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Ehrich

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[54] GAS TURBINE ENGINE WITH MEANS FOR REDUCING THE FORMATION AND EMISSION OF NITROGEN OXIDES

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[52] **U.S. Cl.** .... **60/226 R,** 60/266, 60/39.65, 60/39.66, 60/39.74 R, 60/DIG. 11
[51] **Int. Cl.** **F02c 7/18,** F02c 7/22
[58] **Field of Search** .... 60/39.65, 39.66, 39.67, 60/39.23, 39.07, DIG. 10, 226 R, 262, 266, 39.74 R

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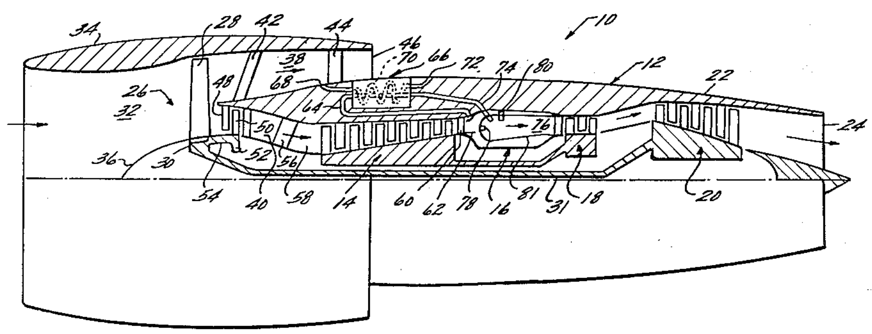
Assistant Examiner—Robert E. Garrett

[57] **ABSTRACT**

Means for reducing the formation and emission of nitrogen oxides in a gas turbine engine provide for bleeding and cooling a portion of the airflow pressurized by the compressor. The cooled compressor bleed airflow is then introduced into the primary combustion zone of the combustor in order to reduce the flame temperature effecting a reduction in the rate of formation of oxides of nitrogen.

