

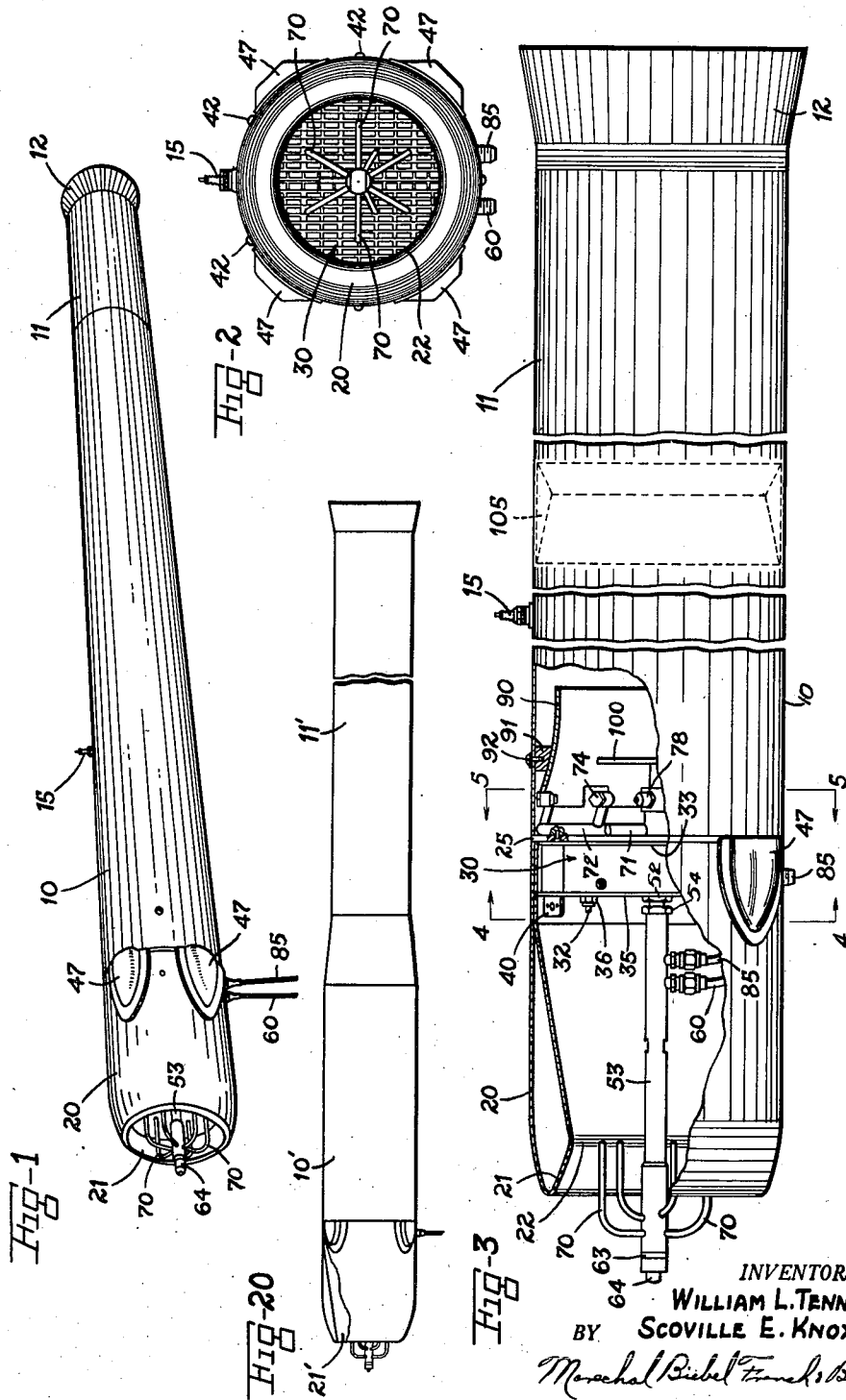
July 16, 1957

W. L. TENNEY ET AL
METHOD OF AND APPARATUS FOR FEEDING FUEL TO
A RESONANT PULSE JET ENGINE

2,799,137

Filed Feb. 26, 1952

4 Sheets-Sheet 1



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Fig-4

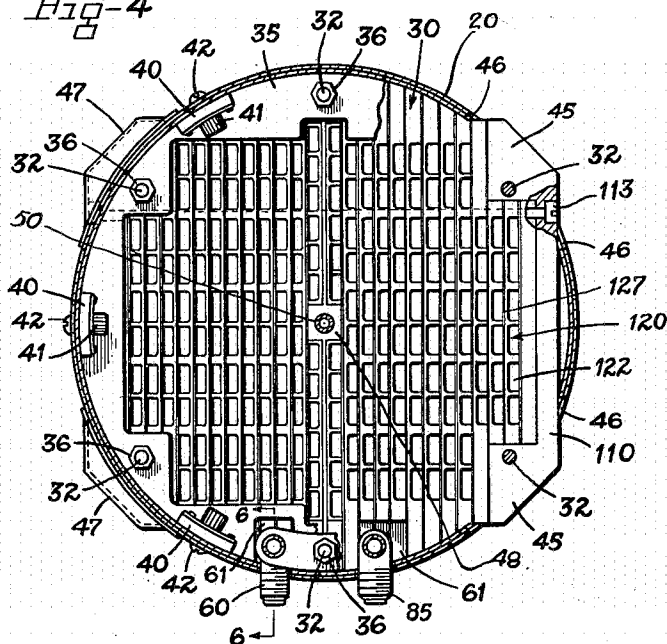


Fig-6

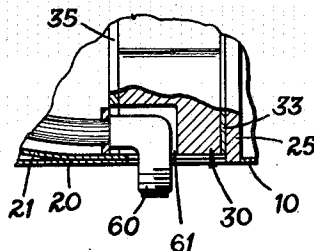
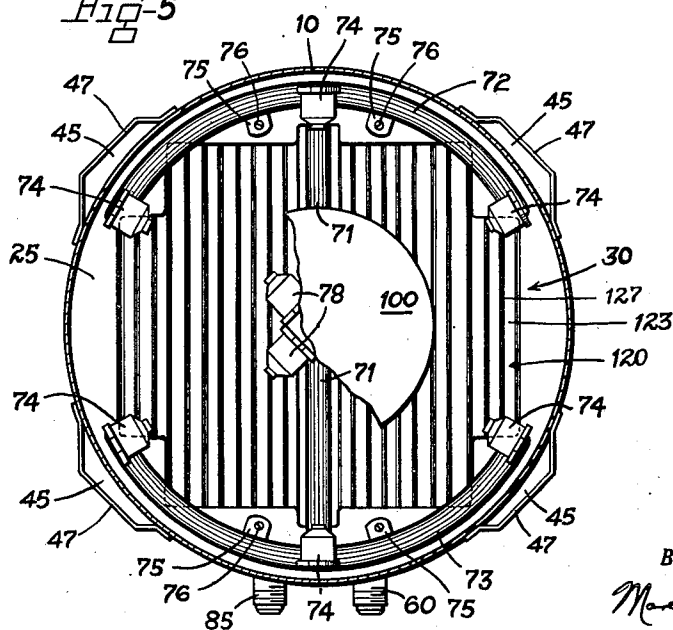


