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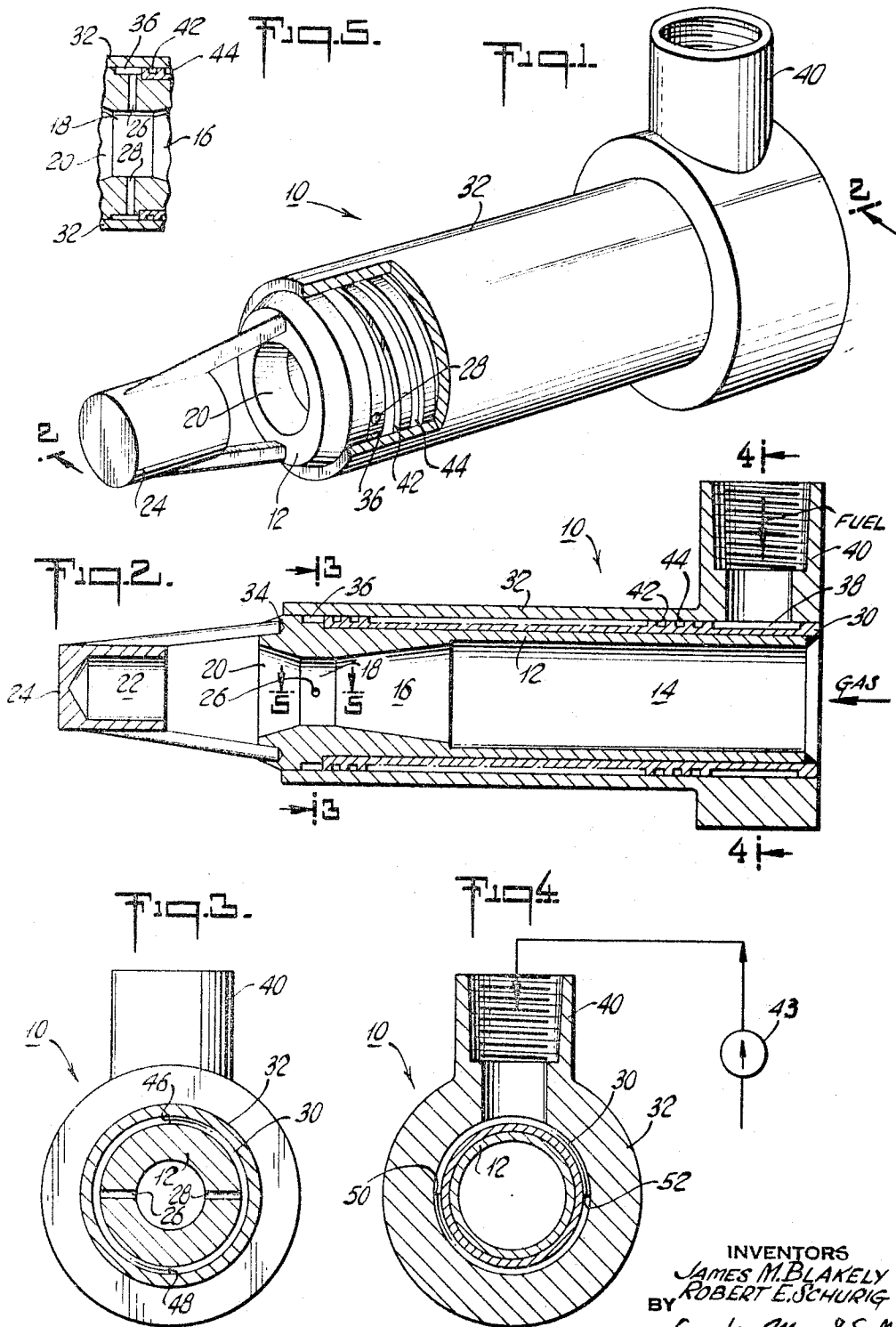
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3,320,744

