March 30, 1965 R. M. SCHIRMER ET AL 3,175,361

TURBOJET ENGINE AND ITS OPERATION

Original Filed Aug. 5, 1959 3 Sheets-Sheet 1

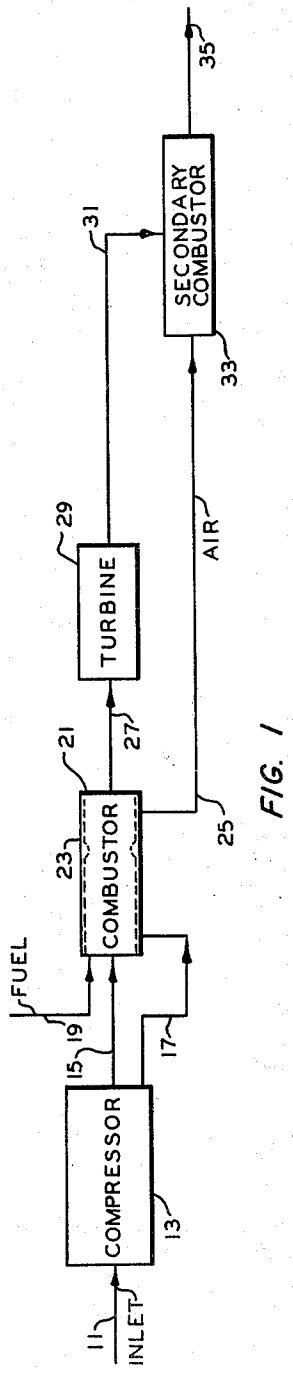


FIG. 1

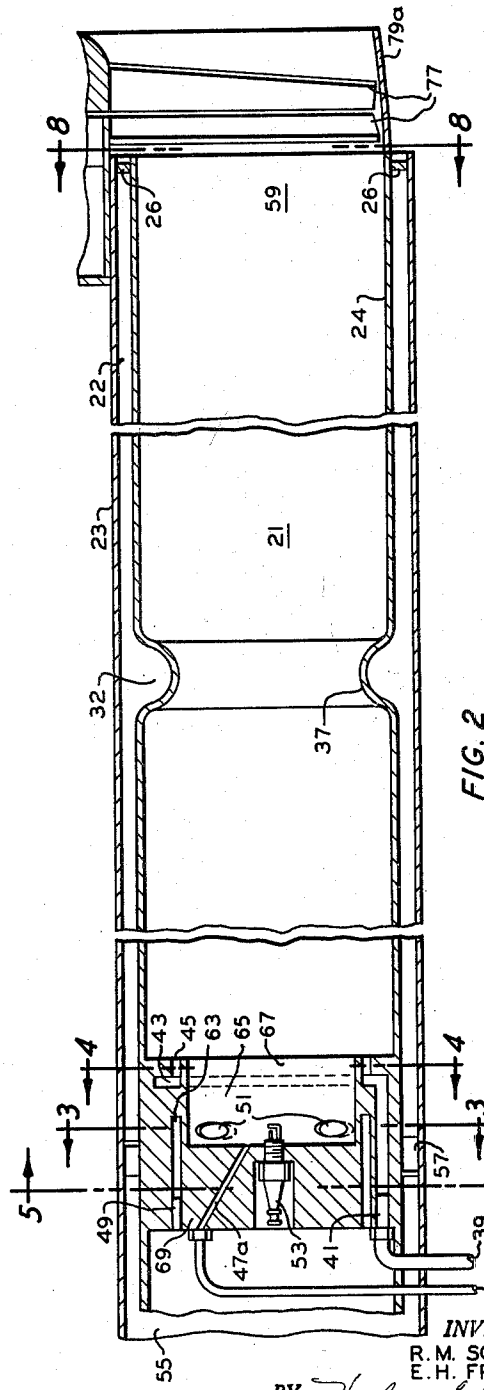


FIG. 2

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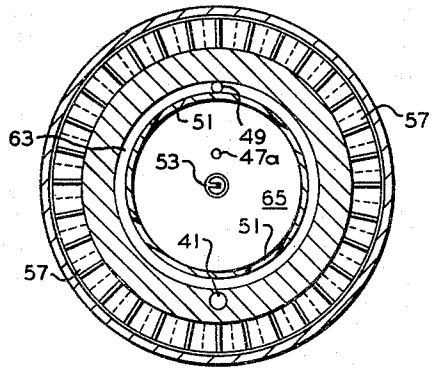


