

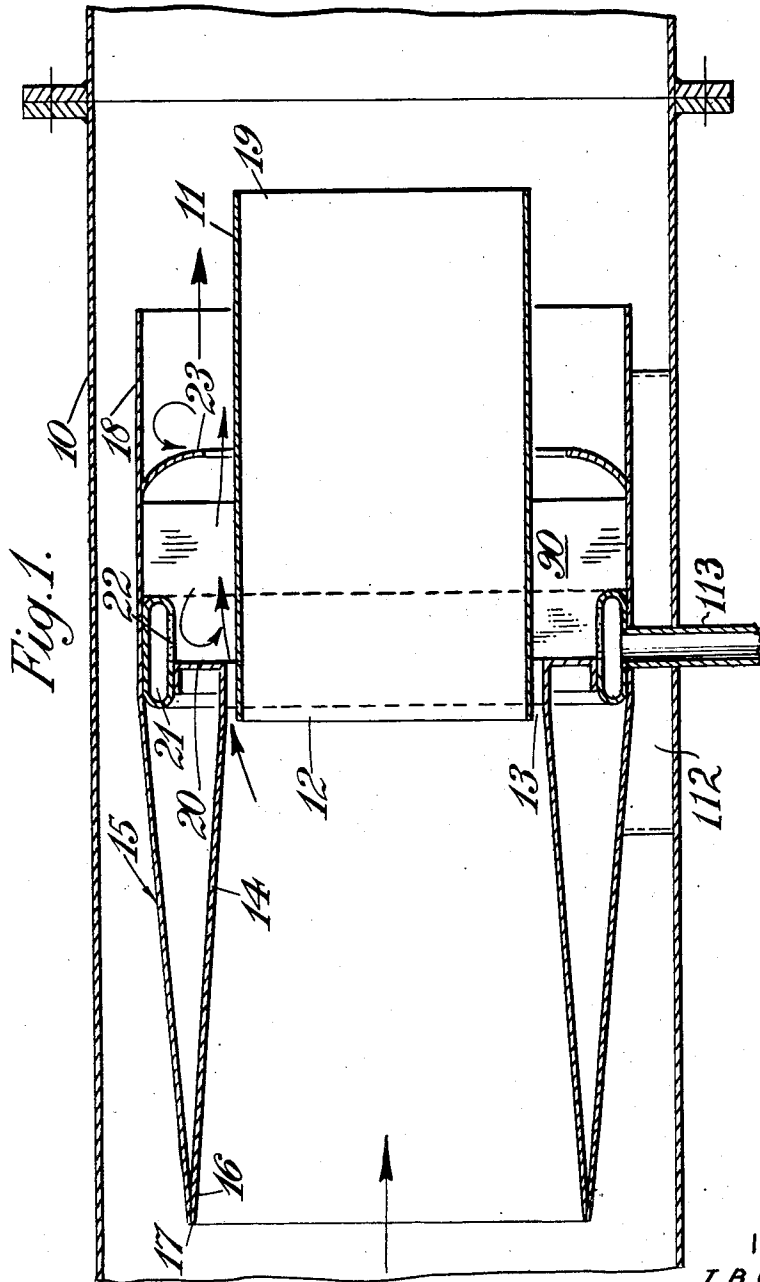
April 1, 1958

I. B. OGILVIE
COMBUSTION CHAMBERS INCLUDING SUDDENLY
ENLARGED CHAMBER PORTIONS

2,828,609

Filed March 26, 1951

6 Sheets-Sheet 1



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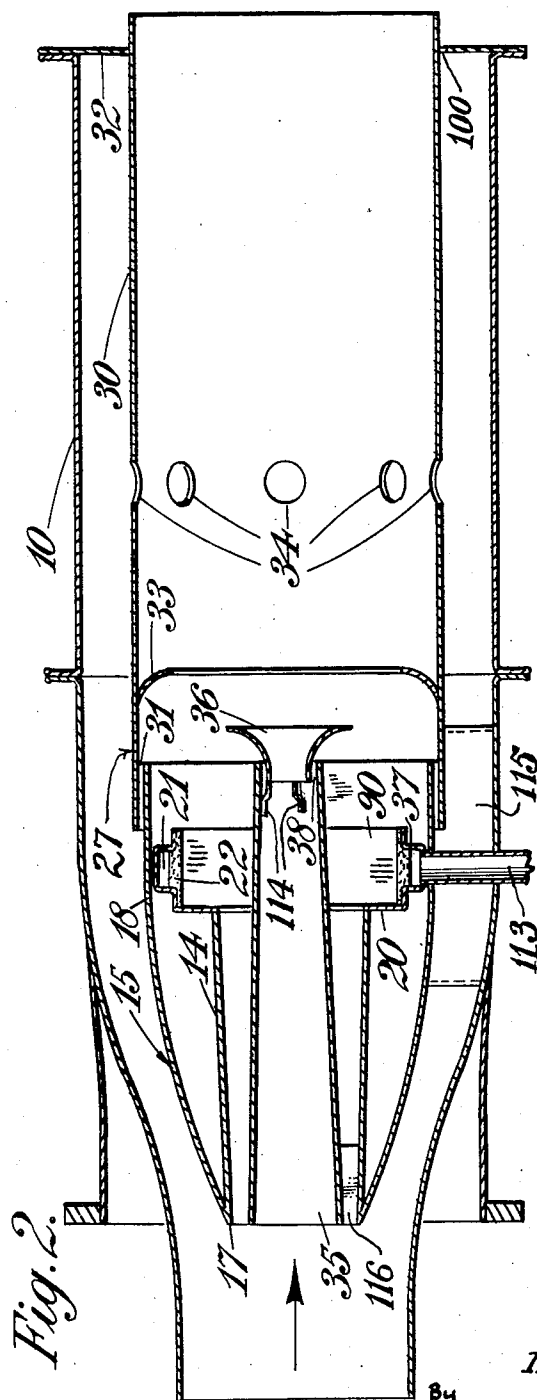
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6 Sheets-Sheet 2



