Nov. 20, 1962 J. G. TOMLINSON 3,064,424

FLAME TUBE

Filed Sept. 30, 1959 2 Sheets-Sheet 1

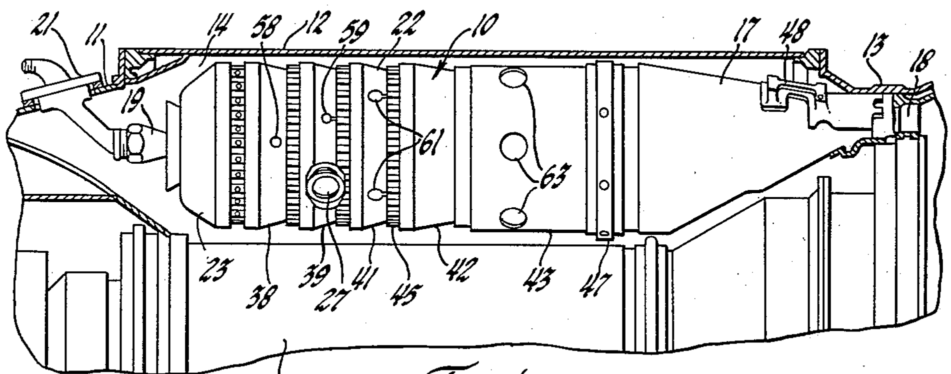

Fig. 1

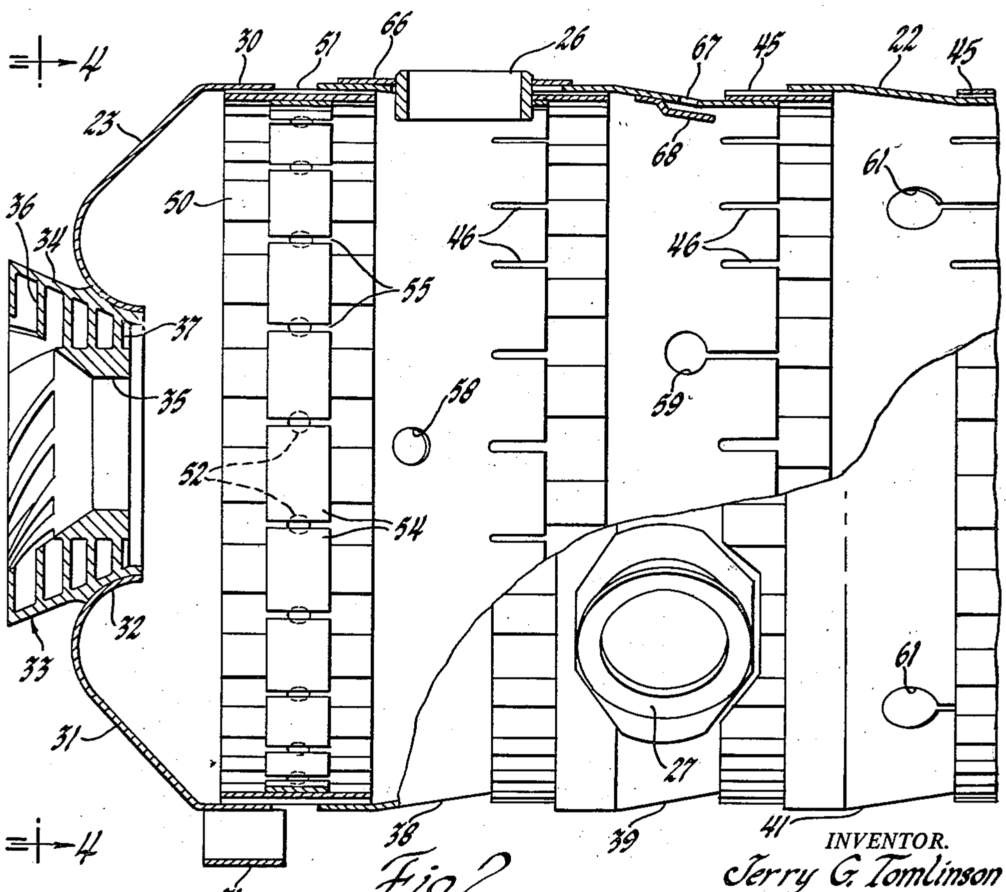

Fig. 2

INVENTOR.
Jerry G. Tomlinson

BY

Paul Fitzpatrick
ATTORNEY

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2 Sheets-Sheet 2