GAS TURBINE ENGINE BURNER

Filed Nov. 15, 1965

3 Sheets-Sheet 1



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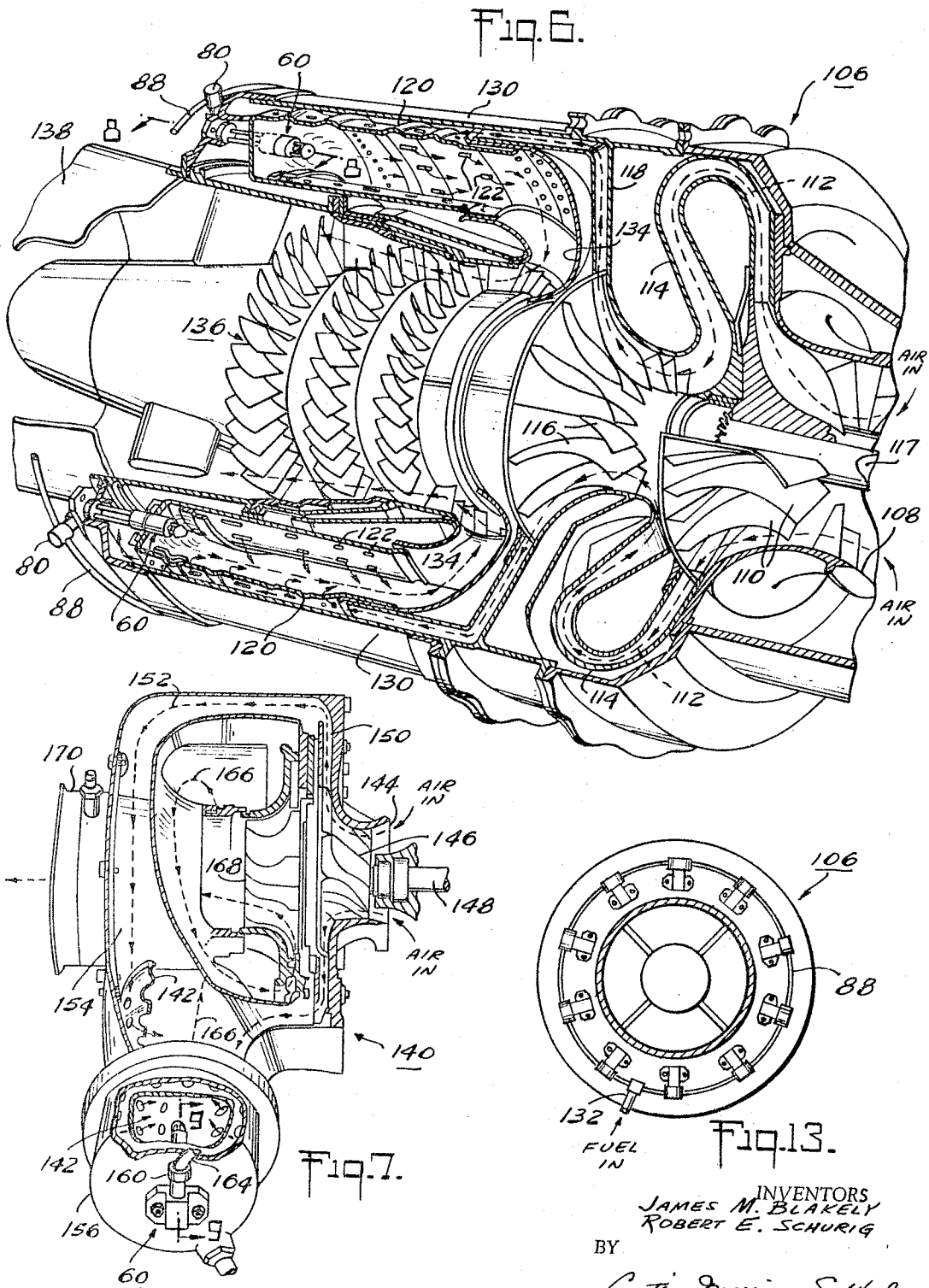
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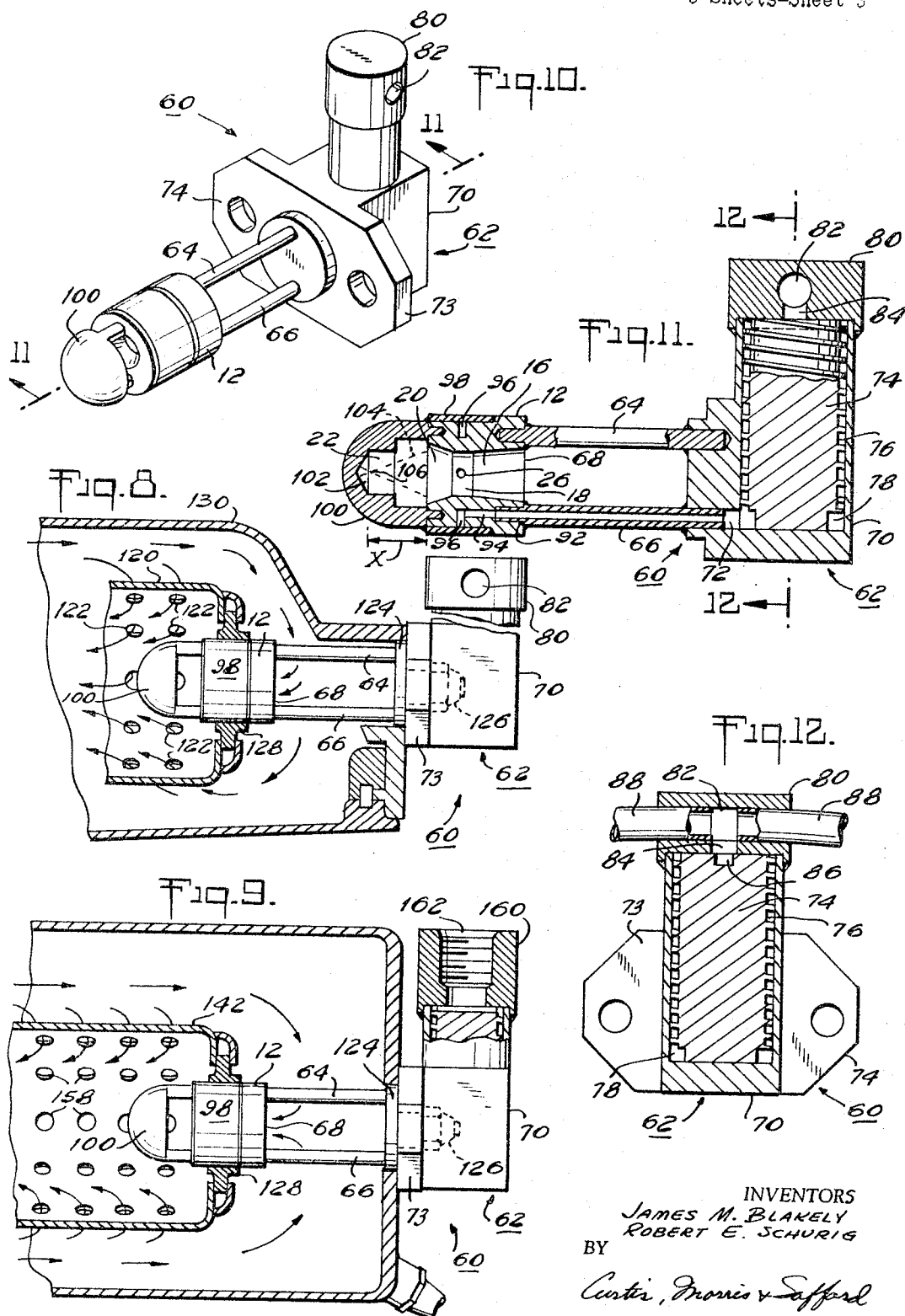
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GAS TURBINE ENGINE BURNER

