

April 20, 1954

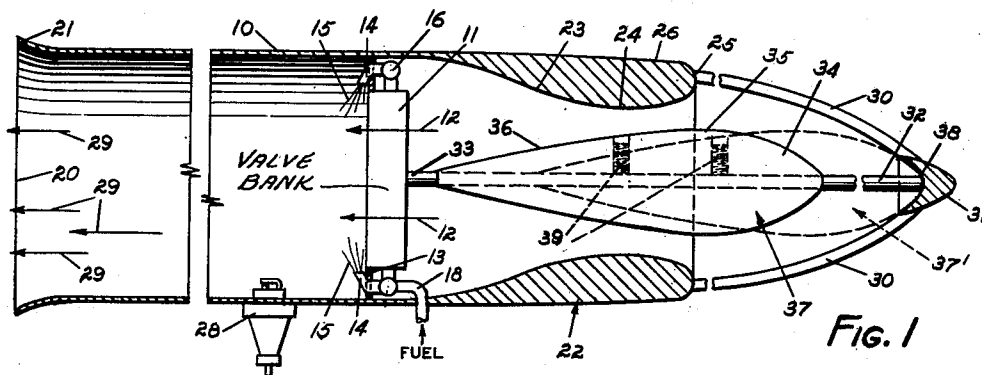
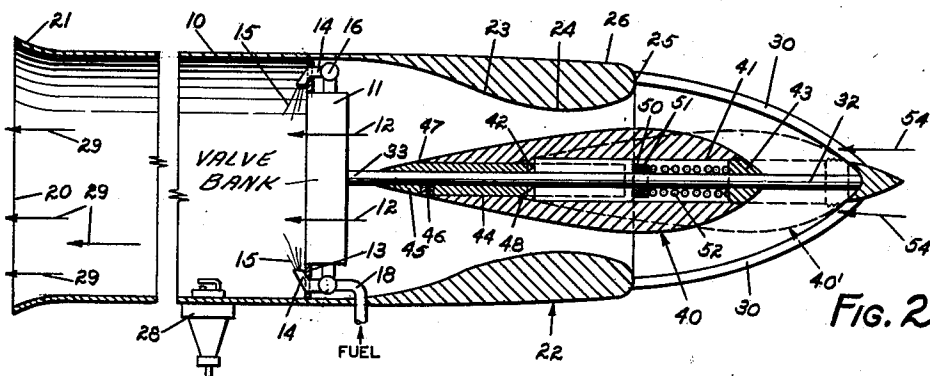
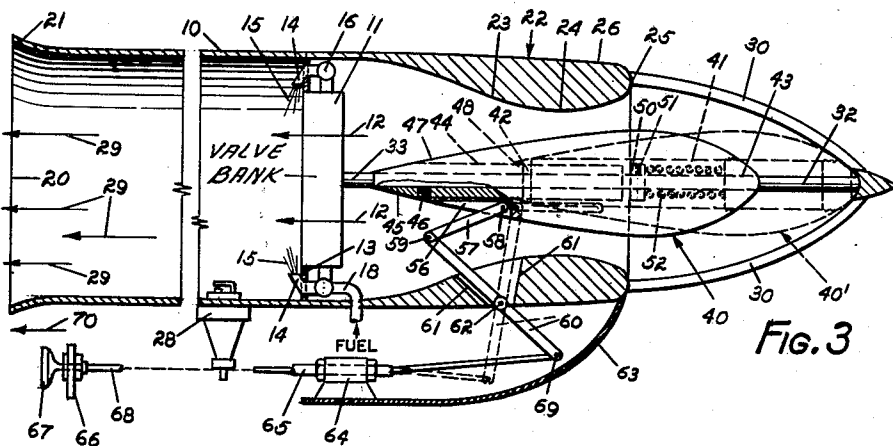
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2,675,670