Fig-5



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Fig-8

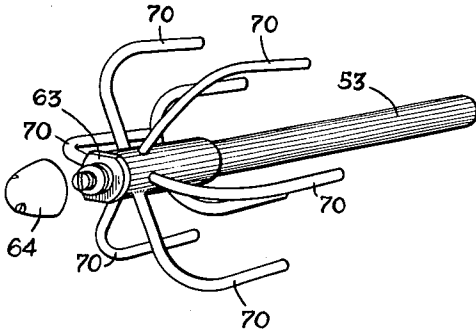


Fig-10

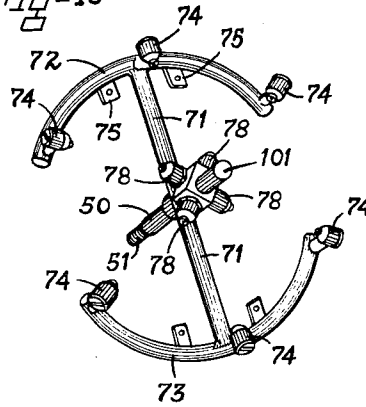


Fig-9

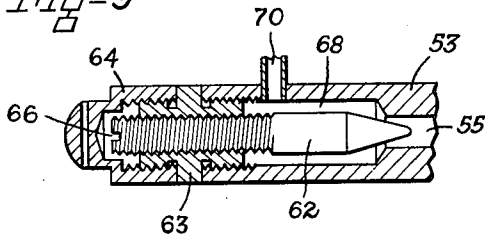


Fig-11

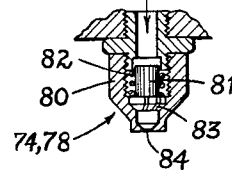


Fig-12

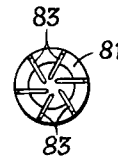


Fig-7

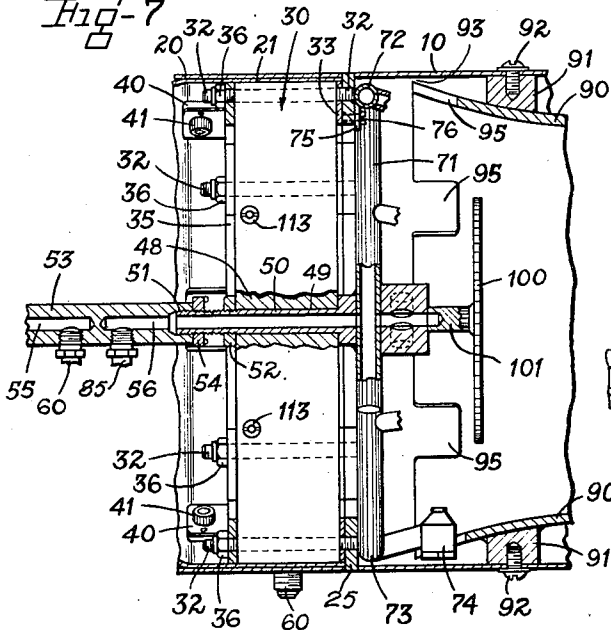


Fig-13

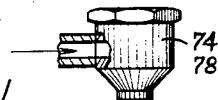
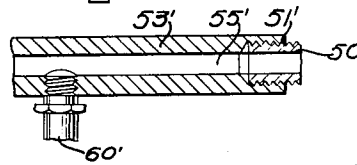


Fig-21



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Fig-14

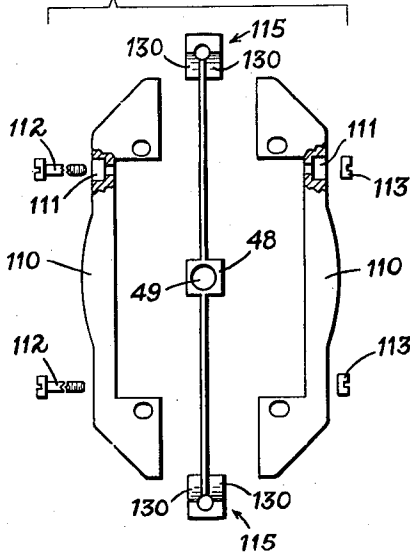


Fig-15

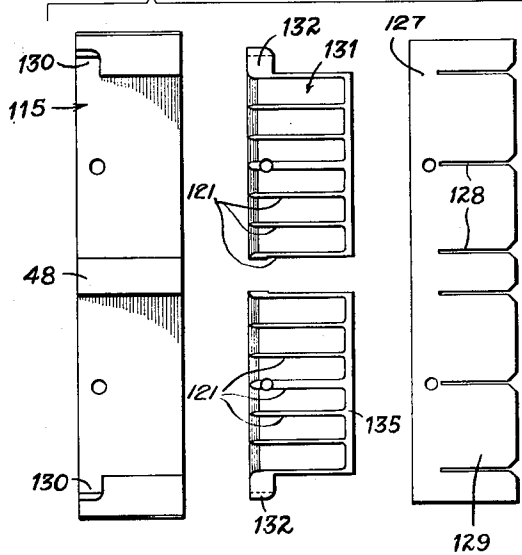


Fig-16

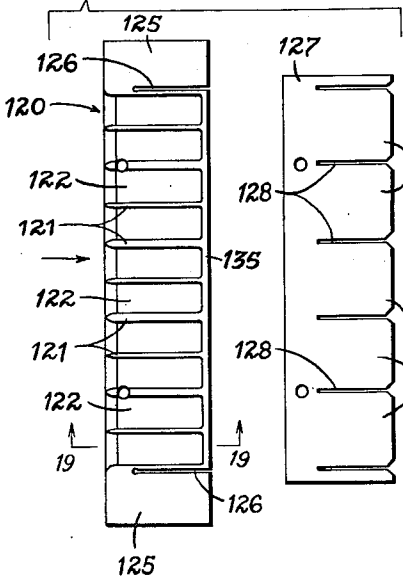


