PULSE COMBUSTER OR JET ENGINE

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ATTORNEYS
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The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

The present invention relates in general to pulse combustors and more particularly to a pulse combustor or jet engine of the valveless type.

While pulse jet engines of the valveless type as heretofore constructed have the advantage of simplicity and economy of manufacture due to elimination of valves, problems are presented in the attainment of adequate thrust especially static thrust and self aspiration under static conditions, and the attainment of effective scavenging and compression with improved thrust relative to weight and size of engine, and improved efficiency in fuel consumption. Other problems are the attainment of reliability in operation with high power to weight ratio, adaptability to operation on simple readily obtainable types of fuel, and reduction in length, giving improved adaptability to propeller tip propulsion.

Accordingly among the objects of the invention are:

To improve the output efficiency and general performance of the valveless type of pulse jet engine without complication of structure.

To provide an engine of the above type which shall be self aspirating with attainment of effective scavenging and compression.

To improve the power load by attainment of an improved power to weight ratio.

To attain sufficient reduction in length to enable practical application as a propeller-tip engine.

To provide a valveless pulse jet engine capable of use as a combustor element for gas turbines, and to reduce the operating noise.

Various other objects and advantages of the invention will become apparent upon perusal of the following specification and the drawings accompanying the same.

In the drawings:

Fig. 1 is a side view, partly in section along its axis, of a preferred embodiment of the invention.

Fig. 2 is a section on line 2—2 of Fig. 1 on a larger scale.

Fig. 3 is an enlarged detail view showing the outlet end of the multi orifice nozzle.

Fig. 4 is a perspective view of a modified form of input nozzle.

Fig. 5 is a fragmentary longitudinal section of a combustion chamber with the nozzle of Fig. 4 mounted therein.

Fig. 6 is a section on the line 6—6 of Fig. 5.

Fig. 7 is a side view partly in section along its longitudinal axis of a modified form of the invention.

The embodiment in Figs. 1 and 2 is in the general form of a cylindrical tube closed at the forward end and open at the rear end, the forward portion being of relatively large diameter and short length to form a combustion chamber 10 having its exhaust section 15 connected through a reducing portion 11 with the rearward portion of smaller diameter and greater length to form a tail section 12. The tail section is open and flared at the rear end 13. For initial ignition of a fuel-air mixture in the combustion chamber, suitable ignition means is provided in the form of a spark plug 14 which may be energized and controlled through any known or other suitable means not shown. Fuel-air mixture is formed primarily in a relatively long inlet tube 16 providing the combustion chamber parallel to the axis of the combustion chamber and tail section. The inlet tube opens at its rear end through a flared portion 17, and has its forward end extended into the combustion chamber 10 through an input nozzle 18 of special functional form. Fuel either in gaseous, liquid or other suitable form is injected under pressure through a multiple orifice fuel nozzle 19 into the inlet tube 16, by way of a fuel supply tube 21 coiled around the forward portion of the tail pipe to form a heat interchanger coil 22. The input end 23 of the coil leads from a source of fuel not shown but which may be any known or other suitable form of a source of fuel supply under pressure. In the present embodiment the multiple orifice nozzle 19 consists as indicated in Fig. 3 of the outlet end portion of the supply tube 21 provided with a plug element containing a plurality of apertures 24. Partly by some venturi action due to the high velocity injection of fuel into the inlet tube 16 and mainly by aspiration due to a drop to sub-atmospheric pressure in the combustion chamber after entrainment of burned gases through the tail pipe acting as a piston on its down stroke, a large volume of fuel air mixture is urged through the inlet tube 16 into the combustion chamber 17 into the combustion chamber during the intake or charging phase of the cycle. In the use of gaseous fuel such as butane, propane or the like, starting may be accomplished without injection of auxiliary air or use of auxiliary heating means for the heat interchanger 22. However, where liquid fuel is used, that is fuels not self gasifying such as gasoline or diesel fuel or those intermediate or between, starting may be accomplished by the injection of auxiliary air through the external air nozzle 20 at sufficient pressure and volume to break up the fuel and provide a suitable starting mixture, air being supplied from a suitable source of compressed air 25, or alternatively, starting may be accomplished by use of an auxiliary heater such as an electric heater here shown diagrammatically at 36, to vaporize the fuel in the heat interchanger 22. It will be understood that any known or other suitable form of auxiliary heating means may be used.

