July 15, 1952 **D. C. IPSEN ET AL** **2,603,535**

LIQUID SPRAY NOZZLE

Original Filed Oct. 16, 1945

3 Sheets-Sheet 1

Fig. I.

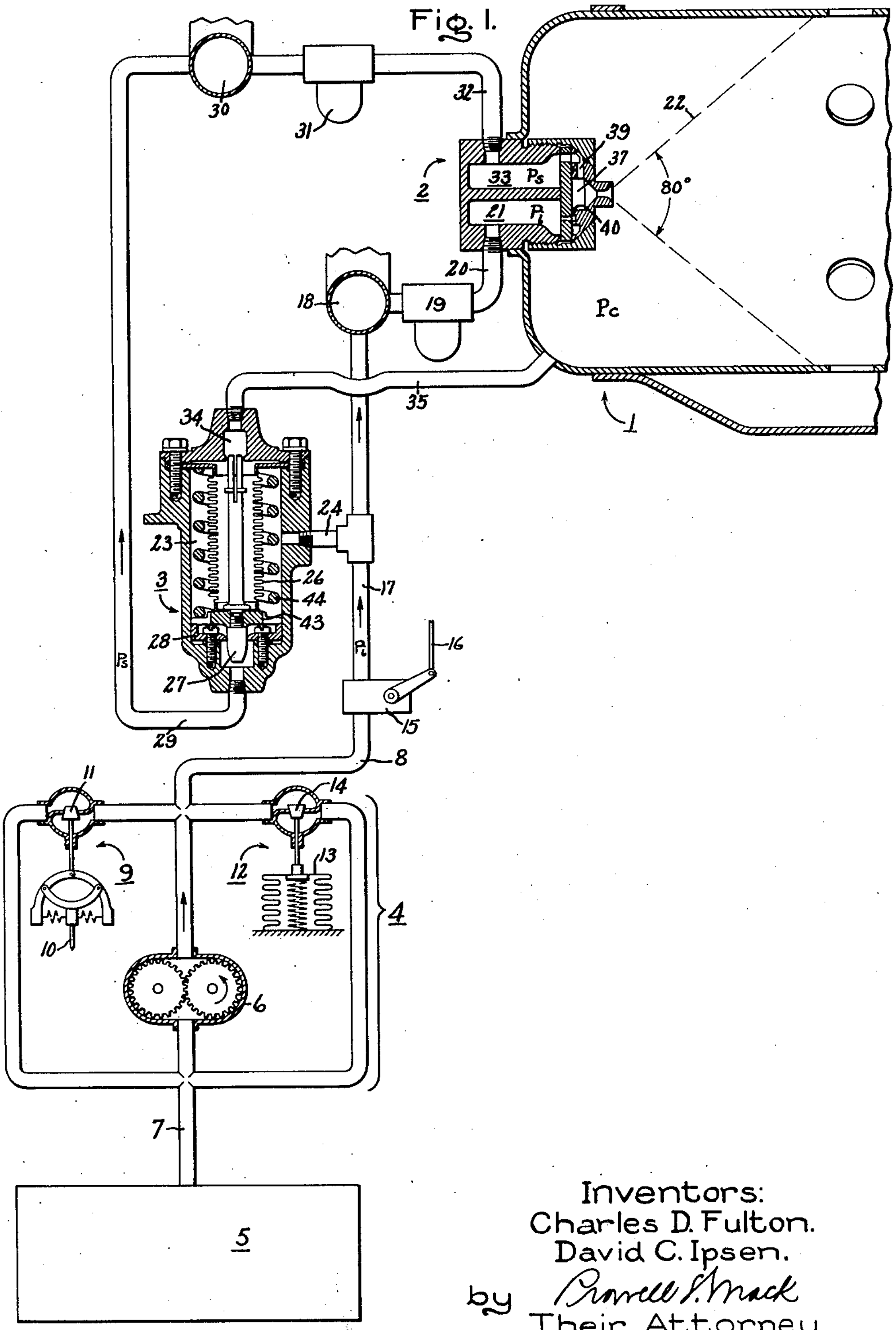

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Fig. 2.

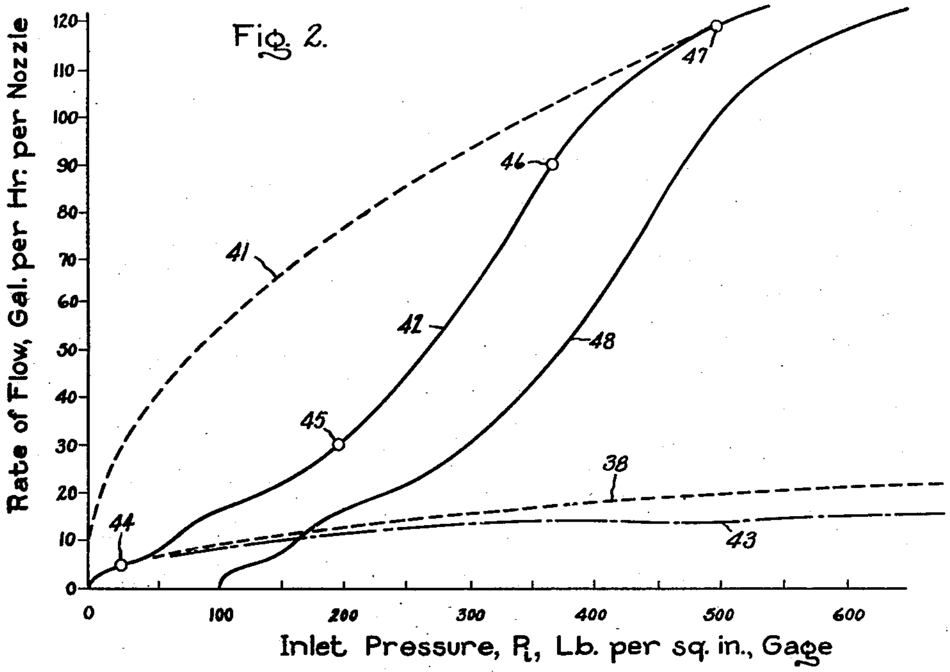


Fig. 3.

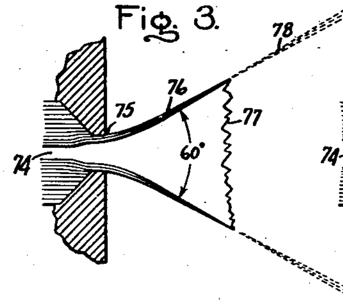


Fig. 4.

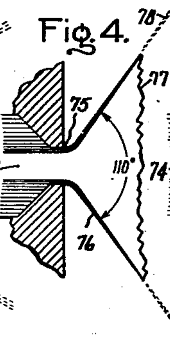


Fig. 5.

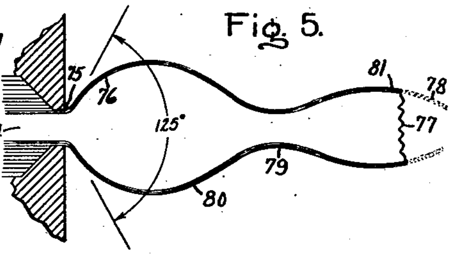


Fig. 6.

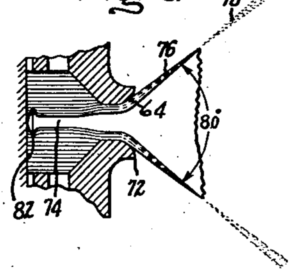


Fig. 7.

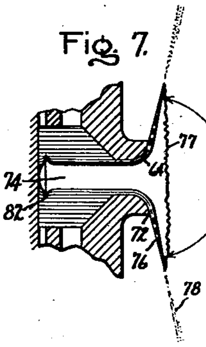
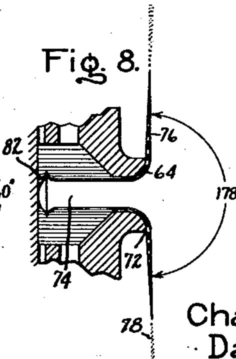


Fig. 8.