Fig-17

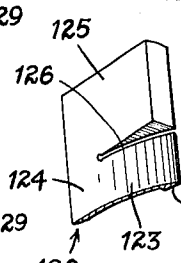


Fig-18

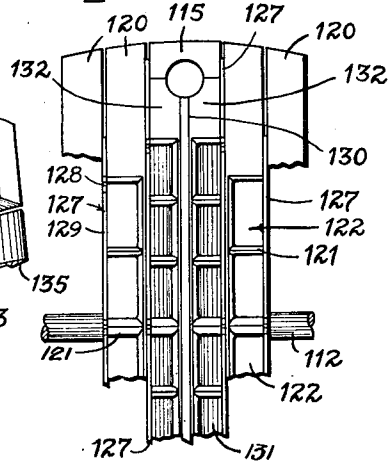
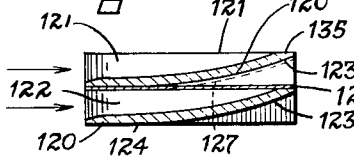


Fig-19



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2,799,137

METHOD OF AND APPARATUS FOR FEEDING FUEL TO A RESONANT PULSE JET ENGINE

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Application February 26, 1952, Serial No. 273,432

4 Claims. (Cl. 60—35.6)

This invention relates to resonant pulse jet engines and more particularly to an engine of this character adapted to develop a high thrust for its cross-sectional area and capable of operation at high forward velocities.

