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(54) **LEAN PREMIXED, RADIAL INFLOW, MULTI-ANNULAR STAGED NOZZLE, CAN-ANNULAR, DUAL-FUEL COMBUSTOR**

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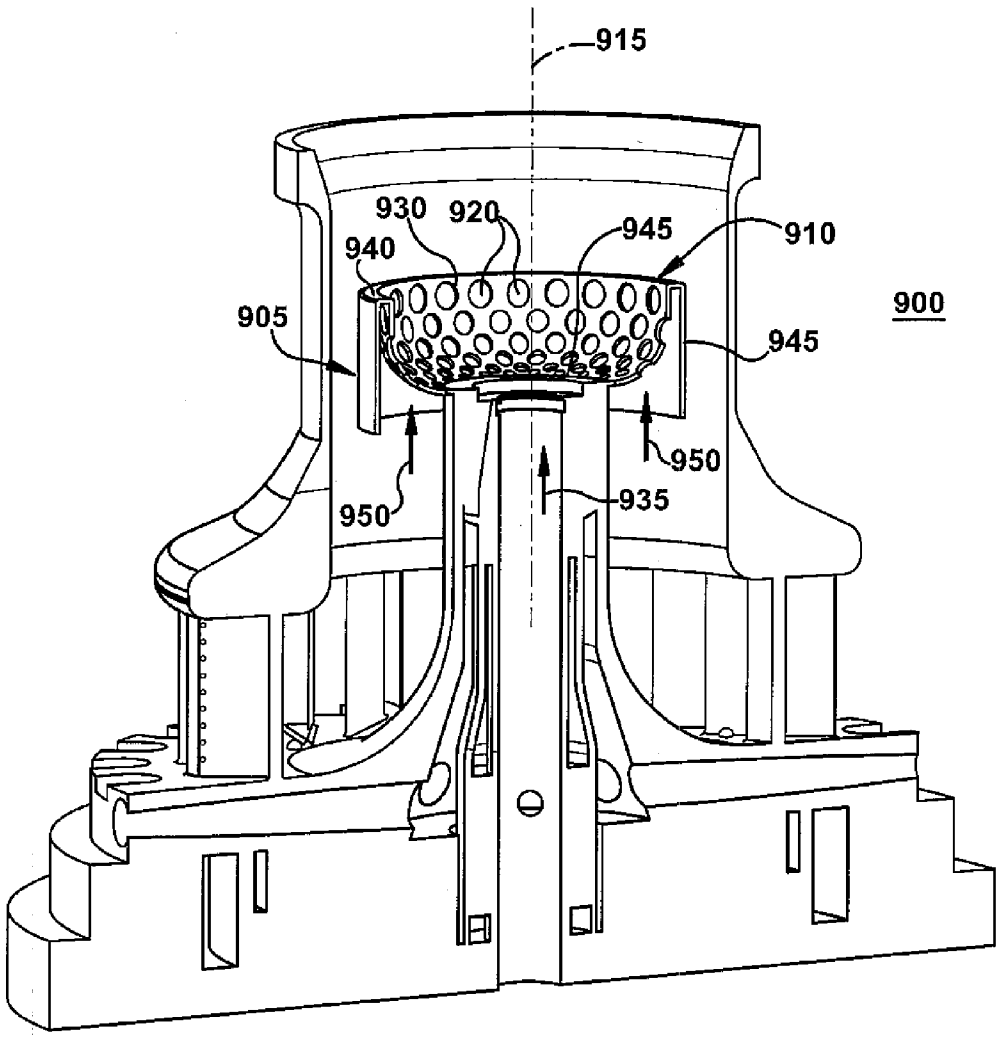
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(57) **ABSTRACT**

A lean premixed, radial inflow, multi-annular staged nozzle for creating three independent combustion zones within a can-annular, dual-fuel gas turbine combustor is provided. The nozzle includes a pilot zone fueled by a gas pilot nozzle and center cartridge; a flame holder zone fueled by an inner main gas fuel; a main flame zone fueled by an outer main gas fuel; a main radial swirler for mixing a portion of incoming air to the nozzle with the inner main gas fuel supply and the outer main gas fuel supply; an endcover; and means for controlling the ratio of an inner main gas fuel supplied and an outer main gas fuel supplied.