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Original Filed Oct. 16, 1945 3 Sheets-Sheet 3

Fig. 9.

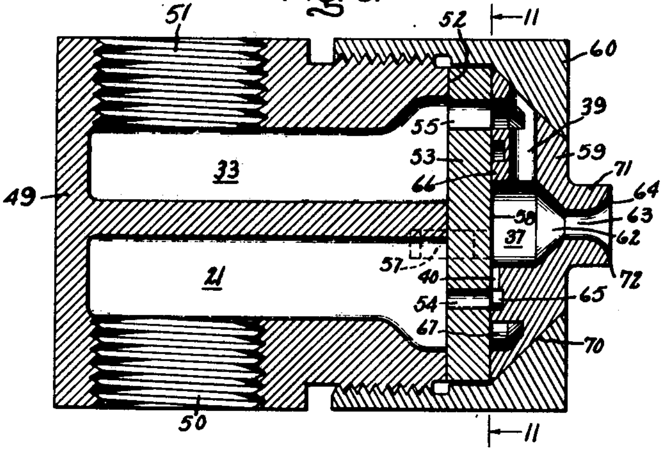


Fig. 11.

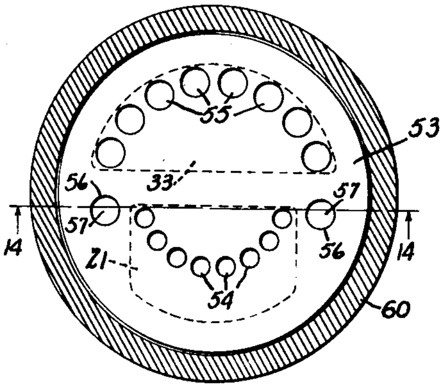


Fig. 12.

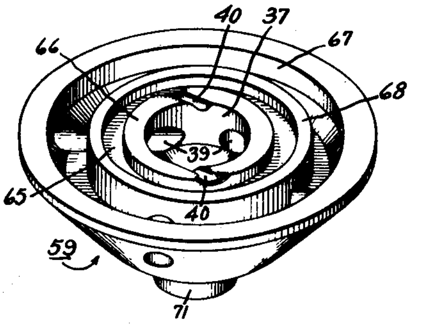


Fig. 10.

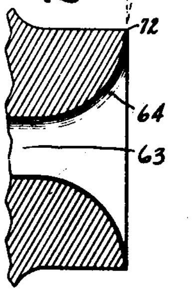


Fig. 13.

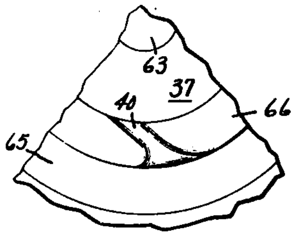
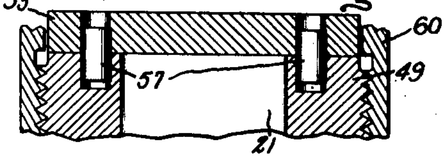


Fig. 14.



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Their Attorney.

UNITED STATES PATENT OFFICE

2,603,535

LIQUID SPRAY NOZZLE

David C. Ipsen, Schenectady, and Charles D. Fulton, Scotia, N. Y., assignors to General Electric Company, a corporation of New York

Original application October 16, 1945, Serial No. 622,604. Divided and this application January 25, 1947, Serial No. 724,408

5 Claims. (Cl. 299—114)

This invention relates to liquid atomizing spray nozzles, particularly for use in apparatus for producing an atomized spray of liquid fuel in a combustion device. It is particularly adaptable to liquid fuel combustion systems, as used in gas turbine powerplants.

This is a division of our application Serial No. 622,604, filed October 16, 1945, now Patent No. 2,580,853.

The advent of gas turbine powerplants for the propulsion of aircraft raised a need for new and greatly improved methods and apparatus for spraying liquid fuels over a wide range of flow rates. In addition, the operating conditions encountered by an aircraft are extremely difficult because of the enormous range of atmospheric temperatures and pressures encountered, particularly in high altitude aircraft. Furthermore, it is generally necessary to employ a plurality of fuel spraying nozzles discharging either into a number of small separate combustion chambers or into one large chamber. For successful use in gas turbine service, it is absolutely essential that fuel be supplied equally to each nozzle and discharged uniformly into the combustion space, in order that the temperature of the hot gas produced will be entirely uniform. This is of the greatest importance because the modern high performance gas turbine operates at a temperature level exceedingly close to the maximum allowable temperature, so that any "hot spot" in the operating medium has a serious effect on the life of the apparatus as well as on the combustion efficiency and fuel economy of the powerplant. With all the increased difficulties encountered, a fuel system for use in aircraft must of course be of the utmost reliability. The requirements of military aircraft are particularly stringent because of the rapid changes in operating conditions met with in fighter aircraft, the need for maximum fuel economy in order to improve the operating range, and the supreme importance of absolute reliability.

In the past, various types of liquid fuel spraying nozzles have been resorted to in order to obtain a wide range of flow rates. One of these was the "recirculating" or "Peabody" type of nozzle, in which a supply pump at all times furnishes liquid approximately at the maximum rate ever required, and a portion of the fuel supplied to the nozzle is returned to the pump or "recirculated" to reduce the amount discharged from the nozzle to the desired rate. Such a nozzle may be satisfactory for stationary or marine use where the size and weight of the fuel system and the power consumed by the pumping apparatus are not critical. It is undesirable however for aircraft use, where size, weight, and power consumed are of the utmost importance.

A perhaps less well-known type of wide range nozzle is what will be referred to herein as the "duplex" type. This nozzle has a discharge orifice, a vortex whirl chamber, two separate sets of orifices or ports for supplying liquid to the vortex chamber, and a liquid supply system arranged to supply liquid to the two sets of ports at various pressures in order to secure the desired total flow rate, while still preserving the velocities required in the vortex chamber to produce a spray with satisfactory characteristics. The duplex nozzle system has important advantages for use in connection with aircraft gas turbines by reason of the fact that all the liquid supplied by the pump is delivered by the nozzle; that is, there is no surplus "recirculation" flow which must be handled by the pump. Therefore with the duplex system, the pump, liquid lines, nozzles, and other components of the system can be made smaller and therefore lighter for given performance characteristics than is possible with a system of the recirculating type.

The present invention relates to a new and improved nozzle of the duplex type.

An object of our invention is to provide a liquid fuel nozzle for use in a spray system capable of producing a satisfactory atomized spray having a pattern in the shape of a hollow circular cone with a definite preselected minimum vertex angle over an extremely wide range of initial supply pressures and flow rates.

Another object is to provide a liquid spray nozzle of the duplex type capable of producing a well atomized spray having a pattern in the form of a wide angle cone over an extremely wide range of flow rates.

Still another object is to provide an improved arrangement of liquid supply orifices or ports in a duplex type nozzle.

A further object is to provide an improved form of discharge orifice particularly advantageous in a nozzle of the duplex type.

Another object is to provide an improved form of duplex nozzle which facilitates accurate and easy balancing or matching of sets of nozzles to be used together.

Still another object is to provide a duplex type nozzle with an orifice tip member which can be easily manufactured, and having ports arranged so that their size can be controlled to extremely accurate limits by simple manufacturing methods.

Other objects and advantages will be apparent from the following description, taken in connection with the accompanying drawings in which Fig. 1 is a diagrammatic representation of a complete liquid fuel spraying system having a nozzle in accordance with our invention; Fig. 2 is a graphic representation of the flow characteristics of the system of Fig. 1; Figs. 3, 4 and 5 represent diagrammatically the liquid discharge from a duplex nozzle having a plain orifice; Figs. 6, 7 and 8 represent the flow obtained with our improved form of nozzle; Fig. 9 is a sectional view of a preferred structure of our improved duplex nozzle; Fig. 10 is a more detailed view of the flared orifice of the nozzle shown in Fig. 9; Fig. 11 is a sectional view in the direction of the arrows **11**—**11** in Fig. 9; Fig. 12 is a perspective view of our improved nozzle orifice tip; Fig. 13 is a plan view, to an enlarged scale, showing the shape of one orifice or port of the nozzle tip shown in Fig. 12; and Fig. 14 is a partial sectional view on the plane **14**—**14** in Fig. 11.

