Nov. 18, 1958 H. M. FOX 2,860,483

APPARATUS FOR BURNING FLUID FUEL IN A HIGH VELOCITY AIR STREAM WITH ADDITION OF LOWER VELOCITY AIR DURING SAID BURNING

Filed Jan. 2, 1953 4 Sheets-Sheet 1

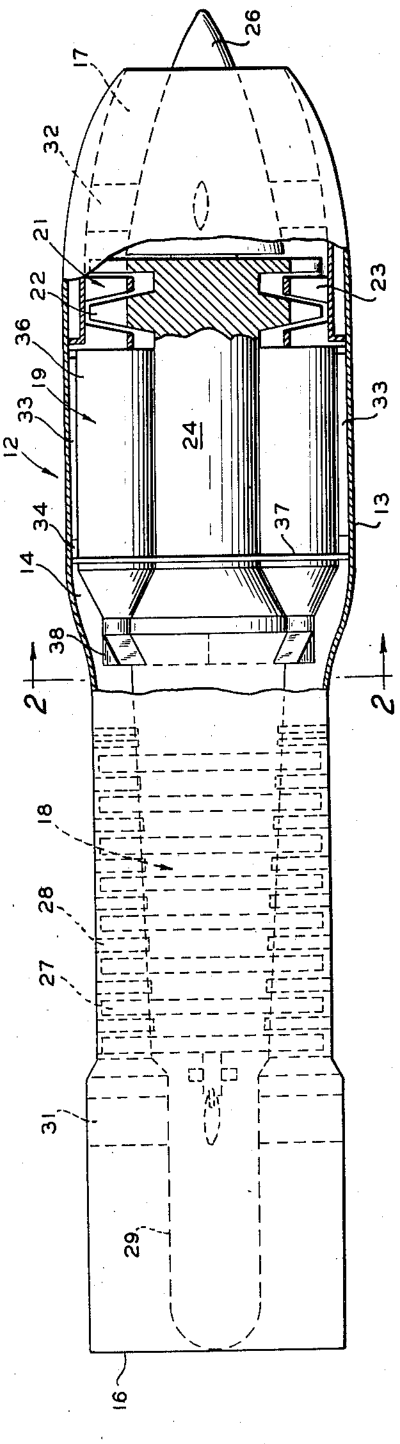

FIG. 1

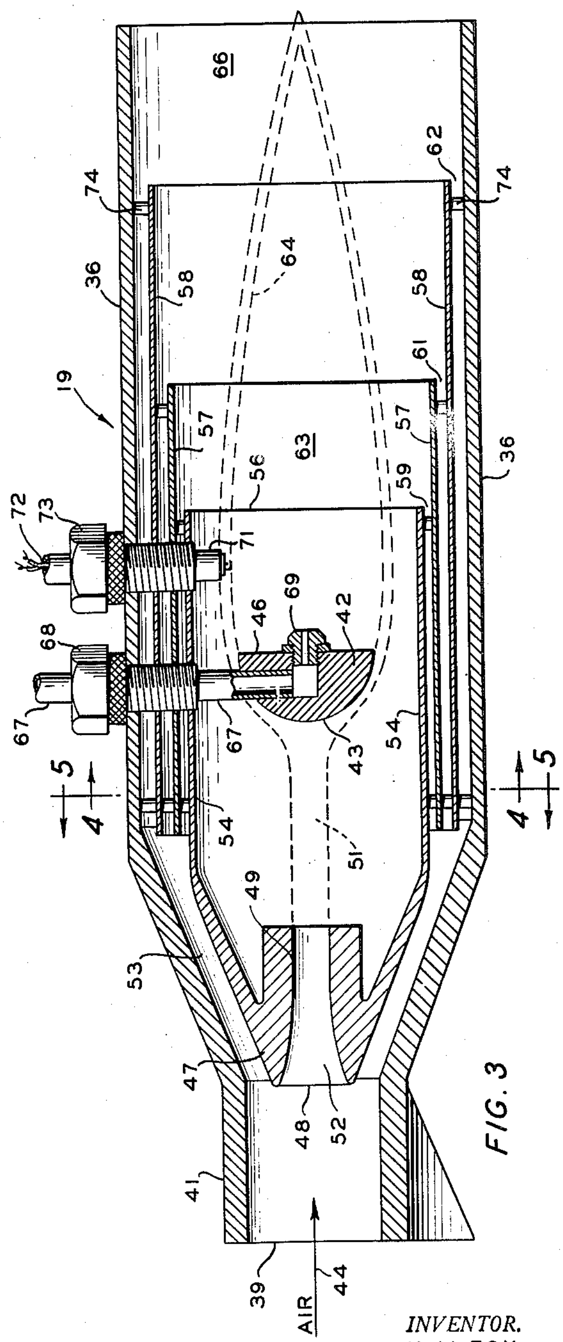

FIG. 3

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Filed Jan. 2, 1953 4 Sheets-Sheet 2