PULSE JET ENGINE HAVING VARIABLE INLET CONTROL

Filed May 15, 1948

2 Sheets-Sheet 1



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PULSE JET ENGINE HAVING VARIABLE INLET CONTROL

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2 Sheets-Sheet 2

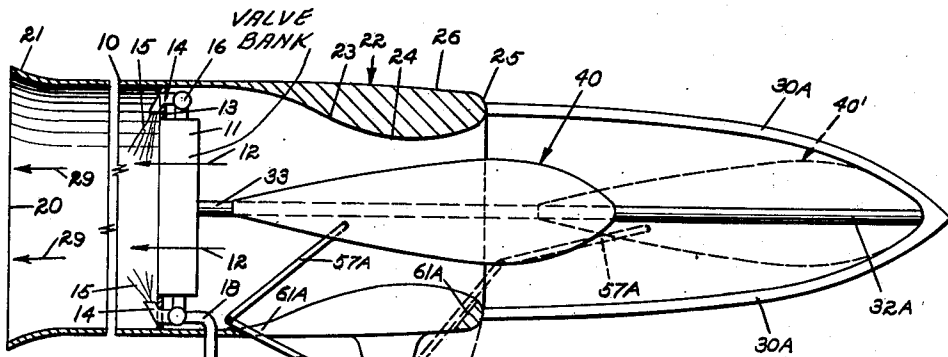


FIG. 4

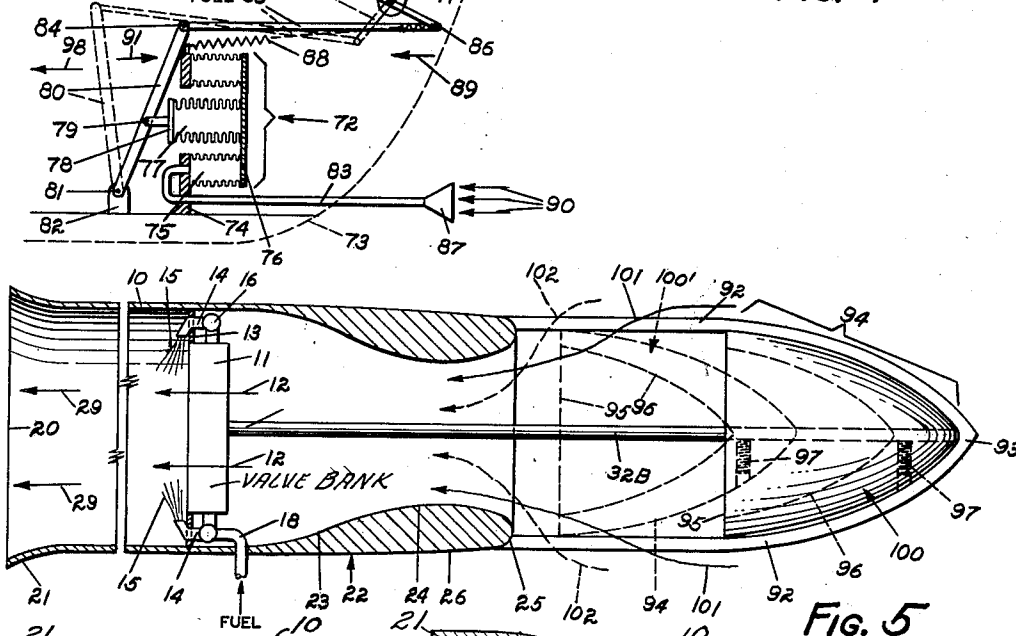
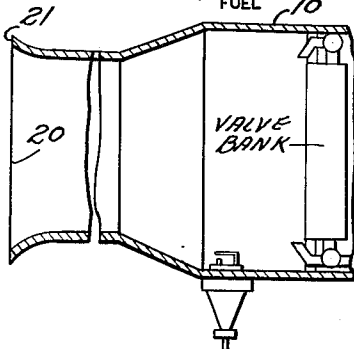


FIG. 5



UNITED STATES PATENT OFFICE

2,675,670

PULSE JET ENGINE HAVING VARIABLE
INLET CONTROL

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Application May 15, 1948, Serial No. 27,158

