

- [54] **SELF-STABILIZING PRESSURE COMPENSATED INJECTOR**
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- [51] Int. Cl. **F02g 1/00**
- [58] Field of Search 60/39.74, 39.23, 60/258, 39.65; 123/119 R; 137/81.5

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[57] **ABSTRACT**
 A construction for stabilizing pressure conditions in a

combustion chamber, in flow passages, or the like, utilizing fluid amplifier principles to achieve the desired stabilization. The passages carrying fuel or oxidizer, or both types of passages, are formed with diverging outlet portions and these outlet portions are provided with auxiliary passages located so as to respond to abnormal local pressure conditions and to control the flow of fluid through said outlet portions in a manner to compensate for the abnormal local pressure conditions. In one form, the auxiliary passages are exposed to the interior of a combustion chamber at points spaced from the outlet ports and sense abnormal local pressure conditions in the regions of the ports, operating as fluid amplifiers to produce compensating flow conditions in the fluid traversing the diverging passages. In another form, the auxiliary passages are in the walls of a burner, by-passing parts of the main diverging outlet passage portions and acting to oscillate the outlet streams between the outlet passage portions, greatly increasing the fuel surface area exposed to the oxidant, creating substantial turbulence, and, thereby improving combustion efficiency and reducing pollution of the surrounding environment.

17 Claims, 13 Drawing Figures

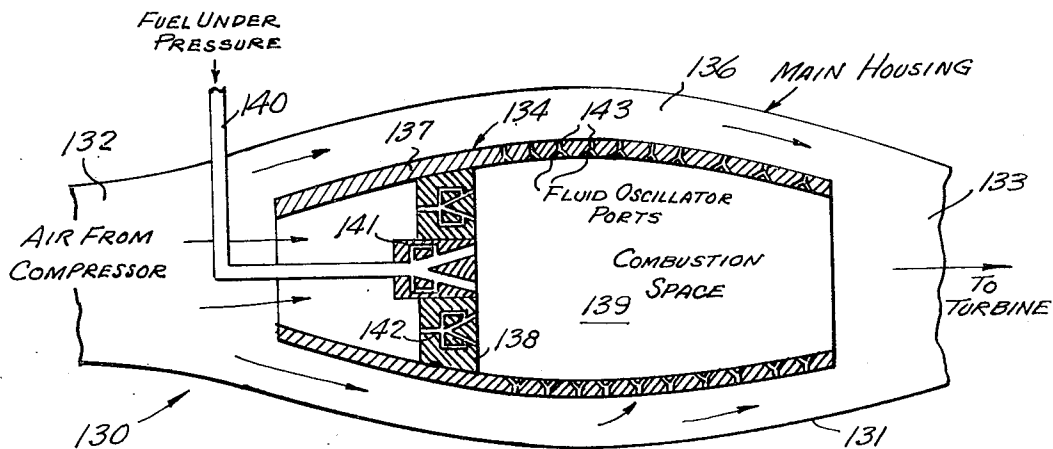


FIG. 1.

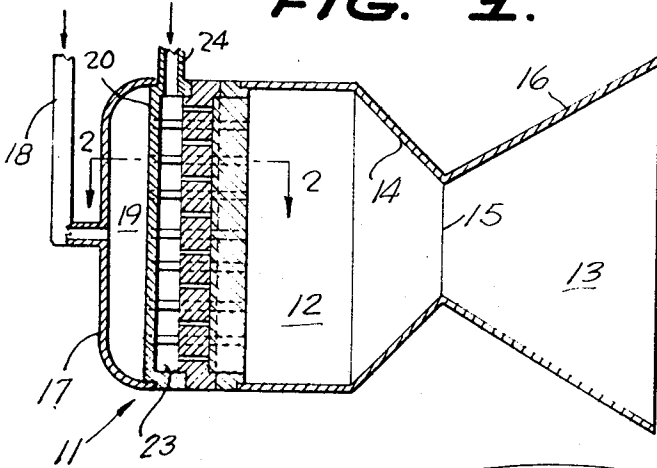


FIG. 2.

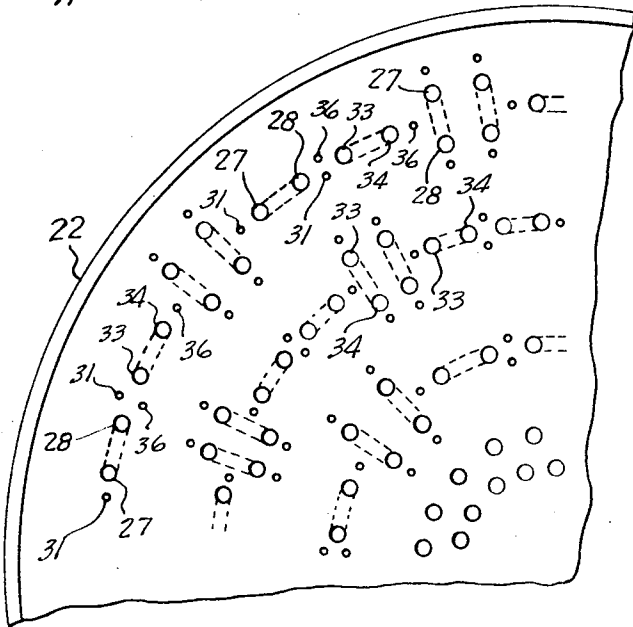
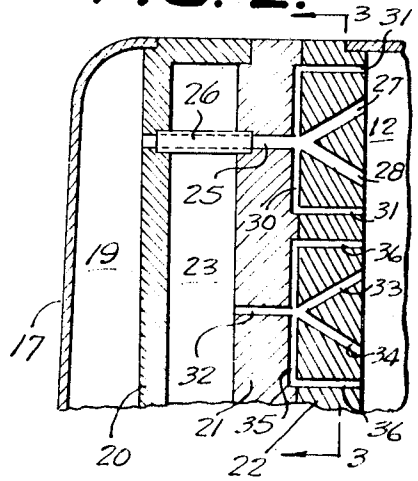


FIG. 3.

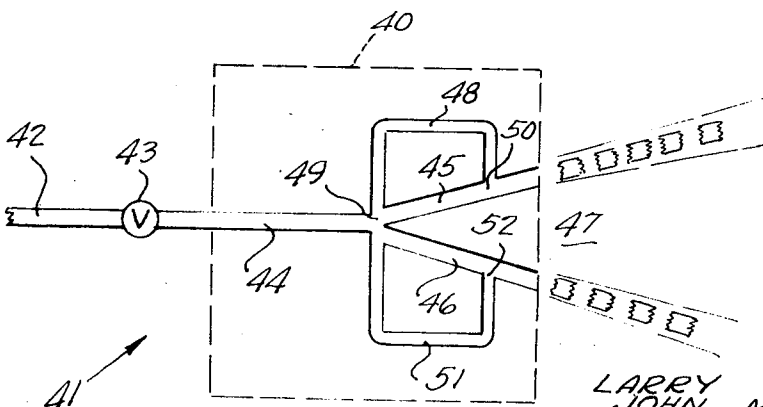


FIG. 4.

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FIG. 5.

