

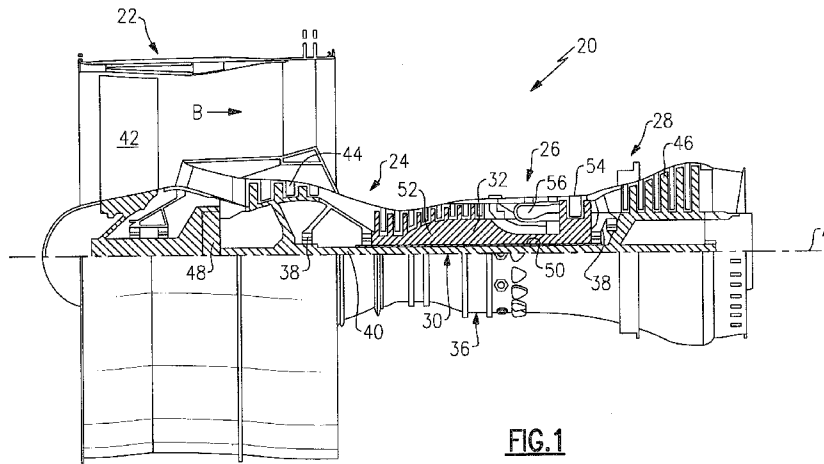


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(54) **Title:** GAS TURBINE ENGINE COMBUSTOR



**FIG. 1**

(57) **Abstract:** A swirler assembly for a gas turbine engine includes an outer annular injector which at least partially surrounds an inner injector.

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combustion includes three serially arranged combustion zones: a rich burn zone at the forward end of the combustor, a quench or dilution zone axially aft of the rich burn zone, and a lean burn zone axially aft of the quench zone.

[0005] During engine operations, a portion of the pressurized air discharged from the compressor enters the rich burn zone of the combustion chamber. Concurrently, fuel injectors introduce a stoichiometrically excessive quantity of fuel into the rich burn zone. Although the resulting stoichiometrically fuel rich fuel-air mixture is ignited and burned to release the energy content of the fuel, some NO<sub>x</sub> formation may still occur.

[0006] The fuel rich combustion products then enter the quench zone where jets of pressurized air radially enter through combustion air holes into the quench zone of the combustion chamber. The pressurized air mixes with the combustion products to derich the fuel rich combustion products as they flow axially through the quench zone. The fuel-air ratio of the combustion products thereby changes from fuel rich to stoichiometric which may cause an attendant rise in combustion flame temperature. Since the quantity of NO<sub>x</sub> produced in a given time interval increases exponentially with flame temperature, quantities of NO<sub>x</sub> may be produced in this initial quench process. As the quenching continues, the fuel-air ratio of the combustion products changes from stoichiometric to fuel lean which cause an attendant reduction in the flame temperature. However, until the mixture is diluted to a fuel-air ratio substantially lower than stoichiometric, the flame temperature remains high enough to generate NO<sub>x</sub>.

[0007] RQL injector designs operate on the principle of establishing a toroidal vortex followed by vortex break-down and the formation of a re-circulating zone to stabilize the flame and provide continuous ignition to the fresh reactants. This mode of operation requires results in

relatively high shear stresses which, in turn, may lead to pressure oscillations from heterogeneous chemical release rates.

[0008] NO<sub>x</sub> formation is not only a function of temperature, but also of flame residence time and Oxygen concentration in the reaction zone. Increasing the flame strain tends to reduce the residence time in the flame, but may also increase the Oxygen concentration in the flame. These intermediate effects of strain rates tend to increase the production rate of NO<sub>x</sub>. At high strain rates, however, the reduction in flame temperature overcomes the influence of the Oxygen concentration, and NO<sub>x</sub> production rates are reduced.

[0009] Dry Low NO<sub>x</sub> (DLN) combustors utilize fuel-to-air lean premix strategy which operate near flame stability envelope limits where noise, flame blow-off (BO), and flashback may affect engine performance. For this reason, DLN strategy is limited to land-based Ground Turbine applications.

### SUMMARY

[0010] A swirler for a combustor of a gas turbine engine according to one disclosed non-limiting embodiment of the present disclosure includes an inner injector, and an outer annular injector which at least partially surrounds the inner injector.

[0011] In a further embodiment of the foregoing embodiment, the inner injector is operable to generate a first swirl and the outer annular injector is operable to generate a second swirl, the first swirl different than the second swirl.

[0012] In a further embodiment of any of the foregoing embodiments, the inner injector is operable to generate a first swirl and the outer annular injector is operable to generate a second swirl, the first swirl greater than the second swirl.

[0013] In a further embodiment of any of the foregoing embodiments, the inner injector provides a one-dimensional swirl and the outer annular injector provides a three-dimensional swirl.

[0014] In a further embodiment of any of the foregoing embodiments, the swirler  
5 includes an annular recess tube within the outer annular injector. In the alternative or additionally thereto, in the foregoing embodiment the annular recess tube is upstream of an annular divergent exit.

[0015] In a further embodiment of any of the foregoing embodiments, the inner injector defines a convergent-divergent exit. In the alternative or additionally thereto, the  
10 foregoing embodiment includes an annular recess tube within the outer annular injector. In the alternative or additionally thereto, in the foregoing embodiment the annular recess tube is upstream of an annular divergent exit.

[0016] In a further embodiment of any of the foregoing embodiments, the inner injector defines a central passage and an inner annular passage radially outboard of the central  
15 passage.

[0017] In a further embodiment of any of the foregoing embodiments, the outer annular injector defines an outer annular passage radially outboard of the inner annular passage.

[0018] A combustor section for a gas turbine engine according to another disclosed non-limiting embodiment of the present disclosure includes an inner injector which defines an  
20 axis, an outer annular injector which surrounds the inner injector, and a combustor vane along the axis.

[0019] In a further embodiment of the foregoing embodiment, the combustor vane defines a length between 35%-65% of said combustion chamber.

[0020] In a further embodiment of any of the foregoing embodiments, the combustor section includes a combustor vane with a multiple of fuel injectors which flank the combustor vane.

[0021] In a further embodiment of any of the foregoing embodiments, the inner  
5 injector defines a central passage and an inner annular passage radially outboard of the central passage, the central passage includes convergent-divergent exit. In the alternative or additionally thereto, in the foregoing embodiment the outer annular injector defines an outer annular passage radially outboard of the inner annular passage. In the alternative or additionally thereto, in the  
10 foregoing embodiment the inner injector selectively receives a fuel-air mixture. In the alternative or additionally thereto, in the foregoing embodiment the outer annular injector selectively receives a fuel-air mixture. In the alternative or additionally thereto, the foregoing embodiment includes an annular recess tube within the outer annular injector. In the alternative or additionally thereto, in the foregoing embodiment the inner annular passage selectively receives an airflow.

15

#### BRIEF DESCRIPTION OF THE DRAWINGS

[0022] Various features will become apparent to those skilled in the art from the following detailed description of the disclosed non-limiting embodiment. The drawings that accompany the detailed description can be briefly described as follows:

20 [0023] Figure 1 is a schematic cross-section of a gas turbine engine;

[0024] Figure 2 is a partial longitudinal schematic sectional view of a combustor according to one non-limiting embodiment that may be used with the gas turbine engine shown in Figure 1;

[0025] Figure 3 is a partial longitudinal schematic sectional view of a CUNERB  
5 swirler assembly according to one non-limiting embodiment;

[0026] Figure 4 is a front perspective view of the CUNERB swirler assembly of Figure 3;

[0027] Figure 5 is an expanded front perspective view of a recessed tube of the CUNERB swirler assembly of Figure 3;

10 [0028] Figure 6 is a mathematical relationship and associated schematic for the CUNERB swirler assembly;

[0029] Figure 7 is a partial longitudinal schematic sectional view of the CUNERB swirler assembly in a “Start-Up” mode;

[0030] Figure 8 is a partial longitudinal schematic sectional view of the CUNERB  
15 swirler assembly in a “Low Power” mode;

[0031] Figure 9 is a partial longitudinal schematic sectional view of the CUNERB swirler assembly in a “High Power” mode;

[0032] Figure 10 is a partial longitudinal schematic sectional view of the CUNERB swirler assembly in a “Transient” mode;

20 [0033] Figure 11 is a partial longitudinal schematic sectional view of a combustor with combustor vanes according to another non-limiting embodiment that may be used with the gas turbine engine shown in Figure 1;

[0034] Figure 12 is a sectional view taken along line 11-11 in Figure 11;

[0035] Figure 13 is a schematic view of a fuel injector for the combustor vanes according to one non-limiting embodiment; and

[0036] Figure 14 is a schematic view of a fuel injector for the combustor vanes according to another non-limiting embodiment.