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8 Claims. (Cl. 60—39.74)

This invention relates to internal combustion engines, and, more particularly, to fluid fuel atomizing, burning and feeding systems used in such engines. In an illustrative embodiment of the invention described herein, a gas turbine is equipped with a gas-operated atomizer and burner utilizing sonic energy in the atomizing and burning process. This application is a continuation-in-part of co-pending U.S. patent application Ser. No. 439,738, filed Mar. 15, 1965.

Down through the years there has been a continuing search for better fuel atomizing and burning systems for use in internal combustion engines. This search has been particularly intense in the field of gas turbine engines because of the problems met in using existing systems.

One problem with presently available gas turbine burners is that they have too limited a range over which the fuel flow rate through the burner can be varied while still obtaining satisfactory atomization. As a result, in many engines several different types and sizes of nozzles must be provided in a single engine so as to give sufficient fuel-flow rangeability. This requirement limits the type of combustion chamber which may be used in a gas turbine engine of a given size and type. As a result, the horsepower-to-weight ratio of the engine is not as high as it would be if the most suitable type of combustion chamber were used.

Another problem with prior atomizers and burners is that they usually do not produce a flame of the most desirable shape. For example, most such prior flames are elongated and narrow, and the flaming gases move at relatively high velocities. This means that a relatively long combustion chamber must be used to enable the fuel to burn completely. Furthermore, this dictates that only certain types of combustion chambers can be used so as to best utilize the flame pattern.

A problem with some atomizing and fuel burning systems is that they require that the liquid or gaseous fuels be pumped to relatively high pressures. The high-pressure pumping equipment required for such systems adds weight, expense, complexity and unreliability to the engine.

Another problem with prior atomizers and burners is that their fuel flow passages are so small that they easily become clogged by foreign particles in the fuel. Further aspects of this problem will be discussed in greater detail below.

The cost of fuel for internal combustion engines always has been a problem, and an atomizing and burning system capable of using low-cost, low-grade fuels long has been sought after. The fact that the prior high-cost fuels are more volatile and more hazardous to use has heightened the intensity of the search for such a system. It has been attempted to burn low-grade fuels with prior burners without creating excessive carbon deposits in the engine. However, it is believed that such prior efforts have fallen far short of their goal.

In accordance with the foregoing, it is an object of this invention to provide an internal combustion engine, particularly a gas turbine engine, which is relatively small in size and has a relatively high horsepower-to-weight ratio; an engine with a fuel atomizing and burning system capable of highly efficient atomizing and burning over a wide range of fuel flow rates. It is another object of the present invention to provide such a system which does not

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require the fuel to be supplied at high pressures, whose fuel feed passages are self-cleaning and highly clog-resistant, and which produces a flame shape which is readily variable to suit specific combustion chamber needs. Also, it is an object of the present invention to provide such a system which can effectively and efficiently utilize low-cost, low-grade, relatively contaminated fuels as well as normal liquid fuels, natural gas, and similar gases. Furthermore, it is an object of the present invention to provide such a system which is simple in construction, lightweight, free of moving parts, and requires little maintenance.

Further objects of the present invention will be set forth in and apparent from the following description and drawings, in which:

FIGURE 1 is a perspective, partially broken-away view of a fuel-burning atomizer in accordance with the invention;

FIGURE 2 is a cross-sectional view taken along line 2—2 of FIGURE 1;

FIGURE 3 is a cross-sectional view taken along line 3—3 of FIGURE 2;

FIGURE 4 is a cross-sectional view taken along line 4—4 of FIGURE 2, and includes a schematic diagram of the system used for pumping fuel to the atomizer;

FIGURE 5 is a cross-sectional view taken along line 5—5 of FIGURE 2;

FIGURE 6 is a partially broken-away and partially schematic perspective view of a gas turbine engine constructed in accordance with the present invention;

FIGURE 7 is a partially broken-away and partially schematic perspective view of another gas turbine engine constructed in accordance with the present invention;

FIGURE 8 is a partially broken-away cross-sectional view taken along line 8—8 of FIGURE 6;

FIGURE 9 is a partially broken-away cross-sectional view taken along line 9—9 of FIGURE 7;

FIGURE 10 is a perspective view of another embodiment of the fuel-burning atomizer of the present invention;

FIGURE 11 is a cross-sectional view taken along line 11—11 of FIGURE 10;

FIGURE 12 is a cross-sectional view taken along line 12—12 of FIGURE 11; and

FIGURE 13 is a partially cross-sectional rear elevation view of the engine shown in FIGURE 6.