Referring now to Fig. 1, a combustion chamber or "combustor" **1** is supplied with atomized liquid fuel by a vortex spray nozzle **2** of the duplex type. One set of ports **40** in the duplex nozzle is supplied with liquid at the full inlet pressure, while the other set **39** is supplied with liquid at a reduced pressure produced by a metering device **3**. Liquid fuel under pressure is furnished by a supply system represented diagrammatically at **4**.

The fuel supply system **4** may be of any suitable type such as that disclosed in abandoned application Serial No. 525,416, filed in the name of Austin G. Silvester on March 7, 1944, and assigned to the same assignee as the present application. This system includes a fuel supply tank **5**, a positive displacement pump **6**, represented as being of the well-known gear type driven by any suitable means (not shown) and having a suction conduit **7** and a discharge conduit **8**. A combination of auxiliary devices control the discharge pressure of the pump **6** so as to supply liquid to discharge conduit **8** at a pressure which varies as a preselected function of the throttle setting, or of the fuel flow or heat liberation desired. These control devices are represented in Fig. 1 as comprising a speed responsive flyball governor **9** arranged to be driven at a speed proportional to a rotational speed of the powerplant through a shaft **10**. This speed governor actuates a bypass valve **11** which permits liquid from the discharge conduit **8** to be returned to the pump inlet conduit **7** as a function of speed. Similarly, barometric device **12** comprises an evacuated bellows **13** arranged to actuate a bypass valve **14** to reduce the liquid pressure in conduit **8** as a function of altitude, or some other pressure appurtenant to the operation of the system.

Instead of the supply system **4**, many other arrangements may be used for supplying fuel to the conduit **8** according to a preselected pressure schedule. One other such system is shown in application Serial No. 605,960, filed July 19, 1945, in the names of M. A. Edwards, D. E. Garr, and H. M. Ogle, and assigned to the same assignee as the present application.

At **15** in Fig. 1 is represented a valve actuated by any suitable linkage **16** which may be arranged to serve both as a stopcock for completely shutting off the supply of liquid to the nozzle system, and also as a throttle valve for metering the fuel in accordance with the fuel flow or heat liberation desired. One such valve is also disclosed in the aforementioned patent application of Austin G. Silvester. It will be apparent that the valve **15** may be considered a part of the fuel supply system **4**.

As will be seen from Fig. 1, liquid supply system **4** and valve **15** produce a pressure P_i in the main inlet or "primary" conduit **17**. Liquid at pressure P_i is supplied directly from conduit **17** to a manifold **18**, thence through a suitable filter **19** and branch conduit **20** to the primary chamber **21** of nozzle **2**. For convenience it will be assumed herein that pressure drops in the conduits and filter **19** can be neglected so that the pressure in chamber **21** of the nozzle is the same value P_i as obtains at the entrance to the fuel nozzle system, that is, the discharge side of valve **15**. The flow of liquid from the chamber **21** to the fuel spray cone **22** in the combustor **1** will be described more particularly in connection with Figs. 3 to 13 inclusive.

Liquid from conduit **17** is admitted to chamber **23** in the metering device **3** (hereinafter referred to as the "flow divider") through branch conduit **24**. The pressure P_i of the liquid in chamber **23** causes flexible bellows **26** to collapse to a certain extent and position the metering pin **27** relative to orifice plate **28** so as to vary the effective area of the annular orifice defined thereby as a preselected function of the inlet pressure P_i.

It will be readily seen from Fig. 1 that when the inlet pressure P_i rises to a certain value, metering pin **27** will be retracted so as to provide an annular clearance space with orifice plate **28** so that liquid from chamber **23** can flow into conduit **29** and thence to manifold **30**, filter **31**, branch conduit **32**, and into a secondary supply chamber **33** in nozzle **2**. For convenience the pressure P_s in the secondary chamber **33** of the nozzle will be considered equal to that obtaining in conduit **29** at the downstream side of metering device **3**.

While only one combustor **1** and one nozzle **2** have been illustrated in Fig. 1, it will be understood by those skilled in the art that our system is particularly adapted for use with a plurality of combustors having fuel nozzles in parallel and supplied by branch conduits similar to **20**, **32** from manifolds **18** and **30** respectively. Gas turbine powerplants embodying such an arrangement of combustors are disclosed in applications Serial Number 506,930, Alan Howard, filed October 20, 1943, now Patent No. 2,479,573, and Serial Number 525,391, Dale D. Streid, filed March 7, 1944, now Patent 2,432,359, issued December 9, 1947.

In order to make the description of our improved nozzle system as simple and clear as possible, it will be assumed that the pressure P_c in the combustor is equal to ambient atmospheric pressure. For such operation, the port **34** communicating with the interior of bellows **26** of the flow divider **3** may simply be left open to ambient atmospheric pressure. However, when our fuel nozzle system is used in a gas turbine powerplant, such as those of the above-mentioned Howard and Streid applications, the combustion chamber pressure P_c may vary considerably from atmospheric pressure, in which case we have found it sometimes desirable to bias the flow divider by communicating the combustion chamber pressure P_c to the interior of bellows **26**, as by means of a conduit **35**. This biasing arrangement has a certain complex effect on the operation of the system which has been found to be beneficial in connection with some of the fuel regulators with which our fuel nozzle system has been used. When biasing conduit **35** is connected to flow divider **3** as shown in Fig. 1, the entire system from inlet conduit **17** to fuel spray **22** constitutes a "closed" hydraulic system, so that a given static pressure drop between **17** and **22** will produce a definite flow rate regardless of the absolute magnitude of the pressures existing in the system. In other words, the flow rate is determined only by the pressure drop, or differential pressure, across the system. Such an operating characteristic is advantageous in certain types of fuel regulators.

However, certain other types of fuel regulators operate more satisfactorily in conjunction with our fuel nozzle system when the biasing conduit **35** is not used, and the interior of the bellows **26** is either at ambient atmospheric pressure, or sealed with a certain amount of gas inside, or evacuated and sealed. Elimination of the pressure sensing conduit **35** has the very considerable advantages of mechanical simplicity, freedom from clogging or freezing of the conduit **35** during high altitude operation, and avoids the possibility of a large amount of liquid fuel being admitted to combustion chamber **1** through conduit **35** in the event of failure of bellows **26**. When the pressure sensing conduit **35** is not used, the nozzle system is no longer a closed hydraulic system for a third pressure, namely, that existing inside bellows **26** exerts an influence on the position of metering pin **27**. The effect of this influence is explained later.

The details of the construction of combustor **1** are not necessary to an understanding of the present invention. It is sufficient to note that this combustor is preferably made in accordance with the invention of application Serial No. 750,015, filed May 23, 1947, now Patent No. 2,601,000, in the name of Anthony J. Nerad and assigned to the same assignee as the present application. An important characteristic of such a combustor is that the fuel must be sprayed into it with a pattern in the form of a hollow circular cone having a vertex angle which may not decrease below a preselected value, on which the design of the combustor is predicated. In Fig. 1 the fuel spray cone **22** is represented as having an angle of about 80 degrees, which value is selected by analysis and experiment so that unburned liquid particles from the nozzle **2** will not be discharged from the exit portion of the combustion chamber (not shown), and in order to obtain uniformity of temperature distribution in the hot gas leaving the combustor, and for other reasons more fully disclosed in the aforementioned application of Anthony J. Nerad. For the successful and efficient operation of this type of combustor, the fuel spray angle must never under any operating conditions to be encountered fall below the preselected value. It is an important feature of our invention that the nozzle and liquid supply system described herein provides a fuel spray pattern in the form of a cone having an angle which never decreases below this critical value, even though the flow rate and other operating conditions vary over an extremely wide range.

