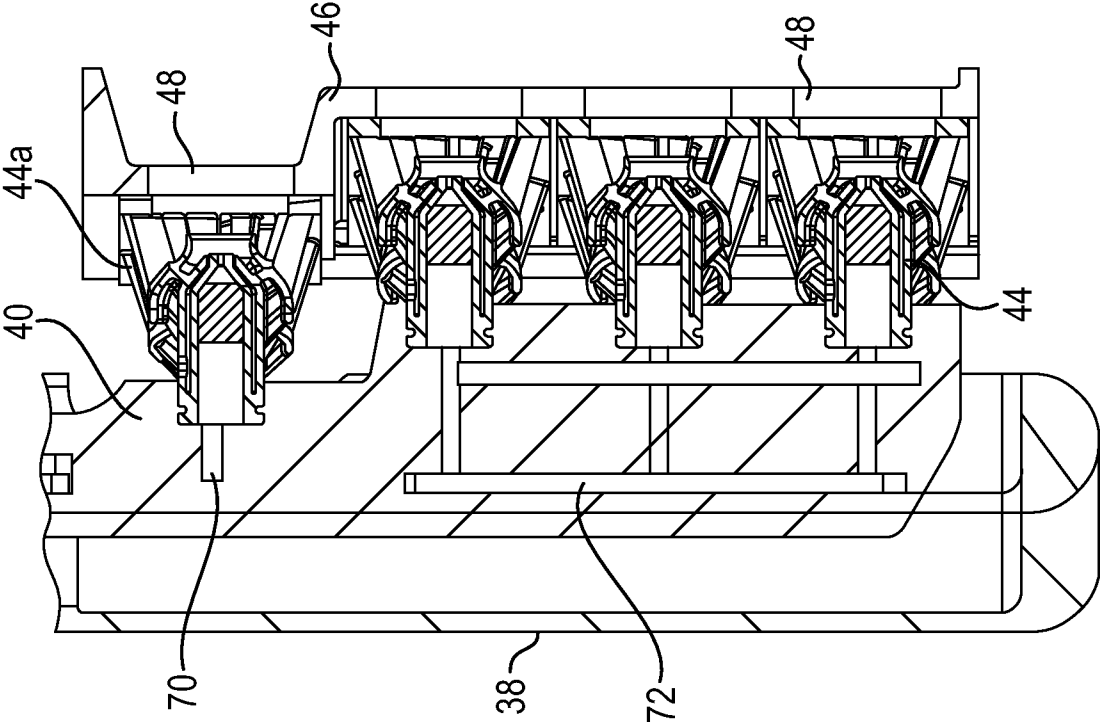


FIG. 5

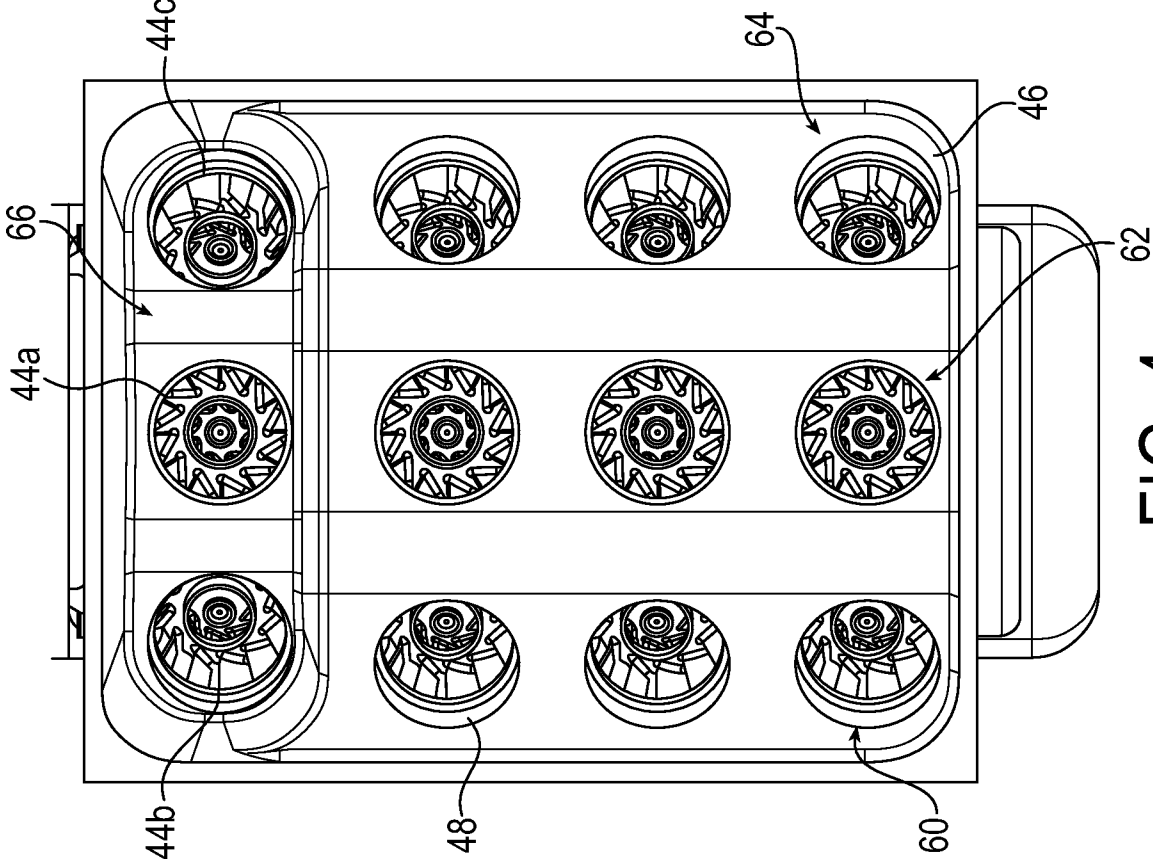