In the present invention, an internal combustion engine is equipped with a gas-operated atomizer and burner using sonic energy in the atomizing and burning process. Advantageously, the gas flow through the atomizer can be created solely by pressure-changing means forming a part of the engine, and separate gas compression means is not required. For example, in a gas turbine, the atomizer and burner is mounted in a wall of the combustion chamber with its outlet exiting into the chamber and its inlet positioned in a passageway through which pressurized combustion air flows from the compressor of the engine into the combustion chamber. Thus, the operating air for the atomizer is supplied solely by the compressor of the engine, that is, by the same means that is used to supply combustion air to the combustion chamber. The effective pressure of the air fed through the atomizer is equal to the relatively low value of the pressure difference between the compressor air and the gas inside the combustion chamber.

The atomizer and burner has unique features which make its fuel flow passages self-cleaning and practically clog-proof. Also, a unique structure is provided for feeding air into the burner. Further, the burner components are constructed so as to protect them from overheating in the combustion chamber.

The atomizer and burner structure of the present invention now will be explained with reference to FIGURES 1 through 5 of the drawings.

The atomizer 10 shown in the drawings is constructed in accordance with the teachings of co-pending U.S. patent applications Ser. No. 260,738, filed Feb. 25, 1963, now Patent No. 3,240,253; Ser. No. 332,502, filed Dec. 23, 1963, now Patent No. 3,240,254; Ser. No. 239,236, filed Nov. 21, 1962, now Patent No. 3,230,923; and Ser. No. 247,221, filed Dec. 26, 1962, now Patent No. 3,230,924, all owned by the assignee of the present patent application, and all of whose disclosures hereby are incorporated in the present application. Thus, atomizer 10 includes a nozzle member 12 having a compressed gas-receiving section 14, a converging inlet section 16, a cylindrical stabilizing section 18, and a diverging exit or outlet section 20. Nozzle member 12 is adapted to convert pressurized gas, e.g. air, into a high-speed gas stream which is issued into the ambient air with an internal pressure at the exit of the nozzle less than the pressure of the ambient medium. The high-speed stream or jet is directed into a "pulsator" or resonator cavity 22 in a support member 24.

Liquid to be atomized is delivered into the gas stream through a pair of opposed feed holes 26 and 28 which are aligned in a direction perpendicular to the longitudinal axis of the nozzle and which exit into the stabilizing section 18.

In accordance with the above-identified patent applications, this arrangement develops sonic pressure waves whose magnitude is increased by means of resonant amplification in cavity 22. The liquid input to the atomizer is believed to be atomized by the combined forces of the shock waves in the high-speed gas stream and the amplified sonic pressure waves. The liquid is broken up into very small droplets of highly uniform size. The low pressure at the nozzle exit causes "implosion" of ambient gas (air) into the jet and greatly improves the atomization.

When a combustible liquid fuel is atomized in the atomizer, and the resulting spray is ignited, a flame with unrivaled qualities is produced. Combustion in the flame is virtually complete, and it is very difficult to extinguish. What is more, because of the opposed dual liquid feed passages, the flame has a "fan" or flattened shape well suiting the burner for use in such equipment as gas turbines.

One extremely beneficial feature of the atomizer 10 is that the fuel feed passages 26 and 28 are comparatively quite large in diameter. Thus, they do not easily become clogged by foreign particles in the fuel and only a relatively low liquid supply pressure is needed to feed liquids through the holes 26 and 28 at a satisfactorily high rate.

Another extremely beneficial feature of this atomizer is that it can be and often is used with very low pressures for the gas which is input to the nozzle 12. For example, in many uses, such as in gas turbines, the input gas pressure ranges from less than one-half p.s.i.g. (pounds per square inch gage) to no more than five p.s.i.g. Under such circumstances the pressure at the exit of the feed-holes 26 and 28 often is below atmospheric pressure, with the result that fuel is drawn into the nozzle by the low pressure and positive pressure is not needed.

Although the low fuel-feed pressure requirement of the atomizer 10 is a distinct advantage, when the atomizer is used in combination with many fuel-feed control systems, special problems arise. Such control systems often use the pressure at the input of the atomizer, i.e., the "back pressure" from the atomizer, as an input signal to the control system. Since the fluid pumps controlled by such systems often supply relatively high output pressures, they quite often require a similarly high-pressure input signal from the atomizer. If the back-pressure signal is not sufficiently high, the control system often tends to "hunt" or be unstable, with the results that the fuel is fed quite unevenly and the flame fluctuates in a similar manner.

Thus, in the past it has been the practice to insert an orifice or line restrictor in the fuel feed line so as to provide a high "back pressure" signal to the control system. However, this has a very serious disadvantage in that the restrictor must have an orifice of a diameter smaller than that of the tube in which it is located, thus making it a prime source of clogging. In fact, if such a restrictor were to be used in connection with an atomizer having large liquid feed passages such as in applicant's atomizer 10, the anti-clogging benefits of the large passages would be lost.