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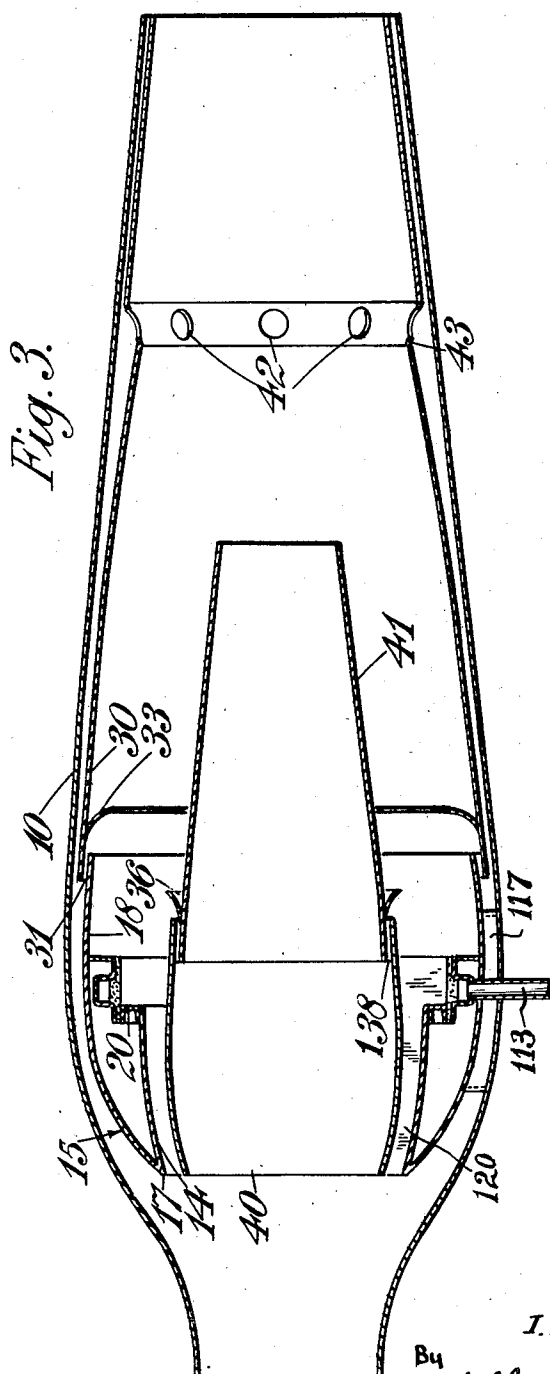
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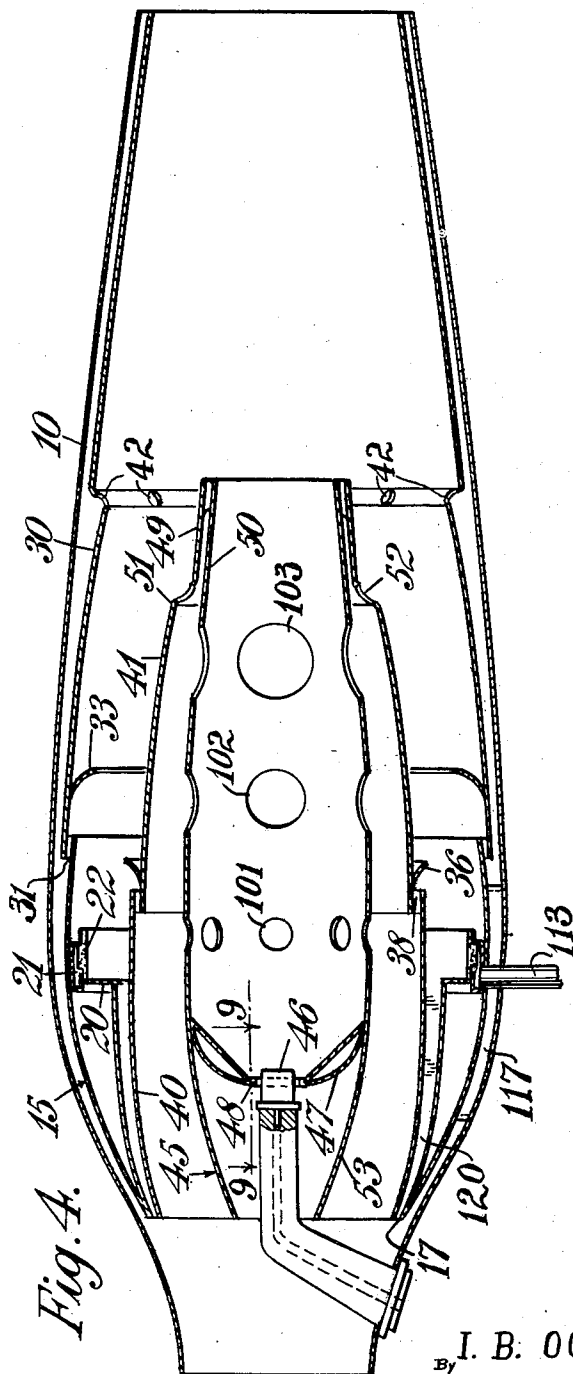


Fig. 4.