5 Claims, 4 Drawing Figures



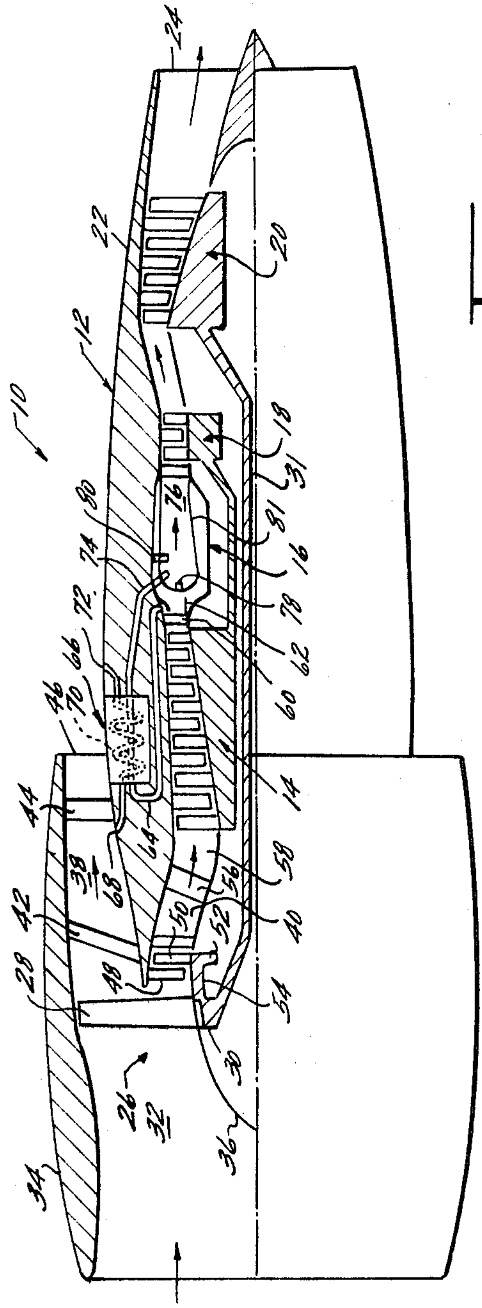


Fig 1

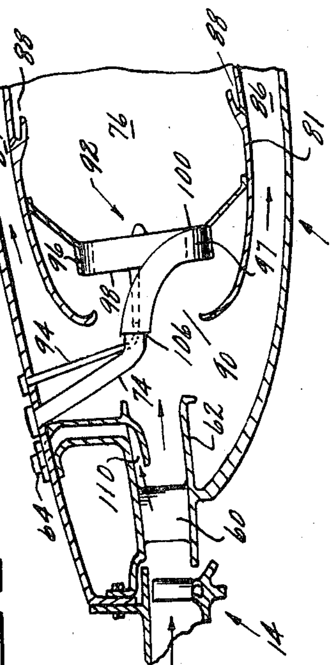


Fig 2

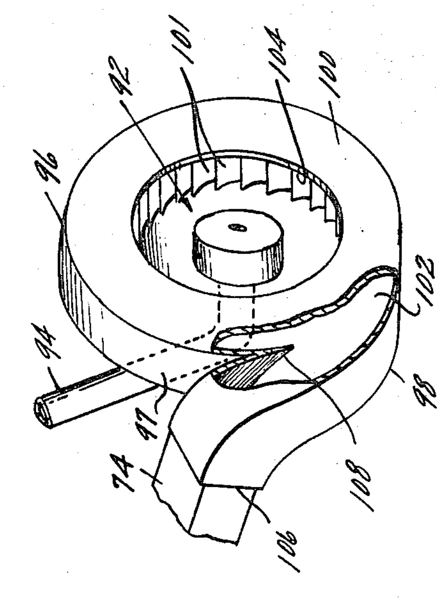


Fig 3

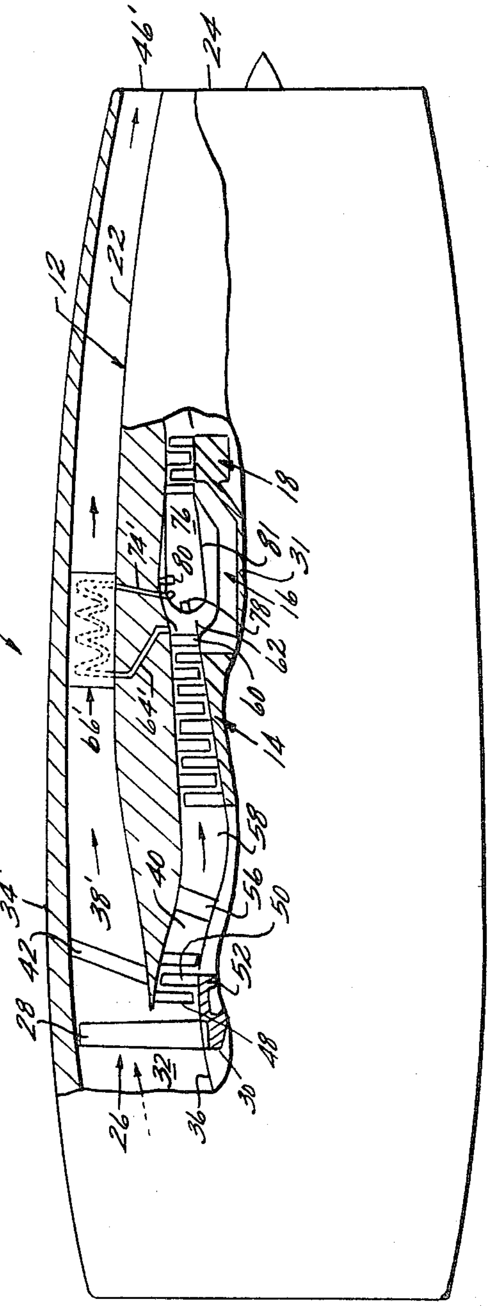

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Fig 4

GAS TURBINE ENGINE WITH MEANS FOR REDUCING THE FORMATION AND EMISSION OF NITROGEN OXIDES

BACKGROUND OF THE INVENTION

This invention relates generally to a gas turbine engine having means for significantly reducing the formation and emission of nitrogen oxides and, more particularly, to a gas turbine engine having means for cooling a portion of the compressor discharge air and then introducing the precooled air into the primary combustion zone to reduce the flame temperature and effect a corresponding reduction in the formation of nitrogen oxides.