Pulse jet engines have commonly embodied a combustion chamber and a jet exhaust tube of substantially smaller diameter extending therefrom, and it has heretofore been considered important in order to maintain combustion under varying conditions that such exhaust tube be more or less restricted, by having a smaller cross-sectional area, and as a result the thrust obtainable from an engine of given combustion chamber diameter has been definitely limited. In accordance with the present invention a resonant pulse jet engine is provided in which substantially increased thrust for a given cross-sectional area is obtained through the provision of a construction in which the exhaust tube is not materially reduced in cross section below that of the combustion chamber, down to its open discharge end. By this arrangement the limits heretofore existing with regard to the amount of thrust which can be developed from an engine of given size have been substantially exceeded. This is accomplished in accordance with the present invention by a different construction which makes it possible to maintain proper combustion conditions with the engine both stationary and when moving at high velocity, notwithstanding the substantial increase in the size and area of the exhaust tube, relative to the combustion chamber.

The fact that the cross-sectional area of the combustion chamber is comparable with that of the exhaust tube, and not considerably greater as customary in the past, means that the flow velocity in the combustion chamber will be relatively high, and this increased flow velocity will be further increased in response to high forward speed. In order to accommodate such increased flow velocities and to maintain proper and reliable combustion conditions, the invention embodies features of construction which are novel and important.

It is therefore a principal object of the invention to provide a resonant pulse jet engine in which the construction and configuration of the engine tube are such that a high thrust per unit of cross-sectional area is secured, and which operates reliably both in the stationary position and when moving at high speed such as on an aircraft or the like.

It is a further object to provide a resonant pulse jet engine having a combustion chamber and automatically operating valve means with injection of fuel both upstream and downstream relative to the valve means, the fuel introduction being controlled to obtain efficient combustion and engine operation under varying conditions of forward velocity, altitude, etc.

It is a still further object to provide for controlled introduction of the fuel and combustion air, including the introduction, baffling, and deflection thereof in such manner as to combine effective atomization, vaporization and turbulence with effective ignition and efficient overall combustion.

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It is also an object to provide a novel valve construction for such an engine that makes possible prolonged valve life without the necessity for frequent replacement, in which the valve parts are simple in construction, readily replaced, and which give a high degree of opening providing good freedom of flow therethrough.

Other objects and advantages will be apparent from the following description, the accompanying drawings, and the appended claims.

In the drawings:

Fig. 1 is a perspective view of a resonant pulse jet engine constructed in accordance with the present invention;

Fig. 2 is a front and elevational view of the engine;

Fig. 3 is a broken view on a larger scale partly in elevation and partly in section;

Fig. 4 is a cross-sectional view looking at the upstream face of the valve means on the line 4—4 of Fig. 3;

Fig. 5 is a cross-sectional view looking at the downstream face of the valve means, also showing the downstream fuel supply means, on the line 5—5 of Fig. 3;

Fig. 6 is a detail sectional view through one of the fuel supply means on the line 6—6 of Fig. 4;

Fig. 7 is a vertical sectional view through the valve portion of the engine with the valve means being shown in elevation;

Fig. 8 is a perspective view of the upstream fuel introducing means;

Fig. 9 is a detail sectional view of the control valve for the upstream fuel injection;

Fig. 10 is a perspective view of the downstream fuel injection assembly;

Fig. 11 is a sectional view through one of the nozzle injectors of the downstream fuel injection;

Fig. 12 is a bottom elevational view of the nozzle insert in the injector of Fig. 11.

Fig. 13 is an elevational view of one of the outer nozzle injectors of the downstream fuel injection;

Fig. 14 is a view showing the main structural elements of the valve means with the grid bars and valve leaves removed therefrom;

Fig. 15 is an exploded view of the central section of the valve means showing the central structural member, the central grid bars, and one of the valve leaves;

Fig. 16 is a view showing one of the outer grid bars and the corresponding valve leaf;

Fig. 17 is a perspective view of one end of a grid bar showing the curved rear face thereof and the heavier end supporting section;

Fig. 18 is an enlarged broken view showing a portion of the valve assembly looking toward the upstream face thereof;

Fig. 19 is a sectional view on an enlarged scale on the line 19—19 of Fig. 16 showing the relationship of adjacent grid bars and the intermediate valve leaves;

Fig. 20 is a broken side elevational view of a modified form of engine intended particularly for high speed conditions; and

Fig. 21 is a detail view of a modified fuel supply arrangement.