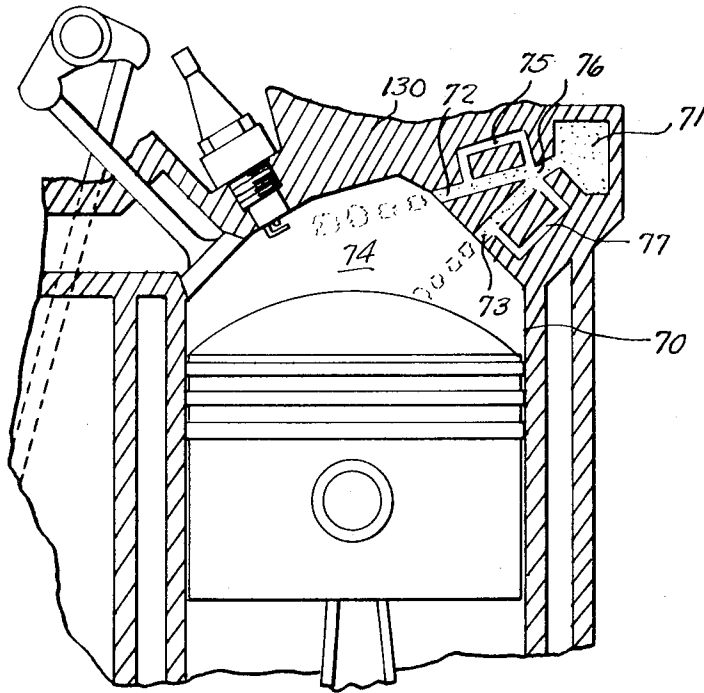


FIG. 6.

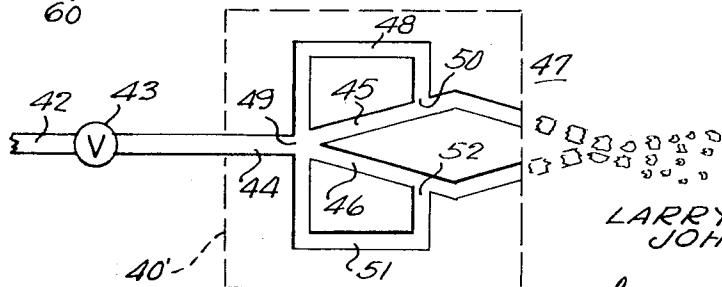
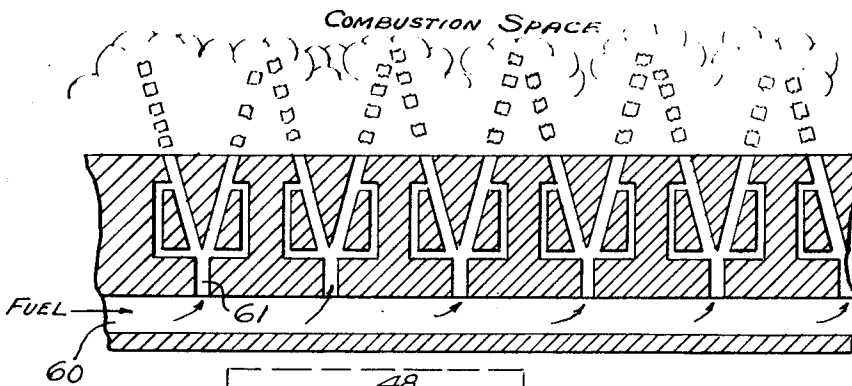


FIG. 10.

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FIG. 11.

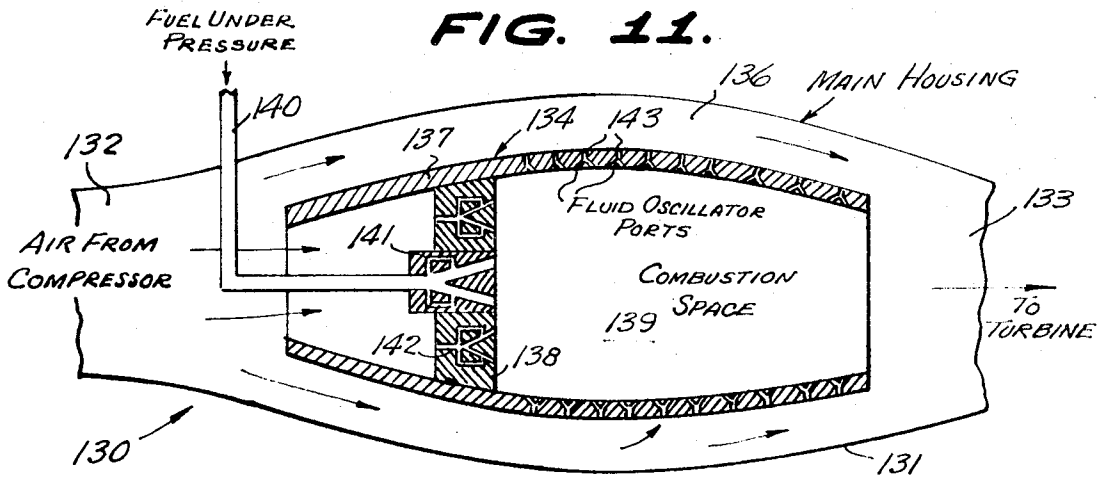


FIG. 12.

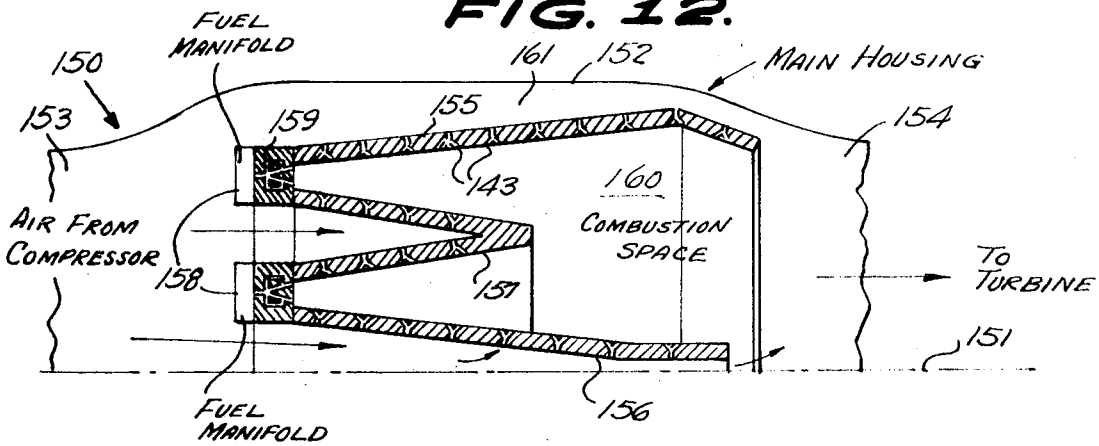
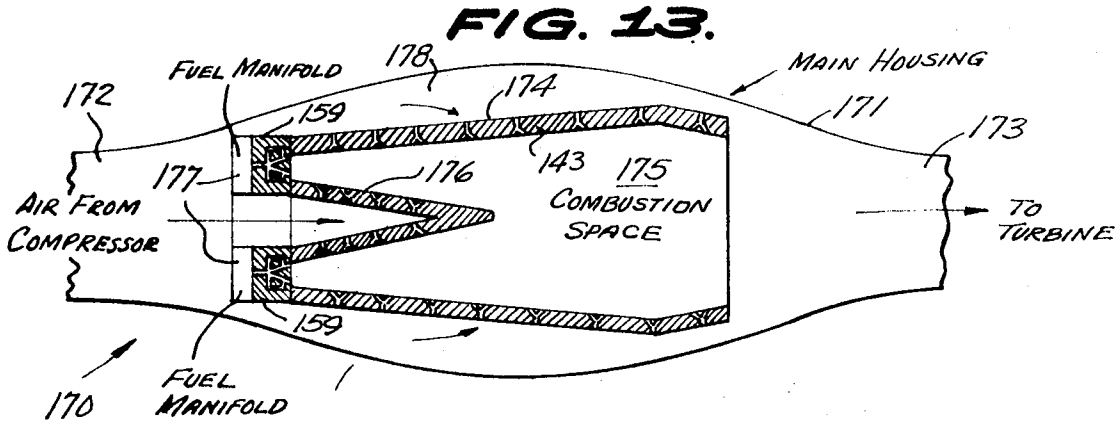


