

July 26, 1960

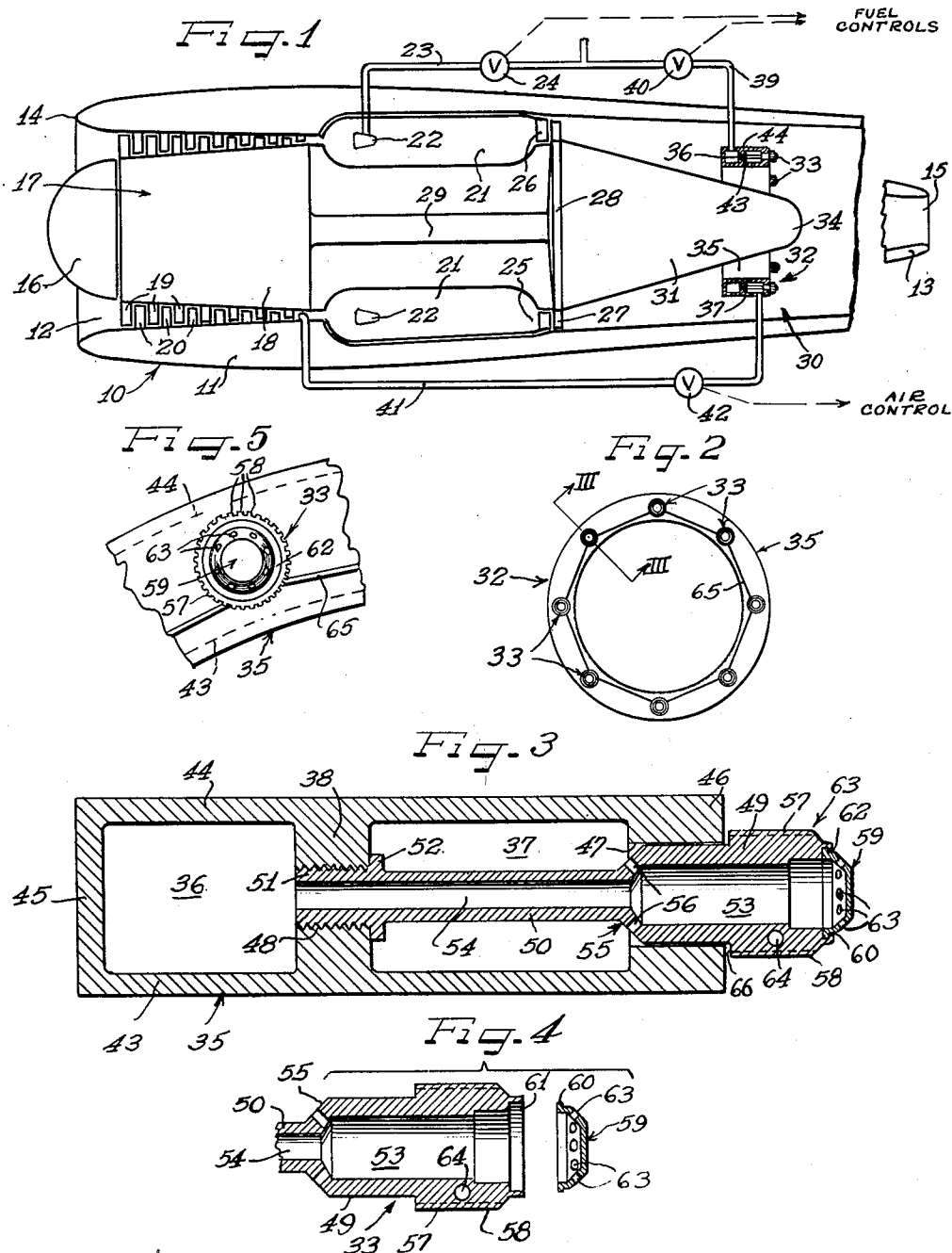
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2,946,185