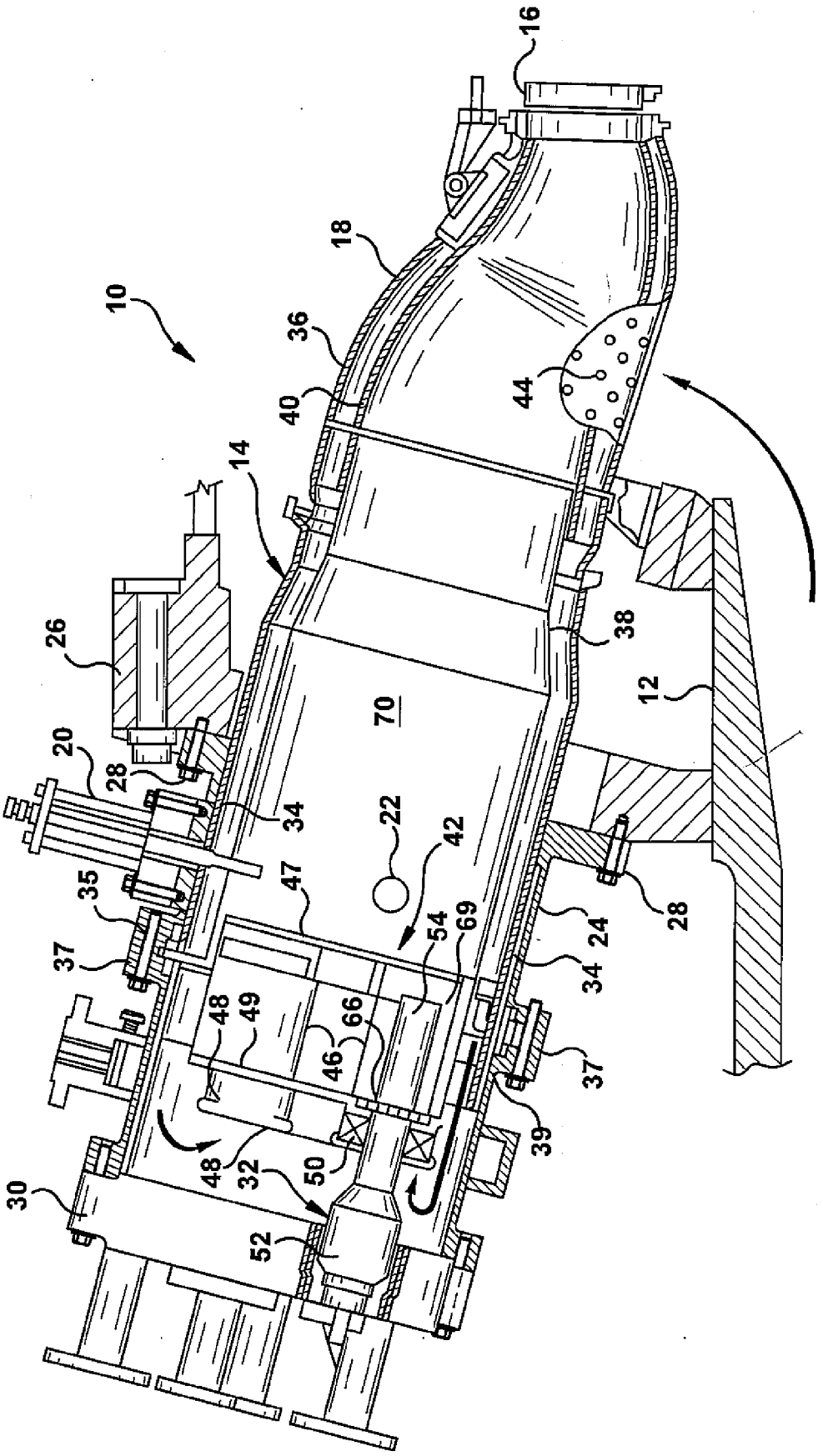

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Fig. 1

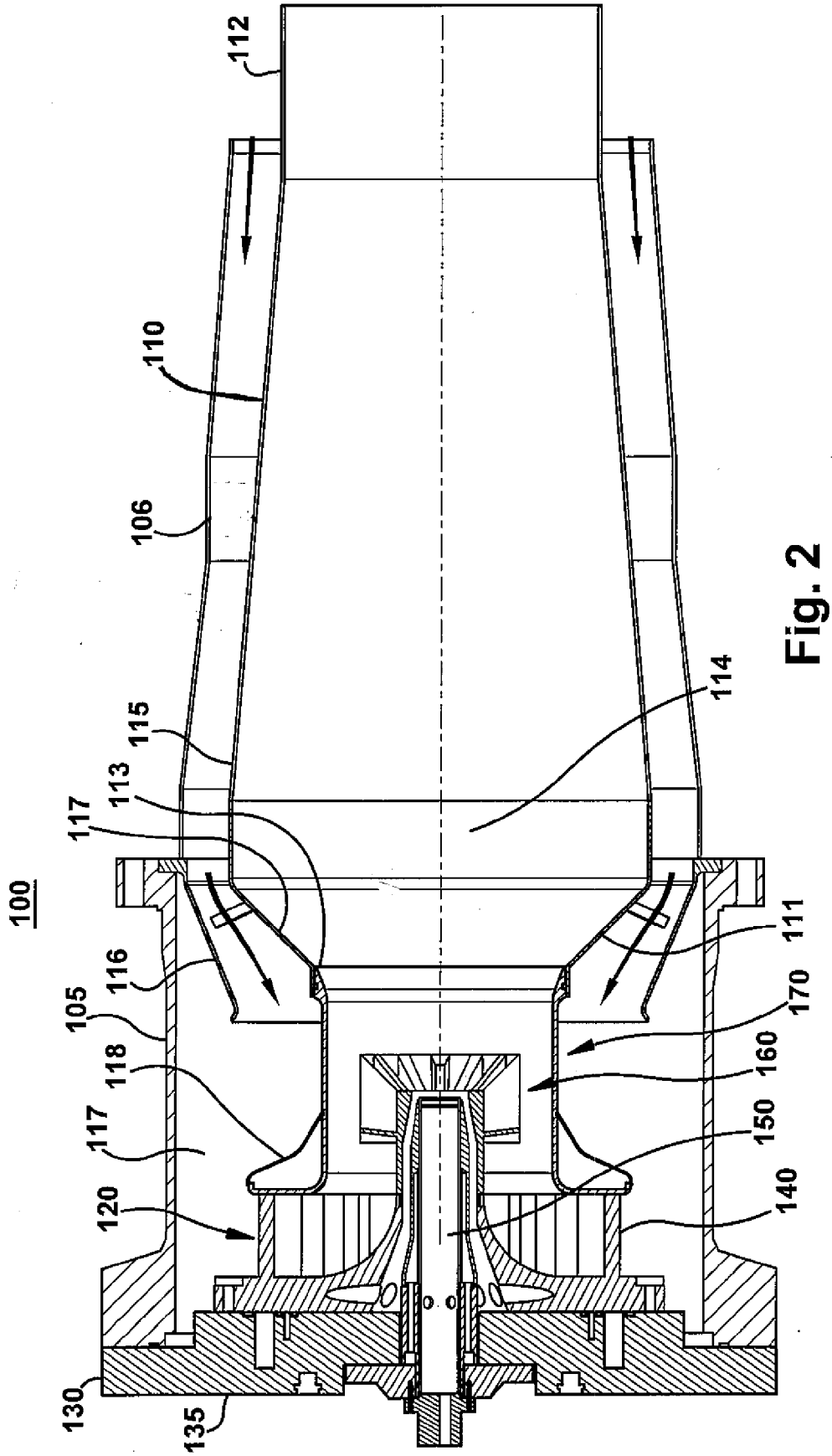

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Fig. 2

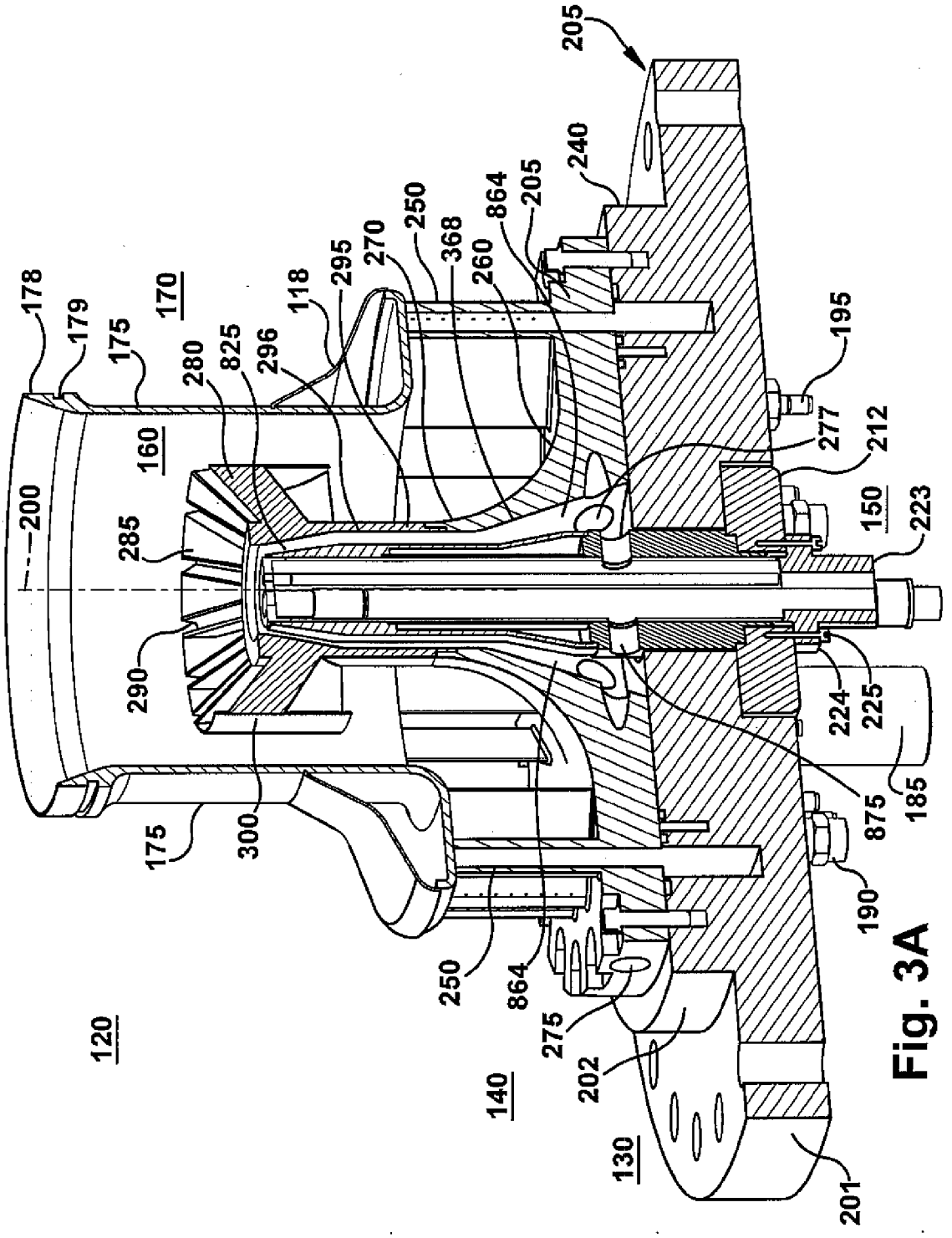

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Fig. 3A

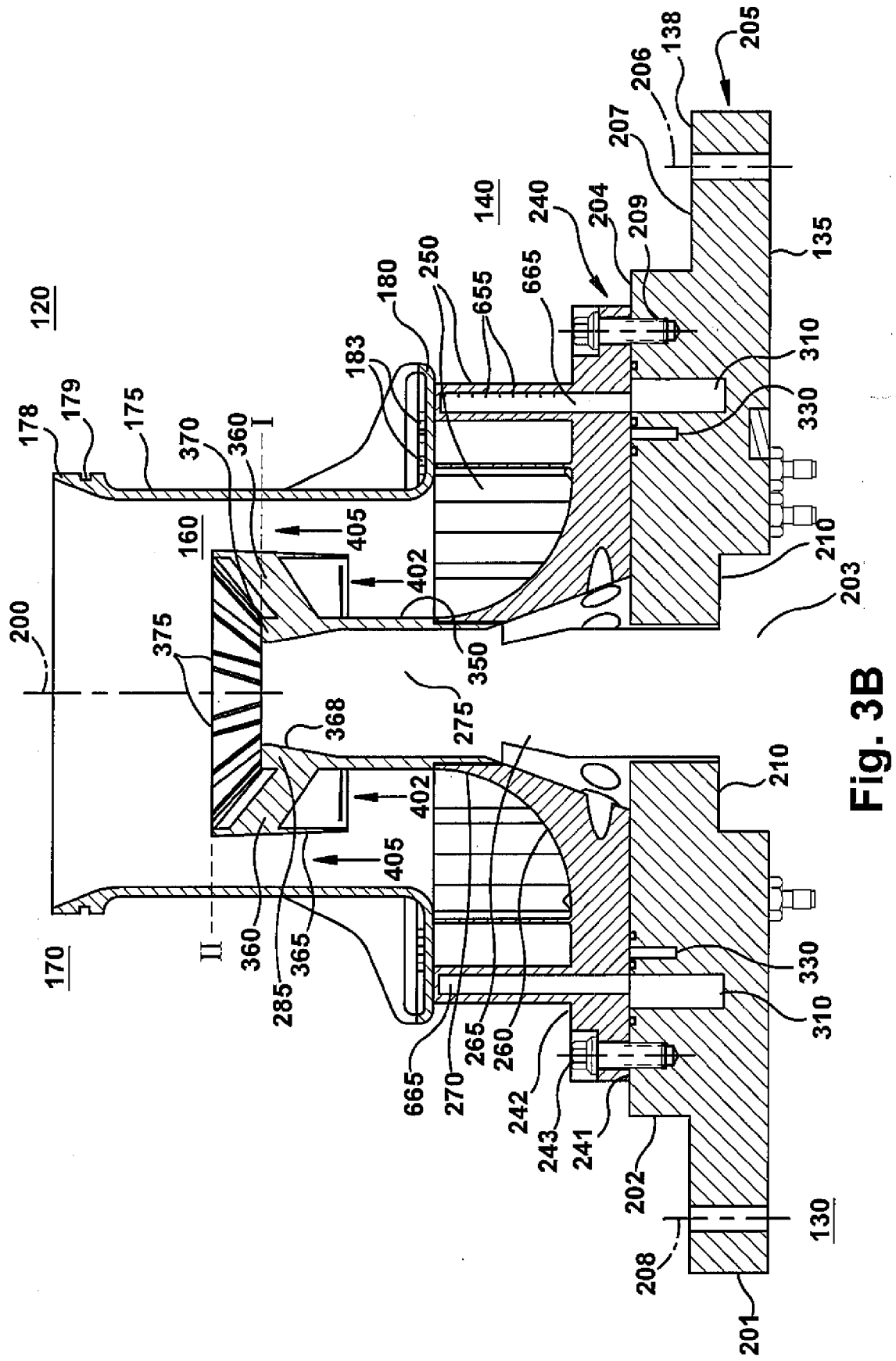

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Fig. 3B

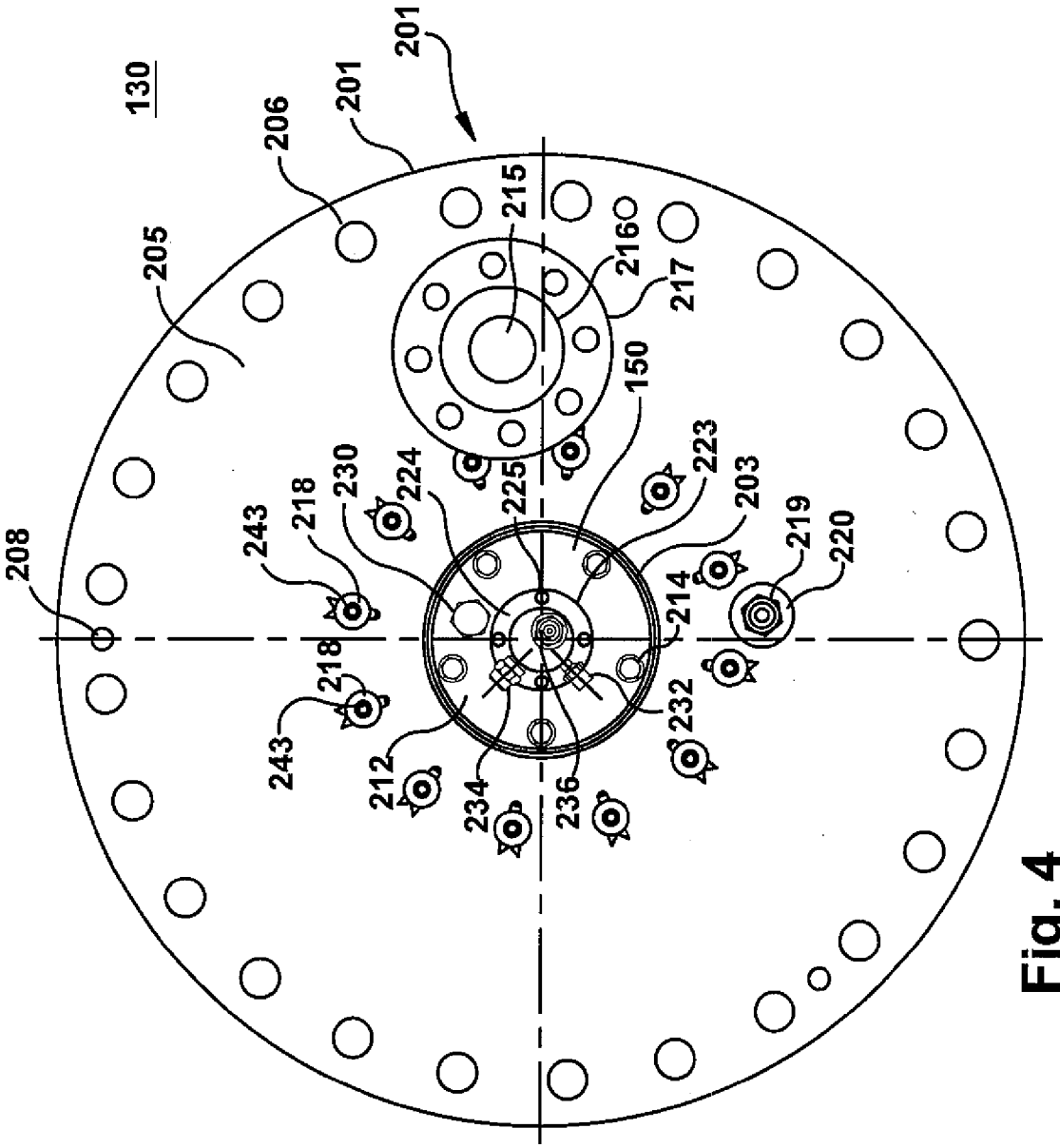

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Fig. 4

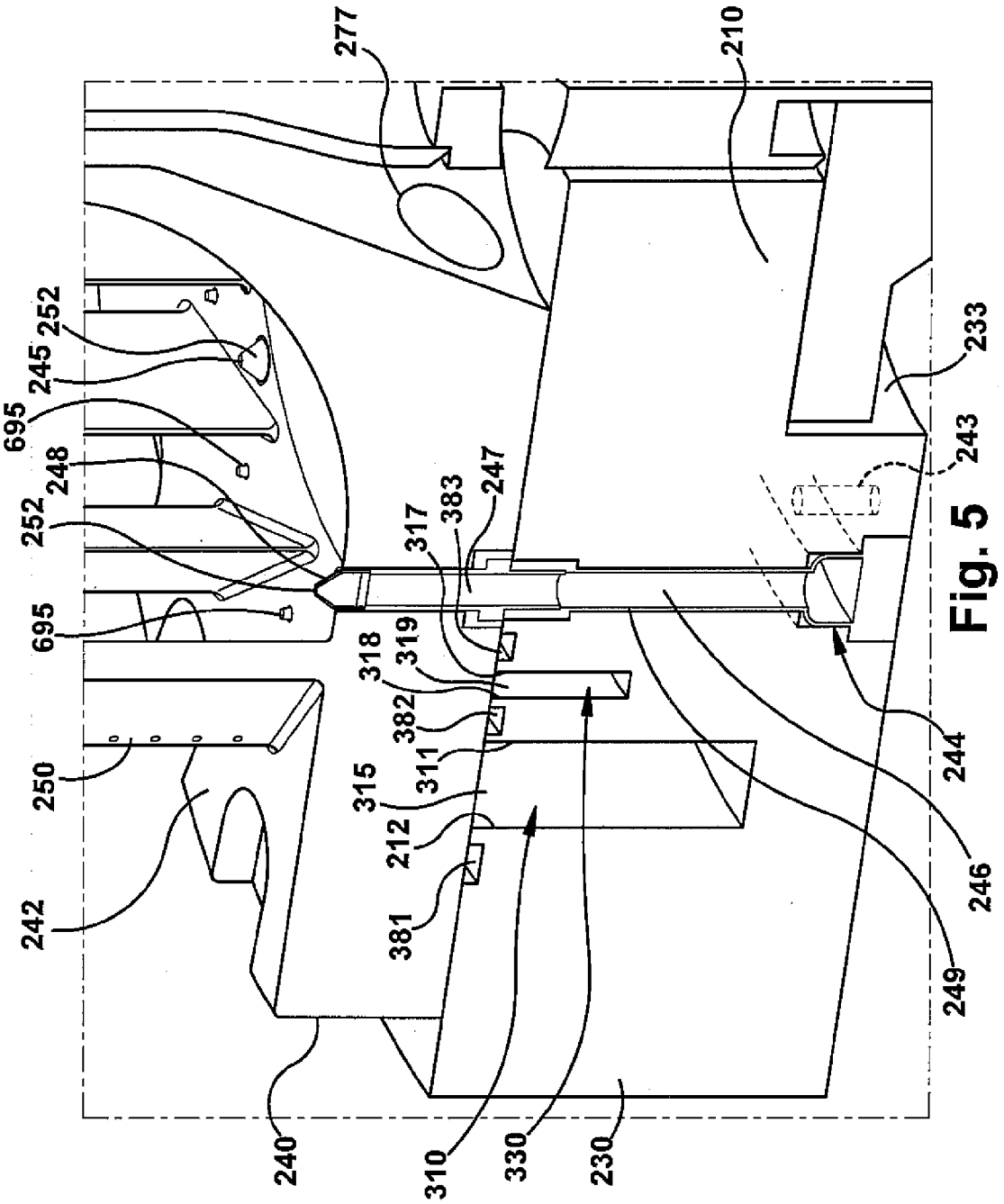

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Fig. 5

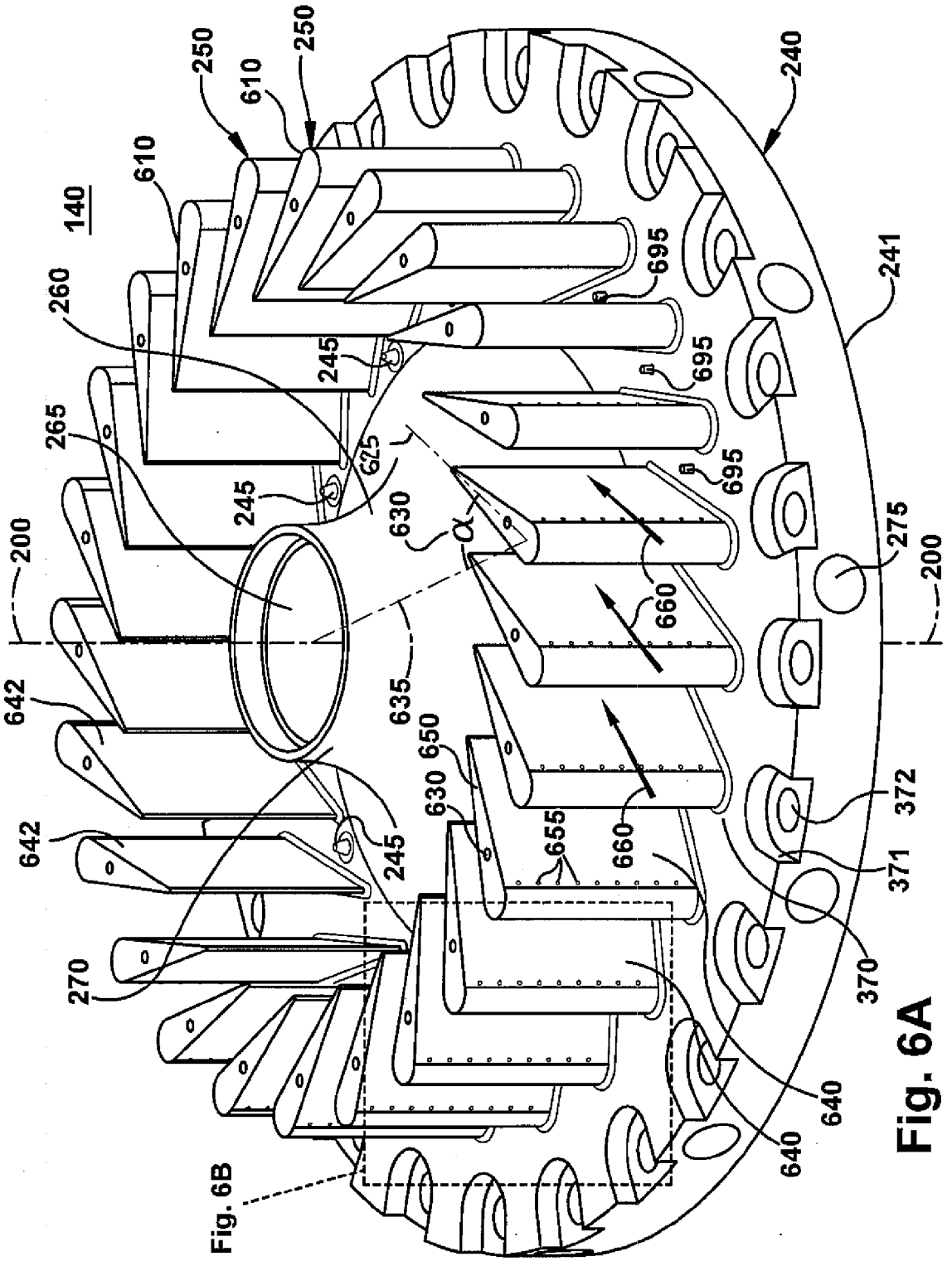

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Fig. 6B

Fig. 6A

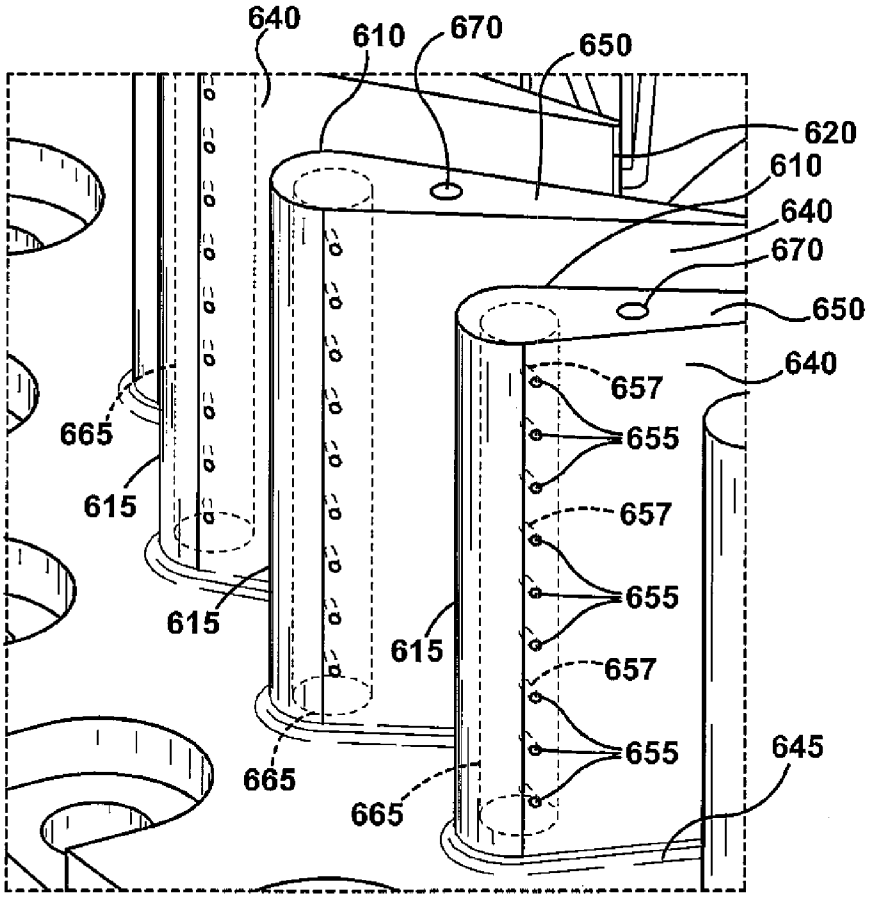

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Fig. 6B

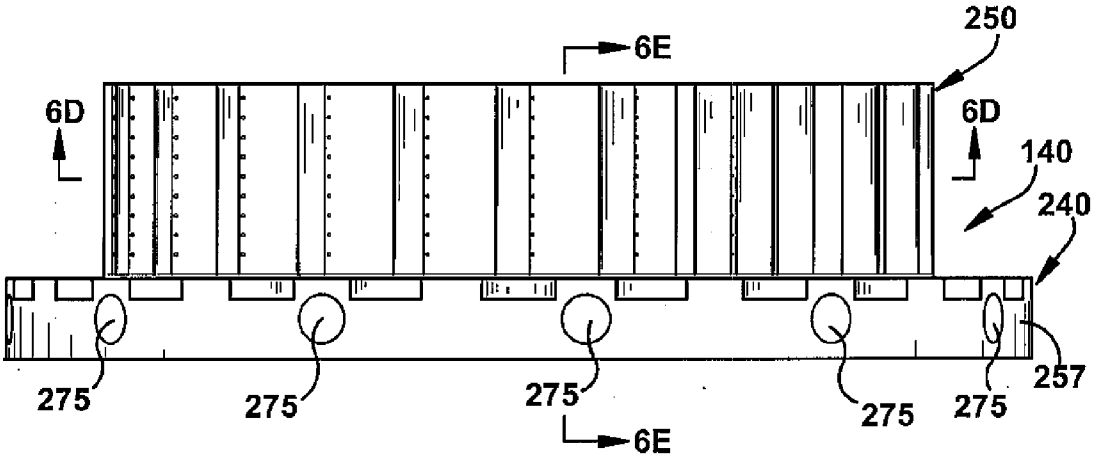

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Fig. 6C

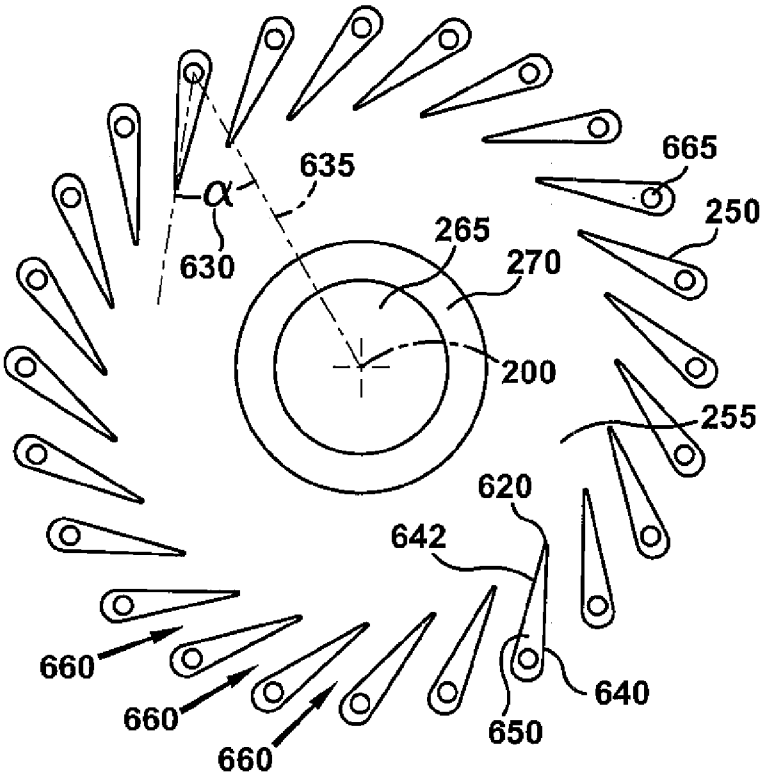

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Fig. 6D

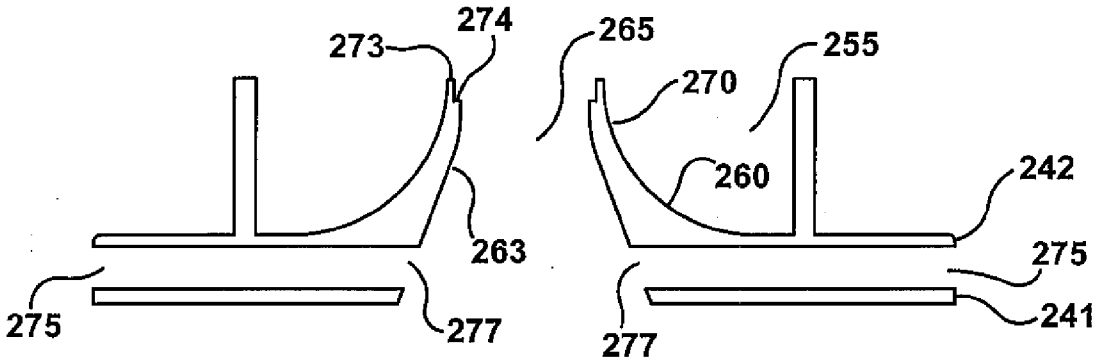

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Fig. 6E

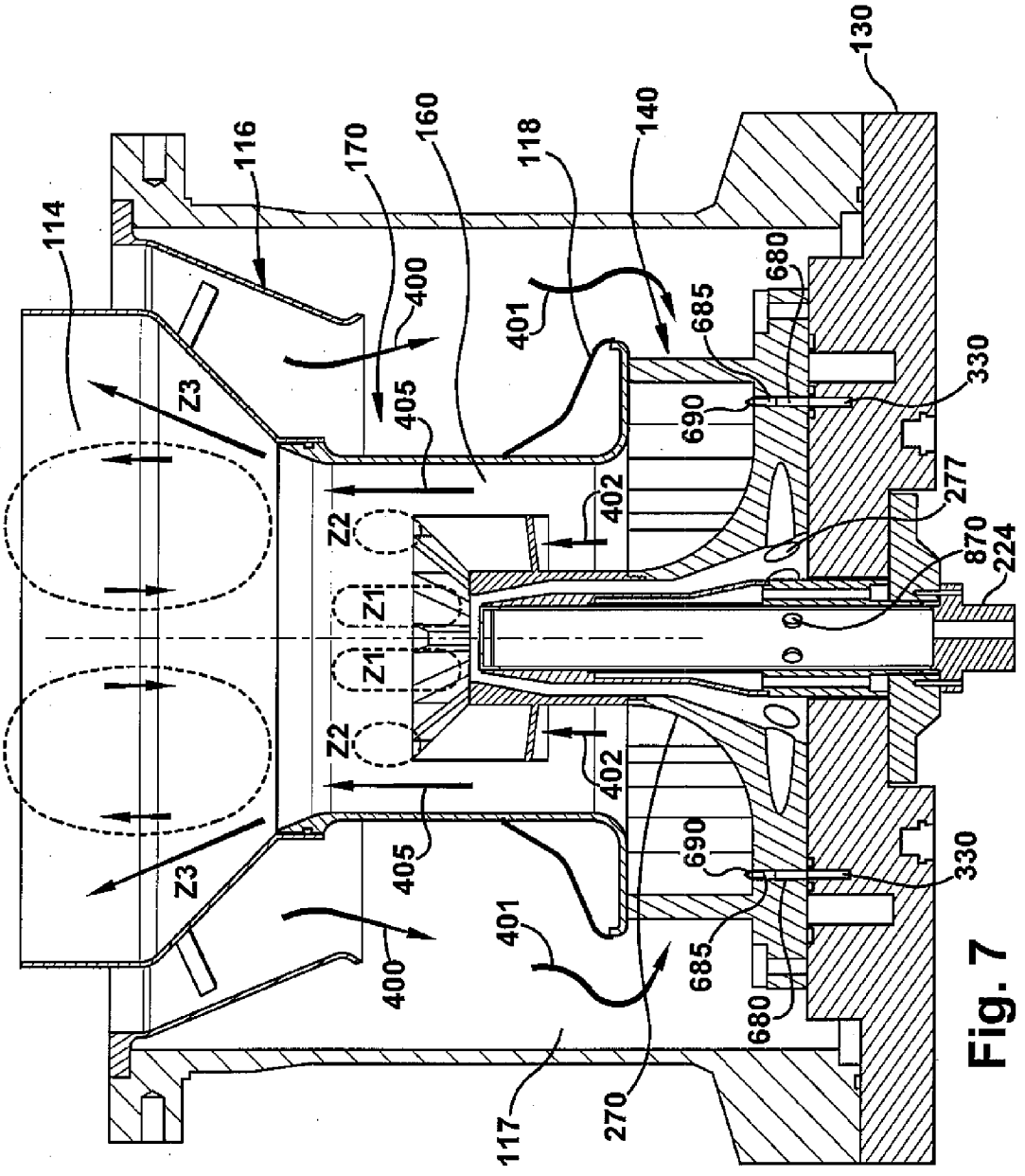

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Fig. 7

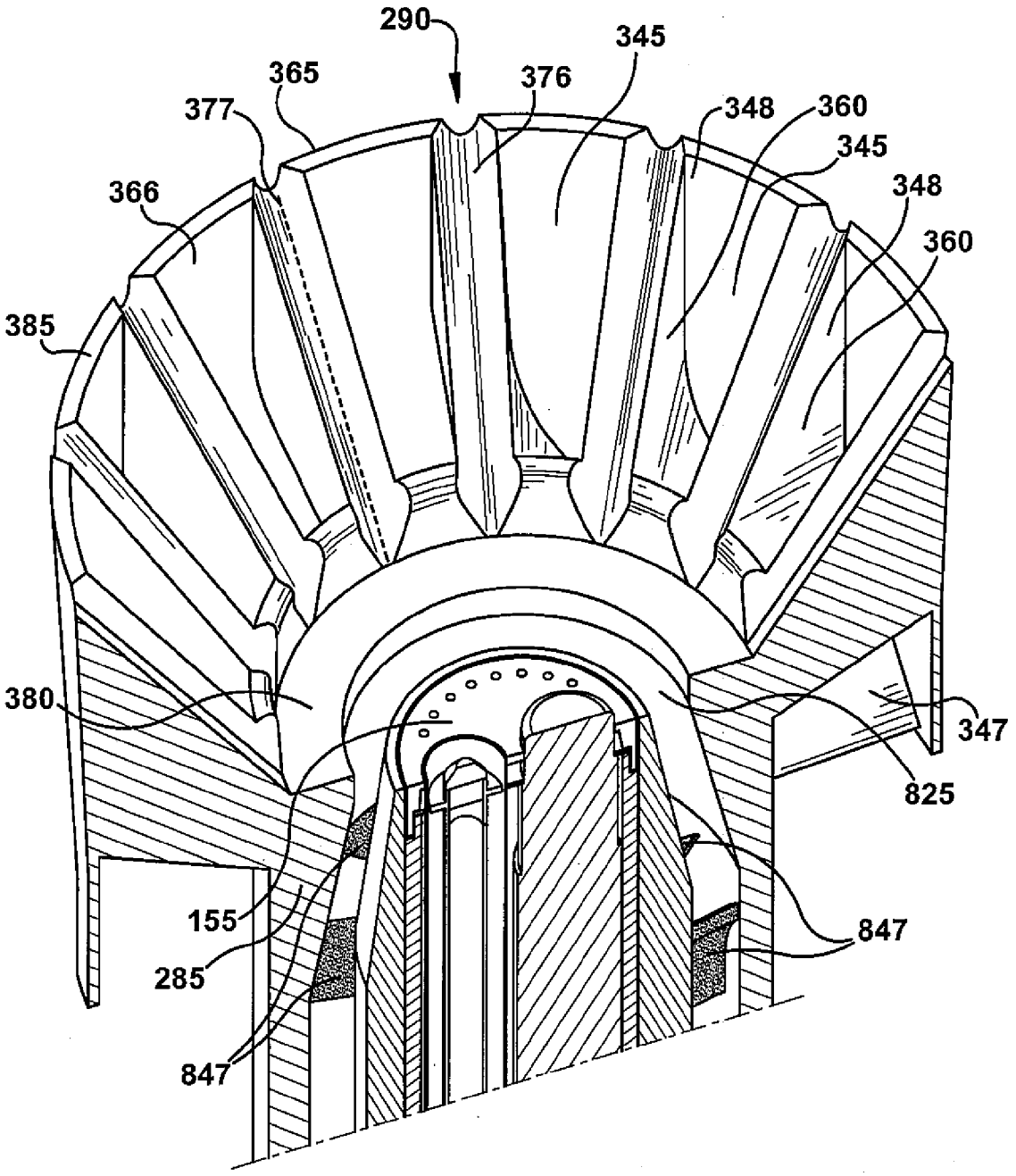

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Fig. 8

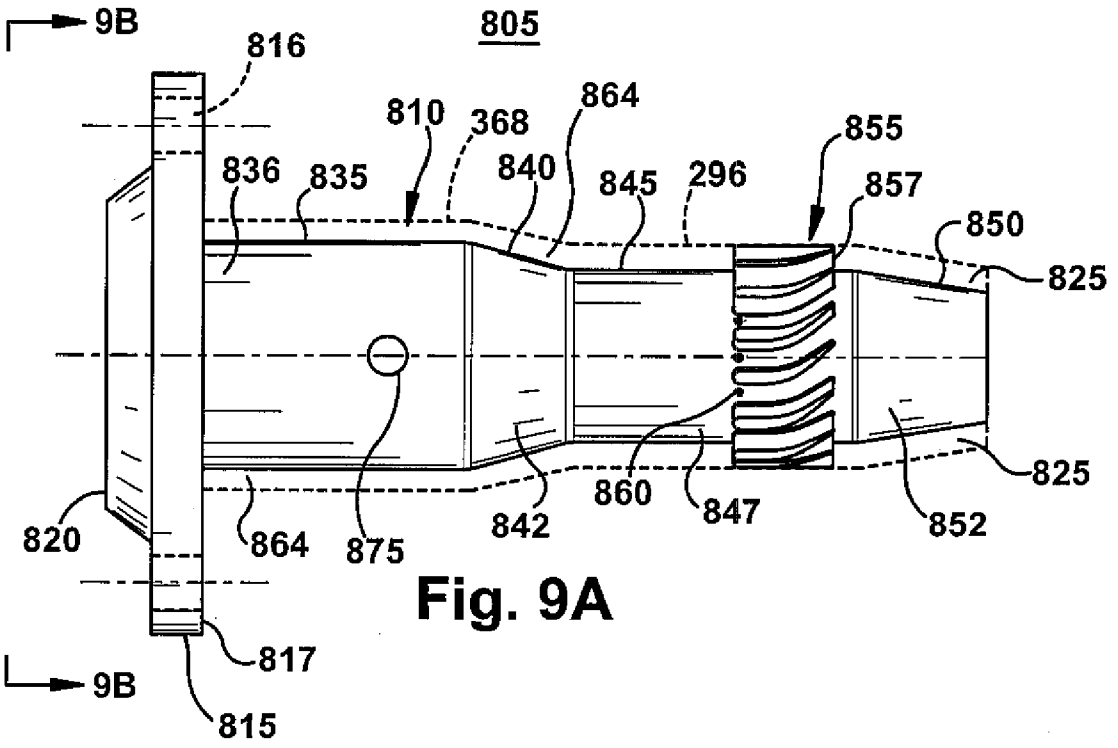

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Fig. 9A

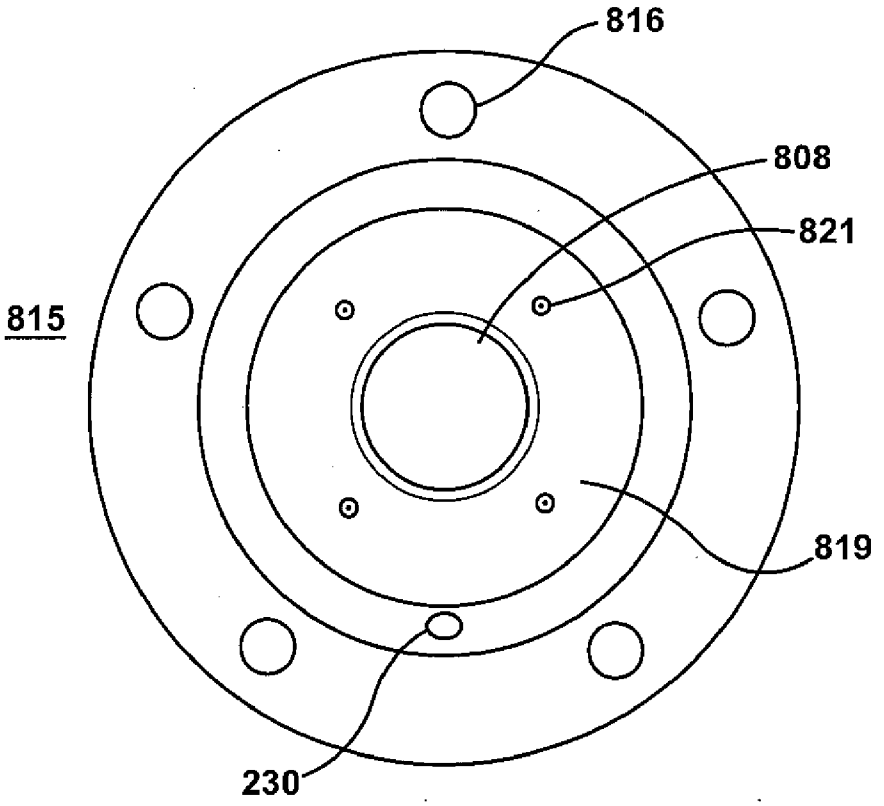

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Fig. 9B

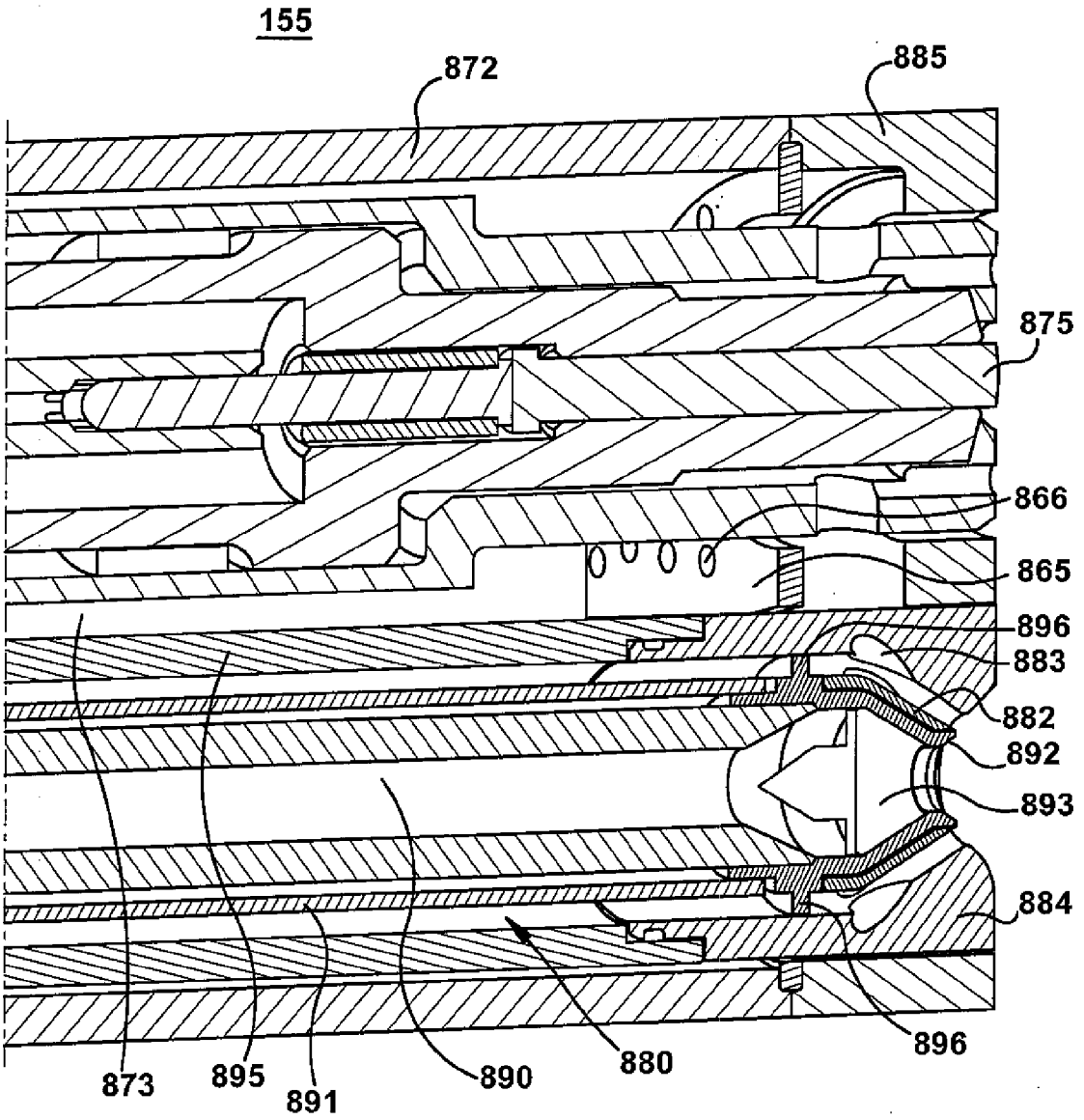

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Fig. 10

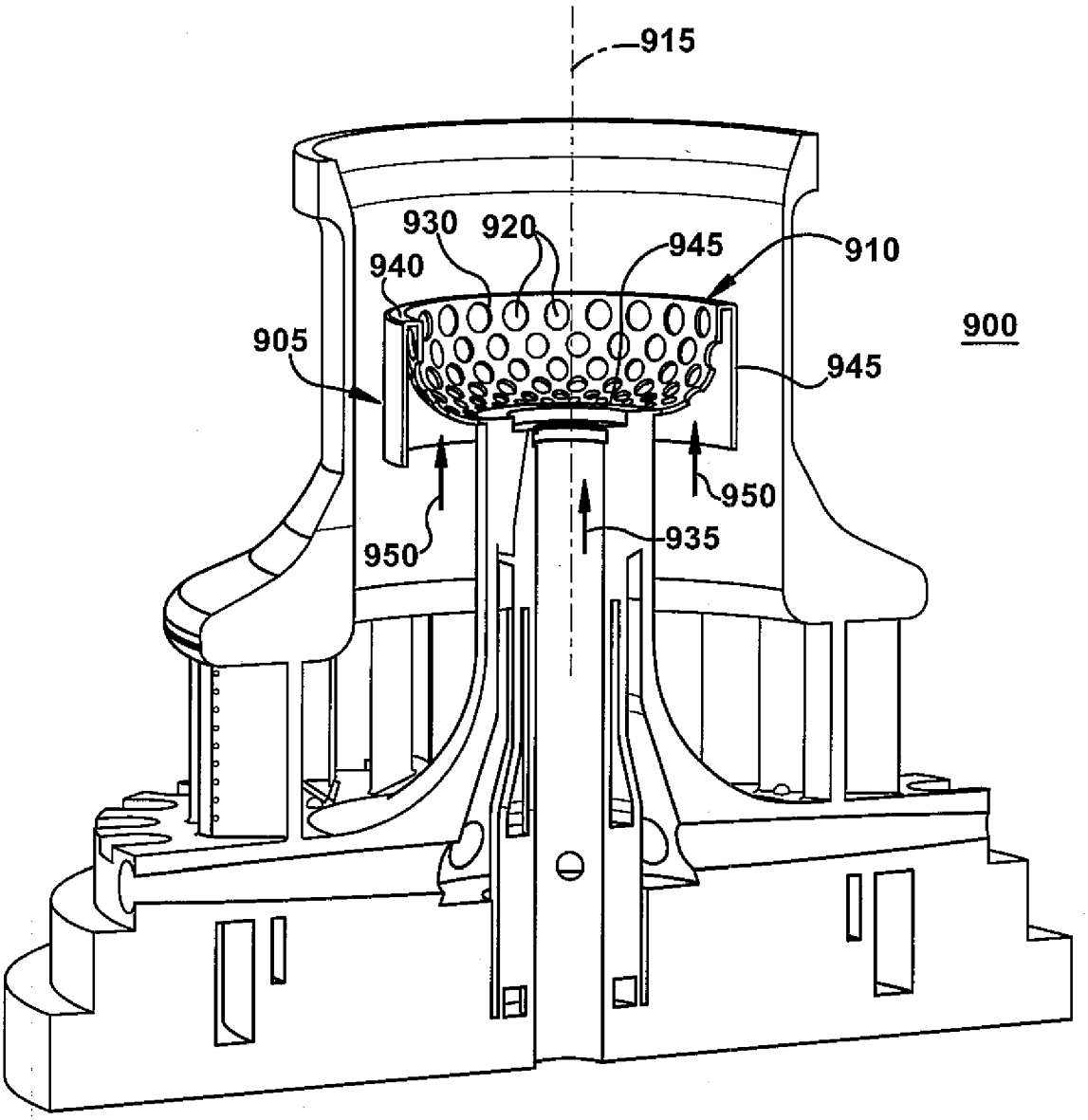


Fig. 11

LEAN PREMIXED, RADIAL INFLOW, MULTI-ANNULAR STAGED NOZZLE, CAN-ANNULAR, DUAL-FUEL COMBUSTOR

BACKGROUND OF THE INVENTION

[0001] The invention relates generally to gas turbine combustors and more specifically to a lean premixed, radial inflow, multi-annular staged nozzle for a can-annular dual-fuel combustor that dramatically reduces or eliminates combustion dynamics.