The present day emphasis on the elimination of air pollution has resulted in a great deal of work and effort by aircraft gas turbine engine manufacturers who have succeeded in significantly reducing most forms of polluting emissions. Nitrogen oxides, however, are one form of pollutant emitted from a gas turbine engine which have not been satisfactorily reduced. Although it is not fully understood how oxides of nitrogen are formed, it is believed that such oxides are produced by the direct combination of atmospheric nitrogen and oxygen at the high temperatures occurring in primary combustion zones. The rates with which nitrogen oxides form depend upon the flame temperature and consequently a small reduction in flame temperature will result in a large reduction in the nitrogen oxides.

One proposed solution for reducing the emission of nitrogen oxides involves the introduction of more air to the critical primary combustion zone during peak periods of nitrogen oxide formation. The introduction of more air operates to reduce the fuel air ratio and corresponding flame temperature. The formation of oxides of nitrogen are generally most severe at the high power settings of the engine such as during takeoff. However, if the engine were designed to provide an excess of air during the peak power period at takeoff, then the fuel to air ratio at low power settings or at lightoff would likely be too lean to sustain or initiate combustion. Therefore, it becomes necessary to provide variable geometry apparatus to modulate the flow of air to the combustor in a manner which provides an excess of air during high power settings of the engine and reduces the airflow at low power setting to prevent the combustor flame from blowing out. Variable geometry, however, generally adds weight and complexity to a gas turbine engine and consequently is not an entirely satisfactory solution to the problem of eliminating nitrogen oxide emissions.

Another proposed solution for reducing the emission of nitrogen oxides relates to the effect of vitiating the combustion air with inert products such as recirculated cooled exhaust products or steam, wherein the flame temperature is reduced mainly by dilution and by the increased specific heat of the mixture. One difficulty with recirculating cooled exhaust products or steam, however, is that the combustor is generally at a higher pressure than the exhaust necessitating the addition of a pump or blower to introduce the exhaust products directly into the combustor. The addition of a pump or blower again adds weight and complexity to the gas turbine engine with an attendant reduction in engine efficiency.

The addition of a pump or blower could be eliminated by reintroducing the exhaust products directly into the compressor inlet; however, this method also incurs certain disadvantages. Foremost is the increased risk that air contaminated by exhaust products will be circulated through the aircraft cabin from malfunctioning airconditioners which utilize compressor bleed air. Also, introducing exhaust products into the compressor inlet would accelerate the overall corrosion within the compressor.

Still another proposed solution for reducing the emission of nitrogen oxides relates to the introduction of a spray of water into the primary combustion zone in order to lower the flame temperature. This, however, necessitates that water storage tanks and pumps be added to the aircraft which could significantly increase the weight of the aircraft.

Therefore, it is a primary object of this invention to provide a simple means for reducing the formation and emission of nitrogen oxides from the combustor of a gas turbine engine without the use of variable geometry, blowers, pumps or water storage tanks.

It is also an object of this invention to provide a simple means for lowering the flame temperature within the primary combustion zone of a gas turbine engine in order to reduce the formation of nitrogen oxides therein.

It is a further object of this invention to provide a simple means for cooling a portion of the compressor discharge air and then introducing the precooled air into the primary combustion zone to quench the thermal reaction and reduce the formation of nitrogen oxides.

SUMMARY OF THE INVENTION

Briefly stated, the above and other objects are achieved in the present invention by providing a gas turbine engine which may be of the bypass front fan type having a core compressor, combustor and turbine in serial flow relation, with a simplified means for reducing the formation of oxides of nitrogen within the combustor. In the gas turbine engine, there is included means for bleeding a portion of the airflow pressurized by the compressor together with means for directing the airflow bled from the compressor into heat exchange relation with the bypass airflow in order to cool the compressor bleed airflow. Means are further included for introducing the cooled compressor bleed airflow into the primary combustion zone of the combustor in order to reduce the flame temperature and rate of formation of oxides of nitrogen.

BRIEF DESCRIPTION OF THE DRAWINGS

While the specification concludes with claims distinctly claiming and particularly pointing out the invention described herein, it is believed that the invention will be more readily understood by reference to the discussion below and the accompanying drawings in which:

FIG. **1** is a side view, partly in cross-section, of a gas turbine engine embodying means for reducing the formation of nitrogen oxides within the engine combustor.

FIG. **2** is a partial cross-sectional view of the forward end of a gas turbine engine combustor embodying means for reducing the formation of nitrogen oxides therein.