4 Claims. (Cl. 60—35.6)

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This invention relates to pulse jet engines and more particularly to intake controls therefor. In jet engines of this character air is introduced at the forward end of the engine into a combustion chamber which may be merely a forward section of the jet tube. Fuel is likewise introduced into the combustion chamber or section and the combustible fuel-air mixture is exploded therein. The resultant products of combustion and any augmentation air which may have been drawn into the open end of the exhaust tube are ejected forcibly from a rearwardly extending tail pipe or jet nozzle and thus produce the thrust effort of the engine which serves to drive it and its load in a forward direction.

The frequency of the explosions in the unit depends primarily upon the length and other physical dimensions of the combustion chamber-tail pipe assembly. In small engines suitable for the propulsion of model airplanes, boats, cars and the like, the frequency of the explosions are in the order of 200-300 cycles per second, whereas in larger units such as are suitable for the propulsion of target airplanes, guided missiles and the like, the explosion frequency is lower.

The operation of pulse jet engines is exceedingly critical in that even slight and almost negligible variations in the physical constants and operating conditions cause substantial and largely unexplained variations in thrust, fuel consumption and the like. Such theory as has been advanced to explain such phenomena as (1) re-ignition without sustained external ignition apparatus, (2) frequency of explosion, (3) variation in thrust and fuel consumption with changes in speed and altitude and other factors, is largely speculative and for the most part unsubstantiated. Such progress as has been made is based primarily on experimentation, using the trial and error method.

In my experiments it has been discovered that thrust, fuel economy and indeed, even the maintenance of the cyclic explosive phenomena is considerably dependent upon the rate of introduction of the air component of the combustion mixture into the combustion chamber. Thus, utilizing a pulse jet engine of the general design described in copending applications Serial No. 649,882 filed February 25, 1946, now Patent No. 2,609,660, and Serial No. 661,280 filed April 11, 1946, now Patent No. 2,587,100, it has been found that when the unit is standing still and hence is not receiving any ram air, certain thrust and specific fuel consumption are obtainable, yet

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when the same unit is permitted to obtain an appreciable velocity or is subjected to variations in air pressure within the range of atmospheric variations, relatively substantial decreases in thrust and fuel economy ensue. The same phenomena hold true for larger size units which I have tested. In extreme instances the effect of velocity and pressure variations may be so pronounced that the unit ceases to function in that cyclic operation does not continue. It has also been observed that as the velocity increases with wide open intake, the zone of combustion as indicated by most pronounced heat liberation, shifts towards the exhaust end of the jet tubes.

In seeking to overcome these objections I have discovered that the condition of maximum thrust and minimum specific fuel consumption can be better maintained under varying conditions of velocity and atmospheric pressure (or altitude) by varying the restriction at the air intake throat, and it is an object of the invention to provide for such variation.

More specific objects of the invention include provision of mechanisms in pulse jet engines for adjusting the air intake for various conditions; to provide a pulse jet engine wherein the throat restriction is adjusted automatically in response to speed or in response to the joint action of speed and altitude and to provide an improved pulse jet engine having means for manually adjusting the air intake either at the intake itself by the use of various forms of restrictions or remotely controlled.

Other and further objects of the invention are those inherent in the apparatus herein illustrated, described and claimed.

The invention is illustrated with reference to the drawings wherein

Figure 1 is a side view of a pulse jet engine, partly in section, showing one form of adjustable intake;

Figure 2 is a side view of a pulse jet engine, partly in section, showing a second form of adjustable intake which is automatically responsive to velocity;

Figure 3 is a side view of a pulse jet engine, partly in section, showing a third form of adjustable intake, which is capable of manual adjustment;

Figure 4 is a side view of a pulse jet engine, partly in section, showing a fourth form of adjustable intake which is automatically responsive to variations in velocity and altitude (barometric pressure);

Figure 5 is a side view of a pulse jet engine,

partly in section, showing another form of adjustable intake;

Figs. 6 and 7 are side views partly in section showing modified forms of exhaust tube.