The method of operation of the liquid fuel spraying system shown in Fig. 1 is briefly as follows: It will be assumed first for purposes of illustration that the combustion chamber pressure P_c is equal to ambient atmospheric pressure. For all inlet pressure P_i below a certain value, the metering pin **27** of the flow divider **3** is in a position where it completely fills the orifice in plate **28**, so that there is no flow through the flow divider into line **29**. Therefore, there is no flow from the chamber **33** through the secondary slots **39** to the vortex chamber **37** of nozzle **2**, and the entire amount of fluid discharged from the nozzle flows through conduits **17**, **18**, **19**, **20** to chamber **21** and through the primary slots **40** to the vortex chamber **37**. When the above-mentioned value of pressure P_i is exceeded, bellows **26** in flow divider **3** collapses progressively and retracts the metering pin **27** so as to define with plate **28** an annular orifice through which fuel begins to flow to the secondary slots **39** of the nozzle through conduits **29**, **30**, **31**, **32** and chamber **33**. The total fuel flow is then the sum of the flow through the respective primary and secondary slots.

The flow characteristics of our system are more specifically illustrated in Fig. 2, in which the abscissa is inlet pressure P_i in pounds per square inch gage pressure, while the ordinate is the rate of flow in gallons per hour of kerosene, for one nozzle. Curve **38** is approximately a true parabola representing the variation of flow with inlet pressure obtained if the flow divider metering pin **27** is held in closed position (as shown in Fig. 1) so that no liquid flows to conduit **29** and secondary slots **39**, all the discharge coming from the small primary slots **40**. On the other hand, if the flow divider should be blocked in its wide open position (metering pin **27** fully retracted), then the combined flow through both primary and secondary slots will be represented by the dotted curve **41**, which is also nearly a true parabola passing through zero flow at zero pressure. Because combustion chamber pressure P_c was assumed equal to ambient atmospheric pressure, the inlet gage pressure P_i also represents substantially the pressure drop across the nozzle with flow divider blocked open.

If now the flow divider metering pin **27** is permitted to move freely in its intended manner, then as inlet pressure P_i increases the total discharge from nozzle **2** will increase along the solid curve **42** until at a value of perhaps 40 pounds per square inch the flow divider begins to open and admit liquid at an increasing rate into conduit **29**. The result is that solid curve **42** increases more rapidly than parabola **38**, the difference representing approximately the flow through the large or secondary slots **39**.

The mechanical characteristics of the flow divider **3** are such that the effective area of the orifice defined between metering pin **27** and plate **28** increases as a preselected function of initial pressure P_i. By a simple test it is possible to determine the axial position of the spider **43** carrying metering pin **27** as a function of the amount the bellows **26** is collapsed against the resistance of spring **44** by inlet pressure P_i acting on the exterior surface of the bellows. Account can also be taken, by calculation, of the small effect on the position of pin **27** caused by the variation of the pressure P_s acting on the projected area of the portion of pin **27** subjected to the pressure P_s in the discharge chamber of the flow divider.

Knowing the position of pin **27** as a function of inlet pressure P_i and pressure P_s, it is possible to design the exterior contour of metering pin **27** so that for any given position (corresponding to known values of these pressures) the effective area of the annular orifice defined between the metering pin **27** and the plate **28** is of the exact size required to give the flow into the large slots required at that particular value of P_i. As will be seen from Fig. 2, the solid curve **42** merges with the dotted curve **41** at a value of P_i of about 500 pounds per square inch. This represents the point at which the flow divider reaches its fully open position; and at values of pressure P_i above this point the system performs as if the flow divider were blocked open.

With the flow divider free to move in its intended manner, the flow through the small primary slots **40** does not follow exactly the curve **38**, which represents the flow when the flow divider is blocked closed. Instead, as the flow divider begins to open the primary slot flow drops below curve **38**, in accordance with the dot-dash curve **43**. The reason for this deviation will be discussed more particularly hereinafter.

From a consideration of the structure of our liquid fuel spraying system in the light of the above discussion, it will be readily apparent that the precise shape of the "characteristic curve" **42** from the point where it leaves the parabola **38** to the point where it merges with parabola **41** can be made any desired shape by proper proportioning of the metering pin **27**, provided only that curve **42** lies in the area defined between curves **38** and **41**.

Curve **42** is one sample of many shapes which we have designed for particular applications. Many other desired shapes may be readily obtained, such as for example a straight line, or a curve concave upward or concave downward. This is an important feature of our invention, for it permits the designer great latitude in matching the characteristics of the fuel nozzle system to the requirements of the powerplant and regulating system with which it is used. For instance, if the system is used in connection with a jet propulsion gas turbine powerplant for aircraft, point **44** corresponding to a flow of approximately 5 gallons per hour per nozzle and an inlet pressure of 20 pounds per square inch gage may represent "idling" operation at high altitude (40,000 feet or above), which is the operating condition requiring minimum fuel flow. The fuel flow for "cruising" operation at medium altitudes (25,000 to 35,000 feet) may be represented by the point **45**, corresponding to 30 gallons per hour per nozzle at an inlet pressure of 190 pounds per square inch. "Take-off power" at sea level would similarly be represented by point **46**, corresponding to 90 gallons per hour at 365 pounds per square inch; while "military power" rating would be indicated at point **47**, corresponding to 120 gallons per hour at an inlet pressure of 500 pounds per square inch.

Thus, for the particular gas-turbine requiring the characteristic curve **42**, the fuel system would need to operate satisfactorily over a range of pressures from 20 to 500 pounds per square inch and a range of fuel flow rates from 5 to 120 gallons per hour per nozzle, a range of about 25 to 1. While this range is all that is required for the particular engine on which curve **42** is based, our fuel nozzle and system is actually capable of producing a much greater range. For instance, satisfactory operation may be obtained with apparatus as described herein from approximately 2 gallons per hour to 100 gallons per hour, or a range of 50 to 1.

While our system has so far been described as if the combustion chamber pressure P_c were equal to ambient atmospheric pressure, it should be noted that the effect of increasing the pressure P_c is to shift the curves **38**, **41**, **42** and **43** laterally to the right, without changing their shape (assuming that biasing conduit **35** is used). Thus with a combustion chamber pressure P_c of 100 pounds per square inch, the characteristic curve **42** would become the curve **48**, which is "parallel" to the curve **42**, with a constant horizontal distance between. It will be obvious that this curve drops to zero flow at an inlet pressure P_i of 100 pounds per square inch, since at that value there is no pressure differential across the nozzle **2**.

In many aircraft gas turbines the combustion chamber pressure P_c is found to follow a definite schedule versus the rate of fuel flow; so that when our fuel system is used in a given case, the rate of fuel flow when plotted against inlet pressure P_i will be found to lie approximately on curve **38** at idling flow **44**, to lie from 5 to 15 pounds per square inch to the right of curve **42** at cruising flow **45**, to lie from 35 to 50 pounds per square inch to the right of curve **42** at take-off flow **46**, and from 50 to 75 pounds per square inch to the right of curve **42** at military rating flow **47**. In each case the horizontal distance by which inlet pressure P_i is displaced from the curve **42** shown in Fig. 2 is exactly the combustion chamber pressure P_c at the particular value of P_i (when biasing conduit **35** is used). A curve can be drawn through the points thus determined. Our entire system can be readily designed to take these factors into account.

If biasing conduit **35** is not used, line **48** no longer occupies the position shown in Fig. 2, but would assume a position intermediate lines **48** and **42**. In other words, the effect of increasing combustion chamber pressure P_c above atmospheric pressure is somewhat compensated when the biasing conduit **35** is not used. A careful mathematical analysis is required to determine this case precisely. We have made such analyses and have designed a number of our fuel systems to operate with biasing conduit **35** not connected.