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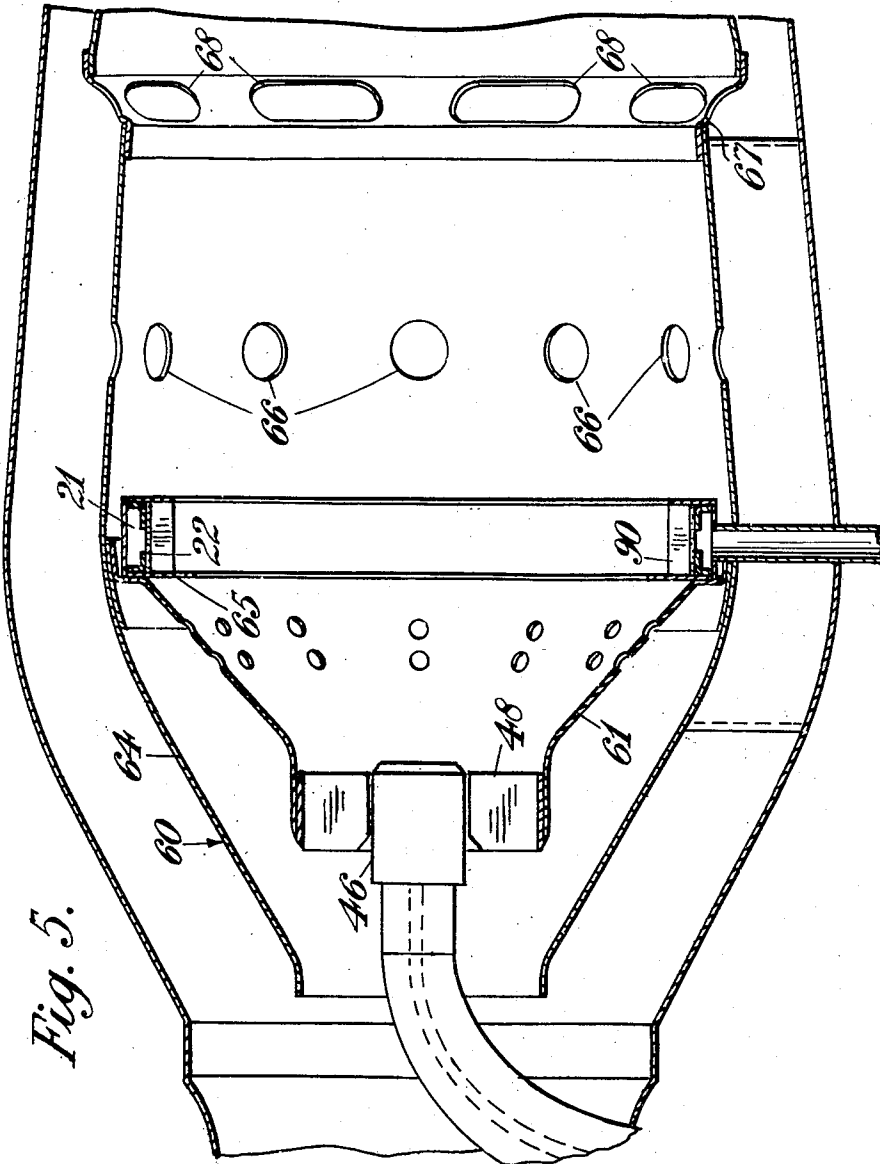


Fig. 5.