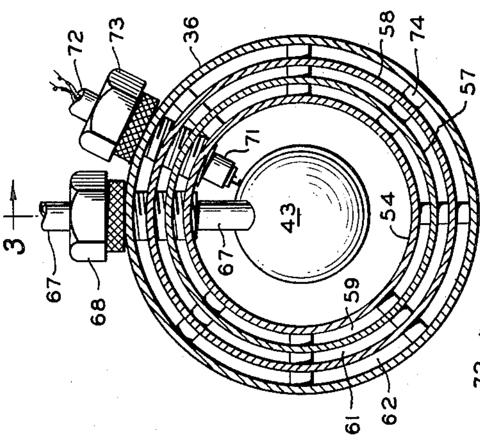

FIG. 4

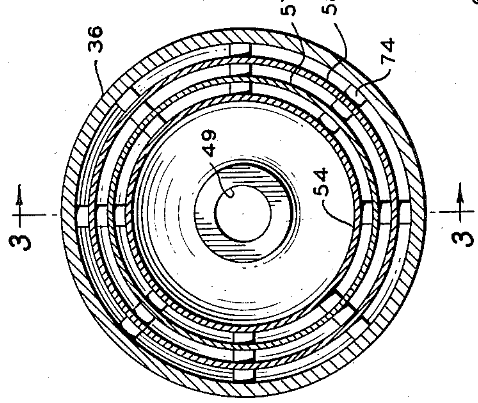

FIG. 5

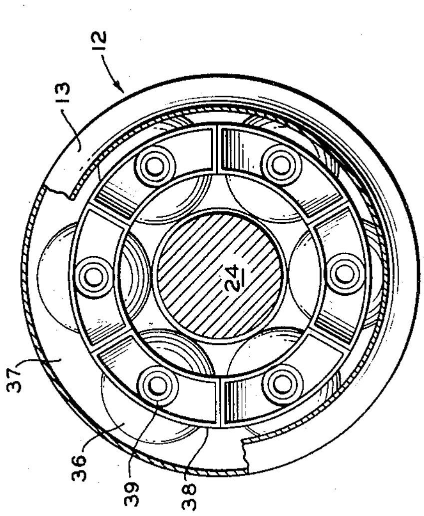

FIG. 2

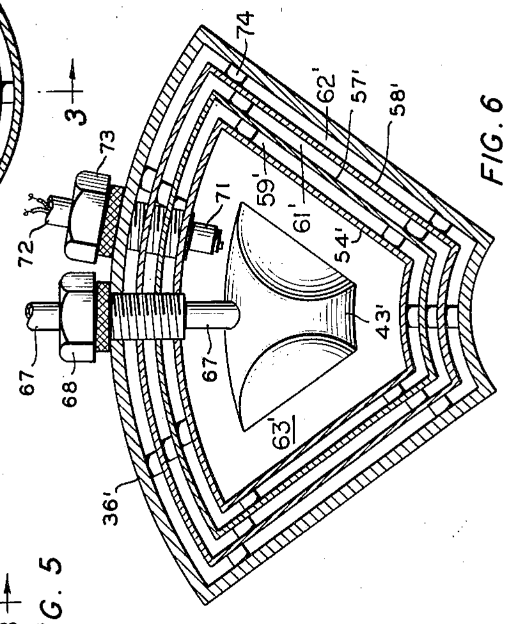

FIG. 6

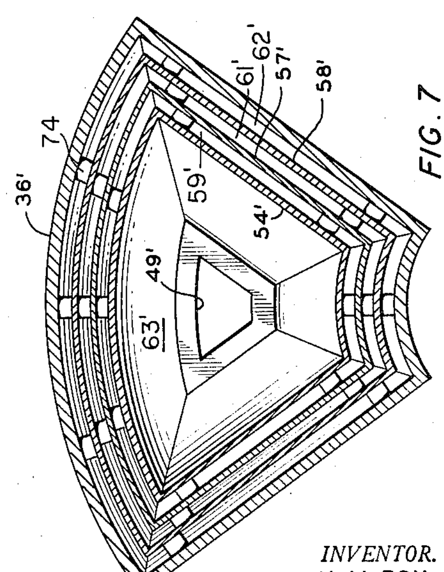

FIG. 7

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APPARATUS FOR BURNING FLUID FUEL IN A HIGH VELOCITY
AIR STREAM WITH ADDITION OF LOWER
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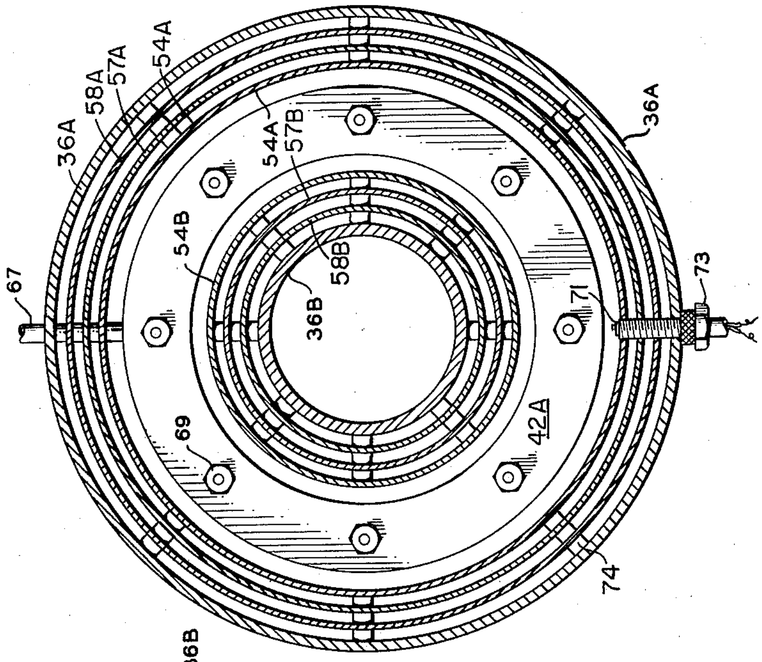