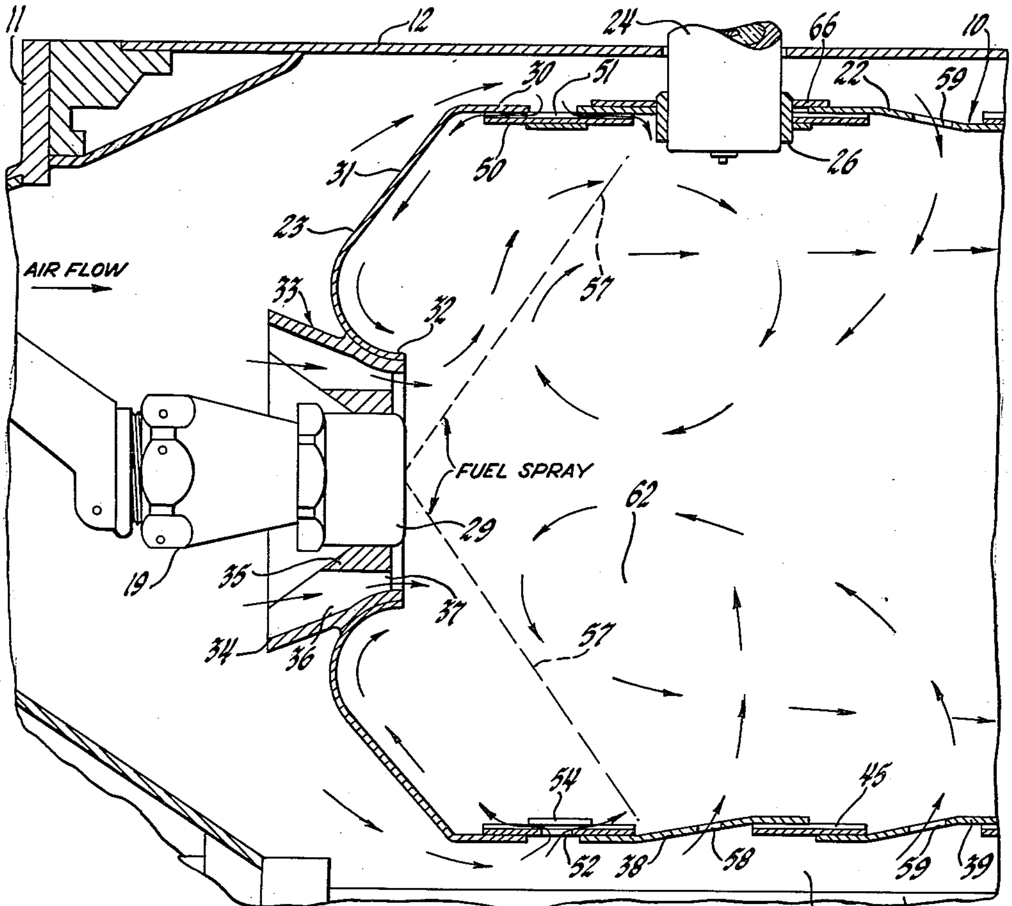

Fig. 3

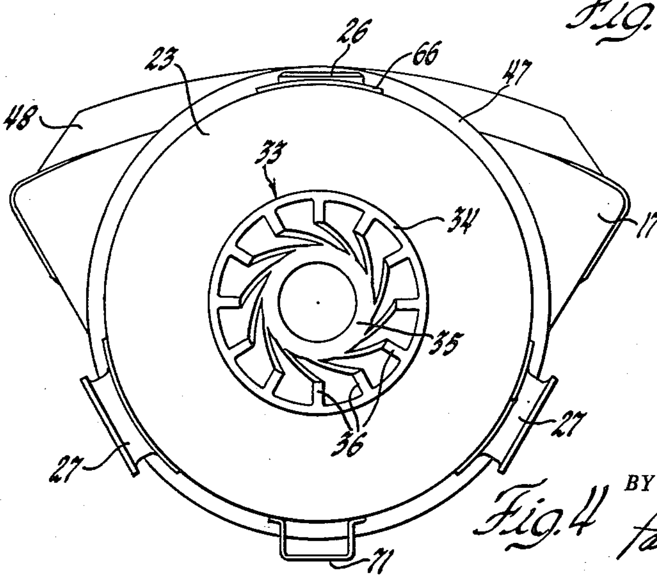

Fig. 4

INVENTOR.
Jerry G. Tomlinson

BY Paul Fitzpatrick

ATTORNEY

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FLAME TUBE

Jerry G. Tomlinson, Speedway, Ind., assignor to General Motors Corporation, Detroit, Mich., a corporation of Delaware