Referring to the drawings which illustrate a preferred embodiment of the invention the engine is shown in perspective in Fig. 1 as comprising an outer main tubular casing 10 defining the combustion chamber and continuing with substantially the same diameter to constitute the resonant jet exhaust or outlet tube 11. Adjacent the end of that tube, the casing flares outwardly as shown at 12, in accordance with the disclosure in applicant's copending application, Serial No. 661,280, filed April 11, 1946, now Patent No. 2,487,100, issued February 26, 1952. As shown, the outlet tube has a cross-sectional area not substantially less than that of the combustion

tube and in the construction of Fig. 1 the tube areas are the same and are defined by the continuous extension of the casing 10. A spark plug 15 is mounted in the casing 10, its use being unnecessary except for starting and being discontinued as soon as the engine begins operation, if desired.

A separate casing 20 is located in position at the forward portion of the engine defining the air inlet, this casing having a curved inner wall 21 forming a venturi throat 22 producing a high air velocity in the inflowing air at this point.

Referring more in detail to the structural arrangement, and with reference to Fig. 7, a plate 25 is secured to the forward end of casing 10 as by welding and the two casing walls 20 and 21 of the air inlet extend up to that plate in overlapping relation as shown. A valve structure indicated generally at 30 is mounted between the air introducing means and the combustion chamber, and for this purpose stud bolts 32 are fastened into plate 25, extending axially forwardly, with the valve assembly 30 being mounted thereon and sealed against the plate by a gasket 33. A forward plate 35 is mounted on the opposite or forward face of the valve assembly and the studs 32 extend therethrough to receive fastening nuts 36, thereby removably mounting the valve assembly in place.

Plate 35 carries flange pieces 40 which have plate nuts 41 extending radially and by means of which the double casing wall section 20, 21 is assembled and detachably secured in place by means of bolts 42 (Fig. 4). The valve assembly 30 has a contoured outer peripheral shape including projecting corner portions 45 to provide additional strength in the valve assembly and the casing is notched as shown at 46 and receives streamlined cover caps 47 which are welded or formed in place on the casing 20 to cover such corners and to prevent air turbulence as a result thereof. Both plates 25 and 35 are formed in a corresponding pattern to avoid overlying the working portions of the valve means.

As shown in Fig. 7 the valve assembly 30 has a central supporting member 48 which is apertured at 49 to receive a hollow tube 50 which projects forwardly and has a threaded end 51 fastened by nut 52 and on which is mounted a supply pipe 53 locked in place and sealed against fluid leakage by means of nut 54. Pipe 53 has two passages 55 and 56, preferably separated from each other by a solid section, providing for separate supplies of fuel to the two fuel introducing means. Passage 55 provides for supply of fuel to the upstream fuel introducing means, located in the throat of the air intake section 22. In order to supply this fuel introducing means, a supply pipe 60 extends through a recess 61 (Fig. 6) in the valve assembly and connects into the passage 55. As shown in Fig. 9, a needle valve 62 controls the flow through the passage 55, being mounted in a gland 63 and protected by a cap 64 removably mounted upon the gland threaded into the end of the tube 53. It will be evident that on removal of cap 64, a screw driver may be inserted in the slot 66 of the needle valve and the valve moved to vary the size of the flow passage for the fuel supply.

The fuel flows into a manifold chamber 68 and is distributed therefrom through a series of delivery tubes 70 which extend downstream in the direction of flow as shown in Fig. 3, terminating substantially in the throat of the air intake 22 where the maximum intake air flow velocity takes place. Fuel introduced upstream of the valve means is atomized by the high velocity air flow with at least partial vaporization resulting in cooling the valve assembly.

The downstream fuel injection means is located on the opposite side of the valve assembly and in the foremost portion of the combustion chamber. Such assembly is shown in Fig. 10 and comprises the tubular member 50, connecting with a pair of radially extending arms 71 which in turn support arcuate tubular pieces 72, 73. A

series of nozzles 74 are mounted upon these arcuate pieces, and so arranged as to direct their fuel discharge streams radially inward, and thus substantially transverse to the flow of the gases through the chamber. This assembly is bolted to the face of plate 25 by means of ears 75 and bolts 76.