Mechanically, our arrangement including the single flow divider **3** supplying fuel to a number of nozzles **2** from manifold **30** is far superior to other known arrangements which have some sort of metering device associated with each separate nozzle. With our nozzle system, it is much easier to obtain uniform performance from the individual nozzles, and this is a very important feature of our system. Also, it is possible to change the characteristics of the entire nozzle system readily by merely substituting a re-designed flow divider, without changing the nozzles or other components.

Also, it is possible to obtain more precise operation with the single relatively large flow divider **3** than would be possible with small and intricate metering devices associated with each nozzle. Further, our system is simpler and much less costly than would be a system having separate devices in each nozzle.

Fig. 9 is an enlarged view of the duplex nozzle shown in Fig. 1. It comprises a body member **49** provided with a first longitudinally arranged recess **21** having a threaded inlet port **50** and a second recess **33** parallel to recess **21** and having a separate inlet port **51**. The cross-section shape of the recesses **21** and **33** is represented by dotted lines in Fig. 11. It will be apparent from Fig. 9 that recesses **21** and **33** open through the cylindrical right-hand end of the body member **49**. The end face **52** is carefully machined and lapped, or otherwise finished so that all parts of that surface lie accurately in a common plane transverse to the axis of the nozzle.

Held securely against the surface **52** is a backplate **53** shown in section in Fig. 9 and in plan view in Fig. 11. The rear surface of the backplate is likewise carefully finished to a high degree of accuracy so as to form good sealing engagement with the end surface **52** of nozzle body **49** when in assembled relation.

It will be apparent from Figs. 9 and 11 that the chamber **21** is in communication with a number of holes **54** drilled through the backplate **53** and arranged with their centers on an arc of a circle having its center at the geometrical center of the backplate. Likewise chamber **33** is in communication with a series of holes **55** arranged with their centers on an arc of a circle having its center at the center of the backplate, but having a radius appreciably larger than that of the arc on which the holes **54** are arranged.

The backplate **53** is also provided with two holes **56** (Fig. 11) into which project two dowel pins **57** shown in dotted lines in Fig. 9 and more clearly in Fig. 14. Dowels **57** may be pressed into holes drilled in the end of the nozzle body **49** in a manner which will be obvious from Fig. 14. Their function is to hold backplate **53** in proper radial alignment with nozzle body **49**, as well as to make sure that the backplate cannot be assembled in any but the proper orientation relative to the nozzle body.

While we have represented the passages through the backplate **53** as being in the form of a series of round holes **54** and **55**, respectively, it will be obvious that the row of drilled holes **54** might be replaced by an arcuate slot or similar opening; and the holes **55** could likewise be replaced by some equivalent opening.

Associated with the front surface **58** of backplate **53** is the orifice tip **59**, a perspective view of which is shown in Fig. 12. In Fig. 9 it will be seen that the rear surface of tip **59** lies in a common plane perpendicular to the axis of the nozzle. This rear surface is carefully finished, as by grinding and lapping, so as to form good sealing engagement with the front surface **58** of the backplate **53** when in assembled relation therewith. A suitable cap member **60** is threaded onto the cylindrical end of the nozzle body **49** and serves to clamp the tip **59** tightly against backplate **53**, which latter is in turn held securely against end surface **52** of the body member **49**. The cooperating conical surfaces **70** on tip **59** and cap **60** are also carefully machined and polished so as to form a liquid-tight joint.

From Figs. 9 and 12 it will be seen that the nozzle tip **59** is provided with a cylindrical vortex or whirl chamber **37** extending axially inwardly from the flat rear surface of the tip **59** and being provided with a conical end surface **62** communicating with a cylindrical bore **63** forming part of the discharge orifice. It should be particularly noted that the discharge orifice is flared at **64** in a manner shown in more detail in Fig. 10. The precise shape of this flare and the importance of it will be pointed out more particularly in connection with Figs. 3 to 8, inclusive.

By reference to Fig. 12, it will be seen that the whirl chamber **37** is surrounded by a concentric annular groove **65** forming the annular land **66**. In Fig. 9 it will be seen that holes **54** in backplate **53** communicate with this annular groove **65**. The two small or primary slots **40** are formed in the land **66**, equally spaced circumferentially, so as to discharge in a direction substantially tangential to the outer circumferential portion of the whirl chamber **37**, at the extreme rear thereof adjacent surface **58** of the backplate. These primary slots may be formed in any one of several different ways. They may be engraved by hand or machined by various known processes. However, because of the extremely small size of these slots, and the exceedingly high accuracy required so as to obtain the necessary control over their effective area (for purposes of "balancing" or matching a set of nozzles), we have found it most advantageous to form them by a special process, as follows. We first impress the flat top surface of the land **66** with a small coining die so as to form a depression having the proper shape in plan view and the proper contour with respect to depth, but having at all points a depth greater than desired. Then, in order to reduce the effective area of the slots very accurately to the precise value desired, the entire plane rear surface of nozzle tip member **59** is carefully lapped with fine abrasives until the depth of slots **40** is reduced to a value giving precisely the effective cross-section area required. While this method of forming the small slots is of primary value because of the ease with which slots of the precise size and shape needed may be formed, we have found that it has an additional advantage in that the die-forming process produces a slot having a very smooth finish and a surface which is slightly work-hardened so that it has increased resistance to erosion from flowing liquid. This is important because a very small percentage increase in the area of the small slots, caused by erosion, may throw a matched set of nozzles out of balance, with possibly serious results to the combustion efficiency and life of the parts of the fuel burning system.

The shape of the small slots is indicated by the enlarged plan view in Fig. 13; and it may be seen in Fig. 12 how the bottoms of the slots and the approaches to the slot inlets are carefully rounded so as to give optimum fluid flow. The depth of the small slots should be approximately equal to the width for best results.

As will also be seen in Fig. 12, a second annular groove **67** surrounds groove **65** so as to form the land **68**. Groove **67** is arranged to be in communication with chamber **33** by way of the holes **55** (Fig. 9). Arranged in the nozzle tip **59** intermediate the rear portion containing the small slots **40** and the forward portion containing the conical end **62** of the whirl chamber are a plurality of round holes **39** arranged with their axes in a plane perpendicular to the axis of the nozzle and discharging into the forward portion of the whirl chamber **37** in a direction substantially tangential to the outer portion thereof. The radially outer portion of each of the holes **39** communicates with the annular groove **67** in a manner which will be clear from Fig. 9. It will be seen that groove **67** is appreciably deeper than groove **65**; and it will now be seen why the holes **55** and **54** must be arranged on arcs of different radii so as to communicate properly with the grooves **65** and **67** respectively. By carefully machining the end surface **52** of nozzle body **49**, both front and rear surfaces of backplate **53**, the rear surface of nozzle tip **59** and the conical surfaces **70**, and by clamping the parts firmly together by means of the cap member **60**, leakage from the chamber **21** to chamber 33, or from groove 65 to groove 67 or to whirl chamber 37 is prevented.

For convenience the term "slots" will be used herein for the orifices discharging into the whirl chamber 37, but this term should be considered to include grooves like those shown at 40, round holes as shown at 39, and orifice passages of other suitable shapes. The "large slots" 39 may be conveniently formed by drilling and reaming operations before the conical surface 70 of the nozzle tip 59 is machined off. Because of their comparatively large size, these holes may be made with the accuracy required by careful drilling and reaming operations. The exact size of the large slots is not as important as in the case of the small slots, and the percentage error involved in a careful drilling and reaming operation will ordinarily be within the allowable limits. Also it is unnecessary to streamline the entrances to the large slots.

The hydraulic characteristics of our improved form of nozzle shown in Figs. 9–13 will now be considered.

The dimensions and proportions of whirl chamber 37, the size of the cylindrical portion 63 of the discharge orifice, and the size and number of the secondary or large slots 39, are determined in accordance with well-known principles of vortex fluid flow, which need not be discussed here in detail in order to point out our invention. These dimensions and proportions are determined by the maximum flow which is desired, the spray angle desired at maximum flow, and the maximum pressure furnished to the nozzle by the liquid supply system.