Accordingly, another object of the present invention is to provide a clog-resistant feed system which provides a relatively high back pressure at the atomizer feed input so as to provide a relatively high input signal to a feed control system. A further object of the present invention is to provide such a feed system adapted to feed fluids to atomizers requiring relatively low or no fluid feed pressure.

Referring especially to FIGURE 2, the liquid feed structure which meets these objects includes an inner sleeve 30 which is fitted onto a cylindrical portion of the outside of nozzle member 12 and abuts a shoulder near the forward or downstream end of nozzle member 12. An outer sleeve 32 is fitted onto the exterior surface of inner sleeve 30 and is secured at its downstream end to a raised annular portion 34 of nozzle member 12 which is a raised land forming an annular groove or passageway 36. The inlet openings of fluid feed passages 26 and 28 are located within the groove 36.

An annular groove 38 in the upstream end of inner sleeve 30 forms an annular fluid inlet passageway. Passageway 38 communicates with a pipe coupling 40 which forms a part of outer sleeve 32.

As is shown in FIGURE 4, fuel is pumped into the inlet coupling 40 by means of a high pressure pump and control system 73. The back-pressure of the fuel in inlet passageway 38 is sensed by the control system and is used as an input signal.

In accordance with the present invention, the back pressure in passageway 38 is made quite high by providing a pair of parallel helical grooves 42 and 44 in the outer surface of sleeve 30. Grooves 42 and 44 form, with sleeve 32, elongated, winding flow-resisting fluid flow tubes connected between inlet passageway 38 and feed holes 26 and 28.

As is seen in FIGURE 3, the exit openings 46 and 48 of the helical passages 42 and 44 are spaced 180° apart from one another and along an axis 90° from the axis of holes 26 and 28. Similarly, as is shown in FIGURE 4, the inlet openings 50 and 52 to helical passages 42 and 44 are located 180° apart and 90° from the inlet coupling 40 so as to maintain even feeding at the inlet.

Grooves 42 and 44 preferably are cut into sleeve 30 as threads and are square in cross section. Each groove has a uniform cross-sectional area along its length. Preferably, the grooves 42 and 44 are equal to one another in cross-sectional area, but their areas deliberately may be made unequal in order to alter the shape of the spray or flame emitted by the atomizer. The bottoms of grooves 42 and 44 are even with the land forming the bottom of outlet groove 36, and with the bottom of groove 38 so as to provide a smooth, continuous bottom wall for the inlet and outlet to grooves 42 and 44.

Each helical groove 42 or 44 provides frictional resistance to the flow of fluid through it. The length of each groove is set at a value sufficient to provide the desired back pressure in the inlet passageway 38. For example, in a typical installation of the atomizer 10 in a gas turbine, the grooves 42 and 44 provide a pressure of 60 or more p.s.i.g. at their input but very low pressures at their output.

Grooves 42 and 44 advantageously provide a relatively great amount of pressure drop in a relatively small space. The inner sleeve into which the threads 42 and 44 are cut forms a part of the cylindrical nozzle structure so that

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the grooves 42 and 44 can be made quite long and yet require very little space that would not ordinarily be required for the atomizer itself.

Most importantly, the cross-sectional area of grooves 42 and 44 is large relative to the orifice diameter of a conventional line restrictor which might be suggested for use in providing the desired pressure drop. Thus, grooves 42 and 44 easily pass fuels containing large quantities of contaminants without clogging whereas other more conventional atomizers quickly become inoperative due to clogging when using the same fuels.

FIGURES 10 through 12 of the drawings show another embodiment of the atomizer and burner structure of the present invention. The atomizer and burner 60 shown in FIGURES 10 through 12 is quite similar to the device 10 shown in FIGURES 1 through 5, and the same reference numerals are used for corresponding components of the two devices. The main differences between the devices 10 and 60 are that in the device 60 the nozzle body 12 is relatively short and is secured to a fluid feed structure 62 by a rod 64 and a tube 66. This construction leaves the inlet opening 68 of converging nozzle section 16 open to the atmosphere and enables the nozzle to receive compressed air directly from the turbine compressor, as will be described in greater detail below.

The fluid feed structure 62 includes a housing 70 with a pair of flanges 73 and 74 with holes for mounting the structure 60 in an engine. Housing 70 includes a vertical cylindrical cavity with a lateral hole 72 communicating with the cavity. One end of fluid feed tube 66 is force-fitted into the hole 72 so as to communicate with the vertical cavity in the housing 70. One end of tube 64 is fitted into a similar hole in housing 70 located above hole 72.

Fitted into the vertical cavity in housing 70 is a cylindrical member or "plug" 74 which has a helical groove 76 of square cross-section cut into its external surface. The lower end of the plug 74 has a smaller diameter than the rest of the plug so as to form an annular chamber 78 in the housing 70 which communicates with the fluid feed tube 66. A cap 80 is secured over the top of housing 70 with its bottom substantially flush with the top of the helical plug 74. Cap 80 has a horizontal hole 82, and a centrally-located vertical hole 84 communicating with horizontal hole 82.