FIG. 13.



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SELF-STABILIZING PRESSURE COMPENSATED INJECTOR

This invention relates to means for stabilizing pressure conditions in combustion chambers, flow passages, or the like, and more particularly to pressure-stabilizing devices employing fluid amplifier principles.

The main object of the invention is to provide a novel and improved structure for stabilizing pressure conditions in a combustion chamber or similar enclosure carrying fluid to prevent instability of pressure in the combustion chamber or enclosure and to thereby prevent rough operation of the associated device or damage or destruction thereof, the improved pressure-stabilizing means involving relatively simple structural components and acting to efficiently sense and to eliminate abnormal local pressure conditions in the combustion chamber or associated flow passage and responding in a manner to quickly and efficiently compensate for the abnormal local pressure conditions.

A further object of the invention is to provide an improved structural arrangement for stabilizing pressure conditions in a combustion chamber, flow passage, or the like, said arrangement operating on the principles employed in fluid amplifiers to detect abnormal local pressure conditions and to react thereto in a manner to dissipate such abnormal conditions, the arrangement producing good combustion efficiency, when employed in a combustion chamber, preventing the development of undesirable or destructive pressure waves in the chamber, and acting to redistribute fluids in the chamber to break up a pressure wave.

A still further object of the invention is to provide an improved means for stabilizing pressure conditions in combustion chambers, flow passages, or similar enclosures through which fluid passes or in which fluid is admitted for combustion, the stabilizing means involving no moving parts, being highly sensitive to the presence of abnormal local pressure conditions in the associated chamber or enclosure, and providing a quick compensating action which automatically redistributes the fluid in such a manner as to remove the abnormal pressure condition.

A still further object of the invention is to provide an improved fluid amplifier device for facilitating combustion in a fuel burner, the device operating to oscillate the stream of fuel entering the combustion chamber of an associated burner assembly in a manner to greatly increase the available fuel surface area exposed to the oxidant combining with the fuel in the process of combustion, whereby the combustion is accomplished very rapidly and with high efficiency and wherein the fuel is mixed into the oxidizer rather than the oxidizer being mixed into the fuel, as in conventional devices, the arrangement thus providing high economy in the utilization of fuel as well as greatly improved stability of operation.

A still further object of the invention is to provide an improved fluid amplifier device for facilitating combustion in a fuel burner in an efficient manner so as to reduce the amount of condensed carbon and incomplete products of combustion, thereby reducing pollution of the surrounding environment and providing a safety benefit.

Further objects and advantages of the invention will become apparent from the following description and claims, and from the accompanying drawings, wherein:

FIG. 1 is a longitudinal vertical cross-sectional view taken through the combustion chamber and thrust chamber assembly of a pressure-fed or pump-fed rocket engine employing improved means for stabilizing pressure conditions in the combustion chamber in accordance with the present invention.

FIG. 2 is an enlarged fragmentary horizontal cross-sectional view taken substantially on the line 2—2 of FIG. 1.

FIG. 3 is a fragmentary vertical cross-sectional view taken substantially on the line 3—3 of FIG. 2.

FIG. 4 is a somewhat diagrammatic view of an improved fluid stream-oscillating burner constructed in accordance with the present invention and employing the fluid amplifier principles of the invention.

FIG. 5 is a fragmentary vertical cross-sectional view taken through the upper portion of an internal combustion engine cylinder provided with turbulence generating means according to the present invention employed between the fuel supply manifold and the combustion chamber portion of the cylinder.

FIG. 6 is a fragmentary cross-sectional view taken through the wall of a typical multi-unit burner assembly employing gas stream-oscillation means similar to that shown in FIG. 4 and employing fluid amplifier principles according to the present invention.

FIG. 7 is a diagrammatic cross-sectional view taken through a typical steam or air atomization burner employing fluid amplifier principles according to the present invention.

FIG. 8 is a diagrammatic cross-sectional view of another form of a typical steam or air atomization burner employing fluid amplifier principles according to the present invention, and representing a modification of the structure of FIG. 7.

FIG. 9 is a generally diagrammatic cross-sectional view showing another typical form of a fuel burner employing fluid amplifier principles according to the present invention and including an aspirated or injected primary air supply means.

FIG. 10 is a diagrammatic view similar to FIG. 4 but showing a modified form of fluid stream-oscillating burner according to the present invention, designed to produce increased turbulence.

FIGS. 11, 12 and 13 are diagrammatic longitudinal vertical cross-sectional views showing the application of fluid amplifier injectors of the present invention to jet engines.

In explaining the theory of operation of the present invention, it will be useful first to consider typical devices to which the invention is applicable. One of such devices is a rocket engine.

A typical rocket engine operating cycle is as follows: If the engine is pump-fed, the oxidizer and fuel from the propellant tanks enter the low pressure side of their respective turbo pumps. The turbo pumps can be either of the axial or the centrifugal type, and are driven by a hot gas multi-stage turbine. The hot gases are produced by a gas generator which is essentially a small combustion chamber supplied by propellants tapped off either side of the high pressure turbo pump discharge. Alternatively, the turbine may be driven using hot gases tapped off directly from the main combustion chamber. The turbo pumps supply propellants at high pressure to the main combustion chamber. Alternately, the propellants may be supplied using only the propellant tank ullage pressure and acceleration head instead