[0002] FIG. **1** illustrates a prior art combustor for a heavy-duty industrial gas turbine **10**, which includes a compressor **12** (partially shown), a plurality of combustors **14** (one shown for convenience and clarity), and a turbine **16** (represented by a single blade). Although not specifically shown, the turbine **16** is drivingly connected to the compressor **12** along a common axis. The compressor **12** pressurizes inlet air, which is then reverse flowed to the combustor **14** where it is used to cool the combustor **14** and to provide air to the combustion process. Although only one combustor **14** is shown, the gas turbine **10** includes a plurality of combustors **14** located about the periphery thereof. A transition duct **18** connects the outlet end of each combustor **14** with the inlet end of the turbine **16** to deliver the hot products of combustion to the turbine **16**.

[0003] Each combustor **14** includes a substantially cylindrical combustion casing **24** which is secured at an open forward end to a turbine casing **26** by means of bolts **28**. The rearward end of the combustion casing **24** is closed by an end cover assembly **30** which may include conventional supply tubes, manifolds and associated valves, etc. for feeding gas, liquid fuel and air (and water if desired) to the combustor **14**. The end cover assembly **30** receives a plurality (for example, five) of fuel nozzle assemblies **32** (only one shown for purposes of convenience and clarity) arranged in a circular array about a longitudinal axis of the combustor **14**. Each fuel nozzle assembly **32** is a substantially cylindrical body having a rearward supply section **52** having inlets for receiving gas fuel, liquid fuel and air (and water if desired) and a forward delivery section **54**.

[0004] Within the combustion casing **24**, there is mounted, in substantially concentric relation thereto, a substantially cylindrical flow sleeve **34** which connects at its forward end to the outer wall **36** of the transition duct **18**. The flow sleeve **34** is connected at its rearward end by means of a radial flange **35** to the combustion casing **24** at a butt joint **37** where fore and aft sections of the combustor casing **24** are joined.

