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(54) **PARTIAL PREMIX DUAL CIRCUIT FUEL INJECTOR**

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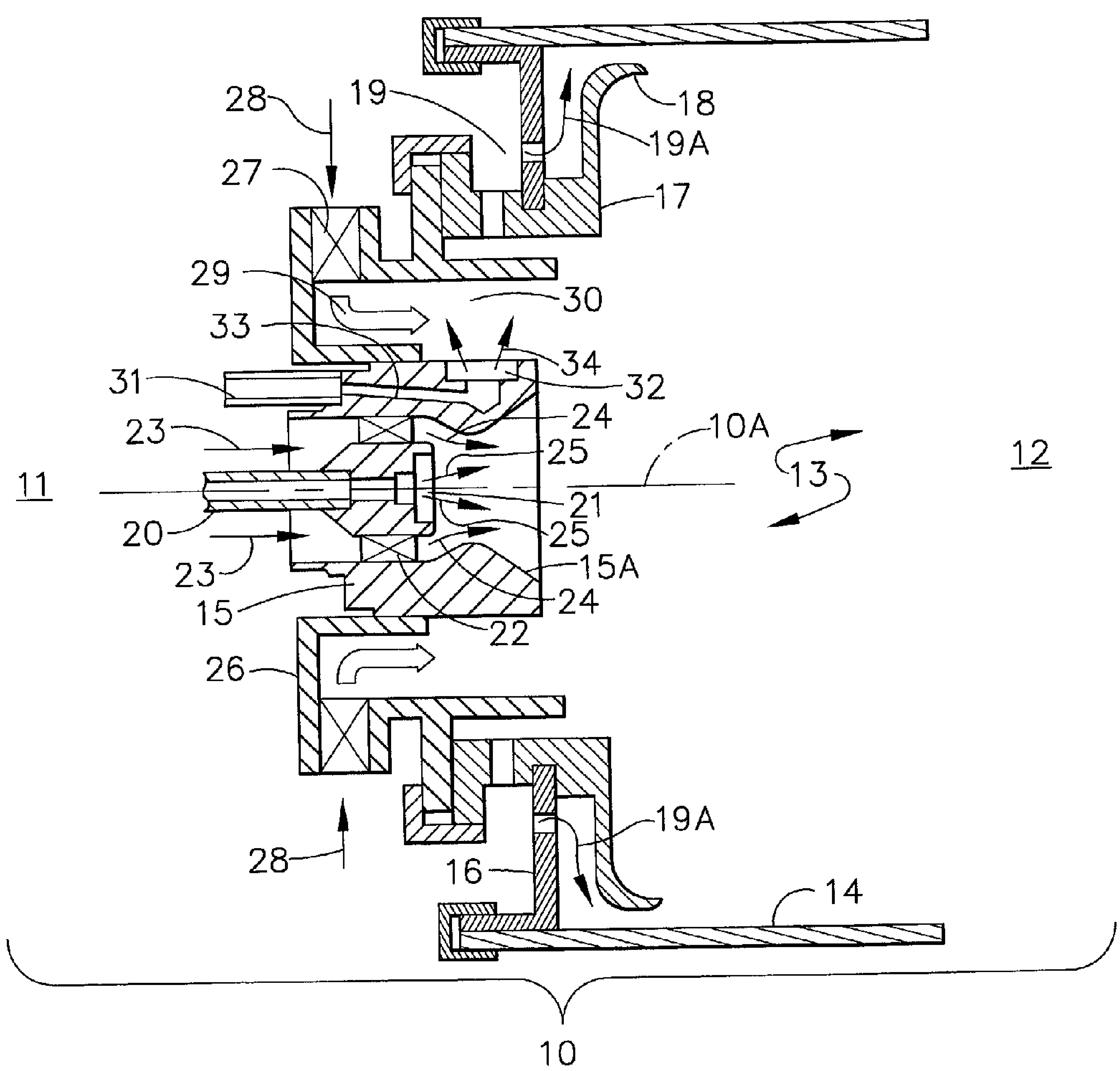
(57) **ABSTRACT**

A low emission fuel injection system and combustion chamber for use in gas turbine engines comprises one fuel injection body having a dual circuit to supply both pilot and main fuel systems. Both pilot fuel circuit and a main fuel circuit inject fuel at essentially the same axial and radial location. The recessed pilot fuel injection site is along the combustor centerline into a swirling air passage produced by axial air swirlers. The main fuel is injected radially through a plurality of injection sites, at a compound angle, into the inner diameter of a swirling air passage produced by radial air swirlers. The fuel/air residence time prior to entering the combustion chamber is relatively short, minimizing the likelihood of auto ignition. During pilot circuit only operation, the flame is stabilized by a swirler produced recirculation zone, producing high temperatures to completely burn the fuel producing low CO and UHC emissions. During intermediate and high engine power conditions, both the main fuel and pilot circuits discharge fuel into a swirler produced, high air flow, recirculation zone producing a fuel lean, low temperature flame to reduce NOx emissions.