FIG. 4

FIG. 6

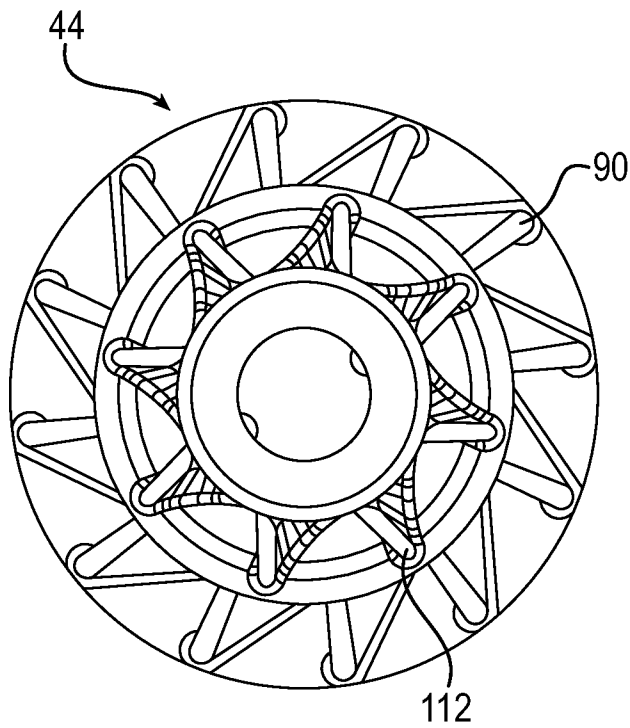
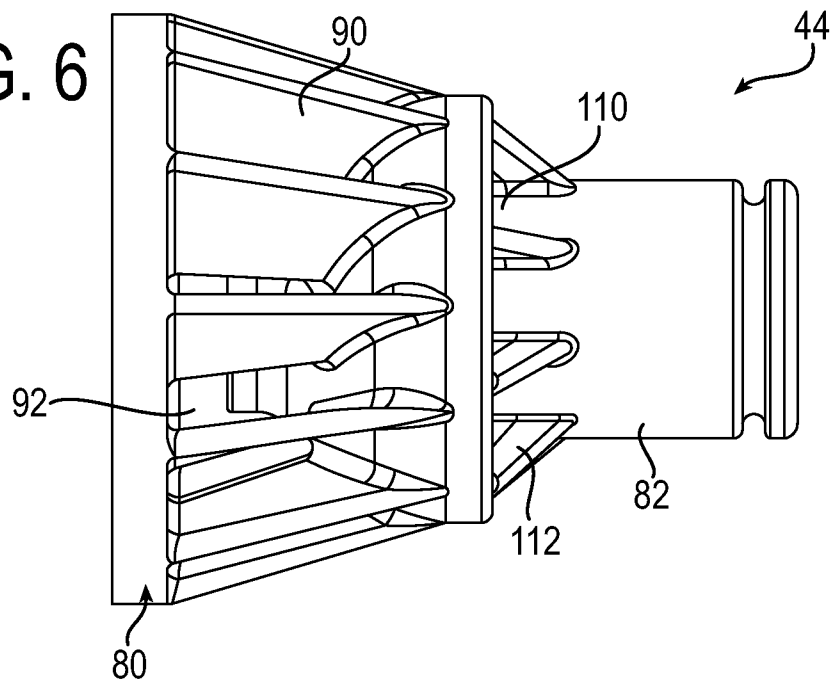