[0005] Within the flow sleeve **34**, there is a concentrically arranged combustion liner **38**, which is connected at its forward end with the inner wall **40** of the transition duct **18**. The rearward end of the combustion liner **38** is supported by a combustion liner cap assembly **42** which is, in turn, supported within the combustion casing **24** by a plurality of struts **39**. It will be appreciated that the outer wall **36** of the transition duct **18**, as well as that portion of flow sleeve **34** extending forward of the location where the combustion casing **24** is bolted to the turbine casing **26** (by bolts **28**) are formed with an array of apertures **44** over their respective peripheral surfaces to petit air to reverse flow from the compressor **12** through the apertures **44** into the annular space between the flow sleeve **34** and the liner **38** toward the upstream or rearward end of the combustor **14** (as indicated by the flow arrows shown in FIG. **1**).

[0006] The combustion liner cap assembly **42** supports a plurality of premix tubes **46**, one for each fuel nozzle assembly **32**. More specifically, each premix tube **46** is supported within the combustion liner cap assembly **42** at its forward and rearward ends by front and rear plates **47**, **49**, respectively, each provided with openings aligned with the open-ended premix tubes **46**. The premix tubes **46** are supported so that the forward delivery sections **54** of the respective fuel nozzle assemblies **32** are disposed concentrically therein.

[0007] The rear plate **49** mounts a plurality of rearwardly extending floating collars **48** (one for each premix tube **46**), arranged in substantial alignment with the openings in the rear plate **49**. Each floating collar **48** supports an annular air swirler **50** in surrounding relation to the respective fuel nozzle assembly **32**. Radial fuel injectors **66** are provided downstream of the swirler **50** for discharging gas fuel into a premixing zone **69** located within the premix tube **46**. The arrangement is such that air flowing in the annular space between the liner **38** and the flow sleeve **34** is forced to again reverse direction in the rearward end of the combustor **14** (between the end cap assembly **30** and sleeve cap assembly **42**) and to flow through the swirlers **50** and premix tubes **46** before entering the burning zone or combustion chamber **70** within the liner **38**, downstream of the premix tubes **46**. Ignition is achieved in the multiple combustors **14** by means of a spark plug **20** in conjunction with cross fire tubes **22** (one shown) in the usual manner.