Throughout the drawings the combustion chamber and jet tube (or exhaust tube, as it is sometimes designated) are foreshortened so as to afford a larger scale for illustration of the intake end of the several engines which are the principal subject of the invention, but it will be understood that the combustion chamber and exhaust tube are of appropriate length, suitable for the service involved. In use the devices shown in the drawings produce a thrust and tend to move from left to right. The portion on the right in each figure is accordingly referred to as the "forward" end, portion or direction. The portion at the left is the "rear" end, portion or direction.

Throughout the drawings corresponding numerals show corresponding parts.

Referring to the drawings the basic engine is illustrated in Figures 1 through 5 and consists of a combined combustion chamber and jet exhaust tube 10 which is provided at 11 with a valve or valve bank of any suitable design capable of permitting the flow of air or a fuel-air mixture therethrough cyclically according to valve operation and in the direction indicated by the arrows 12. The valve bank 11 may be of any suitable design such as that illustrated in Patent No. 2,609,660, or application Serial No. 661,367 filed April 11, 1946, now abandoned. The valve mechanism in the illustrative structure herein is shown as being mounted in a bulkhead wall 13 and spaced from the interior surface of the combustion chamber and exhaust jet tube 10 so as to provide an area through which fuel jet nozzles 14 protrude. The nozzles 14, of which a plurality are used, are oriented so as to provide a spray discharge towards the central area downstream from the valve bank 11, the spray discharge of the nozzles being illustrated at 15. The fuel thus introduced into the combustion chamber mixes with the inflowing air stream which enters through the valve bank 11 and provides an explosive mixture which is exploded cyclically in the operation of the device. The plurality of nozzles 14 are connected together by a ring header-tube 16 which circumscribes the valve bank 11. At one point a fuel supply line is connected to the ring, as indicated at 18. Fuel under pressure is pumped to the header ring 16 from an external supply.

Other fuel injection mechanisms, such as those illustrated in the aforesaid Patent No. 2,609,660, may be utilized, if desired. Likewise one or more valve banks, such as those illustrated in said application may be utilized at 11.

The tube 10 not only forms the combustion chamber but also forms the jet exhaust tube of the device and may be of uniform diameter throughout or may, if desired, have a larger diameter adjacent the valve bank as shown in Fig. 6 so as to form a combustion chamber which is then connected by an intermediate section of smaller diameter to the terminal end 20 which may, if desired, be flared as illustrated at 21. The tube 10, if desired, may have a gradually increasing diameter towards the terminal end followed by a reverse curve similar to a wine goblet section as shown in Fig. 7 so as to provide for supersonic jet velocities of jet exhaust.

The intake section generally designated 22 has a smooth interior Venturi curved section 23 having a minimum diameter at 24 which is smoothly

curved to the entering or nose section 25. The exterior surface 26 is preferably kept as free as possible of protuberances so as to cut down parasitic drag where the unit is used in free flight as in a guided missile, but where the unit is housed the housing is shaped so as to provide the least parasitic drag. This much of the construction is uniform throughout the various figures in the drawings.