FIG. 7

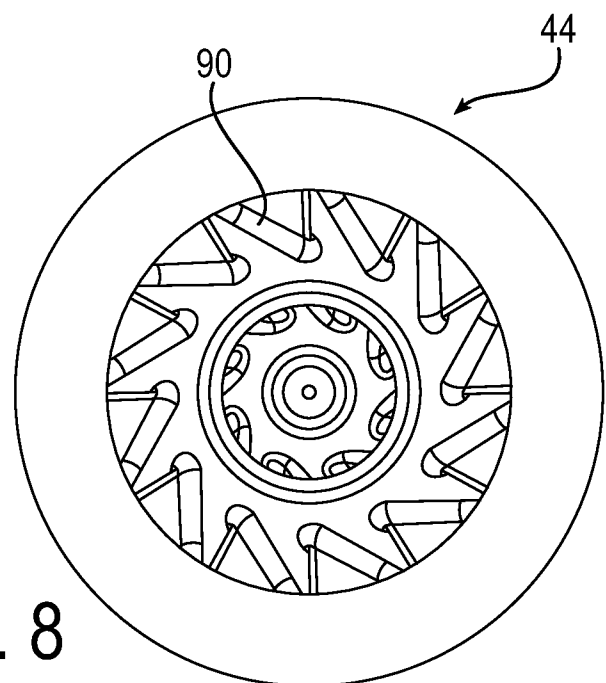


FIG. 8

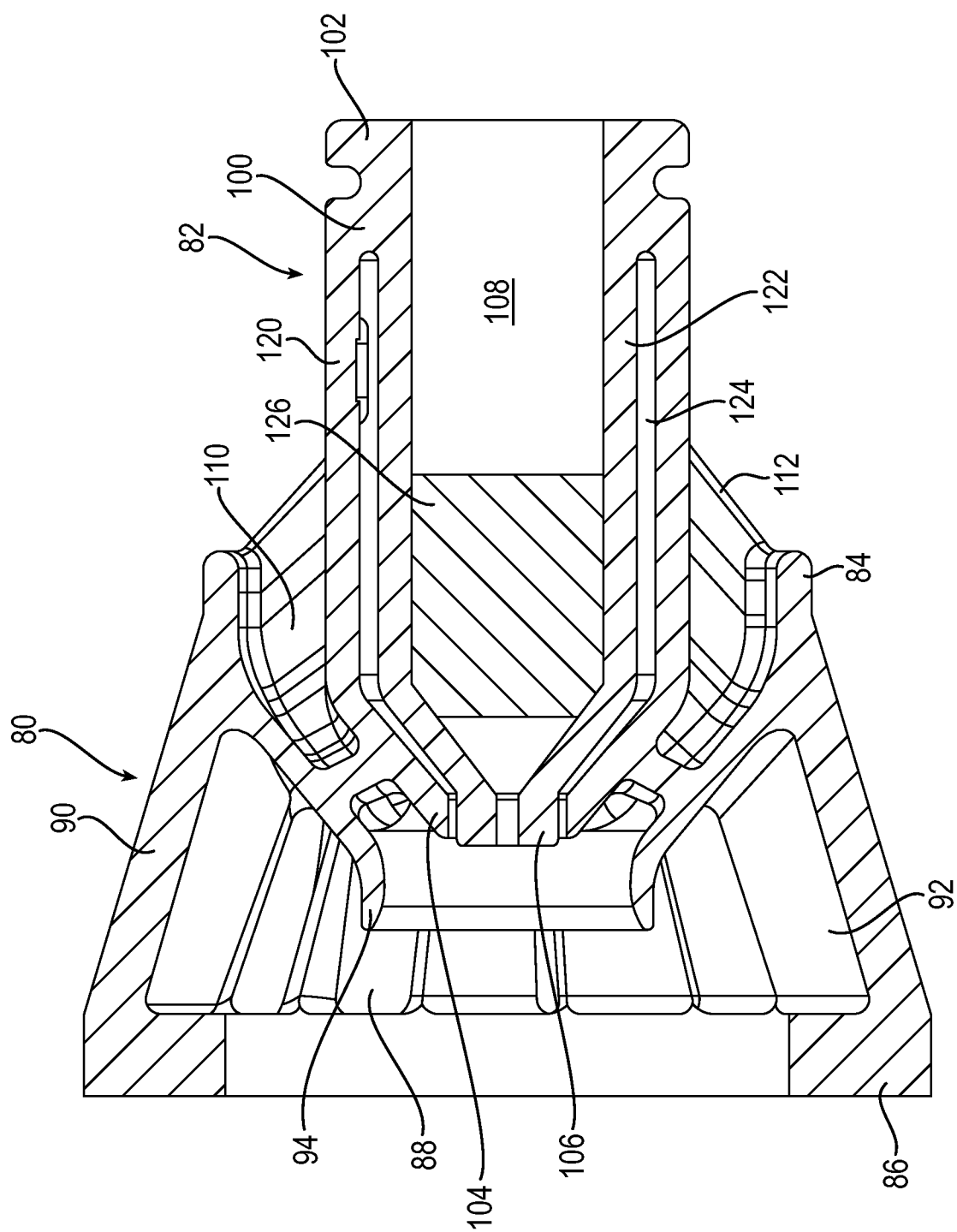


Fig. 9

144

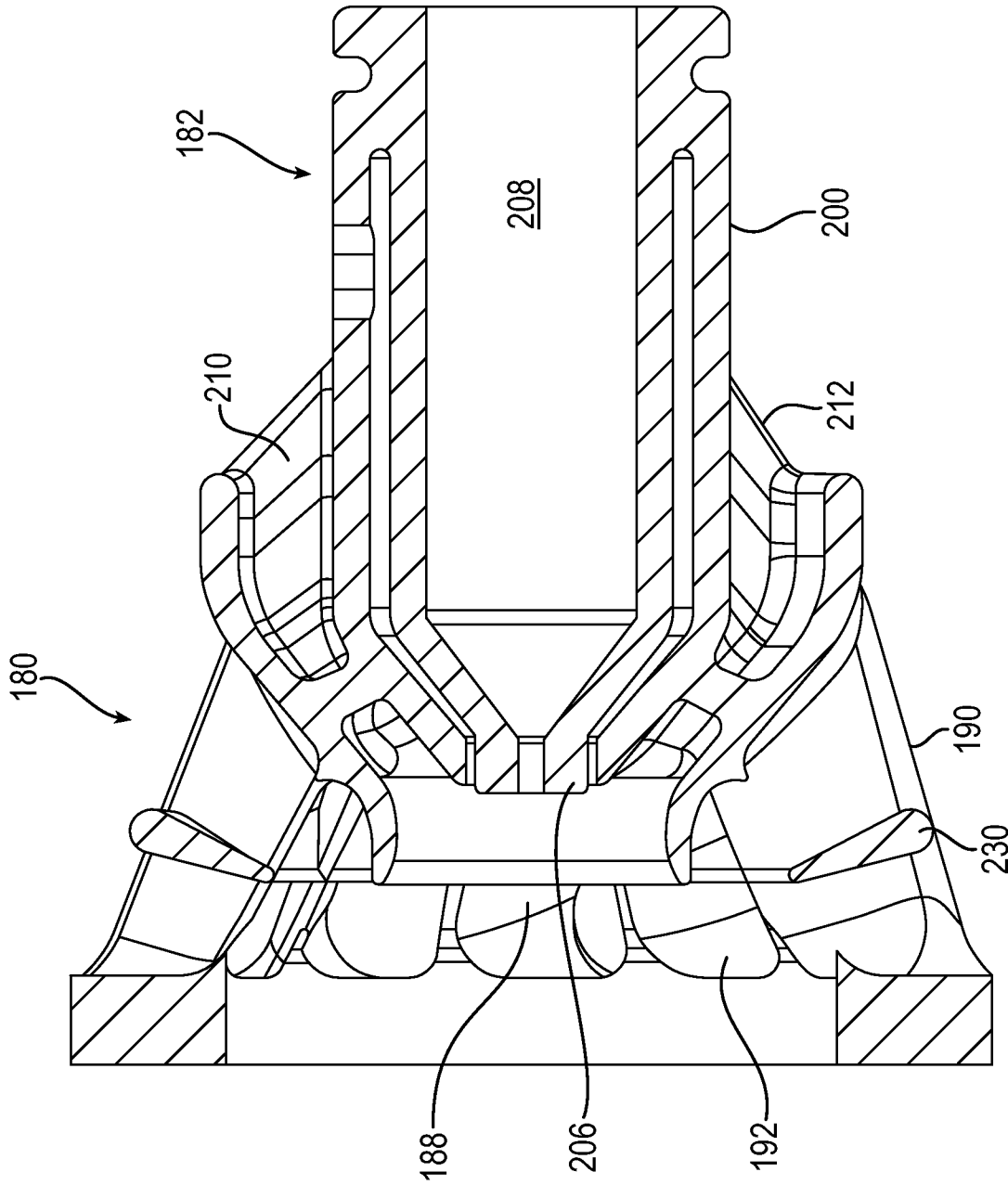


FIG. 10

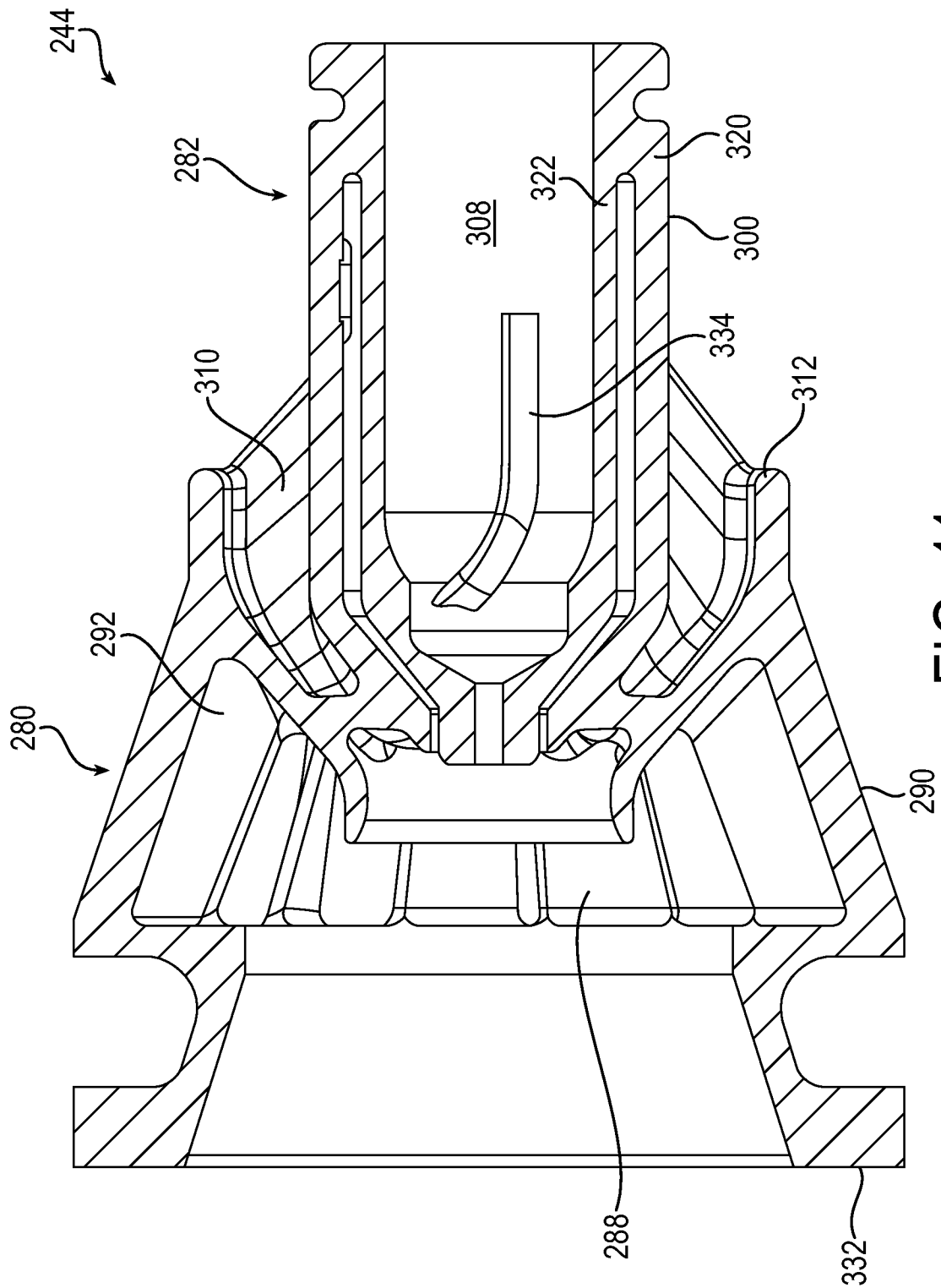


FIG. 11

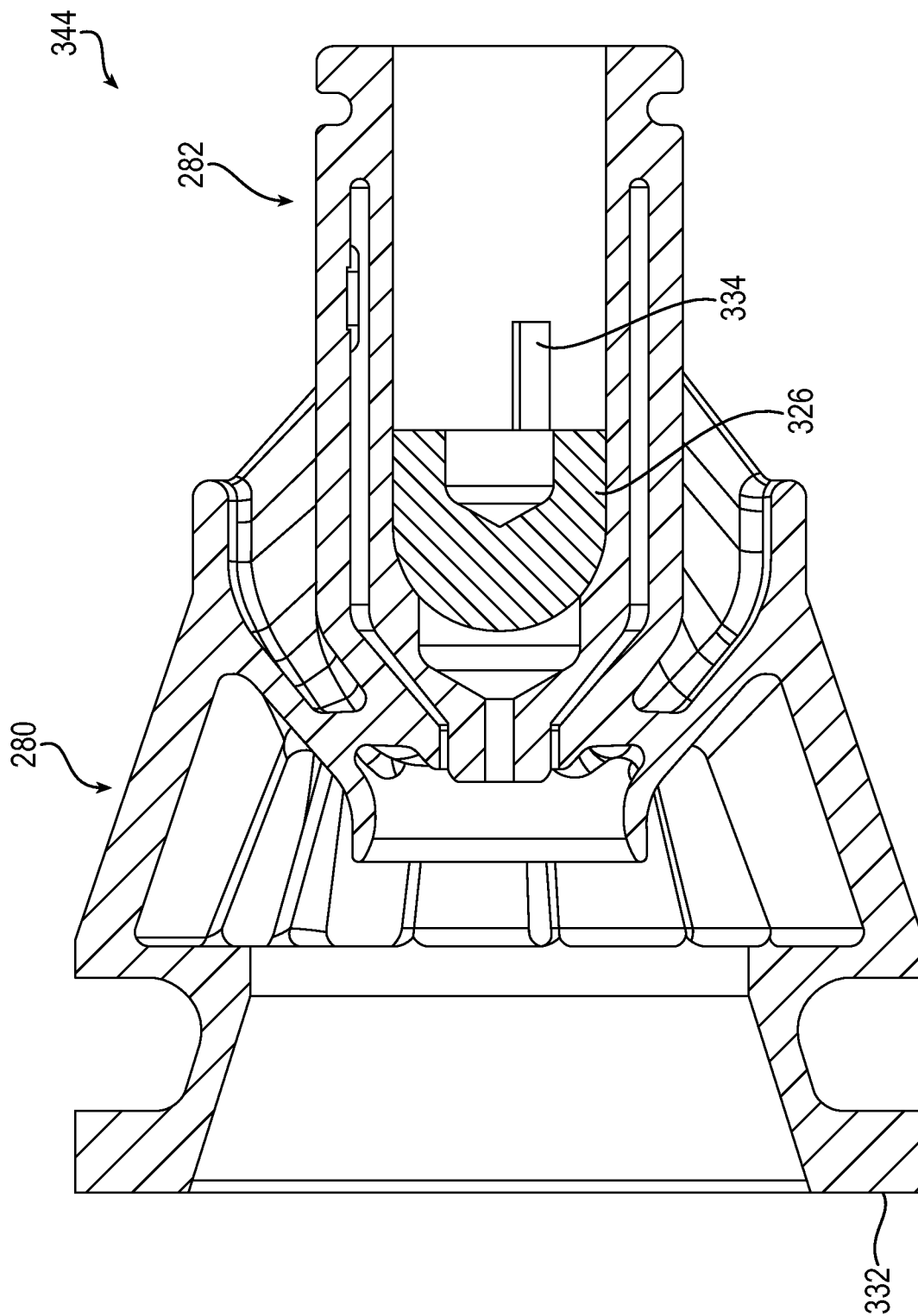


FIG. 12

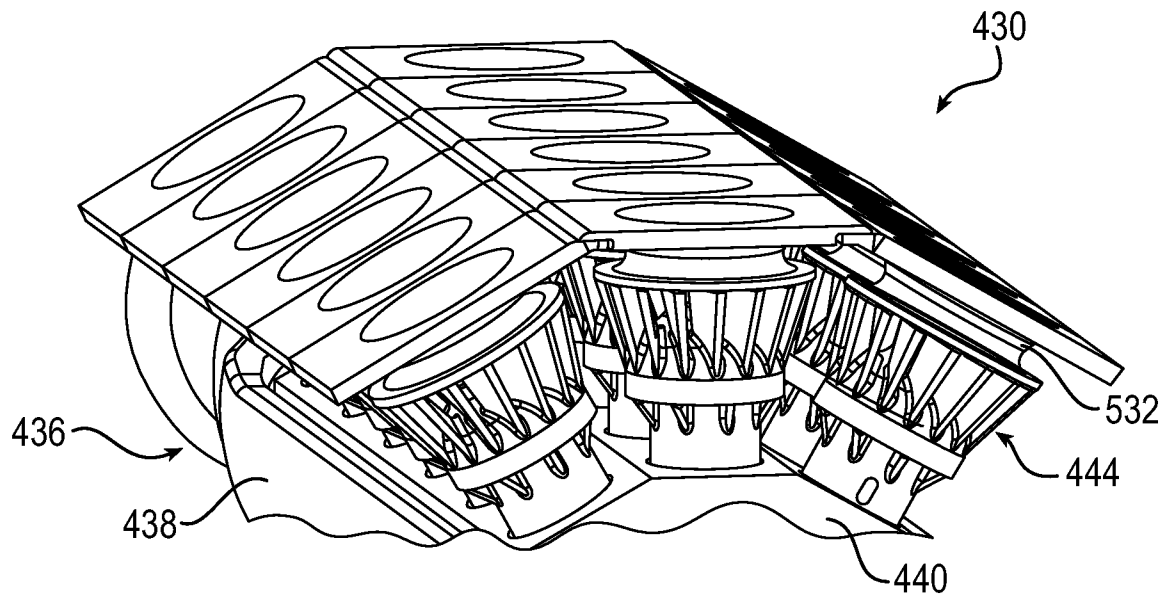


FIG. 13

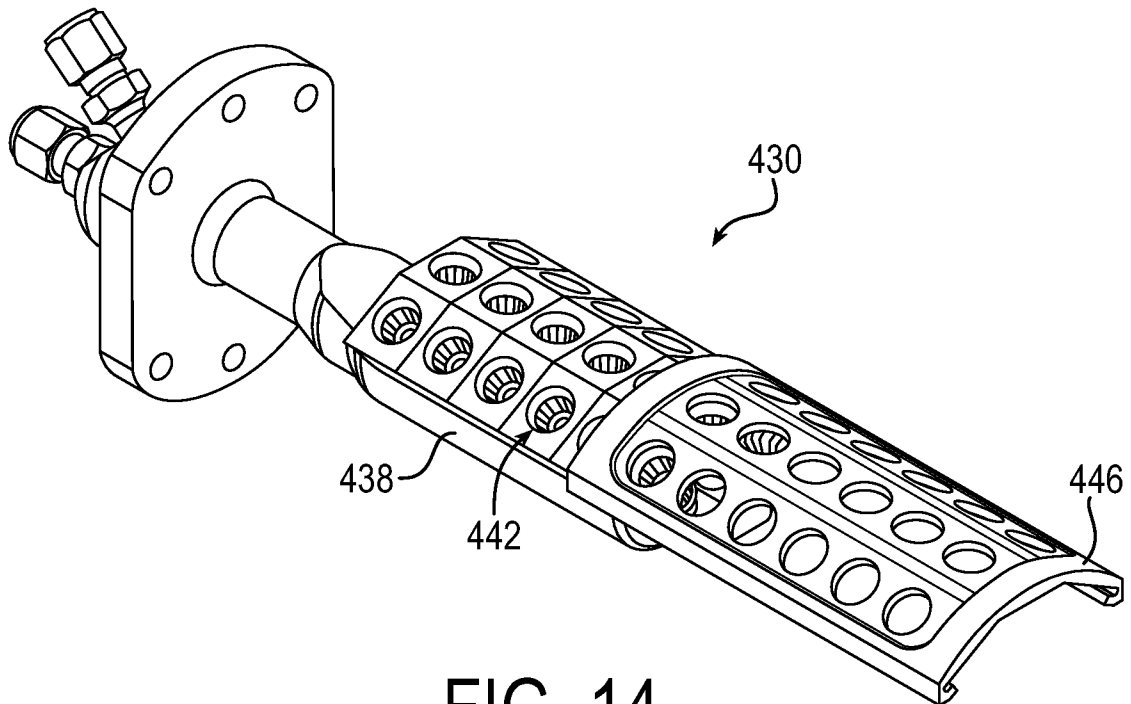