While the number of large slots 39 used is not critical, we prefer to use four because that number in most cases will give the capacity required with a hole of a size reasonably easy to drill and ream, and will give a symmetrical spray. In certain extreme cases, it may be desirable to use more than four large slots. Reducing the number of holes below four may result in holes of such large diameter that the axial length of the whirl chamber would be increased unduly, and may also result in an unsymmetrical spray; whereas increasing the number above four may result in the diameter of the hole required falling below a size which can be easily formed by drilling and reaming, and requires more machine work.

In order to obtain the greatest possible range of low rates with a satisfactory spray, it is necessary that the small or primary slots be of extremely small cross-section area so that at the lowest rate of fuel flow the liquid can be injected into vortex chamber 37 at the highest possible velocity. The smaller these slots are, however, the greater is the care and accuracy required in order to produce a cross-section area within allowable limits of percentage deviation from the exact value desired. The sensitiveness with which the rate of flow in one nozzle of a matched set responds to a small error in the area of the small or primary slots is very great, and therefore the sizing of these slots is extremely critical from the standpoint of the "balancing" of such matched sets of nozzles. We have found that "balancing" a set of nozzles is greatly facilitated by locating the small slots on the plane rear face of the nozzle tip in order that the tip may be lapped and these slots thus reduced to the exact area desired. At least two small slots are necessary to insure a symmetrical spray. If more than two are used, unnecessary complexity is added to the nozzle; and each slot will be smaller and therefore more difficult to form correctly, also more susceptible to clogging by dirt. We have found no case where it was necessary to use more than two small slots.

We have found through analysis and experiment that the optimum diameter of vortex chamber 37 in the duplex nozzle as developed by us is between 2 and 3 times the diameter of the discharge orifice 63, the optimum ratio being from 2.4 to 2.5. The greatest range of flow rates with a satisfactory spray will be obtained if these exact proportions are used.

We have also discovered that best results are obtained when the axial length of the vortex chamber 37 is as short as possible. It will be noted in Fig. 9 that the plane of the small slots 40 and their supply groove 65 is located as close as possible to the plane of the large slots 39 and their groove 67. It should be understood that the small slots are arranged to produce rotation of the liquid in whirl chamber 37 with the same direction of rotation as that produced by the large slots 39, so that the effect of the two sets of slots in producing a high rotational velocity in vortex chamber 37 is additive.

While not a particularly important factor with respect to liquid flow in the large slots 39, the surface finish and shape of the small slots has been found to have a most important effect on the overall performance obtained from the nozzle and on the accuracy with which matched sets of nozzles can be "balanced." We have found it necessary to form the small slots with well faired or streamlined approaches to the inlet portion of the slot in order that the jet issuing into the whirl chamber 37 from the discharge end of the slot will be completely stable in direction for all rates of flow and, particularly, will have a minimum of turbulence and internal friction. For the same reasons it has been found necessary to provide an extremely smooth finish on the surface of the small slots. All of these requirements may readily be fulfilled by the above-described method of forming the small slots with a coining die. Of course, additional polishing may be done on the surfaces of the small slots to obtain an even finer finish, but we have generally found this unnecessary because of the excellent finish given by the coining die method.

Another most important factor affecting the hydraulic performance of this nozzle is the shape of the flare 64, which forms an extension of the cylindrical orifice 63 in the boss 71. The details of this flare are shown to an enlarged scale in Fig. 10. The precise shape of the curved flare is not particularly critical, and the arc 64 may be part of a circle, an ellipse, parabola, hyperbola, on any compound combination of such curves, provided the following factors are taken into account. The curve 64 must form a very smooth continuation of the cylindrical bore 63. The surface 64 must have no abrupt changes in rate of curvature. And finally, surface 64 must be shaped so that a tangent to it at the sharp corner 72 and lying in a plane through the axis of the orifice will form an angle 73, relative to a plane normal to the axis of the nozzle, having a value within certain definite limits, as explained more in detail hereinafter. We have discovered that the surface smoothness of the orifice surfaces 63, 64 has an extremely important effect upon the performance of the nozzle. For this reason these surfaces are provided with a very high polish, by any suitable known method.

The effect of the flare **64** on the performance of the nozzle can be seen from a consideration of Figs. 3 to 8, inclusive. It should be noted that these figures are diagrammatic representations, not drawn with mathematical accuracy though based on much experience and photographs of actual sprays. The effect of gravity on the spray patterns shown has been neglected; that is, the flow represented would actually be that obtained with the nozzle directed vertically downward, so that gravity would cause no deflection of particles in a direction transverse to the axis of the spray pattern.

Figs. 3, 4 and 5 represent the spray conditions obtained with high, medium, and low rates of flow, respectively, with a duplex nozzle having a plain cylindrical discharge orifice with no flared portion. Fig. 3 represents the spray which might be obtained at the point **47** in Fig. 2, that is, with an inlet pressure P_1 of about 500 pounds per square inch and a flow rate of about 120 gallons per hour. Fig. 4 and Fig. 5 represent the spray obtained at points **45** and **44**, respectively. Figs. 6, 7 and 8 indicate the improved performance obtained with a nozzle identical to that shown in Figs. 3, 4 and 5, with the same rates of flow and other operating conditions but having a discharge orifice with a flared portion **64** designed in accordance with our invention.

As noted above, Fig. 3 may represent the spray condition obtained at "full military power" (point **47** in Fig. 2). With the inlet pressure corresponding to point **47**, the whirl chamber is nearly full of liquid, with only a very small air core **74**. The liquid leaves the sharp annular corner **75** with a considerable rotational velocity, each particle of liquid tending to travel in a straight line after leaving the corner **75**, so that the initial portion of the conical sheet of liquid **76** is a hyperboloid of revolution. A short distance from the exit edge **75**, the spray pattern is substantially indistinguishable from a straight-sided cone having a vertex angle of approximately 60 degrees. The value of the vertex angle obtained with an unflared orifice as shown in Figs. 3, 4 and 5 will be referred to herein as the "intrinsic angle," defined as that angle produced with a plain cylindrical sharp-edged orifice with given inlet pressure, rate of flow, and other operating conditions. This angle can be calculated from known principles of vortex flow, having given the pressure at the small and large slots, respectively, the effective areas of the slots, the size and shape of the whirl chamber and of the cylindrical discharge orifice **63**, and the characteristics of the liquid being used, particularly the viscosity.

The liquid leaving the nozzle forms a substantially conical sheet **76**, which more or less gradually breaks into discontinuous liquid particles, until at some location indicated by the irregular line **77** the continuous sheet has completely broken into a discontinuous spray indicated by the dotted lines **78**. The location of this transition plane **77** varies somewhat with the pressures on the small and large slots. Furthermore the distinctness of this plane varies considerably, becoming less definite as the pressures increase.

Fig. 4 represents the spray conditions at the point **45** in Fig. 2. Because the large slots at this condition are somewhat throttled by the flow divider, the size of the air core **74** has considerably increased; and the spray angle has increased to an intrinsic value of 110 degrees. The transition plane **77** is more definite than in Fig. 3.

Fig. 5 represents the unsatisfactory spray condition obtained for a plain cylindrical unflared orifice if operated with the low flow conditions represented by the point **44** in Fig. 2. With these conditions, the intrinsic angle has increased to 125 degrees. The liquid sheet **76** initially leaves sharp edge **75** with this intrinsic angle but almost immediately begins to collapse, to form a node **79** defining a somewhat ellipsoidal "bubble" **80** and usually part of a second bubble **81**. As the pressures and flow are varied in this region of operation, the transition plane **77** will move axially along the flow pattern, and may occur at various locations either in bubble **80** or bubble **81**.