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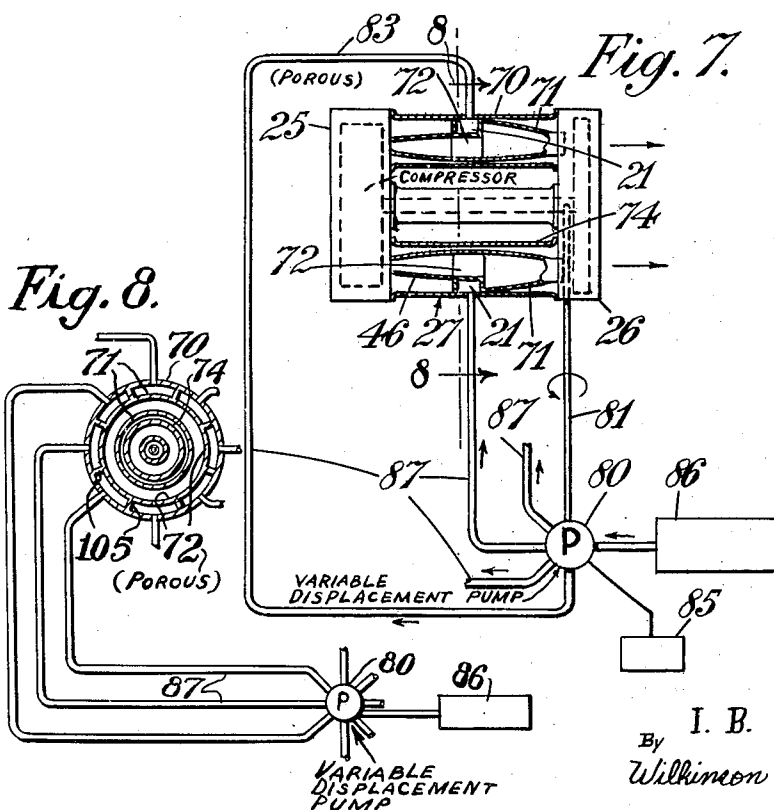
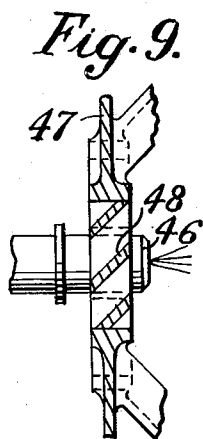
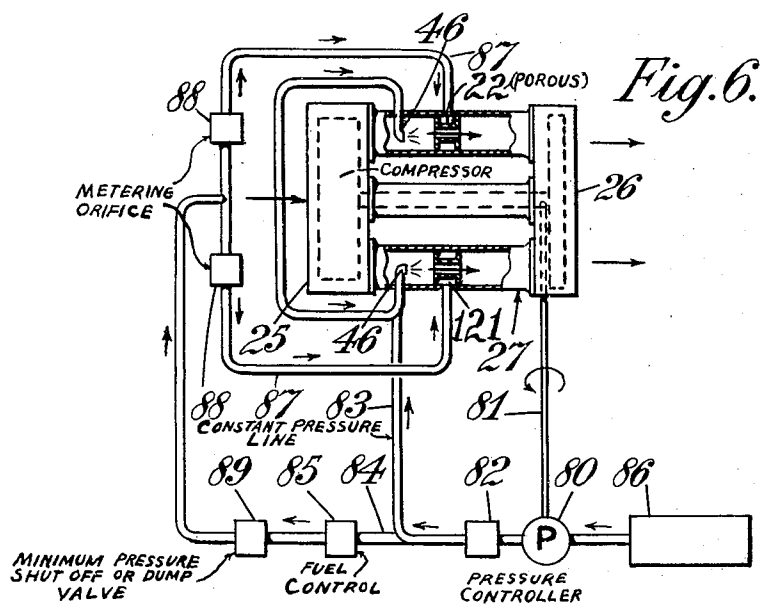
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6 Sheets-Sheet 6



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COMBUSTION CHAMBERS INCLUDING SUDDENLY ENLARGED CHAMBER PORTIONS

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Claims priority, application Great Britain April 3, 1950

11 Claims. (Cl. 60—39.65)

This invention relates to means for burning fluid fuel in a ducted stream of combustion-supporting medium. While not limited thereto, the invention is more particularly concerned with the burning of liquid fuel in a ducted airstream, as for example in a ram-jet engine or in a combustion turbine engine, either between a compressor and a turbine or in a jet pipe as a reheating system. The invention may also be used in the firing of boilers and such like applications.

In known combustion systems of this kind, particularly as used in combustion turbine engines, it is usual for part of the airflow to be separated from the main flow and used for the primary combustion of liquid fuel supplied by a so-called atomizing spray injector into a zone through which the mean velocity is sufficiently below the rate of flame propagation to avoid the flame being blown out. As combustion proceeds, it is furthermore usual to allow additional, secondary, air to mix with the burning gases, and when combustion is substantially complete the remainder of the airflow, amounting, say, to 60% or more of the initial supply, is mixed with the products of combustion.

The reason for this process is that in order to keep the temperature of the heated airflow within the capacity of the materials available for construction of the turbine it is not possible to operate with an overall air/fuel ratio much lower than 60 at full load, rising perhaps to 300 during idling, whereas to obtain a reasonably rapid rate of combustion an air/fuel ratio of the order of 15 is required.

It will be appreciated that with varying rates of initial air and fuel supplies the air/fuel ratio in the combustion zone is bound to vary and to depart from the optimum value, thus giving rise under certain conditions to an increased length of flame. Since it is essential for the highly heated products of combustion to be thoroughly mixed with the diluent air before passing into the turbine, and this is not readily accomplished with the long "solid" type of flame which generally results from the use of an atomizing spray injector, it is clear that a greater length and/or volume of combustion chamber is necessary than would be required if the fuel could be burnt under conditions of greater dispersion.

The object of the present invention is to provide a combustion system wherein the flame is more dispersed over the cross-section of the flow of combustion-supporting medium so that it has a greater ratio of surface area to volume. In this way improved mixing of secondary air with the burning gases can be obtained, thereby shortening the flame, and mixing of the products of combustion with diluent medium is facilitated, thereby further shortening the combustion chamber and substantially reducing the back-pressure of the system, since this latter is produced largely at the mixing stage.