of a turbo pump. In any case, the fuel and oxidizer are kept physically separated prior to entering the main chamber by the use of appropriate manifolds. Before entering the combustion chamber, the propellants are fed through an essential hardware item known as the injector. The injector is simply a structure which regulates and controls the flow of propellants. This is accomplished normally by the use of a large number of small flow passageways located within the injector. The use of small passageways produces a fine spray pattern and therefore provides good combustion efficiency. In addition, the flow passages can be oriented so as to impinge streams of oxidizer and fuel upon one another in various patterns to further aid in breaking up the propellant streams into small droplets. In theory, a rocket engine main combustion chamber would operate normally and safely using a straightforward injector design. This, however, is not the case. The injector, rather than being a simple slab of steel filled with holes, is the most sensitive and critical part of a rocket engine. This is because the injector almost exclusively determines whether or not the combustion chamber operates under stable conditions. The essential ingredients for the existence of combustion instability is organization of related combustion and thermo-dynamic processes. For example, one predominant mode of instability consists of a pressure wave bouncing back and forth across the combustion chamber, reflected off the interior chamber walls in much the same way an echo is reflected off a flat surface. The pressure wave becomes harmful only when an energy source is available at the proper time to sustain and intensify the wave. As a mild pressure wave propagates through the unburned propellant spray, the local increase in pressure along the wave causes a local increase in the burning rate. The increase in burning rate is delayed by a short period of time, governed by the local thermo-dynamic condition and the specific chemical reactions that are involved. All chemical reactions require a finite time to release energy after ignition. The time delay allows a zone of high energy release to form behind the original pressure wave. The pressure wave therefore increases in velocity and intensity, which in turn further increases the driving energy force, thereby establishing a "boot strap" type process. The pressure wave quickly builds up to a strong supersonic shock. At this point, the combustion chamber pressure is completely out of control and the rocket engine will be destroyed in rather short order if not shut down by an emergency detection system. The important question to consider therefore is as to how combustion instability can be prevented.

One semi-successful approach has been to attach baffles to the injector face so that the baffles break up oncoming pressure waves. Baffles are combined with a trial-and-error injection hole pattern to attempt to eventually develop a workable design. This approach is time-consuming and expensive.

The most logical and straightforward approach to solving the combustion instability problem is to eliminate the problem source, that is, the pressure wave driving force which derives its energy from the combustion process. Since the energy wave is a local phenomenon, the wave must be destroyed locally. This cannot be accomplished using current injector design techniques, since the spray pattern is fixed and continuously supplies a uniform, constant propellant flow rate into the combustion chamber volume such that the

driving force energy source is always present in the form of unburned propellants. If, however, by some means it is possible to change the propellant spray pattern when a pressure wave starts to build up, then the propellant energy can be used to destroy the pressure wave and thereby prevent its intensification. This is the approach employed by the present invention.

By computing the rate of pressure wave propagation through the unburned propellants and then relating the wave motion to the combustion chamber geometry, it is possible to locate pressure taps in the injector face which sense a local differential pressure within the combustion chamber and then this pressure is used to activate a fluid amplifier device to redistribute the propellants so as to break up the pressure wave. Such a design would make a rocket engine inherently stable.

Referring now to FIGS. 1, 2 and 3, 11 generally designates the combustion chamber and thrust chamber assembly associated with a typical rocket engine. The assembly 11 is provided with improved fluid amplifier injector means according to the present invention, presently to be described.

The assembly 11 comprises the combustion chamber 12 and the thrust chamber 13 connected to the combustion chamber 12 by way of the annular convergent wall 14 leading through the throat portion 15 to the flaring annular wall 16 of the thrust chamber 13.

The assembly 12 is provided with the oxidizer dome 17 adapted to receive suitable oxidizer fluid from an oxidizer supply conduit 18. The oxidizer is supplied under pressure to the conduit 18 from a conventional oxidizer pump or other pressure source, not shown. The oxidizer is delivered into the interior of the dome 17, the interior space of dome 17 being shown at 19. Space 19 is defined between the dome 17 and a transverse partition wall 20. The housing of the chamber 12 includes a pair of transverse plates 21 and 22 secured together and spaced from the partition wall 20, defining a fuel manifold space 23. Fluid fuel material is admitted to the space 23 from a supply conduit 24 connected thereto, as shown in FIG. 1, the fluid fuel material being furnished from a suitable conventional fuel pump or other pressure source, not shown.

As shown in FIG. 2, the transverse plate 21 is formed with a plurality of oxidizer passages 25, connected with the oxidizer space 19 by conduits 26 extending between partition wall 20 and plate 21 and traversing the space 23. The passages 25 communicate with diverging outlet passage portions 27, 28 leading to the combustion chamber 12.

As shown in FIG. 2, the plates 22 and 21 are formed to define auxiliary passages 30 extending transverse to the main oxidizer passages 25 and terminating in detector ports 31, 31 spaced away from and located on opposite sides of the pair of divergent outlet passage portions 27, 28.

In a similar manner, the plate 21 is formed with fuel injection passages 32, each leading to a pair of divergent outlet portions 33 and 34 discharging into the combustion chamber 12. The plates 21 and 22 are formed to define transverse auxiliary passages 35 having end portions 36, 36 exposed to the combustion chamber 12 at locations spaced away from and located on opposite sides of the divergent outlet portions 33, 34. The auxiliary passages 30 and 35 with their end portions 31, 31 and 36, 36 serve to control the main-stream oxidizer injectors, passages 25, and the main-

stream fuel injectors, passages 32, by responding to local abnormal pressure conditions in the combustion chamber 12. The sets of oxidizer ports 27, 28 and their associated fluid pressure amplifier elements 30, 31, 31 and the fuel ports 33, 34 and their associated fluid amplifier elements 35, 36, 36 are distributed over the connected partition plates 21, 22 in any suitable manner, for example, in concentric groups, as shown in FIG. 3, and are oriented in different directions so as to be able to sense pressure waves regardless of the directions in which the waves are traveling.

Under normal operating conditions, the propellants, namely, the oxidizer and the fuel, will randomly flow through either of their associated sets of divergent outlet passage portions 27, 28 and 33, 34, but will not flow through both divergent passages. Thus, the oxidant passing through one of the conduits 26 will normally flow through one of the divergent outlet passage portions 27 or 28. Similarly, fuel flowing through a passage 32 will normally flow through one of the associated divergent outlet passage portions 33 or 34. When a pressure wave travels across the face of the injector plate 22, those switching ports or passages 31 and 36 at or near right angles to the pressure wave are able to sense the wave and automatically provide reactions in their associated passages 30 and 35 which will switch the propellants, changing the flow of the propellants through the divergent outlet passages in a manner to so distribute the propellants in front of the wave as to destroy the wave. For example, assume that fuel is flowing normally through the lower passage 32 and the upper divergent passage portion 33 in FIG. 2. Further assume that a pressure wave develops causing a low pressure condition to be sensed by the lower fluid amplifier detection port 36 in FIG. 2. This low pressure condition is transmitted to the passage 35, thereby inducing a shift of the flow of fuel from the upper outlet passage portion 33 to the lower outlet passage portion 34 which discharges into the region adjacent to the sensed low pressure. The discharge of fuel into this region immediately raises the pressure and thereby eliminates the low pressure condition. The effect is to break up and destroy the incipient pressure wave.

The pressure sensing taps 36 and 31 are located sufficiently far from the propellant injection ports so as to be able to sense the wave early enough for the propellant redistribution to be successful.

FIGS. 1, 2 and 3 are merely representative of one typical arrangement employing fluid amplifier pressure wave detection means in accordance with the present invention. An infinite number of discharge port distribution patterns are possible, all of which could be equally successful. For example, the conventional type of fuel injection ports may be employed in conjunction with oxidizer ports, such as the ports 27, 28, provided with fluid amplifier sensing means 30, 31, 31. Conversely, conventional oxidizer injection ports may be employed in conjunction with fuel injection ports including the discharge portions 33, 34, provided with fluid pressure amplifier wave detection means 35, 36, 36.