FIG. 14

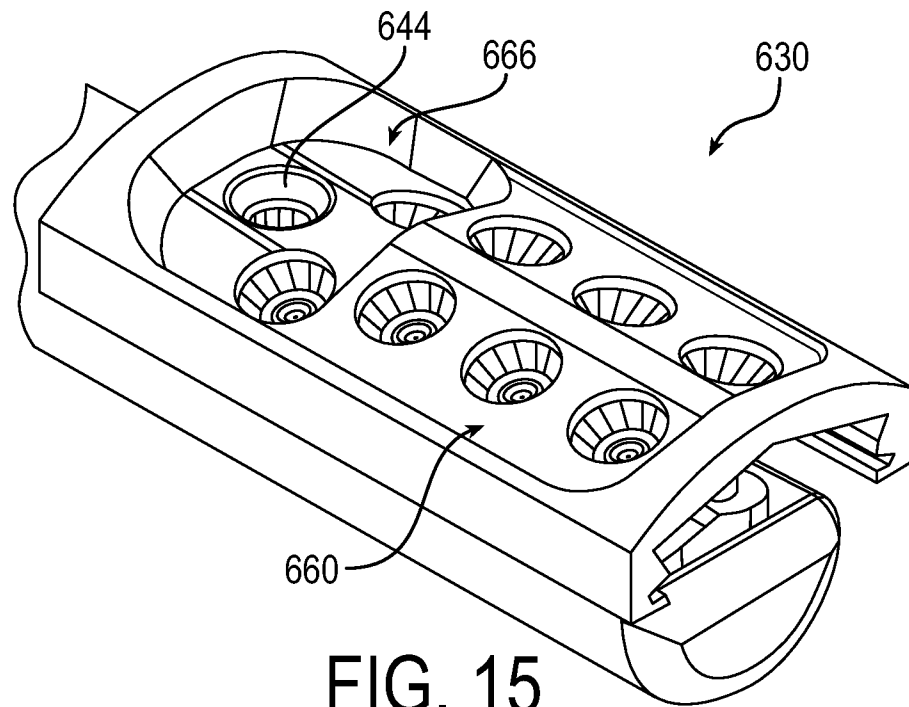


FIG. 15

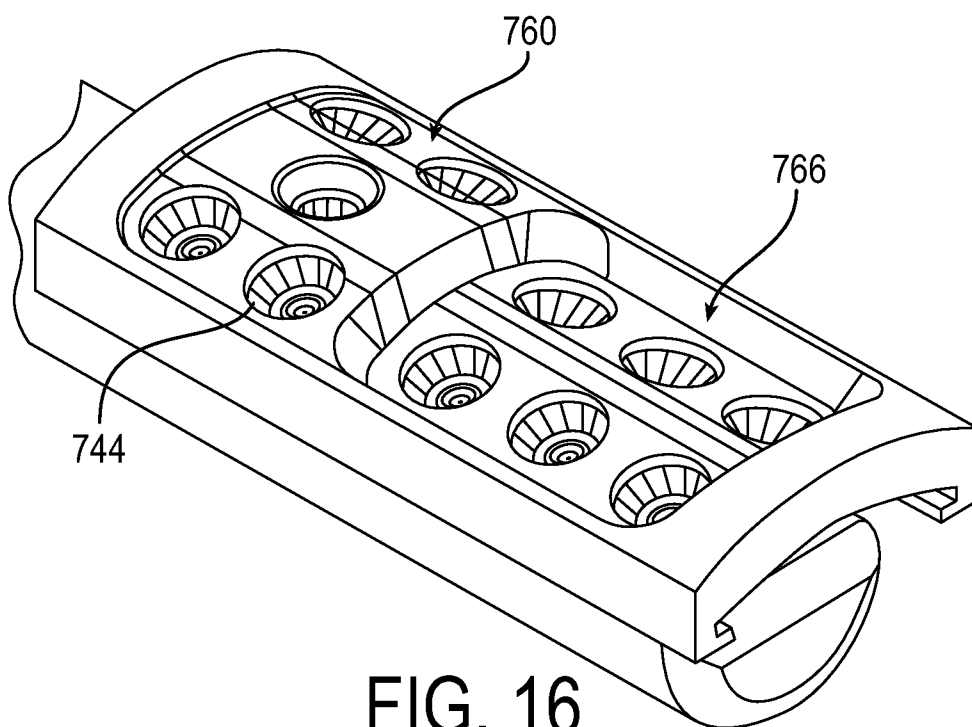


FIG. 16

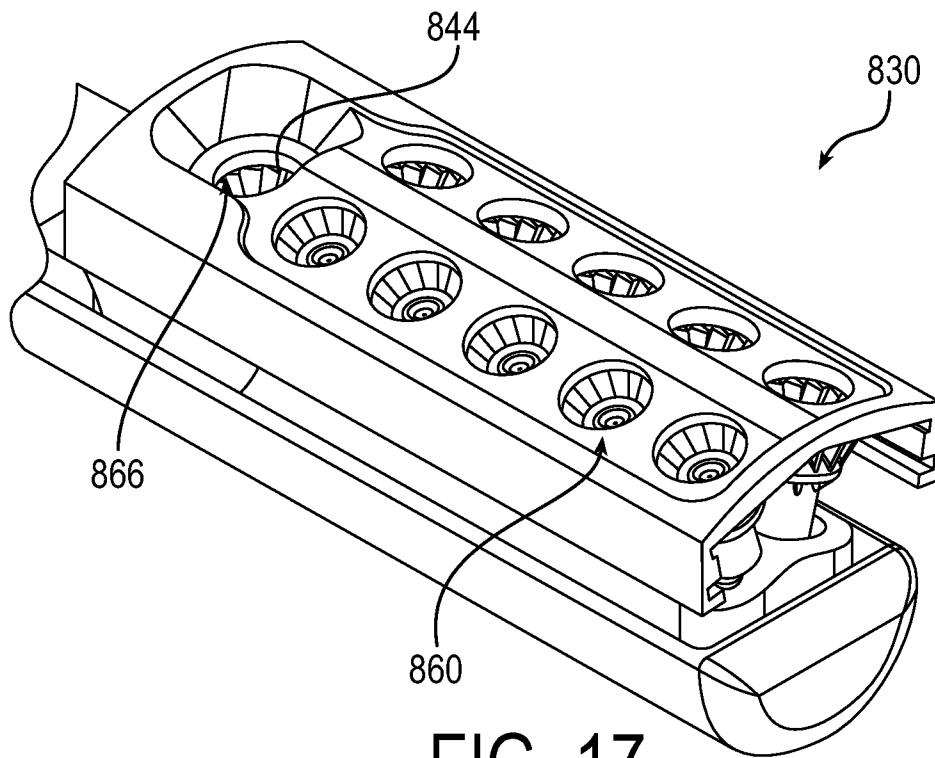


FIG. 17

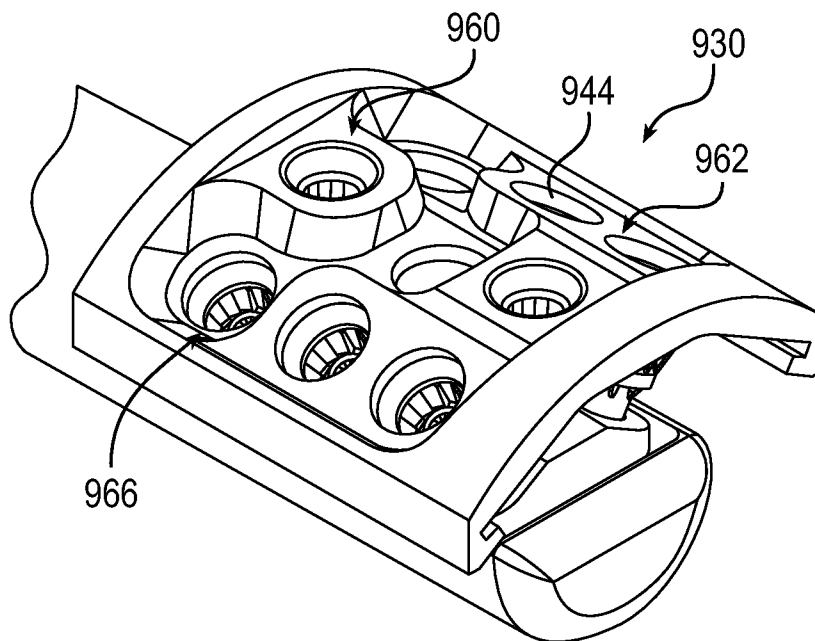


FIG. 18

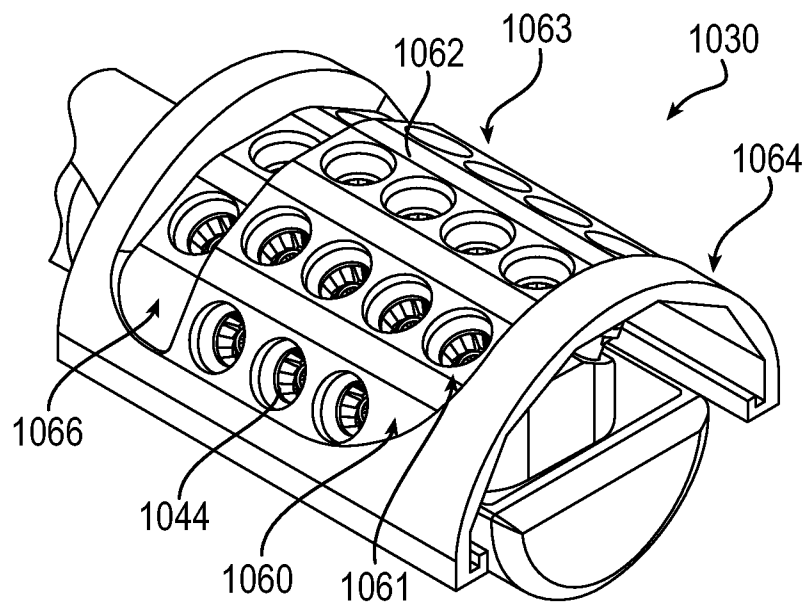


FIG. 19

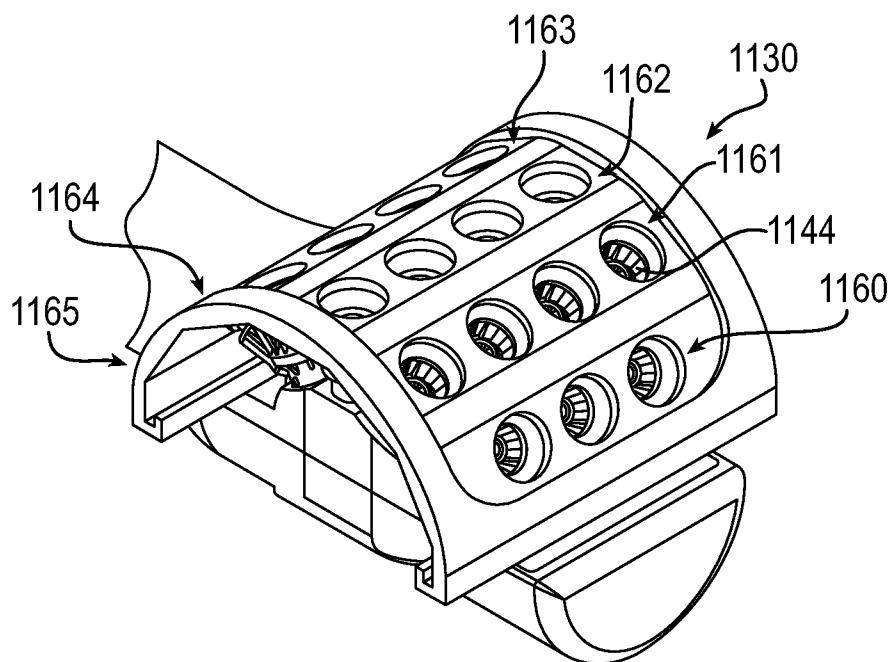


FIG. 20

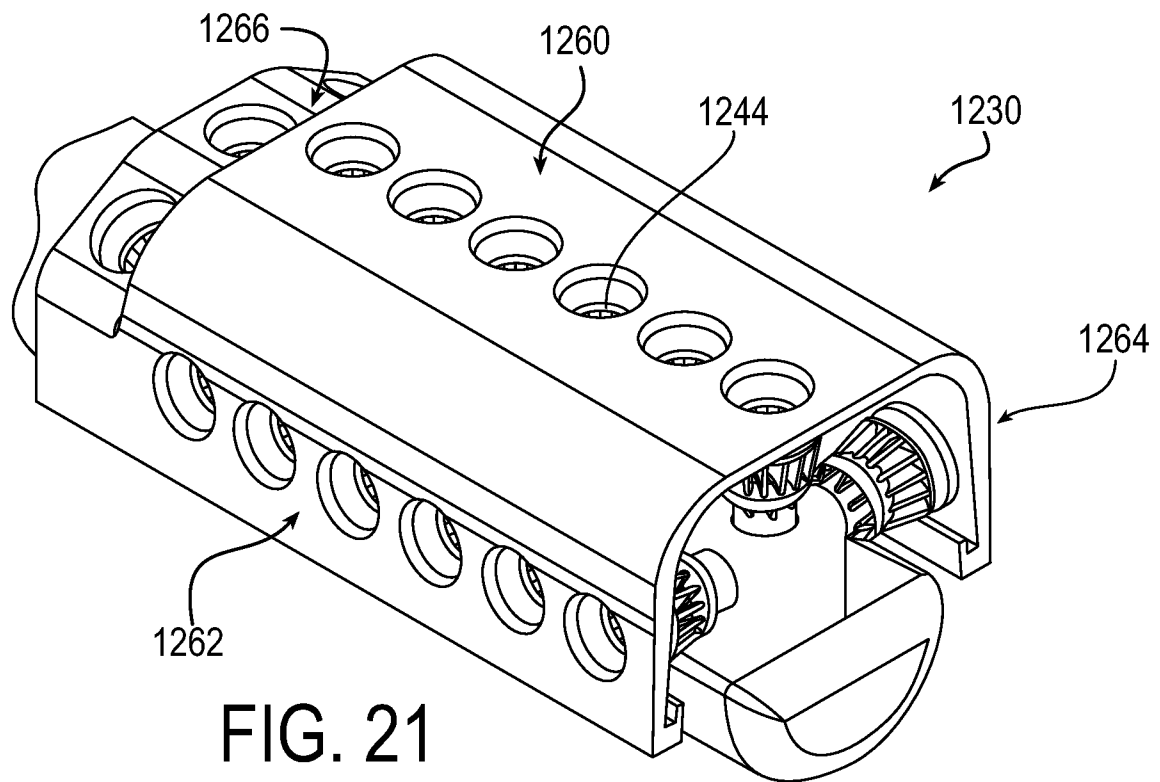