FUEL-AIR MANIFOLD FOR AN AFTERBURNER

Filed Oct. 29, 1953

2 Sheets-Sheet 1



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Fig. 6

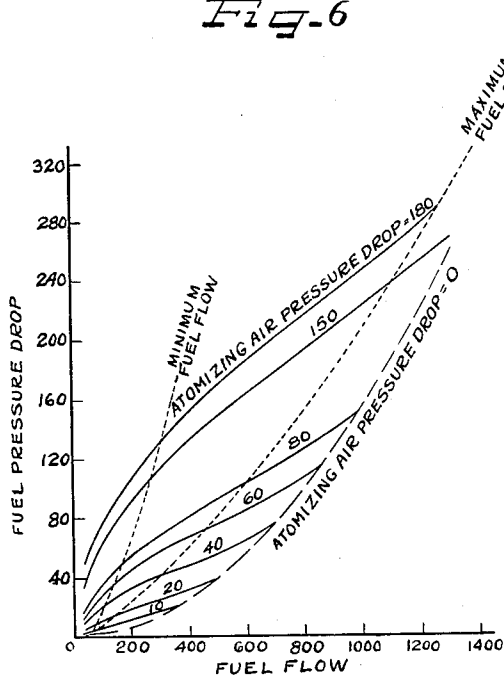


Fig. 8

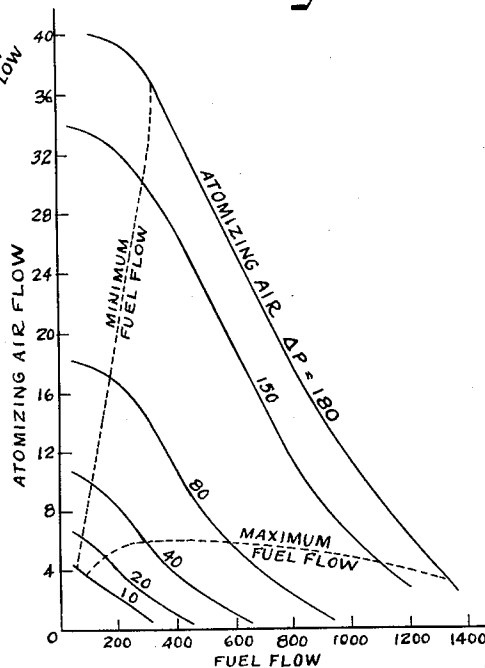
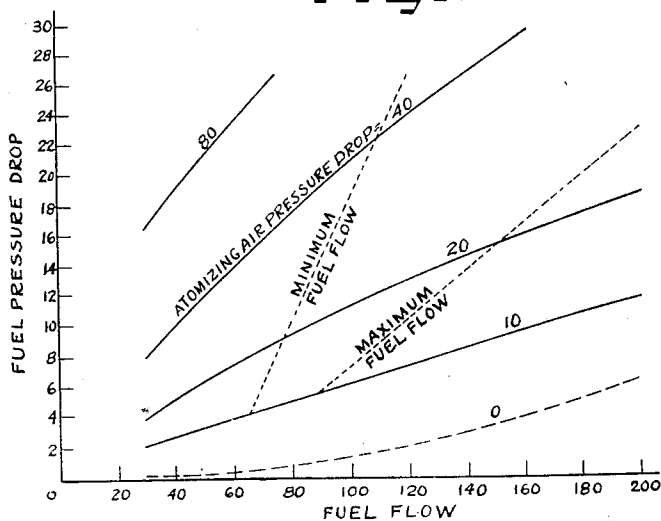


Fig. 7



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2,946,185

FUEL-AIR MANIFOLD FOR AN AFTERBURNER

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Filed Oct. 29, 1953, Ser. No. 389,083

2 Claims. (Cl. 60—35.6)

The present invention relates to an air atomizing fuel nozzle assembly and method of fuel distribution thereto. More particularly, the present invention relates to an afterburner fuel nozzle assembly for jet engines and the like and a method of maintaining substantially equal fuel pressure and flow to the plurality of nozzles in the assembly.

It is well known in the art that the performance factors generally and the thrust forces specifically generated by jet type engines are greatly enhanced and improved by the inclusion of an after burner or the like in the exhaust area or chamber of the jet type engine mechanism. Heretofore, numerous types of after-burner constructions and assemblies have been developed in attempts to supply the obvious demand therefor. Most common among the heretofore known types of after-burners include simple spray nozzles for ejecting fuel into the exhaust stream. This type of nozzle, although frequently considered to be one of the better of the heretofore known types of nozzles, had many limitations and difficulties resulting in rather poor after burning effects and heavy fuel consumption.