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13 Claims. (Cl. 60—39.65)

My invention is directed to combustion apparatus, and particularly to such as is used in gas turbine engines. Combustion devices of this sort are characterized by very high energy release for unit volume and time, and thus have presented difficult problems in the achievement of satisfactory combustion. It is generally believed that a rapid and intimate mixture of finely sprayed fuel and combustion air and some turbulence and recirculation of the combustion air and combustion products are essential to burning fuel at a high rate in the small combustion space of the usual gas turbine engine.

Prior efforts have succeeded in developing combustion apparatus which are, in general, very satisfactory, in which combustion is relatively stable, and in which the life of the combustion liner or flame tube within which burning is effected is satisfactory.

However, efforts to obtain even temperature distribution of the combustion products delivered and to achieve complete burning and freedom from smoke in the combustion products have not been fully successful. My invention is directed particularly to improvements in the forward, upstream, or inlet end of flame tubes, which may otherwise be in accordance with the best known practices in the art, so as to improve the temperature distribution and eliminate smoky combustion, and retain or improve stability of combustion under various conditions of air pressure and fuel rate.

The nature of the invention, and the advantages thereof, will be apparent to those skilled in the art from the succeeding detail description of the preferred embodiment of the invention and the accompanying drawings thereof.

FIGURE 1 is a partial view of an axial flow gas turbine engine taken on a plane containing the axis of the engine.

FIGURE 2 is a view, with parts cut away and in section, of the forward portion of a flame tube.

FIGURE 3 is an enlarged view of the forward portion of the combustion apparatus, taken on the same plane as FIGURE 1, and illustrating air flow within the flame tube.

FIGURE 4 is a front elevational view of the flame tube taken on the plane indicated by the line 4—4 in FIGURE 2.

Referring first to FIGURE 1 for a description of the preferred environment of the invention, the flame tube 10 or combustion liner of the invention is incorporated in the combustion apparatus of a gas turbine engine of known axial flow type. The engine comprises a compressor outlet or diffuser section 11, a combustion chamber case 12, and a turbine case 13. An annular combustion space or chamber 14 is defined between the case 12 and an inner combustion space wall 15. The compressor of the engine, not shown, discharges air through the diffuser 11 into the space 14, from which it flows through apertures to be described into a number of substantially parallel flame tubes 10 distributed around the axis of the engine. Each flame tube has at its rear end a transition section 17 which varies in section from circular at the forward end to a sector of an annulus at its rearward end. The rear end of the transition section is mounted in the turbine case 13 and discharges into the nozzle 18 of a turbine, the remainder of which is not illustrated. The turbine drives the compressor, which supplies air to the combustion apparatus in which fuel is burned. The resulting combus-

2

tion products are the motive fluid of the turbine. The fuel is admitted to each flame tube or liner 10 by a fuel nozzle 19, which includes a mounting plate 21 fixed to the diffuser structure 11.

In addition to the transition section 17, each liner includes a generally cylindrical body 22, composed of a number of sections welded together, and a dome 23 at the forward end of the body. Referring to FIGURE 3, an igniter 24 suitably mounted on the engine projects through a ferrule 26 fixed in the body 22. Two connections 27 are provided for crossover tubes which connect each flame tube to the two adjacent ones for propagation of flame between them. Ordinarily, only one or two flame tubes are provided with igniters 24, the others being provided with supports which take the place of the igniters.

Each flame tube is supported at its rear end by a piloting engagement of the transition section 17 on the turbine nozzle and at the forward end by a piloting engagement of the dome on the tip 29 of the fuel nozzle. It is located axially by the igniter plug 24 or equivalent locating means.