FIG. 3

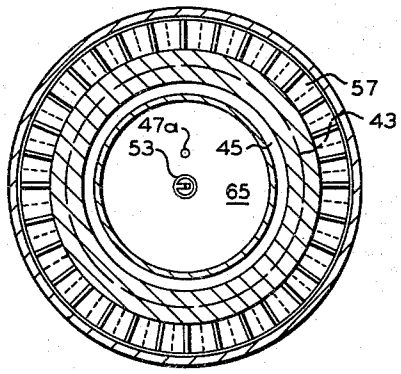


FIG. 4

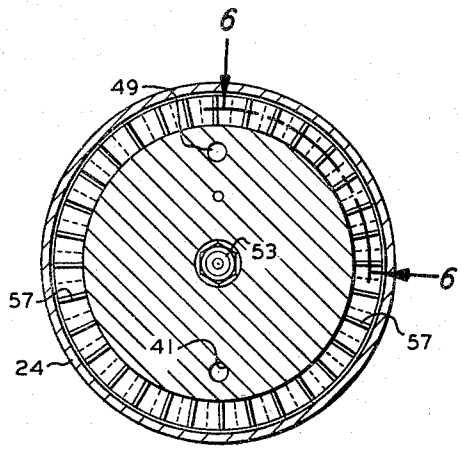


FIG. 5

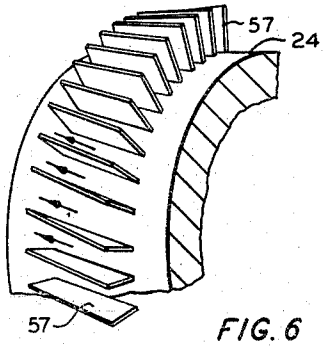


FIG. 6

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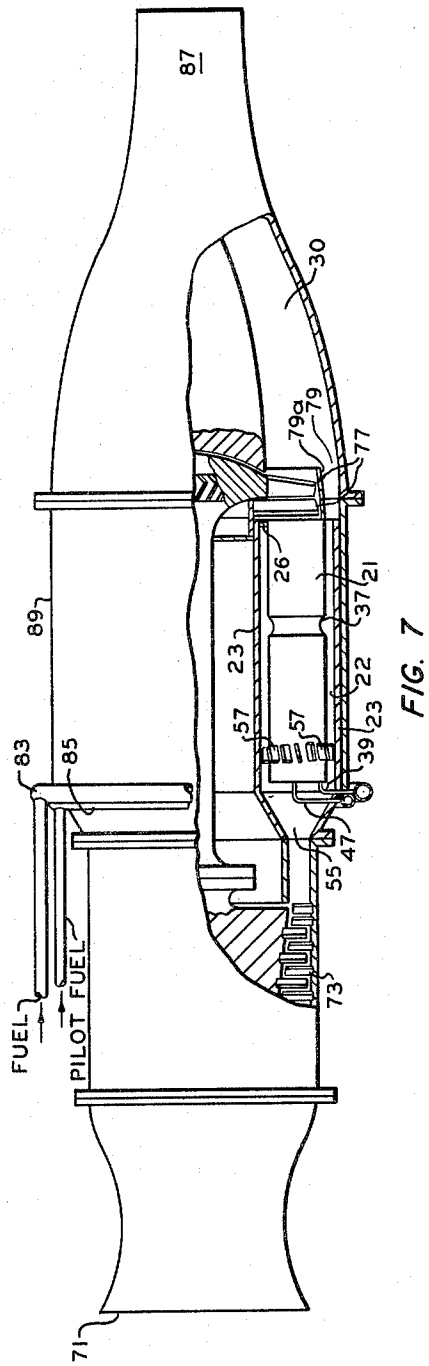