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### DETAILED DESCRIPTION

[0037] Figure 1 schematically illustrates a gas turbine engine 20. The gas turbine engine 20 is disclosed herein as a two-spool turbofan that generally incorporates a fan section 22, a compressor section 24, a combustor section 26 and a turbine section 28. Alternative engines might include an augmentor section (not shown) among other systems or features. The fan section 22 drives air along a bypass flowpath while the compressor section 24 drives air along a core flowpath for compression and communication into the combustor section 26 then expansion through the turbine section 28. Although depicted as a turbofan gas turbine engine in the disclosed non-limiting embodiment, it should be understood that the concepts described herein are not limited to use with turbofans as the teachings may be applied to other types of turbine engines such as a three-spool (plus fan) engine wherein an intermediate spool includes an intermediate pressure compressor (IPC) between the LPC and HPC and an intermediate pressure turbine (IPT) between the HPT and LPT.

[0038] The engine 20 generally includes a low spool 30 and a high spool 32 mounted for rotation about an engine central longitudinal axis A relative to an engine static structure 36 via several bearing structures 38. The low spool 30 generally includes an inner shaft 40 that interconnects a fan 42, a low pressure compressor 44 ("LPC") and a low pressure turbine 46 ("LPT"). The inner shaft 40 drives the fan 42 directly or through a geared architecture 48 to

drive the fan 42 at a lower speed than the low spool 30. An exemplary reduction transmission is an epicyclic transmission, namely a planetary or star gear system.

[0039] The high spool 32 includes an outer shaft 50 that interconnects a high pressure compressor 52 (“HPC”) and high pressure turbine 54 (“HPT”). A combustor 56 is arranged  
5 between the high pressure compressor 52 and the high pressure turbine 54. The inner shaft 40 and the outer shaft 50 are concentric and rotate about the engine central longitudinal axis A which is collinear with their longitudinal axes.

[0040] Core airflow is compressed by the low pressure compressor 44 then the high pressure compressor 52, mixed with the fuel and burned in the combustor 56, then expanded  
10 over the high pressure turbine 54 and low pressure turbine 46. The turbines 54, 46 rotationally drive the respective low spool 30 and high spool 32 in response to the expansion.

[0041] The main engine shafts 40, 50 are supported at a plurality of points by bearing structures 38 within the static structure 36. It should be understood that various bearing structures 38 at various locations may alternatively or additionally be provided.

15 [0042] In one non-limiting example, the gas turbine engine 20 is a high-bypass geared aircraft engine. In a further example, the gas turbine engine 20 bypass ratio is greater than about six (6:1). The geared architecture 48 can include an epicyclic gear train, such as a planetary gear system or other gear system. The example epicyclic gear train has a gear reduction ratio of greater than about 2.3, and in another example is greater than about 2.5:1. The  
20 geared turbofan enables operation of the low spool 30 at higher speeds which can increase the operational efficiency of the low pressure compressor 44 and low pressure turbine 46 and render increased pressure in a fewer number of stages.

[0043] A pressure ratio associated with the low pressure turbine 46 is pressure measured prior to the inlet of the low pressure turbine 46 as related to the pressure at the outlet of the low pressure turbine 46 prior to an exhaust nozzle of the gas turbine engine 20. In one non-limiting embodiment, the bypass ratio of the gas turbine engine 20 is greater than about ten (10:1), the fan diameter is significantly larger than that of the low pressure compressor 44, and the low pressure turbine 46 has a pressure ratio that is greater than about 5 (5:1). It should be understood, however, that the above parameters are only exemplary of one embodiment of a geared architecture engine and that the present disclosure is applicable to other gas turbine engines including direct drive turbofans.

[0044] In one embodiment, a significant amount of thrust is provided by the bypass flow path B due to the high bypass ratio. The fan section 22 of the gas turbine engine 20 is designed for a particular flight condition - typically cruise at about 0.8 Mach and about 35,000 feet. This flight condition, with the gas turbine engine 20 at its best fuel consumption, is also known as bucket cruise Thrust Specific Fuel Consumption (TSFC). TSFC is an industry standard parameter of fuel consumption per unit of thrust.

[0045] Fan Pressure Ratio is the pressure ratio across a blade of the fan section 22 without the use of a Fan Exit Guide Vane system. The low Fan Pressure Ratio according to one non-limiting embodiment of the example gas turbine engine 20 is less than 1.45. Low Corrected Fan Tip Speed is the actual fan tip speed divided by an industry standard temperature correction of  $(T / 518.7)^{0.5}$  in which "T" represents the ambient temperature in degrees Rankine. The Low Corrected Fan Tip Speed according to one non-limiting embodiment of the example gas turbine engine 20 is less than about 1150 fps (351 m/s).

[0046] With reference to Figure 2, the combustor 56 generally includes a combustor outer liner 60 and a combustor inner liner 62. The outer liner 60 and the inner liner 62 are spaced inward from a diffuser case 64 such that a combustion chamber 66 is defined therebetween. The combustion chamber 66 is generally annular in shape and is defined between  
5 combustor liners 60, 62.

[0047] The outer liner 60 and the diffuser case 64 define an outer annular plenum 76 and the inner liner 62 and the case 64 define an inner annular plenum 78. It should be understood that although a particular combustor arrangement is illustrated, other combustor arrangements will also benefit herefrom. Each liner 60, 62 generally includes a respective support shell 68, 70  
10 that supports one or more respective liner panels 72, 74 mounted to a hot side of the respective support shell 68, 70. The liner panels 72, 74 define a liner panel array that may be generally annular in shape. Each of the liner panels 72, 74 may be generally rectilinear and manufactured of, for example, a nickel based super alloy or ceramic material.

[0048] The combustor 56 includes a forward assembly 80 immediately downstream  
15 of the compressor section 24 (illustrated schematically) to receive compressed airflow therefrom. The forward assembly 80 generally includes an annular hood 82, a bulkhead assembly 84, a fuel supply 86 (illustrated schematically) and a multiple of swirler assemblies 90 (one shown). The annular hood 82 extends radially between, and is secured to, the forwardmost ends of the liners 60, 62 and includes a multiple of circumferentially distributed hood ports 82P that direct  
20 compressed airflow into the forward end of the combustion chamber 66 through the swirler assemblies 90.

[0049] The bulkhead assembly 84 includes a bulkhead support shell 84S secured to the liners 60, 62, and a multiple of circumferentially distributed bulkhead heatshields segments

98 secured to the bulkhead support shell 84S around the central opening 90A. The forward assembly 80 directs a portion of the core airflow (illustrated schematically by arrow C) into the forward end of the combustion chamber 66 while the remainder may enter the outer annular plenum 76 and the inner annular plenum 78. The multiple of swirler assemblies 90 and  
5 associated fuel communication structure (illustrated schematically) supports combustion in the combustion chamber 66.

[0050] With reference to Figure 3, the swirler assembly 90 generally includes an inner injector 92 and an outer annular injector 94 orchestrated together as one and referred to herein as a “CUNERB” swirler assembly. The inner injector 92 operates as a relatively high  
10 swirl injector and the outer annular injector 94 operates as a relatively low swirl injector. The inner injector 92 also generates a relatively one-dimensional swirl while the outer annular injector 94 generates a relatively three-dimensional swirl.