The dome 23 is of hemi-toroidal shape, being a surface of revolution including a marginal flange 30, a conical portion 31 and a curved rearwardly-directed central portion 32. An inlet air swirler 33 is fixed in the portion 32 of the dome. The swirler comprises an outer annular wall portion or ring 34, an inner ring 35, and a number of helical vanes 36 extending between the inner and outer rings. The passages between the vanes converge rearwardly so that the air discharged from the outlet 37 between the vanes flows at high velocity. The vanes preferably are pitched at an angle of about 60° to the axial direction to impart a strong tangential or swirl velocity to the air. The forward inner portion of the ring 34 and of the vanes 35 defines a conical funnel which facilitates mounting the flame tube over the nozzle tip 29 when the engine is assembled.

Proceeding with the preferred structural details of the body portion 22 of the flame tube, this comprises a series of slightly coned rings 38, 39, 41, and 42 and the cylindrical section 43. These are aligned coaxially with the forward end of each approximately in the same plane as the rearward end of the one just ahead of it, and are connected by corrugated strips 45, the inward corrugations of which are spot-welded to the forward adjacent ring and the outer corrugations of which are spot-welded to the rearward adjacent ring. Notches 46 in the rearward edges of the rings eliminate stresses due to differential expansion which might otherwise cause undue distortion or cracking of the liner. The spaces left by the corrugated rings 45 between the adjacent liner sections admit film cooling air which flows along the inner surface of the liner, providing a considerable degree of cooling.

An air-cooled stiffening ring 47 is fixed to the rear end of the section 43, and an air-cooled reinforcing structure 48 is fixed to the outer rear surface of the transition section 17. These structures and, in general, the portion of the liner from section 42 to the discharge end thereof may be the same or substantially the same as that described in application Serial No. 699,784 filed November 29, 1957, now abandoned, of common ownership with this application. (This application is abandoned, but reference may be made to British Patent No. 851,125 or Canadian Patent No. 635,106).

The dome 23 is fixed to the forward body section 38 by a corrugated strip or ring 50 which extends around the inside of the circumference of both the dome and the body. The strip 50 has flat, shallow corrugations extending axially of the liner. There is a gap indicated at 51 between the dome and the remainder of the liner which is bridged by the strip 50. The outward corrugations of the strip are spot-welded to the dome **23** and to section **38**. Air entering through the gap **51** flows forwardly and rearwardly as indicated in the upper portion of FIGURE 3, through the spaces defined by the inward corrugations of the strip **50**. A hole **52** is provided in each outward corrugation of the strip **50** for admission of air. The holes **52** are underlaid by a segmented ring **54** spot-welded to the ring or strip **50**. The segmented ring **54** is provided by spot-welding a continuous ring to the strip **50** and then slotting the ring as indicated at **55** beneath each outward corrugation of strip **50**. The slotting or dividing of ring **54** eliminates thermal stresses. The slots are quite narrow, but provide for relative expansion or contraction of ring **54** and the strip **50**. The ring **54** deflects the air entering through the openings **52** so that substantially all of it also flows in both forward and rearward directions, as indicated in the lower portion of FIGURE 3. It will be seen, therefore, that the air admitted through the gap between the dome and the liner is divided into two portions, each of which provides a substantially continuous film or sheet of air, one sheet moving rearwardly to provide film cooling of the section **38** of the liner, and the other portion flowing forwardly and then being deflected inwardly and rearwardly by the dome, as indicated by the arrows in FIGURE 3.

The air thus deflected rearwardly by the dome mixes with and is energized by the high velocity swirling air entering through the swirler outlet **37** which, because of its swirling motion, tends to move radially outwardly as well as rearwardly. The mixing of the swirling and non-swirling streams of air results in considerable highly desirable turbulence and provides a cone of turbulent air moving into the cone of the fuel spray indicated by the broken lines **57** in FIGURE 3. This turbulent air mixes rapidly with the fuel spray and provides favorable conditions for initiation of combustion.

Additional air is supplied to the primary zone of combustion through relatively small holes in the first three sections **38**, **39**, and **41** of the liner. Two diametrically opposite holes **58** are provided in section **38**, three approximately equally spaced holes **59** are provided in section **39**, and four approximately equally spaced holes **61** are provided in section **41**. These holes provide primary or combustion air. The air entering through these holes is admitted in a generally radial direction and the air admitted through holes **58** and **59** tends to veer forwardly towards the fuel nozzle because of a vortex ring created by the outward flow of the fuel and of the air flowing from the dome and swirler. The result is a vortex ring in the area indicated by **62** in which air heated by combustion, combustion products, and partially burned fuel are thoroughly and evenly mixed, with symmetrical combustion about the axis of the liner.