FIG. 7

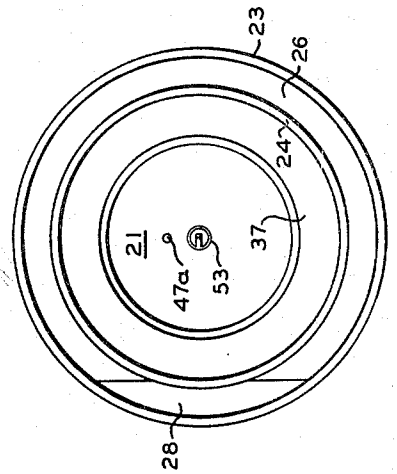


FIG. 8

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TURBOJET ENGINE AND ITS OPERATION

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Original application Aug. 5, 1959, Ser. No. 831,788. Divided and this application July 27, 1962, Ser. No. 215,762

4 Claims. (Cl. 60—39.69)

This invention relates to improved turbojet engines. In one aspect it relates to construction of improved combustors employed in turbojet engines. In another aspect it relates to construction of afterburners employed in turbojet engines. In yet another aspect it relates to a method for the operation of turbojet engines.

This application is a division of our copending application Serial No. 831,788, filed August 5, 1959, now abandoned.

In the usual combustor of turbojet engines, flame is initiated in a stream of high velocity air. Mechanism must be provided to decelerate at least a portion of the stream of air below effective flame velocity in the combustible mixture in order to pilot and to maintain a steady flame in the apparatus. Addition of fuel is made either directly to the high velocity stream of air upstream of the deceleration device or in the region of a quiescent zone downstream of the deceleration device. In such engines combustion is maintained in a flame tube which completely surrounds the flame and openings in the flame tube are provided for the addition of sufficient air for the formation of a near stoichiometric mixture of fuel and air. The loss of pressure in an apparatus of this type is considerable.

In combustion apparatus commonly employed in gas turbine power plants it is necessary to achieve stable and efficient combustion of fuel and air at high rates of heat release in a relatively confined space through which a stream of air is moved at high velocity. It is desirable in such a combustion system that the pressure loss be as small as possible, that the temperature distribution over the cross section of flow be uniform, and that stable and efficient combustion be maintained over a wide range of fuel-air ratios and severity of inlet conditions.

An object of this invention is to provide apparatus for use in turbojet engines. Another object is to provide a method for operating such jet engines at an extremely high level of thrust without overheating the turbine. Another object is to provide a turbojet engine operating cycle in which the first or primary combustor is operated in such a manner as to discharge combustion gases having a relatively low temperature. Still another object is to operate the primary combustor of a turbojet engine at a sufficiently low temperature that turbine blades disposed immediately downstream of the combustor can be employed for long periods of operating time without deterioration or failure due to high temperatures. Other objects and advantages of this invention will be realized upon reading the following description, which taken with the attached drawing, forms a part of this specification.

We achieve these and other objects and advantages by operating the first or primary combustor under fuel-rich combustion conditions to produce sufficient energy at a relatively low temperature for driving the turbine and compressor without undue deterioration of turbine blades, and a second combustion chamber or afterburner positioned downstream from the turbine. The stream of compressed air from the compressor is divided into two portions, one portion being employed in the partial combustion operation in the primary combustor and the other portion being used to complete the combustion of the effluent gases from the primary combustor in the secondary combustion chamber. The major portion of the combustion and thrust development takes place in the secondary combustion chamber.

In the drawing,

FIGURE 1 illustrates, in diagrammatic form, a flow diagram employed in the practice of this invention.

FIGURE 2 is a longitudinal view, partly in section, of a primary combustor of our invention.

FIGURE 3 is a sectional view taken on the line 3—3 of FIGURE 2.

FIGURE 4 is a sectional view taken on the line 4—4 of FIGURE 2.

FIGURE 5 is a sectional view taken on the line 5—5 of FIGURE 2.