[0008] In power plant design, reducing emissions of harmful gases such as nitrogen oxides (NOx) into the atmosphere is of prime concern. Low NOx combustors employing lean premixed combustion with a plurality of burners attached to a single combustion chamber, such as described in FIG. **1**, have been developed to approach this problem. Each burner includes a flow tube with a centrally-disposed fuel nozzle comprising a cylindrical hub, which supports fuel injectors and an air swirler and has a flat face on its downstream end. In addition to a premix-injection stage for low NOx operation, each fuel nozzle can include a diffusion-injection stage for start-up and emergency operations and a liquid fuel-injection stage for liquid fuel operation.

[0009] Diffusion gas fuel and liquid fuel are typically injected via orifices located on the flat end face of the fuel nozzle. During low NOx (premix) operation, fuel is injected through the fuel injectors and mixes with the swirling air in the flow tube. The diffusion and liquid fuel circuits are typically purged with air during premix operation to keep flame gases out of the passages. The combustion flame is stabilized by bluff-body recirculation behind the fuel nozzle and swirl breakdown, if swirl is present. With premixed systems, strong pressure oscillations are typically produced as a result of combustion instabilities. The combustion instabilities are believed to be related to the shedding of spanwise vortices from the bluff end of the fuel nozzle. These pressure oscillations can severely limit the operation of the device and in some cases can even cause physical damage to combustor hardware. Furthermore, the flow of purge air through the diffusion and liquid fuel circuits is injected directly into the recirculation zone. This direct injection reduces the local temperature and strength of the recirculation, producing an adverse effect on flame stability. Accordingly, there is a need for a low NOx combustor, which reduces pressure oscillations and avoids the adverse effects of injecting purge air directly into the recirculation zone.

[0010] As previously described, these contemporary heavy-duty industrial Dry-Low NOx (DLN) can-annular gas turbine combustors typically employ a multiplicity (or gang)

of premixing nozzles interfaced with a can combustor liner using a flat or angled cap/dome assembly. Multiple nozzles are required for the mixing and the staging of fuel to achieve turndown and performance throughout the intended operability and design space. This approach, however, creates a complicated and expensive assembly.

[0011] Also, distributing the air and fuel uniformly to the cluster of premixing fuel nozzles at the headend is difficult and generally results in less than ideal, uniform air flow to all the nozzles, or a substantial amount of parasitic pressure drop/loss. Swirl-stabilized, lean premixed (LP) combustion tends to be highly susceptible to combustion-driven oscillations (dynamic instability) compared to conventional, diffusion style combustion.

[0012] Historically, in the gas-turbine-engine industry, flame temperature (or primary zone temperature) has been reduced in LP systems to reduce NOx emissions. As acceptable NOx exhaust emissions levels have been decreased down to single digit parts-per-million (ppm) levels (driven primarily by new government regulations) flame temperature has been driven very near to the lean-blowout (LBO) limit, at least for fuels with a high methane content. For such lean mixtures, slight, periodic variations in local fuel-to-air mixture ratio results in relatively large, periodic variations in local heat release and heat-release rates—even including local, periodic flame extinction. Discrete, oscillation frequencies (or tones) can grow in amplitude when the heat-release fluctuations are constructively in phase with the acoustic pressure fluctuations encountered inside the combustion chamber.

[0013] As present LP combustors become leaner and more spatially uniform to meet increasingly lower NOx emissions, and are increasingly required to meet those emission targets while running on a broadening range of fuels, the risk of encountering unacceptably high levels of combustion dynamics goes up for a given system.

[0014] Although, large single-nozzle DLN, low-NOx can-annular gas-turbine combustion systems have been tried previously, most have failed due to operability, durability, and emissions problems. Lack of smart, tunable operating parameters and a lack of multiple independent combustion staging zones has led the industry to embrace modular, multi-nozzle (gang) configurations. Multi-nozzle designs allow for the staging or skewing of fuel distribution to subgroups of nozzles to not only facilitate lightoff and turndown, but to provide a tunable operability parameter to skirt dynamics (or oscillations) encountered while running in the design, operating space.

[0015] The downside of skewing the fuel distribution in the combustor is that hotter temperature zones are created that drive NOx production. Thus, if too much skewing is required to squash dynamics or instability, the breaching of regulatory NOx emissions limits could occur, possibly putting the unit out of commission. LP combustion dynamics in industrial gas turbines are typically abated passively in a few ways, usually a trial and error process, which can be expensive and uncertain. Some of the methods are listed below: 1) shifting the fuel injection points to alter the fuel transport time from the point of injection to the flame front, 2) changing the fuel injection orifice sizes to alter the pressure drop and the acoustic impendence across the holes, and 3) modifying chamber or nozzle geometries (e.g., diameters, angles, lengths) to affect vortex shedding, frequencies and amplitudes, or flame shape in the chamber.

[0016] These methods attempt to force any perturbations in heat release to be out of phase (or destructively in phase) with pressure or acoustic perturbations in the combustion chamber. Combustor dynamics have also been reduced or eliminated by adding acoustic damping (e.g., Helmholtz resonators or quarter-wave tubes) to the combustion system. In the past, the above methods have tended to be considered and exercised ex post facto to discovering high combustor dynamics, instead of designing for them proactively during the initial design phase in the program.

[0017] Accordingly, there is a need to provide a simpler, scalable, less-expensive LP combustor that is fundamentally much less likely, in a statistical and absolute sense, to excite or drive discrete combustion oscillations at any loading within the design/operating space, while having an above average tolerance to fuel-mixture quality. Assuming that if the above solution were found, and that, consequently, the risk of ever encountering discrete dynamics in the given design operating space were greatly reduced, then the efficiency and probability of tuning for the minimum emissions for a given system would be greatly increased. Essentially, dynamics would no longer be such a significant and intractable part of the overall combustor-design procedure.

BRIEF DESCRIPTION OF THE INVENTION

[0018] The present invention relates to an apparatus and method creating three independent combustion zones in a gas turbine combustor with a lean premixed, radial inflow, multi-annular, staged nozzle, thereby providing stable combustion with low nitrogen oxide (NOx) emissions.

[0019] Briefly in accordance with one aspect of the present invention, a lean premixed, radial inflow, multi-annular, staged nozzle for creating three independent combustion zones within a can-annular, dual-fuel gas turbine combustor is provided. The lean premixed, radial inflow, multi-annular, staged nozzle (hereinafter referred to as a single large radial nozzle) includes a pilot zone fueled by a center cartridge; a flame holder zone fueled by an inner main gas fuel; a main flame zone fueled by an outer main gas fuel; a main radial swirler for mixing a portion of incoming air to the nozzle with the inner main gas fuel supply and the outer main gas fuel supply; an endcover; and means for controlling the ratio of pilot gas fuel supplied, inner main gas fuel supplied, and an outer main gas fuel supplied.

[0020] In accordance with another aspect of the present invention, a can-annular, dual-fuel combustor for a gas turbine engine is provided. The combustor includes a lean premixed, radial inflow, multi-annular, staged nozzle (hereinafter referred to as a single large radial nozzle), incorporating an outer burner tube and a main radial swirler, mounted on an endcover to a combustor casing. A main combustion zone is provided downstream from the outer burner tube of the single large radial nozzle. A source of compressed air from a compressor source is provided. An air inlet plenum radially surrounds the single large radial nozzle and is bounded radially by an outer wall of the combustor. A diffuser for the compressed air receives the compressed air in a reverse flow path from the compressor and discharges the compressed air at a restored pressure to the inlet plenum. A fairing mounted atop the main radial swirler and surrounding a portion of the outer burner tube is provided for smoothing air flow from the diffuser to the air inlet plenum.

[0021] In accordance with a third aspect of the present invention, a method is provided for utilizing a lean premixed,

radial inflow, multi-annular, staged nozzle (hereinafter referred to as a single large radial nozzle) with independent combustion zones, wherein the single large radial nozzle includes a pilot zone, a flame holder zone and a main zone, within a gas turbine combustor for providing stable combustion with low Nitrogen Oxide (NOx) emissions. The method includes providing a large supply of air to the nozzle; intra-nozzle staging; breaking up of the heat release into a multiplicity of discrete zones in space; distributing the heat release in time; and ventilating a downstream central recirculation zone.

BRIEF DESCRIPTION OF THE DRAWING

[0022] These and other features, aspects, and advantages of the present invention will become better understood when the following detailed description is read with reference to the accompanying drawings in which like characters represent like parts throughout the drawings, wherein:

[0023] FIG. **1** illustrates a prior art combustor with multiple nozzles;

[0024] FIG. **2** illustrates an embodiment of an inventive combustor including an inventive large single radial nozzle combustor;

[0025] FIG. **3**A illustrates an isometric cutaway showing an internal structure for an embodiment of the inventive large single radial nozzle structure;

[0026] FIG. **3**B illustrates an axial cross-section showing an internal structure for an embodiment of the inventive large single radial nozzle structure;

[0027] FIG. **4** illustrates an supply-end view of the end-cover plate for an embodiment of the inventive large single radial nozzle:

[0028] FIG. **5** illustrates fuel galleries and fuel penetrations in the endcover and backplate of an embodiment of the inventive large single radial nozzle;

[0029] FIG. **6**A illustrates an isometric view for a main radial swirler of an embodiment of the inventive large single radial nozzle;

[0030] FIG. **6**B illustrates details of main swirl vanes on the main radial swirler of an embodiment of the inventive large single radial nozzle;

[0031] FIG. **6**C illustrates an elevation view of the main radial swirler for an embodiment of the inventive large single radial nozzle;

[0032] FIG. **6**D illustrates a section through the main swirl vanes and central hub of the main radial swirler for an embodiment of the inventive large single radial nozzle

[0033] FIG. **6**E illustrates a section through the backplate and central hub of the main radial swirler of an embodiment of the inventive large single radial nozzle;

[0034] FIG. **7** illustrates a cross-section of the head end of the inventive combustor depicting air flow and independent combustion zones of an embodiment of the inventive large single radial nozzle;

[0035] FIG. **8** illustrates the central flame holder, gas pilot annulus, and center cartridge of an embodiment of the inventive large single radial nozzle;

[0036] FIGS. **9**A and **9**B illustrate the nozzle body of the gas pilot nozzle for an embodiment of the inventive large single radial nozzle;

[0037] FIG. **10** illustrates an axial section view of a dual-fuel center cartridge of an embodiment of the inventive large single radial nozzle; and

[0038] FIG. **11** illustrates an alternate embodiment for the flameholder cup for the inventive large single radial nozzle.

DETAILED DESCRIPTION OF THE INVENTION

[0039] The following embodiments of the present invention have many advantages, including several innovative and unique features: (1) allowing for multiple (e.g., six) premixing nozzles (per can) and a combustor-chamber cap to be replaced with just one large radial nozzle and a liner modification, thereby achieving a significant part-count reduction, a cost savings, and a dramatic simplification of the combustor's head-end; (2) using a dome-diffuser design to backside, convectively cool the liner's dome, while, simultaneously recovering static pressure prior to premixing the fuel and air in the large radial nozzle, thereby causing less parasitic pressure loss and malting more air available for premixing; (3) providing the capacity to rapidly (e.g. <3 msec) and thoroughly vaporize and mix large quantities of fuel (~2 lbm/sec) and air (~60 lbm/sec) at a relatively low pressure drop (e.g., <4%); and (4) using either gas fuel or liquid fuel, it is more robust dynamically and less prone to combustion-driven oscillations than contemporary lean-premixed (LP) gas-turbine combustion systems, by strategically distributing or smearing out both the heat release (in time and space) and fuel transport time in the chamber, while still delivering the necessary system turn-down performance and low exhaust emissions.

[0040] The effect of the design is multifaceted: (1) the replacement of five or more nozzles per can with one for a dramatic cost and parts-count reduction; (2) the dramatic reduction or even complete elimination of combustion dynamics/oscillations at discrete frequencies within industrial gas turbine combustion chambers, while maintaining required emissions levels; (3) gas and liquid fuels flexibility, which is tied to the success of combustion dynamics improvement; (4) DLN with liquid fuels like No. 2 diesel oil, while eliminating the need for water injection and high-pressure atomizer air; and (5) low single-digit (ppmv) noxious emissions.

[0041] To go from a multi-nozzle arrangement to a large single nozzle, successfully, requires intra-nozzle staging. A zone of angled v-gutter flame holders, used in this design, provides a region for fuel staging within the main premixing nozzle. For example, biasing the fuel-air ratio to be richer near the hub (or centerbody) in the premixer, can allow a central flame-holder zone to burn at a higher equivalence ratio relative to the bypassing flow, which may be advantageous (or even necessary) for ignition, machine acceleration, low-load operation, or handling sudden load transfers. Biasing the fuel-air ratio, in conjunction with other staging features (like a premixed pilot), will allow for a single large radial nozzle to replace multiple nozzles (e.g., six), per can, in gas turbine combustion systems—which would amount to a significant part-count reduction and cost savings for the combustion system and the engine as a whole. Combustion dynamics reduction would be achieved while maintaining or even reducing noxious exhaust emissions (e.g., unburnt hydrocarbons (UHC), NOx, and carbon monoxide (CO)), relative to the firing temperatures encountered in the design space.

[0042] The lean premixed, radial inflow, multi-annular staged nozzle (hereinafter referred to as a single large radial nozzle), by design, is less likely to excite combustion-driven, discrete oscillation frequencies when the set fraction (e.g., about 33% of the nozzle's reactants) of well-mixed reactants is redirected to burn as an angled array of discrete, v-gutter

zones upstream of the main chamber. The array of axial jets passing through the conical v-gutter-pack structure abates discrete dynamics and improves emissions in a few ways.

[0043] First, the array breaks up the heat release into a multiplicity of discrete reaction zones in space, each reacting at spatial scales that are much smaller than that of the overall combustion chamber. This effectively limits the amount of energy release that can constructively couple at a particular acoustic, resonant frequency within the chamber.

[0044] Second, the angled v-gutters create a multiplicity of fuel transport times, which distributes (or smears out) the heat release in time. That is, each point along the v-gutter length has its own associated transport time: the time between the point(s) of fuel injection and the point(s) of burning. This, too, effectively limits the amount of heat-release energy that can constructively couple at a particular chamber acoustical, resonant frequency.

[0045] Third, the function of the de-swirler pack is the "ventilation" of the downstream central recirculation zone (CRZ), resulting from vortex breakdown. From the central cone, the expanding array of jets injects non-swirling, axial momentum directly into the CRZ, which reduces the size and the bulk residence time of the CRZ. This, in turn, reduces nitrogen oxide (NOx) production by reducing the average time that the combustion-product molecules spend at the primary-zone (flame) temperature inside the combustor. The concept of "time at temperature" for NOx production becomes increasingly significant at flame temperatures above 2900 F, where the Thermal NOx (or Zeldovich) mechanism begins to accelerate and its contribution to overall system NOx levels begins to significantly increase.

[0046] The nozzle further provides an anti-coke design for operation with diesel liquid fuel that requires no water and no atomizer air. Aspects of the design prevent fuel gallery coking through an insulated fuel gallery wall for high reliability. Liquid fuel is rapidly atomized and thoroughly dispersed into the premixer airflow, keeping it off of hot premixer surfaces to vaporize and mix quickly with the air. The liquid injection scheme does not adversely impact gas operation. Eliminating the need for water injection and high-pressure atomizer air further provides a cost saving.