The film cooling air serves primarily for liner cooling and then dilution of the combustion products, although it is possible for it to enter the combustion to some extent. A relatively large portion of the air, which serves entirely as dilution air, is admitted through six large holes **63** in the section **43** of the liner. Further mixing of this dilution air and combustion products occurs during its flow rearwardly to the turbine nozzle.

A few details of the combusion liner shown in the drawing may be referred to. A reinforcing plate **66** is mounted around the igniter sleeve **26** and welded to the liner. Several small holes **67** are provided in section **39** downstream of the igniter. Air entering through these holes is deflected rearwardly by a small plate **68** fixed to the inside of the liner. A strap or bracket **71** fixed to the dome may be engaged with a hook on the inner combustion space wall **15** to provide a loose temporary attachment of the liner prior to its engagement with the nozzle during assembly of the engine.

It has been found by test that a combustion liner of the configuration shown in the drawings and described gives exceptionally uniform temperature distribution at the outlet and is free from smoking or incomplete combustion under all normal operating conditions. These beneficial results arise from the improved configuration of the forward end of the liner, since prior liners with which it has been compared are substantially identical except for the arrangement of the parts forward of the location of the crossover tubes.

It will be helpful in understanding the operation of my improved liner to set out the presently preferred proportions of air flow through the various openings or entrances to the liner. It will be understood, however, that these proportions are variable to suit specific conditions, such as pressure ratio of the engine and so forth. In the preferred liner configured to suit a known turbo-prop engine, the distribution is as follows. Considering the proportion of compressor discharge air which is admitted to one combustion liner as 100%, the swirler admits 4.6% and the forwardly flowing portion of the air admitted through the gap **51** is 7.8%.

Section **38** admits 1.5% through holes **58** and section **39** admits 5.3%, mostly through holes **59**, although a small amount enters through the holes **67**. Section **41** admits 7.2% through the four holes **51**. This is a total of about 26%, which is sufficient air to complete combustion, and all this air may be regarded as the primary or combustion air.

It will be seen that most of the combustion air enters into the vortex ring in the area into which the fuel is injected.

It may be also noted that experiments with the liner structure of the invention indicate that the hemi-toroidal or recurved form of the dome with the flow of air inwardly over the dome is the significant factor in the elimination of smoke from the combustion process. However, the admission of the rapidly swirling air through the inlet swirler improves the stability of combustion, and therefore benefits the overall operation when employed with the toroidal dome.

The film cooling air, including the rearwardly flowing air admitted through gap **51** and the air admitted through the four additional joints between the sections of the liner admits to 39.1%. The remaining 34.5 is dilution air, admitted principally through the six holes **63**, although a small amount enters through the air-cooled reinforcing members **47** and **48**.

It will be apparent that the structure described, in addition to its important advantages from the standpoint of improved combustion, is also a structure minimizing thermal stresses in the parts of the liner and providing good cooling of the wall of the liner.

The description of the preferred embodiment of the invention, for the purpose of explaining the principles thereof, is not to be construed as limiting the scope of the invention, since many modifications may be made by the exercise of skill in the art.

I claim:

1. A flame tube for a combustion apparatus of a gas turbine or the like, the flame tube comprising, in combination, a generally cylindrical body having a forward end and a rearward outlet end, an imperforate hemi-toroidal dome substantially closing the forward end, an air swirler converging in the rearward direction mounted in the center of the dome providing a central opening to receive a fuel spray nozzle, the margins of the dome and body being spaced to define between them a forwardly directed air entrance configured to admit air forwardly of the flame tube, the forwardly admitted air flowing over the inner surface of the dome and being directed rearwardly thereby and mixing with the air admitted through the swirler adjacent the fuel nozzle, the flame tube being provided with further openings downstream of those recited for admission of additional combustion air and dilution air.

2. A flame tube for a combustion apparatus of a gas turbine or the like, the flame tube comprising, in com-

bination, a generally cylindrical body having a forward end and a rearward outlet end, an imperforate hemi-toroidal dome substantially closing the forward end, an air swirler mounted in the center of the dome exteriorly of the flame tube providing a central opening to receive a fuel spray nozzle, a corrugated strip having corrugations directed axially of the flame tube fixed to and within the dome and the body, the strip extending around the circumference of the dome and body, the margins of the dome and body being spaced to define air entries cooperating with the inward corrugations of the strip to admit air forwardly and rearwardly of the flame tube, the forwardly admitted air flowing over the inner surface of the dome and being directed rearwardly thereby and mixing with the air admitted through the swirler adjacent the fuel nozzle, the flame tube being provided with further openings downstream of those recited for admission of additional combustion air and dilution air.