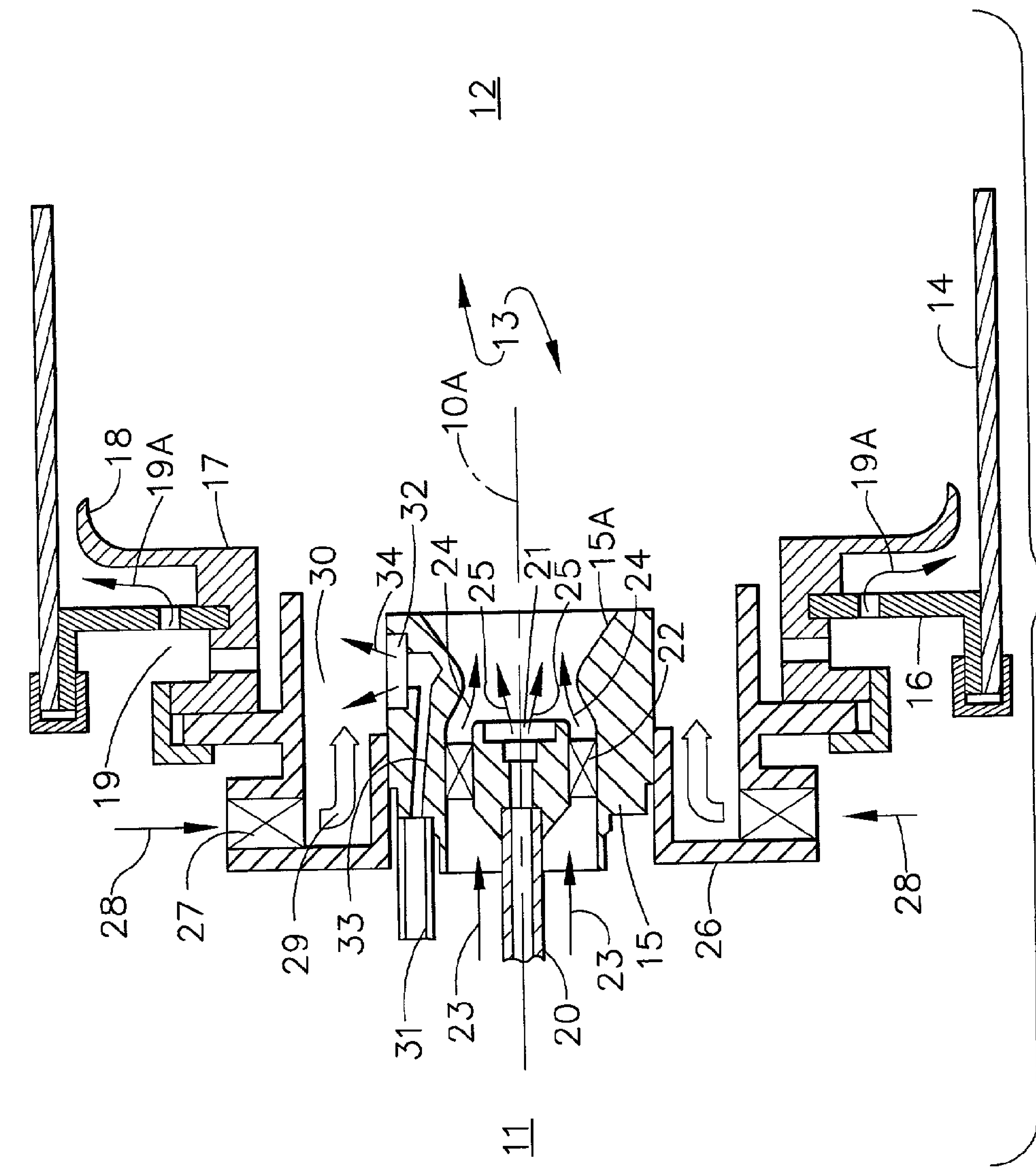


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FIG. 1

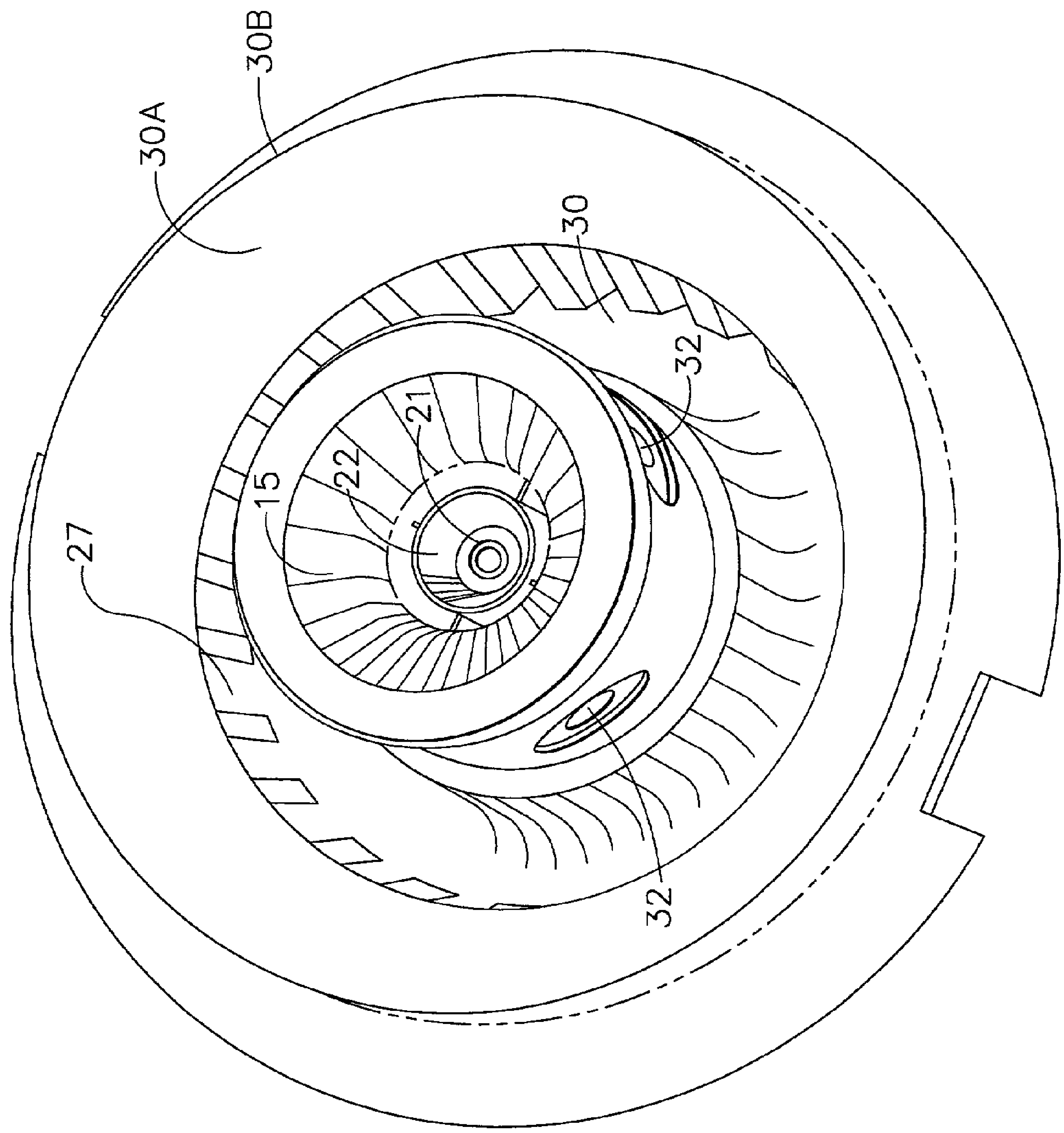

FIG. 2

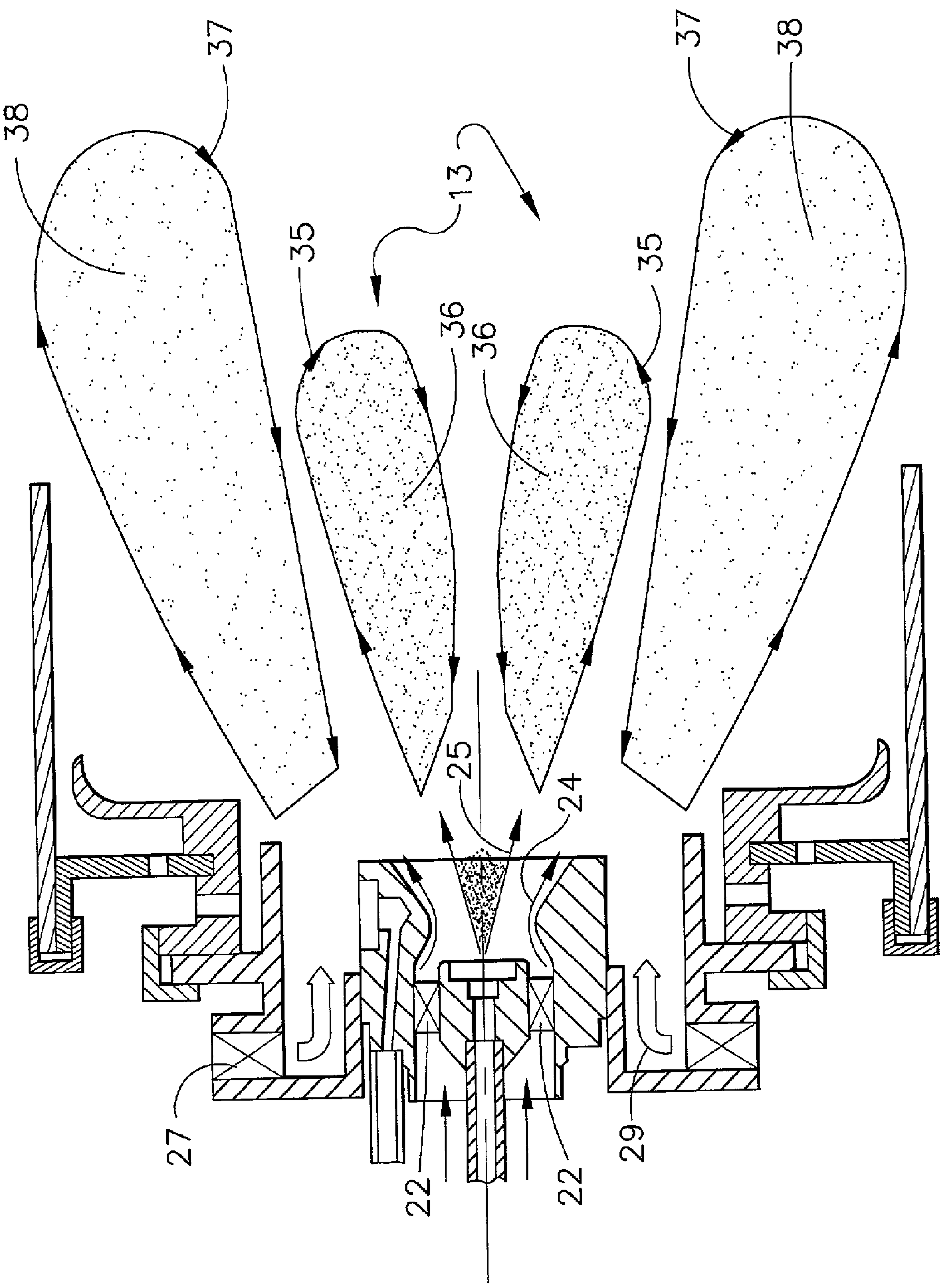

FIG. 3

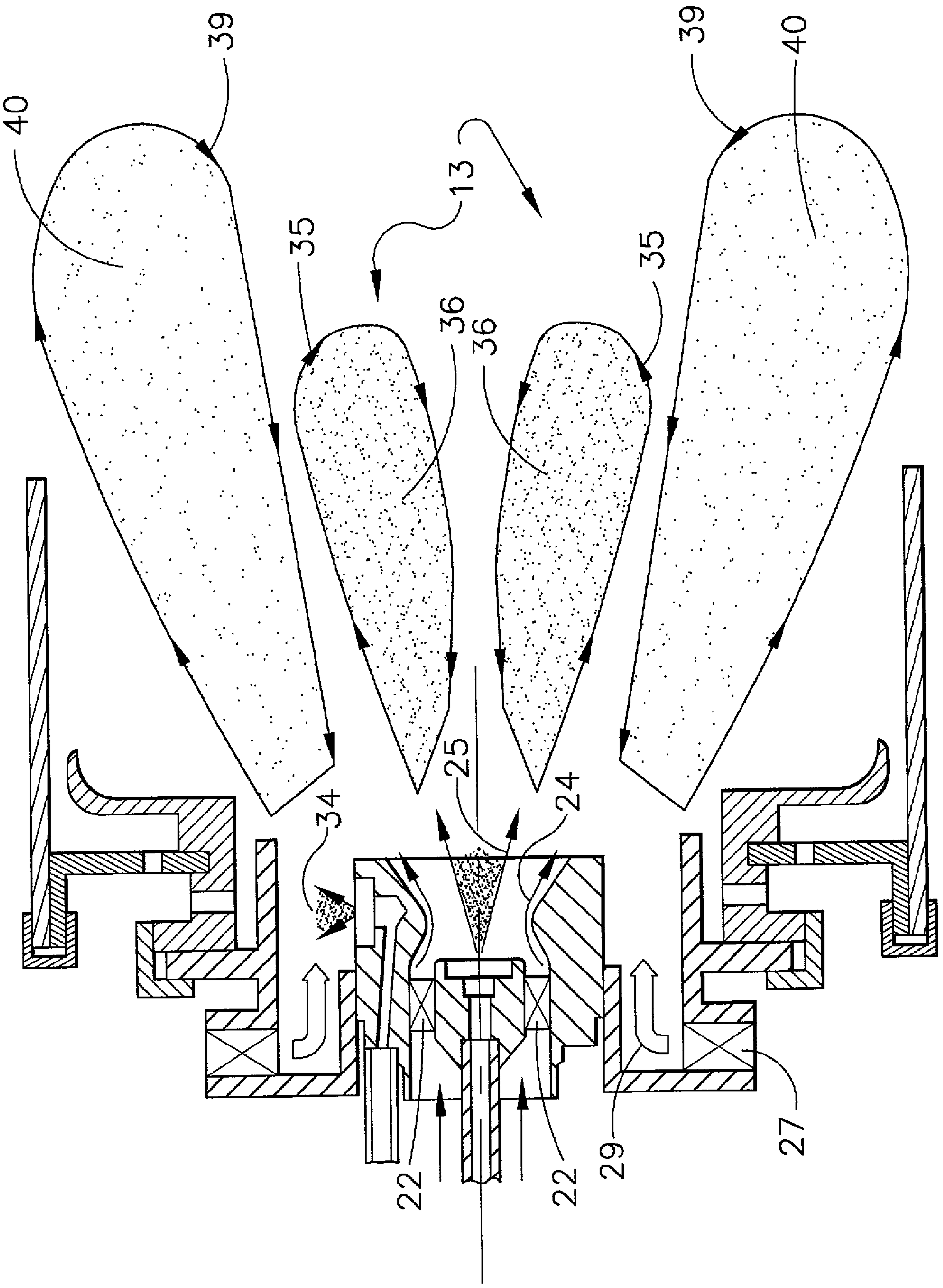

FIG. 4

PARTIAL PREMIX DUAL CIRCUIT FUEL INJECTOR

GOVERNMENT RIGHTS

[0001] The invention described herein was made in the performance of work under NASA Contract No. NAS3-27752 awarded by NASA Glenn Research Center, and is subject to the provisions of Section 305 of the National Aeronautics and Space Act of 1958 (42 U.S.C. 2457). The Government has certain rights in this invention.

BACKGROUND OF THE INVENTION

[0002] This invention relates generally to fuel injectors used in gas turbine engine combustors and, in particular, to a fuel injector design primarily for aerospace applications, which produces a stable flame at low power, generating low CO and UHC pollutants, and also provides enhanced fuel-air mixing to reduce NOx emissions at high-power.

[0003] Atmospheric pollution concerns and effects worldwide have led to enactment of increasingly stricter emission controls and standards requiring most industries to significantly reduce the emissions of pollutants. The strict emission controls have required implementation of numerous design changes in gas turbines used for industrial, power generation and propulsion applications. Thus typical gas turbine engines are now required to operate