Inner nozzle injectors are likewise provided, being mounted directly on the tube 50 and shown as embodying four nozzles 78 arranged to discharge their streams radially of the chamber and in an outward direction, preferably intermediate the streams from nozzles 74, the respective sprays being in the form of cones mutually intersecting. Nozzles 74 are essentially the same as nozzles 78 and are preferably constructed as shown in Figs. 11 and 12 with an outer casing 80, a removable insert 81 and a spring 82 urging the insert to seating position. A series of grooves 83 are located on the face of the insert through which the fluid is discharged in order to provide atomization in combination with the small aperture 84. The insert may be unseated by means of a suitable tool to clean the passages. Fuel is supplied to the downstream nozzles through a supply pipe 85 (Fig. 3) connected into passage 56.

In order to direct and confine the air-fuel mixture immediately following the downstream injection of fuel thereinto, a flared outer liner 90 (omitted in Fig. 5 for clarity) is secured in the forward portion of the combustion chamber by means of lugs 91 thereon and bolts 92 passing through the wall of casing 10. The liner 90 does not necessarily extend into actual contact with the wall 10 of the combustion chamber but a gap 93 may be left of the order of $\frac{1}{16}$ to $\frac{1}{8}$ inch so that there is an annular passage outwardly of this liner. Also, as shown in Fig. 7, its forward end is notched as shown at 95 in the area immediately adjacent each of the nozzles 74, so that such nozzles may fit into the notches and thus the downstream fuel injection occurs within the circumference of this flared liner. As clearly shown in Fig. 3 the liner does not extend axially throughout more than the initial portion of the combustion space.

Additional means for promoting vaporization, intermixture and high turbulence immediately following the downstream injection of fuel is provided in the form of baffle or deflector plate or disk 100 having a central stem 101 by means of which it is mounted upon the nozzle assembly 78.

While it is difficult to determine the exact condition taking place in the combustion zone, it is believed that disk 100 acts in part as a flame holder and turbulence producing device. Further, being adjacent the flame zone it operates at high temperature and because of its position aids in vaporization of the fuel droplets. Fuel injected forwardly of baffle plate 100 is caused to mix with the air and to produce a turbulent condition in the inlet portion of the liner. A highly turbulent, relatively low velocity, wake results downstream of this disk. This wake is a flame retaining area which serves to aid in ignition of the high velocity gases passing through the combustion chamber. A similar turbulent, relatively low velocity, wake is produced by the flared liner 90 which likewise results in a flame retaining wake at the wall of the combustion chamber. Thus the high velocity gases traveling through the combustion chamber pass through an annular area bounded on both sides by highly turbulent, lower velocity flame retaining areas which aid in ignition of the high velocity gases. Likewise the liner 90 operates at a comparatively high temperature, particularly at its downstream end, and thus serves to add heat to the incoming mixture and promote fuel vaporization and efficient combustion. Baffle plate 100 may be varied in size in accordance with the optimum designed forward velocity of the engine, the design of the valve bank, and other factors, providing a simple and convenient means for adjusting conditions within the combustion chamber for most efficient combustion.

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It will be seen that fuel is injected downstream of the valve means and upstream thereof as well. Experiments have indicated that the amount of upstream fuel injection should be increased with increase in the valve area and jet outlet pipe area, and that when proper and efficient combustion is obtained under these conditions, higher air flow velocity conditions through the combustion chamber result, together with increased thrust. It is accordingly found that the needle valve controlling the amount of upstream fuel injection can be set to introduce additional fuel at this point as may be desired to accomplish the most satisfactory operating conditions. Where separate control of the fuel introduction is not required, passages 55 and 56 are continuous and may be supplied from a single supply pipe. Such an arrangement is shown in Fig. 21, wherein like parts are designated by the same reference numerals as in Fig. 7, and similar parts are designated by the same reference numerals with a prime (') added. The single passage is shown at 55', and the single supply tube at 60'.

Where the engine is to be operated at high velocities, additional difficulties occur, and this has been particularly the case with only downstream injection where a velocity exceeding about Mach 0.4 was required. Obviously at high velocity conditions of forward travel of the engine, the mean air flow velocity through the combustion chamber also tends to increase. As the combustion system of the engine may be operating at or near its peak velocity under static operating conditions, the increase in air velocity through the combustion chamber at high forward speeds of movement may readily exceed the limitations of the combustion system. The dual fuel injection system provided by the present invention has been found to maintain good combustion conditions at substantially increased mean air flow velocities, and by suitable proportioning of the fuel flow through the dual injection system, the combustion chamber can be maintained at optimum conditions for a given velocity. It has been found that increasing the proportion of the flow fed to the upstream nozzles contributes to markedly improved operation at higher velocities.