In the operation of a device of this character air enters at the forward end 25 at a velocity depending upon the engine design and condition of operation, as well as the forward motion of the unit. After entering through the Venturi nozzle 24 the air or fuel-air mixture, in the event the fuel is introduced in the nozzle section 22, impinges upon the valve bank 11 or other suitable inlet section and passes into the combustion section which is the portion of tube 10 immediately downstream from the valve bank 11. Initially ignition is accomplished from an external source such as by means of a spark plug 28. As soon as the combustible mixture is ignited the pressure developed in the combustion zone forces the products of combustion in the forward portion of the tube and the fresh air mass in the rear portion of the tube rearwardly through the tube 10 and out of the terminal end 20 as indicated by the arrows 29. The explosion likewise causes the valves of the valve bank 11 to close until the pressure of the explosion has subsided. Even when the unit 22 is static, that is to say it has no forward velocity, the rearward flow or mass action of the gases moving in the direction of arrows 29 produces what is apparently a negative pressure condition in the combustion zone (to the left of the valve bank 11 as shown in the figures), and this causes a fresh flow of air or air-fuel mixture to be drawn through the valve bank 11 whereupon the second explosion occurs. A negative pressure also occurs at the rear end of tube 10, causing a flow of fresh air back into the rear portion of the tube through the terminal end 20. This action is repeated cyclically and soon after operation begins the high tension supply to the spark plug 28 is interrupted and re-ignition occurs thereafter due to the inherent functioning of the apparatus. The zone of most intense heating is somewhat removed to the left from the valve bank 11, since the fresh inflow of air or fuel-air mixture through the valve bank 11 serves to cool the valve bank and somewhat to lower the temperature of the region immediately adjacent thereto, and the cyclic fresh air influx through the terminal end 20 tends to cool the region adjacent thereto.

When the device is moving rapidly through the atmosphere the air flow through the venturi 24 increases due to the ram air effect, and it has been observed that the zone of most intense heating or combustion moves farther and farther away from the valve bank towards the outlet of the jet tube 20 as the ram air effect increases. A decrease in barometric pressure has an opposite effect for while the velocity of the incoming air flow may be increased the decrease in barometric pressure has the effect of decreasing the incoming mass of air. Therefore, to some extent an increase in velocity is counterbalanced by a decrease in barometric pressure, though not in equally compensating amounts.

As the ram air or velocity effect increases the thrust afforded by the engine decreases and the specific fuel consumption, in pounds of fuel per pound of thrust per hour, increases. I have dis-

covered that by valving the Venturi tube section 24, this decrease in thrust and increase in fuel consumption can be partially or completely counteracted, depending upon other operating conditions and details of engine design, and as a result the unit provides improved thrust and fuel economy as compared with previous pulse jet engines.

In Figure 1 the Venturi section is provided with a frame composed of two or more forwardly and inwardly curved struts 30 which are joined together by a streamlined nose section 31 which serves as a central support for the forward end of the rod 32, the rear end 33 of which is attached to the valve bank. Upon the rod there is mounted an object which has a streamlined surface presenting the comparatively blunt nose portion 34, a maximum diameter section 35 and the long tapered end section 36. This object generally designated 37, which may be termed a Venturi flow restrictor, is mounted so as to be movable forward or back upon the rod 32 and since the rod 32 is mounted at the longitudinal axis of the Venturi section 24, the flow restrictor 37 may thus be adjusted so as to be at any position from the forward (least restricting) position shown by dotted lines 37' to the rearward (most restricting) position shown in full lines. In the forward position the blunt nose section 34 fits neatly within the correspondingly curved surface 33 of the central nose 31. The flow restrictor is provided with one or more set screws or other fastening devices at 39 by which its position may be fixed by manual adjustment so as to be located anywhere along the rod 32. In this form of the invention the restrictor is adjusted at any position so as to provide maximum thrust and minimum fuel consumption for any desired speed or barometric operating conditions.

Referring to Figure 2 there is illustrated another form of the device of generally similar construction except that in this form the flow restrictor, generally designated 40, is mounted so as to be automatically movable between fixed least-restricting and most-restricting positions with reference to the Venturi section 24. The flow restrictor 40 is internally bored at 41 and is provided with a web at 42 having an aperture therein sized so as to slide neatly upon the rod 32. The front end of the bore 41 is provided with a screw-in plug 43 which is likewise apertured so as to slide upon the rod 32. The rear end of the restrictor 40 has bore 44 in which the long cylindrical stop member 45, which is fixed to the rod 32 by means of set screw 46, is adapted to slide. The member 45 is fixed upon the shaft 32 and the restrictor 40 slides thereon from the position shown in full lines to the position shown in dotted lines. It will be noted that in the dotted line position the trailing edge 47 of the restrictor is still supported on the forward end 48 of the stop member 45. When the web 42 is against the front end of the stop member 45, the flow restrictor 40 is in the most restricting position. Upon the rod 32 there is provided a collar 50 which is held in any adjusted position on the rod by means of a set screw 51. The collar 50 serves as a stop for the spring 52, the forward end of which pushes against the screw-in plug 43. Spring 52 is shown compressed in Figure 2 and the force exerted by it upon the plug 43 is in the forward direction. Thus, the spring 52 naturally tends to expand and to force the entire flow restrictor 40 to the forward or dotted line position 40', in which the flow restrictor resides when the device is in static con-