The nozzle 18 is in the general form of a straight sided tube mounted to enter the combustion chamber in a direction downwardly and forwardly at an angle of approximately 45°, and to avoid undue turbulence in the inlet tube and nozzle, the change in direction between the two is made less abrupt by use of a connecting section 26 of intermediate angle, or for greater perfection the transition in angle may be made through a substantially continuous curve. This avoidance of undue turbulence has been found to reduce the rate of flame propagation back through the mixer tube and thus prevent combustion within the tube during intake of the fuel-air mixture through the inlet tube and nozzle 18 to the combustion chamber 10. It is to be noted in passing that some momentary back-fire takes place through the inlet tube. However, being expelled rearwardly any reaction derived from this accelerated movement of material of low mass though slight is in aid to the thrust of the engine. In operation the amount of this back flow and its duration relative to other phases of the engine cycle is so brief as not to detract from the mass of gases moving out through the tail pipe, or interfere with
adequate intake through the inlet tube during the charging phase of the cycle. An important feature of the invention is the special functional form of the inlet nozzle 18 and its position relative to the combustion chamber and relative to the direction of discharge from the combustion chamber into the tail section. As shown in Fig. 1, the nozzle element 18 where it enters the combustion chamber is in the form of a straight sided tube extended about half way downwardly and forwardly into the combustion chamber at an angle of about 45°. As shown in Fig. 2, the nozzle where it projects into the combustion chamber, is somewhat flattened into an oval cross-section to present a forward aspect area of at least one-fourth and not more than one-half the area of the combustion chamber. Thus, so shaped and proportioned it functions as a baffle between that portion of the combustion chamber where explosion takes place and the outlet end of the chamber, blocking sudden expansion of the bulk of the burning gases to increase the rate of pressure rise during burning with resultant increase in burning rate and improvement in combustion efficiency. It is to be noted also that the simple arrangement prevents by the incoming air to an extent insufficient to detract from the thermal efficiency of the engine but sufficient to substantially retard deterioration due to high temperature.

The nozzle is open at the end and along the rear side, the open end being indicated at 27 and the open rear side at 28. A result of this arrangement is that during intake the nozzle directs the incoming stream of fuel-air mixture in a downward and forward direction against the lower wall of the combustion chamber to produce a movement of the fresh mixture toward the front or head portion of the chamber and up and back, tending to sweep the burned gases back around the sides of the intake nozzle into the tail section. During the explosion phase of the cycle, exhaust gases rushing past the open end of the nozzle produce a venturi effect or lowering of the pressure in the vicinity of the nozzle opening, while the gases rushing past the rearwardly facing opening 28 produce a drag which also tends to lower the pressure in the nozzle 18 and inlet 16 below the free stream venturi pressure, so that the pressure at the nozzle opening is substantially below that of the combustion chamber. Thus while the tendency to a lowering of the pressure is not sufficient to prevent all back flow through the inlet, it is sufficient to effect aspiration through the inlet tube during the explosion phase, it acts substantially to reduce back flow of burning gases through the inlet tube. This lessening of back flow through the inlet results in a greater percentage of tail outflow compared to inlet back flow, so that the aspirating phase following explosion is improved due to the relatively greater mass of gases passing out through the tail section.

Analysis of steady flow effects of the angularly entrant inlet nozzle as compared with the conventional nonentrant or flush inlet throat connection, has been made using two engines with the different types of inlet and with the front wall of the combustion chamber removed and the chamber connected with a source of air under sufficient pressure and volume to maintain steady flow through combustion chamber and tail pipe. Under this test the pitot tube pressure in the inlet tube near the rear end or entrance of the inlet tube was about twelve times the pressure in the engine with the nonentrant inlet nozzle in the engine with the angularly entrant inlet nozzle. This of course means a higher ratio of tail momentum to inlet tube momentum for the engine with angularly entrant intake nozzle or a ratio of about 15.5 as against a ratio of about 4.45 for the engine with conventional nonentrant intake nozzle.