When arranged circularly within the propulsion exhaust chamber and with a common fuel manifold, the simple nozzles were subject to widely varying fuel distribution. Due to gravitational effects on the fuel, fuel flow differences between top and bottom nozzles often attained a value of about 50% of the average fuel flow. This resulted in a fuel distribution ranging within $\pm 25\%$ of the average flow; this problem was particularly acute at low fuel flow rates.

Another problem existing with heretofore known types of after burner nozzles at low fuel flow rates was the failure of the nozzles to properly atomize the fuel as it was ejected into the propulsion exhaust stream. Most frequently, the fuel ejected had a bubble type characteristic rather than an atomized or fog type characteristic. Still another difficulty obtaining with the employment of heretofore known types of nozzles resulted from improper fuel mixing and distribution into the propulsion exhaust stream.

By the principles of the apparatus and method of the present invention the above problems and difficulties resident in heretofore known types of after-burners and after burning methods are obviated and the effects thereof are substantially prevented. It is an important feature of the present invention to uniformly distribute fuel to a plurality of after burner nozzles, having a common fuel manifold, in such a manner that fuel distribution may be maintained within the close range of about $\pm 10\%$ to 12% of the average weight rate of fuel flow.

It is therefore, an important object of the present invention to provide a method of fuel distribution to a plurality of arcuately arranged after burner nozzles having a common fuel manifold by supplying both fuel and atomizing air to a mixing chamber or the like within each nozzle.

It is another important object of the present invention

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to provide a method of fuel distribution for attaining substantially equal fuel distribution to a plurality of nozzles provided with a common fuel manifold and arranged at normally different altitudes between nozzles, by supplementing the fuel supply to the nozzles with atomizing air supplied to the nozzle.

Still another important object of the present invention is to provide a method of improving the fuel pressure drop versus fuel flow rate characteristic for fuel nozzles operable at lower fuel rates by simultaneously supplying fuel and atomizing air to the nozzles.

Fuel pressure drop versus fuel flow rate characteristics for heretofore known types of fuel nozzles and particularly after-burner nozzles for jet type engines and the like, had generally parabolic plots which opened in the direction of increasing pressure drop across the nozzle. These parabolic characteristics readily indicated that at low weight of fuel flow rate, extremely poor operating conditions obtained. By the present invention, however, the stated characteristics, and therefore the operational characteristics, are improved and particularly improved at low rate of fuel flow rates. By improving the pressure drop versus fuel flow characteristics in the low fuel flow range the elevational differences between several nozzles of an after burner assembly have a reduced effect on fuel distribution among the nozzles connected to a common fuel manifold.

Another important object of the present invention is to provide a method for proper atomization of the fuel, particularly at low fuel flow rates, by supplementing the fuel supply to after burner nozzles with atomizing air. Heretofore known after burner nozzles and the like had poor low fuel flow rate atomization since this feature of those types of nozzles was governed primarily by the maximum pressure drop limitations in the desired flow range. By the present invention, however, these limitations and factors are removed as governing qualities.

That is, in accordance with the principles of the present invention, maximum fuel pressure drop limitations in the desired flow range do not critically control the low flow atomization.

Another important object of the present invention is to provide an after burner assembly for a jet engine or the like having a main burning chamber, a rotary compressor supplying air to said chamber, a turbine driven by exhaust from said chamber and an arcuate substantially right conical, toroidal propulsion exhaust chamber, comprising, a double manifold ring positioned coaxially in the exhaust chamber, a fuel manifold circumferentially within the ring and axially displaced from fuel manifold, a first plurality of apertures in a rearwardly transverse face of the ring communicating with the air manifold, an equal plurality of said apertures coaxial with said first plurality of apertures respectively and extending from the air manifold to the fuel manifold, and an equal plurality of nozzle structures having substantially cylindrical bodies respectively extending through said first apertures and threadably engaging said second apertures sealingly separating the air manifold and the fuel manifold, a mixing chamber in each of said nozzle bodies, a fuel passage in each of the nozzle bodies extending from the fuel manifold to the mixing chamber, a plurality of orifices in each of the nozzle bodies communicating the air manifold with the mixing chambers respectively, and orificed nozzle heads terminating each of the mixing chambers, respectively, fuel supply means to convey fuel to the fuel manifold, and an air supply means to convey air to the air manifold from the compressor.