The means according to the invention for burning fluid fuel in a ducted stream of combustion-supporting medium comprise inner ducting spaced from the main duct and defining a path for part of the flow comprising a zone of sudden enlargement wherein turbulent conditions are produced in said stream allowing the maintenance of

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stable combustion, part of the wall of this zone being of porous material and backed by a fuel distribution chamber, and means following said zone for combining the burning mixture or the products of combustion in one or more stages with at least the major part of the remainder of the combustion-supporting medium, the latter constituting diluent or secondary combustion medium or partly diluent and partly secondary combustion medium.

Preferably the inner ducting defines a path for part of the flow comprising at least two sudden enlargements, the first enlargement constituting a primary zone for stable combustion, part of the wall of this zone being of porous material and backed by a fuel distribution chamber, and the following enlargement or enlargements constituting subsequent zones wherein a further stage or stages of stable combustion may take place, with or without admission of secondary combustion-supporting medium, and means are provided following the final combustion zone for combining the products of combustion with at least the major part of the remainder of the combustion-supporting medium.

The use of porous material for parts of combustion chambers which are subject to intense heating has already been proposed, a cooling gas or liquid being caused to percolate through the material towards the hot side so as to carry heat away, and it has also been proposed to obtain cooling of turbine blades and reheating of the working medium between turbine stages by feeding liquid fuel through turbine blades having porous surfaces. The present invention, on the contrary, is not concerned with the cooling of highly heated parts, and although such cooling is consequential to the means employed, it is of no functional significance since, except in certain applications, the parts are not subjected to intense heating and would not in any case attain temperatures outside the capacities of available materials.

In the preferred arrangement the inner ducting of the system according to the invention defines a path of annular section to and through the combustion zones, and diluent combustion-supporting medium passes through the interior and over the outside of the annular path. In this way an annular flame of large surface in relation to its volume is obtained so that secondary medium can be readily mixed with the body of burning gas, thereby promoting its rapid combustion, and the thin annular stream of products of combustion is easily dispersed into the diluent medium, or vice versa.

According to a further feature of the invention the porous part of the wall of the primary combustion zone is a short cylindrical portion adjacent a shoulder constituting the first sudden enlargement. Subsequent enlargements may be formed by similar shoulders or by deflectors or baffles which form a constriction of the combustion path followed by a sudden enlargement.

A combustion chamber wherein, as already described, the inner ducting defines a path of annular section to and through the combustion zones may, according to a further feature of the invention, also comprise a flame tube, including a spray injector for liquid fuel, arranged within the inner ducting and spaced from it by a passage for diluent medium. With such an arrangement the two fuel admission means may be used concurrently for the same or different fuels, or one may be used for starting and running at low powers and be supplemented or replaced by the other at higher powers. Instead of the two fuel admission means supplying fuel into separate streams of combustion-supporting medium they may supply into the same stream.

Several practical embodiments of the invention will now be described, by way of example, with reference to the accompanying drawings whereof:

Figure 1 is a sectional elevation of a combustion chamber, in accordance with the invention, for use in a ram-jet device,

Figures 2 and 3 are sectional elevations illustrating two constructions of a dispersed combustion chamber for use in a combustion turbine engine,

Figure 4 is a view similar to Figure 2 and showing a combustion chamber in accordance with this invention which incorporates a known type of flame tube mounted within the chamber,

Figure 5 is a sectional elevation showing a part of another construction of combustion chamber and a known form of flame tube mounted therein,

Figure 6 is a diagrammatic illustration of a gas turbine engine incorporating dispersed combustion chambers in accordance with the invention and of means for supplying fuel thereto,

Figure 7 is a view similar to Figure 6 illustrating the application of the invention to an annular combustion chamber for a gas turbine engine,

Figure 8 is a diagrammatic representation of the dispersed combustion chamber shown in Figure 7 and of the connections to the various chambers thereof on the plane 8—8 of Figure 7, and

Figure 9 is a view along line 9—9 in Figure 4.

Referring to Figure 1: the combustion system for the ram-jet device is contained in a cylindrical length of duct 10 and comprises internal ducting made up substantially of three portions, the innermost of which is a plain cylinder 11 of diameter of about half that of the main duct 10 and length about equal to the diameter of the main duct. From a position near the upstream end 12 of portion 11, and annularly spaced outwardly from it by a small gap 13, the second portion 14 extends upstream in a slightly flaring manner for a distance approximately equal to the diameter of the main duct. The third portion 15 of the inner ducting extends downstream from the upstream end 16 of portion 14, to which it is attached to form a circular knife edge 17, at first in a slightly divergent form and then parallel to (as at 18) and spaced away from the main duct and it finishes somewhat short of the downstream end 19 of portion 11. The portions 15 and 14 are carried from the ducting 10 by three angularly spaced vanes 112, and the portion 11 is carried from the portion 15 by vanes 90 later described. From the downstream end of portion 14 a flat annular ring 20 extends radially outwards towards portion 15, and in the downstream corner formed between these two members is arranged a ring shaped fuel distribution chamber 21 having its inner cylindrical surface 22 made from porous sintered bronze material, the radial thickness of the chamber being such that it occupies only a part of the space between portions 14 and 15 at this position. Fuel is supplied to the chamber 21 through a pipe 113.