Fig. 20 shows a modified form of engine which may be used to give improved results when operating at high forward velocities. In this form the diameter of the exhaust tube 10' is slightly less than that of the combustion chamber 11', for instance, about 90% thereof, so that its cross-sectional area is somewhat less but still representing substantially more than 50% of the area of the combustion chamber. Also in place of using the venturi type inlet as shown in Fig. 3, a diffuser type inlet 21' may be used. In other respects the engine is the same as that described in connection with the form shown in Fig. 1. This limited reduction of area in combination with the other features described herein is advantageous where the engine is intended to operate with especially high forward velocities, the velocity of flow through the combustion chamber being somewhat less than in the form shown in Fig. 1 under comparable conditions.

With pulse jet engines of the character described herein the tube is of rather substantial length, for example an engine having an internal tube diameter of 8 inches having an overall length measuring rearwardly from the valve assembly of approximately 104 inches. Where it is desired to reduce this overall length, while still retaining proper operating characteristics, a restrictor ring may be incorporated at an intermediate point in the engine tube, indicated at 105 in Fig. 3 as approximately one-third of the way back from the valve assembly. Such a ring may reduce the effective diameter to approximately 85-90% of the full diameter, the ring being suitably secured to the tube wall as by welding about its entire periphery and being of such material that it will withstand the high temperature conditions to which it is subjected in use.

Referring now to the valve means, this is shown in Figs. 4, 5 and 14 through 19. The valve structure occupies a

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large portion of the cross-sectional area of the combustion chamber and contributes to the desired high velocity flow of gases by offering only limited resistance to the passage of the flow. The valve construction embodies structural members alternating with valve leaves formed of spring steel or other suitable material, the structural members having contoured flow passages beneath flat surface areas. The leaves are so arranged that they occupy a flat position when closing the flow passages, and are deflected in response to the pulsating action of the resonating system, being guided in a curved path of relatively long radius when so deflected by the back face of the structural members. Because of the fact that the leaf spring portions of the valves are flat when the valves are closed, the initial construction and likewise the replacement and any maintenance are rendered much more simple than when it is necessary to establish a flexed or bent position which requires stress in the valve material to hold it in the closed position. Thus the difficulties involved in the careful bending or stressing of a large number of valve leaves to the right point to assume their exact proper closed position is eliminated, and the parts can be easily formed and shaped in a flat condition, and assurance is provided that when assembled in such flat relation, they will then function properly under the pulsating action of the resonating combustion system. The construction thus employs flat leaf springs installed against flat valve seats, making the correct setting and assembly a simple and rapid operation.

The valve assembly 30 includes a pair of generally C-shaped end sections 110 (Figs. 4 and 14) which are drilled as shown at 111 to receive elongated retaining bolts 112 which with nuts 113 lock the whole assembly together. There is also a solid central section shown generally at 115 which embodies the apertured portion 48 through which there extends the tube 50 for supplying fuel to the downstream fuel injection means as described above.

The valve is made up of a series of structural members including vane-like grid bars shown at 120, each having a plurality of vertically spaced ribs 121 extending horizontally from the main body of the bar, with the edges of ribs 121 aligned vertically to provide a flat side face 121' (Fig. 19) against which a like grid bar is stacked. Contoured flow passages 122 are provided between adjacent grid bars by reason of the curved back face thereof, as shown at 123 (Fig. 17), and it is this surface against which the valve leaves deflect when they are moved to open the flow passages 122. The bars are formed with a flat area 124 which extends lengthwise and lies beyond the curved portion 123, this flat area serving to grip and retain the leaves in assembled relation between adjacent bars. The ends of the grid bars are relatively heavy as shown at 125 and are partially separated from the intermediate portions by cuts 126 which extend over the major portion of the width of the bars, thereby avoiding an absolutely rigid construction and allowing the valve seats to yield under the closing impact of the valve leaves resulting in considerably prolonging valve life.

The valve leaves are shown at 127 being a thin section of spring steel or other suitable material capable of maintaining its flexibility under the conditions to which it is subjected in use. The springs may be slotted as shown at 128 to define a series of separate portions 129 contributing to greater flexibility of movement under the pulsating action. It will be noted from Fig. 16 that alternate ribs 121 are thicker and the assembly is such that slots 128 overlie such thicker ribs.

It has been found important to maintain flexibility not only in the intermediate grid bars but in the central grid bar as well, and for that purpose a special construction is provided including notched portions 130 at the ends of the central structural element 115 and a special form of grid bar 131 having ears 132 adapted to be received within notches 130. The grid bar 131 is merely stacked in face to face relation with the central structural member 115,

its ears being interlocked in the corresponding recesses, but without other fastening thereto, except for through bolts 112. This allows for a yielding motion, and has been found to contribute to substantially prolonged life of the valve springs which work against the central grid bars so that their life in use is made comparable with that of the others.