As is best shown in FIGURE 12, the helical plug 74 has a square groove 86 cut into its uppermost surface. Fuel feed tubes 88 are fitted into the hole 82 and fuel is fed through tubes 88, hole 84 and groove 86 to the helical fluid flow passageway 76. The passageway 76 provides resistance to the flow of fluid and supplies a relatively high back pressure to the fuel supply system, much in the manner described above in connection with FIGURES 1 through 5. The helical plug preferably is force-fitted into the vertical cavity in housing 70 so as to provide a fluid-tight passageway for fuel flow, and the seams and joints between components of the structure 60 preferably are welded together to provide a fluid-tight fit.

Referring again to FIGURE 11, the left end 92 of tube 66 has a reduced external diameter and is fitted into a mating hole in the nozzle body 12. A hole 94 in the body 12 communicates between tube 66 and a groove 96 which extends around the periphery of nozzle body 12 and communicates with the two opposed fluid feed holes 26 and 28 which exit into the stabilizing section 18 of the nozzle. A cylindrical ring 98 is secured over the groove 96 to seal it shut.

The resonator 100 shown in FIGURES 10 and 11 is different in several ways from the resonator 24 shown in FIGURES 1 and 2. The resonator structure 100 is shorter and has a hemispherical instead of cylindrical external shape. Also, the reflecting rear surface 102 of the cavity 22 is positioned considerably closer to the nozzle exit openings than the corresponding reflecting surface of the cavity 22 shown in FIGURES 1 and 2. The dashed

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lines 104 shown in FIGURE 11 indicate the probable outline of oblique shock waves believed to be set up between the exit of the nozzle and the reflecting surface 102. These shock waves are believed to be repetitive waves with a wave-length which is capable of being calculated in accordance with the above-mentioned co-pending patent applications. The distance X in FIGURE 11 is the distance between the end of the nozzle and the first intersection point 106 of the shock wave outline 104. This distance is equal to one-half wave length of the shock wave pattern. The reflecting surface 102 is located just beyond the intersection point 106; in other words, surface 102 is located in the first portion of the second half wave-length from the exit opening of the nozzle 12. In contrast, the reflecting surface of the resonator in FIGURES 1 and 2 is located in the last portion of the second half wave-length. Also, the depth of cavity 22 in FIGURE 11 is not as great as that of the corresponding cavity in FIGURES 1 and 2. In this manner, the resonator 100 does not extend nearly as far forward of the nozzle as the resonator 24. This reduces the tendency toward heating of the resonator structure in the turbine combustion chamber. The hottest part of the flame occurs well downstream from the resonator 100.

The hemispherical shape of resonator 100 is believed to create thicker gas boundary layers between the resonator surface and the gases flowing around the resonator so as to provide insulation against heat transfer from the flame to the resonator metal. The material of which the resonator 100 is made preferably is heat-resistant steel such as that known by the trade designation "Inconel 600."

The diameter of resonator 100 is greater than the diameter of the resonator 24 shown in FIGURES 1 and 2. Preferably, this diameter is approximately the same as the external diameter of nozzle member 12. This provides a shorter, more wide-spread flame so as to minimize the length of combustion chamber needed in the engine and maximize flame spreading.

FIGURES 6, 8 and 13 show a gas turbine engine 106 utilizing ten of the atomizing and burning devices 60. With the exception of the combustion system, the construction of the engine 106 is known in the prior art. Many of the known features of this engine are used, for example, in the type "331" turbo-prop engine manufactured by Airesearch Manufacturing Division of Garrett Corporation. Air enters the engine by means of an air scoop 108 and is directed to the impeller blades 110 of a first compressor. The air flows through the engine along the path indicated by the dashed lines 112. The compressed air from the first compressor flows through a duct 114 which conducts the air to the impeller blades 116 of a second compressor. Impellers 110 and 116 of the two compressor stages are mounted on a common drive shaft 117 which also provides rotary output drive power to drive an aircraft propeller, electrical generator or a similar load.

The compressed air is conducted from the second compressor through a duct 118 to a passageway between the engine outer wall 130 and an annular-shaped combustion chamber 120. The side walls of the combustion chamber 120 have multiple holes 122 (see FIGURE 8) through which the compressed air flows into the combustion chamber.

Referring now to FIGURE 8, the atomizing and burning unit 60 has a short cylindrical portion 124 extending from the fluid feed housing 70. Portion 124 is fitted into a cylindrical receptacle in the rear wall of the engine housing. Bolts are fitted through the holes in flanges 72 and 74 and nuts 126 (shown in dashed outline in FIGURE 8) are screwed onto the bolts to hold the unit 60 in place in the engine.

The nozzle section 12 is fitted into a ring 128 which is secured in an opening at the rear end of the combustion chamber 120. Thus, the compressed air flowing in the space between the outer wall 130 of the engine housing

and the combustion chamber 120 is supplied directly to the inlet opening 68 of the nozzle. Because the holes 122 in the combustion chamber restrict the flow of air into the combustion chamber 120, a pressure difference exists between the interior and exterior of the combustion chamber. As noted above, this pressure differential varies in a typical engine from approximately one-half of one p.s.i.g. to five p.s.i.g. It is this pressure differential which is used to force air through the nozzle 12 and operate the atomizing and burning unit 60. It is to be noted that the turbine compressor is the sole means used to provide pressurized air for operating the atomizer. No auxiliary air compressor is needed, although such a compressor could be provided if desired.