It has been found that in combination with the form and arrangement of inlet nozzle above described, a proper determination of the ratio of tail length to diameter of combustion chamber can lower the combustion chamber pressure, following an explosion phase of the cycle, long enough to effectively scavenge the combustion chamber and effect aspiration of the necessary fresh charge. It is to effect further and more complete mixing of the constituents of the fuel-air mixture entering the combustion chamber, that the forward lip of the intake nozzle 18 is serrated to divide the intake into multiple streams as it enters the chamber. Another arrangement for dividing the inlet flow where it enters the combustion chamber is shown in Figs. 4, 5, and 40. Where the intake elements take the form of a plurality of short length straight sided tubes 29, 30 and 31, each opening downwardly and rearwardly at the end and closed along the front side. The tube sections being spaced laterally from each other and from the sides of the combustion chamber, permit exploding gases to pass between and around the sides of the tubular nozzle elements to bring about a reduction in pressure in the vicinity of the rearwardly facing openings 26 in a manner and with the advantageous result as pointed out above in connection with the single nozzle 18 of Fig. 1. It has been found that this dividing of the inlet stream where it enters the combustion chamber substantially reduces back flow, thereby rendering the engine more adaptable to use as a wing tip engine, or other uses where a shorter length is desired without sacrifice of thrust.

In one practical embodiment of the invention constructed as above described, the relative dimensions are approximately as indicated in Fig. 1. With an embodiment having approximately the dimensions here indicated, a static thrust of about 6 pounds was achieved, with a combustion chamber of about 2.4 inches inside diameter. The positioning of the intake nozzle within the combustion chamber at substantially downwardly, as indicated in Fig. 1, is an important feature of the invention and its advantage has been found to be more accentuated in the moving engine than in a static engine. Engines with the 45° intake nozzle reached the highest velocity and were more stable than engines with the intake nozzle positioned at 37° downward and forward of the perpendicular although the latter had produced equal static thrust.

While provision for injecting the fuel into the inlet tube with the air supply is very satisfactory and makes for compactness of structure with avoidance of extra inlet openings to effect aspiration through the inlet tube during the explosion phase, it is found that the benefits of the angularly entrant intake nozzle are not lessened by its use solely for air intake in combination with the use of separate fuel intake directly into the combustion chamber. The latter arrangement is embodied in the modification shown in Fig. 7. Here the construction is substantially similar in all respects to that of Figs. 1 and 2, except that the fuel which may be in the form of hot vapor or liquid fuel such as gasoline, is injected directly into the combustion chamber 32 through fuel nozzles 33 by way of suitable preheating means such as the coil 22 of Fig. 1. Fuel is injected continuously while air is injected intermittently, that is during the aspirating phase of the operating cycle, through the inlet tube 34 and nozzle 35. It is to be noted that the embodiments of both Figs. 1 and 7 may be modified to include a plurality of inlet tubes where desired.

While in the embodiment shown in Fig. 1 using hot gaseous fuel in the form of hot vapor of a liquid fuel such as gasoline, it is preferable to inject the fuel into the inlet tube at a point substantially in the plane of the mouth of the tube and near the top, for high thrust, it has been found that injection at other points in the inlet tube make for other advantages and modes of operation. Where the fuel nozzle farther into the inlet say a distance of about two diameters of the inlet tube from the mouth of the tube, results in a relatively low specific fuel consumption. Liquid fuel injected with auxiliary air as a wide
angle spray at the opening or mouth of the tube makes for ease of starting. In addition to injection of liquid fuel as above, hot gaseous fuel may be injected into the inlet tube by way of a fuel supply pipe 37 (Fig. 1) where the inlet tube joins the inlet nozzle 18, and this arrangement is most advantageous in large engines in attainment of low specific fuel consumption and high thrust by the opening tending to reduce the force of back flow through the inlet tube, and means for injecting fuel into said combustion chamber.