efficiently over a wide range of conditions while at the same time producing minimal quantities of noxious emissions. The common precursors to gas turbine engines cause atmospheric pollution include Carbon Monoxide (CO), and Unburned Hydrocarbons (UHC) at low engine power conditions, and Nitrous Oxide (NOx) at intermediate and high engine power conditions.

[0004] Reductions in gas turbine emissions of NOx have been obtained primarily by the reduction of flame temperatures in the combustor. Some of the techniques employed include lean burn pre-mix combustors in which the fuel to air ratio is reduced as far as possible in the higher operating range; staged combustors, whereby fuel is admitted to the combustion chamber at different axial locations thereby staging the combustion process; lean-direct injection involving methods of injecting fuel and air into a combustion chamber where the mixture is fuel-lean, or below the stoichiometric fuel/air ratio; and other related techniques known to those skilled in the art as "rich burn" and "quick quench".

[0005] Gas turbine propulsion engines employ annular and can-type combustors to burn fuel. The fuel is metered and sprayed into the combustor through a single or a plurality of fuel nozzles along with combustion air having a designated amount of swirl. In the typical gas turbine engine, flame stability, variable cycle operation, and emission control dominate combustor design requirements. The characteristics of a given fuel injector under light-up and low speed conditions are different to those under full power conditions. Consequently a fuel injector is often a compromise between two designs to enable it to operate under both of these conditions.

[0006] Typically, fuel is supplied through one supply duct under starting or low power conditions and through another or through both fuel supply ducts under high power conditions. During light up and low speed conditions, only the pilot fuel injectors are used whereas both the pilot and the main fuel injectors are used under higher speed conditions. The pilot combustion stage is usually long in comparison with the main combustion stage. Consequently, the residence time of the fuel in the pilot stage is comparatively long, limiting emissions of hydrocarbons and carbon monoxide. Conversely, the residence time of the fuel in the main stage is comparatively short, limiting emissions of the oxides of nitrogen.

[0007] Many techniques have been utilized in the prior art to enable efficient gas turbine engine operation over a wide range of conditions while at the same time producing minimal quantities of noxious emissions. Of particular interest in this regard are the following references and examples:

[0008] U.S. Pat. No. 4,701,124 discloses a can-type combustor intended for industrial applications and designed to use oil or natural gas as the fuel. The fuel is injected at a compound angle in the main fuel chamber at the air swirler vane exit plane.

[0009] U.S. Pat. No. 5,062,792 also targets industrial burners and uses oil or natural gas as the fuel. In this design, the oil is used to fuel the pilot circuit, while the natural gas is used to fuel the main circuit.

[0010] U.S. Pat. No. 5,069,029 involves a staged combustor, wherein fuel is admitted to the combustion chamber at different axial locations, thereby staging the combustion process. Axial-type air swirlers are utilized for both pilot and main fuel circuits.

[0011] U.S. Pat. No. 5,816,050 discloses a can-type combustor with pilot fuel system that injects the fuel axially into the swirling air stream, which is kept separate from the main air stream by a containment wall. Separate fuel injectors are utilized for the pilot and main systems, the latter injecting the fuel near the outer diameter of the air swirler.

[0012] U.S. Pat. No. 5,862,668 teaches a radial-staged combustion system, whereby the pilot system is operated at low power (inward and radial location) and the main and pilot are operated at high power conditions. The combustor is considered a premix type system due to the longer residence time of fuel and air in the premixing tubes.

[0013] U.S. Pat. No. 6,151,899 involves a can-type combustion chamber whereby main fuel is injected axially into the swirling air passage, and pilot fuel is injected in two discreet axial and radial locations.