As shown in Fig. 4, and also Fig. 18 both of which are views looking toward the upstream face of the valve assembly, the grid bars and springs are stacked in alternating relation, preferably being of somewhat different length in accordance with the pattern indicated to fit within the general C-shaped contour of the ends 110. When so stacked, the retaining bolts 112 are fastened and the assembly is a self-supporting, readily removable unit. It will be understood that the upstream side of each valve is that part which presents the open face, i. e., the direction indicated by the arrows in Fig. 19 showing the direction of flow of the gases through the valve. Thus the rearward edge 135 of the grid bar represents the face against which the valve leaf rests in the undeflected or closed position. In response to the pulsating action of the system and the flow of air towards the downstream end, the valve leaves are caused to flex away from the flat surface 135, and to fold back against the curved face 123 of the adjacent grid bar as shown in dotted lines in Figure 19, thereby allowing the flow passage to open for the downstream travel of the air.

The valve assembly therefore provides for flexible seating of each valve leaf throughout the entire structure, which contributes to prolonged valve life as opposed to having the valves seat against a stiff or rigid structure. The assembly is removable as a unit and when required any one of the grid bars and valve leaves may be easily removed and replaced without requiring special tools or flexing or special bending of any of the spring parts. Further, the leaves bend over a curve of relatively long radius avoiding high stress concentrations at any one point in the valve. It has also been found that control of the curvature of the valve in the open position, where it is solidly backed up over its full free length, results in improved valve action and consequent increased valve endurance.

An engine constructed in accordance with the present invention and having a combustion tube diameter of approximately 8 inches has been operated to provide a static thrust in excess of 200 pounds, operating at a specific fuel consumption of less than 2 pounds of fuel per pound thrust per hour. Valve life was better than 14 hours, and satisfactory operation was maintained at all velocities between zero and 350 M. P. H.

While the form of apparatus herein described constitutes a preferred embodiment of the invention, it is to be understood that the invention is not limited to this precise form of apparatus, and that changes may be made therein without departing from the scope of the invention which is defined in the appended claims.

What is claimed is:

1. The method of operating a resonant pulse jet engine having a combustion chamber and including an air inlet controlled by a valve means located between said air inlet and said combustion chamber and operable under the pulsating action of resonant combustion in the combustion chamber and a freely open jet exhaust tube extending from the outlet of the combustion chamber, which comprises the steps of introducing fuel into said air inlet upstream of said valve means and simultaneously introducing fuel downstream of said valve means to maintain self-supporting combustion in said combustion chamber under periodic resonant conditions, and increasing the amount of fuel introduced upstream of said valve means with respect to the fuel introduced downstream of said valve means in relation to an increase in the velocity of air entering said air inlet.

2. The method of operating a resonant pulse jet engine having a combustion chamber and including an air

inlet controlled by a valve means located between said air inlet and said combustion chamber and operable under the pulsating action of resonant combustion in the combustion chamber and a freely open jet exhaust tube extending from the outlet of the combustion chamber, which method comprises the steps of introducing fuel into said air inlet upstream of said valve means, simultaneously introducing fuel downstream of said valve means into the upstream portion of said combustion chamber to maintain self-supporting combustion in said combustion chamber under periodic resonant conditions, and increasing the ratio of fuel introduced upstream of said valve means with respect to the fuel introduced downstream of said valve means in relation to increase in the velocity of air entering said air inlet.

3. A resonant pulse jet device adapted for operation with high velocity air flow thereinto and having a combustion chamber with a freely open discharge end, an air inlet means at one end of said combustion chamber forming an inlet passage for high velocity flow of air there-through, valve means between said air supply means and combustion chamber operable automatically under the pulsating action of said air flow, a jet exhaust tube opening directly from said combustion chamber and forming therewith a system resonant in gases for the periodic pulsating flow of gases therethrough, said exhaust tube having a cross-sectional area not substantially less than that of said combustion chamber and being substantially unrestricted up to its open discharge end, means for introducing fuel into said gas flow downstream of said valve means including a plurality of nozzles for directing streams of fuel in a direction substantially transverse to the direction of flow of said gases with resulting rapid atomization of said fuel, a flared outer liner of substantially less axial length than said combustion chamber and having the larger upstream edge thereof supported adjacent the wall of said combustion chamber and adjacent said nozzles and having the smaller downstream edge thereof located downstream from said nozzles for directing and confining the flow of gases therethrough, and a deflector disk located substantially centrally of said combustion chamber and intermediate the ends of said liner, said liner and said disk providing turbulent relatively low velocity flame retaining areas around the wall of said combustion chamber and substantially centrally thereof and surrounding the flow of high velocity gases traveling through said combustion chamber to aid in ignition of the high velocity gases.

4. A resonant pulse jet device according to claim 3 including means for introducing fuel upstream of said valve means.

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