FIG. 9

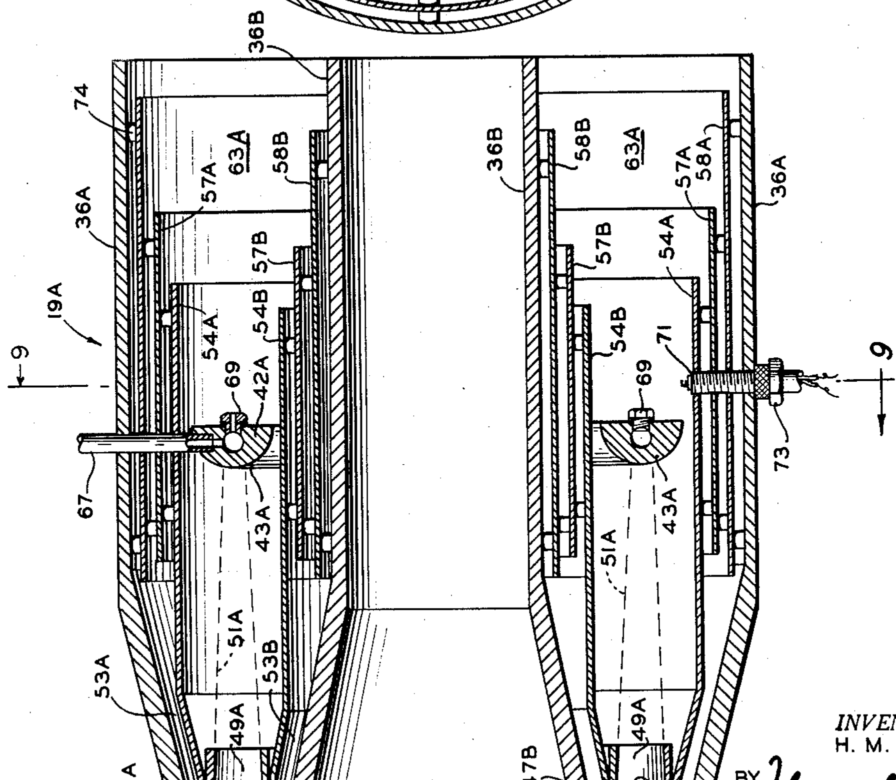

FIG. 8

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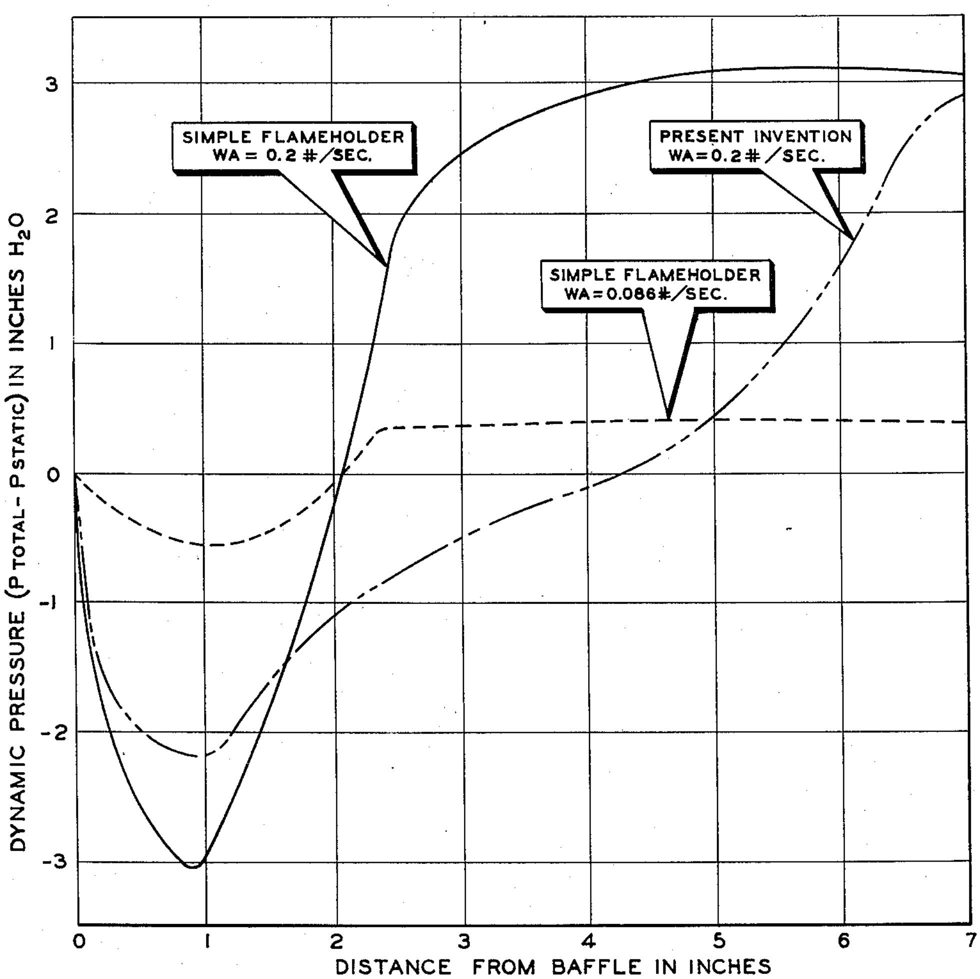

FIG. 10

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APPARATUS FOR BURNING FLUID FUEL IN A HIGH VELOCITY AIR STREAM WITH ADDITION OF LOWER VELOCITY AIR DURING SAID BURNING

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Application January 2, 1953, Serial No. 329,296

4 Claims. (Cl. 60—39.65)

This invention relates to combustion apparatus for a propulsive gaseous stream. In one aspect it relates to combustion apparatus useful in gas-turbine engines. In another aspect it relates to combustion apparatus useful in jet engines, or the ram jet type, or of the gas-turbine jet engine type.

In combustion apparatus of the prior art for use in propulsive gaseous streams considerable difficulty has been experienced in obtaining thorough and continuous mixing of fuel and air, with the result that burning is erratic and the flame goes out, or extends further than desired and comes into contact with turbine blades or other parts of the apparatus, which should not be so exposed to flame. As a result the rate of heat release is not high enough and there is too great a drop of pressure through the combustion apparatus which impairs the combustor efficiency and tends to promote instability as well as reduce the efficiency of the entire device.

One object of the present invention is to provide an apparatus which will produce continuous combustion at a high rate of heat release.