The hydraulic process which produces bubbles such as **80** and **81** in Fig. 5 is fairly well known and such bubbles are familiar to those skilled in this art. This phenomenon is caused by surface tension in the liquid—that is, the force existing in a film of liquid which tends to contract the film. In the case of vortex fuel nozzles, bubbles such as those shown in Fig. 5 will always form at a low flow rate and low pressure if a flared orifice is not used. At these conditions, the solid sheet is traveling at a low velocity and the surface tension has considerable time in which to act upon the sheet in a short distance. The sheet therefore bends inward and collapses. The effect is aggravated by the fact that at low pressures and flows the transition plane of breakage **77** moves farther away from the discharge orifice than at high pressures, thus giving the surface tension still more time and distance in which to collapse the sheet. The transition plane **77** occurs where the sheet has accumulated sufficient disturbance, from the tearing effect of the air and from initial disturbances in the sheet as it leaves the discharge orifice, to result in overcoming the "tensile strength" of the liquid. Although use of a duplex type nozzle greatly postpones the formation of the "bubble," as the rate of flow decreases the bubble does eventually appear as shown in Fig. 5. This is the principal type of failure of the spray when a duplex nozzle with a plain cylindrical discharge orifice is used.

The spray condition represented in Fig. 5 is completely unsuitable in a high performance combustor of the type used in gas turbine powerplants, and it is a primary requirement of a fuel nozzle for such service that the bubble be not formed at any point within the normal operating range of the combustor. The reasons why such a spray pattern is unsatisfactory will be apparent from a consideration of the characteristics of the combustor **1**, as more specifically defined in the aforementioned application of Anthony J. Nerad. A most important characteristic of our improved nozzle is that it permits operation over a much wider range of pressures and flow rates with spray angles and spray velocities sufficiently large to prevent formation of the bubble.

Fig. 6 shows the spray pattern produced by the flow conditions of Fig. 3 when the nozzle is provided with a flared portion **64** designed in accordance with our invention. As in Fig. 3, the whirl chamber is flowing nearly full with a very small air core **74**. The primary effect of the flared orifice portion **64** is to increase the spray angle to 80 degrees or more, as compared with 60 degrees for the unflared orifice of Fig. 3. This effect is thought to be due to the tendency of the liquid to wet the surface of the orifice, plus the tensile force or cohesion effect existing between the film of liquid which wets the surface of the orifice and other adjacent portions of the liquid. It will be seen that with the high pressure existing at point **47** in Fig. 2 the liquid does not follow the orifice flare all the way to the sharp corner **72** but breaks away from the flare at an intermediate location, from which the liquid cone leaves in approximately straight lines tangent to the surface of the flare. Here the liquid does not form as solid a conical sheet as at **76** in Fig. 3. With the conditions represented by Fig. 6 the velocities in the spray pattern are high and there is considerable turbulence, making the cone **78** highly disturbed and rough, with atomization beginning even before the liquid leaves the surface of the orifice flare.

In order that the spray cone will not break away from the flare suddenly (causing a sudden decrease in spray angle) and will not suddenly adhere to more of the flare (causing a sudden increase in spray angle), as the flow is caused to travel up and down the characteristic curve (**42** in Fig. 2), the flare must have the proper contour and must be very smooth and highly polished. The precise contour for best results may be determined by experiment, but will depend on the interior dimensions of the nozzle, such as the area of the slots, vortex chamber diameter, and so forth. A discussion of this matter in further detail is thought unnecessary in defining the present invention. It may be noted, however, that the contour shown in Figs. 9 and 10 has been developed by us for use in combination with the nozzle shown in those figures and has been found satisfactory. It consists essentially of a simple circular arc having a radius of the order of one to one and one-half times the diameter of the cylindrical portion **63** of the orifice. This arc is of course tangent to the straight cylindrical bore **63**.

Fig. 7 represents the flow with conditions as at point **45** in Fig. 2. Here the air core **74** has increased, as noted in connection with Fig. 4. Because the pressure and velocity are lower, the solid conical sheet of liquid **76** follows the orifice flare **64** nearly to the sharp cut-off corner **72**, with the result that the spray angle increases to 160 degrees, as compared with the intrinsic angle of 110 degrees.

As shown in Fig. 8, the effect of the orifice flare **64** is most pronounced at the low flow conditions represented by the point **44** in Fig. 2, the spray angle having increased to very nearly 180 degrees. With this large angle the tendency of the solid sheet of liquid **76** to form a bubble is completely overcome and a satisfactory atomized spray **78** is produced.

While the reason for the annular "cusp" **82** shown in Figs. 6, 7 and 8 is not definitely known, it is believed to be related to the fact that the boundary between the laminar layer of liquid adjacent the backplate **53**, and the turbulent liquid in the whirl chamber slightly forward of the backplate, lies in a plane passing through the cusp.

We have discovered that friction is a most important factor affecting the ability of a duplex nozzle to perform satisfactorily over the extremely wide range possible with our improved nozzle. In order to obtain the outstanding results achieved with our nozzle, it has been found necessary to observe carefully the following factors in the design: (1) The small slots **40** must have a relatively small cross-section area, must be as short in length as possible, must be well streamlined (particularly at the entrance to the slots), and must have an exceedingly fine surface finish. (2) The whirl chamber **37** must have an axial length as short as can conveniently be obtained, must have a diameter from 2 to 3 times that of the discharge orifice **63**, and must likewise have a good surface finish. (3) The discharge orifice **63** must also have as small a diameter as possible consistent with the minimum intrinsic spray angle required at maximum flow. (4) The flared orifice **63**, **64** must also have an exceptionally fine surface finish. Unless all these design features are provided, friction may have an exceedingly deleterious effect on the performance and range of the nozzle.

The importance of the sharp cut-off edge **72** and the angle which the terminal portion of the flared surface **64** makes with a plane perpendicular to the axis of the nozzle may be seen from a consideration of Fig. 8. The sharp edge **72** is necessary to enable the solid liquid sheet **76** to leave the orifice surface cleanly with a definite break. Even with this sharp corner provided, the solid cone **76** has a tendency to deflect slightly backwards towards the nozzle after leaving the edge **72**. It has been found that if tangents to the flare **64** at the sharp corner **72** form an angle **73** of less than 2 degrees (see Fig. 10), then the solid portion of the spray cone **76** may under certain operating conditions deflect backward sufficiently to strike adjacent portions of the nozzle or the rear wall of the combustion chamber surrounding the nozzle. This is damaging to good atomization and efficient combustion and therefore must be avoided. On the other hand, we have found that if the angle **73** exceeds a certain critical value, then the tendency appears for the spray cone to collapse and form a bubble. It has been determined that for effective performance the angle **73** must be held within a range of from 2 to 15 degrees, being represented in Fig. 10 as approximately 10 degrees.

While a full statement of the reasons would require much space, it has been determined by extensive testing of duplex nozzles that the performance of this particular type of nozzle is improved by the addition of a flared discharge surface **64**, designed in accordance with our invention, to a degree which is far in excess of that which might be expected from a consideration of the influence of the flare in itself. An important consideration is that the flare permits the attainment of satisfactory spray angles with small or primary slots of a cross-section area appreciably larger than those which must be used to obtain a given range with an unflared orifice as shown in Figs. 3, 4 and 5. Therefore, for a given range the small slots can be formed more accurately and easily and are less subject to being plugged by dirt particles in the fuel.

The somewhat obscure, but very important, way in which the use of our flared orifice adds to the range of flow rates over which a satisfactory spray can be obtained with a duplex nozzle may be summarized as follows. If a given spray angle, for instance 80°, is required at maximum flow, then the orifice **63** must be of a certain size in order to produce that angle at the required flow and pressure. If now our flared orifice is used, the intrinsic spray angle at that maximum condition may be made less than the required 80°, and the flare may then be so designed as to increase the spray angle to 80°. For example, the intrinsic spray angle may be made 60°, as in Fig. 3, and the flare may be designed to increase that 60° angle to 80°, as in Fig. 6. The advantage of this is that the orifice **63** can be made smaller with the 60° intrinsic angle; and when the orifice is smaller, the quality of the spray when operating on the small slots alone is considerably improved because friction in the vortex chamber is considerably reduced, as explained hereinafter, and the spray will become unsatisfactory at a lower flow rate. An unsatisfactory spray is one in which the size of the liquid particles is great enough that incomplete combustion results. When particle size increases to this degree, it is said that the spray "fails." Thus the range of the nozzle is extended when our flared orifice is used, because the orifice diameter can be made smaller than it would otherwise have to be. The reason that friction in the vortex chamber is reduced with a smaller orifice when operating on the small slots alone is that the velocities in the vortex chamber are kept lower and the pressure is kept higher. The mechanical energy in the liquid is thus better conserved up to the orifice itself, at which point the pressure in the liquid is converted efficiently into velocity. Therefore the liquid leaves the nozzle with a higher velocity. This has been discovered by analysis and verified by experiment.