Additionally, the fluid pressure wave sensing and dissipating means above described may be employed in conjunction with apparatus using monopropellants instead of bipropellants described in connection with FIGS. 1, 2 and 3. Furthermore, the injector portion of the engine or other device could be of any suitable

shape, for example, could be annular in shape instead of being circular as illustrated in FIGS. 1, 2 and 3.

As above described, the action of the fluid pressure detection means is to perform a switching action in the discharge of the associated fluid in a sense required to compensate for the abnormal pressure conditions sensed in this region. As above explained, when a lower pressure condition is sensed by the lower fluid amplifier sensing port 36 it produces a switching of the fuel from the upper branch 33 to the lower branch 34, causing discharge of fuel into the lower pressure region. Similarly, if the fuel is normally flowing through the lower branch 34, a high pressure sensed by the lower sensing port 36 will switch the fuel to the upper branch 33, reducing the pressure in the sensed region. The overall effect is therefore to damp out or attenuate fluctuations in pressure in the combustion chamber. The stabilizing or damping effect is accomplished by controlling the path of movement of the associated oxidizer or fuel fluid in a manner to provide improved stability of operation of the device. The general concept utilized in the rocket engine combustion chamber and thrust chamber assembly 11 of FIGS. 1, 2 and 3 may be extended so as to be applicable in connection with many other devices, for example, domestic or industrial fuel burners. The general function of a burner is to provide a means of facilitating combustion in order to provide a heat energy source. This heat energy can then be used for anything from a small home heater to a large industrial power plant boiler: From a power mower engine to an aircraft engine. Regardless of the intended use, the design of a burner is always oriented toward achieving the maximum amount of combustion efficiency. This is in contrast to the design objective of a rocket engine where, although efficiency is desirable, the prime criterion is always stability. The main reason for desiring stability in the design of a burner is to insure that the flame will not become extinguished. The problem of combustion instability is not so much a factor in the case of ordinary domestic or industrial burners as in the operation of rocket engines, the main factor in the case of domestic or industrial burners being that of efficiency of combustion.

There is, of course, an upper limit to combustion efficiency for a burner. Complete combustion is theoretically attained when all of the available fuel is completely oxidized. In addition, the ratio of the fuel burned to the amount of oxidizer required for burning directly influences the theoretical combustion temperature. At a unique ratio of fuel to oxidizer, the theoretical combustion temperature is a maximum and occurs for a fuel-oxidizer mixture for which there is exactly the proper amount of oxidizer to react with the available fuel. This mixture ratio which results in maximum temperature is referred to as the "stoichiometric" condition. Stoichiometric combustion is desirable for fuel and oxidizer requirements combined with maximum energy releases, and therefore, maximum efficiency. To achieve complete combustion, it is generally necessary to burn the fuel with an excess amount of oxidizer. This must be done since it is extremely difficult to completely mix the fuel and oxidizers so that a truly complete reaction can occur. Such attempts usually result in a lower than desired temperature, as well as excessive requirements for oxidizer. The problem of attaining maximum efficiency, therefore, reduces to the simple but elusive objective of obtaining maximum effec-

tive mixing. In addition, this mixing of the fuel and the oxidizer should occur at the stoichiometric mixture ratio. Unless these conditions are met, the temperature advantage of stoichiometric burning cannot be realized. A number of burner designs are available for specific applications. Either liquid or gaseous fuels may be employed. The gas burners may operate using either a high or low pressure fuel supply. Liquid fuel burners are categorized into four groups as follows:

- a. Self-atomizing burners.
- b. Air-atomizing burners.
- c. Steam-atomizing burners.
- d. Mechanical-atomizing burners.

The objectives of each of the burner types are the same, that is, to provide maximum fuel atomization over a wide flow rate requirement range, to minimize excess oxidizer requirements and to provide both a cost and maintenance advantage. Self-atomization is accomplished by forcing the liquid fuel under pressure through a restriction which tends to form a spray. This approach is simple but requires a higher than desirable fuel supply pressure, in addition to a large amount of excess oxidizer. Air-atomization is accomplished using the energy of compressed air (oxidizer) to break up the liquid fuel. The method is impractical and is not used except for special applications simply because a compressed air facility is expensive. Also, the air required for atomization is in excess of that needed for efficient combustion. Steam atomization is accomplished using the energy of the steam to break up the liquid fuel. Since the steam is substantially hotter than compressed air and lower in molecular weight, a much smaller amount of steam is required, compared to using air. Also, since only heat is needed for producing steam in contrast to mechanical compression equipment needed for air, the steam atomization approach has a distinct advantage over air atomization. Even so, the steam saps energy from the system for its production and cannot actively participate in the combustion process to produce useful energy. Lastly, mechanical atomization is accomplished using a moving mechanical device to break up the liquid fuel. Either the fuel must be at a sufficiently high pressure to propel the mechanical device, or a separate power supply must be provided. In either case, the mechanical parts reduce the burner reliability and lifetime. Low pressure gas burners are relatively simple and are used for most domestic applications. The gas is delivered through a multi-outlet manifold to aid in mixing the gas and the oxidizer. The air is supplied by natural convection caused by the heat of combustion. Both efficiency and capacity are low.

High pressure gas burners are somewhat more sophisticated than the low pressure type burners and are also more efficient because the gas pressure can be used to provide better gas-air mixing, although some excess air is still required.

Having briefly described the burner designs available in the prior art, it will be now explained how the present invention utilizes a completely new approach to burner design. Reference is therefore now made to FIGS. 4 and 10 which diagrammatically illustrate burners according to the present invention, utilizing a fluid amplifier structure, designated generally at 40 or 40'. The burner assembly, designated generally at 41, typically employs gas fuel, provided from a supply conduit 42 through a gas valve 43 to a conduit or passage 44 leading to a pair of divergent outlet passage portions 45

and 46 discharging into a combustion space 47. As shown in FIG. 4 or 10, the upper passage 45 is provided with a fluid amplifier by-pass passage 48 connecting a region 49 at the forward end of the common junction of the divergent outlet passage portions 45 and 46 to a region 50 spaced a considerable distance along passage portion 45. Similarly, the lower outlet passage portion 46 is provided with a by-pass passage 51 connecting the region 49 to a region 52 located a considerable distance from region 49 in the outlet passage portion 46.

When the gas valve 43 is opened, gas flows into the unit through the passage or conduit 44 and flows through the space 49, entering one or the other of the outlet passage portions 45 or 46. For example, assuming that the gas stream enters the passage 45, the discharge into the space 47 will be through the outlet end of passage 45. Some of the gas is by-passed and fed back from region 50 through passage 48 and is injected into the space 49. This causes the gas stream to flip from passage 45 to passage 46, thus shifting the output of gas from the upper passage of FIG. 4 or 10 to the lower passage discharging into space 47. A similar action occurs by the operation of the by-pass passage 52, returning the gas stream to the upper passage 45 in FIG. 4 or 10. Therefore, the output stream oscillates between outlet passage portions 45 and 46 at a relatively high frequency, for example, at a frequency as high as 1,000 cycles per second. The oscillation of the gas stream between the outlet passage portions 45 and 46 produces a many-fold increase in available fuel surface area exposed to the air, as compared to that obtained by conventional designs. Since the burning rate is directly related to the surface area, the combustion is accomplished more rapidly and therefore more efficiently than in such previous designs. Also, the fluid amplifier type burner 41 has a unique feature not found in any of the other burner types. This feature is that the fuel is mixed into the oxidizer, as opposed to mixing the oxidizer into the fuel. The burner can use liquid for fuel instead of gas fuel, if desired. Fuel supply pressure can be either high or low. Since no moving parts are needed, the lifetime of the burner is indefinite. Also, since compressed air, steam boilers, power supplies, or other elaborate equipment is not required, the cost of the installation is comparatively low.