[0014] U.S. Pat. No. 6,158,223 also teaches a can-type combustion chamber providing for a pilot fuel injection point in the same plane as the main fuel/air injection point. The design utilizes a plurality of main air swirlers for each pilot air swirler.

[0015] U.S. patent application Ser. No. 09/492,678, filed Jan. 27, 2000, for Combustor with Fuel Preparation Chambers, by the same inventor as this application, and also assigned to the assignee of this application, discloses an annular combustor having fuel preparation chambers mounted in the dome of the combustor with the objective of uniformly mixing fuel and air so as to reduce NOx formed by the ignition of the fuel/air mixture.

[0016] With the exception of the last reference, none of the above-cited prior art is specifically intended for lightweight, aerospace type applications, and some suffer from one or more of the following disadvantages:

[0017] a) aerospace type fuels cannot be utilized.

[0018] b) fuel-air residence times prior to entering the combustion chamber are relatively long, thus increasing the danger of autoignition or flashback situations, which are a safety concern for aerospace applications.

[0019] c) complexity in fabrication and operation.

[0020] d) inability to retrofit the system on existing engines.

[0021] e) the fuel injection system is usable for can type or annular combustors, but not for both.

[0022] For the foregoing reasons, as can be seen, there is a need for a simple, retrofittable, gas turbine engine fuel injector system primarily for aerospace applications, which produces a clean stable flame at low power, provides enhanced fuel-air mixing to reduce noxious emissions at high-power, and can be employed on both can-type and annular type combustion systems.

SUMMARY OF THE INVENTION

[0023] In one aspect of the present invention, a fuel injector system is provided to produces a stable flame at low power operations, generating low CO and UHC pollutants.

[0024] In another aspect of the present invention, a fuel injector system is provided to produce enhanced fuel-air mixing to reduce NOx emissions at intermediate and high power operations.

[0025] In a further aspect of the present invention, a gas turbine engine fuel injection system, comprised of a single fuel injection body incorporating both pilot circuit and main circuit fuel injectors, is provided that produces minimal quantities of CO, UHC and NOx emissions.

[0026] In yet another aspect of the present invention, a simple, low cost gas turbine engine fuel injection system is provided that is capable of producing minimal quantities of noxious emissions, and which can be retrofitted into existing products, including engines for aerospace applications.

[0027] In a still further aspect of the present invention, a gas turbine engine fuel injection system is provided that is capable of producing minimal quantities of noxious emissions, and which can be utilized on annular as well as can-type combustors.

[0028] The present invention is comprised of one fuel injection body to supply both pilot and main fuel systems. The fuel injection body is further comprised of a pilot fuel circuit and a main fuel circuit, both of which inject fuel at essentially the same axial and radial location. The recessed pilot fuel injection site is along the combustor centerline into a swirling air passage produced by axial air swirlers. The main fuel is injected radially through a plurality of injection sites, at a compound angle, into the inner diameter of a swirling air passage produced by radial air swirlers. One main air swirler is utilized for each pilot air swirler. The fuel/air residence time prior to entering the combustion chamber is relatively short, minimizing the likelihood of auto ignition.

[0029] A method for producing a low noxious emission gas in a combustor is also disclosed. The method includes injecting pilot circuit fuel spray into a swirling passage along the combustor centerline for low power operations. For intermediate and high power operations, main circuit fuel spray, together with pilot circuit fuel spray, is discharged into a radial swirler air passage, and thereafter fluidly communicates with a single combustion chamber. The swirling mixture of pilot circuit and main fuel and air enters the combustion chamber, is expanded, and ignited to form low emission gas.

[0030] These and other objects, features and advantages of the present invention, are specifically set forth in, or will become apparent from, the following detailed description of a preferred embodiment of the invention when read in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0031] **FIG. 1** is a longitudinal cross section of a gas turbine engine combustor assembly having the inventive partial premix dual circuit fuel injector;

[0032] **FIG. 2** is a perspective view of the inventive partial premix dual circuit fuel injector;

[0033] **FIG. 3** is a cross section of the combustor assembly showing air and fuel flow patterns during low power operation; and

[0034] **FIG. 4** is a cross section of the combustor assembly showing air and fuel flow patterns during intermediate and high power operation.

DETAILED DESCRIPTION OF THE INVENTION

[0035] The following detailed description is of the best currently contemplated modes of carrying out the invention. The description is not to be taken in a limiting sense, but is made merely for the purpose of illustrating the general principles of the invention, since the scope of the invention is best defined by the appended claims.

[0036] Referring to **FIG. 1**, there is shown a longitudinal cross section of a gas turbine engine combustor assembly **10**, having an upstream end **11** and a downstream end **12**. The combustor fuel mixing zone **13** is located along the downstream end **12**. The combustor assembly **10** is cylidrically shaped and bounded along its longitudinal outer periphery by a combustor outer casing housing **14** which is attached along its internal, upstream end **11** to an annular sheet metal dome **16**. The sheet metal dome **16** serves as a connecting member as well as a shield, protecting upstream end **11** components from exposure to excessive temperatures generated at the combustor. Thermal protection is provided by a heat shield **17** and cooling skirt **18** as well as a plurality of circumferentially disposed dome cooling nozzles **19** which dispense cooling air flow **19A** from the gas turbine engine compressor stage.