The amount by which the flare **64** can increase the spray angle at maximum flow depends largely on the radius of curvature of the flare. The larger the radius of curvature (that is, the more gradual the flare and the larger the flare) the more will the spray angle be raised. Too large a flare, however, will cause excessive friction at low rates of flow, so that there is an optimum size and radius of curvature of the flare for each new design of nozzle. This optimum can be calculated roughly but can be arrived at more precisely only through experiment.

In summary, the three particularly beneficial effects which the flared orifice produces in combination with a duplex type nozzle are that it (1) prevents the formation of the bubble within the desired wide range of operation; (2) increases the degree of atomization throughout the operating range; and (3) makes a greater range possible because it permits the discharge orifice to be made smaller. We have found that by using our flared orifice, approximately twice the range of flow rates can be traversed with a satisfactory spray, as compared with the range obtainable with a duplex nozzle not having the flared orifice.

We have also discovered that an important improvement in the performance of our duplex nozzle, from the standpoint of stability and balance, is obtained by locating the small slots **40** at the rear of the whirl chamber **37**, with the large slots **39** discharging into chamber **37** at a location intermediate the small slots and the discharge orifice **63**.

It will be obvious to those skilled in the art that many modifications of the precise mechanical construction of the duplex nozzle are possible. However, we have described herein a construction which we consider particularly advantageous from the standpoint of ease and cost of manufacture with the characteristics required for efficient operation under the difficult conditions encountered in aircraft gas turbine powerplants and similar applications.

The data on which the above discussion and the accompanying drawings are based was obtained using liquids such as kerosene and gasoline, but are equally valid for other liquids of similar characteristics. Heavier oils will behave in the same manner if heated so as to lower their viscosity to a value approaching that of the liquids mentioned.

The duplex nozzle described herein and our new method and apparatus for operating it results in a liquid fuel spraying system of great versatility, permitting adaptation to many different powerplants having widely diverse requirements, and capable of producing a satisfactory atomized spray pattern in the form of a hollow cone with a preselected minimum vertex angle, over an extremely wide range of operating conditions.

It has been found that the nozzle described, with the flow divider for metering the fuel to the secondary slots, is particularly advantageous for use in gas turbine powerplants for the propulsion of aircraft. The spray pattern produced is well atomized, has satisfactory spray angles, and is stable under the most difficult operating conditions. With our nozzle system, it has been found that the combustor flame is much less likely to "blow out" at high altitudes, and also when the throttle is suddenly reduced from a high flow to a low flow position or vice versa. The ability to thus vary the throttle position suddenly contributes to the maneuverability of a military fighter plane, permits sudden descent with minimum power output as well as frequent and sudden reduction of powerplant operation to the idling condition and rapid acceleration to full power. Our system also makes possible a much lower idling speed and power which are important in aircraft jet-propulsion gas turbines. Because of the stable and uniform nature of the fuel spray pattern, combustion efficiency is excellent over a wide range, with the result that the fuel economy of the powerplant is improved and the operating range of the aircraft increased. Powerplant life is prolonged by reason of the lower and more even temperatures resulting from the absence of sudden, non-uniform supply of "slugs" of fuel. It has also been found that use of our system facilitates the initiation of flame in a combustor, for instance if it should happen to blow out at extremely high altitudes or under other difficult operating conditions. Our system also makes possible much lower gas temperatures when starting the gas turbine, and more rapid accelerations in starting without excessive temperatures.

What we claim as new and desire to secure by Letters Patent of the United States, is:

1. In a duplex type fluid spray nozzle, the combination comprising a body member defining therein at least two independent fluid supply passages having end portions defining independent discharge openings in an end wall of said body member, a backplate having a first surface for sealingly engaging said end wall and forming at least two passages extending axially through the backplate for registering with said independent openings, a nozzle tip member having a second surface for sealingly engaging said backplate and defining therein a substantially cylindrical whirl chamber extending forwardly from said second surface and communicating with a discharge orifice formed therein, said tip member also forming at least two radially spaced annular grooves extending forwardly and axially from said second surface, said tip member also forming therein independent primary and secondary slots communicating with the whirl chamber and with said annular grooves respectively for establishing at least two independent

flow passages through the nozzle, and means securing the tip member and backplate in sealing engagement and in register with each other and with said end wall surface of the body member.

2. In a duplex type fluid spray nozzle, the combination comprising a body member having a cylindrical end portion and forming therein separate first and second fluid passages having independent delivery openings in an end surface of said end portion, a backplate having a front face and also having a rear face for sealingly engaging said end surface, said backplate forming first and second passages extending therethrough for registering with said respective openings, a nozzle tip member having a rear surface for sealingly engaging the front surface of the backplate and forming a coaxial whirl chamber extending forwardly from said rear surface and in communication with a discharge orifice in the front portion of the tip member, said tip member forming a pair of spaced concentric annular grooves extending forwardly from the rear surface thereof for registering with the respective passages in the backplate and also forming at least two primary slots equally spaced circumferentially and extending forwardly from the rear surface thereof and between the innermost groove and the periphery of said whirl chamber, said tip member also forming therein a plurality of secondary slots in the form of round holes disposed between the primary slots and the discharge orifice and establishing communication between the outermost groove and the periphery of said whirl chamber for discharging fluid thereto in a substantially tangential direction and in the same direction of rotation as that discharged from the primary slots, and means securing said tip member and the backplate in sealing engagement and in register with each other and with the end surface of the body member.

3. In a fluid spray nozzle, the combination of a body member having a plurality of independent fluid supply passages therein with separate discharge openings in an end surface of the body member and in communication with the respective passages therein, said end wall having a first surface lying in a plane transverse to the axis of the nozzle with portions of the surface entirely surrounding each of said discharge openings, a backplate having a second plane surface for sealingly engaging said first surface and forming a plurality of transverse passages extending therethrough for registering with the respective discharge openings, the backplate also having a third surface with portions entirely surrounding the other ends of the respective passages therein, an orifice tip member forming therein a swirl chamber of substantially cylindrical cross-section in communication with the orifice and having a fourth surface for sealingly engaging said third surface, the tip member also forming independent primary and secondary slots therein for registering with each of said transverse openings, said primary slots being angularly and axially spaced from said secondary slots and with the primary and secondary slots in communication with the swirl chamber, and means securing the body, backplate, and tip member together with the first, second, third, and fourth surfaces in sealing engagement and with the respective passages and openings in register to define a plurality of independent fluid paths through the nozzle.

4. In a duplex type atomizing nozzle for spraying liquids, a nozzle tip member having a whirl chamber of circular cross section and a discharge orifice coaxial with the whirl chamber, said discharge orifice including a rearward portion communicating with the whirl chamber and a forward flared portion, said flared portion merging smoothly with the rearward portion and curving gradually outward and terminating at a sharp annular cut-off edge, the slope of said flared surface at the cut-off edge being less than 15 degrees with respect to a plane transverse to the axis of said tip member.

5. In a duplex type atomizing nozzle for spraying liquids, a nozzle tip member having a cylindrical whirl chamber and a discharge orifice coaxial with the whirl chamber, said discharge orifice including a cylindrical rearward portion one-half to one-third the diameter of the whirl chamber and communicating with the whirl chamber and a forward flared portion, said flared portion merging smoothly with the rearward portion and curving gradually outward and terminating at a sharp annular cut-off edge, the slope of said flared surface at the cut-off edge being greater than two degrees and less than 15 degrees with respect to a plane transverse to the axis of the tip member.

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