FIG. 3 is a perspective view, partly cut away, of the nitrogen oxide reducing means of FIG. 2.

FIG. 4 is a side view, partly in cross-section, of a gas turbine engine embodying an alternate embodiment of the means of FIG. 1 for reducing the formation of nitrogen oxides within the engine combustor.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIG. 1, there is shown a gas turbine engine **10** of the bypass front fan type comprising a core engine **12** having a compressor **14**, a combustor **16**, a gas generator turbine **18** for driving the compressor **14**, and a power turbine **20** arranged in axially spaced serial flow relationship. The inner turbomachine, or core engine **12**, is enclosed within a cylindrical casing **22** which terminates at its downstream end in an exhaust nozzle **24** through which the combustion products of the core engine **12** may be discharged to produce thrust. To provide additional thrust a fan **26** is mounted upstream of the core engine **12** and is driven by the power turbine **20**. The fan **26** is comprised of a plurality of fan blades **28** which extend radially outward from a fan wheel **30**, which is coupled for rotation with the power turbine **20** through the interconnecting shaft **31**. The fan blades **28** extend radially across a bypass duct or passageway **32** defined between an outer cylindrical casing **34** and a "bullet nose" **36** located upstream of the fan blades **28**. Downstream of the fan blades **28**, the passageway **32** is divided into two passages **38** and **40** by the casing **22**. Radially positioned between the casing **34** and casing **22** are a plurality of fan stator vanes **42** which are followed by a plurality of fan outlet guide vanes **44**. Thus a portion of the air entering the passageway **32** flows through the fan blades **28** into the passageway **38**, through the stator vanes **42**, and through the outlet guide vanes **44** and thereafter exits through an outlet opening **46** formed by the casing **34** and the casing **22**. Since this air is pressurized in flowing through the fan blades **28**, it provides forward thrust to the turbofan engine **10**.

The remainder of the air flowing through the passageway **32** and fan blades **28** enters the passageway **40**. Located within this passageway **40** are a plurality of inlet guide vanes **48** for the core engine **12** which may be followed by a plurality of rotatable booster blades **50**, extending from a disc **52** and coupled for rotation with the fan blades **28** by means of the disc **52** and a shaft **54**. Located downstream of the booster blades **50** is a row of stator vanes **56**. Air passing through the stator vanes **56** next flows into the core engine **12** through passageway **58**.

The gas turbine engine **10** may be either a high bypass ratio machine or a low bypass ratio machine wherein the "bypass ratio" refers to the ratio of the mass flow of fluid in the bypass passageway **38** to the mass flow in the core engine **12** (or passageway **40**).

The compressor **14** discharges pressurized air through a plurality of circumferentially spaced apart outlet guide vanes **60** which extend radially between the walls of a diffuser passageway **62**. A portion of the pressurized air exiting from the diffuser passageway **62** is bled through a conduit **64** to a heat exchanger **66**. The heat exchanger **66** receives a portion of the cool bypass airflow from passageway **38** through inlet **68** whereupon the bypass airflow is directed through conduit **70** in heat exchange relation with the compressor discharge air and then discharged back into the bypass passageway **38** through outlet **72**. Whereas the temperature and pressure of the compressor discharge air has been raised by the compressor **14**, the heat exchanger **66** operates to reduce the temperature of that portion of the compressor discharge air bled through conduit **64**.

The heat exchanger herein described is of conventional design and may take on many different forms with the only requirement being that the bypass airflow be used to cool a portion of the compressor discharge air. In practice the heat exchanger **66** may be annular with the fluids passed through the heat exchanger in paths as illustrated. If desired, however, alternative flow arrangements can be used for providing more effective heat transfer. For example, each of the streams could be directed through the heat exchanger twice in radial outflow passes. It is thus essential that there be two sets of independent passages disposed in heat exchange relationship within the heat exchanger, the bypass air flowing through one set of passages and the compressor discharge air flowing through the other set of passages.

The cooled compressor discharge air exiting from the heat exchanger **66** is directed to the combustor **16** by way of conduit **74** from whence it is dumped into the primary combustion zone **76** of the combustor **16**. Fuel from a source of pressurized fuel (not shown) is introduced into the primary zone **76** of combustor **16** through fuel nozzle **78**. Once the fuel is introduced into combustor **16**, it may be ignited by igniter **80**. The primary combustion zone **76** is generally defined within liner **81** in the area adjacent fuel nozzle **78**.