Still another object of the present invention is to provide an after burner manifold ring for a plurality of after

burner fuel nozzles and having a common fuel manifold for the several nozzles and a common air manifold for the several nozzles.

Still another object of the present invention is to provide an after burner fuel nozzle or the like with fuel inlet means and air inlet means whereby atomizing air may enter into a mixing chamber within the nozzle.

Still another object of the present invention is to provide an after burner assembly of arcuate configuration for proper incorporation into the propulsion exhaust chamber of a jet engine or the like and having a fuel manifold and an air manifold therein separated by a partition wall and a plurality of after burner nozzles each including a fuel tube extending into the fuel manifold and orifices communicating the interior of the nozzle with the air manifold whereby fuel and atomizing air may simultaneously enter into a mixing chamber within the nozzles respectively.

Still another object of the present invention is to provide a new and improved nozzle structure for after burners or the like, the nozzle including a mixing chamber, a fuel tube communicating with said mixing chamber, atomizing air orifices communicating with said mixing chamber, and a nozzle head terminating one end of the mixing chamber and provided with proper orifices for atomizing expulsion of the fuel-air mixture in the mixing chamber.

Still another object of the present invention is to provide an after burner assembly wherein a plurality of after burner nozzles are properly positioned at relatively different elevations by a double manifold ring and means are provided for simultaneously admitting the fuel and atomizing air to the nozzles to improve the operational characteristics thereof and further to maintain proper fuel distribution thereto within a pre-selected range of the average fuel flow.

Still other objects, features and advantages of the present invention will readily present themselves from the following detailed description of the principles of the present invention, and a preferred embodiment thereof, from the claims, and from the accompanying figures of drawing, wherein like reference numerals refer to like parts, and wherein:

Figure 1 is a more or less schematic, longitudinal sectional elevational view through a jet-type engine equipped with an after burner assembly in accordance with the principles of the present invention;

Figure 2 is a rear end view of the after burner assembly of Figure 1;

Figure 3 is an enlarged sectional view through the double ring manifold and nozzle construction taken substantially along the line III—III of Figure 2;

Figure 4 is an exploded, fragmentary longitudinal sectional assembly view of the body and head portion of the nozzle structure;

Figure 5 is a head end elevational view of an individual nozzle and a fragmentary portion of the manifold ring;

Figure 6 is a graphic illustration of a family of characteristic curves, for after burner assemblies embodying the principles of the present invention, showing the fuel pressure drop versus fuel flow rate for various specified atomizing air pressure drops;

Figure 7 is a graphic illustration of the same family of curves as those of Figure 6, but is limited to the low fuel flow rate range thereof and is expanded to more clearly illustrate these characteristics in the low fuel flow rate range; and,

Figure 8 is a graphic illustration of a family of characteristic curves showing the atomizing air flow rate plotted against fuel flow rate for varying atomizing air pressure drops in after burner assemblies incorporating the principles of the present invention.

There is schematically illustrated in Figure 1, a jet type engine mechanism 10, having housing or casing 11

of substantially teardrop external configuration. The housing 11, is axially hollowed with an enlarged air entrance at its forward or front end 12, thereafter tapering to an exhaust-nozzle-like rear end 13. Both the front or intake end 12 and the exhaust end 13, of the housing 11, have substantially smooth curved edges 14 15 respectively. A nose bell 16, of substantially semi-spherical configuration is positioned coaxially within the housing 11, preferably so that it is intersected by the plane of the leading edge 14, at the intake end 12, of the engine 10.