There are many potential applications for which burners of the type shown diagrammatically in FIG. 4 or 10 may be employed. For example, such burners can be employed in domestic appliances such as furnaces, refrigerators, clothes dryers, kitchen ranges, air conditioning units and water heaters. Also, this type of burner may be employed in large industrial applications, for example, in devices employing multiple burners, for example, a multiple-burner arrangement such as that illustrated diagrammatically in FIG. 6.

Thus, as shown in FIG. 6, the burner assembly may comprise a single fuel supply manifold 60 feeding a plurality of successive fluid amplifier burner units, each comprising a main supply inlet passage 61 provided with divergent outlet passage portions, said passage portions being provided with respective fluid amplifier by-pass passages. This produces an oscillatory effect described above in connection with the single unit illustrated in FIG. 4 or 10.

FIG. 5 diagrammatically illustrates another possible application of the improved oscillating burner arrangement of FIG. 4 or 10 employed in the fuel mixture sup-

ply system associated with the cylinder 70 of an internal combustion engine. Thus, the gas-air supply manifold 71 communicates with the divergent outlet passage portions 72 and 73 which discharge into the combustion space 74 of the cylinder. The passage portion 72 is provided with a fluid amplifier by-pass passage 75 connecting the junction space 76 with a region spaced a substantial distance along passage portion 72. Similarly, a fluid amplifier by-pass passage 77 connects the space 76 to a region spaced a substantial distance along the other passage portion 73. The arrangement shown in FIG. 5 provides an oscillating action similar to that described in connection with FIG. 4 or 10, and thereby provides greatly improved efficiency of combustion of fuel in the combustion space 74 of cylinder 70.

FIG. 7 illustrates another typical application using the fluid amplifier principle employed in connection with FIGS. 4, 10, 5 and 6. Thus, in FIG. 7 air or steam is admitted into a burner 80 through a conduit 81 located coaxially in a chamber 82 through which fuel oil is supplied, leading to a junction space 83 from which the divergent outward passage portions 84 and 85 extend, discharging into a combustion chamber 86. It will be seen from FIG. 7 that mixture of the air or steam with the fuel oil takes place essentially in the junction space 83. The mixture then flows either through passage 84, or 85, toward the combustion chamber 86.

Passage 84 is provided with by-pass fluid amplifier passage 87 which connects space 83 to a region 88 located a substantial distance along passage 84, and similarly, a fluid amplifier by-pass passage 89 connects junction region 83 to a region 90 located a substantial distance along the outward passage portion 85. The burner device of FIG. 7 operates in a manner generally similar to that described above in connection with FIGS. 4 or 10, 5 and 6, providing an oscillation action which also results in a substantial increase in efficiency of combustion, for the reasons given above.

FIG. 8 is another example of a burner, according to the present invention, using fluid amplifier principles; but wherein the mixture of the fuel and oxidant occurs substantially externally of the burner unit. Thus, 91 generally designates the burner unit in FIG. 8, said unit comprising a housing 92 to which the fuel is admitted, for example, oil. Mounted in the housing 92 is a chamber 93 into which the air or steam is admitted, the air or steam flowing through a conduit passage 94 toward a junction space 95 defined between a pair of divergent outlet passage portions 96 and 97 integrally-formed with the member 93 and discharging into a combustion space 98. As shown in FIG. 8, the walls of the housing 92 extend around, but are spaced from the corners 99, 99 of the member 93, defining respective outlet passages 100 and 101 through which the fuel oil is injected into the combustion space 98. The respective air or steam outlet passage portions 96 and 97 are provided with fluid amplifier by-pass passages 102 and 103 connecting junction space 95 to regions spaced substantial distances along the outlet passage portions, for example, to regions 104 and 105 shown in FIG. 8. The fluid amplifier passages 102, 103, therefore, provide an oscillation action on the air or steam stream, flipping the stream between the passages 96 and 97 in a manner similar to that described above in connection with FIG. 4 or 10. This provides efficient mixing of the air or steam with the fuel discharging into the combustion space 98 through the discharge passages 100 and 101,

and the generation of great turbulence in the combustion space 98, therefore, results in greatly increased over-all combustion efficiency, for the reasons stated above. When steam is used as the fluid in the flow conduit 94, the oxidizer, usually air, is external to the burner assembly and burns with the turbulent steam-oil mixture in the combustion space 98.

FIG. 9 illustrates another modification of a fluid amplifier-type of burner, according to the present invention. Thus, the burner is designated generally at 110 and comprises a block 111 to which is connected a gas-supply conduit 112 through a valve 113 leading to a junction space 114 in block 111. The divergent outlet passage portions 115 and 117 lead to a discharge space 117 from the junction space 114. By-pass fluid amplifier passages 118 and 119 connect junction space 114 to regions 120 and 121 spaced considerable distances along the passages 115 and 116 from the junction space 114. The burner is supplied with oxidant, namely, air through supply conduits 122, 122 connected to the block 111 and connected by passages 123, 123 to the space 114 ahead of the connections of the by-pass passages 118, 119 thereto. The air may be merely aspirated into the burner from the supply conduits 122, 122, or alternatively, may be introduced under pressure. The fuel and the air are primarily mixed in the junction space 114, but secondary mixing occurs in the ignition space 117, which may be exposed to the ambient air. The fluid amplifier by-pass passages 118, 119 provide an oscillating action, as described above in connection with FIG. 4 or 10, which promotes the efficient combustion of the air-fuel mixture for the reasons described above.

As above mentioned, the air admitted through the conduit 122 may be under ordinary atmospheric pressure and may be aspirated into the burner, or alternatively, can be supplied under pressure, if so desired.

In accordance with the present invention, the oscillating jet arrangement employed in the devices illustrated in FIGS. 4 to 10 may be employed in combination with pressure wave-control ports similar to those illustrated in FIGS. 1, 2 and 3. Thus, a random sprinkling of oscillator devices such as that shown in FIG. 4 or 10, or in FIGS. 5 to 9, may be employed among the pressure wave-control configurations illustrated in FIGS. 1, 2 and 3.

As above-mentioned, the fluid amplifier-type of fuel combustion device described above may be employed in many types of apparatus, for example, in automobile engines in the manner illustrated in FIG. 5. With such applications, not only is efficiency of combustion obtained in a more efficient manner, but also greatly increased safety, since the more complete combustion substantially eliminates practically all of the carbon monoxide. Also, the complete combustion of the fuel reduces the formation of carbon and soot. It will thus be understood that the fluid amplifier-type of burner described above could be advantageously employed as an air pollution-control device and may be employed in combination with conventional burners so as to obtain the advantages of conventional burners along with those of the fluid-amplifier-type of burner. In certain applications, where cost is not an important factor, compressed air or steam energy can be employed to complement the energy of the oscillating stream in order to obtain the ultimate in combustion efficiency.