3. A flame tube for a combustion apparatus of a gas turbine or the like, the flame tube comprising, in combination, a generally cylindrical body having a forward end and a rearward outlet end, an imperforate hemi-toroidal dome substantially closing the forward end, an air swirler mounted in the center of the dome providing a central opening to receive a fuel spray nozzle, a corrugated strip having corrugations directed axially of the flame tube fixed to and within the dome and the body, the strip extending around the circumference of the dome and body, the margins of the dome and body being spaced to define air entries cooperating with the inward corrugations of the strip to admit air forwardly and rearwardly of the flame tube, a flat ring fixed to and within the corrugated strip and substantially bridging the gap between the dome and body, the corrugated strip having apertures in the outward corrugations thereof cooperating with the ring to admit air forwardly and rearwardly of the flame tube, the forwardly admitted air flowing over the inner surface of the dome and being directed rearwardly thereby and mixing with the air admitted through the swirler adjacent the fuel nozzle, the flame tube being provided with further openings downstream of those recited for admission of additional combustion air and dilution air.

4. A flame tube for a combustion apparatus of a gas turbine or the like, the flame tube comprising, in combination, a generally cylindrical body having a forward end and a rearward outlet end, an imperforate hemi-toroidal dome substantially closing the forward end, an air swirler converging in the rearward direction mounted in the center of the dome exteriorly of the flame tube and providing a central opening to receive a fuel spray nozzle, a corrugated strip having corrugations directed axially of the flame tube fixed to and within the dome and the body, the strip extending around the circumference of the dome and body, the margins of the dome and body being spaced to define air entries cooperating with the inward corrugations of the strip to admit air forwardly and rearwardly of the flame tube, a flat segmented ring fixed to and within the corrugated strip and substantially bridging the gap between the dome and body, the corrugated strip having apertures in the outward corrugations thereof cooperating with the ring to admit air forwardly and rearwardly of the flame tube, the forwardly admitted air flowing over the inner surface of the dome and being directed rearwardly thereby and mixing with the air admitted through the swirler adjacent the fuel nozzle, the flame tube being provided with further openings downstream of those recited for admission of additional combustion air adjacent the dome for admixture with the air admitted through the swirler and forwardly at the margin of the dome.

5. A flame tube for a combustion apparatus of a gas turbine or the like, the flame tube comprising, in combination, a generally cylindrical body having a forward end and a rearward outlet end, an imperforate hemi-toroidal dome substantially closing the forward end and providing

a central opening to receive a fuel spray nozzle, a corrugated strip having corrugations directed axially of the flame tube fixed to and within the dome and the body, the strip extending around the circumference of the dome and body, the margins of the dome and body being spaced to define air entries cooperating with the inward corrugations of the strip to admit air forwardly and rearwardly of the flame tube, the forwardly admitted air flowing over the inner surface of the dome and being directed rearwardly thereby adjacent the fuel nozzle, the flame tube being provided with further openings downstream of those recited for admission of additional combustion air and dilution air.

6. A flame tube for a combustion apparatus of a gas turbine or the like, the flame tube comprising, in combination, a generally cylindrical body having a forward end and a rearward outlet end, an imperforate hemi-toroidal dome substantially closing the forward end and providing a central opening to receive a fuel spray nozzle, a corrugated strip having corrugations directed axially of the flame tube fixed to and within the dome and the body, the strip extending around the circumference of the dome and body, the margins of the dome and body being spaced to define air entries cooperating with the inward corrugations of the strip to admit air forwardly and rearwardly of the flame tube, a flat ring fixed to and within the corrugated strip and substantially bridging the gap between the dome and body, the corrugated strip having apertures in the outward corrugations hereof cooperating with the ring to admit air forwardly and rearwardly of the flame tube, the forwardly admitted air flowing over the inner surface of the dome and being directed rearwardly thereby adjacent the fuel nozzle, the flame tube being provided with further openings downstream of those recited for admission of additional combustion air and dilution air.