The intake end 12, preferably has a slightly flared mouth configuration internally of the housing 11, and together with the semi-spherical configuration of the nose bell 16, gathers inlet air and directs the air into a rotary compressor, indicated generally at 17. The rotary compressor 17 has a substantially frusto-conical rotor body 18, carrying a plurality of rows or rings of air foil contoured blades or buckets or vanes or the like 19 of diminishing lengths respectively from front to rear along the compressor rotor 18. Successive rows or rings of rotor compressor blades 19, are circumferentially disposed about the compressor rotor body 18, and spaced for angular or rotary movement between successive rings or rows of the compressor stator blades 20, fixed to the housing 11. The stator compressor blades 20 are also of diminishing length progressing rearwardly from the inlet to the compressor and direct to the increasingly compressed air stream from one row or circumferential ring of rotor blades 19, to the next row or circumferential ring thereof.

High pressure and high temperature compressed air from the compressor 17, leaves the compressor 17 to enter a plurality of combustion cans 21, forming a combustion chamber, wherein fuel is supplied from main combustion fuel ejection nozzles 22. The fuel may be supplied to the combustion nozzles 22 in any particular desired manner which herein is illustrated merely as a fuel line 23, having a control valve 24 therein operatively connected to a fuel control mechanism (not shown). Within the combustion cans 21, of the combustion chamber the fuel from the nozzles 22 is ignited in the high pressure air from the compressor 18 so that the exhaust gases and flames create extremely high pressure and temperature exhaust conditions.

These extremely high temperature conditions of exhaust gases and flames from the combustion cans 21, of the main combustion chamber are exhausted from the cans through combustion chamber exhaust nozzles or outlet ports 25 and directed against a "turbine diaphragm" 26, comprised of air foil turbine blades or buckets or vanes or the like fixed to the housing 11 to form a stator "nozzle," thereby directing the exhaust fumes and flames against a ring or row of turbine rotor blades or buckets or vanes 27 which are rotatably or angularly driven thereby. The turbine rotor blades 27 are fixed to a turbine rotor 28 which is drivingly connected to a rotor shaft 29, coaxially supported by appropriate bearings or the like (not shown) within the housing 11, for driving the compressor rotor 18 which is also affixed to the shaft 29.

Following the turbine stage, the exhaust fumes and flames enter an exhaust or propulsion afterburner chamber, indicated generally at 30, having a generally toroidal configuration limited or walled by the substantially conical interior of the housing 11 as the external surface of the exhaust chamber in this area, and by a nozzle cone or the like 31, as the interior surface of this toroidal exhaust nozzle chamber. The high temperature and high pressure gases and fumes are, of course, propulsion exhausted through the housing aperture, jet or nozzle 13 at the trailing edge of 15 of the jet engine.

Most frequently there is a surplus of air or oxygen in the exhaust gases and fumes. To remedy this difficulty and thereby substantially increase both the efficiency of the jet engine and the thrust forces generated thereby, an

after burner or the like is positioned at some pre-selected place in the exhaust chamber. A properly operating after burner serves to eject additional fuel into the exhaust gases thereby burning in the surplus air or oxygen to raise the temperatures and pressures of the exhaust fumes.

In accordance with the principles of the present invention the after burner assembly 32 is formed with a plurality of nozzles 33 arranged in ring form or circular form coaxial with the engine housing 11 and nozzle cone 31 etc., and immediately forward from the apex 34 of the nozzle cone 31 in the toroidal propulsion exhaust chamber 30. The several exhaust nozzles 33 are assembled with a utilized double manifold ring 35 secured in the described position by any convenient means (not shown) so that the nozzles 33 face rearwardly of the jet engine or toward the propulsion exhaust nozzle 13.

The double manifold ring 35 has a pair of circumferential, axially displaced, separated cavities 36 and 37. The forwardmost chamber 36 serves as a common fuel manifold for the several after burner nozzles 33 and is separated from the rearwardmost chamber 37 by a partition wall 38 so that the chamber 37 may be operative as a common air manifold for air intake to the several nozzles 33. Fuel is supplied to the common fuel manifold 36 in the double ring manifold 35 from the fuel line 39 (Figure 1) connected to the common fuel supply through an after burner fuel control valve 40 connected to a fuel control (not shown) in any convenient manner. The common air manifold chamber 37 of the double manifold ring 35 is supplied with air from the compressor 17, preferably at the trailing end thereof, via an air supply line 41 supplying air to the manifold 37 at fairly high pressures and temperatures through an air control valve or the like 42 coupled in any convenient manner to an air control (not shown) but as indicated.