Air flowing through the annular gap 13 comes to a sudden enlargement at the downstream end of portion 14 and a turbulent eddy is set up behind the flat annular ring 20 and over the porous surface 22. When fuel is caused to flow through the latter and ignited a stable flame can be maintained in this zone. About halfway between the chamber 21 and end 19 of portion 11 an annular baffle 23 projects from the interior of the portion 15 partway towards portion 11 and provides (on its downstream side) a second zone of sudden enlargement wherein a further stage of combustion may proceed in a stable manner.

It will thus be seen that the internal ducting defines a path for part of the airflow comprising two sudden enlargements 20 and 23 and from which, according to the overall air-fuel ratio at which the device is being run, an annular stream of products of combustion or burning gas leaves and is combined with a central core stream of diluent or secondary air and an outer annular stream of diluent or secondary air passing between the main duct 10 and portion 15 of the inner ducting.

Another form of combustion chamber according to the invention is shown in Figure 2 and is suitable for use as one of a number of dispersed combustion chambers in a combustion turbine engine as shown diagrammatically in Figure 6. Referring thereto the engine comprises a compressor 25, a gas turbine 26 to drive the compressor and a plurality of dispersed combustion chambers 27 to which compressor 25 delivers air and in which fuel is burnt, the hot air and gases from the chambers passing to the turbine to drive it. In Figure 6 the combustion chambers, which are shown only in diagrammatic manner, have an additional fuel supply as required for the constructions shown in Figures 4 and 5 and presently described, but in other respects the arrangement is applicable to Figures 2 and 3.

Referring to Figure 2: the combustion chamber comprises a main duct and internal ducting similar to that described above but in which portion 15 ends a short distance beyond the ring-shaped fuel distribution chamber 21 while a fourth portion of ducting 30 somewhat larger than part 18 overlaps the latter somewhat, and is connected to it in a manner which provides entry openings 31 for secondary air. The portion 30 extends downstream to the end of the combustion chamber, at which point a baffle 32 extending inwardly from the main duct 10 restricts the passage between these two ducts, the baffle ending short of the ducting 30 and leaving a small annular gap 100 between the inner periphery of the baffle and the outer surface of the ducting 30. Somewhat downstream of air gap 31 a flame deflector or baffle 33 extends inwardly from portion 30 and in section is approximately quarter of a circle, so that the secondary air entering through gap 31 is deflected towards the center of the combustion chamber. Duct 30 is provided with a ring of apertures, at 34, through which diluent air passing around the outside of the internal duct system may pass and mix with the products of combustion and the diluent air flowing through the center of the system.

The innermost portion of internal ducting 35, which in the previously described construction was cylindrical and comparatively short (see part 11 of Figure 1) extends in the example now being described with reference to Figure 2 upstream to a point in line with edge 17 and tapers to a somewhat smaller diameter at its downstream end, which is in line with the downstream end of portion 15 (i. e. air gap 31). In the downstream end of portion 35 of the ducting is mounted by tabs 114 a flaring "trumpet" shaped deflector 36 which divides off the outer annular layer of air and deflects it as secondary air into the combustion zone in opposition to the stream of secondary air flowing inwardly through the outer gap. In this arrangement the first sudden enlargement occurs at the square shoulder 20 at the downstream end of portion 14 the porous burner wall 22 being immediately adjacent this shoulder and at a larger radius. The downstream side 37 of the fuel distribution chamber 21 constitutes a second enlargement while the deflecting baffle 33 produces on its downstream side a further turbulent zone of sudden enlargement wherein a further stage of combustion may proceed in a stable manner.

By way of example, the air supplied to the combustion chamber may be divided up approximately in the following proportions: 14% through duct 35, this flow being divided at the end of the duct by the "trumpet" shaped deflector 36 so that 5% is secondary air going through gap 38 and 9% diluent air, 17.5% between ducts 14 and 35 into the primary combustion zone, 68.5% round the outside of duct 15, of which 9 parts pass through the annular gap 31 as secondary air, 52.5 parts pass through the apertures 34 as diluent air, and 7 parts pass on along the outside of duct 30 and between it and baffle 32 through annular gap 100 as cooling air.

With this distribution of air the combustion chamber is designed to operate with an overall air/fuel ratio of 60:1, the ratio in the primary combustion zone being

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10.5:1, weakening off to 19:1 at the end of this zone where the secondary air is admitted.

The portions 15 and 30 are carried from the ducting 10 by three angularly spaced vanes 115, and the portion 35 is carried from the portion 14 by vanes 116 and 90.

In the modification of the arrangement of Figure 2 shown in Figure 3 a larger proportion of air is designed to pass through the innermost portion of internal ducting (indicated by the reference 40) and the "trumpet" shaped deflector 36 has an inwardly tapering frusto-conical portion 41 extending about two diameters downstream from its throat. The secondary air gaps 31 are arranged somewhat downstream of secondary air gaps 138 formed between the deflector 36 and the portion 40, and a ring of apertures 42 is provided in a short portion 43 of the duct 30 which flares conically outwards in the direction of airflow. The outer shell or main duct 10 of this combustion chamber swells outwardly from its upstream end and then inwardly in a "streamline" manner, and the internal ducting is arranged to conform generally to this curvature. The portion 30 is carried from the portion 15 as previously described, and the portion 15 is supported from the ducting 10 by three angularly spaced vanes 117, and the portion 40 is carried from the portion 14 by vanes 120, the portion 40 carrying the deflector 36 and the portion 41.