dition. In this position the number 40 is in the least-restricting condition.

As the velocity of the engine increases the ram air pressure exerted upon the forward end of the flow restrictor 40, indicated by the arrows 54, gradually increases until it is sufficient to overcome the force of spring 52 and as the velocity increases the flow restrictor 40 is gradually pushed back until it reaches the position shown in full lines in which a maximum restricting effect upon the flow through the venturi 24 is achieved. It will be noted in passing that the force exerted by the ram air upon the flow restrictor 40 decreases as the barometric pressure decreases (due to the lesser density of the air) while the force produced in the direction of arrows 54 increases for increases of velocity. Decrease in barometric pressure as is occasioned by high altitude flight partially but not entirely compensates the increase in velocity. The position of member 40 moves to compensate for variation in speed and barometric pressure during operation.

Referring to Figure 3 there is illustrated a device corresponding to that shown in Figure 2, except that the under side of the flow restrictor 40 is notched at 56 to receive an actuating link 57 which is connected to the flow restrictor by the pivot pin 58. The rear end of the actuating link is pivotally connected at 59 to the lever 60 which extends through a slot 61 in the side of the venturi 22, the lever 60 being pivoted at 62 to the Venturi inlet structure. At 63 there is illustrated a housing which may be part of the air foil or other structure into which the engine unit is built and upon this portion of the device there is mounted a pull wire control bracket 64 which serves to hold the housing 65 of the pull wire which extends to a remote operating station 66. An operator control 67 is connected to the wire 68 that extends through the housing 65 and is pivotally connected at 69 to the lever 60. By movement of the operator control 67 in the rearward direction, as indicated by the arrow 70, the restrictor can thus be moved in the forward direction for static operation or operation at low velocities. As the velocity increases or when other conditions require an adjustment of the flow through the venturi 22, the operator control 67 is pulled or pushed and the flow restrictor 40 is accordingly moved to any desired position from fully open (unrestricted flow conditions shown at 40') to the maximum restriction position shown in full lines in Figure 3.

In Figure 4 the apparatus of Figure 3 is shown slightly modified in that a greater range of motion is provided for the flow restrictor 40. This is afforded by extending the braces 30A to a more forward position so as to provide a longer rod 32A on which the flow restrictor is adapted to slide. The movement of the flow restrictor 40 is of the same type as that described with reference to Figure 3, but the range is greater, this being afforded by the lever 60A which is mounted upon a bracket 71 extending outwardly from the outer surface of the Venturi nozzle section 22. The length of the slot 61A, link 57A which is pivoted to both the flow restrictor and to the lever 60A, and the length of the lever 60A are all proportioned accordingly. As a result the flow restrictor may be moved from the least-restricting position shown in dotted lines to the position of maximum restriction of the Venturi tube shown in full lines.

The full range of movement is accomplished by means of a mechanism generally designated