In operation, combustor **16** will generally emit the following combustion products: carbon monoxide, carbon dioxide, water vapor, smoke and particles, unburned hydrocarbons, nitrogen oxides and sulfur oxides. Of these, carbon dioxide and water vapor may be considered normal and unobjectionable. Smoke can be a problem; however, it is generally controlled by design modifications in the primary combustion zone. Particulates which are one form of smoke are generally associated with coal burning plants and are not of immediate concern to gas turbines. Sulfur oxides can be limited by the careful selection of fuels low in total sulfur. This leaves carbon monoxide, unburned hydrocarbons and nitrogen oxides as the emissions of primary concern in the gas turbine engine.

As previously discussed, it is not fully understood how oxides of nitrogen are formed; however, it is believed that such oxides are produced by the direct combination of atmospheric nitrogen and oxygen at the high temperatures occurring in primary combustion zones. The presence of organic nitrogen in the fuel may also aid in the production of nitrogen oxides together with the atmospheric nitrogen. The rates with which nitrogen oxides form depend upon the flame temperature and, consequently, a small reduction in flame temperature will result in a large reduction in the nitrogen oxides.

Previously suggested means for reducing the maximum temperature in the primary zone of a gas turbine combustor have included schemes for introducing more air at the primary combustion zone, recirculating cooled exhaust products or steam back into the primary combustion zone and injecting a water spray back into the primary zone. All of these previously suggested methods, however, involve the addition of either complex or heavy hardware such as variable geometry, blowers, pumps or water storage tanks.

The invention herein described, however, provides for a heat exchanger **66** which precools a portion of the compressor discharge air and directs the precooled compressor discharge air back to the primary combustion zone **76** through conduit **74** in order to reduce the flame temperature thereby inhibiting the formation of oxides of nitrogen. Although it is preferred that a portion of the compressor discharge air be precooled, it would not be outside the scope of invention to bleed and cool a portion of the compressor interstage air and redirect the precooled compressor interstage air back to the primary zone of the combustor.

Referring now to FIGS. **2** and **3** where like numerals refer to previously described elements, there is shown one arrangement by which the precooled compressor discharge air may be introduced into the primary combustion zone **76.** An outer shell **82** is provided to enclose the liner **81** and to cooperate therewith to form passageways **84, 86** surrounding the liner **81.** As will be understood, the passageways **84, 86** are adapted to deliver a flow of pressurized air from the compressor **14** through suitable apertures or louvers **88.** In this manner, the passageways **84, 86** act to both cool the liner **81** and to provide dilution air to the gaseous products of combustion formed within the primary combustion zone **76.**

The upstream end of liner **81** is adapted to function as a flow splitter to divide the pressurized air delivered from the compressor **14** between the passages **84, 86** and an upstream end opening **90.** Located within the liner **81** is a conventional fuel injecting apparatus shown generally at **92** which may be of the atomizing type as is well known in the art. Pressurized fuel may be supplied to the fuel injection apparatus **92** through a conduit **94** which extends through the outer shell **82** and communicates with a source of pressurized fuel (not shown).

Surrounding the fuel injection apparatus **92,** there is a housing **96** which comprises an involute outer wall **97** and generally planar, spaced upstream and downstream annular end walls **98** and **100,** respectively, which are peripherally joined to the outer wall **97.** A plurality of circumferentially spaced apart swirl vanes **101** extend between the upstream and downstream end walls in spaced apart relation to the outer wall **97.** The housing **96** defines a conventional spin chamber **102** having an annular outlet **104** which surrounds the fuel injection apparatus **92.** The outer wall **97** is of spiral shape with progressively decreasing radius from an inlet **106** to a terminal edge or lip **108** which in part defines the opening from inlet **106** to the spin chamber **102.** The inlet **106** is in direct flow communication with the conduit **74** for receiving a flow of precooled compressor discharge air directly from the heat exchanger **66.** In this manner precooled compressor discharge air may be directed from inlet **106** into the spin chamber **102** in a circular motion of ever decreasing radius so as to generate a vortical flow around the fuel injection apparatus **92.**

In operation, a portion of the compressor discharge air is bled through inlet **110** of conduit **64** and directed to the heat exchanger **66** whereupon it is circulated in heat exchange relationship with the fan bypass airflow, and then directed to the spin chamber **102** via conduit **74.** The precooled compressor discharge air is dumped into the primary combustion zone **76** in a vortical flow from outlet **104** of the spin chamber **102** whereupon it reduces the flame temperature in the primary combustion zone **76** and inhibits the formation of oxides of nitrogen.