In a combustion chamber of the general arrangement just described portion 40 of the internal ducting, and the "trumpet" shaped deflector 36 and its extension 41 forming an approximate continuation thereof (see Figure 4), may be made sufficiently large in diameter to house a flame tube 45 comprising a spray type fuel injector 46 (see also Figure 9). Such a flame tube may for example comprise a conical or hemispherical upstream end 47 provided at its center with the spray injector surrounded by a primary air admission opening in which are mounted guide vanes 48 shaped as shown in Figure 9 to produce a swirling motion of the inflowing air. The flame tube tapers downstream from the conical end and is provided with rings of apertures 101, 102, 103 of progressively increasing size for the admission of secondary air. For a length of about three quarters of a diameter from its downstream end the flame tube has an external jacket 49 surrounding it with a small gap 50 for cooling air, the upstream end of this jacket being connected by a frusto-conical portion 51 with the downstream end of the extension 41. The frusto conical portion is provided with apertures 52 for the passage of diluent air. The wall of the flame tube may also extend upstream past the conical end (as at 53) to a position in line with edge 17 and the upstream end of portion 40, the relative diameters of all these ducts at this point being selected so as to meter desired proportions of the airflow into the different channels.

A combustion chamber as described with reference to Figure 4 may be used in several different ways, for example both burners may be run concurrently, with the result that the great dispersion of the combustion zones makes for rapid and efficient mixing of the products of combustion with the diluent air and enables the size of the combustion chamber to be kept down to a minimum. If desired, the porous burner may be shut down during running at low power outputs. Alternatively, the two burners may be used for different fuels, for example liquid and gaseous fuels, or the spray burner may be used for rapid starting and warming up.

Figure 5 illustrates another construction of dispersed combustion chamber for a gas turbine engine according to this invention and incorporating a known form of flame tube. The latter, which is indicated by the reference numeral 60, comprises a conical upstream end 61 provided at its center with a spray injector 46 surrounded by a primary air admission opening in which are mounted guide vanes 48 shaped as shown in Figure 9 to produce

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a swirling motion of the inflowing air, part of the outer wall 64 of the flame tube, downstream of a shoulder or baffle 65, carrying a fuel distribution chamber 21 having a porous inner surface 22. Downstream of chamber 21 the wall 64 of the flame tube is provided with openings 66 for the admission of secondary air, and beyond this again the wall is stepped abruptly outwardly, at 67, with openings 68 for the admission of diluent air. With such an arrangement the spray injector 46 may be of comparatively small capacity so that it operates as a preheating or slow running pilot system, while the main fuel supply is through the porous wall 22.

An important application of the invention provides an annular combustion chamber for a combustion turbine as diagrammatically illustrated in Figures 7 and 8. Such a combustion chamber comprises an outer shell 70 and an inner shell 74, both being substantially surfaces of revolution and defining a duct between the compressor 25 and turbine 26, and intermediate ducting 71 spaced from said shells and defining a path for part of the airflow passing between the shells and comprising a sudden enlargement constituting a primary zone for stable combustion, a ring-shaped part 72 of the wall of this zone being of porous material and backed by fuel distribution chamber 21.

Each of the constructions shown in Figures 1, 2 and 3 may be made in the form of a truly annular combustion chamber in which the longitudinal sections, with respect to the direction of airflow, through the annular main duct on either side of the axis are each similar to the single longitudinal section of the approximately cylindrical combustion chamber. Such arrangements provide two ring-shaped porous burners of which both may be used concurrently at the higher loadings and one only, if desired, at the lower loadings, or the two burners may be used for different fuels. In an annular combustion chamber of this kind the porous burners are preferably made in segments with separate fuel distribution chambers, and the fuel supply system may include means for supplying individually metered quantities of fuel to the separate fuel chambers.

The porous material used for the burner wall must of course be unaffected by the fuel used and resistant to the maximum temperature likely to occur. A suitable material for this purpose is readily available commercially and is composed of compressed and sintered granules of bronze or other metal. Such materials are graded according to the size of the metal granules, and the flow of fuel through them for a given supply pressure varies according to the grade. The law connecting the supply pressure and the fuel flow also varies according to the grade but does not depart greatly from direct proportionality in the useful range. By suitable choice of material or by the use of two materials of different grades in combination it is possible to obtain a substantially linear law which is sufficiently stable to allow the fuel supply to be controlled by varying the pressure of the fuel in relation to the static pressure in the primary combustion zone. An arrangement of this kind is more particularly useful for ram-jet devices where simplicity is of more importance than accuracy of fuel control.

Such fuel supply pressures are very low in comparison with those necessary for the operation of the conventional spray injectors, being only of the order of 2 to 25 pounds per square inch.

In an alternative fuel supply system the metering of the fuel may be effected by means of a fixed area orifice in the fuel line from a supply pump to the fuel distribution chamber of the burner. In this system a sufficiently large drop of pressure is provided at the metering orifice to make such pressure differences as occur in the passage of the fuel through the porous material unimportant.