[0047] Complete fuel-air mixing is rapid (approximately 2 msec), thorough (greater than 97%), and requires a low premixer differential pressure (~2%), thereby reducing the required premixer residence time to create a shorter, more compact design and to stay below the auto-ignition time of diesel at "advanced" gas turbine conditions.

[0048] Several further aspects and advantages of the invention will become clear in the description. Turndown capability is enhanced via fuel staging (3 pseudo-independent combustion zones). Using a backside-cooled dome eliminates the need for liner cooling air in the flame zone.

[0049] Also, axi-symmetric, radial combustion staging does not subject the combustor liner to asymmetric loading, thereby providing improved combustion liner durability.

[0050] Further, improved internal premixer flame-holding resistance/margin: flow is accelerated throughout premixer nozzle; bulk velocity is kept above about 300 ft/sec.

[0051] A v-gutter lean angle (radial-axial plane) and the de-swirler vane profile were chosen as the two parameters to optimize. The v-gutter lean angle was varied between 30- and 60-deg. to maximize the lean angle, while still generating a well defined, continuous v-gutter wake to support an independent combustion zone. For non-reacting CFD, the 40-deg. configuration was the largest angle that still produced a continuous v-gutter wake with other nozzle features being held constant. The de-swirler vane profile was successfully adjusted/optimized by aligning the inlet vane angle with the incoming swirling flow and using the cascade geometry to accelerate the flow through the pack; thus, preventing any flow separation in the pack.

[0052] FIG. **2** illustrates an embodiment of the inventive large single radial nozzle employed in an inventive combustor. The large single radial nozzle combustor **100** includes a substantially cylindrical combustor casing **105**, which may be secured at an open forward end to a transition piece (not shown) for connection with a turbine by plugging a combustion liner into the transition piece. The transition piece may then be secured at an open forward end to a turbine casing by bolts in the usual manner. The rearward end of the combustor casing is closed by an endcover assembly **130** adaptable to conventional packages for supply tubes, manifolds, valves and fittings for gas fuel, liquid fuel, air, and power (not shown). The endcover assembly **130** is part of and secures a large radial nozzle assembly **120** to the combustor casing **105**.

[0053] Within the combustion casing **105**, there is mounted in substantially concentric relation thereto a flow sleeve **106**. Within the flow sleeve **106**, there is concentrically arranged combustion liner **110**, connected at its forward end **112** to the inner wall of the transition liner (not shown), into which it plugs. The rearward end of combustion liner **110** forms a truncated conical dome **111** on a main combustion chamber **114**, the truncated conical dome **111** being open at its center to fuel and combustion products flow from the large radial nozzle **120** and further mating with the outer burner tube **113** of the large radial nozzle **120**.

[0054] Air for the combustion process may be drawn from the air compressor into the transition piece (as previously described with respect to FIG. **1**) and thence through the annular space **115** between the flow sleeve and the outside wall of the combustion liner. At the aft end of the annular space, a concentric mounted diffuser **116** expands the air into the inlet plenum **117** for the large radial nozzle **120**. The dome-**111** serves as an inner concentric wall of the diffuser **116**, thereby permitting backside cooling of the dome **111** by the air flowing through the diffuser **116**. Simultaneously, the diffuser **116** recovers static pressure for the air prior to premixing the fuel and air in the large radial nozzle **120**, resulting in less parasitic pressure loss and more air being available for premixing. A fairing **118** around the center of the large radial nozzle **120** smoothes air entry into the inlet plenum **117** further reducing parasitic pressure loss.

[0055] The large radial nozzle **120** further includes a main radial swirler **140**, a gas pilot nozzle **150**, a central flame holder with a v-gutter flame holder **160**, and an outer flame holder **170**. The central flame holder **160** and the outer flame holder **170** open on their forward end into the main combustion chamber **114**.

[0056] The endcover **130** may be a generally cylindrical-shaped flange designed to mate with a combustor casing **105** and support the radial nozzle assembly **120** within the combustor **100**. The aft surface **135** of the endcover **130** provides penetrations for dual-fuel (gas and liquid fuel) as well as for the gas pilot nozzle **150**. A outer main gas supply **190**, a inner main gas supply **190** and one of a plurality of liquid gas connections **195** are shown in FIG. **3**A. The arrangement of

the penetrations, for fuel and air, permit connection to existing combustor configurations of fuel, air and power lines (not shown).

[0057] FIG. **3**A illustrates an isometric cutaway showing an internal structure for an embodiment of the inventive large single radial nozzle. FIG. **3**B illustrates an axial cross-section showing an internal structure for an embodiment of the inventive large single radial nozzle. The nozzle is axi-symmetric along a central axis **200**.

[0058] The endcover assembly **130** includes an endcover plate **205** with an aft section **201**, a forward section **202** and a central cavity **203**. A main radial swirler **140** includes a backplate **240**, a plurality of swirl vanes **250** and a central hub **260** with a central cavity **265** within. The backplate **240** is bolted at mounting surface **241** to endcover plate **205**.

[0059] A central flame holder **160** is mounted atop the central hub **260**. A center hub **285** of the central flame holder **160** mates with the central hub **260** of the main radial swirler **140** to support the central flame holder **160** radially and axially. Radial vanes **360** support inner burner tube **300** from center hub **285**. A plurality of v-gutters **290** extend between the inner burner tube **300** and the center hub **285**. A central cavity **278** is formed within center hub **285**. Atop the swirl vanes **250** of the main radial swirler **140**, an outer flame holder **170** with cylindrical outer burner tube **175** is mounted with a base section **180** that flares outward radially and attaches with bolts **183** to the top of the swirl vanes **250**. The downstream end **178** of outer burner tube **175** also flares outward and is reinforced to provide support for the conical dome **111** (FIG. **2**) of the combustor. Support ledge **179** mates with combustor conical dome **111**. A fuel-air mixture from the main radial swirler **140** passes to a flameholder zone through **402** and to the main zone through **405** (FIG. **7**). The central cavities **203**, **265** and **278** allow for insertion of a gas pilot nozzle **150** including a gas pilot and a center cartridge including, a liquid pilot and an igniter.

[0060] FIG. **4** illustrates an aft-end view of the endcover plate of an embodiment of the inventive large single radial nozzle with respect to a combustor in which it may be installed. The endcover plate **205** includes the integral cylindrical shaped aft section **201** and a cylindrical shaped forward section **202** (FIG. **3**A) of a smaller diameter, both layers being centered on the central axis **200** of the nozzle. The aft section **201** is sized radially to mate with a rear seating surface of the combustor (not shown) and incorporates a plurality of bolt holes **206** formed axially and in proximity to the outer circumferential surface **207** of the outer section **201** for attaching to the seating surface of the combustor. The aft section **201** may also include a plurality of pilot holes **208** (similarly directed) for positioning the aft section **201** with respect to the seating surface of the combustor, in preparation for bolting. The forward seating surface **205** of the forward section **202** may also include a plurality of bolt holes **209** in a circular configuration concentric with the central axis **200** of the nozzle and adapted to receive bolts from the mounting surface **241** of the backplate **240** for the main radial swirler **250** (FIG. **3**A).

[0061] Two independent gas fuel supplies may be connected to the endcover plate **205**. The aft section **201** includes an outer main gas penetration **215** attached to an outer main gas supply inlet pipe **216** with outer main gas inlet flange **217** for connection to the outer main gas fuel supply (not shown). The aft section **201** also includes an inner main gas penetration **220** with a fitting **219** for connection to an inner main gas supply (not shown). The endcover plate **205** may also include a plurality of liquid fuel supply penetrations **243** located concentric to the central axis **200** of the nozzle.

[0062] FIG. **4** also illustrates the aft end of gas pilot nozzle **150**. The central cavity **203** is defined within the endcover plate **205** extending radially from the central axis **200** and extending through the aft section **201** and the forward section **202** for insertion of a gas pilot nozzle. The central cavity **203** includes a gas pilot nozzle seating surface **210** (FIG. **3**B) with threaded connections for mating with a gas pilot nozzle rear flange **212** to mount the gas pilot nozzle **150**

[0063] FIG. **5** illustrates fuel galleries in the endcover and backplate of an embodiment of the inventive nozzle. The outer main gas penetration **215** (FIG. **4**) is connected to a outer main gas gallery **310** in the endcover plate **205**. The outer main gas gallery **310** defines an annular chamber concentric with the central axis **200** of the nozzle. The inner wall **311** and outer wall **312** of the outer main gas gallery **310** may be radially located with respect to the central axis **200** of the nozzle, such that the open upper end **315** of the outer main gas gallery **310** communicates with a plurality of corresponding outer main gas channels **665** (FIG. **3**B) within the main swirler backplate **240**.

[0064] The inner main gas penetration **220** is connected to a inner main gas gallery **330** in the endcover plate **205**. The inner main gas gallery **330** defines an annular chamber concentric with the central axis **200** of the nozzle. The inner wall **317** and outer wall **318** of the inner main gas gallery **330** may be concentric to the central axis **200** of the nozzle. The inner main gas gallery **330**) is located radially between the outer main gas channel **310** and the central cavity **203**. The inner wall **317** and outer wall **318** of the inner main gas gallery are radially located, such that the open upper end **319** of the inner main gas gallery **330** communicates with corresponding inner main gas channels **680** (FIG. **7**) within the main swirler backplate **240** to supply inner main gas to inner main gas injection points **695** on the base surface **242** between the swirl vanes **250**.

[0065] Liquid fuel supply penetrations **243** extend axially through the aft section **201** of the endcover **205**, communicating with a main liquid fuel gallery **244**. The main liquid fuel gallery **244** defines an annular chamber concentric with the central axis **200** of the nozzle and sealed except for liquid fuel supply penetrations **243** and liquid fuel delivery penetrations **246**. The main liquid fuel gallery **244** is located radially to align with the liquid fuel supply penetrations aft **243** and the liquid fuel delivery penetrations **246** forward on the endcover plate **205**. The liquid fuel delivery penetrations **246** extend through the forward section **202** of the endcover **205** to mate with corresponding liquid fuel delivery penetrations **247** in the main radial swirler backplate **240** leading to atomizers **248** for the liquid fuel in the main swirler backplate **240**. The walls of the main liquid fuel gallery **244** and the liquid fuel supply penetration and liquid fuel delivery penetration **246** in the endcover **205** and fuel delivery penetrations **247** in the backplate **240** may be provided with an insulated lining **249** to keep wall temperatures below 290 degrees F. where coking of diesel liquid fuel begins. Fittings **218** are provided external to the liquid fuel supply penetrations for connection to the liquid fuel supply.

[0066] Because the endcover plate **205** and the main swirler backplate **240** mate in a metal to metal seating surface **241**, provision is made to isolate potential leakage from the fuel cavities along the seating surfaces **204**, **241**. Three annular

recesses (FIG. **5**) concentric with the nozzle central axis **200** may be provided on the upper seating surface **204** of the endcover plate **205**. The first recess **381** is provided outboard of the outer main gas gallery **310**. The second recess **382** is provided between the outer main gas gallery **310** and the inner main gas gallery **330**. The third recess **383** is provided inboard of the inner main gas gallery **330**. The recesses may be provided with C-rings or other suitable gasketing material to prevent flow along the seating surface.

[0067] FIGS. **6**A-**6**E illustrate views of a main radial swirler for an embodiment of the inventive nozzle. FIG. **6**A illustrates an isometric view of a main radial swirler of an embodiment of the inventive nozzle. FIG. **6**B illustrates details of main swirl vanes on the main radial swirler of an embodiment of the inventive nozzle. FIG. **6**C illustrates an elevation view of the main radial swirler for an embodiment of the inventive nozzle. FIG. **6**D illustrates a section through the main swirl vanes and central hub of the main radial swirler for an embodiment of the inventive nozzle. FIG. **6**E illustrates a section through the backplate and central hub of the main radial swirler of an embodiment of the inventive nozzle.

[0068] The main radial swirler **140** includes a backplate **240** with an integral central hub **260**, a plurality of main swirl vanes **250** mounted on the backplate **240** and projecting orthogonally to the backplate **240** (downstream toward the combustion zones), a central cavity **265** to accommodate the gas pilot nozzle **150** and a series of internal passages within the backplate and main swirl vanes **250** to provide for flow of fuel and air.

[0069] The backplate **240** comprises a cylindrical shaped flange centered on the central axis **200** of the nozzle. A base surface **241** of the backplate **240** is sized radially to mate with the forward surface **204** of the endcover plate **205**. The mounting surface **242** of the backplate incorporates a plurality of recesses **371** accommodating bolt holes **372** around the periphery the backplate **240**. The bolt holes **372** extend through to the base surface **241** of the backplate **240** and align with the bolt holes **209** on the forward **204** surface of the endcover plate **205**. The mounting surface **242** of the backplate **240** provides for mounting a plurality of main swirl vanes **250** and housing injection points for fuel into an air flow steam within the main radial swirler **140**

[0070] The plurality of main swirl vanes **250**, each including a solid metal airfoil **610**, may be mounted orthogonal to the backplate **240** and project axially toward the combustion zones. The main swirl vanes **250** may be mounted inboard radially from the peripheral bolt hole recesses **371** and outboard radially from the central hub **260**. A leading edge **615** of each airfoil projects generally outward radially and a trailing edge **620** projects generally inward radially. The axis **625** of each airfoil may form a predesignated acute angle α (approximately 15°) **630** with a radius **635** from the central axis **200** of the nozzle. While the leading edge **615** of the airfoil **610** forms a curved surface, the side surfaces **640**, **641** of the airfoil **610** may form a straight-fine taper to the common linear trailing edge **620**. The bottom surface **645** and top surface **650** of the airfoil **610** form plane surfaces. The bottom surface **645** may be mounted to the mounting surface **242** of the backplate **240** by welding or other suitable process.

[0071] A plurality of injection points **655** for outer main gas fuel are provided along a radius concentric with the central axis **200** of the nozzle, on one side surface **640** of the airfoil **610**, just inboard of the curved leading edge **615**. The injection of outer main gas fuel is provided approximately normal to the airflow **660** passing between the adjacent swirl vanes. However, injection points **655** may also be provided on both side surfaces of the airfoil and at other locations than included in the present embodiment. The injection points may be approximately evenly spaced axially along the side surface **640** of the airfoil **610** to permit even distribution of the outer main gas fuel into the airflow **660** between the airfoils **610** in a circumferential premixing space **605**. The airfoils **610** further include an internal fuel cavity **665** supplying the injection holes **657**. The fuel cavity **665** may be a generally cylindrical-shaped hole rising from the base surface **241**, axially into the airfoil **610** and stretching in proximity to and communicating with the injection holes **657**. The fuel cavity **665** directs outer main gas fuel from the fuel cavity **310** in the endplate **205**. The injection holes **657** within each airfoil **610** extend in a radial direction with respect to the cylindrical fuel cavity **665** to supply fuel to the injection points **655**. The top surface **650** of each airfoil **610** may further include a tapped hole **670** for securing the outer burner tube **175** to the main swirl vanes **250**.

[0072] Inner main gas penetrations **680** (FIG. **7**) in the backplate **240** extend axially towards the mounting surface **242** of the backplate **240** from the inner main gas gallery **330** in the endcover plate **205**. An orifice **685** may be provided in each of the inner main gas penetrations **680** to control gas release. Injection points **690** are provided on the mounting surface **242**, approximately equidistant from the side surfaces **640**, **642** of adjacent airfoils **610** and at a point approximately half-way along the side surface **640**, **642** of the adjacent airfoils **610**. With an exemplary 24 airfoils **610**, 24 injection points **690** are provided. An injection tip **695** at each injection point **690**, extending slightly above the mounting surface **242** of the backplate **240**, causes the gas to be injected above the laminar air flow on the mounting surface.