[0051] The inner injector 92 includes a central passage 96A, an annular central passage 96B, and an inner annular passage 106. The central passage 96A includes a convergent-  
15 divergent section 98 along a central axis F to control the flow split and to attain stable divergent core turbulent flow. Downstream of the convergent-divergent section 98, the annular central passage 96B communicates with a multiple of jets 100 (also shown in Figure 4) that are located through a convergent distal end 102E of a central passage wall 102 to promote a desired degree of turbulence intensity. The convergent distal converges toward axis F. The central passage  
20 96A may include a multiple of central vanes 104 which facilitate generation of spin to the fuel.

[0052] The inner annular passage 106 is radially outboard of the central passage wall 102. The inner annular passage 106 is radially outward bounded by an inner annular wall 108 which includes an inner wall distal end 108E that converges toward the central passage 96A. A

multiple of inner annular passage vanes 110 may be located between the central passage wall 102 and the inner wall 108 to provide structural support therebetween. The multiple of inner annular passage vanes 110 may also be utilized to direct or spin the compressed airflow which flows through the inner annular passage 106. That is, the central passage 96A and annular  
5 central passage 96B communicates fuel, whereas, the inner annular passage 106 therearound communicates airflow.

[0053] The outer annular injector 94 includes an outer annular passage 114 radially outboard of the inner annular passage 106. An outer wall 116 bounds the outer annular passage 114. The outer annular passage 114 includes an annular recess tube 118 to stabilize the flow and  
10 facilitate a desired velocity profile and rotation to settle the flame at a desired location beyond a divergent exit 120 defined by an outer wall distal end 116E of the outer wall 116 and the distal end 108E of the inner annular wall 108.

[0054] The annular recess tube 118 is supported by a multiple of inner and outer support vanes 122A, 122B. An outer wall 124 and an inner wall 126 of the annular recess tube  
15 118 includes a respective multiple of apertures 128, 130 located between the respective support vanes 122A, 122B (Figure 5). The respective multiple of apertures 128, 130 are circumferentially offset to induce a swirl in the annular recess tube 118 and thus from the outer annular passage 114 of the outer annular injector 94. The outer annular injector 94 thereby generates a swirled fuel-air mixture therefrom.

20 [0055] The outer injector 114 of the combustor 56 operates on the principle of matching fluid velocity,  $U$ , from the injector to the flame speed,  $S$ , towards the injector so that the flame is fixed (anchored) or controlled in space relative to a virtual origin; Figure 6. This

control is achieved through the deceleration of the flow in the outer annular injector 94, whose derivation is shown schematically in Figure 6, leading to the following governing equation [1]:

$$x_F = x_o + [1 - \lambda]/K \quad [1]$$

[0056] Where with the corresponding nomenclature for the symbols appearing in

5 Figure 6 as:

[0057] A ~ cross sectional area

[0058] a ~ sonic speed

[0059] C ~ constant

[0060] dA ~ differential area

10 [0061] dx ~ differential distance

[0062] dM ~ Mach No. change

[0063] M ~ Mach No.

[0064] S ~ flame speed

[0065] u' ~ turbulent component of axial velocity

15 [0066] U ~ axial velocity

[0067] x ~ axial distance

[0068]  $\gamma$  ~ specific heat ratio

[0069]  $\delta$  ~ denotes change

[0070]  $\phi$  ~ equivalence ratio

20 [0071] - Subscripts

[0072] F ~ final

[0073] O ~ initial

[0074] L ~ laminar

[0075] T ~ turbulent

[0076] With reference to Figures 7-10, operating modes at Start-Up; Low Power; Transient; and High Power are schematically illustrated. At Start-Up (Figure 7), 100% of the fuel is supplied to the outer annular injector 94. At Low Power (Figure 8), approximately 16% of the fuel is supplied to the inner injector 92 and approximately 84 % is provided to the outer annular injector 94. At High Power (Figure 9), approximately 33 % of the fuel is supplied to the inner injector 92 and approximately 66 % is provided to the outer annular injector 94 to reduce NOx formation where low swirl combustion NOx formation is many times less than that of a high swirl combustion. During transient (Figure 10), in which the engine 20 is throttled toward the Low Power flight mode, 100% of fuel is supplied to the inner injector 92, followed by fuel increase to the outer annular injector 94 until as shown in the Low Power mode (Figure 8).

[0077] The combustor 56 provides 2.5 -5 times lower NOx formation and facilitates flame stability in comparison to lean premixed combustors with higher adiabatic flame temperatures and less propensity for combustion pressure oscillations. During high power flight conditions, the low swirl outer annular injector 94 complements the robustness of the high swirl inner injector 92 at high power flight conditions. During low power flight conditions, flame is generated from the inner injector 92 while the low swirl outer annular injector 94 operate as premixed chambers.

[0078] With reference to Figure 11, the combustor 56' may further include a multiple combustor vanes 200 integrated into the combustor 56' between the liner panels 72, 74 of respective liners 60, 62 according to another non-limiting embodiment. The combustor vanes 200 extends at least partially into the combustion chamber 66 - the primary zone to perform

combustor dilution/mixing requirements - such that a turbine rotor assembly 28A is the first stage immediately downstream of the combustor 56'. That is, no first stage vane such as nozzle guide vanes are required immediately downstream of the combustor 56 as the combustor vanes 200 provide the performance characteristics of a turbine first stage vane in terms of turbine flow metering and compressor cycle matching. In one disclosed, non-limiting embodiment the combustor vanes 200 define an axial length between 35%-65% of the combustion chamber 66. Moreover, the combustor vanes 200 may be positioned to block hot streaks from progressing into the turbine section 28. For further understanding of other aspects of the integrated combustor vane and associated operational modes thereof, attention is directed to United States Patent Application Numbers. 13/627,722 and 13/627,697 both filed on September 26, 2012, each entitled GAS TURBINE ENGINE COMBUSTOR WITH INTEGRATED COMBUSTOR VANE and which are assigned to the assignee of the instant disclosure and which is hereby incorporated herein in its entirety.

[0079] With reference to Figure 12, each combustor vane 200 may be located directly axially downstream of the inner injector 92 along axis F. That is, the leading edge swirlers 202 face the inner injector 92 along axis F. The combustor vanes 200 facilitate a decrease in the overall length of the combustor section 26 and thereby the engine 20 as a result of improved mixing in the combustion chamber 66, and by elimination of conventional dilution holes and the elimination of a separate first stage turbine vane (e.g., nozzle guide vane) of the turbine section 28.

[0080] Each combustor vane 200 is defined by an outer airfoil wall surface 202 between a leading edge 204 and a trailing edge 206. The outer airfoil wall surface 202 defines a generally concave shaped portion forming a pressure side 202P and a generally convex shaped

portion forming a suction side 202S. A fillet may be located between the airfoil wall surface 202 and the adjacent generally planar liner panels 72, 74 (Figure 11).

[0081] A combustor vane 200' with a multiple of fuel injectors 210 flank each combustor vane 200 axially downstream of the outer injector 94 along respective axis F1 to  
5 facilitate further combustion. That is, the combustor vanes 200' face the divergent exit 120 along axis F1. The combustor vanes 200' are spaced from the combustor vane 200 axis F by a distance which is equivalent to the radius from axis F to axis F1.

[0082] The fuel injectors 210 from combustor vane 200' provide a divergent fuel flow spray for further combustion in the secondary stage. The fuels injectors 210 may be located  
10 downstream of a leading edge 204 of each combustor vane 200' on both a compression and an expansion side. It should be appreciated that various arrangements, numbers, sizes, and patterns may alternatively or addiotnally be provided.

[0083] In one disclosed non-limiting embodiment, the fuel injectors 210A are rectilinear (Figure 13). In another disclosed non-limiting embodiment, the fuel injectors 210B  
15 are conical (Figure 14). The results of several tests conducted on side wall combustion found that the conical injectors 210B provide a more controlled combustion close to the combustor vane walls 202' due to lower degree of fuel penetration distance Y1 (Figure 13) vs. distance Y2 (Figure 14).