Turning now to FIG. **4** where like numerals refer to previously described elements, there is shown a modified gas turbine engine **10'** which is also of the bypass front fan type, and which includes an extended cowling or casing **34'** The cowling **34'** is spaced apart from the core engine **12** so as to define a bypass passageway **38'** which extends substantially the length of the core engine **22** and terminates in an outlet opening **46'.** A heat exchanger **66'** is disposed within the passageway **38'** and receives a portion of the pressurized compressor discharge air exiting from the diffuser passageway **62** through conduit **64'.** The compressor discharge air is directed into heat exchange relation with the comparatively cooler fan air flow in passageway **38'**, and then returned to the combustor **16** through conduit **74'** in order to reduce the flame temperature and inhibit the formation of oxides of nitrogen as previously discussed.

From the foregoing it will be appreciated that the formation of nitrogen oxide in the combustor of a gas turbine engine are inhibited by simple means without the addition of variable geometry, blowers, pumps or water storage tanks. It will also be appreciated that a portion of the compressor discharge air which is bled and cooled by the heat exchanger **66** may be directed to the turbine for cooling purposes. Accordingly, while preferred embodiments of the present invention have been depicted and described, it will be appreciated by those skilled in the art that many modifications, substitutions, and changes may be made thereto without departing from the invention's fundamental scheme.

Having thus described one embodiment of the invention, what is desired to be secured by Letters Patent is as follows:

1. In a gas turbine engine having a compressor, combustor and turbine in serial flow relation, means for reducing the formation of oxides of nitrogen within the combustor comprise:

means within said combustor defining a primary combustion zone, a secondary combustion zone, and a dilution zone;

means for bleeding a portion of the airflow pressurized by the compressor;

means for cooling the airflow bled from the compressor;

means for directing the unbled portion of compressor discharge airflow to the primary combustion, secondary combustion, and dilution zones of the combustor in order to support combustion in the primary combustion zone;

and means for introducing the cooled compressor bleed airflow into the primary combustion zone of the combustion in order to reduce the flame temperature.

2. In a gas turbine engine of the bypass front fan type having a core compressor, combustor and turbine in serial flow relation, means for reducing the formation of oxides of nitrogen within the combustor comprise:

means within said combustor defining a primary combustion zone, a secondary combustion zone, and a dilution zone;

means for bleeding a portion of the airflow pressurized by the compressor;

means for directing the airflow bled from the compressor into heat exchange relation with the bypass airflow in order to cool the compressor bleed airflow;

means for directing the unbled portion of compressor discharge airflow to the primary combustion, secondary combustion, and dilution zones of the combustor in order to support combustion in the primary combustion zone, and

means for introducing the cooled compressor bleed airflow into the primary combustion zone of the combustor in order to reduce the flame temperature.

3. The gas turbine engine of claim **2** wherein the means for directing the compressor bleed airflow into heat exchange relation with the bypass airflow includes a heat exchanger having at least two passages arranged in heat exchange relationship wherein one of the passages receives and discharges bypass airflow and the other passage receives and discharges compressor bleed airflow.

4. The gas turbine engine of claim **2** wherein the means for reintroducing the cooled compressor bleed airflow back into the primary zone of the combustor includes:

a spin chamber in general surrounding relation to a fuel injection apparatus wherein the spin chamber receives the cooled compressor bleed airflow and directs the airflow in a circular motion of ever decreasing radius so as to generate a vortical flow around the fuel injection apparatus, and,

conduit means communicating from the spin chamber to the heat exchange means for directing the cooled compressor bleed airflow therebetween.

5. The gas turbine engine of claim **4** wherein the spin chamber includes:

an involute outer wall and generally planar spaced upstream and downstream annular end walls, the outside edges of which are peripherally joined to the outer wall and the inside edges of which define an annular outlet which surrounds the fuel injection apparatus;

a plurality of circumferentially spaced apart swirl vanes extending between the upstream and downstream end walls in spaced apart relation to the outer wall;

and an inlet in direct communication with the conduit means for receipt of the cooled compressor bleed airflow.

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