[0037] Still referring to **FIG. 1**, there is shown an annular swirler housing **26** rigidly connecting the sheet metal dome **16** to a fuel injector body **15** which is located along the longitudinal centerline **10A** of the combustor assembly **10**. The radial air swirler housing **26** accommodates a plurality of radial swirlers **27** peripherally located along the upstream end **11**, each said radial swirler **27** provided to bring air flow, designated by arrows **28**, supplied under pressure from a compressor of the gas turbine engine (not shown). The radial swirler **27** is adapted to bring air flowing inwardly radially, designated by arrows **29**, therethrough to rotate through and around the radial swirler passage **30** and into the combustion chamber's fuel mixing zone **13**.

[**0038**] The fuel injector body **15** incorporates both the pilot circuit fuel injection and the main circuit fuel injection systems. Pilot circuit burner fuel **20** enters the pilot circuit fuel nozzle **21** from the upstream end **11** along the combustor centerline **10**A and into the pilot circuit fuel nozzle **21** where it is atomized and thereafter dispersed, through the convergent-divergent end **15**A, into the fuel mixing zone **13** in the direction essentially as shown by the pilot circuit fuel flow arrows **25**. A plurality of axial pilot circuit air swirlers **22**, located radially outboard of the pilot circuit fuel nozzle **21**, swirls air flow **23** provided from a compressor of the gas turbine engine (not shown), and routes it, as shown by arrows **24**, to the convergent-divergent end **15**A, where it will mix with the pilot circuit fuel flow **25**, to be thereafter ignited.

[**0039**] Main circuit burner fuel **31** enters the main circuit fuel nozzle **32** from the upstream end **11**, is routed through a passageway **33** bored approximately parallel to the combustor assembly centerline **10**A, and rotated approximately 90 degrees to exit the main circuit fuel nozzle **32** at an outwardly radial direction. The main circuit fuel flow represented by arrows **34** is atomized as it exits the main circuit fuel nozzle **32**, is thereafter mixed with the radial swirler air flow **29** in the radial swirler passage **30**, and is then routed to the fuel mixing zone **13** to be thereafter ignited. In the preferred embodiment, main fuel is introduced through at least four main circuit fuel nozzles **32** symmetrically spaced around the outer periphery of the fuel injector body **15**.

[**0040**] **FIG. 2** is a perspective view showing various central elements of the partial premix dual circuit fuel injector assembly. For clarity purposes, the combustor outer casing **14** housing is not shown. The radial swirler exit plane **30**A and radial swirler attachment (to combustor dome) flange **30**B establish the outer boundary of the fuel injector assembly. Multiple main fuel circuit radial swirlers **27** are located along the entire outer periphery adjacent to the base of the radial swirler passage **30**. The fuel injector body **15** is centrally located and is comprised of the recessed pilot circuit fuel nozzle **21** which is itself peripherally surrounded by a plurality of axial pilot circuit air swirlers **22**. Two main circuit fuel nozzles **32** are shown located along the external periphery of the fuel injector body **15**. In the preferred embodiment, at least four symmetrically spaced main circuit fuel nozzles **32** are used. Alternate embodiments may use fewer or additional main circuit fuel nozzles **32**.

[**0041**] Referring now to **FIG. 3**, there is shown a cross section of the combustor assembly showing air and fuel flow patterns during low power operation. Pilot circuit fuel entering the fuel mixing zone **13** is sprayed as represented by arrows **25**. The swirler air flow **24** produced by the axial pilot circuit air swirlers **22** mixes with the fuel and is caused to recirculate in the general direction shown by arrows **35** forming a vortex recirculation zone **36**. When the fuel air mixture is ignited, the fuel rich flame stabilized by the recirculation zone **36**, produces high flame temperatures, helping to improve combustor efficiency by completely burning the fuel and eliminating CO and UHC emissions. Flame stabilization is also somewhat aided by the double vortex effect of radial swirler **27** recirculation air, represented by arrows **37**, which forms a radial swirler air vortex recirculation zone **38**. Main circuit fuel does not flow during low power operation.

[**0042**] Referring now to **FIG. 4**, there is shown a cross section of the combustor assembly showing air and fuel flow patterns during intermediate and high power operation. Fuel entering the fuel mixing zone **13** is sprayed as represented by arrows **25** for the pilot circuit and by arrows **34** for the main circuit. The swirler air flow **24** produced by the axial pilot circuit air swirlers **22** mixes with the pilot circuit fuel and is caused to recirculate in the general direction shown by arrows **35** forming a vortex recirculation zone **36**. Radial swirler **27** air flow, represented by arrows **29**, mixes with the main circuit fuel flow **34** and the mixture is caused to recirculate in the general direction shown by arrows **39** forming a separate vortex recirculation zone **40**. When the pilot circuit and main circuit fuel air mixtures are ignited, the flame stabilized by recirculation zones **36** and **40** produces relatively low flame temperatures since the mixture is fuel lean, with the result that NOx emissions are materially reduced.