[0084] It should be understood that relative positional terms such as "forward," "aft,"  
20 "upper," "lower," "above," "below," and the like are with reference to the normal operational attitude of the vehicle and should not be considered otherwise limiting.

[0085] It should be understood that like reference numerals identify corresponding or similar elements throughout the several drawings. It should also be understood that although a

particular component arrangement is disclosed in the illustrated embodiment, other arrangements will benefit herefrom.

[0086] Although particular step sequences are shown, described, and claimed, it should be understood that steps may be performed in any order, separated or combined unless  
5 otherwise indicated and will still benefit from the present disclosure.

[0087] The foregoing description is exemplary rather than defined by the limitations within. Various non-limiting embodiments are disclosed herein, however, one of ordinary skill in the art would recognize that various modifications and variations in light of the above teachings will fall within the scope of the appended claims. It is therefore to be understood that  
10 within the scope of the appended claims, the disclosure may be practiced other than as specifically described. For that reason the appended claims should be studied to determine true scope and content.

## CLAIMS

What is claimed is:

1. A swirler for a combustor of a gas turbine engine comprising:  
5 an inner injector; and  
an outer annular injector which at least partially surrounds said inner injector.
2. The swirler as recited in claim 1, wherein said inner injector is operable to  
generate a first swirl and said outer annular injector is operable to generate a second swirl, said  
10 first swirl different than said second swirl.
3. The swirler as recited in claim 1, wherein said inner injector is operable to  
generate a first swirl and said outer annular injector is operable to generate a second swirl, said  
first swirl greater than said second swirl.  
15
4. The swirler as recited in claim 1, wherein said inner injector provides a one-  
dimensional swirl and said outer annular injector provides a three-dimensional swirl.
5. The swirler as recited in claim 1, further comprising an annular recess tube within  
20 said outer annular injector.

6. The swirler as recited in claim 5, wherein said annular recess tube is upstream of an annular divergent exit.

7. The swirler as recited in claim 1, wherein said inner injector defines a convergent-  
5 divergent exit.

8. The swirler as recited in claim 7, further comprising an annular recess tube within said outer annular injector.

10 9. The swirler as recited in claim 8, wherein said annular recess tube is upstream of an annular divergent exit.

10. The swirler as recited in claim 1, wherein said inner injector defines a central passage and an inner annular passage radially outboard of said central passage.

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11. The swirler as recited in claim 10, wherein said outer annular injector defines an outer annular passage radially outboard of said inner annular passage.

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12. A combustor section for a gas turbine engine comprising:  
an inner injector which defines an axis;  
an outer annular injector which surrounds said inner injector; and  
a combustor vane along said axis.

13. The combustor section as recited in claim 12, wherein said combustor vane defines a length between 35%-65% of said combustion chamber.

14. The combustor section as recited in claim 12, further comprising a combustor  
5 vane with a multiple of fuel injectors which flank said combustor vane.

15. The combustor section as recited in claim 12, wherein said inner injector defines a central passage and an inner annular passage radially outboard of said central passage, said central passage includes convergent-divergent exit.

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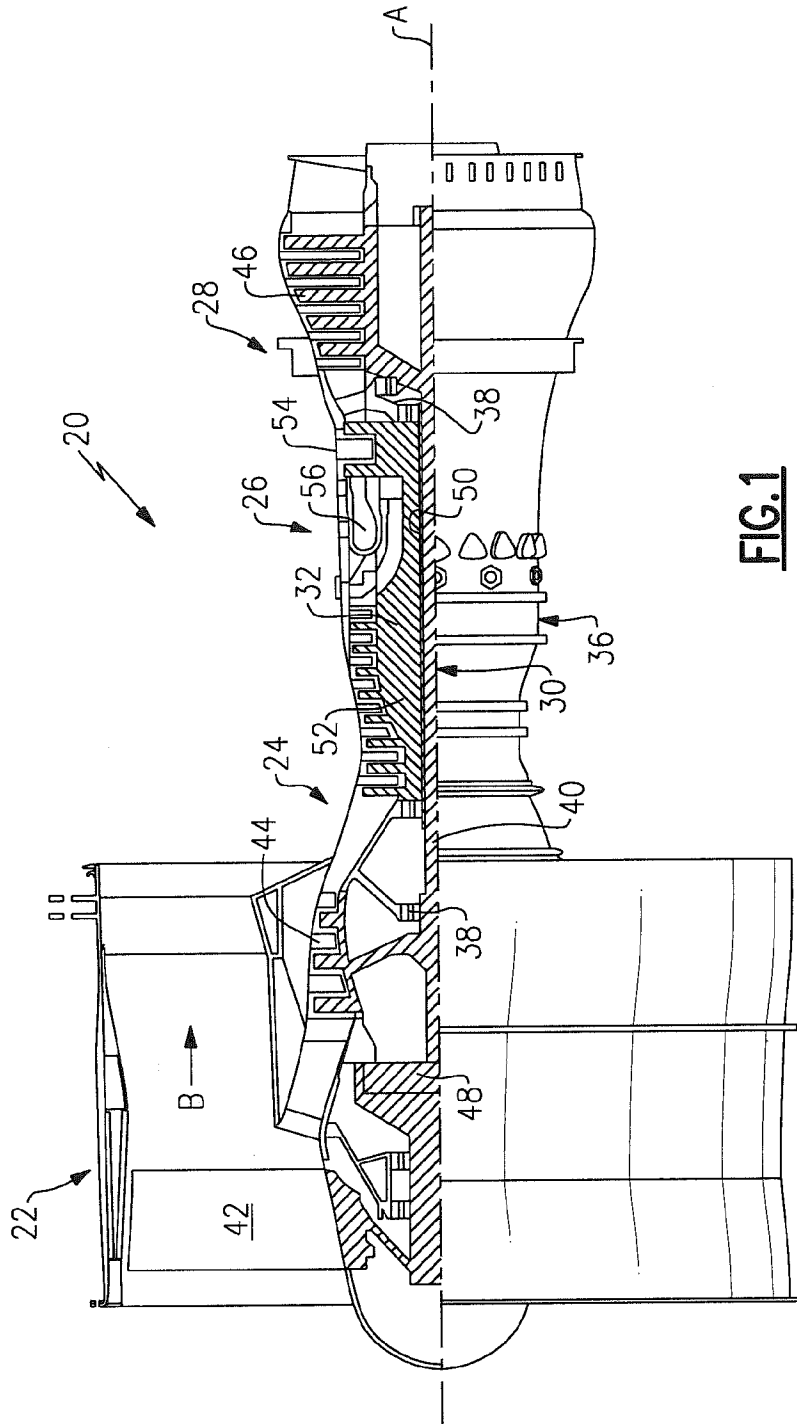
16. The combustor section as recited in claim 15, wherein said outer annular injector defines an outer annular passage radially outboard of said inner annular passage.

17. The combustor section as recited in claim 16, wherein said inner injector  
15 selectively receives a fuel-air mixture.