FIGURE 6 is a sectional view taken on the line 6—6 of FIGURE 5.

FIGURE 7 is an elevational view, partly in section, of the general structure of the turbojet power plant employing the combustor and method of our invention.

FIGURE 8 is a sectional view taken on line 8—8 of FIGURE 2.

In FIGURE 1 is illustrated broadly the method of operation of our jet engine. In this figure reference numeral 11 identifies a conduit for inlet of air to a compressor 13. A portion of the compressed air is passed through a conduit 15 into a primary combustor 21 for the partial combustion of fuel therein added through a fuel inlet line 19. Surrounding combustor 21 is a shell 23 which bounds the outside of an annular space 22 (FIGURE 2) which is separated from the combustion zone by wall 24. Combustion gases from the combustor 21 pass through a conduit 27 into a turbine 29. As is known, in such engines the function of the turbine 29 is to drive a compressor 73 (FIGURE 7). The second portion of air is passed through shell 23 in indirect heat exchange with the combustor; in this manner the combustor temperature is maintained at a relatively low level while this stream of air is heated. The stream of air thus heated is passed through a conduit 25 into a secondary combustor or afterburner 33 into which also is introduced the effluent combustion gases from the turbine through a conduit 31. Substantially fully burned gases issue from combustor 33 through an outlet nozzle 35 with the development of thrust for the engine.

The structure of the combustor 21 and heat exchanger jacket, as illustrated in FIGURE 2, comprises the combustor wall or shell 24 surrounded by shell 23. Shell 23 is sufficiently greater in diameter than shell 24 to provide an annulus 22 therebetween for passage of air undergoing heat exchange with the combustor 21. On the interior of the shell 24 is disposed a flow constrictor 37. This flow constrictor as illustrated herein is merely a short section of combustor wall having a smaller diameter than the diameter of the remainder of the combustor shell 24. However, this flow constrictor can be a separate annular element welded or otherwise rigidly attached to the inner wall of the shell 24. The purpose of this constrictor is to mix gases flowing through the combustor.

A portion of the annular space 22 is closed by a plate 26 at the downstream end of the combustor, the remaining portion of this annular space being open, and this space is identified in FIGURE 8 by reference numeral 28. Turbine blades 77 are illustrated immediately at the outlet end of the combustor 21. Open space 28 is an outlet for the portion of air passed through heat exchange annulus 22. Opening 28 actually discharges into a conduit 79 (FIGURE 7) which conducts this air from opening 28 to the secondary combustor or afterburner 30. Conduit 79 is bounded by a curved plate 79*a* and the adjacent portion of the wall of shell 87.

At the inlet end of combustor 21 is disposed a block 69, as illustrated. This block contains numerous openings which serve purposes as follows. A recess 65 is provided in the surface of the block facing the interior of the combustor 21. A tube 47 extends from outside this combustor to block 69 and communicates with duct 47*a* as illustrated. This tube and duct are for passage of a pilot fuel into the combustor adjacent a spark plug 53 or other suitable ignition means. A conduit 49 leads air from upstream of the combustor through the block to a conduit 63 extending part way around within block 69. This conduit or manifold is identified by reference numeral 63 in FIGURES 2 and 3. Several openings 51 are provided in block 69 to direct air from manifold 63 into the recess 65 in a direction substantially tangential to the cylindrical wall of the recess. The specific positioning of these inlet openings 51 is clearly illustrated in FIGURE 3. A conduit 41 leads from tube 39 into block 69 and communicates with an annulus 43 which, in turn, communicates with a fuel inlet ring 45. This fuel inlet ring 45 is annular in shape and is intended to direct the fuel flowing into the combustor as an annulus of fuel along the inner surface of wall 24. Annulus 43 is merely a distributor manifold for distributing fuel entering from conduit 41 so that fuel can be introduced uniformly through the entire ring 45. The shell 23 extends upstream from the inlet end of this combustor and serves as an air inlet duct 55. From this air inlet duct a portion of the air passes through conduit 49 to the tangential inlet 51 for supporting combustion within the combustor 21. The remainder of the air from inlet duct 55 passes into and through the annulus 22. Disposed in the annulus 22 are a number of vanes 57 which are so disposed as to direct air flowing between them in a helical direction in the annulus toward the outlet end of the combustor. The position of these vanes is best illustrated in FIGURES 3 to 6. It is intended that the air entering the annulus 22 pass through this annulus as a rotating helix in order to serve as a more efficient coolant. In case the constrictor 37 is made as a small diameter section of the wall 22, as illustrated in FIGURE 2, the enlarged space 32 serves to mix or stir the air flowing through the annulus 22 so as to increase the effectiveness of the air as a heat exchange medium. Reference numeral 59 identifies the combustion gas outlet of this combustor.