Although no mention was made of the method of ignition of the fuel in the device shown in FIG. 1, such ignition may be accomplished in any conventional manner, for example, by an electric spark plug, by hypergolic reaction (ignition on contact without further addition of energy), or by a pyrotechnic igniter device or by another flame.

In connection with FIG. 2, it should be understood that since the propellants are liquids, when they pass through the amplifier injection section, the control ports 31, 36 may initially dribble some of the propellants into the combustion chamber. As the pressure builds up in the chamber, the gas pressure then controls the main propellant streams by sensing the pressure on either side of each amplifier.

As above-mentioned, the fluid amplifier burner arrangement of FIG. 4 or 10 may be employed in combination with the control amplifier arrangement of FIGS. 1, 2 and 3, or the oscillating type of stream action of FIG. 4 or 10 may be employed entirely in structures such as that of FIGS. 1, 2 and 3. Thus, the configuration of the fluid amplifier of FIG. 4 or 10 may be substituted for that of FIGS. 1, 2 and 3. Thus, an injector can be made wholly of oscillator elements, or a combination of oscillator elements and pressure-control elements. The injector shown in FIG. 6 is a typical example of one comprising only oscillator elements.

In the case of FIG. 5, this shows an oscillator amplifier device arranged for the distribution of fuel into the internal combustion chamber 74 with pre-mixing having occurred prior to said distribution, the pre-mixed fuel traveling through the manifold 71. Obviously, the structure of FIG. 5 may also represent that required for distributing the fuel directly into the internal combustion chamber 74 from the manifold 71 with the oxidizer (generally air) provided through one of the valves, for example, through the valve 113. It should also be noted that an oscillator element may be employed upstream of the oscillator injector to initially pre-mix the fuel and air before the mixture enters the manifold 71 to feed the oscillator injector comprising the elements 72, 75 and 73, 77. Thus, complete mixing and intermixing may require the fuel and oxidizer (air) to pass through a series of oscillators prior to final injection into the cylinder.

FIGS. 11, 12 and 13 show examples of the application of fluid amplifier injector devices as above described to jet engines. FIG. 11 diagrammatically shows in longitudinal vertical cross-section a typical can structure jet engine burner, designated generally at 130, generally similar to current design but employing the principle of the fluid amplifier injector devices, as above described. The assembly 130 comprises an elongated main housing 131 having a compressed air inlet duct 132 at one end and having a jet outlet duct 133 at its other end. A burner assembly, designated generally at 134, is mounted in the intermediate portion of the housing 131 and is spaced from the wall surfaces of said housing to define an annular cooling air flow space 136 between the burner assembly 134 and the housing. The burner assembly 134 is mounted substantially axially in the elongated main housing 131, and comprises a casing 137 having an arcuately curved longitudinal contour, the casing being provided with a transverse partition wall 138 located adjacent its left, or upstream, end and defining a combustion space 139 to the right thereof, namely, at the downstream side thereof. A

conduit 140 leads from a source of fuel under pressure to a fluid amplifier injector unit 141 centrally located in the partition wall 138. A plurality of fluid amplifier air injector units 142 are provided in the partition wall 138, spaced around the central fluid amplifier injector unit 141.

The wall of the casing 137 surrounding the combustion space 139 is formed with a plurality of fluid oscillator ports, shown at 143, said ports comprising passages having diverging inner branches leading to the combustion space 139, for bleeding air into the combustion space with oscillator action to provide additional turbulence and to stimulate and reinforce the combustion action.

As above mentioned, the fuel under pressure is injected into the combustion chamber 139 through the fluid amplifier injector unit 141. Primary air from the compressor discharge is furnished through the intake duct 132, and is injected into the combustion space 139 through the fluid amplifier injector passage systems 142, so as to mix with the fuel inside the casing 137. Secondary air, also from the compressor discharge, circulates past the exterior of the casing 137 so as to cool the casing. Some of the secondary air bleeds through the fluid amplifier injector devices 143 in the wall of the casing to aid in the combustion process.

In a jet engine, it is essential that the unburned cool air be mixed with the hot products of combustion before the mixture enters the turbine. Poor mixing causes hot spots on the turbine. The use of the fluid amplifier injector units, in addition to allowing a higher efficiency of burning to be provided, caused by more efficient mixing, also provides for a more uniform mixture of combustion products and air through the turbine. The efficient combustion results in a reduction in specific fuel consumption, and the more uniform mixing extends the useable life of the turbine, which is a significant maintenance factor.

The modification illustrated in FIG. 12 employs the same principles as that of FIG. 11 but is somewhat different in geometrical structure. In FIG. 12, the assembly, shown generally at 150, has a longitudinal centerline 151, the figure showing only one-half the structure above, namely, that above the centerline 151. The main housing, shown at 152, has an air inlet duct at 153 and a jet outlet duct at 154. The burner casing, shown at 155, is of annular configuration and has an inwardly tapering coaxial upstream end portion 156 which is exposed to the air inlet duct 153. The cross-sectional shape of the casing also includes inwardly tapering air bleeder portions 157 similarly exposed to the compressed air intake duct 153, as shown.

The casing 155 is provided with fuel manifolds 158 communicating through fluid amplifier injector units 159 with the left end regions of the casing 155, for injecting fuel into the casing in the direction of the combustion space 160 thereof. The casing 155 is spaced from the main housing 152 to define an annular cooling air flow space 161, as in the form of the engine illustrated in FIG. 11. The walls of the casing are provided with secondary air injector passages 143 similar to those of FIG. 11, comprising ports provided with diverging inner branches leading to the combustion space 160.

Fuel and air are injected in an annular pattern around the engine centerline 151, with the combustion taking place in the space 160 in a manner similar to that oc-

curing in the embodiments of FIG. 11. The modification of FIG. 12 allows for a higher air flow rate than that of FIG. 11, since more surface area of the casing is available for air injection.

The further modification illustrated in FIG. 13 is generally similar in principle and design to the modifications of FIGS. 11 and 12. In FIG. 13, the assembly is generally indicated at 170 and the main housing thereof is shown at 171. The elongated main housing 171 is provided with the air inlet duct 172 and the jet outlet duct 173. The burner casing, shown at 174, is coaxially mounted in the main housing and has the generally forwardly flaring wall configuration defining an internal combustion space 175. The upstream, or forward, end portion of the casing 174 is provided with the inwardly projecting tapered coaxial portion 176 centrally exposed to the compressed air intake duct 172, as shown. The upstream end portion of the casing 174 is provided with the fuel supply manifolds 177 similar to the manifolds 158 of FIG. 12. The casing 174 is spaced from the enlarged central portion of the main housing 171 to define an annular cooling air flow space 178 between the burner casing 174 and the main housing 171. The walls of the burner casing 174 are provided with spaced secondary air oscillator injector ports 143 similar to those employed in the embodiments of FIGS. 11 and 12, namely, comprising passages having divergent inner branches leading to the combustion space 175.

In the embodiments of FIG. 13, the fuel and air are injected in an annular pattern around the center line of the engine unit 170. A plurality of units 170 may be clustered around the main engine center line to form individual burner modules. Thus, this arrangement combines the best features of the relatively compact embodiments of FIG. 11 and the relatively bulky embodiments of FIG. 12, providing excellent efficiency and convenient maintenance.