[**0043**] The previously described versions of the present invention have many advantages, including:

[**0044**] a. the capability of utilizing not only aerospace type fuels but other types of fuels as well;

[**0045**] b. the ability to retrofit the inventive fuel injection system on existing gas turbine engines;

[**0046**] c. the simplicity and corresponding low cost of the apparatus whereby a single fuel injection body incorporating both pilot circuit and main circuit fuel injectors is provided;

[**0047**] d. a design which provides for fuel-air residence times prior to entering the combustion chamber to be relatively short, thus reducing the danger of autoignition or flashback situations, which are a safety concern for aerospace applications; and

[**0048**] e. the capability of utilizing the inventive fuel injection system for both can type or annular combustors.

[**0049**] Although the present invention has been described in considerable detail with reference to certain preferred versions thereof, other versions are possible. Therefore, the spirit and scope of the appended claims should not be limited to the description of the preferred versions contained therein.

We claim:

1. A gas turbine engine fuel injection and combustor system, comprising:

an outer casing extending from an upstream end to a downstream end, an internal space of the downstream end defining a combustion chamber;

an annular dome connected to an internal, upstream end of the outer casing;

a radial flow air swirler mounted to an internal surface of the annular dome and to an external surface of a fuel injector body, said swirler providing swirled air to the combustion chamber;

a fuel injector body mounted to an internal surface of the radial flow air swirler, said fuel injector body comprising a plurality of axially oriented air swirlers, an axially located pilot circuit fuel nozzle, and a plurality of radially oriented main circuit fuel nozzles;

whereby during low power gas turbine engine operation, pilot circuit fuel is mixed with axial swirler produced air flow, and is thereby caused to rotate in a vortex around a longitudinal axis of the combustion chamber and upon ignition produces a stable high temperature emission free flame;

whereby during intermediate and high power gas turbine engine operation, pilot circuit and main circuit fuel is mixed with radial and axial swirler produced air flow, and is thereby caused to rotate in a double vortex around the longitudinal axis of said combustion chamber, and upon ignition produces a stable, fuel lean, low temperature, low pollutant emission flame.

2. The gas turbine engine fuel injection and combustor system of claim 1, whereby a single fuel injector body incorporates both the pilot circuit and the main circuit fuel injection systems.

3. The gas turbine engine fuel injection and combustor system of claim 1, whereby the fuel injector body for the pilot and main circuit fuel injection systems is cylindrical.

4. The gas turbine engine fuel injection and combustor system of claim 1, whereby pilot circuit fuel and main circuit fuel are injected in the combustion chamber at essentially the same axial and radial locations.

5. The gas turbine engine fuel injection and combustor system of claim 1, whereby a pilot circuit fuel nozzle encircled by a plurality of axial air swirlers discharges fuel into a combustor creating a rotating vortex of vaporized fuel and air.

6. The gas turbine engine fuel injection and combustor system of claim 1, whereby main circuit fuel nozzles discharge fuel at a compound angle into a radial swirler passage creating a rotating vortex of vaporized fuel and air within the combustion chamber.

7. The gas turbine engine fuel injection and combustor system of claim 1, whereby the combined geometry of the pilot circuit and main circuit fuel injection systems provides short fuel-air residence times prior to entering the combustion chamber.

8. The gas turbine engine fuel injection and combustor system of claim 1, whereby at least four radially oriented main circuit fuel nozzles are employed.

9. The gas turbine engine fuel injection and combustor system of claim 1, whereby said fuel injection system is usable for both can type and annular type combustors.

10. The gas turbine engine fuel injection and combustor system of claim 1, whereby aerospace type fuels can be utilized can be utilized as the combustion medium.

11. The gas turbine engine fuel injection and combustor system of claim 1, whereby a variety of non-aerospace type fuels can be utilized as the combustion medium.

12. A method of producing a low emission gas at low and high power in a gas turbine engine combustor, comprising the steps of:

injecting pilot circuit fuel spray through a axially disposed nozzle into a combustor chamber;

swirling a first portion of air axially and flowing said swirled air into said combustor chamber to form a swirling mixture of pilot circuit fuel and air for low, intermediate, and high power operations;

swirling a second portion of air radially and flowing said swirled air into an air swirler passageway;

injecting main circuit fuel spray through radially disposed nozzles into said air swirler passageway and thereafter into said combustion chamber to form a swirling mixture of main circuit fuel and air for intermediate and high power operations;

expanding and igniting said swirling mixture of pilot circuit fuel and air to form said low emission gas for low and high power operations; and

expanding and igniting said swirling mixture of main circuit fuel and air to form said low emission gas for intermediate and high power operations.

13. The method of claim 12, wherein the step of expanding pilot circuit fuel and air forms a fuel rich, high flame temperature, zone in the combustion chamber.

14. The method of claim 12, wherein the step of expanding main circuit fuel and air forms a fuel lean, low flame temperature, zone in the combustion chamber.

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