In FIGURE 7 the combustor is illustrated in its normal position in the general assembly of a turbojet engine. It is realized that there is a plurality of combustors, such as combustor 21, disposed around the periphery of the engine, with the turbine and compressor shaft centrally located with respect to the combustors. Shell 87 surrounds the afterburner section while shell 89 surrounds the combustor section of the engine. The combustor wall 24 is illustrated as showing the constrictor 37. Wall 23 is spaced from the combustor 24 to provide the heat exchange annulus 22 as hereinbefore described. Air inlet duct 55 is illustrated as being a passage for air from compressor 73 to the inlet end of the combustor. Reference numeral 71 identifies the air inlet end of the engine. Tubular rings 83 and 85 conduct fuel and pilot fuel, respectively, from a source or sources not shown, to the respective fuel inlet pipes 39 and pilot fuel inlet tubes 47.

In the operation of the apparatus hereinabve described it is intended that all of the fuel burned in the engine shall be added through pilot tubes 47 and fuel pipes 39 to the primary combustors. As mentioned hereinbefore, the fuel from pipe 39 flowing through conduit 41, annulus 43 and fuel inlet ring 45 enters the combustor as an annulus of fuel flowing longitudinally downstream in the combustor along its inner wall. The air for combustion of this fuel is introduced through openings 51 which, as mentioned, are so positioned in block 69 that the air

enters the combustor substantially tangentially to the cylindrical wall 67 of the recess 65 and from this recess the helically flowing air flows toward the outlet end of the combustor. Combustion takes place at the shear surface between the annulus of fuel and the rotating helix of air. In this manner combustion is quite complete as regards the air and only a small amount of oxygen remains by the time the gases reach constrictor 37. On passing through this constrictor the gases are rapidly and thoroughly mixed so that by the time the gases reach the outlet end 59 of the combustor there is substantially very little free oxygen remaining. At this point in the combustor it is desired that substantially all of the free oxygen be consumed so that free oxygen will not be present at the combustion outlet temperature because turbine blades made of material most suitable for turbine service deteriorate at high temperatures in the presence of free oxygen. Thus, by making certain that substantially all of the free oxygen is removed from the gases before they contact the turbine blades, the blades are useful for extended periods of service. Furthermore, the constrictor 37 assists in mixing all of the gases passing through the combustor in order that the gases issuing from the combustor will be at a relatively uniform temperature. As will be realized in the combustor upstream of constrictor 37 the interface between the annulus of fuel and the helix of air is the highest temperature area. The temperature of this interface is considerably higher than along the axis of this portion of the combustor. Thus, by use of the constrictor 37 the gases are mixed for substantially complete consumption of the free oxygen and for providing uniform temperatures. Deterioration of the turbine blades is reduced to a minimum.

Only sufficient air is introduced into this primary combustor to provide sufficient combustion for the production of only sufficient energy for operating the turbine. By employing a fuel-to-air ratio in this primary combustor of from about 2 to 6, preferably about 4, times the stoichiometric ratio of fuel to air for complete combustion, substantially no carbon is laid down in this combustor. The inner walls of the combustor and the turbine blades are thus maintained clean as regards carbon deposition. The portion of air passed through annulus 22 for heat exchange purposes, as mentioned hereinbefore, passes on into the secondary combustor to complete the combustion of the fuel entering the secondary combustor from the primary combustors. The gases produced by the partial combustion in combustors 21 are still highly combustible and serve as the fuel for the secondary combustor of the engine. The over-all stoichiometric fuel-to-air ratio is approximately 1.