72 which is automatically responsive to velocity and barometric pressure changes. Thus, within the housing 73 shown in dotted lines merely as representative, upon which the engine unit is mounted, there is provided a bracket 74 having an annular bellows chamber 75 which is connected by the tube 83 to an open-ended air inlet funnel 87. The bellows section 75 is closed at its forward end by the plate 76 to which there is likewise attached the forward end of a barometric Syphon bellows containing a pure gas 77. The rear end 78 of the barometric Syphon bellows 77 is pivotally attached at 79 to a lever 80 which is pivoted at 81 to the bracket 82 on the unit 73. The upper end of the lever 80 which is a motion multiplying lever is attached at 84 to a link 85 which is pivotally attached at 86 to the lower end of the lever 60A. A spring 88 is attached to the mounting panel 74 and to the pivot 86 and accordingly tends to pull the link 88 and the lower end of lever 60A in the rearward direction as indicated by the arrow 89. This tends to push the flow restrictor 40 to the dotted line position. If it is assumed that the flow restrictor is in an intermediate position due to a steady pressure exerted through tube 83 upon the interior of annular bellows section 75, then the effect of a decrease in barometric pressure will be to expand the bellows 77 and to push the lever 80 in the direction of arrow 90. This tends to push the flow restrictor 40 toward the dotted line position. If the velocity of the unit increases greater pressure is exerted in the direction of arrows 90, and this tends to increase the dimension W of the annular bellows section 75. This has the effect of pulling the lever 80 in the direction of arrow 91 and tends to move the flow restrictor 40 toward the full line position. If desired, a servomotor system may be incorporated in the linkage between the actuator 72 and the flow restrictor 40 so as to increase the power for moving the flow restrictor, particularly in larger size units.

In Figure 5 the Venturi nozzle section 22 and the remaining portions of the engine are equipped with two or more forwardly extending ribs 92 which converge together at 93 and serve as a support for the forward end of the rod 32B. Upon the rod there is mounted a flow restrictor generally designated 100 which has a smoothly curved converging forward end 94 and a flat planar or undercut trailing edge 95. This flow restrictor may be undercut as shown by the dotted lines 96 so as to reduce weight. The flow restrictor is provided with a set screw 97 by means of which it may be adjusted in any position from the forward full line position to a position closer to the nose 25 of the venturi. When the flow restrictor is in the forward or full line position shown in Figure 5, the air flow therearound is as indicated by the full line arrows 101. When the flow restrictor is in a position more closely adjacent the nose 25 and the venturi 22, the flow is restricted to a greater degree and is in the direction of the dotted line arrows 102. Any degree of restriction may thus be achieved by adjusting the position of the flow restrictor 100.

As many apparently widely different embodi-

ments of this invention may be made without departing from the spirit and scope thereof, it is to be understood that I do not limit myself to the specific embodiments herein.

What I claim is:

1. A resonant pulse jet engine having a combustion zone enclosure with interior walls constructed for the rapid pulsating flow of gases therethrough and a substantially unrestricted jet exhaust tube emanating therefrom and having a cross section not substantially less than that of the adjacent end of said combustion chamber, said engine also having an automatic valve operable by and in direct timed relation with the resonating pulsations of said engine, a Venturi shaped inlet into said combustion zone enclosure, said inlet being orientated to face in the opposite direction from said jet exhaust tube, said automatic valve being located in said inlet passage, means for introducing air and fuel into said combustion zone enclosure for resonant periodic self-sustaining combustion within said combustion chamber and said exhaust tube, an inlet passage restrictor in the shape of an air foil surface of revolution closed to the passage of air therethrough, means mounting said restrictor substantially coaxially of the Venturi inlet passage and for movement to varying positions with reference to the end of said passage for varying the restriction to air flow through said passage to control the quantity of air supplied to said engine to maintain said self-sustaining combustion therein under varying conditions, and means normally biasing the movement of said restrictor to a position least restricting said Venturi passage.

2. The apparatus of claim 1 further characterized in that stops are provided on the means mounting the passage restrictor for limiting its movement at positions of selected minimum and maximum restriction of said Venturi passage.

3. The apparatus of claim 2 further characterized in that said passage restrictor is mounted for movement under the effect of ram air impinging thereon and said means for biasing has an inherent strength insufficient to maintain said passage restrictor in the least restricting position when the ram air pressure reaches a predetermined amount.

4. The apparatus of claim 1 further characterized in that means is provided connecting said passage restrictor to a remote control for manually varying the position of said passage restrictor from said remote station.

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Addition to No. 779,655