In the unit 10 shown in FIGURES 1 through 5, compressed air is supplied from the turbine compressor to the inlet tube 14 by means of a separate tube (not shown). However, in the structure shown in FIGURES 6 and 8, the need for such an auxiliary tube is eliminated.

Fuel is fed to the fuel feed pipes 88 (see FIGURE 13) through an inlet connection 132. Each of the ten burners produces a "flat" flame which whose broadest dimension is in a direction circumferential with respect to the combustion chamber 120. Thus, the flames from the ten burners unite at their edges and form a substantially continuous ring of flame. The fuel burned in chamber 120 raises the temperature of the air flowing into the chamber and forces the heated air through an outlet opening 134 where it is directed through a 3-stage turbine 136 which is secured to shaft 117. In the turbine 136 the compressed, heated gas is expanded and caused to drive the shaft 117 upon which the turbine blades are mounted. Upon leaving the turbine 136, the gases flow through a diverging diffuser section 138 through which they are exhausted to the atmosphere. Depending upon variable design features of the turbine 136, the turbine can extract either a large part of the work from the gases coming from the combustion chamber so as to provide primarily rotary output power from drive shaft 17, or can extract only enough power to drive the compressors, thus providing substantial amounts of thrust for pure jet propulsion of aircraft.

The atomizing and burning unit 60, like the unit 10 shown in FIGURES 1 through 5, does not require a high pressure fuel supply source and has large fuel flow passages which do not readily become clogged. Furthermore, the sonic energy developed by the unit tends to clean the fuel flow passages and further prevent clogging. The fuel flow range over which good atomization is obtained is relatively wide so that only one nozzle need be supplied to provide good rangeability of fuel flow.

FIGURES 7 and 9 show a gas turbine engine 140 utilizing a single cylindrical combustion chamber 142 in combination with the atomizing and burning unit 60.

Air enters the engine 140 through an inlet 144 and is directed to compressor impeller blades 146 which are mounted on an output drive shaft 148. The compressed air flows through a duct 150 along a dashed line 152 and through a passageway 154 around the outside of the combustion chamber 142. Chamber 142 is shown broken away in FIGURE 7 to reveal internal construction details of the engine.

Referring particularly to FIGURE 9, the compressed air from the compressor flows between the combustion chamber 142 and the external wall 156 of the engine housing. The combustion chamber 142 has a plurality of holes 158 in its surface through which the compressed air enters the chamber. The atomizing and burning unit 60 is mounted in the rear wall of housing 156 and in the rear wall of combustion chamber 142, and the compressed air is forced through opening 68 of the nozzle 12, all in substantially the same manner as is described above with respect to FIGURE 8. However, a cap 160 which is different from the cap 80 is secured to the top of the fluid feed housing 70. The cap 160 has a threaded ver-

tical hole 162 into which a fuel feed line 164 (see FIGURE 7) is connected.

The heated air from combustion chamber 142 flows through a spiral-shaped passageway in the engine along the path indicated by the dashed lines 166, and then flows against the blades of a single-stage turbine 168 where most of the energy is extracted from the heated gases and is converted into rotary power. The heated gases then leave the engine by means of a short diffuser 170.

The engine 140 generally is smaller than the engine 106 shown in FIGURE 6. It should be understood, however, that the engines 106 and 140 are shown merely by way of example of the variety of internal combustion engines in which the invention may be utilized. For example, the atomizer and burner of the present invention can be used in turbo-jet engines in which a plurality of cylindrical combustion chambers are arranged in an annular pattern. Also, the invention can be used in axial-flow type jet engines and, in fact, in many different types of internal combustion engines.

It should be understood that it is not necessary for the nozzle inlet gas of the atomizer and burner to be compressed in order for the device to operate. All that is required is that the nozzle inlet gas pressure be higher than the pressure of the ambient gas at the nozzle outlet. For example, the nozzle inlet may be open to the atmosphere so that the inlet pressure is atmospheric pressure while the nozzle outlet exits into a partially-evacuated chamber. This will create the necessary pressure difference for operation of the atomizer.

The atomizers and burners 10 and 60 have been used successfully as gas turbine burners. They have been tested against conventional nozzles using small orifices through which the fuel is forced under high pressure. For example, in actual tests of a simulated gas turbine using ten of applicant's fuel-burning atomizers 10, the turbine has operated for over ten continuous hours using fuels with large amounts of solid particles (sand, etc.) without showing any signs of clogging. In comparison, when the same simulated turbine was operated with the same fuels and ten of the burner nozzles previously used in the turbine, it operated for only a matter of a few minutes before the turbine become inoperative due to clogging of the fuel feed passages of the nozzles.

What is more, in similar tests the flame produced by applicant's nozzles was quite substantially hotter than the flame provided by the prior nozzles. What is more, fuels of widely different viscosities were used with equal success in applicant's nozzles whereas the prior nozzles would effectively burn only relatively volatile fuels such as kerosene. Moreover, the fuels successfully used in applicant's nozzles were relatively cheap fuels such as Nos. 2, 4 and crude oils. In fact, then, the use of applicant's nozzles makes it possible to use low cost fuels in the turbine and save considerably in fuel costs.

The present invention even makes it possible to change fuels during operation of the engine without shutting the engine off and without any noticeable interruption of combustion. For example, fuels can be changed from high-grade, high-volatility fuels to low-grade, low-volatility fuels, and operation even can be changed to the use of pure natural gas fed through the nozzle of the atomizer.