Another object is to provide an apparatus in which there is a low pressure drop with improved combustion efficiency and stability.

Another object is to provide improved combustion apparatus for propulsive gaseous streams.

A further object is to provide improved gas-turbine engines, ram jet engines, and similar devices, useful in fixed power installations, jet engines for the propulsion of vehicles, and the like.

Numerous other objects and advantages will be apparent to those skilled in the art upon reading the accompanying specification, claims and drawings.

Figure 1 is an elevational view with parts broken away to show details of construction of a gas-turbine jet engine embodying the present invention.

Figure 2 is a cross-sectional view of the device shown in Figure 1 taken along a line 2—2 thereof, looking in the direction indicated.

Figure 3 is a cross-sectional elevational view of one of the burner tubes shown in Figure 1, taken along the line 3—3 of Figures 4 and 5 looking in the direction indicated, which is also suitable for use alone as a ram-jet engine.

Figure 4 is a cross-sectional view of the apparatus shown in Figure 3 taken along the line 4—4 looking in the direction indicated.

Figure 5 is a cross-sectional view of the device shown in Figure 3 taken along the line 5—5 looking in the direction indicated.

Figure 6 is a cross-sectional view similar to Figure 4 of a modified second species of the invention in which the cylindrical elements of Figure 4 have been made arcuate and cannular in Figure 6.

Figure 7 is a view corresponding to Figure 5 of the modification of the invention shown in Figure 6.

Figure 8 is an elevational cross-sectional view of a

modified third species of the combustion apparatus in which the baffle and all of the passages are annular.

Figure 9 is a cross-sectional view of the device shown in Figure 8 taken along the line 9—9 looking in the direction indicated.

Figure 10 is a graphical representation of the results of tests made with the present invention (as shown in Figure 3) and with a simple flame holder.

Figure 1 illustrates the embodiment of the present invention in a gas-turbine jet engine generally designated as **12**. Engine **12** has a housing **13** forming a chamber **14**, with an inlet **16** and an outlet **17** for air from the atmosphere. While the invention is illustrated as applied to a gas-turbine jet engine for propelling vehicles, such as aircraft (not shown), it should be noted that in one aspect the invention is the subcombination of a combustion apparatus for a propulsive gaseous stream and in another aspect relates to processes of burning fuel in a moving air stream to produce a propulsive gaseous stream, as well as the jet engine combination shown. In chamber **14** there are connected in series an air compressor **18**, a combustion apparatus **19**, and a gas-turbine **21**, all being generally designated by the numerals listed and lying in the order described between inlet **16** and outlet **17**.

Gas-turbine **21** preferably comprises a rotor having slanted propeller blades **22** and a stator having suitable slanted guiding vanes **23** to provide a turbine with one or more stages of power output, all of which is well known in the art of turbines. Rotor **22** and shaft **24** are journaled into suitable bearings (not shown) and annular outlet **17** may be provided with a central conoidal tailpiece **26** designed to help direct the propulsive gaseous stream emerging from outlet **17** into an effective propulsive jet.

Gas-turbine **21** drives compressor **18** through shaft **24** secured therebetween. Air compressor **18** comprises a rotor having slanting air-propelling blades **27** and a stator having slanting air directing blades **28**, all arranged in a manner well known to those skilled in the air compressor art. A rounded central nose **29** may be provided in inlet **16** to help direct the air into the compressor **18**. The journals for shaft **24** may be located in nose **29** and tailpiece **26**, which are in turn supported in housing **13** by radial struts, or fins, **31** and **32** respectively, or some similar supporting elements.

In a similar manner the unit comprising combustion apparatus **19** may be supported from housing **13** by longitudinal radial fins **33**, it being desirable to leave some space **34** between said housing and the burner tube, or wall, **36** of the combustion unit **19** in most instances, although space **34** can be entirely eliminated if desired and apparatus **19** be supported by direct contact with said housing. Flow of air through space **34** is reduced, controlled, or prevented entirely, by means of baffle plate, or wall, **37**. The combustion apparatus **19** in Figure 1 is formed from an annularly disposed set of parallel burner tubes **36**, two of these burner tubes having been removed from the near side in Figure 1 in order to show details of construction of the remainder of the device. While the burner tubes **36** of Figure 1 have arcuate cannular intakes **38**, which will be further described with reference to Figure 2, the interior of burner tubes **36** may be as shown in any one of Figures 3 to 7, or the entire burner device **19** may be replaced by the annular device shown in Figures 8 and 9.