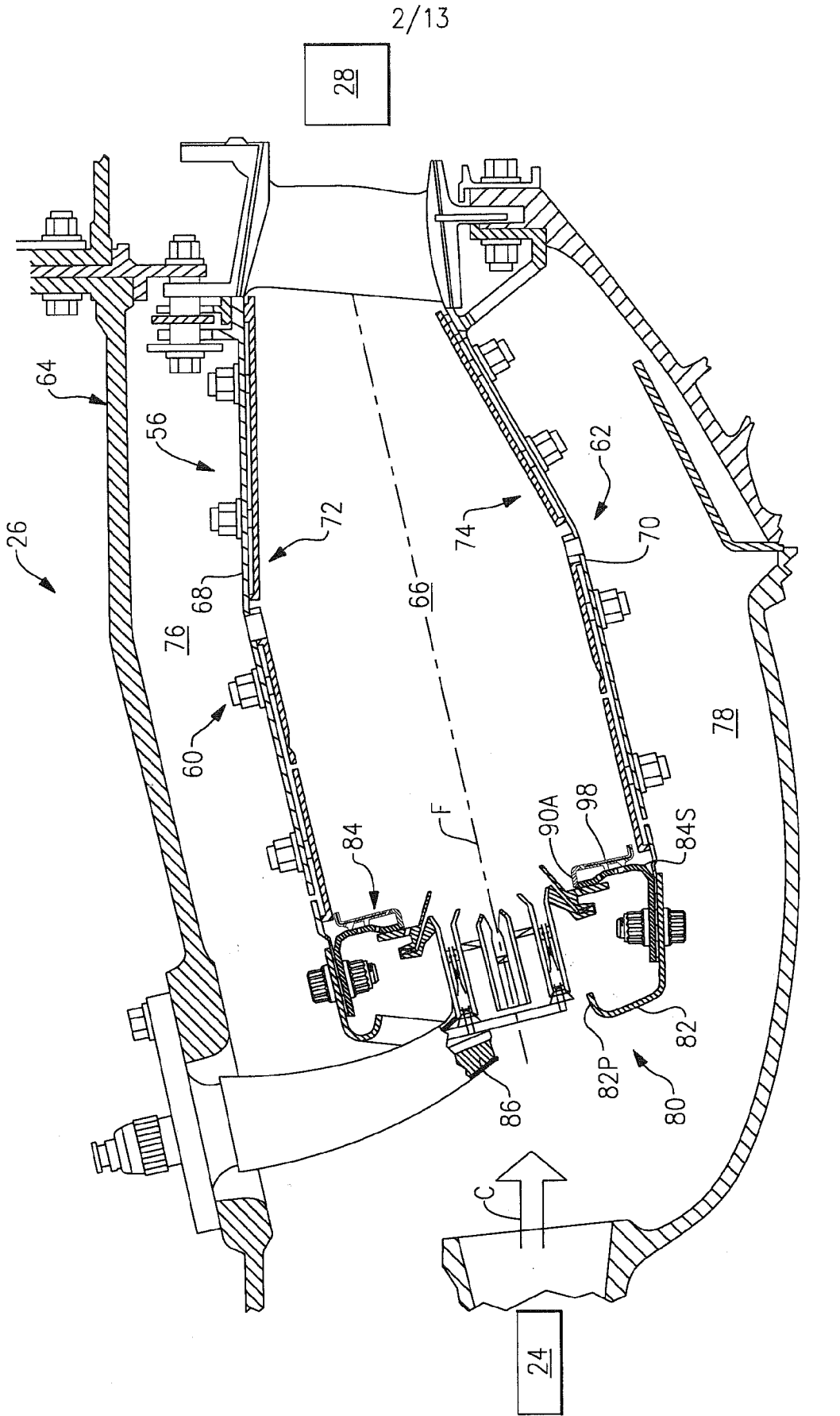
18. The combustor section as recited in claim 17, wherein said outer annular injector selectively receives a fuel-air mixture.

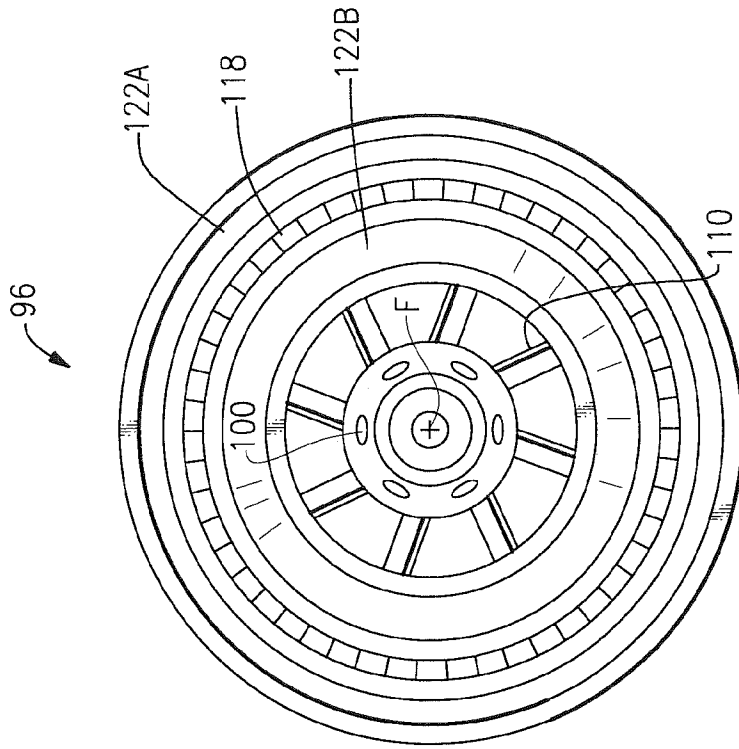
19. The combustor section as recited in claim 18, further comprising an annular  
20 recess tube within said outer annular injector.