The phenomenon of surge frequently causes serious problems in jet engines. The embodiments illustrated in FIGS. 11, 12 and 13 tend to eliminate or to greatly reduce surge problems.

From the above discussion, it will be evident that a large number of possible fuel and air injection patterns or arrangements may be devised, all employing the principles inherent in the present invention.

While certain specific embodiments of an improved structural arrangement for controlling the flow of fluid to use in combustion in a manner to improve or stabilize combustion have been disclosed in the foregoing description, it will be understood that various modifications within the spirit of the invention may occur to those skilled in the art. Therefore, it is intended that no limitations be placed on the invention except as defined by the scope of the appended claims.

What is claimed is:

1. In combination, means defining a combustion space, a source of fluid to be utilized in combustion in said space, and means defining a supply flow passage from said source leading to said space, said means comprising a main supply passage portion connected to said source, a pair of diverging discharge passage portions leading from said main passage portion to said combustion space and opening into said combustion space at spaced locations therein, and means defining auxiliary passage portions connected between the junction of the diverging passage portions and respective regions in

communication with the combustion space and located substantial flow distances downstream from said junction, whereby said auxiliary passage portions act as fluid amplifier pressure sensors and react on the fluid stream passing said junction to direct the flow of the fluid through one or the other of said diverging passage portions in accordance with the pressures at said respective regions, wherein said combustion space includes a boundary wall, said diverging discharge passage portions and said auxiliary passage portions being formed in said boundary wall.

2. The structural combination of claim 1, and wherein the downstream ends of said auxiliary passage portions are located adjacent the downstream ends of the diverging discharge passage portions.

3. The structural combination of claim 2, and wherein the downstream ends of said auxiliary passage portions are exposed directly to the combustion space.

4. The structural combination of claim 3, and wherein the downstream ends of said auxiliary passage portions are located outwardly adjacent the downstream ends of said diverging discharge passage portions.

5. The structural combination of claim 1, and wherein said boundary wall is provided with a plurality of said supply flow passage means distributed thereover and wherein the downstream ends of the auxiliary passage portions thereof are located to detect pressure waves in the combustion space.

6. The structural combination of claim 5, and wherein said supply flow passage means are arranged in concentric groups in said boundary wall.

7. The structural combination of claim 4, and wherein the downstream ends of the auxiliary passage portions and the diverging discharge passage portions are located substantially in the same plane.

8. In combination, means defining a combustion space, a source of fluid to be utilized in combustion in said space, and means defining a supply flow passage from said source leading to said space, said means comprising a main supply passage portion connected to said source, a pair of diverging discharge passage portions leading from said main passage portion to said combustion space and opening into said combustion space at spaced locations therein, and means defining auxiliary passage portions connected between the junction of the diverging passage portions and respective regions in communication with the combustion space and located substantial flow distances downstream from said junction, whereby said auxiliary passage portions act as fluid amplifier pressure sensors and react on the fluid stream passing said junction to direct the flow of the fluid through one or the other of said diverging discharge passage portions in accordance with the pressures at said respective regions, wherein the downstream ends of said auxiliary passage portions are located adjacent the downstream ends of the diverging discharge passage portions, and wherein the downstream ends of the auxiliary passage portions communicate with the respective diverging discharge passage portions at points in said discharge passage portions spaced substantial flow distances from said junction, whereby to cause the flow stream to oscillate discretely between the divergent discharge passage portions.

9. The structural combination of claim 8, and wherein the upstream ends of said auxiliary passage

portions are diametrically-opposite each other and are substantially coplanar with said junction.

10. The structural combination of claim 9, and wherein said combustion space includes a boundary wall, said boundary wall being provided with a plurality of said supply flow passage means distributed there- over, and wherein said diverging discharge passage portions and said auxiliary passage portions are formed in said boundary wall.

11. The structural combination of claim 10, and wherein said boundary wall is formed with a supply manifold communicating with the main supply passage portions of the supply flow passage means.

12. In a jet engine, an elongated main housing having a compressed air inlet duct at one end and having a jet outlet duct at its other end, a burner assembly mounted in the intermediate portion of said housing and being spaced from the wall surfaces of the housing to define a cooling air flow space between the burner assembly and the housing, said burner assembly comprising a casing defining a combustion space, a source of fluid to be utilized in combustion in said combustion space, means defining a supply flow passage from said source leading to said combustion space, said means comprising a main supply passage portion connected to the source, a pair of diverging discharge passage portions leading from said main passage portion to said combustion space and opening into said combustion space at spaced locations therein, and means defining auxiliary passage portions connected between the junction of the diverging passage portions and respective regions in communication with the combustion space and located substantial flow distances downstream from said junction, whereby said auxiliary passage portions act as fluid amplifier sensors and react on the fluid stream passing said junction to direct the flow of the fluid through one or the other of said diverging passage portions in accordance with the pressures at said respective regions, said combustion space including a boundary wall, said diverging passage portions and said auxiliary passage portions being formed in said boundary wall.

13. The jet engine of claim 12, and wherein the wall of the casing is formed adjacent said combustion space with a plurality of secondary air injection passages having divergent inner branches opening into the combustion chamber for bleeding air into the combustion space.

14. The jet engine of claim 12, and wherein the downstream ends of said auxiliary passage portions communicate with the respective diverging passage portions at locations spaced downstream from said

junction.

15. The jet engine of claim 14, and wherein the casing is located substantially coaxially in said main housing to define a substantially annular cooling air flow space between the casing and the main housing.

16. The jet engine of claim 15, and wherein the wall of the casing defining the inner boundary of said cooling air flow space is formed with secondary air injector passages having divergent inner branches leading to said combustion space.

17. In a jet engine, an elongated main housing having a compressed air inlet duct at one end and having a jet outlet duct at its other end, a burner assembly mounted in the intermediate portion of said housing and being spaced from the wall surfaces of the housing to define a cooling air flow space between the burner assembly and the housing, said burner assembly comprising a casing defining a combustion space, a source of fluid to be utilized in combustion in said combustion space, means defining a supply flow passage from said source leading to said combustion space, said means comprising a main supply passage portion connected to the source, a pair of diverging discharge passage portions leading from said main passage portion to said combustion space and opening into said combustion space at spaced locations therein, and means defining auxiliary passage portions connected between the junction of the diverging passage portions and respective regions in communication with the combustion space and located substantial flow distances downstream from said junction, whereby said auxiliary passage portions act as fluid amplifier sensors and react on the fluid stream passing said junction to direct the flow of the fluid through one or the other of said diverging passage portions in accordance with the pressures at said respective regions, wherein the downstream ends of said auxiliary passage portions communicate with the respective diverging passage portions at locations spaced downstream from said junction, wherein the casing is located substantially coaxially in said main housing to define a substantially annular cooling air flow space between the casing and the main housing, wherein the wall of the casing defining the inner boundary of said cooling air flow space is formed with secondary air injector passages having divergent inner branches leading to said combustion space, and wherein said casing has an inwardly tapering coaxial upstream end portion exposed to said compressed air inlet duct and formed with air injector passages having divergent inner branches leading to said combustion space.

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