Figure 2 is a cross-section of Figure 1 taken along the line 2—2 looking in the direction indicated and shows the gas-turbine jet engine **12** comprising a housing **13** and six burners disposed in a circle around shaft **24**, the passage of air around burner tubes **36** being regulated or eliminated by baffle **37**, and each of burner tubes **36** having an inlet 39 with a flaring mouth 38 in the form of an arcuate cannular opening at its inlet end, funneling down to fit the circular inlet opening 39 of the burner.

Figure 3 shows the burner which was used to obtain the data charted on the graph in Figure 10 with the dash-dot-dot line having the legend "present invention." Figure 3 also shows the internal construction of combustion apparatus 19 of Figure 1. Combustion apparatus 19, as shown in Figure 3, however, may be used in other combinations and subcombinations than that shown in Figure 1, for example, the combustion apparatus of Figure 3 is suitable for use in a ram-jet engine which does not have a compressor 18 or turbine 21 as shown in Figure 1, but instead relies on its velocity through the atmosphere to pack air in through circular inlet opening 39 in a sufficient amount to operate as a ram-jet.

Burner 19 is also adapted to be used in any engine in which a continuous combustion apparatus for creating a propulsive gaseous stream, is of value, such as a turbo-prop engine (not shown) which would be like Figure 1 except that shaft 24 would extend axially out of either or both ends 16 and 26 and have one or more screw propellers attached thereto at either or both ends for creating a propulsive slipstream in the atmosphere exterior of housing 13.

In Figure 3, burner 19 comprises a burner tube, or housing, 36 having a conduit 41 with opening 39 disposed to supply a moving air stream 44 as indicated by the arrow. Mounted in housing 36 is a baffle 42 having a stream-lined end 43 disposed upstream of said moving air stream 44, and an abruptly terminating non-stream-lined end 46 disposed downstream of said moving air stream. In housing 36 is disposed axially a duct 47 with its leading edge 48 preferably extending into inlet 39 before any enlargement of 39 has occurred. Duct 47 is disposed to take the first portion of said air 44 from said first conduit 41 and direct the same through nozzle or orifice 49 against the nose 43 of baffle 42 as indicated by dotted lines 51.

While results of value can be obtained with a uniform diameter nozzle 49 (not shown), in which case the velocity of the air stream 44 in conduit 41 is merely maintained and not increased in the gas stream 51, it is preferable to construct nozzle 49 with a converging entry portion 52. By employing a nozzle with a well rounded entry 48, or a converging nozzle orifice 52 it is possible to increase the velocity of air stream 51 over that of 44 and thereby augment the effects that occur when stream 51 strikes nose 43 of baffle 42. It is preferred to have a reduction in area between the cross-sectional area of entrance 48 and exit 49 of at least three to one. This same reduction in the case of the burner actually used to obtain the data of Figure 10 was between four to one and five to one. It is preferred to limit the reduction in area to not more than twenty to one, however.

That portion of air stream 44 which does not enter the duct 48 passes through an annular bypass duct 53, which may have constant area throughout (not shown) but preferably expands in area as it proceeds downstream. Nozzle 47 is provided with a skirt 54 protecting baffle 42 and the area in its immediate neighborhood from contact with the air coming through passage 53, and the portion of air passing through 53 is reunited with the air coming through nozzle 49 downstream of terminal edge 56 of skirt 54. This reuniting of the streams of air may be accomplished in a single step with valuable results, but I prefer to divide the stream of air in passage 53 by two or more cylindrical concentric sleeves 57 and 58 and return the air from space 53 in a series of annular sheets through annular space 59, 61 and 62 to the interior 63, as in that manner it will prolong the length of the turbulent flame 64.

The propulsive gaseous stream produced in burner 19 passes out the outlet end 66.

A fuel injection line 67 connected to housing 36 by suitable connection means 68 may be disposed to act both as a support for baffle 42 and as a means to feed fuel downstream of said baffle, for example by atomizing the same, or spraying the same, through a nozzle 69 of a type well known in the prior art. Fuel nozzle 69 may be either the pressure-atomizing type shown, or may be any type known to the prior art, provided the fuel is sprayed into the flame space outlined by dotted line 64. In order to ignite the fuel-air mixture in the turbulent flame 64 any suitable ignition mechanism of the prior art may be employed, such as a spark plug 71 having electrical leads 72 secured in place by securing means 73. Either a continuous, or intermittent, spark may be employed, or the spark plug need only be actuated at times of igniting the burner.