[0073] During gas operation as described above, gas fuel is injected into the air flow of the main radial-swirler **140** from a multiplicity of injection points **655** located axially along the sidewalls **640** of the airfoils **610** and from injection points **695** on the mounting surface **242** of the backplate **240**. The main gas fuel is fed from two independent feed sources as shown in FIG. **4** in order to affect the fuel-air mixture radial profile in an annular swirl volume (premixer annulus) **255**. That is, the mixture near the central hub **260** which eventually passes through the central flame holder device, can be made richer or leaner compared to the mixture near the swirl vanes **250** (which bypasses the central flame holder) by varying the ratio of the fuel supply from the two sources. External means may be supplied to control this ratio of an inner main gas fuel supplied and an outer main gas fuel supplied. This may include control throttling, pressure control or other means known in the art, which may be exercised external to the nozzle.

[0074] A plurality of liquid fuel injection points **245** are also provided on the mounting surface **242** of the backplate **240** for operation on liquid fuel. The liquid fuel injection points **245** are positioned atop the liquid fuel delivery channels **246** in the backplate **240**. The liquid fuel channels **246** in the backplate **240** may include a thermal insulating layer **249**. The liquid fuel injection points **245** are concentric with the central **200** axis and may be positioned to inject liquid fuel in the annular swirl volume **255** at approximately the locus of the trailing edges **620** of the airfoils **610**. In an exemplary arrangement, six liquid fuel injection points **245** are provided circumferentially equidistant around the mounting surface

242. Each liquid fuel injection point 245 is provided with a tip 252 that includes an atomizer 248 of a conical shape, that screws into threads 253 for the liquid fuel delivery channel 247. The atomizer 248 sprays liquid fuel into the air flow in an axial direction normal to the mounting surface 242.

[0075] FIG. 7 illustrates a cross-section of the head end of the inventive combustor depicting air flow and fuel-air flow establishing the independent combustion zones of an embodiment of the inventive nozzle. As previously described and referring to FIGS. 5-7, the inventive combustor incorporating the large single radial nozzle provides three independent combustion zones. The pilot gas nozzle 150 creates pilot combustion zone Z1. Flame holder combustion zone Z2 is created by the axial flow from the deswirler 280 passing over the v-gutters 290 in the central flame holder 160. Main combustion zone Z3 is created by fuel-air mixture flowing between the inner burner tube 300 of the central flame holder 160 and the outer burner tube 175 of the outer flame holder 170 into the main combustion chamber 114.

[0076] Airflow from diffuser 116 flows into inlet plenum 117. The main swirl vanes 250 establish a flow path 660 for incoming air from the inlet plenum 117 for the combustor. About 95% of the air entering the nozzle flows between the main swirl vanes 250. The incoming air, having had outer main gas injected from the airfoils 610 and inner main gas injected from the injection points 690 on the mounting surface 242 and/or liquid fuel injected from the atomizers 248, is directed by the air foils 610 to swirl in a counter-clockwise direction (viewed from the combustion end) through the annular swirl volume 255 (the volume between the swirl vanes and the central hub). Within the annular swirl volume 255, the continued swirling further mixes the fuel with the air.

[0077] The central hub 260 comprises an outer truncated cylindrical conical surface centered on the central axis 200 of the nozzle to minimize flow resistance to a circumferential flowing fuel-air mixture from the main swirl vanes as it rises up into the central flame holder 160. The central hub 260 forms a smooth surface rising from the mounting surface 242 of the backplate 240 and sloping concave inward to form a radial and axial support for the central flame holder 160. Specifically, at its truncated upper reach, the central hub 260 provides an outer annular support ledge 273 for the central flame holder 160. The inner surface 263 of the central hub 260 defines a cavity 265 that accommodates a gas pilot nozzle 150 and includes an internal flow path for air to the gas pilot nozzle 150. The internal surface 263 of the central hub further includes an inner annular mounting ledge 274 for the central flame holder 160.

[0078] The series of internal passages within the backplate includes passages for outer main gas from the outer main gas gallery in the endcover to the swirl vanes; for the inner main gas gallery in the endcover to gas injectors on mounting surface of the backplate; for liquid fuel from the liquid fuel delivery penetrations in the endcover to atomizers on the mounting surface of the backplate; and air passages from the circumferential outer edge of the backplate to the central cavity for cooling and pilot premix air to the radial nozzles center/core.

[0079] The internal passage 680 for inner main gas to the inner main gas injector tips 695 on the mounting surface 242 of the backplate 240 may include orifices 685 in each passage to control gas flow rates to the gas injector tips 695. The outer circumferential surface 257 of the backplate 240 includes a plurality of radial feedholes 275 directed inward to the central cavity 265 for feeding a flow of cooling air and pilot premix air to the central cavity 265. The axial passages within the backplate for outer main gas 270, inner main gas 680, and liquid fuel 247 are situated in circumferential locations between the various radial feedholes 275.

[0080] The central flame holder 160 may include a center hub 285, a central cavity 278, a deswirler 280, and a plurality of v-gutters 290, an inner burner tube 300 and a support tower 295.

[0081] As airflow from between the main swirl vanes 250 is forced into a rotational flow within the annular swirl volume 255, the only exit path is downstream. About 30% of the fuel-air mixture swirled in the main radial swirler 240 enters the central flame holder 160. The central flame holder 160 includes the support tower 350 that sits atop the central hub 260 of the main radial swirler 240. The support tower 350 mates with the outer support ledge 273 and inner support ledge 274 of cylindrical support hub of the central hub 260 to provide axial and radial support for the central flame holder 160. Support arm 355 of the support tower 300 seats on the outer support ledge 273 and the inner support ledge 274. A central cavity 280 within the support tower 295 and the center hub 285 may accept the gas pilot nozzle 150.

[0082] Referring to FIG. 8, atop the support tower 295 sits the deswirler 280 and the concentric hub-mounted, conical, v-gutter flame-holder pack. The deswirler 280 includes a plurality of annular compartments 345 between the center hub 285 and the inner burner tube 295. The annular compartments 345 are open at upstream entrance 347 and downstream exit 348 for the fuel-air mixture. A radial vane 360 is provided between each individual annular compartment 345, the radial vane extending from the center hub 285 to the inner burner tube 295. Each radial vane 360 curves from a somewhat flat slope at the upstream entrance 347 to a steep slope at the downstream exit 348 of the annular compartment 345. The flat axial slope at the upstream entrance accommodates accepting the swirling circumferential flow of the fuel-air mixture from the main swirl vanes 250 of the main radial swirler 140. About 30% of fuel-air mixture from the annular swirl volume 255 of the main radial swirler flows 140 into the annular compartments 345 of the deswirler 280. The changing slope of the radial vanes 360 redirects the circumferential flow to an axial-oriented flow exiting each individual annular compartment 360. The redirected axial flow provides ventilation for the central recirculation zone (CRZ), as previously described.

[0083] Referring to FIG. 3B and FIG. 8, an annular tip 380 of the center hub 285 defines a plane surface I. An annular tip of the inner burner tube 295 defines plane surface II. Plane surface I is downstream of plane surface II. The radial vanes 360 of the deswirler 280 at their downstream ends form a sloping edge between the annular tip 380 of center hub 285 and the tip 385 of the inner burner tube 300, rising at a slope of about 30%.

[0084] A v-gutter 290 is provided at the downstream end of each radial vane 360. The v-gutter 290 comprises a v-shaped element 375 with the open end 376 facing downstream. A vertex 377 of the v-shaped element 376 is attached to and extends through the annular tip 380 of the center hub, along the downstream edge of radial wall 360 and through the tip 385 of inner burner tube 300.

[0085] An outer flame holder 170 comprises a generally cylindrical outer burner tube 175, which flares at an upstream end to form a annular seating surface for mating with the main

swirler. The cylindrical tube radially surrounds and extends towards the combustion chamber beyond the central flame holder **160**. The downstream end **190** of the outer burner tube **175** is reinforced. Ledge **195** provides a seating surface for engagement with the conical dome **111** (FIG. **2**) of the combustor. An annular seating surface **180** of the outer burner tube **175** flares outward radially at its upstream end. The seating surface **180** forms a roof over the main swirlers **250** of the main radial swirler **140**, thereby limiting the exit path for the fuel-air mixture from the main radial swirler **140** to a downstream flow paths **402** and **405**. The seating surface **180** may attach to the top of each airfoil for the main swirl vanes with a plurality of bolts, one bolt for each tapped hole atop the airfoil. The annular space formed between the inner burner tube **295** of the central flame holder **160** and the outer burner tube **175** of outer flame holder **170** for flow **405** of the remaining 70% of the fuel-air mixture from the main radial swirler **140** to the combustion space.

[0086] FIG. **8** illustrates the central flame holder, gas pilot annulus, and center cartridge for an embodiment of the inventive large single radial nozzle. An air flow path for the remaining 5% of incoming air from the inlet air plenum feeds to the central cavity **260** of the nozzle **140** through a plurality of radial penetrations **275** (12 in the embodiment) from the circumferential edge **257** of the backplate **240**.

[0087] As a means of achieving lightoff, combustor turndown, and improving stability, a central gas pilot nozzle **150** is located inside the conical flame-holder volume at the upstream, smallest-diameter end. The gas pilot nozzle **150** provides a center cartridge **155** which may include an igniter/flame detector and a liquid gas pilot.

[0088] The roughly 5% of airflow to the radial nozzle that enters through radial flowholes **275** in the circumferential surface **257** of the backplate **240** for the main radial swirler **140** is split internally. About 80% of this air flows forward through a air supply annulus between the inner wall of the central hub central cavity **265** and an outer surface **812** of an annular shell **810** of the gas pilot nozzle **150** to an annular axial-swirled gas-pilot premixer **855**. The remainder of the air passes through a plurality of radial feed holes **875** in the annular shell **810** into the center cartridge to be used for liquid-pilot atomization and cooling and purging of the center-cartridge tip.

[0089] FIGS. **9**A and **9**B. illustrate the nozzle body of the gas pilot nozzle for an embodiment of the inventive large single radial nozzle.

[0090] The gas pilot nozzle **150** comprises a body **805** with annular shell **810** that may be breech-loaded into the central cavity **203** of the nozzle **140** through the endcover plate **205**. The annular shell **810** includes aft flange **815** at its aft end with a plurality of bolt holes **816** for mounting its forward surface **817** to the seating ledge **210** within the central cavity **203** of the endcover **205**. The aft flange **815** is also provided with a center hole **818** for insertion of the center cartridge **155** and includes an elevated surface **819** on the rear surface **820** about the center cavity incorporating tapped holes **821** for bolting the center cartridge **155** to the gas pilot aft flange **815**. The aft flange **815** is also provided with a penetration **230** for connection to a pilot gas fuel supply for gas pilot operation.

[0091] The gas pilot nozzle body **805** extends through the central cavities **203**, **265**, **278** of the nozzle **120** and into the cylindrical hub **370** of the central flame holder **160**. The gas pilot annular shell **810** tapers in steps from aft end to forward end. The annular shell **810** includes lower shell **835**, a tapered shell **840**, a central shell **845** and a tapered head **850**.

[0092] An annular gas pilot airflow space **864** is also defined between the inner wall **368** of the cylindrical hub **370** and the inner wall **296** of support tower **295** with the outer surfaces **842**, **847** of the tapered shell **840** and the central shell **845**. Air from inner radial ends **277** of the central radial feedholes **275** in the backplate **240** enters the gas pilot airflow space **864** and flows forward axially to axial-swirled gas-pilot premixer **855**.

[0093] The penetration **230** in aft flange **815** for pilot gas fuel supplies internal pilot gas fuel cavities **862** in the annular shell **810**. The internal pilot gas fuel cavities **842** within the lower shell **835** supply pilot gas fuel to the annular pilot gas space **866** between the inner wall of annular shell **810** and outer surface **872** of center cartridge **155**. The tapered head **850** extends in close proximity to the cylindrical hub **370**, thereby forming a gas pilot annulus **825** between the outer surface **830** of the tapered annular head **850** and the inner surface **368** of the cylindrical hub **370**. A plurality of pilot gas fuel holes **860** extend radially through the annular shell at the upstream entrance between adjacent axial mixing vanes **857** providing pilot gas fuel injection points. The forward portion of the central shell **845** accommodates a plurality of axial mixing vanes **857** in the general shape of airfoils on the outer surface **847** for mixing gas pilot fuel and air moving downstream in the airflow space **864**, thereby constituting the annular axial-swirled gas-pilot premixer **855**.

[0094] The center-cartridge **155** includes cylindrical body **405** mounted on a rear flange **224**. The center cartridge **155** is inserted into the central cavity **203** of the gas pilot nozzle body **805** and bolted through the rear flange **224** onto the raised rear surface **820**. The rear flange **224** provides an axial penetration for connections to an igniter and flame detector **236** and on its circumferential surfaces, a radial penetration **232** for liquid pilot fuel and a radial penetration **234** for an air The center cartridge **155** is aligned with central axis **200** of the nozzle.

[0095] FIG. **10** illustrates an axial tip-end section of the center cartridge **155** for an embodiment of the inventive nozzle. The center cartridge **155** is enclosed radially within a cartridge wall **872** and at the downstream end by an end tip **885**. The igniter **875** extends in an axial direction from the center cartridge flange **224** to the end tip **885**. The liquid fuel pilot **880** extends from the center cartridge flange **224** to the end tip **885**. Air cavity **873** receives air for use within the center cartridge. Air to the center cartridge enters from the radial feedholes **275** in the backplate **240** and exits through holes **277** into the space **864** between the pilot nozzle **150** and the inner surface **368** of the support tower **270**. A portion of the air entering the space **864** enters the center cartridge **155** through the cartridge feedholes **870** filling the air cavity around the igniter **875** and liquid fuel pilot **880** and extending forward to a tip impingement shield **865**. The tip impingement shield **865** seals the upper end of the cavity and includes a plurality of tip holes **867** (18 holes in the present embodiment) Air from the tip impingement shield **865** is directed to an annular air channel **876** at the downstream end of the igniter **875** to support ignition. Air from the tip impingement shield **865** is also supplied to conical annulus **881** around a heat shield **882** on the liquid fuel pilot **880**. A plurality of offset blast holes **883** are provided through air blast atomizer shroud **884**. The liquid pilot fuel is provided through a cylindrical cavity **890** in liquid pilot body **891**. A truncated conical

annulus of a spin chamber wall **892** at the tip defines a spin chamber **893** within for the liquid fuel. An annular air gap **894** is provided around the liquid pilot body **891** for thermal insulation. Around the annular air gap **894** is provided an air assist annulus **895** connected to the air assist supply in the flange **224** of the center cartridge **155**. Within the air assist annulus **895** is located an air-assist swirler **896** (embodiment includes 8 swirl vanes **897**). The swirl vanes **897** impart a swirling motion to the assist air being introduced to the spin chamber **893**.

[0096] FIG. **11** illustrates an alternate embodiment for the central flame holder for the single large radial nozzle **900**. Here the flame holder **905** consists of a perforated cup **910**. The perforated cup **910** consist of a plurality of holes **920** about the central axis **915**, through which 30% (approx) of the air fuel mixture **950** coming from the annulus region passes, it partly mixes with the pilot air fuel mixture **955** coming from the pilot nozzle **960** and partly burns at the exit of these holes **920**. The holes **920** are provided with fillets **930** in order to minimize corner separation. A shroud **940** is provided around the cup **910** to direct the flow into the cup. The lower convex end **945** of the cup **920** is open and conformed to accept the pilot air fuel mixture **955** from the gas pilot nozzle **960**. Thus in this case the heat release takes place in 3 stages. The first stage is the pilot zone. The second stage is the air-fuel mixture burning at the exit of these holes **920** and the third stage is the flow bypassing the perforated cup **920**.