The double manifold ring 35 has a pair of coaxial or concentric inner and outer annular walls, cylindrical ring members, or annuluses 43 and 44 respectively joined by a forward wall or ring 45 of solid construction and a rearward wall or ring 46 also of solid construction except for a plurality of apertures 47 therein for passage of the appropriate portions of the individual nozzles 33 therethrough. The partition wall or ring 38 separates the interior of the double manifold 35 into the common fuel manifold chamber 36 and the common air manifold chamber 37. An equal plurality of threaded apertures 48 appears in the otherwise solid partition wall 38 for threaded reception of an appropriate portion of the nozzles 33, respectively.

As best seen in Figures 3, 4 and 5, each of the nozzles 33 has an axially hollow substantially cylindrical body 49, one end of which comprises a fuel tube 50 extending through the air manifold 37 into the fuel manifold 36. The fuel tube 50 has a length which is about equal to the axial dimension of the air manifold 37 and the axial dimension of the partition wall 38. At the forward or fuel entrance end thereof the fuel tube has a roll threaded slightly increased diameter portion 51 for suitably engaging threaded aperture 48 in the partition wall 38. Immediately rearward of the threaded portion 51 the fuel tube 50 is provided with a circumferential shoulder flange 52 for sealing engagement with the rearward face of the partition wall 38 upon threading the fuel tube into an aperture 48 thereby sealingly separating the fuel manifold 36 from the air manifold 37. The seal is preferably either a metal to metal seal or a gasket seal. The metal to metal seal is preferred to a gasket seal by virtue of the high temperatures present at the double manifold ring.

The nozzle body 49 has a substantially symmetrical axial hollow 53 therein coaxially mating with the longitudinal passage 54 in the fuel tube 50 so that fuel flow passes from the common manifold 36 through the fuel tube passage 54 directly into the nozzle body hollow 53. The nozzle body hollow 53 has a substantially greater diameter than the diameter of the fuel tube passage 54

and the outside diameter of the nozzle body 49 is greater than the outside diameter of the fuel tube 50. The junction between these two portions is preferably substantially frusto conical as indicated at 55, tapering in the direction of the fuel tube 50. A pair of orifices 56 is drilled or like through the frusto conical junction section 55 for communicating the air manifold 37 with the fuel body hollow 53 which serves as a mixing chamber for fuel from the common manifold 36 and atomizing air from the common air manifold 37.

The nozzle body 49 passes through an appropriate aperture 47 coaxial with the threaded aperture 48 into which the fuel tube 50 is threaded. Rearwardly from the rear wall 46 of the double manifold 35, the nozzles 33 have enlarged outside diameters as at 57 wherein they are circumferentially splined as at 58 with the splines extending in an axial direction. The rearward end of the mixing chamber 53 of each of the nozzles 33 is terminated with a nozzle head 59 having a flange 60 which seats in a counter bore 61 in the rearward end of the nozzle body 49. A lip 62 about the counterbore at the rearward end of the nozzle body 49 is rolled or pressed over the flange 60 sealing and securing the nozzle head 59 to the body 49 so that it terminates the mixing chamber 53.

The nozzle head 59 has a preferably slightly frusto conical configuration tapering rearwardly with a plurality of nozzle orifices 63 communicating the mixing chamber 53 with the toroidal exhaust chamber 30 of the jet engine 10. The nozzle orifices 63 are provided through the tapering frusto conical wall section of the flat faced nozzle head 59, so that the atomized fuel passing therethrough is given a conical spray configuration for better mixing with the exhaust gases. The nozzle orifices 63 are preferably eight (8) in number and provided with half quadrature spacing.

The nozzle bodies 49 are also provided with a transverse aperture or drill hole or the like 64 which does not communicate with the mixing chamber 53. This drill hole or aperture 64 is provided for acceptance of a securing line or wire, 65 (Figures 2 and 5) which is run through the apertures 64 in each of the nozzles 33 after the nozzles 33 are threaded into the threaded passage 48. The securing line or wire, etc. 65 passed through the several apertures 64 for the several nozzles 33 respectively prevents loosening of the nozzles 33 from the double manifold ring 35.