Figure 4 is a cross-section of Figure 3 looking downstream as indicated and needs no further description. The construction and disposition of lugs or blocks 74 which hold the concentric cylinders 54, 57 and 58 will be evident from a comparison of Figures 3 and 4.

Figure 5 is the same as Figure 4 except looking upstream and needs no further description.

Figure 6 is a cross-sectional view similar to Figure 4, and Figure 7 is a cross-sectional view similar to Figure 5. Figures 6 and 7 are views similar to Figures 4 and 5 respectively, showing how the device of Figure 3 can be easily modified into an arcuate, cannular form, thereby utilizing all of the space available so as to leave no space between cylinders 36 which is represented by baffle 37 in Figure 2. Parts in Figures 6 and 7 corresponding to those in Figures 4 and 5 have been given the same numbers, the numerals being primed when they differ by being arcuate and cannular in shape. No further description is believed necessary.

Figures 8 and 9 show another modification in which waste space 37 shown in Figure 2 is utilized by making all the parts and spaces annular and continuous around a central tube 36B which may be placed around a shaft similar to shaft 24 shown in Figure 1, except of course such parts as the single fuel line 67, which can supply a plurality of nozzles 69 spaced around the annular baffle 42A, and spark plug 71, as one can ignite a flame all around the annulus without having more than one spark plug.

The parts in Figures 8 and 9 which correspond in functions with like parts in the preceding figures have been given the same numerals with the letter "A" added, and when a further corresponding concentric part is needed to carry out that function, it has also been given the same numeral with the letter "B" added.

In Figure 8 the air enters through annulus 39A and a portion is taken through annulus 49A lying between annulus members 47A and 47B. Annular space 49A may be cylindrical throughout (not shown) but preferably said annular space converges as shown to concentrate the air into annular jet 51A which impinges on the streamlined face 43A of annular baffle 42A. The remaining portion of the air is carried through two annular spaces 53A and 53B and is reunited with the other air in annular space 63A after passing through the annular spaces between cylinders 54A, 57A, 58A and 36A and between cylinders 54B, 57B, 58B and 36B. Fuel coming in line 67 is distributed and spread through a plurality of nozzles 69 into annular space 63A to form a turbulent flame downstream of baffle 42A.

Figure 10 is a graphical representation of comparative data obtained while testing the burner of Figure 3, and a simple flame holder of the prior art comprising a baffle like 42 of Figure 3 with a fuel injector like 69 of said figure placed inside a single cylindrical tube, and both devices tested under similar conditions. The pressure readings were obtained by moving the dynamic entrance to a Pitot tube at different distances from the baffle indicated in Figure 10.

The readings in Figure 10 were made along the axis of the burner and show that much greater turbulence of mixing occurs in the present invention than in a simple flame holder. These readings show that turbulence exists for a greater distance in back of the baffle of this invention than in back of the baffle of the simple flame holder.

Downstream of baffle **42** in the present invention there is negative velocity, or backflow, for some four and one-third inches in the small model tested, as shown in Figure 10.

Operation

The present invention provides for the continuous combustion of fuel with a fuel pressure drop to produce propulsive gaseous streams whereby under relatively severe inlet conditions for combustion, a combustion efficiency of 92 to 98 percent is often obtained, combustion stability is improved, and a maximum stable temperature rise higher than the temperature rise in conventional combustion apparatus, and therefore higher heat release, is developed.

The improved performance of the combustion apparatus of this invention is believed to be the result of the formation of a long and turbulent quiescent zone in which the reverse axial air currents recycle and carry the activated fuel particles back to the combustion zone, which thereby increases the overall velocity of the combustion reaction. The large volume of the quiescent zone obtained in the combustion apparatus of the present invention also permits more complete combustion of the fuel particles.

The radial spacing of cylindrical tubes **57** and **58** is such that sheaths of high velocity air, as is emitted by a jet ejector, are formed around the quiescent zone and reduce its tendency to collapse. Although only three secondary air passages are shown in this embodiment, any number of such passages may be used and also different velocities of air flow from each passage may be provided.