5. In a valveless pulse jet engine of general tubular form having a combustion chamber at its forward end and a rearwardly extending tail section, means for admitting air into the combustion chamber comprising a nozzle in the form of a substantially straight tube projecting into the combustion chamber to a point near the axis of the chamber and in the path of burning gases passing out of the chamber to the tail section, said nozzle extending into the chamber at an angle sloping forward at the forward end of the chamber and shaped to present a forward aspect area of at least \( \frac{1}{8} \) and not more than \( \frac{1}{8} \) the area of the combustion chamber, whereby to form a baffle between that portion of the combustion chamber where explosion takes place and the outlet end of the chamber to increase the rate of burning or explosion with consequent increase in the rate of burning.

6. A valveless pulse jet engine comprising an elongated tubular structure closed at the forward end and open at the rear end, the forward portion being of relatively large diameter and short length to form a combustion chamber and the rearward portion being of relatively small diameter and longer length to form a tail section, ignition means in said combustion chamber, an inlet tube extending longitudinally along the outside of the engine having its rear end open and flared and its forward end diverged into the combustion chamber in the form of a plurality of open side tubes extending into the combustion chamber at an angle sloping forwardly of the combustion chamber about 45° to the axis of the chamber, each tube being open at the end and along a portion of the rear side, the tube sections being spaced laterally from each other and from the sides of the combustion chamber, and means for passing gases to pass rearwardly between and around the sides of the tube sections.

7. A valveless pulse jet engine comprising a closed end combustion chamber and the rearward portion being of relatively small diameter and longer length to form a tail section, ignition means in said combustion chamber, an inlet tube extending into the combustion chamber in a substantially straight line from one side in a direction sloping toward the far side and forwardly toward the closed end of the combustion chamber terminating at substantially the center of the combustion chamber, said nozzle being open at the end and partly up the side facing toward the tail section, an inlet tube extending along the outside of the tail section parallel thereto, communicating at its forward end with said nozzle and open at its rear end, and fuel supply pipe leading from a source of fuel under pressure and terminating in a fuel injection nozzle positioned to inject fuel into the open rear end of the inlet tube at high velocity to tend to induce aspiration of air into and through the inlet tube.

8. An engine as claimed in claim 7 in which the fuel supply pipe leads to the fuel injection nozzle from a heat exchange device arranged to receive heat generated by the engine.

9. An engine as claimed in claim 7 in which the fuel supply pipe leads to the fuel injector nozzle from a heat exchange device arranged to receive heat generated by the engine, together with auxiliary heating means for the heat exchange device.

10. An engine as claimed in claim 7 in which the fuel supply pipe leads to the fuel injector nozzle from a heat exchange device.
interchange device thermally coupled to the wall of said tail section.

11. A valveless pulse jet engine comprising a horizontal tubular casing defining a combustion chamber closed at the forward end and opening into a tail section open at the rear end, the tail section forming an exhaust passage from the combustion chamber, ignition means in the combustion chamber, a combustible mixture inlet tube extending along the outside of the casing and terminating in an inlet nozzle extending into the combustion chamber through one side of the chamber to terminate at substantially the center of the chamber, said nozzle extending in a direction sloping toward the opposite side and forwardly of the combustion chamber and having a solid front side and rearwardly facing opening, whereby passage of gases through the nozzle into the chamber will be directed laterally and forwardly into the chamber and passage of exhaust gases out of the combustion chamber around the nozzle will tend to lower the pressure near said rearwardly facing opening and reduce the force of back fire through the inlet nozzle and inlet tube.

12. In a valveless pulse jet engine of general tubular form having a combustion chamber at its forward end and a rearwardly extending tail section, means for admitting air into the combustion chamber comprising a nozzle in the form of a substantially straight tube projecting into the combustion chamber at an angle sloping toward the forward end of the combustion chamber to a point near the axis of the chamber in the path of burning gases passing out of the chamber to the tail section, said nozzle having an end opening to direct the flow of air into the combustion chamber at an angle sloping laterally and forwardly of the combustion chamber, said nozzle being closed along the front side to shield the interior of the nozzle from the direct force of the explosion and having an opening in the rear side to give direct communication between the inside of the nozzle and the space immediately back of the nozzle wherein is formed a zone of relatively low pressure due to the flow of explosion gases past the nozzle.

13. An engine as claimed in claim 12 together with auxiliary air supply means for injecting air under pressure into the combustion chamber through said nozzle.

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