FIG. 21

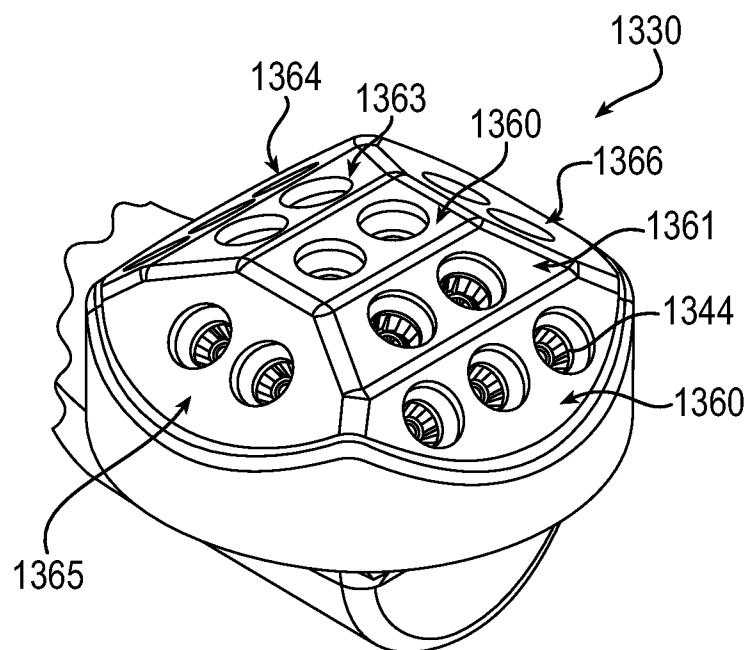


FIG. 22

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2016/019573

A. CLASSIFICATION OF SUBJECT MATTER

INV. F23R3/34 F23D11/10
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

F23R F23D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2014/130161 A2 (PARKER HANNIFIN CORP [US]) 28 August 2014 (2014-08-28)	7-17
Y	page 5, line 26 - page 11, line 25 figures 1-9	1-6, 18, 19
Y	----- US 2012/258409 A1 (MANSOUR ADEL B [US] ET AL) 11 October 2012 (2012-10-11) page 4, paragraph 56 figure 6	1-6, 18, 19
A	----- US 2004/124282 A1 (MANSOUR ADEL B [US] ET AL) 1 July 2004 (2004-07-01) page 3, paragraphs 37, 39 figures 3-5, 7	1, 8, 17, 18



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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"E" earlier application or patent but published on or after the international filing date

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

9 June 2016

Date of mailing of the international search report

23/06/2016

Name and mailing address of the ISA/

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Authorized officer

Gavriliu, Costin

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2016/019573

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2014130161 A2	28-08-2014	GB 2524914 A	07-10-2015
		US 2015354517 A1	10-12-2015
		WO 2014130161 A2	28-08-2014

US 2012258409 A1	11-10-2012	NONE	

US 2004124282 A1	01-07-2004	NONE	