In the following example a stable operation was obtained employing the type of combustor illustrated in FIGURE 2 by using a fuel-air ratio to approximately 3.7 times the stoichiometric ratio of fuel to air for complete combustion at a mass rate of flow of 125,000 pounds of air per hour per square foot of combustor cross section. A typical exhaust gas from such a combustor operated under these conditions employing normal hexane as a fuel is as follows:

Component:	Volume percent
H_2	6.9
CO	15.6
CO_2	2.9
O_2	2.7
N_2	63.6
CH_4	4.1
C_2H_6	1.2
C_2H_4	2.5
C_2H_2	0.5

As will be noted, the combustible constituents of this combustion gas, and particularly the hydrogen, carbon monoxide, and acetylene, are constituents which have extremely rapid rates of flame propagation. The production of

these gases in the partial combustion area of our engine promotes flame stability in the complete combustion area, i.e., the secondary combustor. As mentioned hereinabove, there is no build-up of coke or carbon on the walls of this combustor. Pyrolytic carbon was not formed at the conditions of operation of this combustor.

In this example normal hexane was the fuel which yielded the combustion gases as given, but it is realized that any suitable fuel can be used.

Although the combustion apparatus of our invention is primarily employed in continuous combustion type gas turbine power plants, including auxiliary as well as jet engine power plants, the combustion apparatus is not limited to these applications but can also be employed in furnaces or similar oil burning installations employed for other purposes. Since substantially no pyrolytic carbon is produced by the operating conditions herein illustrated because of the high combustion efficiencies obtained, the combustion apparatus is particularly adapted for use in congested urban areas where air pollution due to smoke, smog, etc., is a problem. The apparatus can also be employed for carrying out chemical reactions involving combustion.

If desired, a second turbine can be employed following the afterburner in ground installations for more nearly complete utilization of the power of the engine. However, in such an installation a second compressor would be required following the blades 77 of the primary turbine.

While certain embodiments of the invention have been described for illustrative purposes, the invention obviously is not limited thereto.

That which is claimed is:

1. A combustor comprising, in operable combination, an elongated flame tube open at its downstream end, a fuel inlet means adjacent the upstream end of said flame tube, said fuel inlet means having an opening near the inner wall of said flame tube and being adapted to admit an annulus of fuel in a downstream direction along the inner periphery of said flame tube, means for admitting air adjacent said upstream end of said flame tube, this latter means being adapted to introduce air as a helix along the axis of said flame tube and within said annulus, an outer elongated tube disposed concentrically around said flame tube in such a manner as to provide an annulus therebetween, the upstream end of said outer tube extending in an upstream direction beyond the upstream end of said flame tube, a plurality of vanes in this latter annulus intermediate the outer periphery of the inlet end of said flame tube and the adjacent inner wall of said outer tube, the axes of said vanes being mutually parallel and disposed as helices in said annulus intermediate said tubes, a segment of said annulus intermediate said tubes being open and the remainder of said annulus being closed at the downstream ends of said combustor, and an annular constriction around the inner surface of said flame tube intermediate its ends and downstream from the point of initial contact of said fuel and said air in said flame tube, said segment of said annulus being adapted for passage of gas from said annulus.