20. The combustor section as recited in claim 19, wherein said inner annular passage selectively receives an airflow.

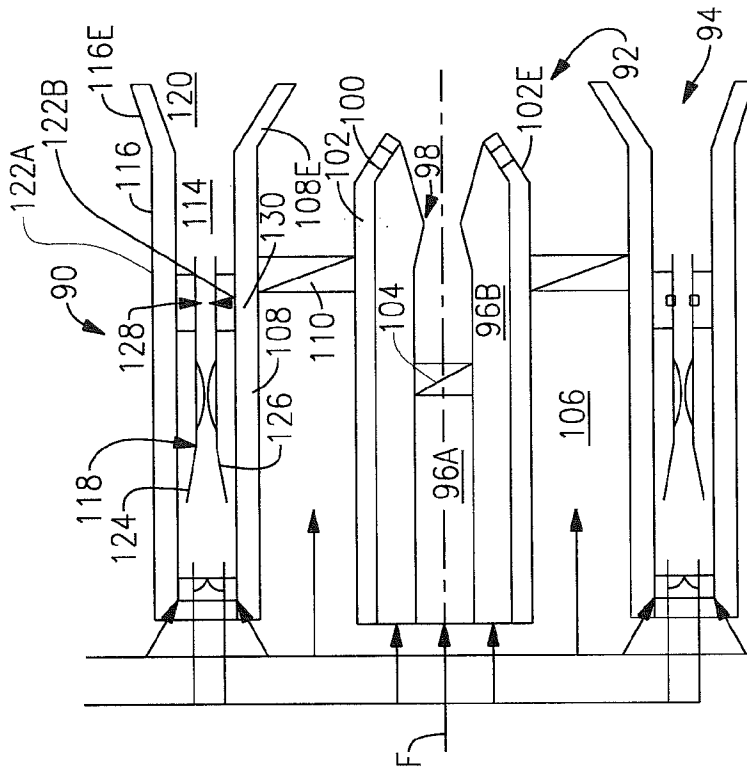


**FIG. 1**

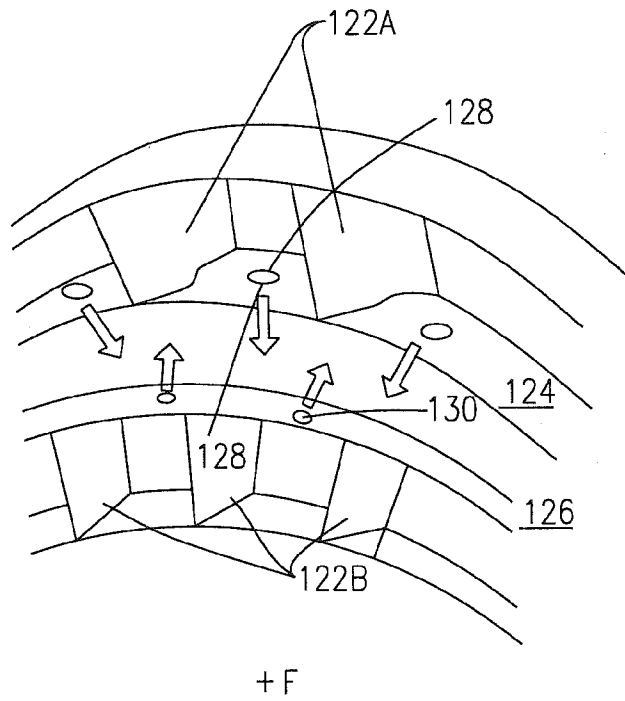




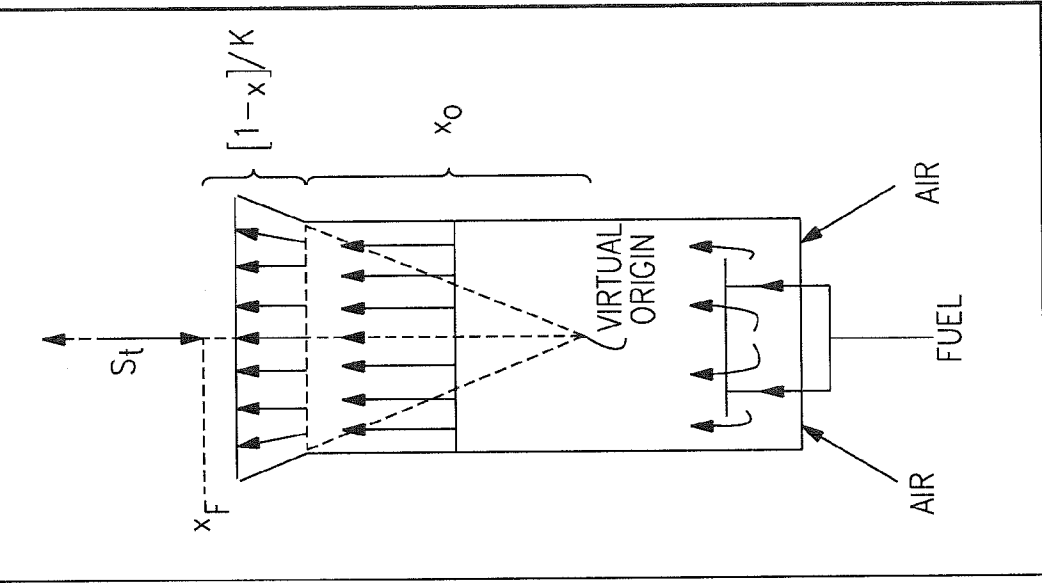
**FIG. 4**



**FIG. 3**



**FIG.5**



$$\frac{dM}{dx} = -\frac{M}{(1-M^2)} \frac{1 + \frac{\gamma-1}{2} M^2}{A} \frac{dA}{dx}$$

where:  $M = \frac{U_0}{a}$

LOW MACH NO. ASSUMPTION LEADS TO

$$\frac{1}{U_0} \frac{dU}{dx} = -\frac{1}{A} \frac{dA}{dx}$$

LEADS TO

$$U_0 - \delta U = St$$

$$U_0 + \frac{dU}{dx} (x_F - x_0) = S_L(\phi)(1 + Cu')$$

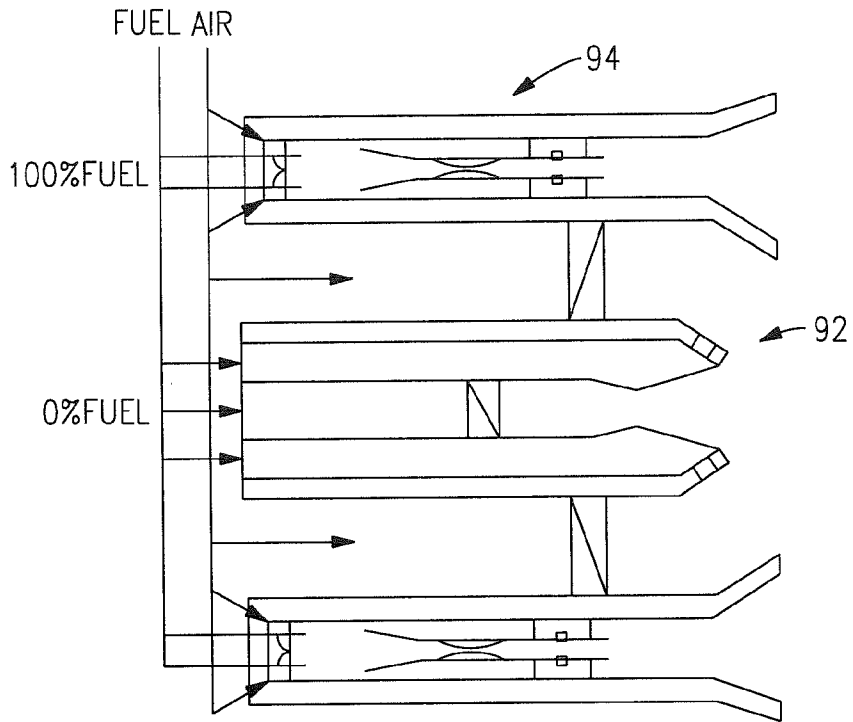
LEADS TO

$$x_F = x_0 + \left[ 1 - \frac{S_L(\phi)(1 + Cu')}{U_0} \right] \left( \frac{1}{A_0} \frac{dA}{dx} \right)$$

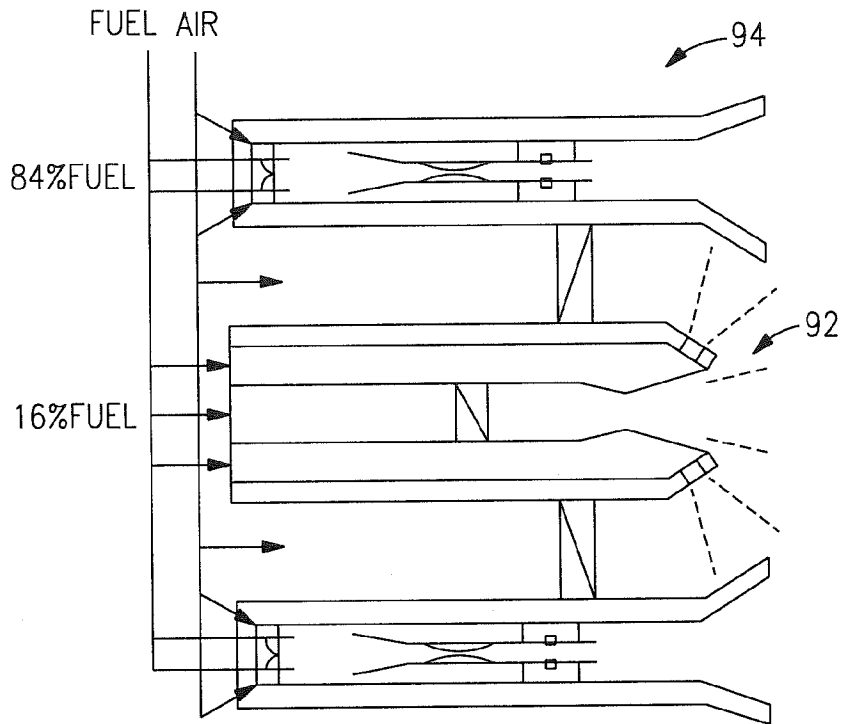
$$x_F = x_0 + [1 - X] K$$

where:  $K = \frac{1}{A_0} \frac{dA}{dx}$  and  $x = \frac{S_L(\phi)(1 + Cu')}{U_0}$