The interfit between nozzle body 49 and aperture 47 is a relatively precision fit for the following reasons. It is important to obtain a substantially perfect seal between the fuel manifold 36 and the air manifold 37 by means of the metal to metal seal at shoulder 52. This being the case, the nozzle body and fuel tube are so formed that shoulder 52 will seat against the partition 38 to prevent leakage of fuel from the fuel manifold into the air manifold. Slight air leakage from the air manifold into the exhaust chamber is far less serious than an internal fuel leak.

In actual practice it would be desirable to prevent air leakage from the air manifold 37 to the exhaust chamber 30 through the clearance along aperture 47 in order to minimize the quantity of atomizing air bled from the compressor of the engine. Although it is difficult to effect a perfect seal at aperture 47 while insuring a perfect seal at shoulder 52, a very good seal with almost negligible leakage is obtained by providing a close slip fit of reasonable length through aperture 47. This is a slip fit for ease of assembly and a small clearance fit for purposes of minimizing air leakage.

The provision of the atomizing air entry ports 56 for entry of atomizing air into the mixing chamber 53 forms an important feature of the present invention since through these means the method of the present invention for improving the fuel distribution to the several nozzles on the double manifold ring and improving the low fuel flow rate atomization and improving the pressure drop

versus fuel flow characteristics, particularly in the low range, is accomplished. In addition to these features better fuel flow rate control obtains by application of the principles of the present invention.

The effect of supplying air to the nozzles is shown in the families of curves of Figures 6 and 7. In these figures fuel pressure drop is plotted on the vertical axis, in arbitrary units, against weight rate of fuel flow on the horizontal axis, in arbitrary units. The family of curves of Figure 7 are an expansion of the family of curves of Figure 6 in the low fuel flow rate region.

The individual curves of Figures 6 and 7 are plotted at selected atomizing air pressure drops also measured in arbitrary units under pre-selected conditions.

With no air flow (atomizing air pressure drops equal to zero) a normal parabolic pressure drop versus fuel flow characteristic results. This normally parabolic pressure drop versus fuel flow characteristic is the one which normally obtains with simple spray nozzles, simple fuel ejection nozzles not provided with atomizing air inlets thereto; examination of the atomizing air pressure drop equals zero curve, shown by the dashed line in Figures 6 and 7, readily illustrates that very poor low fuel flow rate control is available.

On the other hand, by adding atomizing air to the after burner nozzles the fuel pressure drop versus the fuel flow characteristics are greatly improved, particularly in the low fuel flow rate region of operation and better low fuel flow rate control is available. For example, it will be noted that the characteristic curves, identified by atomizing air pressure drop equal to 10, 20, 40, 60, 80, 150, 180, open in the direction of increasing weight rate of fuel flow while the characteristic curve for atomizing air pressure drop equals zero opens in the direction of increasing fuel pressure drop. The variation between these curves in the low weight rate of fuel flow region of operation is particularly noticeable from an examination of the family of curves of Figure 7 wherein it may be seen that zero atomizing air pressure drop curve allows for practically no control while the curves for air pressure drops equal to 10, 20, 40, and 80 permit a high degree of fuel flow rate control in this region.

Another important aspect of the present invention, resulting from supplementing the fuel flow with simultaneous passage of atomizing air to the after burner nozzles, is the improved fuel distribution to the several ring disposed nozzles. A preferred mounting for the several fuel nozzles and after burner assembly has the nozzles mounted circularly in a vertical plane transversely through the toroidal exhaust chamber of the jet engine. Therefore, in normal flight or under normal operating conditions there is an elevational difference between each of the several nozzles. This elevational difference accounts for a fuel pressure difference which exists between each of the several nozzles. In numerous instances an elevational difference equivalent to one unit of fuel pressure will result in a difference in fuel flow between top and bottom nozzles of about 50% of the average fuel flow rate (this condition exists frequently when simple type nozzles are employed). Fuel distribution under these conditions is then only within a range of about $\pm 25\%$ of the average fuel flow rate.

By supplying atomizing air to the nozzles, in accordance with the principles of the present invention, the elevational differences are substantially lessened and obviated. Operating in accordance with the principles of the present invention with so little as an atomizing air pressure drop equal to ten units, the fuel difference between top and bottom nozzles, due to the same elevational differences as set forth above falls within a range of less than 22% of the average fuel flow. Therefore, the fuel distribution as effected by supplying atomizing air to the nozzles falls within a range of less than about 11% of the average fuel flow for any nozzle in the ring.