2. A combustor comprising, in operable combination, an elongated flame tube open at one end, a closure at the other end, an annular groove in the face of said closure facing the interior of said flame tube, a conduit extending through said closure and communicating with said groove for passage of fuel to said groove, said closure having a recess in said face, said recess being concentric with and having a smaller diameter than the diameter of said groove, said recess having an enclosing sidewall and a closed end intermediate said face and the end of said closure opposite said face, means in said sidewall for admission of a gaseous oxidant as a helix along the axis of said flame tube, a conduit extending through said closure and communicating with this latter means for passage of said gaseous oxidant to said latter means, an ignition means extending through the closed end of said recess, a conduit in said closed end terminating adjacent said ignition means for introduction of pilot fuel, an outer elongated tube disposed concentrically around said flame tube in such a manner as to provide an annulus therebetween, the upstream end of said outer tube extending in an upstream direction beyond the upstream end of said flame tube, a plurality of vanes in this latter annulus intermediate the outer periphery of the inlet end of said flame tube and the adjacent inner wall of said outer tube, the axes of said vanes being mutually parallel and disposed as helices in said annulus intermediate said tubes, a segment of said annulus intermediate said tubes being open and the remainder of said annulus being closed at the downstream end of said combustor, and an annular constriction around the inner surface of said flame tube intermediate its ends and downstream from the point of initial contact of said fuel and said air in said flame tube, said segment of said annulus being adapted for passage of gas from said annulus.

3. A combustor comprising, in operable combination, an elongated flame tube open at its downstream end, a fuel inlet means adjacent the upstream end of said flame tube, said fuel inlet means having an annular groove open to the interior of said flame tube in such a way as to admit an annulus of fuel in the downstream direction along the inner periphery of said flame tube, an annular conduit having an annular opening, said annular groove having an annular opening opposite the interior of said flame tube, the annular opening of said annular conduit being in unobstructed communication with the annular opening of said groove, a second conduit communicating with said annular conduit for passage of fuel thereto, said annular conduit being adapted to distribute fuel uniformly from said first conduit to said annular groove, means for admitting air adjacent said upstream end of said flame tube, this latter means being adapted to introduce air as a helix along the axis of said flame tube and within said annulus, an outer elongated tube disposed concentrically around said flame tube in such a manner as to provide an annulus therebetween, the upstream end of said outer tube extending in an upstream direction beyond the upstream end of said flame tube, a plurality of vanes in this latter annulus intermediate the outer periphery of the inlet end of said flame tube and the adjacent inner wall of said outer tube, the axes of said vanes being mutually parallel and disposed as helices in said annulus intermediate said tubes, a segment of said annulus intermediate said tubes being open and the remainder of said annulus being closed at the downstream ends of said combustor, and an annular constriction around the inner surface of said flame tube intermediate its ends and downstream from the point of initial contact of said fuel and said air in said flame tube, said segment of said annulus being adapted for passage of gas from said annulus.

4. A combustor comprising, in operable combination, an elongated flame tube open at its downstream end, a fuel inlet means adjacent the upstream end of said flame tube, said fuel inlet means having an opening near the inner wall of said flame tube and being adapted to admit an annulus of fuel in a downstream direction along the inner periphery of said flame tube, means for admitting air adjacent said upstream end of said flame tube, this latter means being adapted to introduce air as a helix along the axis of said flame tube and within said annulus, an outer elongated tube disposed concentrically around said flame tube in such a manner as to provide an annulus therebetween, the upstream end of said outer tube extending in an upstream direction beyond the upstream end of said flame tube, a plurality of vanes in this latter annulus intermediate the outer periphery of the inlet end of said flame tube and the adjacent inner wall of said outer tube, the axes of said vanes being mutually parallel and disposed

as helices in said annulus intermediate said tubes, a segment of said annulus intermediate said tubes being open and the remainder of said annulus being closed at the downstream ends of said combustor, an annular constriction around the inner surface of said flame tube intermediate its ends and downstream from the point of initial contact of said fuel and said air in said flame tube, said segment of said annulus being adapted for passage of gas from said annulus, said annular constriction being a section of said flame tube having a smaller inside diameter and a smaller outside diameter than the remainder of the flame tube thereby providing an enlarged annular space adjacent the outerwall of said flame tube at the position of said constriction.

References Cited in the file of this patent

UNITED STATES PATENTS

2,458,066	Farkas et al.	Jan. 4, 1949
2,664,702	Lloyd et al.	Jan. 5, 1954
3,067,582	Schirmer	Dec. 11, 1962
3,078,672	Meurer	Feb. 26, 1963