[0097] The foregoing has described a single large radial nozzle for a gas turbine combustor that provides major improvements in operation over multi-nozzle designs. First, the intra-nozzle combustion staging provided by the nozzles premixer design, especially, the conical, de-swirled, v-gutter flame-holder in conjunction with controllable outer main gas fuel injection paths and inner main gas fuel-injection paths, is a unique aspect of this design. This aspect allows multiple nozzles (per combustor) to be replaced by one, resulting in major cost and part-count savings. Second, combustion dynamics/oscillation abatement is created by the smearing out of fuel transport times and heat release in the chamber is a novel manner. This unique property additionally may allow a broader range of fuels to be burned without needing to modify or replace hardware. Finally, the combustor headend design and the way the nozzle is integrated with the combustor dome in creating an annular dome diffuser that recovers pressure while convectively cooling the backside of the liner's dome without a need for introduction of a separate cooling air source provides increased simplicity with functionality.

[0098] Presently, the inventive nozzle has been sized for the GE 9FB heavy-duty industrial engine; however, it can be scaled up or down in size to work for almost any combustor annular design (e.g., 7H, 9H, 7FB, 7FA, 9FA, 6C, etc.). The design could be retrofitted to an existing package, or it could be introduced as a new product offering.

[0099] While only certain features of the invention have been illustrated and described herein, many modifications and changes will occur to those skilled in the art. It is, therefore, to be understood that the appended claims are intended to cover all such modifications and changes as fall within the true spirit of the invention.

We claim:

1. A lean premixed, radial inflow, multi-annular staged nozzle for creating three independent combustion zones within a can-annular, dual fuel gas turbine combustor, the nozzle comprising:
- a pilot zone fueled by a center cartridge during liquid operation and a center gas pilot nozzle during gas operation;
- a central flame holder zone fueled by an inner main gas fuel supply;
- a main flame zone fueled by an outer main gas fuel supply;
- a main radial swirler for mixing a portion of incoming air to the nozzle with the inner main gas fuel supply and the outer main gas fuel supply;
- means for controlling the ratio of an inner main gas fuel supply and an outer main gas fuel supply; and
- an endcover.

2. The nozzle according to claim **1**, the main radial swirler comprising:
- a backplate mechanically fastened in axial alignment to the endcover;
- a plurality of swirl vanes spaced approximately equidistantly in a circular array around a central axis of the nozzle;
- a premixing space in a circumferential space between individual swirl vanes;
- a central hub including a central cavity within; and
- an annular swirl volume between the plurality of swirl vanes and the central hub.

3. The large single radial nozzle according to claim **2**, the backplate comprising:
- a cylindrical plate;
- a central hub projecting axially downstream from a downstream surface of the backplate, wherein the central hub includes a smooth conical surface, truncated at a downstream end;
- a cavity connecting a outer main gas fuel supply from the endcover to the plurality of swirl vanes;
- a plurality of injector nozzles mounted on the downstream surface of the backplate;
- a cavity connecting a inner main gas fuel supply from the endcover to the plurality of injector nozzles;
- liquid fuel atomizers mounted on the downstream surface of the backplate;
- a cavity connecting a liquid fuel supply from the endcover to the plurality of liquid fuel atomizers; and
- a central cavity along the central axis of the nozzle.

4. The nozzle according to claim **3**, the cavity connecting the outer main gas fuel from the endcover to the plurality of swirl vanes further comprising:
- an orifice with the cavity for regulating outer main gas fuel supply to each swirl vane.

5. The nozzle according to claim **3**, wherein the cavity connecting the liquid fuel supply includes a thermal insulating outer liner.

6. The nozzle according to claim **3**, the backplate further comprising:
- a plurality of radial-oriented cavities connecting an outer circumferential surface of the backplate with the central cavity for supplying air to the center cartridge and the gas pilot nozzle.

7. The nozzle according to claim **2**, the swirl vane comprising:

an airfoil projecting axially downstream from a downstream surface of the backplate towards a combustion end of the nozzle, wherein a centerline of the airfoil making a predetermined angle with a radius from the central axis of the nozzle, thereby defines the circumferential premixing space for air flow from outside the main swirler to an annular swirl volume between the main swirl vanes and the central hub;

an internal cavity within each airfoil for the outer main gas fuel supply within the backplate; and

a plurality of gas fuel injector holes for distributing outer main gas fuel supply to the premixing space from the internal cavity.

8. The nozzle according to claim **7**, the airfoils further comprising:

a leading edge;

a trailing edge;

sidewalls tapering from the leading edge to the trailing edge;

the internal cavity within each airfoil extending from a bottom surface of the airfoil along the axial length of the airfoil, and being aligned radially and circumferentially with the outer main gas fuel supply cavity in the backplate; and

the gas fuel injector holes being disposed axially along the length of the internal cavity with the airfoil, each individual hole extending from the internal cavity to an opening on at least one sidewall of the airfoil for injecting outer main gas fuel normal to the airflow between adjacent airfoils.

9. The nozzle according to claim **2**, the premixing volume in circumferential space between individual swirl vanes further comprising:

a radial-flaring portion of an outer burner tube overhead forming a downstream roof.

10. The nozzle according to claim **9**, wherein the radial flaring portion of the outer burner tube is mechanically attached to the top surface of the plurality of airfoils by mechanical means.

11. The nozzle according to claim **1**, the endcover comprising:

a cylindrical plate, including an outer radial mounting surface for mechanical attachment to the combustor and an inner radial mounting surface for attachment to the backplate;

a cavity connecting a outer main gas fuel supply the backplate;

a cavity connecting a inner main gas fuel supply to the backplate;

a plurality of cavities connecting a liquid fuel supply from the endcover to the backplate; and

a central cavity, including a mounting flange, for accepting and mounting a center gas pilot nozzle.

12. The nozzle according to claim **1**, the central flameholder zone comprising:

a center hub;

an inner burner tube wall;

a perforated cup including a plurality of holes about a central axis with fillets between the holes and the perforated cup, a shroud around an upper open-end of the perforated cup, and a circular opening in the bottom of the cup, wherein the shroud mates with the inner burner tube wall and the circular opening in the bottom of the cup is open to the center gas pilot.

13. The nozzle according to claim **1**, the central flameholder zone comprising:

a center hub;

an inner burner tube wall;

a deswirler for converting a circumferential flow of a fuel-air mixture in the annular swirl volume of the main radial swirler and redirecting the airflow in an axial downstream direction; and

a v-gutter flame pack holder.

14. The nozzle according to claim **13**, the deswirler comprising:

a plurality of segmented radial compartments, each compartment formed as an annular segment bounded on an outer radius by an inner burner tube wall and on an inner radius by an outside wall of the center hub, wherein adjacent compartments are separated by vanes of circumferentially-sloping radial walls wherein the slope progressively increases from an upstream entrance to the compartment to the downstream exit from the compartment, for deswirling a portion of the fuel-air mixture in the annular swirl volume.

15. The nozzle according to claim **13**, the v-gutter flame holder pack comprising:

a plurality of radial oriented arms spaced approximately equidistant circumferentially around the inner burner tube, the arms being attached and extending from a downstream end of the center hub to a downstream axial end of the inner burner tube, wherein the attachment at the inner burner wall is located downstream from the attachment at the hub extension thereby forming a predetermined radial-axial angle for the radial oriented arms, and a convex shaped depression in the radial-oriented arms, a vertex of the convex shaped depression pointing upstream.

16. The nozzle according to claim **13**, the center hub comprising:

a cylindrical tube with a central cavity, an irregular shape of an inner surface of cylindrical tube to accommodate the central gas pilot nozzle, and adapted at an upstream end to mate with the central hub of the main radial swirler, further including a hub extension on a downstream axial end of the cylindrical tube, the hub extension being interrupted by v-gutters at equidistant intervals around the hub.

17. The nozzle according to claim **3**, the central gas pilot nozzle comprising:

a generally cylindrical-shaped body with a center cavity and a radially-expanded bolting flange at an upstream end; wherein the nozzle body is adapted to fit within a central cavity of the endcover, the backplate and a center hub of the flameholder zone;

a plurality of radial air feed holes aligned axially on the body to accept airflow from the central cavity of the backplate; and

a central cartridge including a liquid fuel pilot disposed within the center cavity; an igniter disposed within the center cavity; an end tip, providing axial and radial support on the downstream end for the liquid fuel pilot and the igniter; a liquid pilot fuel supply; a gas pilot fuel supply; and a power supply connection for the igniter.

18. The nozzle according to claim **17**, the central gas pilot nozzle further comprising:

an annulus formed between the central cavity of the backplate and the center hub of the flameholder for passing a

portion of air supplied to the central cavity of the backplate to the gas pilot nozzle and the central cartridge;
an annulus, positioned inner radially from an inside wall of the central cartridge, for supplying pilot gas fuel to the gas pilot from a gas pilot supply at the downstream end of the central cartridge;
a plurality of pilot swirl vanes projecting radially outward between the outer surface of the central cartridge and the inner surface of the center hub of the flameholder for mixing air in the annulus with pilot gas fuel, the swirl vanes positioned equidistant around the outer surface;
a plurality of radially extending holes through the central cartridge wall, individual holes, radially-centered and axially-positioned at the upstream entrance between adjacent pilot swirl vanes; and
an annulus located downstream of the swirl vanes for supplying a swirled pilot gas-air mixture to the pilot zone.

19. The nozzle according to claim **17**, the central cartridge comprising:
an axial body for the liquid fuel pilot;
an axial channel through the center of the liquid fuel pilot for liquid fuel;
an insulating annular air gap surrounding the axial body;
an air assist supply for the liquid fuel pilot;
an air assist annulus surrounding the axial body;
a truncated conical liquid fuel spin chamber;
a truncated conical heat shield surrounding the liquid fuel spin chamber;
a truncated conical annulus surrounding the heat shield and
a tip impingement shield with air passage holes for center cartridge air.

20. The nozzle according to claim **19**, the central cartridge further comprising:
a center cartridge air chamber running the axial length of the center cavity of the central cartridge and bounded on the downstream end by the tip impingement shield;
the tip impingement shield including a plurality of axial holes;
an air chamber positioned axially between the tip impingement shield and the end tip;
a channel to the igniter from the air chamber; and
a channel to the truncated conical annulus surrounding the heat shield on the liquid fuel pilot.

21. The nozzle according to claim **1**, the main zone further comprising:
a cylindrical inner burner tube wall centered on a central axis of the nozzle;
a cylindrical outer burner tube wall centered on the central axis of the nozzle, the outer burner tube wall projecting axially downstream from the downstream surface of the main radial swirler and being of larger diameter being than the inner burner tube wall; and
a flared portion of the outer burner tube at its upstream end extending outward radially as an annular circumferential surface, the circumferential surface forming a roof over the plurality of main swirl vanes and channeling the fuel and air into the annular mixing zone.

22. The nozzle according to claim **1**, the means for controlling the ratio of an inner main gas fuel supplied and an outer main gas fuel supplied comprising:
at least one of means for throttling the fuel supplies and means for changing the pressure of the fuel supplies.

23. A can-annular dual-fuel combustor for a gas turbine engine, comprising:
a lean premixed, radial inflow, multi-annular staged nozzle, including an inner burner tube, an outer burner tube and a main radial swirler mounted on an endcover to a combustor casing;
a main combustion zone downstream from the outer burner tube of the nozzle;
a source of compressed air from a compressor;
an air inlet plenum radially surrounding the single large radial nozzle and bounded radially by an outer wall of the combustor;
a diffuser for the compressed air, the diffuser receiving the compressed air in a reverse flow path from the compressor and discharging the compressed air at a restored pressure to the inlet plenum; and
a fairing mounted atop the main radial swirler and surrounding a portion of the outer burner tube for smoothing air flow from the diffuser to the air inlet plenum.

24. The can-annular dual-fuel combustor according to claim **23**, the diffuser further comprising:
an inner wall, the inner wall being coincident with the backside for a dome on the main combustion zone, thereby providing backside cooling to the dome from the compressed air passing through the diffuser.

25. The can-annular dual-fuel combustor according to claim **23**, the outer burner tube further comprising:
a reinforced cylindrical segment in proximity to the downstream end of the tube, including a cylindrical ledge wherein the cylindrical ledge provides axial and radial support for the dome.

26. The can-annular dual-fuel combustor according to claim **23**, wherein the combustor further comprising:
a plurality of supply and control connections to an endcover including:
an outer main gas fuel supply;
an inner main gas fuel supply;
a gas pilot supply
a liquid fuel supply;
a liquid pilot fuel supply;
an air assist supply;
igniter controls; and
flame detector controls.

27. A method for utilizing a lean premixed, radial inflow, multi-annular staged nozzle with independent combustion zones including a pilot zone, a flame holder zone and a main zone, within a can-annular dual-fuel gas turbine combustor for providing stable combustion with low Nitrogen Oxide (NOx) emissions, the method comprising
providing a large supply of air to the nozzle;
intra-nozzle staging;
breaking up heat release into a multiplicity of discrete zones in space;
distributing the heat release in time; and
ventilating a downstream central recirculation zone.

28. The method for utilizing a lean premixed, radial inflow, multi-annular staged nozzle within a gas turbine combustor for providing stable combustion with low NOx emissions according to claim **27**, the step of providing a large supply of air to the nozzle comprising:
providing a channeled reverse flow path for air to the nozzle from an air compressor;
recovering static air pressure by diffusing air flow through a diffuser tube positioned between the reverse flow path for air and an inlet plenum for the nozzle;

smoothing air flow entering the inlet plenum for the nozzle with a fairing shaped around the outer flame holder for the nozzle; and

flowing air through large flow passages of a single large radial nozzle.

29. The method for utilizing a lean premixed, radial inflow, multi-annular staged nozzle within a gas turbine combustor for providing stable combustion with low NOx emissions according to claim **27**, the step of intra-nozzle staging comprising:

providing a outer main fuel supply;

providing a inner main fuel supply;

mixing the outer main fuel supply with air from the inlet plenum at an outboard injection point between adjacent swirl vanes of the main radial swirler, the injection point being outboard radially of the swirl vanes;

mixing the inner main fuel supply with air from the inlet plenum at an inboard injection points radially inboard of the swirl vanes;

controlling the ratio of fuel injected at the outboard injection point and the inboard injection point; and

biasing a fuel-air ratio to be richer near the central hub of the main radial swirler; and

burning fuel in the flame holder zone at a higher equivalence ratio relative to burning in the main zone.

30. The method for utilizing a lean premixed, radial inflow, multi-annular staged nozzle within a gas turbine combustor for providing stable combustion with low NOx emissions according to claim **27**, the step of breaking up the heat release into a multiplicity of discrete zones in space comprising:

providing three spatially-separated burn zones including the pilot zone, the flame-holder zone and the main zone; and

employing a physical separation of a plurality sloping radial arms of the v-gutter pack to create a multiplicity of discrete reaction zones in space, each reacting at spatial scales that are much smaller than that of the overall combustion chamber effectively limiting the amount of energy release that can constructively couple at a particular resonant frequency within the combustion chamber.

31. The method for utilizing a lean premixed, radial inflow, multi-annular staged nozzle within a gas turbine combustor for providing stable combustion with low NOx emissions according to claim **27**, the step of distributing the heat release in time comprising:

establishing a discrete fuel transport time for each point along a length of a v-gutter, effectively limiting the amount of energy release that can constructively couple at a particular resonant frequency within the combustion chamber.

32. The method for utilizing a lean premixed, radial inflow, multi-annular staged nozzle within a gas turbine combustor for providing stable combustion with low NOx emissions according to claim **27**, the step of ventilating a downstream central recirculation zone comprising:

deswirling the a fuel-air mixture, from the main radial swirler, in the central flame-holder;

injecting non-swirling axial momentum into the central recirculation zone; and

limiting the average time that combustion-product molecules spend at flame temperatures in the combustion zone.

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