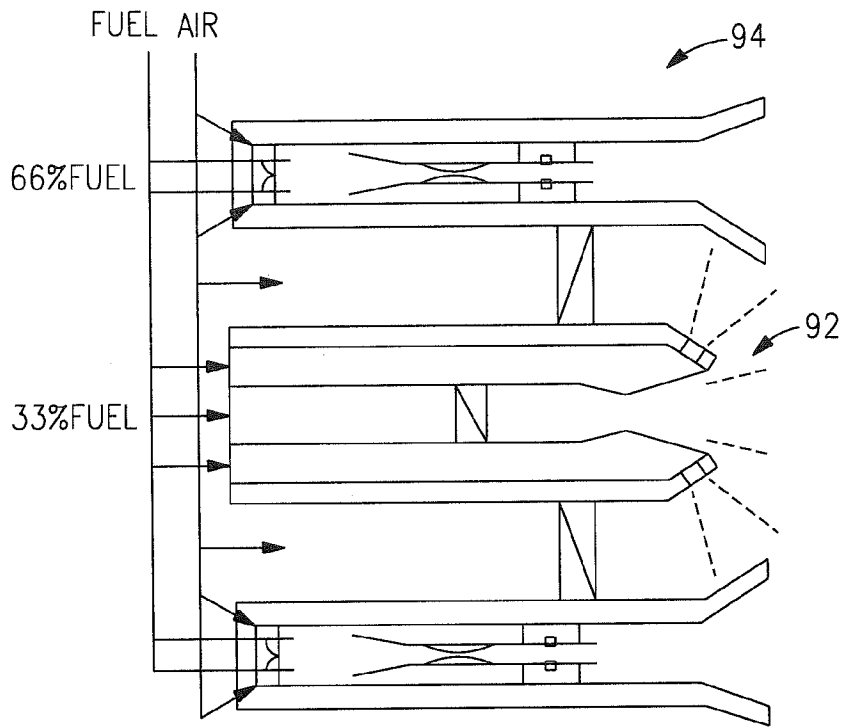
**FIG.6**



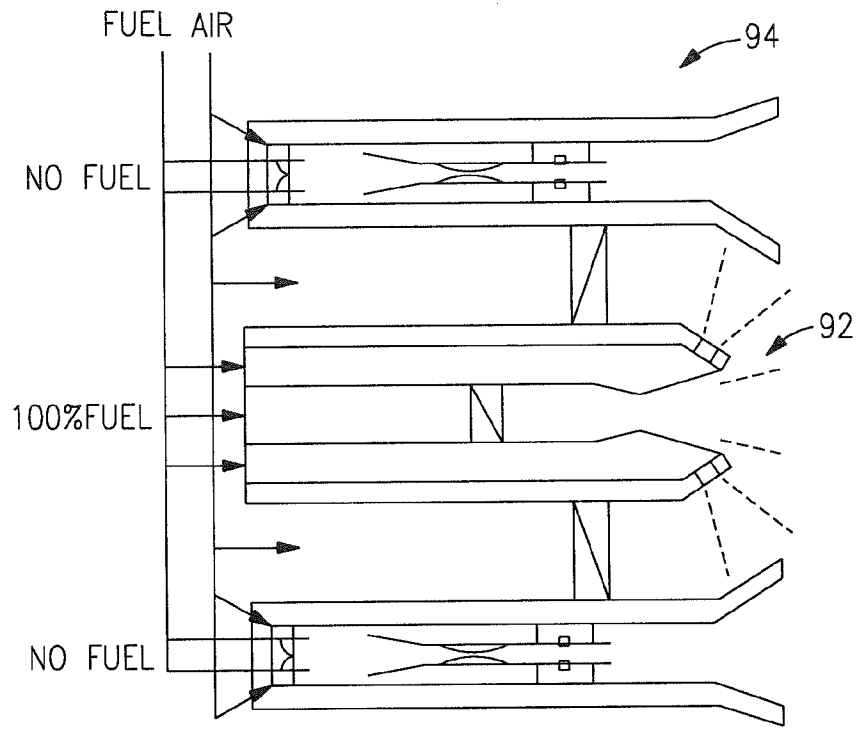
**FIG.7**



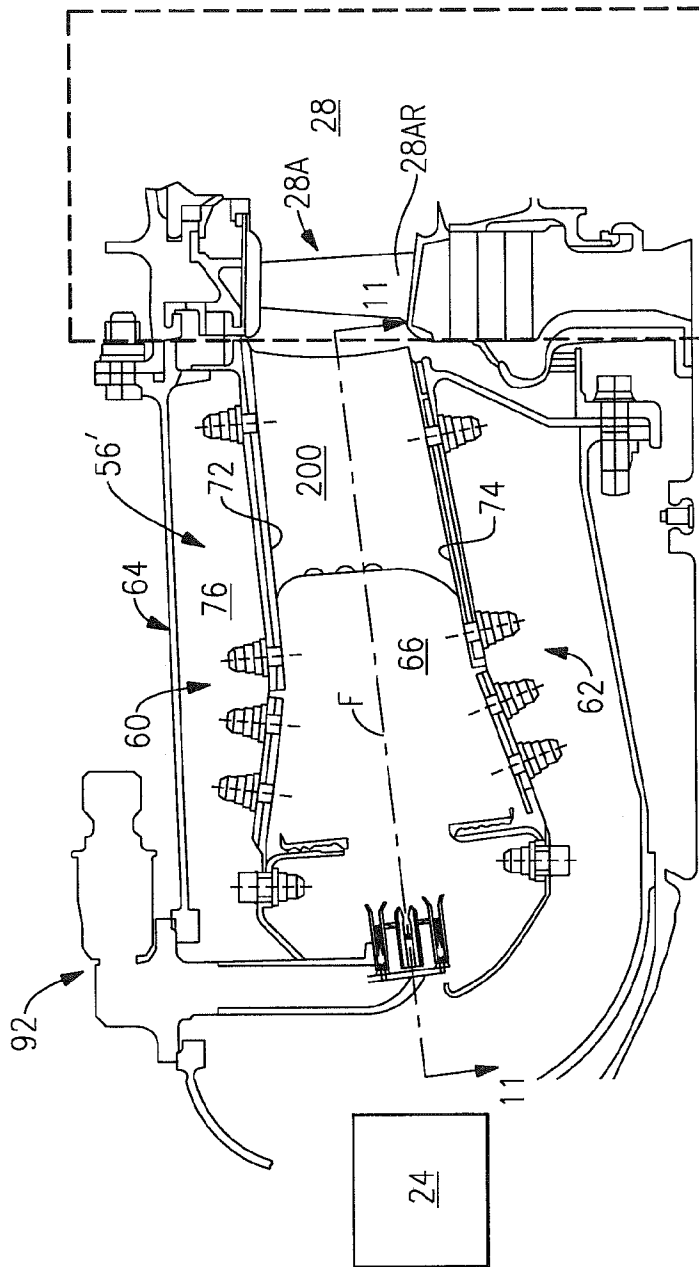
**FIG.8**



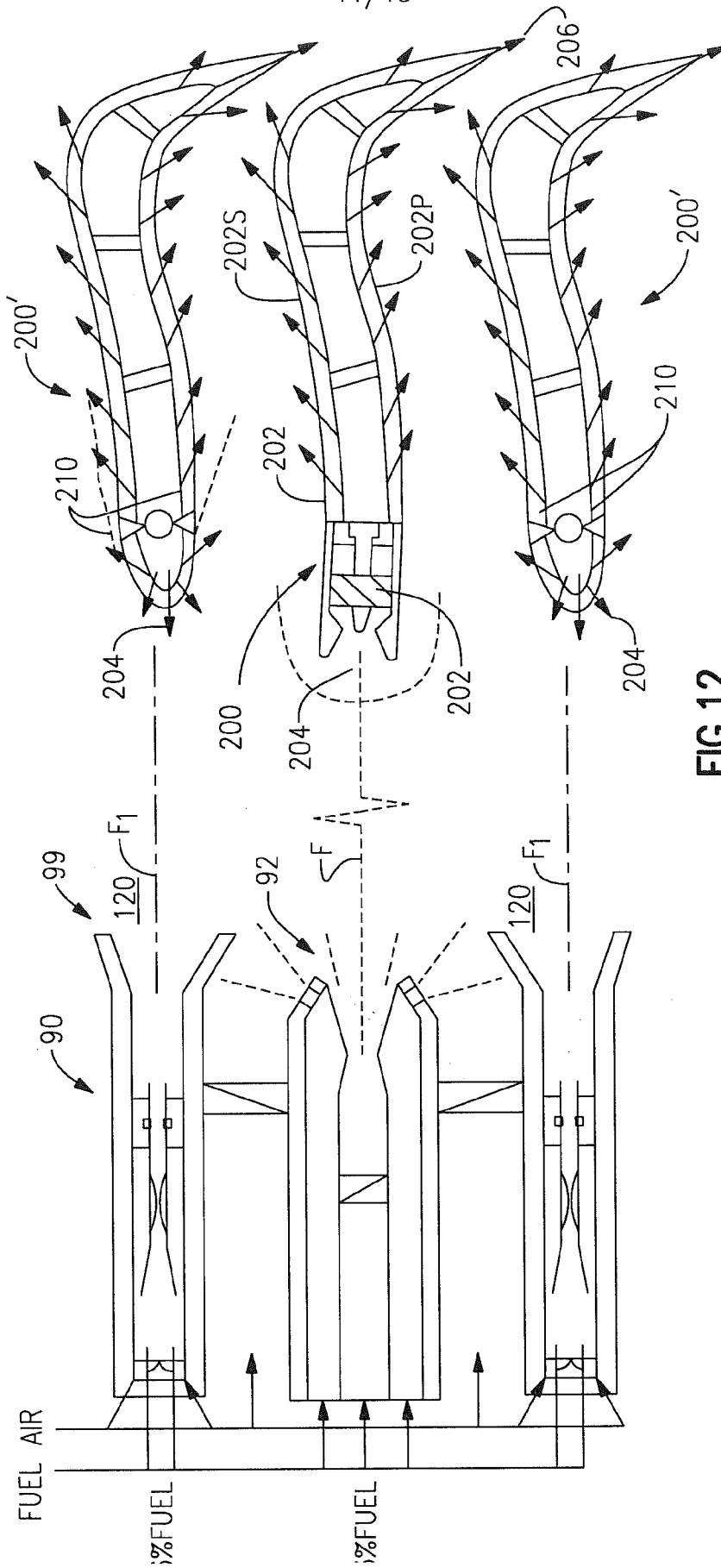
**FIG.9**



**FIG.10**

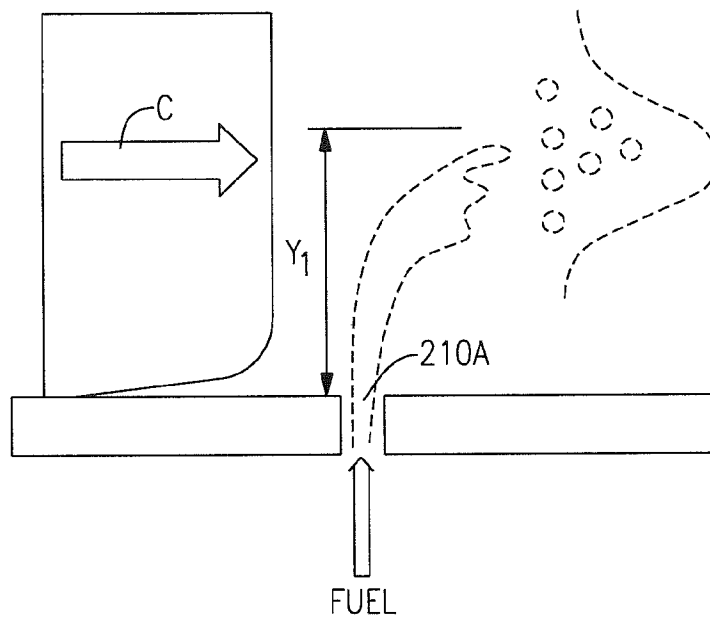


**FIG.11**

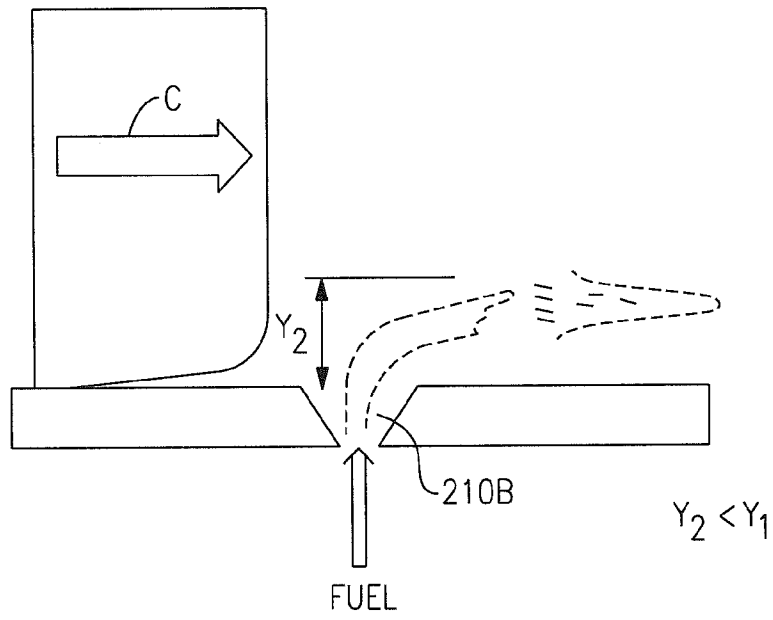


**FIG.12**

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**FIG.13**



**FIG.14**

## INTERNATIONAL SEARCH REPORT

International application No.  
**PCT/US2013/061983****A. CLASSIFICATION OF SUBJECT MATTER****F02C 7/232(2006.01)i, F02C 7/22(2006.01)i, F23R 3/12(2006.01)i**

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

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

F02C 7/232; F02C 7/26; B05B 7/06; F23R 3/14; F02C 6/08; F02G 3/00; F23R 3/30; F23R 3/04; F02C 1/00; F02C 7/22; F23R 3/12

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

Korean utility models and applications for utility models  
Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) &amp; keywords: gas turbine, combustor, swirler, injector, convergent-divergent exit, and combustor vane

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2005-0268616 A1 (WIDENER, STANLEY KEVIN) 08 December 2005 See abstract, paragraphs [0005],[0016],[0020], claim 1, and figures 5-6.	1-6,12-14
Y		7-11,15-20
Y	US 6354072 B1 (HURA, HARJIT S.) 12 March 2002 See abstract, column 3, lines 37-46, column 4, lines 6-9, and figure 2.	7-11,15-20