The family of curves of Figure 8 represent atomizing

air flow versus fuel flow characteristics with weight rate of atomizing air plotted increasingly along the vertical axis and a weight rate of fuel flow plotted increasingly along the horizontal axis. The units for these coordinates have been arbitrarily selected and the air temperature has been maintained constant for all of the curves. The individual curves represent individual atomizing air pressure drops ranging from 10 to 180 units in the same manner as the units selected for the individual curves of Figures 6 and 7.

It will be readily observed from an examination of these curves that operational parameters, selected within the range bounded by the preferred maximum fuel flow range and the preferred minimum fuel flow range, as indicated by the broken line curves on each of these figures, the weight rate of flow of atomizing air is preferably maintained within the range of less than about 10% of the weight rate of fuel flow. These highly advantageous results may be obtained with air temperatures so low as about 60° F. Since normal operating air temperatures at the exit of the compressor stage of the jet engine are seldom less than about 500° F., or 600° F., it will be readily understood that under normal operating conditions the weight rate of atomizing air flow will be within the range of less than about 5% of the weight rate of fuel flow.

When preferred units for the several curves has all pressure drops measured in pounds per square inch (p.s.i.) and weight rates of flow measured in pounds per hour, the several families of curves of Figures 6, 7 and 8 will obtain with the units marked thereon. The curves of Figure 8, with such units, are plotted for an air temperature of about 60° F. As stated, it will be understood that normal operating air temperature conditions will correspondingly change the slopes of the curves.

Thus, performing the method of the present invention of supplying atomizing air into the after burner nozzles will substantially improve the operating characteristics of the jet engines generally and the after-burner specifically. Another important advantage of performing this method resides in the low flow atomization of the fuel at the after burner. With the simple type nozzle low flow rate fuel atomization is governed primarily by the maximum pressure drop limitation at the flow range. In accordance with the principles of the present invention, a low flow fuel rate atomization is substantially increased by the effect of the simultaneous application of atomizing air into the nozzle together with the fuel passed into the nozzle. It is understood, of course, that improved atomization of the fuel increases the burning qualities thereof and thereby increases the effect and the benefits to be obtained from an after burner, or for that matter, any fuel nozzle.

It will be understood that modifications and variations may be effected without departing from the scope of the novel concepts of the present invention.

I claim as my invention:

1. In an afterburner apparatus for a gas turbine power plant having cylindrical casing structure defining an exhaust chamber terminating in an exhaust jet, for exhausting hot gases from the gas turbine to the exhaust jet, the improvement of: an annular manifold ring wholly disposed and mounted within said exhaust chamber in radially spaced relation to said casing structure in a manner wherein exhaust gases may flow past the inner and outer periphery thereof, said ring having separate air and fuel manifold passages therein; means communicating said passages to sources of air and fuel respectively; and a series of injector nozzles removably secured to said ring and having means therein communicating separately with said passages for receiving unmixed air and fuel therefrom and for mixing air and fuel internally of the nozzles, said nozzles being operative to discharge the mixture into the exhaust chamber for combustion.

2. In an afterburner apparatus for a gas turbine power plant having cylindrical casing structure defining an exhaust chamber terminating in an exhaust jet, for exhaust-

ing hot gases from the gas turbine to the exhaust jet, the improvement of: a double manifold ring entirely disposed and supported directly in said exhaust; a chamber in radially spaced relation to said casing structure; a fuel manifold circumferentially within said ring and connected to a fuel supply; an air manifold circumferentially within said ring and axially displaced from said fuel manifold and connected to an air supply; said air and fuel manifolds being each separately defined in part by portions of said ring, said portions being externally exposed to exhaust gases flowing past both the inner and the outer peripheries of said ring; said ring being provided with a plurality of injector nozzles; each of said nozzles having means separately communicating with said passages for receiving air and fuel in an unmixed condition therefrom, and for mixing the same within the nozzle for discharge into the exhaust chamber for producing further combustion in the exhaust chamber.

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