When gaseous fuels are used, they may be fed into the system in the same manner as liquid fuels, or they may be used with the arrangement of FIGURES 1 through 5 as the compressed gas source for driving the atomizer.

As has been pointed out above, another advantage of applicant's atomizers is that they are capable of operating at very low air input pressures, e.g. pressures well below ½ p.s.i.g. Thus, the pressure of the air supplied by the ordinary turbine compressor is more than sufficient to supply the atomizer gas without further compression.

Still another advantage of applicant's fuel-burning atomizers is that they can give a flat-shaped flame pattern

having its widest cross-sectional dimension in the direction of the axis of holes 26 and 28. This flat flame gives an improved turbine burner flame in that a number of the atomizers can be arranged in a circular pattern with their wide flames aligned side-to-side in a gas turbine burner compartment to produce a substantially continuous ring of flame with relatively minor temperature variations around the ring. This even flame temperature distribution provides greatly improved performance for the turbine. The wide-spread flame issuing from each atomizer causes considerable overlapping between adjacent flames and creates this even distribution.

The above description of the invention is intended to be illustrative and not limiting. Various changes or modifications in the embodiments described may occur to those skilled in the art and these can be made without departing from the spirit or scope of the invention as set forth in the claims.

We claim:

1. In a gas turbine engine, fuel burning apparatus comprising, in combination, a gas-operated pressure wave generator comprising a housing forming a gas flow passageway having inlet and outlet openings, first and second spaced positions in said passageway, restrictor means at said first position for reducing the cross-sectional area of said passageway, expansion means for increasing the cross-sectional area of said passageway between said first and second positions in the direction of gas flow through said passageway and expanding and accelerating a gas to supersonic velocities, resonator means positioned adjacent said outlet opening, means for subjecting fluid fuels to the pressure waves produced by said generator and atomizing said fuels, air compression means, at least one combustion chamber providing a combustion area in said engine, means for conducting compressed air from said air compression means to said combustion chamber and to the inlet of said gas flow passageway to operate said pressure wave generator, said pressure wave generator being mounted in a wall of said combustion chamber with its inlet communicating with said conducting means and its outlet opening exiting into said chamber, said combustion chamber having at least one inlet opening communicating with said conducting means.

2. Apparatus as in claim 1 in which said combustion chamber has a jet-forming outlet opening and including turbine means driven by said jet, and means for forming a drive coupling between said turbine means and said compression means.

3. Apparatus as in claim 1 in which said combustion chamber has a plurality of inlet openings communicating with said conducting means, said pressure wave generating means is integral with a wall of said combustion chamber with its inlet communicating with said conducting means and its outlet exiting into said chamber.

4. Apparatus as in claim 1 including means for feeding liquid fuels to said atomizing and burning means, said feeding means including flow retarding means having an elongated serpentine flow passage for resisting the flow of liquids through it and producing a relatively high back-pressure in the liquid supplied to said flow passage.

5. Apparatus as in claim 1 in which said combustion chamber is annular in shape and includes a plurality of said fuel burning devices mounted at spaced intervals around the periphery of said chamber.

6. Apparatus as in claim 3 including a fluid feed structure mounted on said engine outside both said combustion chamber and said conducting means, and at least one

tubular member for conducting fluid fuel to said burning apparatus from said feed structure with said inlet openings of said passageway being open to the ambient gas.

7. Apparatus as in claim 1 in which said combustion chamber is substantially cylindrical in shape and exits into a generally spiral-shaped flow passageway which produces and directs a stream of hot gases against the blades of a turbine.

8. In a gas turbine engine, fuel burning apparatus comprising, in combination, a plurality of gas-operated pressure wave generators each comprising a housing forming a gas flow passageway having inlet and outlet openings, first and second spaced positions in said passageway, restrictor means at said first position for reducing the cross-sectional area of said passageway, expansion means for increasing the cross-sectional area of said passageway between said first and second positions in the direction of gas flow through said passageway and expanding and accelerating a gas to supersonic velocities, resonator means positioned adjacent said outlet opening, means for feeding fluid fuels into said pressure wave generators and subjecting them to the pressure waves produced by said generator and atomizing said fuels, a centrifugal air compressor coupled to an axial shaft, a plurality of turbine blades connected to said shaft, an annularly-shaped combustion chamber encircling said turbine blades and having an exit opening adapted to direct heated gases against said turbine blades to rotate said shaft, said combustion chamber having a plurality of spaced holes in its exterior, an air flow chamber surrounding but spaced from said combustion chamber, means for conducting compressed gas from said compressor into said air flow chamber, the housing of each of said pressure wave generators being mounted in a wall of said combustion chamber with its inlet communicating with said air flow chamber and its outlet opening exiting into said combustion chamber, said fuel feeding means being mounted exteriorly of said air flow chamber and including a tubular fuel feeding member passing into said air flow chamber and connected to said pressure wave generator.

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2,716,863	9/1955	Reingold.		
2,746,246	5/1956	Valota	60—39.65	X
2,875,578	3/1959	Kadosch	239—434	X
2,944,029	7/1960	Jones	158—77	
3,070,313	12/1962	Fortman	158—77	
3,230,923	1/1966	Hughes	116—137	
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