A	EP 1074792 A1 (ROLLS-ROYCE PLC) 07 February 2001 See abstract, claim 1, and figures 2-4.	1-20
A	US 5505045 A (LEE et al.) 09 April 1996 See abstract, column 4, lines 14-29, and figure 1.	1-20
A	US 2002-0011070 A1 (MANDAI et al.) 31 January 2002 See abstract, claim 1, and figure 1A.	1-20

 Further documents are listed in the continuation of Box C. See patent family annex.

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Date of the actual completion of the international search

23 December 2013 (23.12.2013)

Date of mailing of the international search report

**27 December 2013 (27.12.2013)**

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**INTERNATIONAL SEARCH REPORT**

Information on patent family members

International application No.

**PCT/US2013/061983**

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2005-0268616 A1	08/12/2005	US 7137258 B2	21/11/2006
US 6354072 B1	12/03/2002	DE 60028910 D1 DE 60028910 T2 EP 1106919 A1 EP 1106919 B1 JP 2001-208349 A RU 2243449 C2	03/08/2006 25/01/2007 13/06/2001 21/06/2006 03/08/2001 27/12/2004
EP 1074792 A1	07/02/2001	DE 60031744 D1 DE 60031744 T2 EP 1074792 B1 GB 9917957 D0 US 6334297 B1	21/12/2006 22/02/2007 08/11/2006 29/09/1999 01/01/2002
US 5505045 A	09/04/1996	None	
US 2002-0011070 A1	31/01/2002	CA 2353514 A1 CA 2353514 C DE 60135280 D1 EP 1174662 A1 EP 1174662 B1 JP 2002-39533 A US 6594999 B2	21/01/2002 31/10/2006 25/09/2008 23/01/2002 13/08/2008 06/02/2002 22/07/2003