A fuel supply system of this kind suitable for use with a number of dispersed combustion chambers each com-

prising a spray injector acting as a pilot burner and a porous wall as a main burner is illustrated schematically in Figure 6. In this figure a fuel pump 80 is driven from the turbine 26 by a shaft 81 and is capable, in conjunction with a pressure controller 82, of maintaining a sufficiently high constant output pressure, say 200 pounds per square inch, to supply the pilot spray injectors 46 through a pipe 83 from a tank 86, while a branch supply passes from the pump through a pipe 84 and a throttle control unit 85 to distribution pipes 87 leading to the porous burners 121 of the individual combustion chambers through metering orifices 88. To prevent dribbling from the porous burners when the engine is idling, a minimum pressure shut-off valve may be provided as indicated at 89, and may operate on the well known "dump valve" principle to drain fuel from the burner. In cases in which the spray injectors are required to pass variable quantities of fuel in approximately constant ratio with the porous burners the throttle control unit may replace or follow immediately after the pressure controller 82.

According to a further alternative method shown in Figures 7 and 8 as applied to an annular combustion chamber 70, 74 provided with a porous burner divided into a number of separate segments by partitions 105, a fuel pump 80 of the positive displacement variable output type having a working chamber for each segment is connected by pipes 87 to the various segments and is controlled as to output by a control unit 85.

Preferably the fuel is supplied to the distribution chamber in liquid form and does not evaporate until it has passed through, or nearly through the porous material, but it is also possible to use gaseous fuel or to vaporize liquid fuel in the distribution chamber, or in a vaporizer before it reaches such chamber, so that it passes through the porous material substantially in the vapor state.

Until the burners are thoroughly warmed up there is a tendency for liquid fuel passing through to the surface of the porous material to run towards the lower half when the combustion chamber is arranged horizontally, and to minimize this, short radial vanes such as 90 in Figures 1, 2 and 5 lying approximately in the direction of the airflow may be secured to the surface of the burner, or alternatively, other suitable means for opposing the downward flow of such fuel as may be provided. In cases in which the fuel is vaporized before it reaches the combustion zone side of the porous material, or in which normally gaseous fuel is used, such means will not usually be necessary.

I claim:

1. In a combustion system for burning fluid fuel in a gaseous stream of combustion-supporting medium, ducting immersed in the said stream and comprising first and second duct portions both extending generally in the direction of flow of said stream and enclosing between them an annular passage open at both ends, an annular ring portion extending radially from the downstream end of said second duct portion and away from said first duct portion so as to form a sudden enlargement of said annular passage, an annular fuel supply chamber comprising a wall of porous material adjoining that edge of said annular ring which is the more remote from said first duct portion and extending downstream from said edge, a third duct portion extending downstream from said annular fuel supply chamber, and a flame deflector spaced downstream from said fuel supply chamber and extending part way across said passage.

2. Ducting as claimed in claim 1 wherein a fourth duct portion extends downstream from and forms substantially a continuation of said third duct portion and carries said flame deflector.

3. Ducting as claimed in claim 1 further comprising a deflector at the downstream end of said first duct por-

tion for deflecting additional air towards said flame deflector.

4. Ducting as claimed in claim 3 wherein said additional air deflector is provided with a frusto-conical portion extending downstream of the additional air deflector throat.

5. Ducting as claimed in claim 1 wherein a further duct portion forms an approximate continuation of the first duct portion and a flame tube, comprising a spray injector for liquid fuel, lies within said duct portions.

6. Ducting as claimed in claim 5 wherein means are provided for supplying fuel to said injector and wall, said injector and wall being effective for supplying fuel into the stream of combustion-supporting medium.

7. Ducting as claimed in claim 1 including a further duct portion forming a continuation of said first duct portion, a flame tube and a spray injector for liquid fuel lying within said duct portions and a jacket surrounding the downstream end of said flame tube, said further duct portion terminating in a frusto-conical portion connected to the upstream end of said jacket, said frusto-conical portion being provided with apertures for the passage of diluent air.

8. A combustion chamber for a combustion turbine for burning fluid fuel in a combustion supporting medium, said combustion chamber comprising a main duct, and a coaxial inner ducting within said main duct comprising an inner tubular portion, a second tubular portion surrounding said inner tubular portion and forming with said inner portion an annular passage for a portion of said combustion supporting medium, an annular ring extending radially outwards from the downstream end of said second portion and forming a sudden enlargement of said annular passage, an annular fuel supply chamber having a cylindrical wall of porous material disposed on the downstream side of said annular ring and forming a continuation of the outer wall of said passage, a third tubular portion surrounding said second tubular portion and fuel supply chamber and extending rearwardly therefrom, and a fourth tubular portion of larger diameter than said third tubular portion extending downstream to the rearward end of the main duct, said third and fourth portions having overlapping ends between which a gap is formed for the admission of secondary air to said fourth portion, and said fourth portion containing an inwardly projecting flame deflector.

9. A combustion chamber as claimed in claim 8, wherein the fourth tubular portion is formed with a part of short axial extent which flares conically outwards in the direction of air flow and has a ring of apertures for the passage of diluent air.

10. A combustion chamber as claimed in claim 8 including a trumpet-shaped deflector at the downstream end of the inner tubular portion for deflecting additional air towards said flame deflector.

11. A combustion chamber as claimed in claim 8 including a trumpet-shaped deflector at the downstream end of the inner tubular portion for deflecting additional air towards said flame deflector, said trumpet-shaped deflector being provided with a frusto-conical portion extending downstream of the deflector throat.

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