7. A flame tube for a combustion apparatus of a gas turbine or the like having an upstream end portion including a body portion and a hemi-toroidal imperforate dome fixed to the forward end of the body portion bulging forwardly and terminating in a central rearwardly-directed portion, an air swirler mounted in the said rearwardly-directed portion defining a pilot for a fuel nozzle adapted to locate the spray tip of the nozzle centrally of the rearward end of the swirler, means at the outer margin of the dome for admitting a substantially circumferentially continuous sheet of forwardly-flowing air over the rearward face of the dome, the said air being deflected inwardly and rearwardly by the dome and mixing with the air admitted through the swirler to create a turbulent air flow mingling with the fuel spay from the nozzle.

8. A flame tube for a combustion apparatus of a gas turbine or the like having an upstream end portion including a body portion and a hemi-toroidal imperforate dome fixed to the forward end of the body portion bulging forwardly and terminating in a central rearwardly-directed portion, an air swirler mounted in the said rearwardly-directed portion exteriorly of the flame tube, the swirler defining rearwardly converging swirl passages and defining a pilot for a fuel nozzle adapted to locate the spray tip of the nozzle centrally of the rearward end of the swirler, means at the outer margin of the dome for admitting a substantially circumferentially continuous sheet of forwardly-flowing air over the rearward face of the dome, the said air being deflected inwardly and rearwardly by the dome and mixing with the air admitted through the swirler to create a turbulent air flow mingling wtih the fuel spray from the nozzle.

9. A flame tube for a combustion apparatus of a gas turbine or the like having an upstream end portion including a body portion and a hemi-toroidal imperforate dome fixed to the forward end of the body portion bulging forwardly and terminating in a central rearwardly-directed portion, an air swirler mounted in the said rearwardly-directed portion exteriorly of the flame tube, the swirler

defining rearwardly converging swirl passages and defining a pilot for a fuel nozzle adapted to locate the spray tip of the nozzle centrally of the rearward end of the swirler, means at the outer margin of the dome including a corrugated strip connecting the dome and the body for admitting a substantially circumferentially continuous sheet of forwardly-flowing air over the rearward face of the dome, the said air being deflected inwardly and rearwardly by the dome and mixing with the air admitted through the swirler to create a turbulent air flow mingling with the fuel spray from the nozzle.

10. A flame tube for a combustion apparatus of a gas turbine or the like having an upstream end portion including a body portion and a hemi-toroidal imperforate dome fixed to the forward end of the body portion bulging forwardly and terminating in a central rearwardly-directed portion, an air swirler mounted in the said rearwardly-directed portion exteriorly of the flame tube, the swirler defining rearwardly converging swirl passages and defining a pilot for a fuel nozzle adapted to locate the spray tip of the nozzle centrally of the rearward end of the swirler, means at the outer margin of the dome for admitting a substantially circumferentially continuous sheet of forwardly-flowing air over the rearward face of the dome, the said air being deflected inwardly and rearwardly by the dome and mixing with the air admitted through the swirler to create a turbulent vortex ring air flow mingling with the fuel spray from the nozzle, and means providing openings in the body for radially inwardly flowing air jets adjacent the fuel spray adapted to commingle with the air in the vortex ring flow.

11. A flame tube for a combustion apparatus of a gas turbine or the like comprising two coaxial sections having walls lying substantially in a common surface, the walls being separated by a gap, a corrugated strip having corrugations extending across the gap within the sections and directing air entering through the gap axially along the inner surface of both walls, holes in the outward convolutions of the strip, and a deflector ring fixed to the inward convolutions directing the air entering through the holes axially along the inner surface of both walls.

12. A flame tube for a combustion apparatus of a gas turbine or the like comprising two coaxial sections having walls lying substantially in a common surface, the walls being separated by a gap, a corrugated strip having corrugations extending across the gap within the sections and directing air entering through the gap axially along the inner surface of both walls, holes in the outward convolutions of the strip, and a segmented deflector plate ring fixed to the inward convolutions directing the air entering through the holes axially along the inner surface of both walls.

13. A flame tube for a combustion apparatus of a gas turbine or the like comprising two coaxial sections having walls lying substantially in a common surface, the walls being separated by a gap, and a corrugated strip connecting the sections having corrugations extending across the gap and extending within the inside of both sections so as to direct air entering through the gap axially along the inner surface of both walls when a pressure drop into the flame tube causes air to enter through the gap.

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