The baffle **42** is mounted in spaced relationship to air nozzle **49** and the discharge of secondary air passages **59**, **61** and **62** so that a direct stream or jet of high speed air from air nozzle **49** strikes baffle **42** and expands around its surface, only partially filling the annulus between the baffle and the inner surface of flame tube **54**, and leaves the downstream edge of baffle **42** as a tube of air traveling at high speed. The sheaths of high speed secondary air discharged from passages **59**, **61** and **62** promote the formation of this quiescent zone and help to prevent its collapse. In Figure 10 is shown a comparison of the quiescent zones obtained in a conventional low pressure-drop combustion chamber consisting of a conical flame holder in a tube of constant cross-sectional area and the combustion chamber of Figure 3 of this invention employing an air nozzle to accelerate the air and a hemispherical baffle. With the chambers operating at 50 pounds per square inch absolute pressure and mass air flow of 0.2 pound per second, the region of backflow was found to extend only two inches from the downstream edge of the flame holder of the conventional combustion chamber as compared to a region of backflow of over four inches in the combustion chamber of my invention.

The admission of fuel is preferably in the quiescent zone downstream from baffle **42**; however, the admission of fuel may be made in other localities. As shown in Figure 3, the fuel nozzle **69** may be placed on the downstream side of baffle **42** and the fuel line utilized as a support for baffle **42** in the combustion space. Fuel nozzle **69** may be either of the pressure-atomizing or gas-assist type. Various designs of baffles may be used and preferably the baffle should be one which progressively increases in cross-sectional area from the upstream to the downstream end of said baffle so as to impart a high kinetic energy to the stream of air leaving the downstream edges of the baffle. In the design shown in Figure 3 the upstream surface of the baffle is a hemisphere.

While certain specific embodiments of the invention have been shown for purposes of illustration, the invention is not limited thereto.

Having described my invention, I claim:

1. Combustion apparatus for burning a fluid fuel in a moving stream of a combustion supporting gas comprising in combination a body having a conduit therethrough provided with an inlet and an outlet for said gas, a baffle disposed in said conduit having a streamlined end disposed toward said inlet and an abruptly terminating non-streamline end disposed toward said outlet, a plurality of spaced concentric tubes surrounding and spaced from said baffle and disposed in and spaced from the walls of said conduit, said tubes overlapping in longitudinal extent along the axis of said conduit with the tubes terminating progressively closer to said outlet in the same order as their distance from said baffle, a converging nozzle with an inlet disposed in the inlet end portion of said conduit and with an outlet disposed to discharge a reduced area stream of said gas of higher velocity than enters said nozzle against said streamlined end of said baffle, means sealing off the space between said nozzle and the wall of the tube adjacent said baffle upstream of said baffle, said conduit enlarging in area downstream of the inlet of said nozzle, and said tubes and conduit being disposed in said enlarged portion to lower the velocity of said gas passing around said nozzle and reunite the same downstream of said baffle with the gas that has passed through said nozzle, means for injecting said fluid fuel into the space downstream of and adjacent to said baffle, and means to burn said fuel and said combustion supporting gas in said body downstream of said baffle.

2. The combination of claim 1 in which the tubes are imperforate.

3. Combustion apparatus for burning a fluid fuel in an annular moving stream of a combustion supporting gas comprising in combination a body having an annular conduit therethrough provided with an annular inlet and an annular outlet for said gas, an annular baffle disposed in said conduit having an annular streamlined end disposed toward said inlet and an abruptly terminating annular non-streamline end disposed toward said outlet, a plurality of spaced concentric tubes surrounding and spaced from said baffle and disposed in and spaced from the walls of said conduit, said tubes overlapping in longitudinal extent along the axis of said conduit with the tubes terminating progressively closer to said outlet in the same order as their distance from said baffle, an annular converging nozzle with an annular inlet disposed in the inlet end portion of said conduit and with an annular outlet disposed to discharge a reduced area annular stream of said gas of higher velocity than enters said nozzle against said annular streamlined end of said baffle, means sealing off the space between said nozzle and the wall of the tube adjacent said baffle upstream of said baffle, said conduit enlarging in area downstream of the inlet of said nozzle, and said tubes and conduit being disposed in said enlarged portion to lower the velocity of said gas passing around said nozzle and reunite the same downstream of said baffle with the gas that has passed through said nozzle, means for injecting said fluid fuel into the annular space downstream of and adjacent to said annular baffle, and means to burn said fuel and said combustion supporting gas in said body downstream of said baffle.

4. The combination of claim 3 in which the tubes are imperforate.

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